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# Lithic Raw Material Exploitation Between 30,000 BP and 40,000 BP in the Perigord, France

by

Stephen C. Cole

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requirements for the degree of

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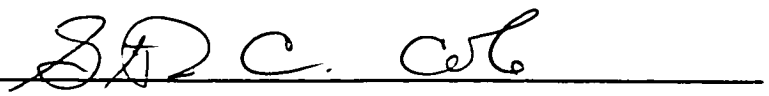
Signature 

Date 21 March 2002

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Abstract

Lithic Raw Material Exploitation Between 30,000 BP and 40,000 BP in the Perigord, France

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The Middle to Upper Paleolithic transition has been difficult to understand because of its vast scope, but the issues could be resolved with more narrowly focused research. This dissertation tackles the question of whether lithic raw material exploitation (RME) changed significantly between 30,000 BP and 40,000 BP in the Perigord of France. This question is addressed within an evolutionary and ecological framework in which RME is viewed as variable and adaptively significant. Competition would favor increased technological efficiency, which can be effected through RME strategies minimizing acquisition and manufacture costs. Those strategies could include an increased reliance on raw materials with higher fracture predictability. More efficient RME strategies would result in higher frequencies of more predictable stone; a lack of correlation between the natural availability of raw materials and their representation in assemblages; and a tighter association between raw materials and several variables including manufacture methods, assemblage technological composition, blade frequencies, and various measures of blank conservation and core reduction intensity.

Six assemblages from the Perigord, belonging to the period 42,000 BP to 27,000 BP, were analyzed. Late Mousterian, Châtelperronian, and Aurignacian industries were all represented. Analysis consisted of recording the raw material type, technological

type, and weight of each object. The data were analyzed mainly with cross-tabulations and chi-square analysis. A separate analysis of the fracture properties of lithic raw materials collected in the Perigord was also carried out, using a pendulum impact tester to quantify fracture predictability and flaking strength. These data were compared with the above data in order to test hypotheses concerning the use of raw material with particular characteristics. There is a moderate tendency for raw material conservation in all the assemblages, but the strategies of achieving it differ. A pattern of non-random acquisition paired with a lack of blank conservation or core reduction intensity gave way around 34,000 – 37,000 BP to a pattern of haphazard acquisition paired with raw material conservation. Changes in RME occurred during the Middle to Upper Paleolithic transition, but they were gradational rather than categorical. This leaves many questions about that period unanswered, and raises new questions.

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# 1

# Introduction

Archaeologists have been struggling to understand the nature of the Middle to Upper Paleolithic transition for decades (Adams 1998; Bar-Yosef and Belfer-Cohen 1988; Bar-Yosef and Pilbeam 2000; Carbonell and Vaquero 1998; Chazan 1995; Clark and Lindly 1989; Clark 1999; Holloway 1985; Karavanic and Smith 1998; Léveque et al. 1993; Mellars 1973, 1990; Mellars and Stringer 1989; Nitecki and Nitecki 1994; Noble and Davidson 1993; Omoto and Tobias 1998; Trinkaus 1989; White 1982), with no end in sight. This failing is not due to a lack of effort; it is partly due to the size and complexity of the relevant database. Since the 1980s, several symposia treating the issue have resulted in an abundance of edited volumes and journal articles, expounding models to explain putative behavioral, biological, and demographic changes that took place in Europe between 40,000 BP and 30,000 BP. The biological issue of the origins of *H. s. sapiens* makes the archaeological issue seem more complex. This is because many archaeological models depend on the Out of Africa model of modern human origins, which posits that all anatomically modern people are descended from a single population that emerged relatively recently (< 500,000 BP) in Africa, then radiated and replaced other *Homo* populations ca. 40,000 BP (Stringer 1989, 1994). The most prominent alternative, multiregional evolution (MRE), posits multiple originating populations with significant gene flow between them at various times and places throughout the Late Pleistocene, resulting in the modern geographic variants of *H. s. sapiens* (Hawks and Wolpoff 2001; Wolpoff *et al.* 1994; Wolpoff 1998; Wolpoff and Caspari 1997). Out of Africa is consistent with models of cultural replacement (Klein

2000), while MRE is more consistent with models of cultural continuity (Clark 1992). This has encouraged the tendency to address issues of cultural and behavioral change using conclusions derived from biological studies.

Unfortunately, tying the archaeological issue to paleoanthropology—a field that is "infamous for polemical divisions and open rivalry," (Stringer and McKie 1996:2)—has resulted in greater controversy rather than consensus. For example, recent evidence concerning skeletal morphology (e.g., Brauer and Broeg 1998, Hublin *et al.* 1996, Pearson 2000, Ponce de Leon and Zollikofer 2001) supports the hypothesis of replacement with little or no gene flow in Europe at 40,000-30,000 BP. Yet, morphological analyses of the Lagar Velho 1 juvenile from Portugal have led Trinkaus and colleagues to argue for substantial long-term gene flow between Neandertals and *H. s. sapiens* (Duarte *et al.* 1999, Trinkaus and Zilhão 1999, Trinkaus *et al.* 1999, Zilhão 2001). Moreover, despite the generally high degree of morphological difference between late Neandertals and early *H. s. sapiens*, there are no clear guidelines for inferring phylogenetic distances based on skeletal morphology (Smith 1994), and this makes it impossible to dismiss the possibility of significant gene flow. Analyses of mitochondrial DNA in living populations once seemed strongly to support the Out of Africa model (e.g., Cann *et al.* 1994), but serious methodological questions have been raised about such studies (Awadalla *et al.* 1999, Elson *et al.* 2001, Eyre-Walker *et al.* 1999, Klein 1994, Strauss 1999). Similarly, recent analyses of DNA extracted from Neandertal bones (Krings *et al.* 1997, Krings *et al.* 2001, Pääbo *et al.* 1997) indicated a lack of Neandertal contribution to the modern gene pool, but the methods used to infer phylogenetic relationships from ancient DNA are very controversial (Adcock *et al.* 2001a, Adcock *et al.* 2001b, Bachman 2001, Cooper and Poinar 2000, Geigle 2001, Hackleberg

1999, Relethford 2001, Scholz *et al.* 2000; see review by O'Rourke *et al.* 2000). Complicating the issue even more, various alternative models of human origins have appeared, some of which combine elements of both Out of African and MRE (e.g., Relethford 1995, Smith *et al.* 1989).

Because this dual biological/archaeological approach entails so many difficulties, it is simpler to evaluate the question of behavioral changes during the Middle to Upper Paleolithic transition using archaeological data alone, which are after all far more abundant than both fossil and genetic evidence (Klein 1994). The models that posit replacement indicate how this might be done: they predict an archaeological discontinuity sometime between 40,000 BP and 30,000 BP as a logical consequence of replacement. For many (e.g., Dennell 1993, Mellars 1996, Tattersall and Schwartz 1999), evidence overwhelmingly supports both replacement and discontinuity. Yet, notwithstanding certain instances of rhetorical posturing (e.g. Gamble 1999a, Mellars 2000), there are valid objections to various claims made in support of the discontinuity hypothesis (e.g., Bordes 1984; Clark and Lindly 1989; Demidenko and Usik 1991; Grayson and Delpech 1994; Karavanic and Smith 1998; Schepartz 1993). Consensus on this issue seems as elusive as consensus on the strictly biological issue of modern human origins.

Thus, in spite of the tremendous amount of attention on the issue in the past decades, progress toward a unified framework for the events of the Middle to Upper Paleolithic transition and their causes is slow. Clark (1997, 1999) blamed this slow progress on deficiencies in how adherents of the replacement-and-discontinuity model perceive archaeological patterns. Those perceptions and the interpretations that accompany them are "theory-laden and paradigm dependent", dependent on "historicist

biases" in the typology of industries, and influenced by preconceptions concerning the biological transition, according to Clark (1997:25). While Clark made important points, his explanation for slow progress in the Middle to Upper Paleolithic transition issue is not parsimonious because it relies upon assumptions about how other people think. Given the contentious tone of his articles, it is doubtful whether those assumptions are based on unbiased perceptions about how replacement advocates think. Clark's argument also presupposes that his own thinking differs radically from the mentality of what he calls the "standard view" in modern human origins research, but Clark and colleagues present a model based on the same cultural-typological units that they criticize as "historicist" (e.g., Riel-Salvatore and Clark 2001)[1].

A more parsimonious and less problematic explanation for slow progress is that models with lengthy, complex empirical consequences have been applied to a complex and messy archaeological record. The Middle to Upper Paleolithic transition is generally framed as an issue with global ramifications, leading some (e.g., Klein 1999, 2000; McBrearty and Brooks 2000) to propose models that account for a database spanning three continents and 20,000 years. Such a broad scope necessarily entails enormous empirical complexity. Reynolds (1991:156) observed that casting the Middle to Upper Paleolithic transition problem as one with global scale "relies on gross oversimplification of the archaeological record and large assumptions as to the interrelatedness of change in different environments." Moreover, the empirical predictions of some archaeological models for the transition lack clear empirical predictions. Therefore, progress toward

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[1] Willermet and Clark (1995) also attempted to explain a perceived stalemate in the Out of Africa/MRE debate as the result of irreconcilable "paradigm" differences. Smith and Harrold (1997) countered that differences between the two schools are due to the different stress that each lays on cladistic analysis, how each defines hominid taxa, and preferences for either punctuated equilibrium or gradual evolution as a model of evolutionary rates, but not to the practice of "normal science".

consensus might come more quickly if the empirical consequences of the models were simplified, shortened, or clarified, and if the empirical complexities of the archaeological record were effectively reduced by focusing on small areas rather than attempting to account for such an enormous database. Partitioning the models into more manageable parts could increase their potential explanatory power.

This dissertation is an attempt to do just that. The subject is the discontinuity hypothesis, which states that the earliest Upper Paleolithic assemblages in Europe differ markedly from Mousterian assemblages. This hypothesis, which I outline more fully below, is one component of the replacement scenario. The replacement scenario, in turn, is an essential component of some important models concerning the origins of "modern humans" and "modern behavior". The scope of this work is narrowed further, compared to those models, by examining the predictions of the discontinuity hypothesis for lithic raw material use, which is only one of several aspects of behavior for which the replacement models posit significant change. To simplify things even more, the analysis is restricted to six assemblages from the Perigord of France. This approach is not new: many others have examined the Middle to Upper Paleolithic transition with data sets restricted in time and space. What may be unusual about this approach is the way in which I have chosen to test the predictions of the discontinuity hypothesis. Before explaining this approach, it is first necessary to outline some of the predictions of various models purporting to explain the Middle to Upper Paleolithic transition.

**Three models of the Middle to Upper Paleolithic transition**

Five such models have received particular attention recently: human revolution (Klein 1992, 2000; Mellars 1986, 1999; Mellars and Stringer 1989); long African development (McBrearty and Brooks 2000); continuity (Clark 1992, 1997; Duff *et al.*

1992; Lindly and Clark 1990; Straus 1999), Neandertal acculturation (Farizy 1990; Harrold 1989; Hublin *et al.* 1996; Demars and Hublin 1989; Mellars 2000; White 1993, 2001); and Neandertal invention (D'Errico *et al.* 1998, Zilhaõ and d'Errico 1999, Zilhaõ 2001). Each views the question of a discontinuity between the Middle and Upper Paleolithic periods differently. While the models are all interesting, no one study can simultaneously test all five. I have chosen to focus on the issue of an archaeological discontinuity, and the first three models above are most germane to this issue.

The "human revolution" model is usually favored in popular accounts of the Middle to Upper Paleolithic transition (e.g., Johanson 1998, McClellan and Dorn 1999, Pfeiffer 1990). It is closely tied to the Out of Africa model of human biological origins (Trinkaus *et al.* 1999). The major tenets of the human revolution model are that *H. s. sapiens* was initially similar to other, contemporaneous *Homo* populations, but around 50,000 BP they developed the technological and social complexity seen in living hunter-gatherers, leading to stark behavioral contrasts with the other *Homo* populations. The ultimate cause of this change may have been the appearance and spread of a genetic mutation giving *H. s. sapiens* increased behavioral plasticity (Klein 1992, 2000). The archaeological manifestations of the change are the Late Stone Age of Africa and the Upper Paleolithic of Europe. Due to the adaptive advantages of their technology and increased social complexity, this population migrated into southwest Asia and Europe, successfully out-competed Neandertals, and drove them to extinction within a relatively short period (Tattersall and Schwartz 1999).

Supporters of this model enumerate the traits that they claim distinguish the Upper from the Middle Paleolithic in Europe (Gargett 1989, 1999; Klein 1992, 1995,

2000; Mellars 1996; Miracle 1998); these are summarized in Table 1.1. Mellars (1996:400-401) summarized the model as follows:

> The earlier stages of the Aurignacian in Europe provide explicit evidence for radical changes in at least five or six separate aspects of behaviour: the technology and typology of stone tool production; the production of bone, antler and ivory artefacts; the emergence of varied and complex personal ornaments; the 'explosion' of representational art and associated abstract ornamentation; and the emergence of greatly expanded networks for the distribution of marine shells and in some cases high-quality raw materials. All these innovations are in place and well documented in the archaeological records of some of the earliest Aurignacian sites in Europe, certainly well before 30,000 BP, and probably before 35,000 BP. In short, we have evidence for a remarkable package of cultural and behavioural innovations which appear relatively suddenly within the archaeological records of Europe over a time span of at most 5-10,000 years and—within individual regions—probably over a much narrower time range of ca. 1-2000 years.

Mellars (1996:412) argued further that these cultural and behavioral innovations signal the arrival of a new and physically different population into Europe: *H. s. sapiens*.

McBrearty and Brooks (2000) proposed the "long African development" model of modern behavior. These authors argue that a profound Eurocentric bias in research, which ignores important data from Africa, erroneously created the impression that behavioral modernity arose suddenly around 40,000-50,000 BP in Europe. They suggest that both Neandertals and *H. s. sapiens* evolved during a Middle Pleistocene adaptive radiation in Africa. They review a wide range of archaeological data from the African Middle and Late Pleistocene, and show that the suite of behavioral traits considered to have arisen suddenly around 50,000 BP developed gradually over a period of at least 200,000 years in Africa. Moreover, for them, many of these traits were not invented exclusively by *H. s. sapiens*, but developed among earlier hominids including *H. erectus*, *H. rhodesiensis*, *H. louisleakeyi*, *H. ergaster* and *H. helmei*. Although this model contrasts strongly with the human revolution model, both share the

premise of a rapid cultural and biological replacement following the migration of *H. s. sapiens* into Europe between 40,000 BP and 50,000 BP. However, the long African development model explains cultural and biological replacement as the outcome of two differently adapted groups competing for the same resources, not in terms of cognitive traits. Like human revolution, this model implies an abrupt archaeological discontinuity in Europe during a short period between 40,000 BP and 30,000 BP.

A third model, the "continuity" model, also opposes the human revolution model, but for completely different reasons. The main tenets of this model are: that behavioral change among mid-Late Pleistocene groups in Europe was gradual; that different aspects of technology and culture changed independently and at different rates, rather than as a suite of interrelated changes; and that biological differences do not explain any of these changes (Clark 1992, 1997; Clark and Lindly 1989; Duff *et al.* 1992; Lindly and Clark 1990; Simek 1992; Straus 1999). Efforts to persuade others of this point of view rely heavily on an epistemological critique of the human revolution model. Whereas Klein (1995) argued that typological differences between Middle and Upper Paleolithic assemblages reflect true behavioral differences, advocates of the continuity model believe those differences are largely the by-product of inherent paradigmatic biases in traditional Paleolithic systematics, leading to the false appearance of categorical differences between the Middle and Upper Paleolithic (Clark 1997, Clark and Lindly 1989, Lindly 1990, Reynolds 1990, Simek and Price 1990). Straus (1999:353) argued further that both the human revolution and Neandertal invention models reflect "extraordinarily normative typological thinking" in their acceptance of the view that archaeological industries can be equated with cultures. He proposed that cultural interaction during the Middle to Upper Paleolithic transition was very complex and took

place as a prolonged series of independent interactions between many small groups of people, rather than as a single confrontation between two large groups.

The continuity model has been formulated so that it will gain support from empirical evidence suggesting either similarity between the Middle and Upper Paleolithic, or greater complexity than indicated by the human revolution model. For example, evidence indicating that the Middle Paleolithic is highly variable over space and time (e.g., Cohen and Stepanchuk 1999) would seem to oppose the human revolution model's premise (Klein 1995) that this cultural tradition was highly invariant and static. Evidence for gradual behavioral change (e.g., Straus and Otte 1996) and evidence that so-called "modern" behaviors appeared in Europe long before the Middle to Upper Paleolithic transition is also consistent with the continuity model. Such evidence has been claimed for bone tools (Defleur 1988), various lithic tool types (Bordes 1984), systematic blade manufacture (Conard 1990, Heinzelin and Haesarts 1983, Révillon 1994, Texier 1996, Slimak 1999), symbolic markings (Bahn 1994), hunting prowess (Baryshnikov and Hoffecker 1994, Gardeisen 1999, Jaubert *et al.* 1990), structured hearths (Farizy 1990), and the colonization of harsh northern environments (Roebroeks *et al.* 1992, and possibly Pavlov *et al.* 2001). Advocates of the model take issue with what they consider biological determinism on the part of those who support the human revolution and Neandertal invention models (e.g., Simek 2001). However, the notion that biological and cultural evolution are not fundamentally linked and should be treated independently is widely recognized (e.g., Conard 1990, Gamble 2001, Hublin 2000, Kuhn and Bietti 2000, Reynolds 1991, Rigaud 1993); this tenet does not distinguish the continuity model from other models.

One of the clearest differences among these three models is how each treats the notion of cultural replacement during the Middle to Upper Paleolithic transition. Human revolution and long African development both rely on a scenario of rapid population replacement following the *H. s. sapiens* invasion of Europe, enabled by differences in adaptive potential, and leading to an abrupt archaeological transition, or discontinuity, in Europe between 40,000 BP and 30,000 BP. For brevity, I abbreviate these three ideas as "replacement," "adaptive differential," and "discontinuity," respectively. These are the essential tenets of the discontinuity hypothesis, as I use that term here. Rapid replacement and adaptive differential are the mechanisms that would explain the putative archaeological discontinuity. The human revolution and long African development models differ significantly in how they conceive the emergence of behavioral modernity, but both models propose rapid replacement, adaptive differential, and discontinuity *in Europe*. This view is rejected by adherents of the continuity model, who support an hypothesis of continuous, mosaic change with or without biological replacement.

**Implications of the models for cultural change**

Despite these differences, all three models share the idea that, if there were a population replacement, and if it occurred with populations that were adaptively unequal in the environment in which they interacted, then replacement would have happened and it would have resulted in clear archaeological differences. Obviously, the continuity model posits that the population replacement either did not happen, or did not happen in this way. Yet, one of the most active supporters of the continuity hypothesis has stated that "If large scale population replacement actually took place in Europe, involving a 'more advanced' hominid [*H. s. sapiens*] that 'arrives' from elsewhere, outcompetes and

displaces ["archaic" *Homo sapiens*] over the European part of its range, then we would expect that replacement event or process to be manifest in many different aspects of the European archaeological record," (Clark 1997). A definitive test of the discontinuity hypothesis would help establish whether or not rapid population replacement and adaptive differential are credible hypotheses for Europe between 40,000 BP and 30,000 BP. This, in turn, would clarify the empirical strengths of the human revolution and long African development models compared with continuity.

Replacement and discontinuity should be treated as independent hypothesis, for at least two reasons. One is the broad support that exists for the idea, mentioned above, that biological change and cultural change are independent. Another reason is to avoid the problems that can ensue when a hypothesis about the chronology of one set of events is treated as dependent on the chronology of a second set of events (Grayson 1984). Making the discontinuity hypothesis dependent on the replacement hypothesis would tie it to the chronology of replacement, but that chronology is currently in dispute (e.g., d'Errico *et al.* 1998, Zilhão and d'Errico 1999, Mellars 2000). The chronology will undoubtedly change as new dates and finds become available, and there is no guarantee that these new data will ultimately be consistent with the putative archaeological evidence for discontinuity. For both these reasons, this dissertation treats the issues of discontinuity and adaptive differential, but not the issue of replacement.

Culture change and adaptive differential are testable ideas. Yet, if they were testable in the way proposed by supporters of human revolution and long African development (e.g., Klein 1994), then consensus should be emerging by now, given the large quantity of evidence that has been generated. The reason why no such

consensus has formed may lie with a problem in the way that the predictions of human revolution and long African development were formulated.

These models make it appear that if the European archaeological record failed to show an abrupt discontinuity in all the ways listed in Table 1.1, then replacement should be rejected. This notion has led to a research focus on the timing of the first appearance of the various traits that the human revolution model lists as uniquely characteristic, or at least more typical, of the Upper Paleolithic, such as antler projectile points (Knecht 1993), pierced ornaments (White 1993, 2001), burials (Gargett 1989,1999), and social networks (Gamble 1999b). However, this approach is misleading because the establishment of cultural, social, and technological similarities between the Middle and Upper Paleolithic would not rule out replacement. Replacement could happen between similar cultures, in which case the archaeological record might show little change. Ecological theory suggests that such a scenario is likely: competition is significant only between populations occupying the same ecological niche (Parsons 1983). If the Middle and Upper Paleolithic represent adaptations to different ecological niches, then competition between the two populations would be less likely. Paradoxically, then, models of replacement and discontinuity depend on significant similarity between these cultural entities.

Thus, while the success of the replacement scenario depends in part on an analysis of trait distributions, it also depends on a demonstration that the trait(s) in question conferred adaptive advantages sufficient to enable an evolutionary *coup d'état*. The date and location of a trait's first appearance have no impact on the replacement scenario without a demonstration of the adaptive consequences of the trait. As stated earlier, the discontinuity hypothesis depends on two mechanisms, replacement and

adaptive differential. The discontinuity hypothesis could be supported by establishing rapid change in a single trait with demonstrable adaptive significance. Therefore, the question of an adaptive differential between the two populations that allegedly interacted between 40,000 BP and 30,000 BP in Europe is a critical issue, perhaps even more critical than the dates and times where various allegedly "modern" behaviors first appeared.

**Lithic raw material exploitation and the discontinuity hypothesis**

According to advocates of replacement, lithic raw material exploitation—the acquisition, processing, use, and transport of tool stone and stone tools—is one of the behaviors that shows an archaeological discontinuity during the Middle to Upper Paleolithic transition in Europe. The proportion of non-local raw materials is frequently cited as an indicator of elaboration or sophistication in lithic raw material use (e.g., Finlayson cited in Balter 2001, Klein 1994, Mellars 1996, Wolpoff 1996). "Non-local" is defined variously, but generally means rocks acquired several kilometers from the site where the assemblage was collected (Féblot-Augustins 1997). A sudden shift toward higher proportions of non-local raw material in assemblages immediately post-dating the replacement would seem to support the discontinuity hypothesis.

Many claims have been made for a higher proportion of non-local stone, or the presence of stone acquired from more distant sources, in Upper Paleolithic assemblages compared with earlier ones (Demars 1982, Geneste 1985, Hahn 1987, Kozlowlski 1982, Le Tonsorer 1979, Mellars 1989, Otte *et al.* 1988, Soffer 1994, Straus and Heller 1988, Svoboda 1993, Tort-Zannoli 1983, Zilhão 1993). Some (e.g., Klein 1995; Mellars 1989, 1996) accept these claims as support for discontinuity. For example, Zilhão (1993:156) concluded from patterns of raw material exploitation in Portugal that "the transition from

the Middle to the Upper Paleolithic was a phenomena of replacement tied to the arrival of modern people" (this and all translations from French in this work are mine). This conclusion is generally based on putative differences in raw material use, as well as the equation of those differences with differences in the sizes of foraging ranges and social networks (Wolpoff 1996). However, this conclusion has two main problems.

First, not all early Upper Paleolithic assemblages show higher proportions of non-local raw material than Mousterian assemblages. Table 1.2 shows data provided by Demars (1982) on the raw material composition of one Mousterian and seven Aurignacian tool assemblages from the Brive basin of the eastern Perigord, in southern France. The percentages for each chert type in the Mousterian assemblage from Chez Pourré (represented here by a sample of sidescrapers) all fall within the range of percentages for the same cherts in the Aurignacian assemblages. The raw material composition of the Chez Pourré sidescrapers is especially similar to that of the tools from the Aurignacian II level from the Abri Dufour, which is probably at least 10,000 years younger. Moreover, the Mousterian sample contained as many kinds of chert as most of the Aurignacian assemblages, despite the fact that the sample is substantially smaller than most of those assemblages (see Table 1.3). However, because some raw materials that occurred in very small amounts may not have been reported by Demars, the numbers in Table 1.3 may be unrepresentative for some assemblages.

Assemblages from the Perigord also do not show a clear increase in the distances from which raw materials were acquired during the Middle to Upper Paleolithic transition. Turq (1996) argued that the provisioning zones inferred from the raw material compositions of Mousterian, Châtelperronian, and Aurignacian assemblages in the southern Perigord were the same. He argued further that the Mousterian,

Châtelperronian and many of the Aurignacian assemblages in this region show a nearly exclusive use of local raw materials, with the frequency of each raw material declining rapidly with increasing distance from the source. A few, but not all, of the Aurignacian assemblages show an elevated proportion of exotic materials compared with the Mousterian and Châtelperronian. There has not been any such comparison for assemblages from the northern Perigord.

According to Straus (1996), whether there was an abrupt transition in raw material provisioning depends on where one looks. In Catalonia, he found evidence of an abrupt transition in technology, tool types, and raw material use. This evidence consisted of clear differences between Mousterian layers at l'Abreda and Abric Romani and the overlying Aurignacian layers at those sites. Yet in Cantabria, Straus and Heller (1988) "showed considerable similarity among the Mousterian and *early* Aurignacian and Châtelperronian lithic assemblages," (Straus 1996:206; itals. in original), in lithic technology and raw material composition. The uppermost Mousterian at Cova Beneito, associated with two radiocarbon dates in the range 30,000 –40,000 BP, has typological and technological affinities to the Upper Paleolithic, although the possibility of contamination from overlying Upper Paleolithic levels is not ruled out (Vallaverde *et al.* 1998). In sum, data from some areas support a discontinuity in lithic raw material exploitation, while data from other areas support continuity.

Second, even if assemblages in the Perigord did show an increase in non-local raw materials or use of increasingly distant raw material sources during the Middle to Upper Paleolithic transition, this would not necessarily support the discontinuity hypothesis. The adaptive significance of raw material composition—the different kinds of raw material present in an assemblage, and their proportions—has yet to be

established. Therefore, in order to evaluate the discontinuity hypothesis using data on raw material composition, it is necessary to examine the adaptive implications of variation in lithic raw material exploitation.

**Adaptive significance of lithic raw material exploitation**

Some have suggested that an increased abundance of non-local raw materials indicates the emergence of social networks (e.g., Finlayson cited in Balter 2001, Klein 1994, Mellars 1996, Wolpoff 1998), which in turn implies the emergence of modern behaviors. However, this is problematic. The social networks argument depends on the premise that inhabitants of harsh environments with significant resource uncertainty must develop social networks in order to obtain critical resources through trade or exchange in times of severe stress. Of course, it is not the availability of tool stone that explains the emergence of social networks: although tool stone availability may fluctuate, stone outcrops do not suddenly disappear. Rather, the social network hypothesis explains the use of non-local tool stone as an indirect result of social networks, which are seen as an adaptation for coping with episodic resource scarcity. The adaptive advantage of social networks, according to this view, is that it creates a safety net that can be used to avoid starvation. Traveling in order to meet with other groups, people encounter lithic raw material, which they collect. Thus, non-local tool stone is acquired as a by-product of social interaction (Gould and Saggers 1985). From an archaeological perspective, the existence of non-local tool stone in an assemblage signifies social networks instead of direct procurement, according to this view.

The social network hypothesis might be plausible for western Europe during the Middle to Upper Paleolithic transition if population densities high enough to support social networks could be demonstrated. Unfortunately, reconstructing population sizes

or densities for this period is quite difficult. Mellars (1973:271) suggested a "substantial increase in overall population densities" in the initial Upper Paleolithic in Europe, as well as an increase in the mean size of residential groups. White (1982) and Rigaud (1993) demonstrated flaws in his argument; Mellars (1996) revised the argument but not the view that Mousterian populations in western Europe were much smaller than early Upper Paleolithic populations. However, that view is not strongly supported by Bocquet-Appel and Demars' (2000) demographic model for Western Europe north of the Alps. Their estimates for population densities ranged from 5400 to 8900 people during the Aurignacian and Gravettian periods and the Last Glacial Maximum, surging to 40,000 in the late Magdalenian, after 16,000 BP. This model implies population densities of only 0.54-1.08/km$^2$ for the early Upper Paleolithic. If human groups numbered approximately 20-30 people, and if camp locations were equidistant, then camps would have been spaced approximately 10-15 km apart. If groups were larger, the spaces between them would have been larger. This model might suggest sufficient conditions for the development of social networks through which non-local raw materials could be acquired. However, the model is undoubtedly simplistic, is based on estimates of population density that have not been tested against independent lines of evidence, and has yet to be applied to the problem of raw material exploitation in Paleolithic Europe. Any such application would have to account for local environmental conditions. Since those conditions varied enormously across Europe during the Late Pleistocene, the adaptive advantages of social networks would probably vary enormously as well.

Furthermore, although many ethnographically documented hunter-gatherers do or did maintain social networks, this gives insufficient reason to assume that the presence of non-local stone in an assemblage can be explained in those terms. There

are ways people can adapt to resource scarcity in the absence of social networks. One is the ability to move quickly over long distances in order to find scarce resources. There are many examples in the ethnographic literature of people who habitually traveled tens of kilometers or more on foot. To cite only one example, Kamadüka, or Bannock Creek Shoshoni, often walked over 200 km to camas collecting grounds from their winter villages near Kelton, UT and Fort Hall, ID (Steward 1938:217). If these foragers would walk such distances to collect resources, there is no reason to rule out that foragers in Paleolithic France did so.

Thus, there is no compelling reason to assume that non-local raw materials in a Paleolithic assemblage indicates acquisition through trade or social networks, and therefore no reason to reject the more parsimonious hypothesis of direct acquisition. Unfortunately, some who use the social networks hypothesis as an explanation for non-local raw material (e.g., Baales 2001) do so without any evidence concerning social interaction, other than the presence of non-local raw materials, and without consideration of ecological or demographic parameters. In the Perigord, it seems more prudent and more parsimonious to assume, as many workers there (e.g., Demars 1982, Geneste 1985, Lucas 2000, Turq 1992) have done, that most or all lithic raw materials were acquired when people visited sources and picked up rocks. This assumption seems safe in view of the fact that lithic raw material sources are abundant, diverse, and widespread in the Perigord.

Other factors besides social interaction could account for an adaptive differential related to variation in lithic raw material use. Any adaptive differential that may have existed between autochthonous and allochthonous Paleolithic groups during the Middle to Upper Paleolithic transition would have been tied to the economics of raw material

procurement and use. These groups were mobile hunter-gatherers who relied heavily on the hunting of large game for their subsistence (e.g., Bocherens *et al.* 1991, Bocherens *et al.* 1999, Richards et al 2000). Undoubtedly, transport costs significantly influenced many aspects of subsistence behavior and technology. The portability of tool stone, including unprocessed blocks as well as finished tools, would have been a significant factor constraining the choice of raw material sources. The choice of which raw materials to use and how much of each to collect, as well as and the ways in which raw material was processed, used, and curated, would all affect the costs and utility of the lithic tool kit. In situations of strong inter-group competition, strategies that tended to lower acquisition costs and/or maximize the utility of transported tool stone would give an adaptive edge.

The proper theoretical framework for this study is evolutionary ecology, which combines the principles of behavioral ecology with those of neo-Darwinian theory. This dissertation uses general principles derived from evolutionary ecology to derive testable implications of the discontinuity hypothesis for lithic raw material exploitation. The following steps outline the general strategy:

1. Demonstrate that certain aspects of lithic raw material exploitation have adaptive significance.
2. Develop a model specifying the potential adaptive consequences of various aspects of lithic raw material exploitation (such as alternative strategies for acquiring or conserving raw material).
3. Use that model to derive predictions that are consistent with the discontinuity hypothesis but not the continuity model.

4. Test those predictions with evidence derived from a detailed analysis of Perigord lithic assemblages, and evidence on the characteristics of Perigord lithic raw materials.

If successful, this program will improve our understanding of possible changes in lithic raw material exploitation in southwest France between 40,000 BP and 30,000 BP. If the test supports the discontinuity hypothesis, the model will identify the aspects of raw material exploitation that were adaptively advantageous and those that were not. This would shed light on the ecological and evolutionary context of lithic technology during this dynamic period. If the test fails to indicate a discontinuity in any adaptively significant dimension of behavior, this could be interpreted either as support for the continuity hypothesis or as evidence that variation in lithic raw material exploitation was not adaptively significant. This research is not expected to solve the question of the Middle to Upper Paleolithic transition, but it may help point the way to a solution.

**A note about chronology**

So far, I have discussed the issue of change during the period 40,000-30,000 BP in terms of "the Middle to Upper Paleolithic transition," and in terms of differences between the Mousterian or Middle Paleolithic and the Aurignacian or early Upper Paleolithic. This framework, adopted by participants in the debate over discontinuity and continuity, implies that the discontinuity hypothesis should be tested by making comparisons between those chrono-cultural units. However, I feel that this framework has its own weaknesses, and that using it for the test introduces unnecessary complications.

As has been noted (e.g., Smith 1994), while both hominid taxa and chrono-cultural units serve useful purposes, they are also very blunt instruments when it comes

to measuring variation of evolutionary significance. It is useful to know how "the Aurignacian" differs from "the Mousterian", but many feel that real variation in lithic assemblages is poorly or wrongly described by those categories (e.g., Bisson 2000; Clark 1993; Kolpakov and Vishnyatsky 1989; Reynolds 1990, Simek and Price 1990). The replacement-and-discontinuity models seem to imply that Mousterian assemblages are all similar, and Aurignacian assemblages are all similar, since each is usually assumed to be the archaeological expression of a different species. Yet, there is significant typological and technological variation within both the Mousterian (Cohen and Stepanchuk 1999) and the Aurignacian (Djindjian 1993, Rigaud 1993). Forcing archaeological data sets into such categories may cause us to overlook important cultural or technological variation (Clark and Lindly 1989), such as adaptively significant variation in lithic raw material use. Furthermore, to characterize the discontinuity hypothesis exclusively in terms of "Middle to Upper Paleolithic transition" is to confound two separate hypotheses: 1) the hypothesis of cultural change, and 2) the hypothesis that this change was coincident with the stratigraphic transition between Mousterian and Upper Paleolithic. Both hypotheses are interesting, and both should be tested. However, they should be tested independently.

How, then, can the discontinuity hypothesis be tested without tying it to the traditional chrono-cultural units? It can be done simply by focusing on the idea that the change occurred within the period 40,000-30,000 BP. That is where the discontinuity should be found, regardless of the cultural identification of the two putative populations in terms of biology or stone tool types. Unfortunately, there is no consensus on the exact timing of the alleged transition. The most logical alternative is to test discontinuity by comparing assemblages that fall earlier and later within that period. If discontinuity is

correct, then assemblages dating close to 40,000 BP should differ measurably in at least one adaptively significant way from assemblages dating close to 30,000 BP. The archaeological predictions I test here are based on this assumption.

**Geographic setting: the Aquitaine and the Perigord**

The Aquitaine is a more-or-less triangular region of low-lying land that makes up an area of approximately 70,000 $km^2$ in southwestern France (Figure 1.1). It is one of twenty-two administrative units in continental France. Those units are, in turn, divided into ninety-six departments. Five of these departments fall within the Aquitaine: Pyrénées Atlantiques, Landes, Gironde, Lot-et-Vézère and Dordogne. The term Perigord closely corresponds to the Dordogne department, an area of 9,000 $km^2$. Some prehistorians (e.g., Jochim 1987, Laville *et al.* 1980, Mellars 1996, Rigaud and Simek 1990) feel that the Perigord was a focal point for important biological, cultural, and demographic events during the Middle to Upper Paleolithic transition.

Today, the Perigord is a lush region of mixed oak-chestnut forests. The topography is dramatic, a wide limestone plateau having been dissected by fluvial erosion during tectonic subduction, leaving limestone massifs towering 200 m. above wide valleys. There are countless caves and rockshelters in these massifs, and this is where most of the more than 300 archaeological sites of the region were discovered. The Perigord's varied geography has led to the designation of three main sub-areas. The white Perigord is the thinly wooded, gently sloping Dronne River valley in the northwestern sector. Its name comes from the color of the chalky limestones. The green Perigord is the northeastern portion, which is underlain by a large incline of crystalline rocks, through which ancient floods originating in the Massif Central have cut deep gorges. The black Perigord corresponds to the southeastern sector, where the

Vézère meanders toward the southwest before joining the Dordogne at Limeuil. The term "black" refers to the dark color of local oak trees.

The lithic assemblages studied here were excavated from four sites in the black Perigord. Le Flageolet I and Caminade Est are rockshelters located along the right bank of the Dordogne River. The lower shelter at Le Moustier is on the left bank of the Vézère River. La-Côte is an open-air site located on the right bank of the Isle River. I describe these sites and the assemblages I studied in Chapter 3.

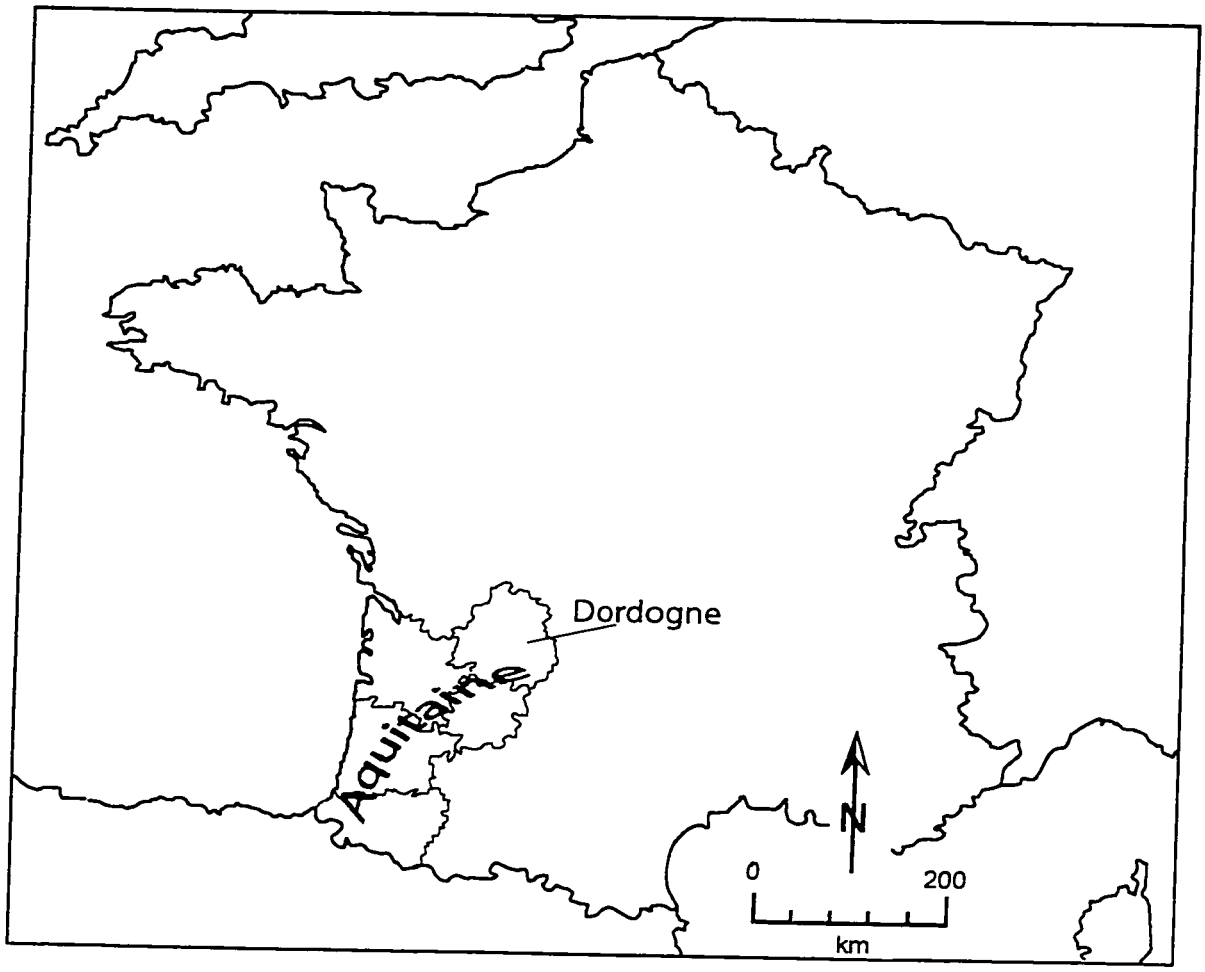


Figure 1.1 Map showing the Dordogne and the Aquitaine in France.

Table 1.1 Traits characterizing "modern behavior" that are present in the Upper but not the Middle Paleolithic, according to the replacement scenario. Compiled from Klein (1995, 2000), McBrearty and Brooks (2000), Mellars (1996), and Miracle (1998).

- systematic blade technology
- a large number of standardized lithic tool types
- first use of bone, antler, and ivory as a raw material for artifacts
- objects of personal adornment
- incontrovertible art
- elaborate burials with evidence of ritual
- more efficient hunting techniques
- fishing
- increased use of non-local lithic raw materials
- maintenance of social networks over large areas
- high population densities
- expansion into harsh periglacial environments in northeastern Europe and northern Asia
- structured living spaces

Table 1.2 Percents, by weight, of raw materials in assemblages from the Brive basin. Data from Demars (1982). Industry: Moust., Mousterian; Aur. I, Aurignacian I; Aur. II, Aurignacian II. N, assemblage size; g, total weight of assemblage in grams; Raw mat, raw material type; distance, estimated source distance. Key to raw material types: 1, black/grey Senonian chert; 2, beige Senonian chert; 3, jasper; 4, Jurassic chert; 5, Bergeracois chert; 6, chalcedony or millstone; 7, miscellaneous. The "-" sign indicates the absence or near-absence of a raw material type; the "+" sign indicates the raw material type was present in small amounts, but no figures were provided.

| Site | | Chez Pourré | Bouitou | Font-Yves | Bassaler | Chanlat inf. | Chanlat sup. | Bos del Ser | Dufour |
|---|---|---|---|---|---|---|---|---|---|
| Industry | | Moust. | Aur. I | Aur. I | Aur. I | Aur. I | Aur. II | Aur. II | Aur. II |
| N | | ? | 1005 | 887 | 1128 | 1622 | 1436 | 2351 | 988 |
| g | | 7439 | 9440 | 15,813 | 18,171 | 48,569 | 30,230 | 65,330 | 23,284 |
| Raw mat. | distance | | | | | | | | |
| 1 | 30 km | 71.9% | 38.4% | 53.0% | 52.6% | 61.7% | 74.2% | 53.9% | 71.2% |
| 2 | 30 km | 10.2% | 8.7% | 17.7% | 24.6% | 8.3% | 17.6% | 12.2% | 8.4% |
| 3 | < 10 km | 10.7% | 4.6% | + | 4.8% | 13.5% | + | 13.2% | 12.5% |
| 4 | < 10 km | 2.8% | - | + | + | 5.9% | + | 12.7% | 0.5% |
| 5 | 70 km | 0.2% | 30.0% | 13.5% | 8.3% | 2.6% | 2.1% | - | - |
| 6 | 30 km | - | 10.3% | + | + | + | + | - | - |
| 7 | ? | - | - | + | + | + | + | - | - |

Table 1.3 Richness (number of raw material types) compared to sample size (N, number of artifacts) for selected assemblages from the Brive basin. Data from Demars (1982). The number of artifacts in the Mousterian sample was not reported.

| Assemblage | Industry | Richness | N | grams |
|---|---|---|---|---|
| Chez Pourré | Mousterian | 5 | - | 7,349 |
| Boitou | Aurig. I | 5 | 1005 | 9,440 |
| Font Yves | Aurig. I | 7 | 887 | 15,813 |
| Bassaler | Aurig. I | 7 | 1128 | 18,171 |
| Chanlat inf | Aurig. I | 7 | 1622 | 48,569 |
| Chanlat sup. | Aurig. II | 7 | 1436 | 30,230 |
| Bos del Ser | Aurig. II | 4 | 2351 | 65,330 |
| Dufour | Aurig. II | 4 | 988 | 23,284 |

# 2

# Theoretical Basis

This dissertation addresses variation and change in lithic raw material exploitation and their relationships to environmental conditions between 40,000 BP and 30,000 BP in the Perigord. The proper framework for such a study is evolutionary ecology, the theory of interrelationships between organisms, natural selection, and ecological variables. These relationships include social interactions, genetic relationships, the flow of energy and materials among organisms, and competitive interactions between organisms in relation to shared resources (Foley 1987:50). Evolutionary ecology is built on "neo-Darwinian bedrock" (Smith 1991:1) consisting of the principles of variation, heritability, adaptive differentials, and natural selection.

Evolutionary ecology has been put to extensive use in anthropology and archaeology (Broughton and O'Connell 1999, Grayson and Cannon 1998, Smith and Winterhalder 1992). The approach is well developed and provides an appropriate starting place for the present study. However, many ecological models in anthropology are based on foraging theory, the branch of evolutionary ecology that examines the acquisition and consumption of food by hunter-gatherers. Those models directly relate to the costs and benefits of energy acquisition; none directly treats the problem of lithic raw material exploitation (RME), which consists of energy consumption and relates only indirectly to energy acquisition (but see Metcalf and Barlow 1992 for a significant mention of this topic). Moreover, foraging theory has largely been developed to explain aspects of central place foraging. As I shall argue below, there is little reason to believe that Paleolithic hunter-gatherers in the Perigord before 30,000 BP were central place

foragers. Thus, evolutionary ecology does not provide any existing models that can be used to treat the subject of this dissertation.

In this chapter, I develop a model that can be used to generate qualitative expectations about RME based on general principles of evolutionary ecology. The purposes of developing this model are to pinpoint those aspects of RME that may have adaptive significance, derive the adaptive consequences of various aspects of RME, and generate predictions for the archaeological signatures of different RME strategies.

**Definitions and general principles**

The concepts and principles of evolutionary ecology are described by Krebs and Davies (1997), Levins (1968), Maynard Smith (1978), and Pianka (1983), and their application to human behavior by Foley (1985, 1987), Smith (1991), and Smith and Winterhalder (1992). In this section, I provide definitions for some terms that have been variously defined by these authors and others, in order to clarify my uses of these terms. The most basic term is adaptation. Adaptation is used in three main ways (Kirch 1980): (1) as the process by which an organism changes in response to environmental constraints; (2) as a description of the actual relationship between an organism and its environment; and (3) as "a measure of the degree of conformity between organismic units and their environment," (Foley 1987:56). This dissertation uses adaptation mainly in the latter sense. The notion conformity denotes the state in which physiological, anatomical, or behavioral mechanisms overcome environmental constraints on survival and reproduction. Natural selection tends to favor the phenotypes of individuals who produce more offspring, and those individuals tend to be more successful in overcoming environmental constraints on survival and reproduction.

I have already used constraints in the sense of limiting factors. The process of adaptation is itself affected by various constraints. These include the time lag between the appearance of new environmental conditions and the appearance of phenotypic responses; historical constraints, including the existing genetic and phenotypic make-up of the population; and the unpredictability of environmental change and of phenotype-environment interactions. Another kind of adaptive constraint is what Foley calls "compromising factors". Organisms are enmeshed in a complex web of ecological relationships, each of which is affected by a different set of factors. Change in one factor may increase the organism's potential fitness in one way while simultaneously decreasing fitness in another way. For example, mustang stallions and male baboons both defend their harems against lone males in order to protect their own stake in the gene pool. However, those defensive actions increase chances of injury, raise caloric requirements, and give other males the chance to mate with the temporarily abandoned females. Conflicts of interest such as these may be resolved by evolutionary trade-offs.

An adaptive differential is the difference between two individuals or groups in the degree of conformity to environmental conditions. This notion applies to pairs of organisms or groups who share a similar adaptation in the same environment but differ in some factor(s) affecting evolutionary success. Therefore, adaptive differentials strongly affect the evolutionary outcome of competition for shared resources.

All behaviors take time and consume energy (Cuthhill and Houston 1997), but an organism's supply of time and energy is finite. This places limits on behavior. Yet, some behaviors also generate energy, such as foraging. An adaptively successful allocation of time and energy requires that organisms take care of all survival needs and still have resources available for reproduction. There are different kinds of costs and benefits;

some relate to an individual's contribution to the gene pool, others to energy captured and expended. This dissertation is concerned with energetic costs and benefits only. Energetic costs and benefits are described by efficiency: "the ratio of energy gained to energy spent," (Cuthill and Houston 1987:99). The term technological efficiency is used here to mean the efficiency of lithic raw material acquisition, processing, and transport, and of tool manufacture and repair.

Technological efficiency is also affected by the efficient function of tools. For example, the super sharp edge of an obsidian blade would be more efficient in many cutting tasks, compared with the duller blade of fine-grained basalt. On the other hand, stronger, less brittle materials should be more efficient in tasks involving heavy blows to hard material, such as woodworking. Thus, the selection of raw materials for making various kinds of tools, and the design of tools for different tasks, will contribute to overall technological efficiency. Fully understanding the relationships between raw material properties and tool use would require a study of wear traces on the edges of tools. Raw material properties would affect the efficiency of tool use mainly in terms of the sharpness of tool edges and the resistance of tool edges to abrasion and fracture when subjected to stresses during use. Sharpness and resistance to abrasion and fracture are functions of raw material fracture properties (brittleness and strength).

Ideally, one could compare data on the brittleness and strength of raw materials with the patterns of use for tools made from each raw material type to assess this component of technological efficiency. However, there are many problems with doing so. Use-wear analysis is notoriously labor intensive, so much so that many months of study are required to analyze a few hundred tools (e.g., Hays 2000). Also, because it has not been established that form equates with function in stone tools, the results of

any such analysis are essentially limited to the specimens analyzed. Moreover, methods for analyzing and interpreting microscopic polish and striations are much better developed than methods for analyzing phenomena that result from fracture (chipping and abrasive wear). Chipping and abrasive wear could affect tool function by changing the sharpness and the shape of a tool's edge, but it is not clear how the formation of polish and striations would affect tool function. Thus, linking a wear study to a study of technological efficiency would probably require developing new and better methods for deriving tool function from abrasion and chipping. I have avoided these difficulties by limiting the present study to the manufacture/consumption component of technological efficiency. It is unlikely that change in technological efficiency is exclusively driven by natural selection on the efficiency of tool use; it is probably also affected by selection on the efficiency of raw material consumption and tool manufacture. Thus, although data on tool manufacture and raw material consumption cannot provide a complete description of technological efficiency, they should be sensitive indicators of technological efficiency.

There are multiple strategies by which an organism might achieve sufficient efficiency for survival and reproduction, and different strategies have different energy and time budgets. A main tenet of evolutionary ecology is that the cost:benefit ratio of each behavior directly affects an organism's reproductive success. "Maximizing efficiency will maximize the amount of energy obtained," (Cuthill and Houston 1997:99), and this will increase evolutionary fitness, on average.

Evolutionary ecologists routinely use the language of problem solving to describe adaptation. The "problems" are needs relating to survival and reproduction. There are inevitably constraints on meeting those needs, such as the elusiveness of prey or an

individual's vulnerability to predators while signaling for mates. "Solutions" are behaviors that overcome those constraints and fulfill the need. Most evolutionary ecologists write about organisms as if they were rational beings making choices among various alternative strategies. Solutions are often described as "strategies", and the appearance of one solution rather than another as a "choice". This language is conventionally used as a heuristic device for generating models; it is generally understood that it does not imply a causal role for rational choice. I follow this convention here.

One approach to applying this framework centers around the notions of optimality and adaptedness. Adaptation is "continuous from fully adaptive to maladaptive," and the entire range is probably represented in the real world (Foley 1987:58). Optimality indicates the degree to which an adaptation approaches the fully adaptive state. To describe a given strategy as optimal is to state that its success in overcoming environmental constraints on acquiring and consuming resources is superior to all other strategies (Nelson 1991). An optimal solution is the best-fit solution among all possible solutions for a given problem, in a given environmental context (Foley 1987). An optimal solution is not necessarily perfect; it is simply more adaptive than alternatives. Also, optimal solutions rarely maximize energy consumption or minimize costs. This is partly because there are limits on behavior (no organism can consume an infinite amount of food), and partly because of all the trade-offs that are involved in most real-world adaptations. Adaptedness denotes the extent to which a given strategy approximates the optimal solution to a given problem.

Here, I do not assume that people always acted either to optimize their adaptations or to maximize some currency, as others have assumed (e.g., Binford 1979, Bleed 1986, Torrence 1983, 1989). Evolutionary theory can only be applied to an

explanation of variation and change in human behavior when there is fitness-affecting variation in behavior. Applying evolutionary theory to human behavior therefore implies that behavior can be adaptive, adaptively neutral, or maladaptive (Dunnell 1980, Leonard and Jones 1987), and this requires us to acknowledge that the adaptations we study may not have been optimal.

The range of alternative actions or behaviors for a given aspect of adaptation is referred to as the phenotypic set (Maynard Smith 1978), or strategy set (Smith 1991). This set of alternatives must be understood in order to understand why natural selection favored one strategy. To a large degree, the success of an analysis of behavioral strategies depends on how adequately we have described the strategy set (Foley 1987).

Evaluating the adaptedness of an organism requires some measure of adaptation; the units of measurement are termed currencies. The ultimate currency is Darwinian fitness, which is difficult to measure among living organisms, and impossible when individual life histories cannot be determined. A common currency in foraging models is the net rate of energetic gain. According to Torrence (1989), the most appropriate currency for studying prehistoric foraging adaptations would be the one on which people placed the most emphasis when making decisions about subsistence, mobility, or technological strategies. That notion stems from an approach stressing past decision making processes, which are assumed to have consistently favored the most optimal solutions to any set of problems. I see two problems with this approach. First, reconstructing past decision making is probably impossible at the level of detail that would be required for a satisfactory explanation of the variation we observe in the prehistoric archaeological record. Those decisions, as Torrence (1989) acknowledges, would have been made in a context of complex environmental and social variation, but

the environmental and archaeological record we have at our disposal provides a very incomplete description of that context. Moreover, we can not know whether people were aware of all possible adaptive strategies to a given set of problems. Second, the reasons people give, or would have given for their behavior are distinct from evolutionary explanations of behavioral variation. Reason-giving and evolutionary explanation are radically different methods of explanation (Dunnell 1980, 1989). The goals of this dissertation will be better served by efforts to construct ecological or evolutionary explanations than by a reconstruction of emic rationalization.

**Application to lithic raw material exploitation**

The above approach is applied with the comparative method: "evaluating the similarities and differences between behaviours and anatomical features in terms of their costs and benefits and comparative survival value," (Foley 1987:64-65). The first step in applying this approach to prehistoric populations is to identify what the problems were facing those populations. One then enumerates the set of possible solutions—the strategy set. By an analysis of costs and benefits, the adaptive value of each strategy in a given environment is estimated and expressed in terms of some currency. This requires an understanding of the constraints operating on the adaptation in question (Nelson 1991). The optimal solution is that with the highest adaptive value. All optimality models contain a strategy set, a currency, and a set of constraints (Smith 1991).

Certain difficulties prevent the current study from following all aspects of the above approach. First, it is not feasible to derive optimal technological solutions to the problem of raw material provisioning among Paleolithic hunter-gatherers. One of the difficulties is that a group's ability to provision itself with raw materials is a complex

function of a large number of factors: the heaviness of rock, the rarity or abundance of raw material sources, the group's need to move, variation in the fracture properties of rocks, risks associated with foraging trips, and so on. Each of these factors may have a different effect on raw material provisioning, and the factors may interact with each other in complex ways. Thus, the strategy set could be very large, and it can be difficult to know the entire range of alternative strategies.

A second problem is that while lithic artifacts were undoubtedly an integral part of a subsistence technology, they provide only partial information about that technology. Missing are the shafts of weapons, the binding agents and hafts of tools (but see Boëda *et al.* 1998, Boëda *et al.* 1999), and any other element that functioned with the lithic elements to procure or process food and organic raw materials. In effect, the costs of RME are a subset of the total cost of subsistence technology. Moreover, RME does not inform us about the benefits side of the equation because, as stated earlier, RME does not entail energy gain, only energy expenditure. Finally, understanding the adaptive constraints on lithic technology is hindered by the inadequacy of our understanding of the functions of lithic artifacts. Although interesting and useful use-wear analyses have been carried out (e.g., Hays 1999, Vaughn 1985), those studies are hampered by methodological difficulties (Grace 1996). More importantly, use-wear analyses can not be applied to tool types as a key for identifying function, and the results of those analyses can only be generalized beyond the studied specimens with difficulty.

All of these reasons make it difficult to know the entire set of cost:benefit relationships in a lithic technical system, and thus to reconstruct the entire strategy set. Therefore, rather than attempting to list the entire range of possible RME strategies and identify a single optimal strategy, a different approach has been chosen for this study. I

shall focus on identifying the RME strategy that was followed as represented by the archaeological signatures in a given assemblage, identify the relative efficiency of that strategy, and compare this with the efficiency of strategies represented in other assemblages. In other words, evidence from two or more assemblages will be compared in order to rank them by adaptedness. If the discontinuity hypothesis is correct, then there should be a set of assemblages that more closely approximate optimal strategies of RME, and these assemblages should be younger than the others.

Implementing this approach requires identifying the environmental and behavioral variables that affect RME in the context of small, mobile hunter-gatherer groups in Late Pleistocene France. The environmental variables that constrain RME are environmental parameters relating to the natural condition of tool stone and its geologic context. In the following section, I discuss those variables.

**Variables that constrain lithic raw material exploitation**

Environmental variables

*1) Density of rock* The most basic environmental variable is that rock is heavy. Because it is heavy, and because Paleolithic hunter-gatherers used so much of it, it would have been quite impossible to carry a lifetime supply on one's person. All users of lithic raw material had to acquire stone during repeated visits to raw material sources. This constrains raw material use in many ways.

*2) Abundance or rarity of raw material.* The rarer the raw material, the stronger the effect of exploitation strategies on technological efficiency. There are two components to lithic raw material abundance: absolute quantities, and spatial distribution. Raw material could be rare in the sense that the absolute quantity of lithic raw material was low. Exhausting the sources would have severe effects on foraging

adaptations in such a case. Since most raw material occurrences are merely surface exposures of very large bodies of rock, depleted occurrences would eventually be renewed by continued erosion and transport, but such processes are typically so slow that they are unlikely to alleviate resource exhaustion within the lifetime of an individual. In the Perigord, lithic raw materials are so abundant, and hunter-gatherer populations were probably so small, that complete depletion of any given occurrence is unlikely (but see Dibble 1991 for possible evidence of source depletion in France).

3) *Spatial distribution of occurrences* Raw material could also be rare in the sense of sparse occurrences. Like thirsty animals coming to a water hole in a desert, people would have to travel to those rare sources frequently, or else live near them. This kind of rarity did not exist in the Perigord. Geneste (1985) provided detailed maps showing about one thousand raw material occurrences in the Perigord, representing over a dozen raw material types. However, the rarity of some *kinds* of raw material might have affected RME in the Perigord. Each of Geneste's raw material types is represented by a different number of occurrences, varying from 470 occurrences of beige Senonian chert to less than 5 occurrences of other raw materials. As I discuss below, these raw materials may also vary in their fracture properties, which is another environmental variable affecting technological efficiency. If two raw materials occur at an equal distance from the site, should we expect them to have been exploited in the same amounts by Paleolithic stoneworkers? The answer might depend on the occurrence densities of each raw material type, as well as its fracture properties. Thus, the effects of absolute abundance, occurrence densities, and fracture properties on RME may depend on how those variables interact in a given setting.

*4) Reductive nature of chipped stone technology* Because chipped stone tools are made by breaking rock apart, and because this breakage invariably results in unusable material, tool manufacture will always entail some waste. Although the relative proportion of waste to useable material can be controlled to some extent by stone working techniques and by the choice of raw material, the generation of waste is an intrinsic property of chipped stone technology.

*5) Fracture properties of raw materials* There are two aspects of the way siliceous cryptocrystalline and microcrystalline rocks break that affect technological efficiency: fracture predictability and flaking strength. I explore each of these terms in detail in Chapter 6; here, I simply give basic definitions. Fracture predictability is the degree to which flake mass and dimensions can be predicted from various controlling parameters, including the applied load. The amount of manufacture waste can be controlled by using more predictable rocks; less waste, in turn, means fewer raw material extraction trips. This, fracture predictability is negatively correlated with acquisition cost and manufacture cost. Flaking strength is the load that must be applied to detach a flake, and it is positively correlated with manufacture cost because higher loads require more energy. Thus, variation in fracture predictability and flaking strength affects RME.

The fracture properties of raw materials must also affect technological efficiency by influencing the aptitude of tools to perform certain tasks. However, as noted above, it was not practical to explore that relationship here.

Behavioral variables

*1) Tool stone carrying capacity* Because people cannot carry all the lithic raw material they will ever need, they must carry a small supply and replenish it as it

becomes depleted. The rate at which they must replenish the supply will depend in part on the size of the package they are able to carry. Each replenishing episode consumes energy and time. Thus, a higher tool stone carrying capacity reduces the number of replenishing trips, and this should result in lower acquisition costs, all else being equal.

*2) Rate of consumption* The rate at which tool stone supplies are replenished also depends on the rate at which tool stone is "consumed", or used up. This will be a function of manufacturing efficiency, the number or frequency of tasks requiring stone tools, and the rate of wear.

*3) Curation* Here, curation is used to mean the conservation of raw material by means of efficient exploitation strategies. This comes into play when tools become dull or broken through use. At that point, people have a choice: go out and obtain more raw material, or refurbish dull edges and repair broken tools. Tool repair, refurbishing, and maintenance are ways to extend the life of a piece of raw material, and they decrease the rate at which new raw material is consumed, which in turn lowers acquisition cost. Other behaviors that conserve raw material include: manufacture methods that result in higher frequencies of useable blanks, such as carefully maintained Levallois or blade cores; using a larger proportion of the blanks to make tools; and using higher frequencies of more predictable raw material.

*4) Storage* Storage of raw materials could decrease costs in two ways. Storing raw materials at the locations of anticipated use would decrease the number of replenishing trips needed. Storage could also be used as a hedge against possible scarcities. Binford's (1979) term "insurance gear", which he applied to the caching of supplies in remote locations as emergency back-ups for future trips to those locations, is

an example. However, there is no clear evidence that lithic raw material was stored during the Paleolithic in the Perigord, and I will not consider this factor further.

Mobility

There are two additional behavioral variables that constrain RME: mobility and embedded acquisition. These affect RME is rather more complicated than the above variables. Unless people live next to an inexhaustible supply of high-grade tool stone, they must travel repeatedly to raw material sources. The diverse raw material composition of most Paleolithic assemblages in the Perigord suggests the prevalence of such a pattern. The way in which people traveled to raw material sources must have been affected by the pattern of residential mobility. Furthermore, our predictions about the character of assemblages depend heavily on assumptions concerning residential mobility. The model I present below makes assumptions about the mobility of Pleistocene hunter-gatherers in Europe and elsewhere, and those assumptions should be examined.

Nearly all assemblages in the Perigord contain small percentages of non-local raw materials (those obtained from sources that lie more than 12 km from the site[1]), and many show evidence of the transport of small amounts of raw material over several dozen kilometers. This could be interpreted in at least two ways. It may mean that people gathered stones from distant sources, either during food foraging trips or during specialized tool stone gathering expeditions, and brought them back to camp. Alternatively, it may suggest high residential mobility and a circulating pattern of landscape use (Geneste 1985, Roth and Dibble 1998). In this case, much of the non-

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[1] In Chapter 2, I give the reason why I chose to define "non-local" this way.

local raw material in any assemblage probably represents the discarded remnants of material that was kept in a mobile tool kit for an extended period. As people moved away from the source of a given raw material, their supply of it gradually dwindled and was replenished as the need or opportunity arose.

These two hypotheses can be distinguished by examining how patterns of technological composition vary over space. Technological composition is the frequency distribution of technological categories—cores, blanks, chunks, and kinds of blanks—within an assemblage. Technological composition is an indicator of the manufacturing activities that took place at the site. For example, extraction sites tend to contain cobbles or nodules that have been "tested"—struck once or twice to check for flaws—along with large cortical flakes, fragments of cobbles and cores, and chunks. In contrast, sites where tool repair was the only activity have very small, non-cortical flakes such as biface thinning flakes, and perhaps some worn and/or broken tools. Technological composition also indicates the form in which lithics were imported to the site. Where raw material was imported as raw nodules or cobbles, evidence of those will remain, although the exact nature of that evidence will vary depending on how much reduction took place after bringing the raw material to the site.

In central place models, people reside for relatively long periods at a residence, make foraging trips for food and other resources, and bring those resources back to the residence, where most processing and consumption occurs. Lithic raw material acquisition would occur in brief trips, which might extend over long distances. In this case, we would expect the technological composition of non-local stone to reflect the import of large, relatively unprocessed units of raw material. That material would have been reduced entirely, or almost so, at the residential site. For example, Henry (1995)

used the raw material composition of non-local materials in an assemblage from Tor Faraj, a Middle Paleolithic site in southern Jordan, to argue for direct provisioning with long-distance foraging trips. The duration of residence at such sites probably exceeded the duration of raw material from a single extraction episode, and multiple episodes of raw material extraction, transport, and consumption would be represented in a single assemblage.

On the other hand, if resources were acquired through frequent residential moves rather than long foraging trips from a central place, then the life cycle of a unit of raw material might extend beyond the time of residence. That is, people would consume raw material as they moved. This leads to an entirely different set of expectations for the technological composition of non-local raw materials. Non-local raw materials would be represented only by the pieces remaining when residence was taken up at the site, and these pieces would represent only the latest phases of manufacture and use. The raw material would show evidence of extensive consumption in between the place where it was acquired and the site where the assemblage was recovered. In addition, the technological composition of local and non-local raw materials would differ.

Many lithic assemblages show a pattern in technological composition that is more consistent with the latter model of mobility. In the Perigord and other regions, the manufacture process was "partitioned" over space (Geneste 1985, 1990). The initial processing of nodules occurred near raw material sources, with subsequent phases of reduction taking place progressively further away. Raw materials were transported in the form of raw or lightly processed nodules for distances of 5 km or less. At sites containing raw material from sources farther than 5 km away, only prepared cores and flakes (retouched or not) are normally represented. Raw materials from sources farther

than 20 km or so from the site are represented solely by flakes, some of which are retouched. This pattern has now been documented in a large number of Middle and Upper Paleolithic assemblages in the Perigord and elsewhere (e.g., Bierwirth 1996, Blades 2000, Byrne 1980, Chadelle 1983, Conard and Adler 1997, Lucas 2000, Martinez 1998, Meignen 1988, Tavaso 1984, Turq 1992).

This pattern is so consistently documented that it led Demars (1994) to predict that chalcedony/millstone was locally available for the Upper Paleolithic inhabitants of the Brive region (Corrèze), despite that the nearest occurrences of this raw material lay about 40 km west. He based this interpretation on three kinds of evidence: the presence of cores of that material, high ratios of debitage to tools, and the allegedly poor quality of the material. According to Demars, these are all characteristics typically associated with local raw materials. Later, Demars (1998) reported finding a natural occurrence of chalcedony/millstone about 40 km east of Brive. This places the Brive sites in between two occurrence areas. If the chalcedony outcrops in those areas belong to the same geologic unit, then it is likely there are additional outcrops, still undiscovered, nearer to Brive. If so, then Demars' prediction, based solely on archaeological data, is true.

Some of this partitioning probably resulted from field processing: the reduction of raw nodules in order to make them more transportable with minimal decreases in their potential utility (Metcalfe and Barlowe 1992). Some of it also resulted from strategies of maintaining a supply of raw materials during extensive travels. This suggests that groups moved residences frequently; stayed at each residence for a relatively short period, compared to the time it took to consume their raw material supply; and acquired most of their raw material from sources encountered during travel or located near camps. Because this interpretation is backed by so much empirical evidence, I base the

following model of RME on the assumption of high residential mobility, in which the duration of a given unit of raw material usually exceeds the duration of residence at any given location.

This residential pattern would generally lower the acquisition costs of lithic raw material relative to central place foraging. Essentially all raw materials would be "local", in that they were collected near residential locations or during travel between residential locations. The presence of non-local raw materials in an assemblage is due to sequential residential moves in a direction that happens to be away from those occurrences. This does not mean that all raw materials entail an identical extraction cost, however. For one thing, there is a difference in cost between collecting cobbles from a stream that runs by one's camp, and making a 10-km round trip to collect nodules from a different source. Even if the absolute magnitude of that difference seems low, we must evaluate the possibility that it had an effect on RME strategies.

Second, even when raw materials are collected "along the way," carrying them costs energy. This cost is directly proportional to the amount of raw material and the distance it is carried. Therefore, we can deduce that if some raw materials were collected in larger amounts than others, they would entail a higher cost (assuming all were carried an equal distance). There is at least one factor that might cause differences in the amounts of stone collected at various sources: raw material fracture properties. Because fracture properties affect manufacture cost, people might stock up on any "high quality" raw materials (presumably, those with higher predictability and perhaps lower strength) that they happened to encounter. Of course, they might also go out of their way or travel unusually long distances to collect such materials. Whether this would result in an overall decrease in cost depends on whether the energy saved by

using more predictable raw materials exceeded the extra energy expended to collect them. In short, each kind of raw material might have a different total cost, and the cost of each might have its own internal structure.

It would be nice to derive an equation from the above relationships that could be solved to obtain the total energy budget of RME and differences in cost between raw material types. One could plug in values for the acquisition and manufacture costs of each raw material, enter the quantities of each raw material type in the assemblage, and then calculate the total acquisition cost of each for comparative purposes. Regrettably, not all of the requisite information can be reliably obtained. Although technological composition can be used to reconstruct the extent to which each raw material was consumed before being introduced to the site, it can not tell us how much of each transported raw material was abandoned before people came to the site. Some nodules from a non-local source could be collected, consumed, and completely discarded before reaching the site, even if other remnants of nodules from the same source remained. This missing evidence problem is far more likely to skew our perception of RME for non-local raw materials than for local ones, since for the latter, some evidence of the material's initial form (nodules or cobbles) is more likely to be well-represented.

However, we can deduce that quantity is correlated with cost, since carrying more stones consumes more energy. Moreover, since locally obtained raw materials were carried shorter distances than non-local ones, a quantity of non-local raw material always represents a higher acquisition cost than an equal quantity of local raw material. Therefore, as the frequency of non-local raw material increases, overall cost increases. This provides a useful way to compare the overall acquisition costs represented by different assemblages.

Embedded acquisition

Binford (1979:259) defined "embedded procurement strategy" as the acquisition of raw materials for implement manufacture "incidentally to the execution of basic subsistence tasks." This is opposed to direct procurement, in which people go "out into the environment for the express and exclusive purpose of obtaining raw material for tools" (Binford 1979:259-260). Direct procurement was very rare among the Nunamiut groups he studied. Their embedded procurement strategy made the costs of raw material acquisition negligible. Thus, whether a given foraging group relied on an embedded or a direct procurement strategy would have significant implications for acquisition costs, which would in turn influence the frequency with which non-local raw materials were used and the forms in which raw materials were imported to residential sites.

Binford intended his conclusion about raw material procurement among the Nunamiut as a general statement about provisioning strategies among foragers. This is clear from his criticism of Gould's (1978) argument that technological factors played a role in raw material provisioning, which was based on a study of lithic raw material procurement at Puntutjarpa Rockshelter in the Western Desert of Australia. Approximately 61% of the adzes in the 10,000-year sequence were made of local white chert, and 27% were made of non-local, "inferior" cherts. To Gould, this appeared to be an anomaly: why import rocks when abundant, high-quality chert is available locally? To resolve this, Gould developed his "exotic stone hypothesis," which would explain the import of non-local chert as a side-effect of reliance on long-distance social networks during periods of drought. That is, the acquisition of non-local chert was embedded within subsistence activities, and this agrees with Binford's general approach.

However, Binford (1979) phrased his argument about embedded procurement in such a way as to exclude technological and utilitarian factors. To show the incorrectness of that argument, Gould and Saggers (1985) examined the functional properties of the raw materials used to make adzes in two archaeological sites. They carried out a series of experiments, making adzes of raw materials found within a 20 km radius of Puntutjarpa and James Range East sites, and then using the adzes to stroke wood until the bits wore out. Their results suggested to them that the non-local raw materials found in the James Range East assemblages were more durable. They concluded that the functional properties of the stone did play an important role in raw material provisioning; that is, not all raw material use depended on the embedding of procurement within subsistence activities.

While disagreeing sharply over the question of whether foragers use an embedded or a direct procurement strategy, Binford (1979), Gould and Saggers (1985), and Binford and Stone (1986) all seem to agree that the question has some universal answer. However, the high degree of variation in human behavior in general suggests that this is a misleading approach. It seems more reasonable to ask what the relative importance of embedded and direct procurement was in a given group of foragers. Binford and Gould could both be right: the Nunamiut may well have lacked direct procurement, while the prehistoric inhabitants of Australia's Western Desert may have relied on direct procurement for some raw material provisioning. Research in both areas stresses the importance of understanding the factors that determine the relative importance of embedded and direct procurement in a given group's provisioning strategy.

Despite the insights offered by the above authors based on their ethnoarchaeological work, there is still great uncertainty about the factors that affect raw material procurement, and we still lack the ability to make accurate predictions about procurement strategies in different environments. For example, Marks *et al.* (1991) claimed that we should expect to see embedded procurement in situations where raw material selection, acquisition and economy are not controlled by the availability of sources; that is, where acquisition costs are low. They suggested that the Avdat/Aquev area in the Negev Desert of Israel, and the Rio Maior Valley in Portugal, are two examples of this situation. Yet, they then presented data on Paleolithic sites from both areas to argue that raw material procurement was "often acquired as a separate and purposeful activity, rather than being embedded in other activities," (Marks *et al.* 1991:132).

This was based on inter-site comparisons in which lithic data from each site, including the sizes of blanks, percentages of cores, mean core weights, and blank:core ratios were compared with environmental data including distance to water and chert sources. For example, in the Avdat/Aqev area, sites interpreted as base camps, and that were near water sources, had smaller blanks, smaller cores, and higher blank:core ratios than sites interpreted as hunting stations and workshops, which were located near raw material sources but further from water. This suggested to the authors that proximity to water was a higher priority for choosing settlement locations than proximity to chert, and that chert was procured directly. Marks *et al.* (1991:138) concluded that, despite their initial expectations, the "predictably uneven distribution" of raw material sources and the spatial relationships of lithic raw material to other resources can have

significant effects on procurement and economy, even when lithic raw material is abundant and widespread.

Although Marks *et al.* (1991) initially suggested that ubiquity of raw material should encourage embedded procurement, this is very different from the conditions that prevailed in the Nunamiuts' habitat, the context in which Binford (1979) defined the term embedded procurement. There, lithic raw materials and other resources appear to have been far-flung, requiring long foraging trips through dangerous terrain, with significant risks of death by starvation or exposure. In such an environment, direct procurement would be a costly strategy. In addition, lithic raw materials in Alaska were found at or near locations where other resources could also be found (fish, game, and fur animals). Finally, lithic raw materials were not an important part of the economy of the Nunamiut, who relied mostly on metal tools. Binford's (1979) inventory of the gear in people's houses does not include stone tools. He mentioned that men invariably carried prepared cores as part of their "personal gear," but his description of their economic activities suggests that stone tools were employed very rarely, and only when more desirable tools were lacking.

Given these conditions, an embedded procurement strategy makes sense: it would significantly lower the cost (and risk) of acquisition. It is not clear why Marks *et al.* (1991) believe such a strategy makes sense in an environment that differs in every relevant way from that of the Nunamiut. As Binford (1979:255) stressed, "the Nunamiut are an 'extreme' case in both their logistic and storage characteristics, as well as in the seasonal variability of their access to different resources." Whether we should expect to see evidence of embedded procurement strategies in Late Pleistocene France is an open question.

The problem of direct versus embedded procurement is an interesting research question, but it cannot be addressed until the archaeological correlates of both strategies have been identified. There have been only a few attempts to infer embedded or direct procurement in Paleolithic contexts, and those are problematic. One of the most intriguing is Henry's (1995) study at two Mousterian sites in southern Jordan. Tor Sabiha is located near several sources of chert, while Tor Faraj is at least 17 km from the most heavily used source. While not differing greatly in the abundance of lithic remains, the single assemblage from Tor Sabiha differed from the three stratified assemblages from Tor Faraj in raw material and technological composition. At Tor Sabiha, primary processing and tool manufacture were both represented, but primary processing was better represented in the Tor Faraj assemblages, along with raw material acquisition (that is, raw blocks and prepared cores). The Tor Sabiha assemblage also showed what might be described as a more even distribution of the raw material sources represented. The Tor Faraj assemblages, while containing the same raw material types, were dominated by a single source of chert. To Henry, these data suggest a pattern of direct procurement at Tor Faraj. In contrast, he interpreted Tor Sabiha as a temporary station that was occupied briefly during foraging episodes, where raw material acquisition was "casual or opportunistic" (that is, embedded within the acquisition of other resources).

On the one hand, the expectations on which Henry's interpretations are based seem logical: a direct procurement strategy targeting a specific source would result in a high degree of primary processing and in a raw material composition dominated by a single kind of chert. Yet, these are not the necessary archaeological correlates of direct procurement as defined by Binford (1979). Those correlates are 1) the co-occurrence of

lithic raw material sources with other resources, and 2) a coincidence of chert procurement with foraging trips for other resources. Therefore, to identify embedded procurement in the archaeological record, we must identify temporal and spatial correlation between the procurement of tool stone and the procurement of other resources. Direct procurement, on the other hand, would be signaled by the absence of those two factors. Henry's data from Tor Faraj only show that a lot of material was acquired from a single source, and that it was transported in bulk to the alleged habitation site. That behavior is equally consistent with direct or embedded procurement. The Nunamiut, for example, appear to have picked up and carried nodules of chert—bulk procurement—even though this was embedded within their subsistence strategies (Binford 1979).

Roth and Dibble (1998) presented an equally intriguing, and equally problematic, argument regarding embedded procurement at the Mousterian site of Combe Capelle Bas in Dordogne, France. This site is located at a large source of Campanian chert, which was heavily exploited there, making up 93% of all the assemblages. About half of the remaining cherts in each assemblage were made of Campanian flint from other, unidentified sources, and half were made of various non-local cherts found up to 20 km away. Roth and Dibble (1998) presented data that they argue shows local and non-local raw materials were exploited with the same intensity. These data consist of frequencies of Middle Paleolithic tool types that they consider to be indicators of retouch intensity based on earlier studies (Dibble 1995, Dibble and Rolland 1992, Rolland and Dibble 1990), and data on the surface area:platform area of flakes. The lack of significant differences in retouch intensity between local and non-local raw materials led Roth and Dibble (1998:58) to conclude that raw material procurement at Combe Capelle Bas "was

embedded in other activities rather than direct (Binford 1979)," and therefore, the use of both local and non-local raw materials was "opportunistic."

Roth and Dibble's conclusions are difficult to accept because they conflated a number of important issues that ought to be considered separately. For example, they argued that raw materials that are transported over longer distances would be used for a longer period of time, and this should result in indicators of greater intensity of use. This could only be true if artifacts were consumed during transport, and if tool use and rejuvenation was more intense during transport than during the occupation of the site where local raw materials were used. However, the issue of whether raw materials were consumed during transport is distinct, strictly speaking, from the issue of direct/embedded procurement. Apparently, Roth and Dibble assumed that raw materials acquired directly would not be consumed during transport but that those acquired in an embedded system would be. Henry's (1995) inferences regarding procurement strategies at Tor Faraj also seem based on that assumption. Yet, according to Binford (1979), at least one Nunamiut hunter carried a single core of chert, acquired within an embedded pattern of procurement, among his personal gear for years without ever using it. He did so in order to insure himself against possible shortages in his personal gear, although such a shortage never occurred.

Binford (1979), Gould and Saggers (1985), Marks *et al.* (1991), Henry (1995), and Roth and Dibble (1998) all seem to conflate the direct/embedded procurement issue with the issue of how technological and/or functional factors affect provisioning. The prevailing idea is that embedded procurement is a casual or opportunistic procurement system, as far as lithic raw materials are concerned, while direct procurement indicates logistic organization. This stems from Binford's (1979) argument that embedded raw

material procurement was unaffected by technological or functional constraints. Yet, Binford's exposition of lithic raw material procurement among the Nunamiut excluded any examination of technological or functional factors.

Binford carried out no experiments on the cherts used by the inhabitants of Anaktuvuk village, nor did he document the abundance or distribution of raw material sources in that area. Thus, when Binford observed Nunamiut collecting lithic raw materials during foraging episodes for other resources (or recorded stories about such episodes), he must have assumed that the sole reason for exploiting those particular sources of raw material was their proximity to other resources. However, it seems possible, or even likely, that Nunamiut foragers in a given location had several chert sources to choose from, but that they ignored some sources in favor of others based on the abundance of nodules at the outcrops, the fracture properties of the stone, or some other technological or functional factor. Binford could not have known about such factors unless he specifically asked the Nunamiut hunters about them. He did not report any such inquiry, and he did not observe the procurement of lithic raw material by Nunamiut. Thus, it is possible that Nunamiut tool stone procurement was dependent on technological and functional factors, even though it was embedded within subsistence activities (Blades 2001). Even if that were not the case with the Nunamiut, there is no logical reason why it could not be the case elsewhere. In sum, the issue of embedded/direct procurement is independent of the issue of whether procurement was affected by technological and functional factors.

Returning to Binford's (1979) exposition of embedded procurement among the Nunamiut, it is clear that the issue is about resource scheduling alone. Embedded procurement is a form of resource scheduling that increases the benefits of foraging trips

by effectively lowering overall costs. Evidence showing that the foraging territories for lithic raw material were the same as those for other resources, such as game, and that these resources were collected simultaneously would support the hypothesis of embedded procurement. However, current methods do not permit us to determine either of these possibilities.

If the tool stone foraging radius was either identical to the foraging radii for other resources, or larger than those foraging radii and encompassed them, then assemblage raw material composition would give an accurate picture of the group's overall foraging radius. However, if the tool stone foraging radius was smaller than those other foraging radii, or differently located, or both, then assemblage raw material composition would say little or nothing about the group's overall mobility or foraging radius. People certainly gathered and consumed several kinds of resources in the Paleolithic: at the least, these included animal foods, plant foods, tool stone, and organic raw materials. Yet, there is no reason to suppose that these resources were gathered from the same locations.

In addition, it is difficult or impossible to compare the foraging radius for tool stone to the foraging radii of other resources because lithic raw material is the only one for which it is possible to infer source locations with some confidence. This is largely due to the fixed nature of tool stone outcrops, compared with mobility of animals and the fluctuating nature of floral and faunal ranges, at the gross level of chronological resolution to which we are generally confined by dating uncertainties. Therefore, it is not currently possible to reconstruct the foraging radii for plant and animal sources in the same manner that has been done for lithic raw materials (e.g., Bricker 1975, Demars 1994, Geneste 1988). We have no way of knowing whether assemblage raw material composition gives an accurate picture of a group's foraging radius and mobility pattern.

We also have no way of knowing whether foraging trips for lithic raw materials occurred simultaneously with foraging trips for other resources, because we lack data that would permit a precise reconstruction of when people did various activities. Therefore, it is not possible to determine whether Paleolithic foragers followed an embedded or a direct strategy of lithic raw material procurement.

However, it should be possible to determine whether raw materials were consumed during transport, or simply picked up and carried all the way back to the residence without being used. Data concerning phases of manufacture, core and flake size, degree of core reduction, and retouch intensity relate directly to that issue. It should also be possible to determine the relative importance of different environmental constraints on raw material provisioning, including the abundance and distribution of raw material occurrences, raw material fracture properties, and variation between raw material types in these factors.

**Model of lithic raw material exploitation**

The concepts and assumptions discussed above can now be used to assemble a model of RME, the purpose of which is to generate a method for assessing the technological efficiency represented in archaeological assemblages. The model is intended to be applied to foragers who meet the criteria discussed above and in the preceding chapter: small groups of hunter-gathers, relying heavily on hunted game, lacking extensive social networks, acquiring lithic raw material directly from sources (rather than from other groups), having high residential mobility (in which the average duration of residence is less than the time it takes to consume a given quantity of raw material), and under stress from competition with similarly adapted groups.

These foragers must address the following questions:

1. How far to go to get tool stone? Or, when to spend energy on special trips for tool stone, as opposed to using only what is encountered incidentally during travel between foraging patches and during residential moves?
2. When unusually high-quality raw materials are encountered, how much should be collected?
3. How much energy to invest in curation techniques? Or, when should curation measures be used to conserve raw material?

The model I develop here assumes that increased technological efficiency is adaptive. The question addressed is, which strategies of RME increase technological efficiency? Since RME costs energy but provides no immediate energetic benefit, differences in the technological efficiency of various strategies will relate primarily to variation in their costs. There are two main components to the cost of RME, acquisition costs and manufacture costs. Lowering them increases efficiency.

Acquisition costs

*Managing source distance*

One way of decreasing acquisition costs is to decrease source distances; that is, to rely more heavily on raw materials available in or near the immediate vicinity. Within a context of high residential mobility in which all raw materials are essentially "local", this factor is not expected to play a large role. However, there is no reason to exclude that extra trips to non-local sources may have been made; if so, decreasing the frequency of such trips would lessen acquisition costs.

*Curation*

Another way to decrease the overall cost of RME is to use curation techniques in order to conserve the raw material supply. As I discussed above, there are various techniques of curation, each relating to a different aspect of raw material consumption:

1. core reduction intensity;
2. blank selection intensity;
3. tool repair and maintenance;
4. manufacture methods that result in higher frequencies of useable blanks (e.g., Kuhn 1995);
5. use of more highly predictable raw material.

Each of these leaves its mark on the technological composition of the assemblage. Core reduction intensity is the degree to which a core's potential to yield useful blanks is realized. One measure of core reduction intensity is the flake:core ratio of individual raw material types. This measure can be used when there are grounds to suppose that the cores and flakes in the assemblage are an unbiased representation of core reduction. If many cores or blanks are missing from the assemblage, then the flake:core ratio is meaningless. Other potential measures of core reduction intensity are the number of striking platforms per core, and the amount of cortex remaining on the core.

Blank selection intensity refers to the proportion of blanks selected for use as tools. Typically, only some of the blanks produced during an episode of core reduction are made into, or used as, tools. As the proportion of blanks selected for tools increases, so does technological efficiency.

Tool repair and maintenance consists of renewing worn and broken tools so that they will continue to be useful. The energy consumed by tool repair and maintenance is

less than that consumed by striking new blanks, especially if the latter requires preparing a new core. Tool repair and maintenance also extend the use-life of a raw material supply, which will tend to decrease the number of raw material acquisition trips. Thus, it decreases manufacture costs and acquisition costs.

"Manufacture methods" are ways of preparing a raw nodule or cobble for use as a core, plus all the steps that are taken in preparation for and including blank production: recurrent unipolar Levallois is one manufacture method; bipolar blade reduction is another. Manufacture methods that result in higher frequencies of useable blanks will also decrease acquisition costs by reducing the need for raw material acquisition trips. It is not clear which manufacture methods offer the highest ratios of useable blanks per unit of raw material, or if any do. The number of blanks struck from any give core is a function of many factors, including the occurrence of large voids in the rock body and accidents, such as large hinge terminations in the middle of a debitage surface. However, if manufacture methods tend to differ in technological efficiency, then using more efficient methods is a form of curation. If manufacture methods depended on raw material fracture properties, then we would expect significant differences in the manufacture methods inferred for raw materials that differ in fracture properties (e.g., Bamforth 1990, Brantingham *et al.* 2000). Such a dependency probably exists, for according to Crabtree (1967:8), "any variation in [a raw material's] quality requires a different method of flaking."

Raw material that fractures more predictably can be used to decrease overall costs, including both acquisition and manufacture costs, because it allows a higher ratio of useful blanks per unit volume. Thus, an increased reliance on the raw material types that have the most predictable fracture will decrease costs. Clearly, if sources of those

materials also happen to be located further from the residence location or foraging path, obtaining them entails a higher cost than obtaining more locally available raw materials. As I discussed above, in this case, using non-local raw materials may increase rather than decrease costs, unless the additional acquisition cost is compensated with a decrease in manufacture cost.

These are all examples of curation. Curation solves the problem of extending the use-life of a limited amount of raw material. It helps resolve the conflict between two opposing constraints on RME: the heaviness of rock and the relatively high rate of waste from chipped stone manufacture. If RME were a function of the first constraint only, then selection would favor carrying the lightest pieces of rock always. Of course, such small pieces would not last long, requiring many more trips for collecting raw material. If RME were a function of the second constraint only (high rate of waste), then selection would favor carrying the largest possible quantity. Most adaptations probably involved carrying a quantity small enough to be transportable without being too small to be useful for an extended period. Any strategy that accomplishes that is an adaptive trade-off. Curation is one set of techniques that can be used in such a strategy.

*Achieving the optimal package size*

Another strategy that serves as a trade-off for the same dilemma is choosing an optimal package size for each unit of raw material. Kuhn (1994) attempted to model optimal solutions to meeting the twin needs of utility and transportability in the "mobile toolkit" or "personal gear" (Binford 1979) of foragers. His model addresses two questions: Should people carry cores or tools; and, What is the optimal size of object to carry? For cores, this model mathematically equates utility and mass; for flakes, the model expresses utility as a function of both length and functional constraints on size.

The model assumes that every object contains a small amount of material than will not be used: the eventual wasted core, or the tool "slug" (Gould and Saggers 1985) that is too small to handle. Kuhn believed that this unusable component makes up a larger proportion of the initial mass of cores than the initial mass of flakes.

Kuhn (1994) used the mathematical terms of the model to generate mass/utility curves for hypothetical cores and flakes. These suggested that carrying flakes results in a higher utility per mass than carrying cores, and that relatively small flakes are better. According to this model, the optimal flake size is 1.5-3.0 times as large as the size of the minimum useable size (the slug). Archaeological data from Mousterian sites in Italy support the predictions of Kuhn's model concerning optimal flake sizes. However, he found the presence of transported cores in many assemblages to be inconsistent with the model, and hypothesized that this results from cores being more multifunctional than flakes. Cores are more multifunctional because they can be used as tools, and because various kinds of blanks can be struck from them depending on one's needs.

Kuhn's (1994) model suggests a way to test whether the portability of transported raw material supplies was a significant factor. If it was, then transported objects—those made of non-local materials—will be smaller than those made of local raw materials. This should hold true for both tools and unmodified blanks. However, the consumption of raw material during transport would complicate the matter. Artifacts made of non-local raw materials might be smaller than those made of local materials because they were retouched and/or resharpened more, and not because of an effort to increase their portability. Several researchers in the Perigord have found that retouched tools are significantly larger than unretouched blanks despite the reductive effect of retouch (Blades 2001, Chadelle 1983, Dibble *et al.* 1995, Roth and Dibble 1998, Geneste 1985).

However, they have not examined the question of whether such a relationship is equally strong in tools made from local and non-local raw material. One way to assess this is to examine differences between retouched and unretouched blanks of local raw materials, and then compare this with the differences between retouched and unretouched blanks of non-local materials. If tools made of non-local materials are smaller than those made of local materials, and if this difference results from greater retouch and modification of the non-locals during transport, then the non-local raw materials should show a larger difference between modified and non-modified flakes than local raw materials do.

Manufacture costs

*Costs regulated by manufacture methods*

Paleolithic stoneworkers were not simpletons who hammered out blanks the only way they knew how. They were masters of a difficult craft, who knew multiple solutions to the problem of obtaining tool quality flakes from nodules and cobbles that vary infinitely in shape and fracture properties (Gallet 1998; Hietala 1983; Kleindienst 2000; Leroi-Gourhan 1943; Van Peer 1992). The presence of multiple blank production methods within individual assemblages attests to this. It also suggests significant variation in manufacture costs. Blank production methods differ in the size and shape of the blanks produced, and also in the ratio of blanks produced to the initial mass of stone. Increasing this ratio would lower overall cost by lowering the quantity of raw material needed for a given quantity of tools.

Popular texts and some scholarly publications maintain the view that blade technology is more efficient than flake technology (e.g., Mellars 1989, Pfieffer 1990). This idea apparently originated with Leroi-Gourhan (1964), who claimed that the rise of blade technology was the late manifestation of a long, gradual increase in the amount of

cutting edge that could be obtained from a given quantity of raw material. According to Leroi-Gourhan, this began when chopping tools, with about 40 cm of cutting edge per kilogram, gave way to flake cores in which 1 to 5 meters of cutting edge could be obtained from a 1 kilogram core. With the introduction of blade cores, that figure increased to tens of meters of cutting edge per kilogram.

Bordes (1967) pointed out a significant problem with this argument: it ignores the enormous quantity of unused flakes and blades found in most Paleolithic assemblages. Bordes also questioned how Leroi-Gourhan's notion of cutting edge could be applied when many blade tools were only retouched on a small area of the blank. For Bordes (1967:41), there was a better explanation: "The abandonment of hand axes was therefore probably not related to the conservation of chert, or to the length of useful cutting edge per kilogram of chert, but to a change in the conception of the tool kit, in which different functions, initially fulfilled by a hand ax, were partitioned into various flake tools."

There is, however, at least one major problem with Bordes' hypothesis: it relies on an equation between a tool type and a functional tool. Bordes (1981, 1969) himself was one of the earliest to acknowledge that typology is an imperfect means of describing stone tools (Rigaud 1993). One of the shortcomings of morphological typology is that we cannot know whether the types we devise performed separate functions. Bordes did not see this as a shortcoming of typology, but rather as a question that must be addressed with other kinds of data. However, others have questioned the usefulness of morphological typology on the basis that many types do not correspond to functionally distinct kinds (e.g, Bisson 2000; Dibble 1988, 1995; Kolpakov and Vishnyatsky 1989). Moreover, as Bordes also noted, some unretouched flakes were used as tools, while

some retouched pieces (such as laurel-leaf points or carinated endscrapers) may never have been used.

Demars (1989, 1994) presented a third explanation for the rise of blade technology. He argued that mobile Upper Paleolithic hunter-gatherers would have benefited from a technology permitting the maximum of utility from the lightest package. According to Demars, blade technology accomplishes this because blades, which he says are lighter than flakes (see also Nelson 1991), have a much greater potential for being re-worked and repaired, due to their shape. Thus, by transporting non-local raw materials in the form of blades, people could have achieved an optimal trade-off, similar to that proposed by Kuhn (1994) for Mousterian hunter-gatherers in Italy. Demars' hypothesis can be tested in the same way proposed above for Kuhn's optimal package size model: by comparing the sizes of retouched and unretouched blades among local and non-local raw materials.

*Costs regulated by choice of raw material*

Demars took his explanation one step further, and argued that certain raw materials would have been favored for blade making because of their fracture properties, or their "aptitude" for blade production. Based on an analysis of the raw material composition of blade and flake tools in over 70 Upper Paleolithic assemblages from the Perigord, he suggested that Bergeracois chert was transported over longer distances than other raw materials, and that it was "privileged" for the use of blade tools because of its mechanical properties (Demars 1994:2, 100, 133). Demars also claimed that fluctuations in the percentages of Bergeracois in Perigord assemblages across the various Upper Paleolithic industries are directly tied to past oscillations in people's reliance on blade technology.

This argument impinges on issues that have been raised recently by a number of lithic technologists who emphasize the importance of toolkit design in hunter-gatherer adaptations (e.g., Bamforth 1986, 1991; Beck and Jones 1990; Bleed 1986; Brantingham *et al.* 2000; Cowan 1999; Eerkens 1998; Ellis 1997; Hitchcock and Bleed 1997; Kelly and Todd 1988; Knecht 1997; Nelson 1991,1997; Shea 1997). Among other findings, this research has shown the importance of several factors that influence the design of mobile tool kits, such as reliability, maintainability, flexibility, versatility, and transportability (see especially Bleed 1986, Bamforth 1986, and Nelson 1991). These studies tend to emphasize the efficient design weapon and tool systems as a strategy for coping with time stress and the risk of failure during foraging episodes. Demars' (1989, 1994) study adds to this developing body of theory by introducing raw material choice as an additional factor affecting efficiency. According to Demars, blade technology increases technological efficiency, and reliance on high quality chert—specifically, a variety known as Bergeracois—enhances that efficiency. Using similar reasoning, Geneste (1985) argued that Mousterian stoneworkers in the Perigord tended to use high quality raw materials for the manufacture of Levallois blanks, reserving lower quality stone for denticulates and other types. The combination of high-quality raw material with efficient blank types represents significant technological organization, according to Geneste. The studies by Demars and Geneste are important developments in the study of technological organization, and they suggest several ways in which raw material choice can affect technological efficiency.

One of the ways in which Demars attempted to support his argument was by showing that blade tools are smaller than flake tools. For him, a significant difference would suggest economizing behaviors. Figure 2.1 (from Demars 1994), in which the

mean weights of flake tools are plotted against the mean weights of blade tools in each assemblage, seems to show this very clearly. However, as Demars (1994) cautioned, there are at least three reasons to treat these results carefully: the presence of patina on many pieces, which might bias the weights of different kinds of chert differently; the fact that he did not weigh whole and broken tools separately; and the biased collection practices of the excavators of most of these assemblages, in which large and/or "typical" tools were collected preferentially. Moreover, Chadelle (1983) and Blades (1999, 2001) have provided data from Upper Paleolithic assemblages in the Perigord showing that retouched pieces were made on the largest blanks, and that tools made of Bergeracois tend to be larger than those made from other raw materials.

Demars also presented data showing that tools from Brive basin sites are smaller than tools from sites nearer to sources of Bergeracois chert, Senonian chert, and chalcedony/millstone. This is especially pronounced among Aurignacian and Gravettian assemblages. As he noted, this suggests a negative correlation between tool size and source distances. For Demars (1994:129), the smaller size of blade tools, and negative correlation of tool size with raw material source distance both indicate that "the absence of raw material in the Brive basin led prehistoric people to use chert in a more exhaustive fashion, to renew tools for a longer period of time, or to use smaller blanks."

This last statement contains two distinct hypotheses. One is that tools were used, renewed and repaired as people moved away from the raw material sources where the tool stone was obtained, resulting in a negative correlation between tool size and raw material source distance. I shall refer to this as the "distance/attrition hypothesis". The other is that people manufactured smaller blanks when they intended to carry those blanks over long distances or for an extended period, which I shall refer to

as the "blank portability hypothesis." Figure 2.2 illustrates how these two hypotheses might be tested.

The principle phenomenon that the blank portability and distance/attrition hypotheses are both designed to explain is a significant difference in size between non-local and local raw materials, with non-locals being smaller than local ones. Thus, the first step is to determine whether such a size difference exists among blanks, retouched or not. If there is no size difference, then neither hypothesis is called for.

If there is a significant difference in size between local and non-local blanks, then the next step is to determine whether there is a significant difference in size between the retouched and unretouched blanks (that is, between "tools" and "raw blanks"). This presupposes, of course, the presence of both raw blanks and tools from non-local occurrences. Here, things become a little tricky. The distance/attrition hypothesis states that non-local blanks are smaller than locals because they were retouched, used, repaired, re-used, and re-repaired for a longer period or to a greater extent than local blanks. Whether the shrinkage that resulted in the sizes of retouched blanks decreased or increased the size differential between tools and raw blanks depends on whether tools were initially larger than, smaller than, or the same size as raw blanks. If they were the same size or smaller than raw blanks, then attrition would gradually increase the size difference. However, it is more common that tools are larger than unretouched blanks (e.g., Chadelle 1983, Geneste 1985, Roth and Dibble 1998), and as I discuss in Chapter 5, this is true of all six assemblages I studied. Therefore, we should expect size attrition from retouch, use, and repair to *decrease* the size differential between tools and raw blanks. Thus, the distance/attrition hypothesis would be supported if this tool/raw blank size differential were less pronounced among non-local than among local raw materials.

If non-local blanks do not show a larger size differential between tools and raw blanks than local raw materials, then it is possible that non-local raw materials are smaller because of efforts to increase blank portability. Such efforts would probably include a selection of the smaller blanks out of the pool of blanks produced during field processing, before blanks were transported. That selection would result in a sample of blanks that is biased with regard to technological composition, in favor of smaller blanks with less cortex (or, a higher frequency of non-cortical blanks). Presumably, there would also be fewer chunks, since those are infrequently retouched and usually lack sharp edges, and fewer or no cores, since those are far less portable than blanks. This test will work best when all raw materials, regardless of source distance, are reduced using the same or similar manufacture methods, and when the technological composition of the products of each reduced core (including the reduced core, all blanks, and chunks) is similar in each case. In the present study, I assume there is such a baseline technological composition. It includes a small number of cores, which however are much heavier than blanks and chunks; a high frequency of non-cortical and semi-cortical blanks, with fewer cortical blanks (because those represent only the outer "skin" of the nodule or cobble); and very small frequencies of rejuvenation blanks, crested blanks, burin spalls, and chunks. Whichever raw material type diverges significantly from this baseline composition is assumed to be the result of a biased selection of pieces prior to transport.

Of course, the absence of nodules, cores, and chunks might be expected in any non-local raw material simply because a minimal level of energy conservation were practiced in which only blanks were transported from the extraction site. This would not necessarily result in a biased composition of blanks, even though it would result in a

different overall technological composition. Therefore, the important question (in terms of blank conservation) is whether there is a difference in technological composition *among blanks*. If raw material conservation was not intense, then we might expect the technological composition of local and non-local blanks to be similar. A significant difference in the technological composition of local and non-local blanks, along with a significant difference in size (where non-local blanks are smaller), would support the blank portability hypothesis.

If non-local blanks have a technological composition similar to that of local blanks, then their smaller size might be related to a difference in the sizes of the blocks of raw material that were reduced. In such a case, there would be little support for either blank portability or raw material conservation through blank reduction intensity.

It may not be necessary to carry out all of these steps on each assemblage. I shall compare mean weights of local and non-local blanks in each assemblage. Only if those mean weights are significantly different will I then begin to follow the process illustrated by the flow chart in Figure 2.2.

*The notion of raw material quality*

The issue of raw material quality is central to the arguments of Demars, Geneste, and others. These authors have demonstrated that associations between raw material quality and technology are the logical expectations of an organized, well-adapted technological system. What they have not demonstrated is whether archaeological data meet this expectation. Notwithstanding the wide consensus among researchers in the Perigord that Bergeracois chert is superior to most other raw material types (Chadelle 1983; Demars 1982, 1989, 1994; Geneste 1985; Larick 1986; Lucas 2000; Rigaud 1982; Turq 1992), there are no published figures supporting that assertion.

Moreover, there are disagreements over the relative merits of various Perigord raw materials for flintknapping. For example, whereas Demars (1982, 1994) and Chadelle (1983) state simply that Bergeracois chert is "excellent" for the debitage of large blades, Geneste (1985) notes that there is wide variety in the knapping quality of Bergeracois chert, and that some nodules possess an unknappable, granular center. For chalcedony/millstone, Rigaud (1982:19) mentions one variety that is "not very good for debitage." Geneste (1985:149) mentions another variety (containing geodes) that is "rather unfit for knapping" and another (small blocks in secondary position) that is "adequate"; while Demars (1982), who distinguishes between chalcedony and millstone, only states that chalcedony is of very good quality. Turq (1992) notes several varieties of chalcedony/millstone ranging in quality from "mediocre" to "excellent". For jasper, Geneste (1985) states that nodules from Tertiary deposits along the western edge of the Massif Central range from good to excellent, but Demars (1982) claims that many of those are very poor in quality, and that only the finer-grained varieties were used. Larick (1986) claims that beige Senonian chert is generally better than black Senonian, while Turq (1992:201, 203) grades black Senonian as "medium to good" and beige Senonian as "mediocre to very good."

Clearly, many of these apparent disagreements result from differences in the completeness of these authors' descriptions of raw material physical properties. Yet, it is equally clear that there is no standard, consistent system of grading the physical properties of lithic raw materials. Subjective assessments of raw material quality are the rule in lithic studies. For example, Andrefsky (1994:29) defined lithic raw material quality as "the ease with which the stone can be chipped and controlled in the shaping process." He went on to explain that "Very-fine-grained homogeneous raw materials

tend to be more easily shaped and reduced than coarse-grained and flawed raw materials, and thus represent better-quality stone." This characterization of "quality" raises a number of difficult questions: How is one to measure the ease with which a stone can be shaped and reduced? Ease of shaping and reduction is undoubtedly caused by a multitude of less easily observed physical properties. How much of a difference in each of those properties is required to effect an observable change in "ease of shaping and reduction"? How much of a change in ease of shaping and reduction is required to effect a change in one's judgement of the quality of the material? How much difference in ease of shaping was required in the past before people's choice of raw material began to be affected? There is no obvious answer to these questions. Moreover, because subjective judgements of raw material quality cannot be quantified, their accuracy is impossible to assess systematically.

Testing the idea that Bergeracois chert or any other raw material is of higher quality or, more precisely, fractures more predictably than other rocks, will require a standard, consistent system of grading the physical properties of lithic raw materials. This system should be based on fracture properties that can be measured quantitatively and that have the greatest relevance to chipped stone technology. With quantitative data on fracture properties, it should be possible to test hypotheses about the effects of variation in raw material physical characteristics on provisioning strategies. In Chapter 6, I present a method for quantifying raw material fracture properties, and analyze the results of applying this method to cherts and quartzite from the Perigord.

*Ways in which fracture properties might be related to RME*

Returning to the main subject of this section—a model of RME—it is now useful to consider what relationships we should expect to see between raw material fracture properties and raw material exploitation, and how those expectations can be tested.

*Acquisition: random or targeted* If increasing frequencies of non-local raw materials are related to increases in technological efficiency, we should be able to demonstrate that the assemblage's raw material composition can not be explained as the expected outcome of a random collection procedure by a mobile group that acquired raw material opportunistically whenever sources were encountered. If the data did support such a random walk model, that would suggest either that the environment was homogeneous with regard to raw material properties and distribution, which we know was not the case in the Perigord, or that raw material conservation did not play a major role in provisioning strategies. If a random walk model is not supported, it may be that lithic raw materials were acquired purely on an encounter basis, but that travel routes were not random, being affected by the geographic distribution of various resources (water, food, shelter). It might also be the case that that technological or functional factors affected the choice of raw materials. Discriminating these last two hypotheses could be accomplished by looking for associations between raw material assemblage composition and raw material fracture properties.

Carrying this test out requires data on raw material natural availability. In Chapter 4, I describe the nature, abundance, distribution, and properties of siliceous raw materials in the Perigord. For each archaeological site, I developed a measure of the natural availability for each raw material. After ranking the raw materials by their estimated natural availability, I ranked them by their frequency in the assemblage. An

opportunistic model of raw material acquisition would be suggested by a significant correlation in the two rankings.

*Frequency of high-quality (predictable) raw materials* Another way of decreasing costs would be to stock up on materials with predictable fracture whenever they are encountered, since those materials decrease manufacture cost. Doing so would prolong the time it took to consume those resources. This, in turn, would increase the chances that some of this material might remain in the raw material supply after people had moved a long way from the source. It would also increase the chances that early stage manufacture products, such as cores or cortical flakes, would be deposited in assemblages far removed from the source. Geneste (1985) provided an example that illustrates this phenomenon by way of contrast. At the confluence of the Euche and Dronne rivers in the northern Perigord, a distinctive variety of Senonian chert named Renamon occurs. At La Tour Blanche, about 15 km up the Euche River, there is a source of a second distinctive variety of Senonian chert. Twenty Middle Paleolithic sites lie between the Renamon and Tour Blanche chert occurrences. Sites nearest the Renamon source had frequencies of 10-14% of that chert. Moving away from the source and toward La Tour Blanche, the frequency dropped steadily, to 2% at a site only 6 km from the source, and zero at sites further away. Similarly, the frequency of Tour Blanche chert was highest (around 20%) in a site near that source, and the frequency decreased to zero at sites more than 5 km away. Geneste interpreted these patterns as indicating high residential mobility. The rapid deterioration in the quantity of each kind of chert with increasing distance from the source suggests a lack of stockpiling.

If there exist detectable differences in the fracture properties of raw materials, and if technological efficiency was increased by taking advantage of those differences,

then assemblage raw material composition will be closely associated with variation in raw material fracture properties. However, because transport distance may also affect acquisition cost, it must also be taken into account. I examine two related questions: 1) Among all raw materials found in an assemblage, do non-local materials have more predictable fracture than the local materials? 2) Among the non-local raw materials, do those with more predictable fracture occur in higher frequencies than those less predictable fracture? The data I will apply to this question include raw material composition, estimated source distances, and raw material fracture properties.

*Fracture properties and manufacture methods* In his study of Lower and Middle Paleolithic assemblages in the Perigord and Lot regions, Turq (1992) described nine different core reduction methods: discoidal, trifacial, Acheulean (or "La Micoque" type), Quina, and five kinds of Levallois debitage. The simpler methods were generally applied to all raw materials, while more complex methods tended to be applied only to the most predictable raw materials. In addition, the natural shapes of the blocks of raw material affected which debitage methods were used, especially among assemblages dating to the Riss period. Bifaces were usually made on natural fragments such as frost-fractured flakes or naturally angular blocks of millstone chert, if those were available; if not, bifaces were made on large flakes detached from round nodules. When more elaborate methods were used (discoidal and Levallois), raw materials of the highest quality were used, according to Turq. For example, in four Mousterian of Acheulean Tradition assemblages (La Burlade, Ségala, La Lizonne, and Les Ardailloux), triangular hand-axes were generally made on non-local chert of quality, such as Bergeracois and chalcedony (Turq 1992:447-448). According to Turq, this material permitted the production of larger blanks.

I will follow Turq's lead by testing the hypothesis that technological efficiency was increased through a careful pairing of manufacture methods with raw materials. However, I will approach the question with a different technique, using likelihood ratio chi-square to examine the data for significant associations between manufacture classes and raw material types. The manufacture classes will be confined to differences between blades and flakes; that is, I will test to see whether blades and flakes tend to be made with different kinds of raw materials, based on the assumption that the majority of blades were made using different methods from the majority of flakes. I will also develop descriptive categories for cores, which correspond to an extent with different manufacture methods, and conductive likelihood ratio tests of association with raw material types.

**Summary**

This is a study of how mobile foraging groups in the Late Pleistocene of southwestern France supplied themselves with lithic raw material. This study will be carried out within a theoretical framework based on evolutionary ecology, in which increasing the efficiency of raw material exploitation increases the adaptedness of foragers who compete for the same raw material sources. Strategies for increasing technological efficiency were constrained by the characteristics of lithic raw material as a natural resource: the heaviness of rock, the reductive nature of manufacture, the distribution and abundance of raw material occurrences, and the fracture properties of rock. These strategies were also constrained by behavioral parameters, including the tool stone carrying capacity, rate of tool stone consumption, and mobility patterns. These constraints were overcome to varying degrees by efficiently managing the acquisition of raw materials, including the choice of raw materials, field processing, the

partitioning of manufacture over space, and technological adaptations to the mechanical properties of the stone. They were also overcome by efficiently consuming raw materials. This was accomplished through an articulation of technological behaviors, such as core reduction intensity and retouch intensity, with the properties of raw material resources. Taken as a whole, these behaviors all constitute parts of the group's provisioning strategy, which is assumed to have been an economically and evolutionary significant aspect of adaptation.

The discontinuity hypothesis requires a demonstration of an archaeological discontinuity corresponding to the cultural replacement, and a demonstration that at least one of the immigrant population's traits was adaptively superior to the corresponding trait of the autochthonous population. If a strategy of lithic raw material exploitation (RME) was such a trait, then the discontinuity hypothesis could be tested by showing a change in the archaeological record toward a more technologically efficient RME strategy. Since RME entails costs but only leads to benefits indirectly, the optimal strategy will differ from others mainly by being less expensive. The costs of RME can be reduced by decreasing the distance traveled for tool stone acquisition, using more predictable raw material, and practicing various forms of tool stone conservation and tool curation.

Some of the data basic to this study concern the environmental constraints on raw material provisioning: abundance of raw material occurrences, density of occurrences, estimated source distances from site, and fracture properties of the stone. The basic archaeological data of this study are the raw material composition and technological composition of each assemblage. These data permit descriptions of manufacture methods, core reduction intensity, and retouch intensity, and they allow one

to determine if variation in each of those dimensions is correlated with variation in raw material characteristics, namely: source distance, occurrence density, and fracture properties.

The relative adaptedness of the groups represented by each assemblage will be assessed in relation to the technological efficiency of RME. Technological efficiency will be measured by:

1. the extent to which raw material composition reflects the natural availability of raw material types in the surrounding environment;
2. the frequencies of more costly raw (i.e., non-local) materials in the assemblage;
3. the degree to which the partitioning of manufacture phases over space relates to the source distances and occurrence densities of raw material types;
4. the strength of association between manufacture methods and raw material types, when those types differ in costs of acquisition and/or in fracture properties;
5. the degree to which more costly raw materials and/or raw materials with special fracture properties were conserved, or curated, as indicated by:
    a. comparisons of blank weights that show the portability of transported blanks was improved;
    b. increased consumption of non-local blanks as shown by a correlation between transport distance and size attrition;
    c. increased core reduction intensity;
    d. increased blank:core ratios;

e. increased retouch frequencies.

Evidence of technological efficiency in RME might be found in all the assemblages to be analyzed. However, if the discontinuity hypothesis is correct, then the allocthonous groups were more adaptive, and this might have resulted in part from greater efficiency in RME. If so, then there will be two sets of assemblages, which will appear distinctly different when the above measures of technological efficiency are applied. The subset with the lowest apparent technological efficiency will be the oldest set, and that with the highest technological efficiency, the youngest. When I refer to the "predictions" of the discontinuity hypothesis, I am referring to the distinctness of these differences in items 1-5 above, including items 5a-e.

For clarity, I have divided the methodological and empirical parts of this dissertation into three main sections, each of which deals with a separate aspect of raw material provisioning: the abundance and distribution of raw material occurrences and how those affected assemblage raw material composition; the technological composition of the assemblages and the degree to which it reflects technological efficiency; and the fracture properties of Perigord raw materials and their effects on provisioning strategies.

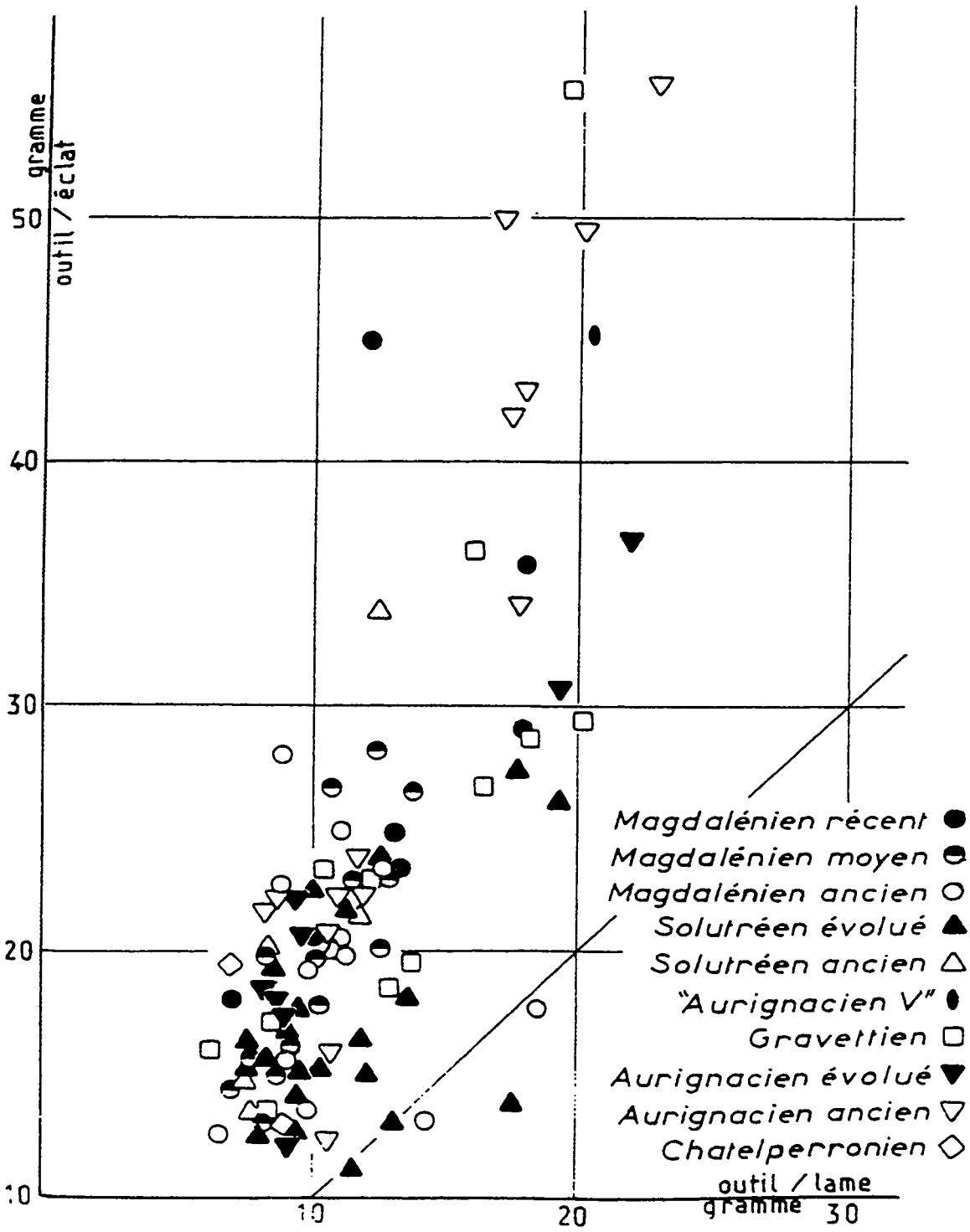


Figure 2.1 Mean weights of flake (abscissa) and blade (ordinate) tools in Upper Paleolithic assemblages from the Brive area. From Demars (1994:123).

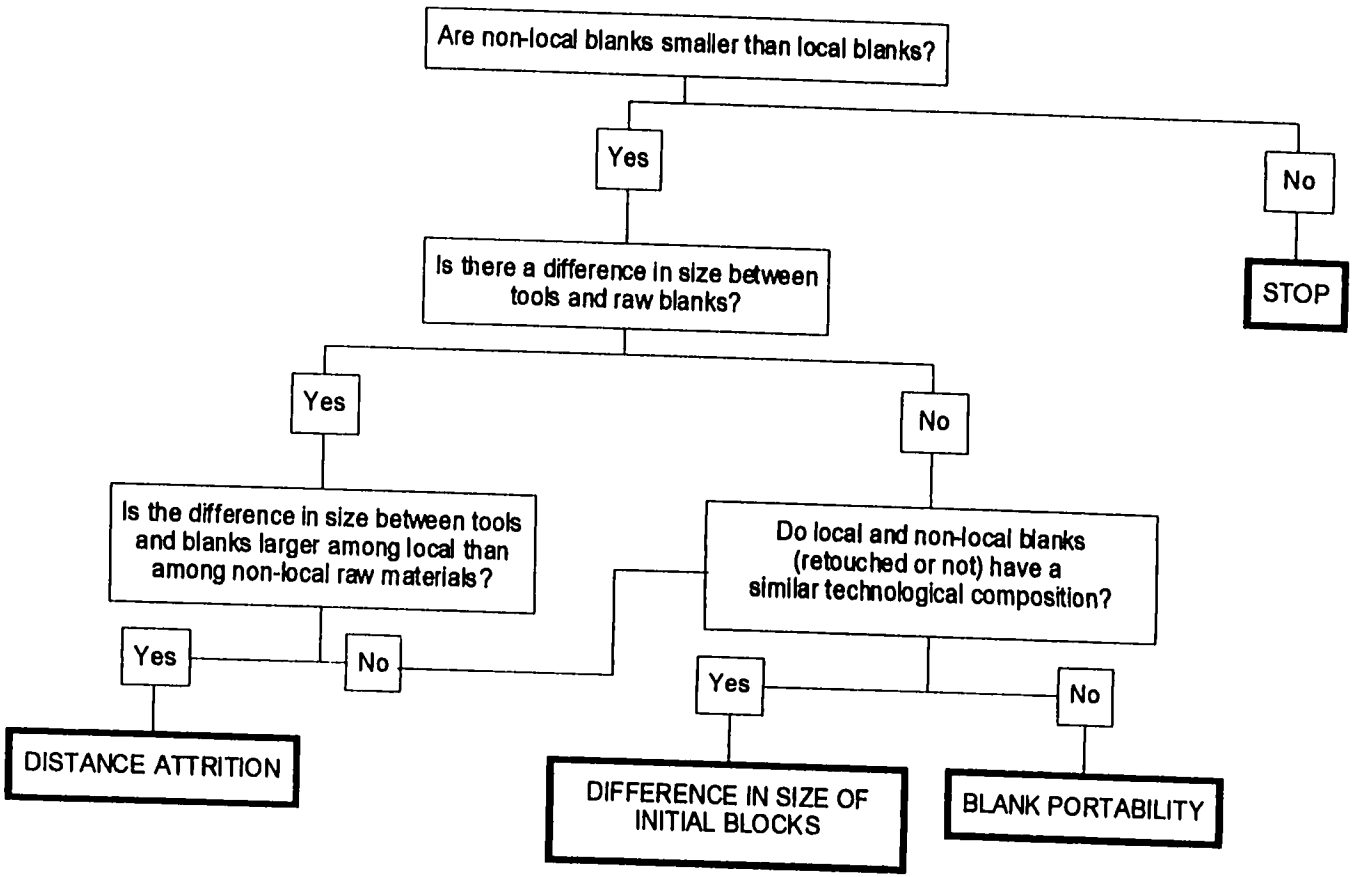


Figure 2.2 Procedure for testing hypotheses about raw material conservation and blank weights.

# 3

# Sites and Assemblages

The approach outlined in the previous chapter places certain demands on the data. Obviously, this study will only be successful if based on assemblages from archaeological and/or geological strata which are discrete from adjacent strata, and for which there is no clear evidence of stratigraphic mixing. Restricting the analysis to such assemblages will greatly lessen the potential effects of multiple occupational episodes on assemblage composition.

Because I am also interested in comparing assemblages belonging to different points in time in order to study possible change, good chronological control is also desirable. There are two ways to help satisfy this need. This first is to rely on traditional cultural typology and on stratigraphy to assign assemblages to the late Middle Paleolithic and early Upper Paleolithic periods. The second is to rely on chronometric data as a measure of age. As I discuss below, I have relied on both methods.

An additional consideration is whether the assemblages were created by groups practicing the same general kinds of activities. For example, in a study of change in raw material provisioning it would not do to compare a Mousterian rockshelter immediately adjacent to a source of good lithic raw material (such as Combe Capelle Bas; Dibble *et al.* 1995) with an Aurignacian open-air site far removed from any raw material source (such as L'Hui; see Ricalens 1990). The differences between the assemblages to be compared should be kept to a minimum in order to increase the probability that inter-assemblage differences are due to change in the behavior in question.

While this is relatively obvious, the solution to the problem is less so. It is sometimes assumed that rock shelter and open-air sites represent different functional contexts, but that is not necessarily true in every instance. There is also no reason to believe that all rock shelters were used in the same way in the past. The proof of functional similarity or dissimilarity lies in a comparison of archaeological data permitting a reconstruction of technological behaviors. Yet, only when the analysis is completed is it possible to know whether functionally similar assemblages have been compared. There is no such thing as perfect control over inter-site functional differences.

I have attempted to overcome these potential difficulties by choosing assemblages that provide good control over the various factors that might have affected raw material provisioning in the past and/or our ability to recognize variation in raw material provisioning. These include the temporal discreteness of the assemblage, the care with which the sites were excavated, and the geographic and geological context of each site.

I studied six assemblages, four of which have been chronometrically dated to within the period 45,000 BP to 26,000 BP (including error terms, and excluding two problematic dates from Le Flageolet I). These are levels XI and IX from Le Flageolet I; levels M3 and G from Caminade Est; level H8 from Le Moustier (lower shelter); and level III from La-Côte (see Figure 3.1). All but the assemblage from Le Moustier have been analyzed previously by other researchers. However, the data on raw material and technological composition required by my approach have not been generated for any of them. Here, I describe the aspects of each assemblage that are pertinent to the present study.

## Le Flageolet I

Situation and history

Le Flageolet is an L-shaped rockshelter about 50 m above the level of the Dordogne River, which flows within a few hundred meters of the shelter. The southwest-facing, narrow shelter rises about 20 m above the ground, which is covered with rich vegetation indicating a slightly warmer and moister microclimate than the immediate surroundings. This, along with the significant exposure to sun and protection from wind, may have had much to do with the frequency of human habitation here.

One leg of the shelter's L contains the Aurignacian and Gravettian deposits of Le Flageolet I, while the other contains the Magdalenian deposits of Le Flageolet II (see Figure 3.2). The two sites lie a little less than 10 m apart, but there is no stratigraphic continuity between them. According to Rigaud (1982), the "Würm III" deposits of Le Flageolet II were eroded by water falling from a solution cavity in the rock face. When cold conditions returned, the waterfall dried up and "Würm IV" deposits were laid directly on the bedrock[1]. The deposits of Le Flageolet I were unaffected by the erosion.

Rigaud excavated Le Flageolet I from 1967 to 1983. The site's fine sediments derive largely from the plateau above the top of the rockshelter. They consist of sands and clays redeposited from the slope above the roof of the shelter. The deposits also contain angular gravels and large limestone blocks from the wall of the rock shelter. The numerous large blocks protected the Gravettian and Aurignacian remains at Le Flageolet I from pothunters, who managed to destroy several cubic meters of Magdalenian sediments at Le Flageolet II before Rigaud discovered the site.

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[1] The terms Würm III and Würm IV refer to Laville's (1988) chronostratigraphic scheme for the Perigord. They correspond to two major glacial episodes during the Pleniglacial.

Stratification

The excavators recognized twelve lithologic levels at Le Flageolet I, containing eight archaeological layers. What follows is Rigaud's (1982:294-297) description of those levels, from bottom to top (please refer to Figure 3.3):

> Level XII. Lenses of brown-yellow clay, containing a few very weathered cryoclastic spalls [*éboulis*] of limestone, lying on small depressions in the rocky soil, which descends in stair-step fashion toward the west. This layer contains no archaeological remains.
>
> Level XI. This level lies directly on the bedrock. It consists of small limestone frost spalls, which are altered and rounded, embedded in a brown sand containing silt and clay. This layer contains an Aurignacian level.
>
> Level X. A chaotic layer of limestone blocks, some of which attain a volume of several cubic meters. These lie directly on level XI, which they have sometimes completely crushed. The collapse of the shelter's roof happened all at once. The blocks are aligned more-or-less parallel to the base of the shelter; many were broken in place, and some are laid in a layer cake fashion. This peculiar arrangement played an important role in the use of space by prehistoric humans. ... the prehistoric occupation, at least for the Gravettian levels, seems to have been limited to the zone between the blocks and the base of the shelter. Above level XI and around the blocks, a fine and mobile sediment accumulated, which is absolutely deprived of archaeological material.
>
> Levels IX and VIII. This sedimentary ensemble is made up of flat limestone fragments, with angular edges, embedded in dark brown clay- and silt-rich sand. This material filled the spaces between the blocks of level X, without however entirely covering them. During the first seasons of excavation, because of a higher density of the limestone fragments toward the base of the ensemble, we distinguished level IX at the base and level VIII at the top. Additional excavation failed to recover a similar density of the limestone fragments elsewhere, suggesting that it may be a local variation in the facies. This sedimentary ensemble contains several archaeological levels.
>
> Level VII. Like the overlying ensemble, level VII partly filled the spaces between the roof fall blocks, though without totally covering them. Level VII is made up of plaquettes and limestone frost spalls; their size seems to diminish from the bottom to the top of the level. They are contained in a brown-red sandy matrix with clay and silt. The very top of this level is marked by a higher density of small plaquettes (2 to 5 cm in length), which are associated with more numerous limestone gravels. At the very top of this layer are found the first archaeological level of the Gravettian.

Level VI. This is a fine sediment with few stones. Its contact with level VII is distinct and even. Toward the south of the shelter, its base contains a small number of limestone plaquettes, sparse but evenly distributed. Toward the north, an increase in limestone gravels is undoubtedly related to the stream erosion of the Würm III levels during the Würm III/IV Interstadial. This layer contains a Gravettian level.

Level V. It is made up of angular plaquettes and small limestone blocks in a brown-yellow sand with clay and silt.

It shows several important facies changes: the proportions of plaquettes and blocks are strongly associated with changes in topography. At the base of the shelter, they become thicker and the very top of the level is sometimes underlined by fleeting accumulations of limestone gravels. Toward the southern end of the shelter, against the rock face, these gravels are replaced by biogenic tracks or burrows [*passées terreuses]*, which seem to correspond to the filling up of small depressions carved out by stream deposits. This layer contains a Gravettian level.

Level IV. Made up of fine, brown-yellow, sandy-clayey-silty sediment, it contains some limestone frost spalls, especially at its base. Its contact with level V is distinct. Gravettian archaeological level.

Levels I to III. At the beginning of the excavation, we distinguished three distinct formations underneath the disturbed uppermost layer:

Level III: sediment similar in all respects to that of level I, but with a higher number of plaquettes and small limestone blocks at its base, above the contact with level IV. However, as the excavation progressed, we abandoned these subdivisions because "level II" was in fact only a lens, which we find at different elevations within the accumulation of limestone gravels that make up levels III and I. It seems more accurate to call this ensemble I-III or level I-III.

Level II: brown-yellow sand with clay and silt, practically deprived of limestone gravels and frost spalls.

Level I: rounded, washed limestone gravels in a matrix of dark brown-yellow sand with clay and silt, surrounding some angular frost spalls and plaquettes.

Level 0 [*sic*]. During test pits and excavation outside of the walls of the medieval house, we observed a stratigraphic sequence that appeared very similar to level I-III: a layer of limestone gravels sometimes containing frost spalls with borrows filled with fine sediment, very comparable to the former level II.

Paleoenvironment

The weathering of frost spalls in level XI and the existence of clay in the fine sediment led Rigaud and Laville (reported in Rigaud 1982) to infer a rather moderate, wet climate. The enormous roof fall in level X was seen as evidence of very cold conditions. They interpreted the level IX-VIII ensemble as the result of cold and wet conditions. Pollen grains were only found in levels XI and 0. Diot's analysis of this pollen (also reported in Rigaud 1982) showed evidence of a temperate, wet climate at the onset of level XI, followed by a progressive decrease in temperatures and humidity.

Grayson and Delpech (1998) and Delpech *et al.* (2000) recently reported the number of identified specimens of ungulate and carnivore species from all levels except 0-III at Le Flageolet I. Table 3.1 shows the data they reported for levels XI and IX. Based on the small frequency of gnaw marks and high frequency of cut marks, they concluded that the bones were primarily or entirely introduced by humans. In all the analyzed levels, large mammal remains were dominated by ungulates, and among ungulates, red deer and reindeer were dominant. According to Grayson and Delpech, fluctuations in the numbers of taxa between levels of the site were caused by changes in diet breadth. They identified two groups of assemblages, one corresponding to a high, and the other to a low, diet breadth. Level IX falls in the first group, while Level XI falls in the second group. They attributed these changes in diet breadth to environmental changes in the availability of different taxa, which agrees with Enloe's (1999) conclusion that ungulate abundances in French early Upper Paleolithic sites reflect environmental conditions. During the deposition of all levels of Flageolet I, the climate was much cooler than today.

Chronology

A series of conventional and accelerator $^{14}C$ dates from nearly the entire stratigraphic column of Le Flageolet I has resulted in a coherent sequence, stretching from 34,000 BP to 18,000 BP. When we exclude the infinite date for level XI, the remaining three dates span a confidence interval range of 31,190 - 35,600 bp (Table 3.2). The date of 20,070 ± 1760 bp for level IX (reported in Grayson and Delpech 1998) should be excluded because it is obviously too recent for the Aurignacian and does not agree with the remaining dates. The other three dates for level IX give a confidence interval range of 26,000 – 30,590 bp. The intervening layer, level X, has one conventional and two accelerator $^{14}C$ dates, ranging from 27,000 bp to about 30,000 bp (Lucas 2000). Thus, the radiocarbon results are in excellent agreement with the stratigraphic relationships among these levels, and they place the earliest Aurignacian occupations of the rock shelter within a confidence interval of 26,000 bp - 35,600 bp.

Typology

Excavated over an area of 35 $m^2$, level IX contained the largest of the three Aurignacian assemblages of Le Flageolet I. At the time of Rigaud's publication, 679 retouched tools and several thousand pieces of debitage had been tabulated. The tools are dominated by endscrapers, of which Caminade and carinated endscrapers are particularly abundant. There are also a few bone/antler tools, including two sagai points.

Level XI, which covered a more restricted horizontal area, contained a modest amount of Aurignacian material. Rigaud (1982) declined to attribute this level to a specific Aurignacian industry because of the small number of retouched tools. Additional excavation in this level in 1993 greatly increased the size of the lithic assemblage. This, along with a small number of objects that were re-assigned to new levels on the basis of

a global analysis of stratigraphic projections from three-point provenience data, led Lucas (2000) to do a new typological analysis of all levels.

The latter author reported 926 tools (retouched pieces) from level IX, including: 76 Caminade endscrapers (8.21%), 47 Dufour bladelets (5.07%), 25 bladelets with fine direct or indirect retouch (2.70%), 32 endscrapers on blades (3.45%), 51 dihedral burins (5.51%), 34 carinated endscrapers (3.67%), 8 carinated burins (0.86%), and 24 busked burins (2.59%). The assemblage is thus typologically characteristic of the early Aurignacian, which agrees with Rigaud's preliminary assessment. For level XI, Lucas reported 292 tools. These are also characteristically Aurignacian, but the figures differ from those for level IX by having higher frequencies of Caminade endscrapers (67, or 22.94%) and retouched bladelets (22, or 7.50%) (including two Dufours). Unlike the two overlying levels, level XI has eight Aurignacian retouched blades (2.74%). The assemblage also contains 17 endscrapers on blades (5.82%), five carinated endscrapers (1.71%), seven muzzled or shouldered carinated endscrapers (2.39%), one carinated burin (0.34%), and thirteen busked burins (4.45%).

Like Lucas (2000), I included this more recent material in my analysis; thus my tables show more tools and debitage than the tables presented in Rigaud (1982).

Technology

Lucas (2000) carried out a detailed analysis of the raw material and technological composition of all the Aurignacian and Gravettian levels of Le Flageolet I. Some of her findings about levels XI and IX are identical or similar to those of the present study, and these are discussed below, in Chapter 5. Here, I briefly summarize some of her conclusions. She found that Senonian chert was by far the most abundant in all levels of the site; Bergeracois chert was second in abundance, and several others

(chalcedony/millstone, jasper, Fumelois chert) were much more rare. The technological composition of the raw material classes showed that Senonian chert was the only raw material for which all stages of core reduction and tool production were consistently represented. Bergeracois chert showed evidence of having been reduced entirely *in situ* only in three levels, including level IX but not level XI. Based on an analysis of the blanks on which tools were made, as well as on the frequencies of non-cortical blades in the debitage, she concluded that lithic manufacture was primarily oriented toward blade production. This tendency was especially pronounced in Bergeracois chert. Curiously, she also noted a near-absence of evidence for blade debitage among cores from the Aurignacian levels of the site. Lucas also found evidence in her data for the intentional production of bladelets of specific morphology and size, and the biased selection of raw bladelets for the manufacture of marginally retouched bladelets, Dufour bladelets, and Caminade endscrapers.

Lithic raw materials

The nearest likely source of lithic raw material for Le Flageolet is the Dordogne River, whose gravels could be reached in less than a half-hour on foot. In 1996, I found abundant quartzite and basalt cobbles, as well as two chert cobbles, on small islands made of well-worn and well-sorted cobbles along the left bank of the river, opposite the cliff containing the Le Flageolet rock shelter. Because of the proximity of Senonian chert and chalcedony/millstone, both may have been obtained from the river. However, they may also have been obtained from *in situ* occurrences because those are also found nearby.

In order to estimate distances to known occurrences (other than stream gravels) of various chert types, I have relied on maps provided by Geneste (1985). Geneste

mapped all known occurrences, both primary and secondary (but excluding stream gravels), that were discovered by several workers conducting raw material prospecting over the previous 15 years in the Perigord. He provided a composite map showing the location of all 954 occurrences, as well as separate maps for each of several raw material types[2]. The maps cover an area described by a square 120 km on each side and centered on a point roughly 10 km NE of Les Eyzies. To obtain accurate estimates, I plotted the location of each of the four sites, measured the distances to occurrences of each raw material type with an engineering scale, and converted the measurements to kilometers. Table 3.3 shows the most relevant of these data.

Le Flageolet lies in the zones where black and beige Senonian chert and chalcedony/millstone are abundant. Dense clusters of both black and beige Senonian chert lie in various directions, at distances of approximately 2-4 km. Occurrences of chalcedony/millstone are much less densely clustered, but there are some just over 2 km to the north of the site, and others about 4 km to both the east (upstream) and south (across the river). There are several other kinds of chert that may have been available to people living at Le Flageolet in the past, but these are more distant. The nearest boundary of the zone containing Bergeracois chert lies 34 km downstream. Mussidan chert can be found about 58 km away, to the west and northwest in the Isle River valley. In the same general area, there are also several rare chert types including "colored, jasper-like chert of Bergeracois" (Geneste 1985), jasper-like chert, fine-grained and isotropic petrified wood, and a pink, speckled chert that may belong to either Bergeracois or Senonian (Pelegrin 1986). The few known occurrences of fine-grained

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[2] Most of these occurrences are also shown on maps provided by Demars (1982) and Turq (1992).

Gavaudun and Fumelois chert lie over 30 km south in the semi-arid plateau between the Lot and Dordogne valleys.

Small clusters of Hettangian jasper outcrop along the edge of the boundary between the Massif Central and Jurassic limestones. The nearest of these outcrops to Le Flageolet lie a little over 50 km to the east and north at Puy d'Arnac and Exideuil, respectively. However, there are homogenous, brownish-yellow jasper nodules that occur alongside boulders of chalcedony/millstone on the Plateau de Bord near Domme, and these lie a mere 15 km to the east of Le Flageolet. Geneste (1985) and Turq (1992) also report other varieties of jasper or jasper-like chert, some of which occur near Le Flageolet. For instance, Geneste (1985:163) showed three occurrences of a "jasper-like chert" in Senonian formations within 1 km of Le Flageolet. The eight occurrences reported by that same author of "brown or beige jasper-like chert of the valleys of the Couze and Dordogne" lie between about 15 and 35 km southeast of Le Flageolet. He also reported a few occurrences of a jasper-like chert in the same area where Bergeracois chert occurs, 35-40 km west.

In short, there are many occurrences of various kinds of chert both in the immediate vicinity of Le Flageolet and extending out to nearly 60 km in several directions, in addition to what could be gathered from the nearby river.

**Caminade Est**

Situation and history

Caminade is a collapsed rockshelter that lies about halfway up an approximately 80 m tall cliff at the southwestern edge of the plateau called Bois de Bontemps. It overlooks a small, flat, dry valley containing a tiny stream, which has been diverted into a ditch beside the Sarlat-Souillac road (D 704). The shelter faces toward the west-

southwest. Like Le Flageolet, Caminade is also roughly L-shaped, and its deposits were also cut by a Pleistocene stream. This stream emerged from a small cave at the rear of the site and ran through a shallow ravine, eroding early Würm deposits from the western portion of the shelter (Laville and Sonneville-Bordes 1967). After the erosional episode, sediments were again deposited in that sector, which is named Caminade Ouest.

Those sediments contained two Aurignacian levels, attributed to an early and late Aurignacian (Sonneville-Bordes 1960). On the other side of the small ravine lies Caminade Est, which contained three Mousterian and four Aurignacian assemblages. The excavators were unable to establish precise stratigraphic correlations between the deposits of Caminade Ouest and Est. However, the two halves of the site were probably once part of a single, continuous series of deposits. If so, the Aurignacian levels in Caminade Ouest would represent the western portion of some of the Aurignacian levels in Caminade Est (Sonneville-Bordes 1969). Mousterian deposits may never have extended into Caminade Ouest; if they did, they must have been eroded away before the deposition of the Aurignacian levels (Laville *et al.* 1980).

Caminade Est was excavated between 1955 and 1965 by F. Bordes and D. de Sonneville-Bordes (Sonneville-Bordes and Mortureux 1955; Sonneville-Bordes 1960; Sonneville-Bordes 1969, 1970). The following summary is based on several reports (Delpeche 1970; Laville and Sonneville-Bordes 1967; Paquereau 1969, 1970; Sonneville-Bordes 1969, 1970) as well as the summary in Laville *et al.* (1980). At the base of the shelter, covered by deposits dating to late Stage 3, lies a bedrock bench, which extends horizontally two and a half meters out from the base of the shelter before sloping sharply downward (Figure 3.4). The deposits containing the Mousterian assemblages lie only on that slope and occupied an area of 10 $m^2$, whereas the

Aurignacian-containing deposits stretch over the bench and back to the rear of the shelter. The Aurignacian deposits were excavated over an area of approximately 38 $m^2$, and yielded much more material than the Mousterian deposits did.

Stratification

Sonneville-Bordes (1969:294) reported the following stratigraphic sequence for the three lowermost levels of Caminade Est, described from bottom to top:

> M1. Lowermost level; between 0.10 and 0.30 m thick, with limestone granules. Flint artifacts, some of which have a fresh appearance, lie in place directly on the bedrock, which shows traces of fire reddening in places. Within the mass of granules, some of the flints are somewhat broken (M1 base); at the top of the level, the more numerous granules mix with a more yellow clayey sand. They contain rare but fresher flints, showing some traces of mechanical wear (M1 summit).
>
> M2. Middle level of sandy red sediment, from 0.20 to 0.30 m thick. Near the top of the level, it is loaded with frost spalls [*éboulis*] as it passes into the overlying level. Toward the base of the level, the archaeological level is marked by traces of fire (burned stones, scattered charcoal) with flints that, often fresh, lie horizontally (M2 base). At the top, a zone with more concentrated flints that are sometimes trimmed [?; *dressés*], associated with a few traces of hearth (M2 summit).
>
> M3. Yellowish layer of frost spalls, 0.30 to 0.50 m thick, within which are distinguished a more earthy level at the base and a layer of large, angular frost spalls at the top, separated from each other in places by a more earthy, red lens. The flints were distributed in a diffuse fashion within the frost spalls; however, it was possible to distinguish between a series at the base (M3 base), a series at the summit (M3 summit), and a series at the very top (M3+).

Laville *et al.* (1980:112) divided level M3 into three geologic sub-layers or units: M3c, M3b, and M3a (listed in order from bottom to top). According to those authors, these three units all consisted of "voluminous blunted stone" and "phantom eboulis" in a red-yellow sandy matrix. The chief difference between the three units seems to have a been a progressive downward increase in the coarseness of the texture. M3a is the thickest unit; M3b attains a maximum thickness of 10 cm toward the front of the site and

thins to nothing toward the rear; and M3c is also about 10 cm thick. Laville *et al.* (1980:113) described archaeological level M3+ as being "at the very top of the M3a unit," level M3 summit as "lower down in the M3a unit," and level M3 base as "lying in the M3c unit." Thus, unit M3b represents an occupational hiatus between the sediments containing M3 base and those containing M3 summit and M3+.

The stratigraphic sequence for the four uppermost levels of Caminade Est were described as follows (Sonneville-Bordes 1970:79-83; I have rearranged her description in order to continue the bottom-to-top stratigraphic order; refer to Figure 3.5):

> Archaeological level G (Aurignacian I). Separated from the overlying level F by tiny grains of limestone concretions, this level consists of angular limestone fragments of cryoclastic origin, of which some have decomposed into gritty sand, mixed up and fused with larger concretions in the form of pellets [*grenailles*]. In the [eastern] part of the site, which corresponds to the rocky bench that runs more or less parallel to the wall of the shelter where there is no Mousterian accumulation, level G either lies directly on the bedrock bench, following all its contours, or is separated from it by a sterile level of loose sand of variable thickness, which fills the natural hollows in the rock. 0.15 to 0.20 m thick.
>
> In the eastern part of the site, where the Mousterian deposits had been preserved on a small terrace...the Aurignacian levels, which were practically horizontal both on the frontal section and on the sagittal section, were separated from the summit of the Mousterian layers by a sterile layer about 20 cm thick of sand and small blocks. In contrast, toward the west, in the direction of the ravine [but still in Caminade Est]...where the bedrock shows a marked slope, which forms the left bank of the ravine, the Aurignacian layers show a corresponding slope and the base of level G lies either directly on the bedrock, from which the Mousterian layers were removed by erosion, or on the small part of those layers that remains. In square C3 at the base of level G were found two Châtelperronian points, near one another; these are either the residues of an occupation that was later destroyed, or of a rare passage by the men of the Lower Perigordian...
>
> Archaeological level F (Aurignacian I). Reddish sand mixed with small frost spalls from the front of the shelter. Near the wall of the shelter, these have weathered into "ghosts". There is an amorphous hearth of charcoal near the base. 0.20 to 0.25 m thick.
>
> Level E. Indurated, reddish, clayey sand, which sometimes contains small fractured blocks, or small, rounded calcareous granules, either strewn about or in pockets. These solifluction granules have re-worked the summit of the

underlying level F, and sometimes have worked their way down to the summit of level G. Level E is completely sterile over most of its extent, but it contains a few flints from the re-working of level F. 0.15 to 0.00 m thick.

Archaeological level D2 (Aurignacian II). Indurated, reddish sand, separated from D1 by a thin, sterile, clayey level that is 0.05 m thick. Level D2 is subdivided into two archaeological levels, upper D2 (D2s) and lower D2 (D2i). These are separated from each other in places by a thin clayey film 0.01 m thick, and in other places by medium to large blocks. The level D2s is diffusely distributed within coarse sand, while D2i is in fine sand. The attribution of the tool assemblages to one or other of the two levels was done according to observations made during the excavation and the position of flints on the diagrams, but the distinction was sometimes difficult to establish.

Archaeological level D1. Yellowish sand, mixed in places with frost spalls. [Its form is] inconsistent and irregular, sometimes undulating, cutting into the summit of the underlying layer, with rare, scattered flints. 0.10 to 0.15 m thick.

Surface: Under the organic litter, a sterile layer of enormous, concreted, cryoclastic frost blocks lie directly on the Aurignacian accumulations and in front of the rockshelter. 1.0 to 1.5 m thick. In the part situated against the current rock face, between frost spalls and the archaeological levels, there is a sterile, brown sandy layer, full of gravels, about 1.5 m thick, dated to the Würm IV by H. Laville.

Age

The chief source of data on the age of the deposits is Laville's granulometric and geochemical study and his attempt to correlate the strata with glacial phases (Laville and Sonneville-Bordes 1967). According to him, level M1 formed under variable but cold conditions. M2 represents warm, humid condition, and M3, a return to cold and dry conditions. This is consistent with deposition during the first half of $^{18}O$ Stage 3 ("Würm II" according to Laville 1975, 1988). The contact between the top of M3 and the base of level G represents a warm phase ("Würm II/III"). Layers G and F were probably deposited during a very cold and dry phase during the second half of Stage 3 ("Würm III"). Because Laville's methods of reconstructing past climate have come under intense criticism (e.g., Bertran *et al.* 1995; Bertran and Texier 1990, 1994, 1995; Campy and

Chaline 1993; Texier 1990; Texier *et al.* 1998; Van Steijn *et al.* 1995), his chronostratigraphic interpretations of the Caminade Est deposits are not secure.

For the present study, the most important problem stemming from this uncertainty is that it leaves open the question of how old the Mousterian assemblages are. Although the Aurignacian tradition spans a relatively long time interval (approximately 40,000 BP to 27,000 BP), the Mousterian spans a much longer interval in the Perigord (from > 120,000 BP to at least 30,000 BP), and so the typological nature of the artifacts provides no acceptable chronological resolution. The nature of contact between the M3 and G layers is crucial to an understanding of the age of M3, but unfortunately this contact is not straightforward, as the preceding stratigraphic description makes clear (Sonneville-Bordes 1970).

According to the sedimentological, geomorphological, and chemical analyses of Laville and Sonneville-Bordes (1967) and Laville *et al.* (1980), the M3/G boundary was affected by three geologic events that took place between the abandonment of the shelter by Mousterian people and its re-occupation in the Aurignacian. First, a soil formed during a period of climatic amelioration. As the climate became increasingly warm and moist, running water eroded the soil along with the upper portion of the Mousterian deposits in most of the shelter (and all of the Mousterian deposits in Caminade Ouest). Finally, the return of very cold conditions caused severe cryoclastic weathering of the shelter itself, leading to the retreat of the shelter's wall and the formation of a limestone shelf. The debris from this episode of mechanical weathering was transported from the site by water and gravity. The Aurignacian occupation that followed was laid down upon this bare limestone shelf in the rear of the shelter, and

upon a mix of rubble and the weathered surface of the M3 deposit toward the front of the shelter. At that time the climate was still cold and becoming progressively drier.

While there is no reason to doubt the integrity of the data generated by these analyses, their interpretation by Laville and his colleagues has been strongly criticized. Actualistic studies on periglacial and glacial processes (e.g., Bertran and Texier 1995; Texier *et al.* 1998) have made it clear that some kinds of data that were a key part of Laville's chronostratigraphic interpretation, such as stratification of different size clasts, often result from periglacial and glacial disturbances of existing sediments in a very short time frame (seconds or minutes) rather than from climatic oscillations on a scale of centuries.

Nevertheless, some evidence from the Caminade study favors the hypothesis of a relatively short temporal hiatus between the Mousterian and Aurignacian deposits. First, the sediments that contained Mousterian artifacts formed a continuous stratigraphic sequence with no evidence of erosional episodes or major depositional hiatus. Second, the Aurignacian of level G lies directly upon level M3. Therefore, "in order to attribute the Mousterian block to Würm I times, one would be forced to adopt the argument either that the erosional phase which succeeded their deposition carried away an entire block of Würm II deposits which must once have overlain them or that, for some unknown (and unlikely) reason, deposition at the site ceased altogether throughout Würm II times," (Laville *et al.* 1980:123).

A radiocarbon analysis on burned bone from the lower level of Caminade Ouest (GrN-1491) produced an age of 29,100 ± 300 bp (Delibrias and Fontugne 1990). Inexplicably, Laville *et al.* (1980:123) reported the same date as 27,150 ± 300 bp; they also questioned its accuracy. Neither Laville *et al.* (1980) or Delibrias and Fontugne

(1990) indicated whether the figures they reported represented calibrated ages. Recently, H. Valladas completed radiocarbon analyses on bone collagen from all four Aurignacian levels of Caminade Est, yielding a date of 37,200 bp ± 1500 for level G (F. Delpeche, pers. comm.). This date is about 5,000 years older than Sonneville-Bordes' (1960) typology-based chronology of Upper Paleolithic industries had suggested. The difference between expectations and the date obtained might easily be attributed to the shortcomings of typological chronology. Nevertheless, it is worth noting that the dated bone consisted of small, weathered fragments that probably were dispersed throughout level G.

Although the radiocarbon date and stratigraphic evidence are both open to question, they are consistent with the assignment of level M3 to the middle part of Stage 3. Unfortunately, there is no direct source of information on the age of level M3; the most that can be said is that it is probably older than 37,000 BP. Because of the stratigraphic position of levels M2 and M1 below level M3, they could easily be much older than M3; therefore, I exclude them from my analysis.

Jean-Philippe Rigaud kindly permitted me to conduct thermoluminescence analyses on a burned chert flake from level G. I analyzed this flake with the intention of doing isochron dating, because the lack of sediment samples precluded the calculation of the natural dose rate. (The site was excavated in its entirety and now lies on private property, making the collection of sediments nearly impossible.) In this method, the dose rate is calculated on the basis of a regression line through the equivalent doses of several samples from the same geologically homogenous layer. This method depends on all the samples having received the same external dose. After calculating the TL and equivalent dose on one sample, I halted the project because it became clear that it

would not be possible to calculate a reliable date. The chief difficulties were the small number of burned flints, uncertainty about the exact three-point provenience of the flints to be dated, and indications that the sediment matrix was very heterogeneous. Because the Caminade Est sediments include large and small blocks within fine sediment, I could not be certain that all flakes had the same external dose rate.

Paleoenvironment

If we exclude the aforementioned sedimentological analyses as a source of information on the paleoenvironment of Caminade, we are left with the palynological and faunal analyses. Paquereau's (1969, 1970) analysis of pollen samples (200-300 grains each) suggested that six pollen "zones" were represented in the Mousterian layers, corresponding to the six climatic phases of the "Würm II". Three of these phases occurred as level M3 was deposited, and were marked by the following sequence of climatic change: cold, very dry steppe (base of M3); climatic amelioration and strong humidity (first half of M3); very cold steppe (second half of M3). The percentage of arboreal pollen remained at between 10-12% throughout level M3, and this was dominated by pine, with smaller frequencies of juniper and beech. The non-arboreal pollen was dominated by steppe species including grasses, artemesia, and tubulifolores. She noted a strong similarity with the pollen diagrams for the Würm II sequence at nearby Combe Grenal. For the Aurignacian layers, Paquereau (1970) noted cold conditions during level G times, followed by a gradual rise in temperatures that continued through the middle of level D. Three samples from level G had arboreal pollen of 7%- 8%, which was dominated by pine but also included willow and birch. The grasses included many steppic and xerophilic species. The pollen ensemble as whole indicates cold steppe conditions.

Delpech (1970) carried out faunal analyses at Caminade Est. Unfortunately, acidic conditions greatly damaged whatever bones were originally deposited. The 59 identifiable faunal remains from the four Aurignacian levels plus level E consisted mainly of teeth. In level G, the only identifiable taxa were red deer, reindeer, and bovids. Based on metrical comparisons, Delpech concluded the two bovid molars from level G were from *Bos primigenius* rather than bison, while expressing reservations due to the small sample size and imperfect nature of the comparative sample. Delpech's results for level G do not contradict the interpretation of cold steppe conditions, but she did not regard them as conclusive because they are based on only 7 specimens.

Typology

In her typological description of the Mousterian assemblages, Sonneville-Bordes (1969) grouped the artifacts from M3 base and M3 summit, but treated the tools from M3+ separately. She based this on perceived typological differences between M3+ and the other two layers in M3, as I explain below. However, I feel that stratigraphic conclusions should be considered independently of typological analyses. The number of artifacts being very small from all three sub-layers (n = 502 for M3 base, M3 summit, and M3+ combined), I followed Laville *et al.* (1980) and combined the material from all three sub-layers in my analyses.

Sonneville-Bordes reported 69 tools (essential count) from M3 base, 25 from M3 summit, and 40 from M3+. This gives a total of 134 for level M3, more than were found in either M2 or M1. Typological indices for the combined M3 base and M3 assemblages are shown in Table 3.4. Most of the 55 sidescrapers are made on Levallois flakes, and simple sidescrapers were the most common type. The remainder of the tools consist of 3 endscrapers, 1 burin, 4 backed knives, 4 raclettes, 3 truncated flakes, 7 notches, 6

denticulates, a chopper, 4 miscellaneous tools, and 15 pieces with abrupt, alternating, thin "retouch".

Sonneville-Bordes (1969) remarked that the 40 tools from M3+, which she analyzed separately, presented a "very different" typological aspect from the other Mousterian assemblages. In particular, the M3+ assemblage has a very low Levallois index, low blade index, high sidescraper index, and high Quina index. She thus concluded that this assemblage from the top of the Mousterian sequence belonged to the Quina Mousterian, despite its small sample size. She attributed the combined assemblages from M3 base and summit, as well as those from M2 base and summit, to the Ferrassie Mousterian; and the M1 base and summit assemblages to the Typical Mousterian.

Mellars (1986, 1996) has cited Caminade Est as one among several sites with an industrial sequence supporting his claim of a temporal succession of Mousterian variants, from Ferrassie, to Quina, and finally Mousterian of Acheulean Tradition (MAT). However, the small sample sizes of the Caminade Est assemblages should lead us to be cautious in accepting this. In addition, the published reports leave some important questions unanswered. In particular, it is not clear why Sonneville-Bordes grouped the artifacts from levels M3 base and M3 summit despite the fact that they were separated by a sterile geologic unit (M3b), while keeping separate the artifacts from M3 summit and M3+, which belonged to the same geologic unit (M3a) according to Laville *et al.* (1980).

Sonneville-Bordes (1970) attributed layers G and F to Aurignacian I and layers D2 inf. and D2 sup. to Aurignacian II. She reported 348 stone tools and two pieces of worked bone from level G. The bone tools consist of a 6 cm long, lozenge-shaped antler piece, which she interpreted as a point, and a larger but fragmentary point, possibly of

the split-based type. The typological nature of level G is summarized by the indices and percentages shown in Table 3.5. There is one chopper made of basalt, and there are two chopping-tools of chert.

Two of the most interesting aspects of this assemblage are the sidescrapers and Châtelperronian points. There are 22 sidescrapers in the assemblage (= 6.60%), and these include one exquisite example of a Quina sidescraper on a large flake. Sonneville-Bordes (1970:95-96) suggested that "...at least some of them may belong to the Mousterian levels because the distinction between the top of the Mousterian deposits and the base of level G was not always certain. In addition, the Aurignacians themselves could have collected sidescrapers exposed by the erosion episode between the two occupations." This assemblage also contains three Châtelperronian points, two of which were collected *in situ* at the base of level G and on the slope of square C3, the other one having been found in the screen.

The presence of Châtelperronian points, the abundance of sidescrapers, and the presence of at least one very Quina-like sidescraper in this Aurignacian assemblage raise the possibility of significant stratigraphic mixing with one or more underlying layers, possibly including a very eroded Châtelperronian layer. However, to adequately evaluate that hypothesis would require closer scrutiny of taphonomic and depositional processes at this site than was done at the time of excavation.

Lithic raw materials

Caminade is just inside the southern boundary of the Senonian chert zone, and just north of the zone where chalcedony/millstone is found. Yet, there are only a dozen chert occurrences within a 5 km radius of the site on the maps presented by Geneste (1985). Senonian chert occurs within 100 m to a few km from the site, and

chalcedony/millstone about 5 km away. There are occurrences of jasper-like chert that lie at about the same proximity. An outcrop containing both chalcedony/millstone and jasper is only 5 km to the south, near Domme. Outcrops of Hettangian jasper lie 40 km east at Puy d'Arnac, and 50 km north near Exideuil.

Although a ditch today carries water that once belonged to a creek, the flow is too gentle to carry gravels. Walking to the nearest alluvial source of raw materials, the Dordogne River, would require traversing a plateau, a distance of about 2 km; or following the creek downstream for a distance of about 3 km. Prehistoric foragers could have accessed abundant river gravels quickly by following either route. Other raw materials, which I described in the above section on the lithic raw materials of Le Flageolet, lie more than 30 km away in all directions (see Table 3.3).

**Le Moustier, lower shelter**

Situation and history

Le Moustier is a pair of low rockshelters in Coniacian limestone at the end of a promontory overlooking the confluence of Vimont Creek with the Vézère River. The shelters lie about 500 m from the right bank of the Vézère, and both face the south. The lower shelter is below a narrow shelf in the limestone rock face, and the upper shelter is above that shelf, about 10 m above the roof of the lower shelter (Soressi 1997). The base of the lower shelter lies only 5 m above the mean water level of the Vézère, and it has been flooded in historic times (Laville and Rigaud 1976).

The upper shelter is the eponym for the Mousterian tradition; it was discovered in the 1860s and dug at various times by Lartet and Christy (1875), Bourlon (1905, 1906 1910), Peyrony (1930), and Hauser, whose findings were not published. The lower shelter was discovered in 1905 (Bourlon 1905), plundered by Hauser in 1907-08, and

then acquired on behalf of the state by D. Peyrony. Peyrony's excavation began in 1910, and his collections are housed at the prehistory museum in Les Eyzies (Laville and Rigaud 1976). An adult and an infant Neandertal skeleton were found in the lower shelter. Recent TL and ESR estimates from this site (see below) would make those among the most recent of dated Neandertal remains from Europe, although there is uncertainty about the exact geologic provenience of the fossils.

In 1969, Laville and Rigaud (1973, 1976) conducted a limited excavation and profile cleaning in order to refine Peyrony's stratigraphic interpretations, and to prepare the sites for visitation during the Ninth Congress of the Union Internationale des Sciences Préhistoriques et Protohistoriques. Their collection was done without any detectable collector bias, but unfortunately also without screening of sediment (Soressi 1999). I studied material from their excavation, but not the material from the Peyrony excavation, for reasons I list below.

Stratification

Peyrony (1930), Bourgon (1937), and Bordes (1969b) all proposed various chronostratigraphic interpretations of the lower shelter. The following description of the sediments comes from the more recent and more detailed work by Laville and Rigaud (1976:83). I have translated their summary and reversed the order, so that it follows the strata from bottom to top (see Figure 3.6):

> Level A: Subdivided into: A2, fine sand with local stratification; and A1, very coarse sand within a clay matrix.
>
> Levels C and B: Alluvial formation composed of quartzite cobbles and rolled nodules of chert, in coarse sand. At the base, there are lenses of silty clay (Peyrony's level D).
>
> Level D: Products of cryoclastic weathering transported by the Vézère. Subdivided into: D2, small limestone elements with a flat, very rounded shape,

very friable, associated with a coarse sand deposited in oblique and cross-cutting strata; D1, larger limestone cobbles, flat and very well rounded, in a coarse sand.

Level E: Alluvial silts with clay and some sand.

Level F: Clayey silty sand with some angular frost spalls.

Level G: Homogeneous deposit of clayey-silty sand, containing numerous large limestone frost spalls, with rounded forms. The interstitial sediment, quite plastic in its wet state, shows localized occurrences of moderately well developed, angular, polyhedral structures. These structural features, along with the flints, are sometimes covered in a thin clay film. This deposit is subdivided into four levels: G4, small frost spalls and numerous gravels; G3, large, globular frost spalls, and at the base a thin layer of pisiform gravels; G2, frost spalls with the same morphology but smaller and more rare; G2, frost spalls of moderate size.

Level H: Heterogeneous formation consisting of 9 superimposed levels (H9 to H1), of which some may be further subdivided according to the density of archaeological material and textural and morphological characteristics of the sediment (H7d to H7a, H2e to H2a).

Level I: clayey-silty sand of fluvial origin, with rounded frost spalls that are more abundant at the very top and at the base (levels I 1, I 2 and I 3).

Level J: Clayey-silty sand with limestone frost spalls and gravels, the varying proportions of which permit us to distinguish levels J 5 to J 1. Level J 5 appears to correspond to the base of level K as Peyrony defined it. The Denticulate Mousterian that F. Bordes attributed to the base of level K could belong to this deposit instead.

Level K: Weathered frost spalls and gravels in a clayey sand with little silt.

Level L: Thickness: 0.25 m. Slightly rounded limestone frost spalls, and gravels of the same nature, in a dark brown, silty sand with a slight clay component.

The several archaeological layers in this site contain a dense concentration of anthropogenic sediments. The industries from each layer are shown in Table 3.6.

Chronology

According to Laville and Rigaud (1973, 1976), levels A to F consist of alluvial sediment deposited by the Vézère, while levels G to L consist mainly of cryoclastic sediments originating in the rockshelter itself. Based on their sedimentological and

stratigraphic analysis, they placed levels H to J in the first four phases of Würm II (following the climatic scheme of Laville 1975). However, that interpretation was called into question by a series of TL dates on burnt flints from throughout the profile. Thirty-four burned flints from levels G -K were dated, with the highest concentration in level H (Valladas *et al.* 1986; see Figure 3.6 and Table3.7).

Laville and Rigaud (1973) divided Layer H into nine levels on the basis of variation in fabric. These are, from bottom to top, H1-H9. In addition, levels H2 and H7 were subdivided into two sub-levels each. Valladas *et al.* (1986) reported the results of thermoluminesence analyses on burned flints from the site, including 24 samples from Layer H (Table 3.7). Level H7, directly below H8, yielded three ages with an unweighted mean of 44,470 bp. Layer H9, directly above H8, yielded three ages with an unweighted mean of 42,100 bp. The TL ages within Layer H are roughly in agreement with their stratigraphic position; for example, the four ages from H1 have a mean of 46,300 bp, older than any other level. The 24 ages place level H8 at approximately 42,500 ± 2000 bp, the weighted mean average for the 20 ages from levels H2-H9 (Valladas *et al.* 1986). ESR dates on animal teeth (Mellars and Grün 1991) from level H agree closely with the TL ages (see Figure 3.6).

Sample selection

In addition to the age of layer H8, two other factors led me to select it among those available from Le Moustier: assemblage size and representativeness. Though small, the area excavated by Laville and Rigaud (½ m by 2 m) produced a profusion of material; their collection from H8 alone yielded 1100 lithics, including cores, tools, and debitage. Soressi (1997, 1999), who studied Levallois reduction methods in level G, noted that the collection excavated by Peyrony was strongly affected by the excavator's

bias in favor of large and/or typologically distinct tools, whereas the material from the Laville/Rigaud excavation was collected without any such bias. She noted further that "from a qualitative perspective, the Peyrony collection is not statistically different from the Laville/Rigaud collection when we correct the biases introduced by the conditions of excavation," (Soressi 1999:115). It is for the same reasons that I analyzed only material from the Laville/Rigaud recent excavation. Because of the density of artifacts, this collection from a small part of level H8 has a greater potential to be statistically representative of the raw material and technological composition of the entire level than the much larger collection excavated by Peyrony in the 1910s and 1920s.

Technology

The material from level H8 has not been previously analyzed. Marie Soressi, of the University of Bordeaux I, is conducting her own dissertation research on the material from Laville and Rigaud's excavation, from all levels. At this writing, only the results from her analysis of level G were available (Soressi 1997, 1999). She found the assemblage of 1705 artifacts clearly testified to unipolar, recurrent, serial Levallois debitage. In this method, a Levallois core prepared, its debitage surface is reduced by the removal of 2-4 Levallois flakes from the same striking surface, a new striking surface is prepared, and additional Levallois flakes are then removed from that surface. Because the Levallois flakes in the assemblage are, on average, larger than non-Levallois flakes, and because they tend overwhelmingly to have a square shape, she reasoned that there was some effort to standardize the morphology of the products beyond what can be achieved by relying on Levallois reduction. Nearly all (99.9%) of the assemblage is made on Senonian flint, which was probably gathered from the banks of the nearby river and reduced *in situ* at the rock shelter.

Lithic raw materials

The nearest known occurrence of lithic raw materials near Le Moustier is the Vézère River, which flows about five hundred meters from the rock shelter. During a systematic study of the lithologic composition of river gravels along the bank of the river at Le Moustier in 1996, I found cobbles of quartzite, basalt, and chert.

In addition, Geneste's (1985) data show 34 primary and secondary occurrences within a 5 km radius of the site. These belong mostly to beige Senonian chert, along with some black Senonian. There are three known occurrences of chalcedony/millstone nearby along the Beune River, 4-9 km distant. According to Geneste's (1985:155) data, there are three occurrences belonging to "varieties of beige, marbled chert with jasper-like texture" within a distance of 1.5-2.0 km, west of Le Moustier. Geneste (1985:163) also showed two occurrences of Senonian jasper-like chert west of the site, at distances of 7 and 10 km. There are a few other scattered occurrences of that chert along the Dordogne river due south of Le Moustier.

Further south, the occurrences containing both chalcedony/millstone and jasper on the Plateau de Bord near Domme are approximately 25 km away. Brown and beige jasper-like chert is also found in two clusters of occurrences in the Couze valley, 31-36 km to the southwest. Also to the south, Gavaudun and Fumelois chert lie 45 and 48 km away, respectively. To the east, Hettangian jasper from Puy d'Arnac lies 53-56 km away. To the north, other occurrences of the same kind of chert are found 35 km away in the valley of the Auvézère near Exideuil. To the west, Bergeracois chert and related varieties occur at a minimum distance of about 33 km, and the several varieties of chert found in the region around Mussidan occur about 53 km from of Le Moustier.

**La-Côte**

Situation and history

This small open-air site is located on the right bank of the Isle River, in an area of low relief near Neuvic (see Figure 3.1), about 10 m above the level of the river. The site was discovered in 1966 and tested in 1971. When a road-widening project threatened to destroy La-Côte in March 1972, Jean Gaussen and Jean-Pierre Texier conducted a salvage excavation.

The three archaeological levels all appear to be Upper Paleolithic. Level I contained only 8 artifacts, and level II contained 85 (including 7 tools). Level III, which is typologically Châtelperronian, yielded over a thousand artifacts, of which 104 were retouched. According to Gaussen and Texier (1974:518): "a large part of the habitation must have been destroyed by the construction of Departmental Route 3." Thus, level III, which was excavated in an area of roughly 7 $m^2$ (see Figure 3.7), was only very partially recovered. Nevertheless, as these authors remarked, level III is important because unlike most other Châtelperronian assemblages, it was "sealed" between intact loess bodies. This, and the absence of any Mousterian or Aurignacian levels at the site, excludes the possibility of contamination by artifacts from other industries. Perhaps for this reason (see Rigaud 1993), the assemblage has few Mousterian tools and lacks both sidescrapers and characteristic Aurignacian tools. La-Côte is also "the only Upper Paleolithic Neuvic site other than Solvieux whose archaeological deposits extend deep below the plow zone" (Sackett 1999:12).

Stratification

The following description of the stratigraphic sequence is taken from Gaussen and Texier (1974:500-502; the order of the units rearranged so that they follow stratigraphic order from bottom to top):

> Level 8: The base is not visible. Its color is identical to that of level 7 [light brown to yellow-red]. However, it is distinctly higher in clay content and lower in silt (a silty clay). It shows a poorly developed polyhedral structure. The sediment is porous, sticky and very plastic.
>
> Level 7: Thickness, 20 cm. The color is light brown to yellow-red. It is composed of clayey-sandy silts (in fact, the proportions of silts, sand, and clays are almost identical). Its structure is angular to polyhedral, and thin films of bright clay are visible at the surface of the structures. The sediment is of low porosity, viscous and plastic. Its lower limit is distinct and undulating, and is marked by a poorly developed pebble lens.
>
> Level 6: The thickness is quite variable, from 5 to 15 cm. It is formed of sandy silts, more clayey than those of level 5. It is also more structured than the overlying level. Dark to light brown in color, it contains rather numerous stains of iron and manganese. The sediment is porous, non-viscous and plastic. It is at the base of this ensemble, above a well-developed pebble lens, that the largest archaeological level of the site (level III) was discovered.
>
> Level 5: Thickness of 4 to 10 cm. These are light brown, sandy-clayey silts. The structure is angular with light coatings. The sediment is non-viscous and low in both porosity and plasticity. A second archaeological level (level II) was identified at the base of this level.
>
> Level 4: Very thin, 3 to 7 cm thick. It is made up of sandy-clayey silts with an angular structure. Against a background of brown-yellow to light brown color can be seen small, dark stains from iron oxides and manganese. The sediment is porous, non-viscous and not very plastic. At the base of this level is a small pebble lens.
>
> Level 3. Medium thickness, 10 cm. It is formed of sandy-clayey silts, brown-yellow in color and with an angular structure. The sediment is porous, non-viscous, and not very plastic. The base of this level is marked by a very diffuse pebble lens of small quartz elements.
>
> Level 2. Quite variable thickness, 10 cm on average. The color is identical to level 1 [dark brown yellow]. However, it is more structured than that level (subangular) and distinctly more silty. The sediment is low in porosity, viscosity, and plasticity. Its lower limit has pockets of cryoturbation and traces of ancient

> roots, which have inserted themselves in the underlying sedimentary ensembles. It is at the base of this level that archaeological level I was found.
>
> Level 1. Mean thickness of 40 cm. It represents recent [agricultural] disturbances...

Texier (Gaussen and Texier 1974) interpreted the silts as loess that developed during full glacial conditions. The structural features are primarily related to post-depositional solifluction that re-worked silt and sand from the overlying alluvial terrace.

Age

Based on a series of granulometric, chemical, and morphoscopic analyses (micro-artifact inventory and particle morphology), Texier proposed a chronological interpretation that placed level 6 (and thus level III) within phase II of the Würm III, which would correspond to a time in the second half of Stage 3. He interpreted the pebble lens at the base of level 6 as belonging to the beginning of the Würm III. These conclusions must be treated with caution, based as they are on a heavily-criticized sedimentological method of reconstructing climate and on the general difficulty of correlating terrestrial records with marine isotope stages.

There are no chronometric dates from La-Côte. No bone was recovered there, and the entire site was destroyed by road construction after the recovery of archaeological materials. Nor can any precise guesses be made from existing dates on Châtelperronian assemblages elsewhere. According to d'Errico *et al.* (1998) and Zilhão and d'Errico (1999), all reliable chronometric dates on Châtelperronian assemblages confirm that this "technocomplex" preceded the earliest Aurignacian, and thus pre-dates 38,000 BP. In a critical reply, Mellars (1999) argued that the majority of reliable radiocarbon dates for Châtelperronian assemblages cluster within the period 38,000 – 33,000 BP, and that this represents the true age of the Châtelperronian tradition.

However, radiocarbon dates in this range are very susceptible to three potential sources of error: contamination with older carbon, the uncertainty in radiocarbon calibration at this extreme end of the radiocarbon range, and the possible existence of two plateaus in radiocarbon between 40,000 BP and 30,000 BP (Pettitt 1999). In short, the assemblage from La-Côte is probably older than 33,000 bp and younger than 43,000 bp. In all likelihood, therefore, it is older than levels XI and IX from Le Flageolet I, and younger than level H8 from Le Moustier. Nothing more specific can be said about its absolute age, but this relative chronological placement suffices for the needs of the present study.

Typology

The tool assemblage (n = 104) is dominated by endscrapers on flakes (9.6%), Châtelperronian points (15.4%), and notched pieces (19.2%). There are 22 endscrapers in all, of which only three were made on blades. The excavators reported only five burins, "mostly of poor quality manufacture," (ibid, p. 514), but Pelegrin (1986:439), who re-analyzed the tools, interpreted two of these as bladelet cores on flakes, and one as a broken blade. This leaves 2 burins, both made on thick flakes. The assemblage contains only "3 or 4 burin spalls," (Ibid). Gaussen and Texier reported 22 Châtelperronian points, while Pelegrin put the total at 18; according to both reports, seven of those artifacts are complete, the remainder being fragments. They tend to be small (< 5 cm long). In addition there were five backed blades (six according to Pelegrin). There were 23 (15.4%) truncated pieces, ten of which were made on blades or bladelets. Pelegrin (1986:442) put the total number at 10, because he re-interpreted what Gaussen and Texier had called "truncated flakes" as "simple core maintenance flakes." The assemblage also contains five blades with fine, continuous retouch. The six "miscellaneous" pieces include two choppers, a naturally backed knife, and an

alternating burin bec. Pelegrin also discovered a small flake with micro-denticulations along its distal edge that had been overlooked by previous analysts.

Technological aspects

Pelegrin (1986) carried out a detailed analysis of La-Côte level III, along with level 8 of Roc de Combe, as part of a study of Châtelperronian debitage systems. I reserve my discussion of his conclusions about core reduction for a later chapter. Here, I simply mention one of his chief conclusions, which is that the technological system primarily represented the intention to produce small blades and manufacture Châtelperronian points on them. This was based on several findings. Châtelperronian points are one of the few kinds of tools in the assemblage, along with truncated blades, backed blades, and blades with continuous retouch, that are made only on blades or bladelets. Flakes and "unidentified" blank types were more frequently used for other kinds of tools. Moreover, the most regular and symmetrical blade blanks were reserved for making Châtelperronian points, while asymmetrical or more curved blades were used for other tool types. Blank production methods at La-Côte were specifically designed for the production of small, uniform blades, which were produced using direct, soft hammer percussion. In addition, 62% of blades/bladelets were retouched into formal tools, compared with only 35% of flakes. According to Pelegrin (1986:470), most of the flakes in this assemblage are "obviously not the product of a primary intention, but products derived from blade debitage and only partially used."

Lithic raw materials

Unlike the preceding three sites, La-Côte lies outside the boundaries of the densest zone of chert occurrences. Geneste's (1985:138) composite map shows only 8

*in situ* occurrences of chert within a 5 km radius of the site. Nevertheless, the immediate environs of this site hold at least as great a variety of chert types as at the others.

La-Côte lies outside the zone of beige Senonian occurrences, but not by much: Geneste's map (1985:144) shows three occurrences of this chert on the other side of the Isle River, at distances of approximately 2-3 km. There are several kinds of chert available at distances of about 8-13 km from La-Côte. Mussidan chert, for example, is known from about a half-dozen occurrences, all of which lie 9-10 km downstream on the opposite bank of the Isle. In addition, Geneste (1985) and Turq (1992) mention some less completely documented varieties of jasper-like chert, and some of these are found fairly close to La-Côte. One has been described as "petrified wood" of the region near Mussidan; Geneste (1985:163) displayed a dozen occurrences of this material within 2-10 km from La-Côte. Brightly colored, jasper-like chert of Bergeracois occurs on a plateau about 8-11 km to the south. Gaussen (1980) mentioned a very unusual fine-grained, pink, speckled chert, which he found about 9 km downstream from La-Côte near Mussidan. According to Pelegrin (1986), this may be a variety of beige Senonian or of Bergeracois. The zone in which chalcedony/millstone is densest lies 30 km to the south, beyond the left bank of the Dordogne River, but Geneste (1985) reported a few scattered occurrences of this raw material extending far north; four of those lie 11-13 km upstream from La-Côte.

On the plateau that borders the left bank of the Isle River, there are a few occurrences of a fine-grained black chert. Demars (1982) listed these as Maastrichtian in age, but they do not resemble Bergeracois, the best-documented chert in those formations. I examined one occurrence of this chert, a road bank on the plateau about 85 m above the Isle and 4 km due east of La-Côte. Abundant nodules of the black chert

lay in loose soil in a ditch along the side of the road. The nodules were relatively small (ca. 1 kg) and well-rounded, and had very thin, smooth cortex. Breaking them open produced very translucent, sharp flakes with a vitreous luster.

Further away, a band containing many dozens of occurrences of black Senonian chert, aligned in a NW-SE axis, lies about 17-20 km from La-Côte, upstream and northeast of the site. The nearest occurrences of Bergeracois chert shown on Geneste's maps lie about 19-20 km to the south near Bergerac, along the Dordogne River and one of its tributaries, the Caudau. The two best known zones of jasper or jasper-like chert (Plateau de Bord and Puy d'Arnac) lie at about 55 km and 100 km east of the site, respectively. Two other possible sources of this material are found in the vicinity of Exideuil, about 55 km NE of La-Côte, and (significantly, as I explain below), upstream; one lies along the Auvézère, the other along the Loue.

Black Senonian chert, chalcedony/millstone, and Hettangian jasper may have been transported from the primary occurrences toward La-Côte by streams. Geneste (1985:158) observed that the limestone occurrences of Hettangian jasper generally consist of easily eroded, friable sediment. He has observed "occurrences in secondary position. . . scattered in the alluvial sediments of the Côle and the Dronne up to 15 or 20 km downstream of their zones of origin." Nevertheless, this would still place the nearest sources of this chert at least 35 km and perhaps 50 km from La-Côte. Limestone occurrences of black Senonian chert and chalcedony/millstone are not far upstream, however. Sackett (1999) suggested that black Senonian was gathered in the form of alluvial cobbles at the banks of the Isle during the occupation of Solvieux, 6 km downstream from La-Côte. If so, then it is fully possible that both black Senonian and chalcedony/millstone were available in close proximity to La-Côte. In any case, the

people who inhabited this site would have had a more diverse array of homogenous, fine-grained cherts at their disposal than the occupants of Le Moustier, Le Flageolet, or Caminade, despite the smaller number of occurrences found around La-Côte than around the other sites.

**Summary**

The six assemblages belong to four sites: Le Flageolet I and Caminade Est along the right bank of the Dordogne; Le Moustier, to the north on the left bank of the Vézère; and La-Côte, which lies 65 km east of Le Moustier on the Isle. Le Flageolet I, Caminade Est, and Le Moustier are rockshelters containing thick sequences of Late Pleistocene deposits, while La-Côte is a buried open-air site containing loess.

The assemblage of level H8 from Le Moustier, attributed to the Mousterian of Acheulean Tradition (MAT), was buried within a long sequence of alluvial units, stratigraphically sandwiched between several levels that have a weighted mean TL age of 42,500 bp ± 2000. There are abundant occurrences of chert within 5 km of the site, including beige Senonian, black Senonian, and chalcedony/millstone. The site is also within a few hundred meters of the gravel beaches of the Vézère River, which have quartzite and chert cobbles. The assemblage was collected by Rigaud and Laville in 1969; the larger assemblage collected by Peyrony in the 1910s will not be analyzed.

Level M3 from Caminade Est is the uppermost of three geologically defined units pre-dating a warm climatic oscillation late in $^{18}O$ Stage 3. These units consist of cryoclastic debris mixed with probable colluvium and geochemically altered sediments. Level M3 contained three sub-units, and the assemblage I analyzed consisted of the pooled lithics from three small Mousterian layers within two of those sub-units (3a and 3c). Level M3 is undated, but a radiocarbon date from the overlying level (G) suggests it

is older than 37,000 bp. Stratigraphic analyses suggest that the hiatus between M3 and G was relatively brief, so M3 is probably less than 47,000 years old, although this is only a guess. The contact between layer M3 and the immediately overlying layer G is discontinuous and marked by evidence of an intervening episode of pedogenesis and subsequent erosion. Bones from layer G yielded a radiocarbon date of 37,200 ± 1500 bp; the layer contains a very large Aurignacian assemblage. Pollen data suggest that layers M3 and G were deposited during very cold and dry episodes, when the area was covered with steppe vegetation. Compared to the other three sites, Caminade Est lies in a zone that is relatively poor in lithic raw materials, although there are several occurrences of chert within a few kilometers, and the site is 3 km or so from the Dordogne River, where river cobbles are abundant. Typological analysis suggested that M3 should be attributed to Ferrassie or Quina Mousterian, but the tool assemblage is too small for secure attribution. The assemblage from level G is typical of the early Aurignacian.

Level III from La-Côte was found within the sixth of eight geological layers. The eight layers were interpreted as a sequence of loess deposition punctuated by the formation of several paleosols. Contamination from adjacent layers can be ruled out, and the artifacts were too deep to be disturbed by plows. Level III appears to have been found intact, except for a large portion that was destroyed by road-building equipment, and was interpreted as representing a single occupational episode. Typologically, the 104 tools are distinctly Châtelperronian. There are no chronometric dates from La-Côte, but other Châtelperronian assemblages in France date to 33,000-43,000 bp. The number of raw material occurrences near La-Côte is smaller than at the other three sites, but there are a larger number of different *kinds* of raw material.

Le Flageolet I is a deeply stratified rockshelter with abundant cryoclastic debris, including many large limestone boulders, as well as slope wash sediment from the plateau above the roof of the shelter. The two Aurignacian assemblages I studied from the site—levels XI and IX—were the lowermost archaeological levels there, and were found near the base of the sequence. Higher levels contained other Aurignacian and Gravettian assemblages. Three radiocarbon dates from level XI span the range 31,190–35,600 bp (including error terms); the three acceptable dates from level IX span the range 26,000–30,590 bp. Thus, these are the two youngest of the six assemblages studied here (if all the age estimates are accurate). The site is located with a lithologic zone that is rich in lithic raw material occurrences, especially Senonian chert and chalcedony/millstone.

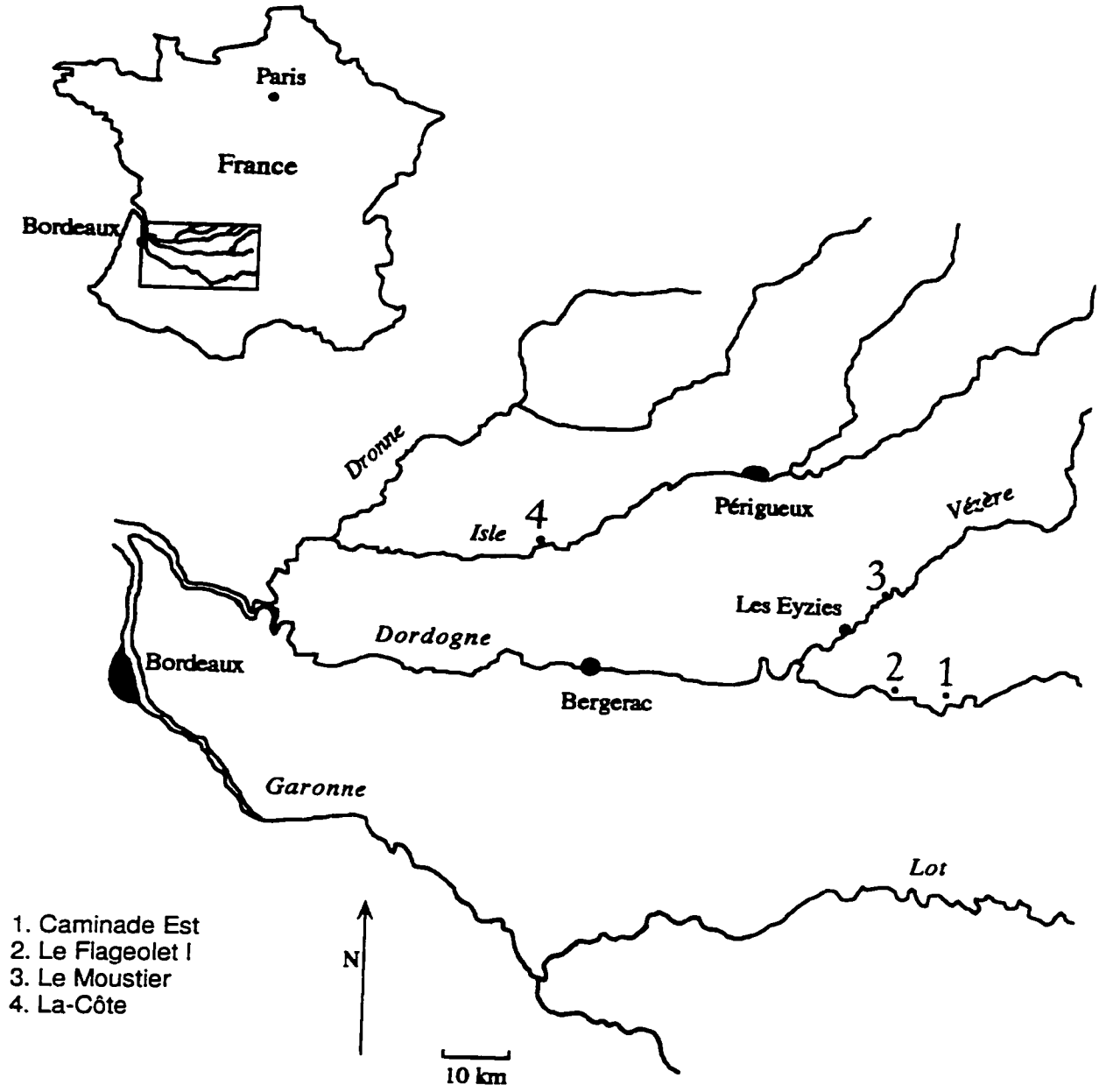



Figure 3.1 Site locations.

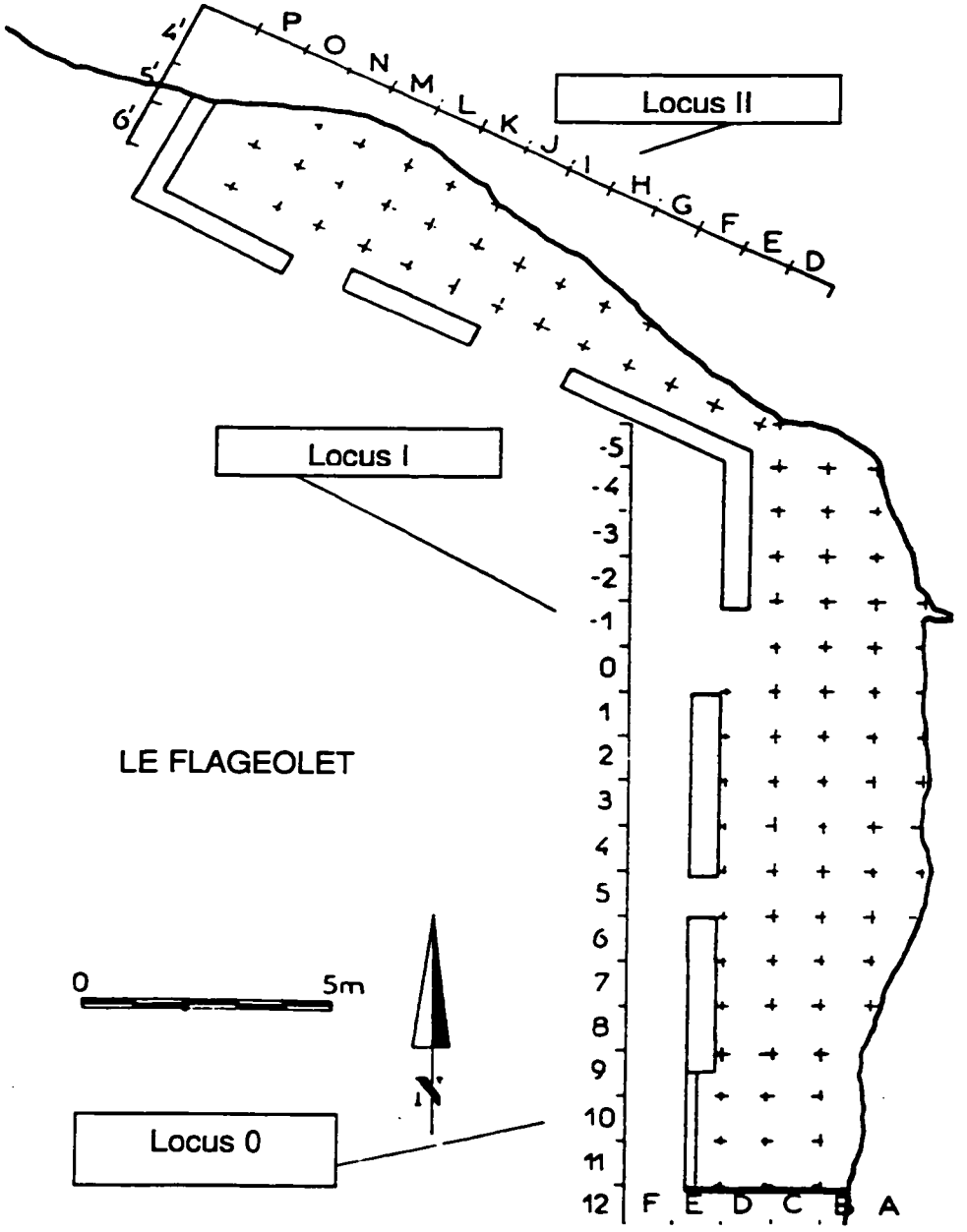



Figure 3.2 Plan view of Le Flageolet I and II, from Rigaud 1982.

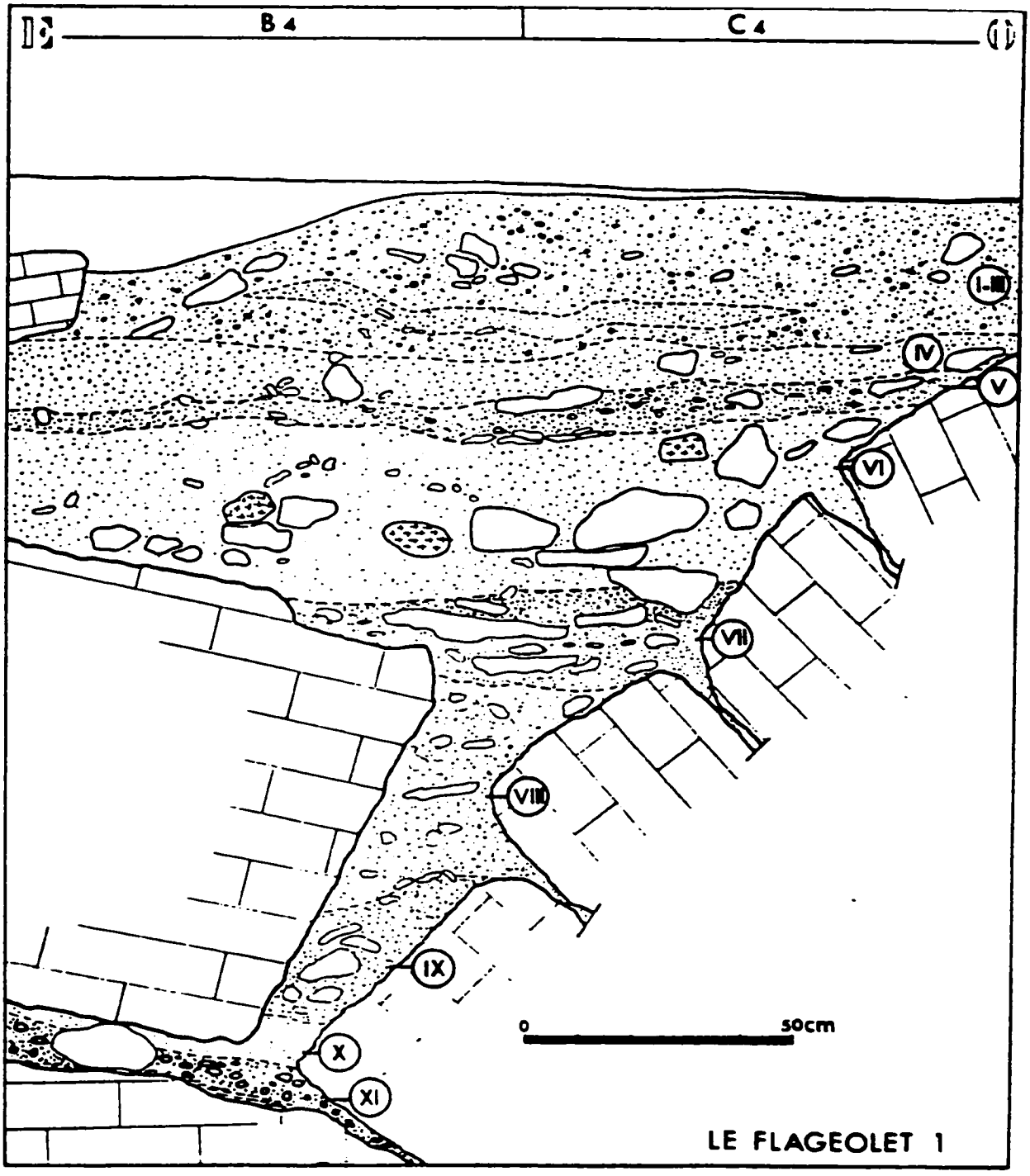



Figure 3.3 Stratigraphic profile from Le Flageolet I, from Rigaud 1982.

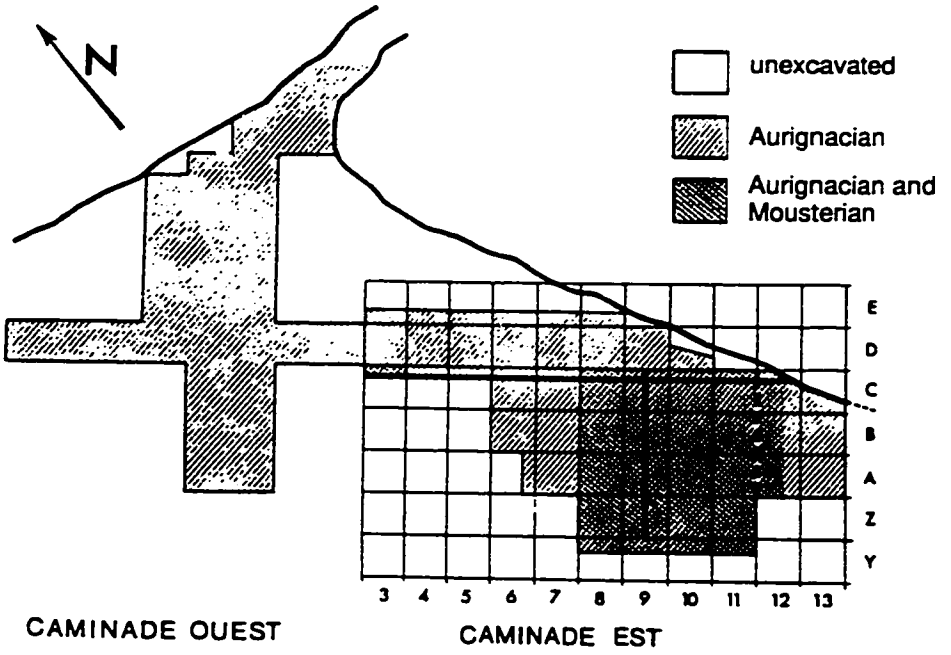



Figure 3.4 Plan view of Caminade Est and Caminade Ouest, from Sonneville-Bordes (1970).

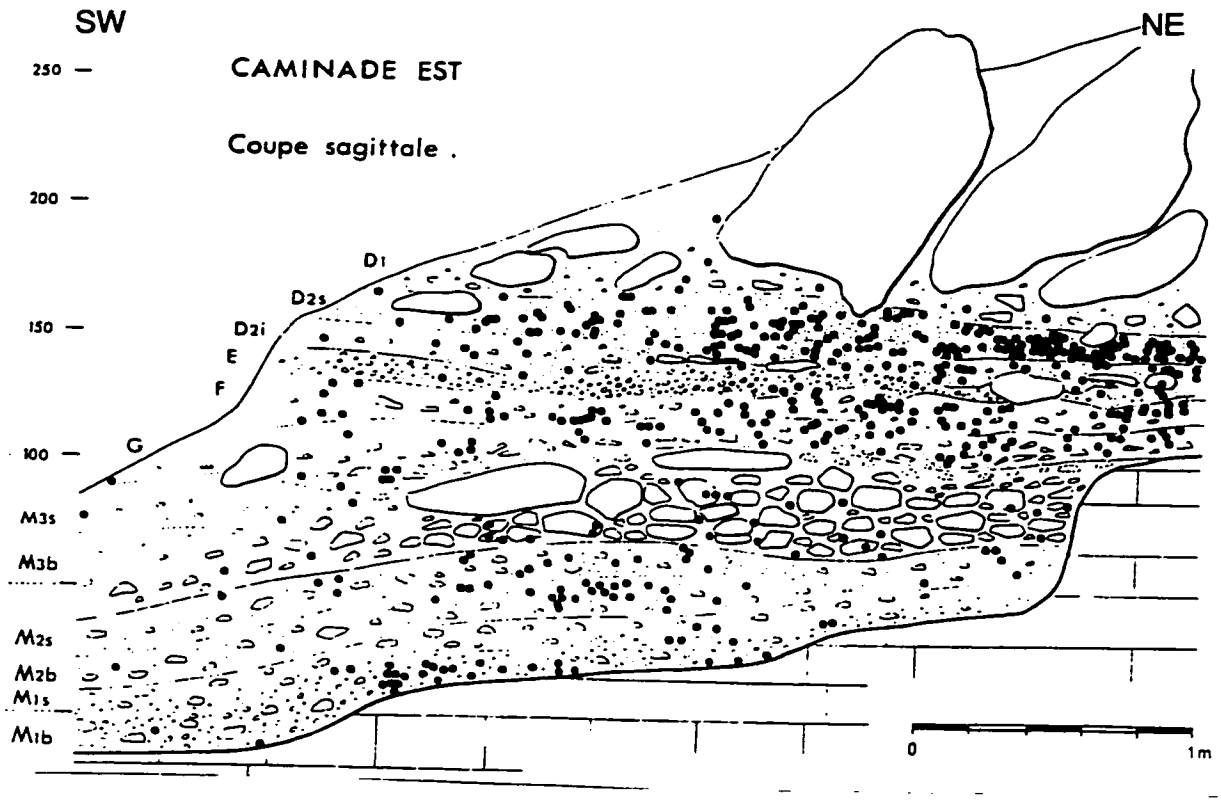



Figure 3.5 Stratigraphic profile from Caminade Est, from Sonneville-Bordes (1969).

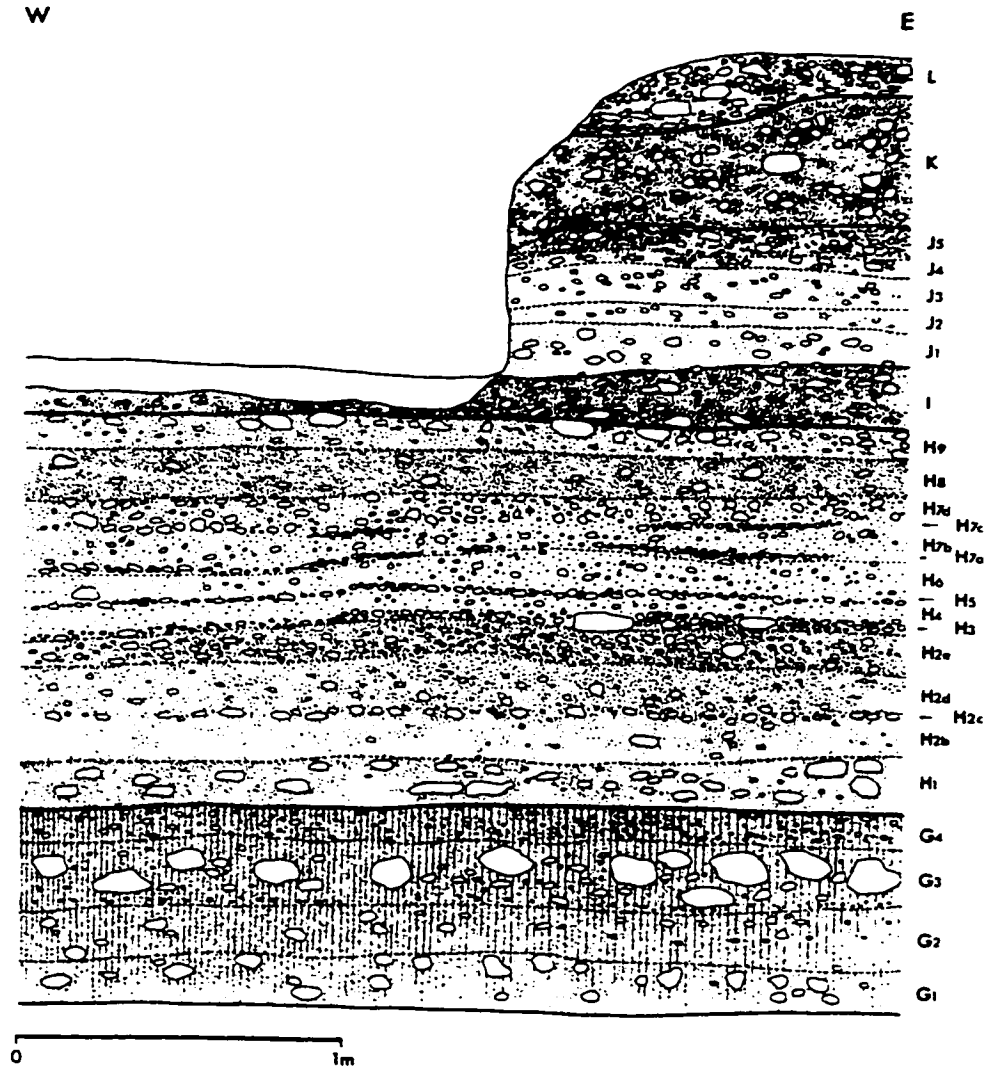



Figure 3.6 Stratigraphic profile at Le Moustier. From Laville and Rigaud (1976).

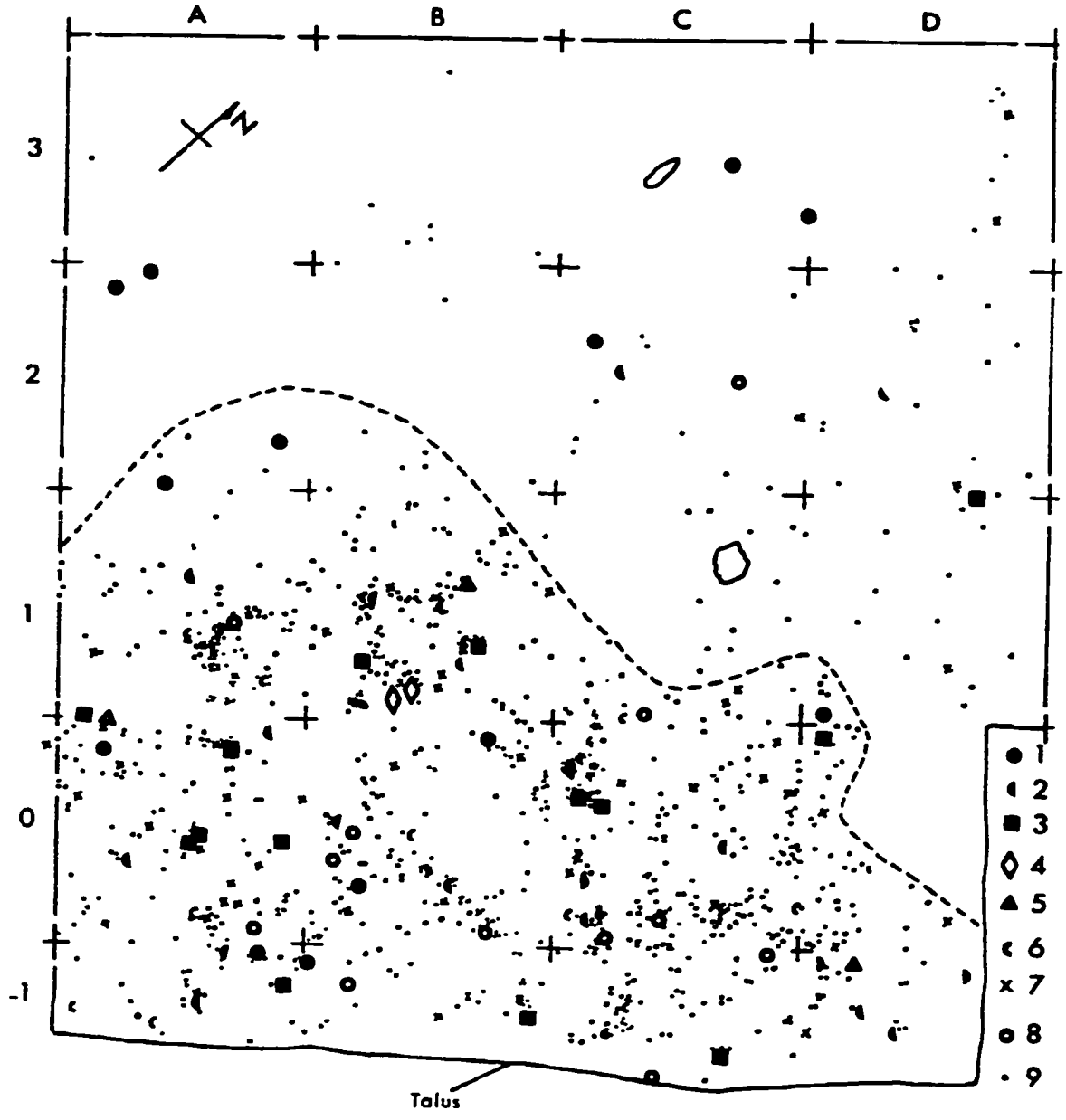



Figure 3.7 Plan view of La-Côte, from Gaussen and Texier (1974). Key: 1, endscrapers; 2, backed pieces; 3, truncated pieces; 4, burins; 5, becs; 6, notches and denticulates; 7, other retouched pieces; 8, cores; 9, raw flakes, blades, and shatter. Dashed : zone of highest artifact density.

Table 3.1 Ungulates and carnivores at Le Flageolet I, levels IX and XI: NISP by taxon (including specimens identified as "cf."). Data from Grayson and Delpech (1998).

| | Level | | |
|---|---|---|---|
| Taxon | IX | XI | Totals |
| Ungulates | | | |
| *Bos/ Bison* | 34 | 38 | 72 |
| *Capra* spp. | 12 | 15 | 27 |
| *Cervus elaphus* | 79 | 18 | 97 |
| *Rupicapra* sp. | 10 | 3 | 13 |
| *Capreolus* sp. | 9 | | 9 |
| *Equus* sp. | 1 | | 1 |
| *E. caballus* | 50 | 66 | 116 |
| *E. hydruntinus* | 11 | | 11 |
| *Mammuthus* sp. | 1 | | 1 |
| *Megaceros* sp. | 1 | | 1 |
| *Rangifer tarandus* | 468 | 511 | 979 |
| *Sus* sp. | 5 | | 5 |
| Totals | 681 | 651 | 1332 |
| No. of taxa | 11 | 6 | |
| Carnivores | | | |
| *Canis lupus* | 3 | | 3 |
| *Lynx* sp. | 1 | | 1 |
| *Ursus* sp. | 1 | | 1 |
| *Vulpes/ Alopex* | 18 | 5 | 23 |
| Totals | 23 | 5 | 28 |

Table 3.2 Assemblages examined.

| Site | Level | Tradition | Date, yrs BP | N[1] | n[2] |
|---|---|---|---|---|---|
| Le Moustier | H8 | Mousterian | ca. 42,500 | 1099 | 1074 |
| Caminade Est | M3 | Mousterian | | 502 | 477 |
| La Côte | III | Châtelperronian | | 1245 | 610 |
| Caminade Est | G | Aurignacian | 37,200 ± 1500 (GifA 97185) | 5779 | 3084 |
| Le Flageolet I | XI | Aurignacian | 33,800 ± 1800 (OxA598)<br>> 31,500 (Ly 2727)<br>32,040 ± 850 (GifA 95538)<br>34,300 ± 1,100 (GifA 95559) | 6216 | 2751 |
| Le Flageolet I | IX | Aurignacian | 20,070 ± 1760 (Ly-1749)<br>27,000 ± 1000 (Ly 2726)<br>28,520 ± 670 (GifA 95560)<br>29,840 ± 750 (GifA 95541) | [3]6840 | 5967 |

[1] Total number of lithic objects in assemblage.

[2] Number of lithic objects weighing ≥ 1 g; all results in this paper are based on this fraction of each assemblage.

[3] Some screening material from Le Flageolet I, level IX was not counted in this total.

Table 3.3 Estimated distances to nearest occurrences (excluding river gravels) of various chert types for each site. Based on measurements made from maps presented by Geneste (1985). "Occ. ≤ 5 km", number of occurrences within 5 km radius of site. Under "Senonian" are listed distances to the two nearest occurrences of black Senonian chert, followed by distances to the two nearest occurrences of beige Senonian chert. Under "Bergerac." and "Mussidan" are listed the distances to the nearest and farthest occurrences of Bergeracois chert and Mussidan chert, respectively. Under "Jasper" are listed the two or three nearest occurrences, which in all cases are Tertiary; the last two figures for each site represent the two nearest occurrences of Hettangian jasper. Under "Fumelois/Gavaudan" is listed the distance to the nearest occurrence of Fumelois chert, followed by the distance to the nearest occurrence of Gavaudun chert, in that order. All distances reported in kilometers.

| Site | Occ. ≤ 5 km | Senonian | Bergerac. | Chalced. | Jasper | Fumelois/ Gavaudun | Mussidan |
|---|---|---|---|---|---|---|---|
| Caminade | 12 | 0.1<br>0.1<br>2.7<br>2.9 | 45.3<br>60.0 | 6.1<br>7.2<br>8.0 | 3.7<br>5.3<br>40.0<br>50.1 | 39.2<br>39.5 | 69.6<br>71.5 |
| Flageolet | 37 | 2.1<br>2.7<br>2.7<br>3.7 | 34.4<br>44.8 | 2.4<br>3.7<br>4.2 | 1.0<br>2.7<br>15.5<br>50.6<br>53.3 | 30.7<br>32.5 | 57.9<br>59.2 |
| Moustier | 34 | 4.2<br>4.8<br>0.1<br>1.2 | 32.8<br>48.0 | 4.0<br>5.1<br>6.1 | 6.9<br>10.7<br>34.7<br>54.9 | 45.1<br>48.0 | 53.3<br>55.5 |
| La-Côte | 8 | 16.5<br>18.9<br>2.9<br>7.5 | 19.0<br>28.8 | 11.2<br>11.7<br>13.3 | 1.6<br>3.5<br>4.3<br>54.6<br>102.7 | 65.3<br>72.0 | 8.5<br>10.1 |

Table 3.4 Typological indices from Caminade Est, layers M3 base and M3 summit combined, from Sonneville-Bordes (1969).

| Index | % |
|---|---|
| Levallois index | 38.05 |
| Facetting index | 62.02 |
| Strict facetting index | 54.43 |
| Blade index | 18.58 |
| Typological Levallois index, real count | 30.70 |
| Typological Levallois index, essential count | 1.08 |
| Sidescraper index, real count | 35.90 |
| Sidescraper index, essential count | 59.74 |
| Aurignacian tool index, real count | 0.65 |
| Aurignacian tool index, essential count | 1.08 |
| Burin index, real count | 0.00 |
| Burin index, essential count | 0.00 |
| Quina index | 5.45 |

Table 3.5 Typological indices and percentages of selected tool classes from Caminade Est, layer G; from Sonneville-Bordes (1970).

| Indices | |
|---|---|
| Endscraper index | 28.39 |
| Aurignacian endscraper index | 13.20 |
| Burin index | 18.33 |
| Dihedral burin index | 10.31 |
| Truncation burin index | 5.44 |
| Perforator index | 3.72 |
| | |
| Percentages of selected tool classes | |
| Carinated endscrapers (nos. 11, 12) | 5.45 |
| Muzzled endscrapers (nos. 13, 14) | 7.75 |
| Busked burins (no. 32) | 0.86 |
| Pieces with continuous retouch (nos. 5, 56, 66) | 13.78 |
| Pieces with Aurignacian retouch (nos. 6, 66, 67) | 4.59 |
| Dufour bladelets | 0.28 |

Table 3.6 Industries at Le Moustier, lower shelter, listed from top (Level L) to bottom (Level B). From Laville and Rigaud (1973, 1976).

| Level | Industry |
|---|---|
| L | Aurignacian I |
| K | Châtelperronian (top of level) |
| | Denticulate Mousterian (lower down) |
| J | Typical Mousterian |
| I | Denticulate Mousterian |
| H | MAT, type B |
| G | MAT, type A |
| F | Denticulate Mousterian |
| B | Typical Mousterian |

Table 3.7 TL ages from Layer H of Le Moustier, lower shelter. The levels are given in stratigraphic order, from top (H9) to bottom (H1). From Valladas *et al.* (1986).

| Layer | Sample No. | Age (kyr BP) |
|---|---|---|
| H9 | 141 | 41.9 ± 3.9 |
| H9 | 142 | 43.4 ± 5.1 |
| H9 | 150 | 41.1 ± 3.2 |
| H7D | 200 | 44.3 ± 4.5 |
| H7C | 220 | 42.2 ± 3.5 |
| H7B | 242 | 46.9 ± 3.0 |
| H4 | 302 | 39.9 ± 3.8 |
| H2E | 360 | 40.0 ± 4.4 |
| H2E | 362 | 39.5 ± 4.0 |
| H2E | 363 | 48.1 ± 5.8 |
| H2B | 401 | 40.3 ± 4.0 |
| H2B | 402 | 45.9 ± 4.0 |
| H2B | 407 | 47.8 ± 6.0 |
| H2B | 421 | 45.5 ± 5.6 |
| H2B | 423 | 45.2 ± 5.1 |
| H2B | 428 | 43.4 ± 4.9 |
| H2A | 443 | 35.3 ± 3.6 |
| H2A | 464 | 42.7 ± 5.7 |
| H2A | 480 | 43.7 ± 4.2 |
| H2A | 482 | 41.2 ± 3.6 |
| H1 | 500 | 43.2 ± 4.5 |
| H1 | 501 | 48.3 ± 4.4 |
| H1 | 502 | 46.1 ± 4.8 |
| H1 | 503 | 47.7 ± 5.6 |

# 4

# Lithic Raw Materials and Assemblage Composition

Three of the environmental variables affecting lithic raw material use (RME) are the natural abundance or rarity of raw materials, the distribution of raw material occurrences in the landscape, and fracture properties of stone. Variation between raw material types within each of these categories is also important. The costs of each RME strategy will be affected by the interrelationships between behavioral patterns and these environmental constraints. In this chapter, I describe the lithologic landscape of the Perigord with regard to the abundance and distribution of several categories of lithic raw material, including chert, quartzite, and basalt. One of the basic tools of this study is a typology of lithic raw materials; I present such a typology and explain its application to the assemblages. I then describe the results, which consist of the raw material composition of the assemblages.

I also describe my method for estimating minimum source distances and the natural availability of each raw material type. These two variables are essential for evaluating one of the predictions of the discontinuity hypothesis for RME: that more efficient strategies will depend on an increased exploitation of those raw materials that decrease overall costs in some way. This increased exploitation will register, in part, as evidence that the raw material acquisition pattern was non-random relative to the available raw materials: certain raw materials will be exploited more intensively than expected based on occurrence densities and minimum source distances. Whether

those raw materials possess fracture properties conducive to greater technological efficiency is the subject of Chapter 6.

**Paleogeographic history of the Aquitaine, and formation of chert**

The rocks that make up the surface of the Aquitaine were deposited entirely during the Secondary and Tertiary Periods (Thibault 1976). They lie within a unique paleogeographic setting (Figure 4.1):

> The northern and north-eastern limit is formed by the basement together with the Paleozoic formations of the Vendée and the Massif Central (from Limousin to the Montagne Noire). The whole sedimentary series crops out widely over this border and forms a vast monocline which dips slightly to the South-West. This arrangement is symmetric to that of the southern border of the Parisian Basin in relation to the ancient Vendée-Limousin axis.
>
> To the South, the limit is of an entirely different nature: it is an orogenic margin bringing the thickest part of the basin into abrupt contact with the Pyrenean chain.
>
> The western limit is constituted by the shoreline of the Golf de Gascogne. Offshore, the continental shelf extends for 60 to 150 km. It dominates the abyssal plain by means of continental slope which represents the true western limit of the basin at present. (B.R.G.M. 1974, Planche 1)

The cryptocrystalline and microcrystalline siliceous rocks that formed in this setting owe their physical properties and distribution to the paleogeographic history of Aquitaine. The earliest deposits formed in the Middle (Dogger) and Late Jurassic (Hettangian) (Thibault 1976). Throughout the Jurassic and the Late Cretaceous, the Aquitaine was submerged in a shallow sea, where marine and terrigenous sediments accumulated. Two paleogeographic features had a major effect on the evolution of Aquitaine sediments. One is the Celtaquitaine Flexure, located just south of the present-day Garonne River (BRGM 1974). To the north of this flexure, the Aquitaine was a relatively shallow, gently sloping basin; Jurassic and Cretaceous rocks there are no

more than 2000 m thick. To the south of the flexure, the Aquitaine was marked by strong subsidence during the Jurassic, forming two deep troughs. Sedimentary rocks there attain a thickness of up to 10,000 m.

The other feature is the Poitou isthmus, a saddle between the Armorican Massif to the northwest and the Massif Central to the southeast. When the Poitou isthmus was submerged, waters from the Paris and Aquitaine basins mixed, as demonstrated by similarities in the planktonic flora and fauna in the two basins. Alternating cycles of subsidence and stability, and rapid and slow sedimentation combined to create periods of relatively deep or shallow water in the Aquitaine. During the Early and Middle Cretaceous, a marine regression left most of the Aquitaine on dry land, while the southernmost portion, in the Pyrenees trough, remained submerged. Continental deposition occurred, but all traces of that were subsequently eroded during a generalized transgression in the Late Cretaceous (Senonian). For that reason, there are no Early or Middle Cretaceous formations in the Perigord, and Senonian limestones lie directly upon Jurassic rocks. At the end of the Cretaceous, the sea again retreated, and there were only brief periods of marine deposition, and then only south of the Celtaquitaine Flexure.

This geologic history resulted in the formation of limestones, sandstones and molasse[1]. The last is particularly thick in the Eocene deposits of the southern Aquitaine. During the Quaternary, the erosion of limestones produced a karstic terrain with sinkholes, caves, and rockshelters. The Dordogne, Lot, Vézère, and Isle Rivers carved

---

[1] Molasse is "a partly marine, partly continental or deltaic sedimentary facies consisting of a thick sequence of soft ungraded fossiliferous conglomerates, sandstones, shales, and marls..." (Bates and Jackson 1984:332-333).

wide valleys into the limestone plateau (Rigaud 1982). During the early Tertiary, the erosion of first the Massif Central, and later the Pyrenees brought poorly sorted sands and clays to the Perigord. Those deposits, which are referred to as the Siderolithic (Laville and Texier 1976), "Perigord sands and clays," (Thibault 1976), or "sands and clays with iron oxides" (Daugas 1981), covered the limestones that had formed during the Jurassic and Cretaceous. In the later Tertiary, these loose sediments were sometimes re-transported and re-deposited. Consequently, thick Siderolithic deposits cover large areas throughout the Perigord, especially the southwestern quadrant (Laville and Texier 1976, Rigaud 1982; see Figure 4.2).

The lithic raw materials used by the Paleolithic hunter-gatherers of the Perigord formed in these Jurrasic, Cretaceous, and Siderolithic sediments, through both diagenesis and epigenesis. In the Middle and Late Jurassic, a carbonaceous platform supported an internal sea, separated from the open ocean by an oolitic carbonaceous barrier or barrier reef (Séronie-Vivien 1990). Outside this barrier, in medium water depths, the water was rich in silica from abundant sponges and silica plankton. Thalassinians (small, long-tailed, lobster-like crustaceans of the family Thalassinidæ) borrowed into fine-grained, relatively firm calcareous sediment. The burrows remained intact after burial, and silica migrated into them, eventually solidifying into chert nodules cast into branching shapes. Within the carbonaceous barrier, in shallower water, periods of relatively low salinity favored the proliferation of diatoms. This environment tended to result in beds and lenses of chert.

In the Late Cretaceous, sediments accumulated mainly on a gently sloping carbonaceous platform, open to the ocean (Séronie-Vivien 1990). This was a vast platform covered by 50 to 200 m of water, with little terrigenous deposition. These

conditions favored a particularly dense silica concentration, which filled crustacean burrows and fossilized sponges, oysters, echinoderms, brachiopods, and bryozoa. This period of chert formation ended with the retreat of marine waters at the end of the Maasstrichtian (the last of the six Senonian eras). The formation of Late Cretaceous shallow marine chert in Aquitaine closely resembled that of the famous Late Cretaceous Chalk flint of southern England (Larick 1986).

In addition to these diagenetic marine cherts, there are various kinds of epigenetic chert in the Perigord. There were at least three modes of chert epigenesis. According to Séronie-Vivien (1990), the border of the Massif Central became weakly tectonic at the end of the Jurassic, leading to the deposition of sulfur minerals, fluorine, barytine, and silica on the surfaces of early and Middle Jurassic limestones bordering the crystalline rocks of the massif. Localized massive silicification of limestone took place, often preserving the original structure and fossil inclusions. The most common silicifications were jaspers in tabular form, with mudstone texture, or with the oolitic texture of the silicified limestones. Séronie-Viven (1990) named occurrences of these jaspers in Charente, Dordogne, Quercy, Agenais, and Midi-Pyrennes, all of which occur in the thin band of Jurassic limestone that runs in a southeast-northwest axis between the border of the Massif Central and Cretaceous limestones further west (see Figure 4.1).

Based on the age of the limestone in which these jaspers occur, Séronie-Vivien (1990) and Demars (1982) assigned them to the Hettangian (Late Jurassic). However, according to Daugas (1981), this epigenesis occurred during the Tertiary. In his account, silica migrated downstream (or down the stratigraphic column), where it contributed to the neoformation of clay minerals and the genesis of quartz. It also

penetrated the substratum, where it epigenetically altered the calcite cement and bioclasts. The formation of jasper-like chert resulted from the chemical substitution of silica for carbonates, during which many of the original structures in the Jurassic limestone are preserved.

If Daugas (1981) is correct about the age of the jasper, then its formation was contemporaneous with a separate episode of epigenesis, which occurred during or after the deposition of the Siderolithic sands and clays (early Tertiary). Those sediments originated in the eroding Massif Central, to the east. After being washed into the Aquitaine basin, they filled karstic cavities where groundwater provided the source of silica, which then penetrated and permineralized the limestone substrate. The chert blocks and nodules that resulted were then penetrated by trace amounts of cobalt, nickel, tin, and copper, producing vivid colors (Turq 1992). The limestone substrate eventually eroded away, leaving the chert nodules encased in unconsolidated matrix, which was dispersed through erosion and transport. Silicifications of this nature are particularly abundant in two neighboring areas, one centered near Bergerac on the right bank of the Dordogne, the other near Mussidan along the left bank of the Isle. Although Bergeracois chert is commonly referred to as Maastrichtian because of the presence of *Orbitoïdes media* fossils (e.g. Demars 1982, 1994), it is always found in altered, unconsolidated sediments (Geneste 1985, Rigaud 1982), and the work of Daugas (1981) favors the hypothesis of an epigenetic origin. Mussidan chert lacks *Orbitoïdes* fossils and the bright colors of Bergeracois but is identical to it in other respects.

The third kind of epigenetic chert in the Perigord consists of chalcedony and *meulière*, or millstone. At least some of this chert was contemporaneous with the migration of silica and other minerals from the eastern massif (Daugas 1981) and the

formation of jaspers. However, it is distinct from all other Perigord cherts. The term *meulière* derives from the way these large rocks have been used in France since the Middle Ages. They are opaque, dull in luster, and coarse-grained compared to other varieties of chert. They also contain voids, which sometimes contain traces of clay and quartz crystals. The chalcedonies tend to be finer-grained, more lustrous, and more transparent than millstone. Both are found in the same geographic locations, and undoubtedly formed in the same way. For this reason, they are treated as variants of the same chert type (Demars 1982, Geneste 1985, Turq 1992).

However, the exact way in which chalcedony/millstone formed is poorly understood. According to one hypothesis it formed in small, scattered lakes during the Oligocene (Demars 1982, Rigaud 1982, Turq 1992). These would have been alkaline and/or saline lakes containing high concentrations of silica and little iron. Chalcedony tends to be chemically more homogenous than chert and flint, and its formation is hindered by the presence of clays and iron minerals (Leudtke 1992). Similar chert can be observed forming today in Lake Magadi in Tanzania (ibid), but descriptions of Magadi chert bear little resemblance to Perigord millstone and chalcedony. Turq (1992) offered two alternative explanations for the latter. They may have formed in pedogenic horizons on the surface with high concentrations of silica, related to the desilicification of silicified limestones. They may also have formed on dry land within the water table in an environment of high silica concentration, low oxygen, and neoformation of clays. In short, the only thing that seems clear about the millstone and chalcedony is that they formed epigenetically in non-marine contexts during the Tertiary.

The confusion about how some kinds of Perigord chert formed recalls what Leudtke (1992:36) wrote about the complexity of chert formation:

> Chert is more variable in its origin than most of us realize. Its formation often involves several steps, and it continues to be subject to alteration after it has formed, both while it is encased in bedrock and when it is exposed on the ground surface. To a considerable extent, this variation in mode of origin causes the variation in [the chemical, visible, and mechanical] properties [of chert].

This complexity in chert formation, and our relatively poor understanding of it, are the main obstacles to effective classifications of chert (Turq 1992).

**Taxonomy of Lithic Raw Materials in the Perigord**

The current state of the art in lithologic descriptions of siliceous rocks in the Perigord is the result of a continuous, collective effort on the part of several French Quaternary scientists. Their efforts began in the late 1960s (Rigaud 1982), and have resulted in the discovery and mapping of approximately 3,000 individual occurrences (J.-M. Geneste, pers. comm.), representing over a dozen distinct types of chert. Samples of chert from almost all these occurrences have been catalogued in a "*lithothèque*", or lithic reference collection, housed at the Service Régional d'Archéologie in Bordeaux. J.-M. Geneste kindly permitted me to study this *lithothèque*.

There are slight variations between the taxonomic schemes that archaeologists have used to describe the lithology of siliceous rocks in the Perigord (Chadelle 1983, Demars 1982, Geneste 1985, Larick 1986, Morala 1980, Rigaud 1982, Turq 1992). Nevertheless, the authors are in general agreement on the main kinds of chert, their geologic origins, geographic distribution, and physical characteristics. Here, I rely mainly on the works of Demars (1982) and Chadelle (1983). Their taxonomy distinguishes between kinds of rocks based on macroscopic characteristics, including color, color patterns, texture, luster, translucence, cortex, and presence of microfossils. These features permit the reliable identification of rocks belonging to different geologic

formations. Each combination of characteristics defines a type of siliceous rock, which is in turn linked to a given geologic formation. Table 4.1 lists the raw material types in this taxonomy. For simplicity, Table 4.1 includes only those raw material types that I observed in the six assemblages I studied. Others (especially Turq 1992, Turq *et al.* 1999) have identified additional, more rare varieties of chert, but I found no examples of those in the collections I studied.

The terms I use to describe each raw material type below demand a brief explanation. In my experience, standardized color templates, such as Munsell or Cayeux, are of little use in describing chert. The trouble is that the apparent color changes as one moves the piece closer to one's eyes. It can appear to be a solid color at first, but closer inspection shows that is an illusion, the combined effect of many small specks or streaks of quite different colors. Furthermore, color is often an optical effect caused by the absorption of light or by the bending of light as it passes through the chert. The color of a chert thus depends partly on the thickness of the observed flake. Therefore, I simply use everyday color terms, and I do not intend them to be precise designations.

Texture refers to the relative smoothness of the fractured surface. As with all the other terms, it is applied subjectively, based on the feel of the chert. Luster refers to the appearance of the fractured surface as it reflects light; it is commonly described with terms like waxy, vitreous, oily or dull. The opacity or translucence of the rock is most readily seen near the edges of thin flakes, but can nevertheless be observed even on thick pieces by the penetration of light into the chert. Homogeneity describes the structure and composition of the material. All chert is heterogeneous, being composed of many kinds of minerals in various forms; those described as homogenous are just

comparatively less heterogeneous at a macroscopic scale. Although most of the following descriptions are based on my personal observations of artifacts and geologic specimens, I also relied on the descriptions of Chadelle (1983), Demars (1982), Geneste (1985), and Turq (1992).

Black and grey Senonian chert

The color is medium grey to black, sometimes with dark and light mottles of grey and/or red. The texture is moderately smooth to very smooth, and the luster is matte, waxy, or vitreous. Pieces thinner than 3 mm are translucent. The composition is very homogenous, but it sometimes contains grainy inclusions, light grey chalcedony fossils up to several mm in diameter, or <1 mm clay inclusions. The cortex is thick (1-3 cm) and calcareous, and forms a very distinct boundary with the chert. Nodules are usually 10-20 cm in diameter, but can be up to 50 cm (Geneste 1985); they are globular, oblong or branching, characteristic of thalassinian burrows. This chert is also known in tabular form, for example in the Campanian limestone near the town of Plazac. Hereafter, I refer to this type simply as "black Senonian".

Beige Senonian chert

This chert occurs in a larger variety of colors than black Senonian, including beige, light brown, dark brown, reddish-brown, and olive-brown. The texture is from moderately smooth to very coarse, the latter being due to the presence of numerous quartz crystals. The luster is matte or waxy. It is generally opaque, but some varieties are translucent. The composition is very homogenous, but it sometimes contains inclusions of chalcedony or quartz grains. The cortex characteristics, nodule shapes and nodule size range are identical to those of black Senonian.

*Comparison of black and beige Senonian, and explanation of indeterminate Senonian*

Black and beige Senonian cherts are together routinely referred to as *silex du Sénonian*. However, both varieties occur in limestone formations belonging to each of three Senonian ages, Coniacian, Santonian, and Campanian. Various authors have pointed out subtle differences between Coniacian, Santonian, and Campanian cherts, but these are tendencies rather than distinct differences. Rocks from the three ages cannot be reliably distinguished in archaeological collections (Bricker 1975, Demars 1982, Geneste 1985, Turq 1992), and they are often identical even when geologic specimens of known provenience are compared. For that reason, I follow the example of Geneste (1985) and group Coniacian, Santonian, and Campanian cherts as "Senonian".

The only clear difference between the black and beige Senonian varieties is their color. The black color results from a reducing environment during diagenesis, while the beige, brown and reddish-brown colors result from an oxidizing environment (Turq 1992). However, there are many rocks of definite Senonian origin that are intermediate between black and beige; my term "Indeterminate Senonian" refers to these varieties. Demars (1982) and Chadelle (1983) both noted the same problem. Both authors noted that at certain outcrops, both varieties occur side-by-side. There are even nodules of Senonian chert containing both black and beige zones, which could result from a change in the chemical nature of the environment during silicification. Since both black and beige Senonian chert outcrop in the same area, introducing a separate type for the intermediate varieties will not affect estimations of source distance.

Bergeracois chert

Bergeracois chert occurs in various hues of brown, beige, and grey. In some cases, concentric bands of black, pink, red, violet, and yellow appear as if laid down upon a brown or grey background. This chert is opaque, with a smooth texture and matte luster. As a rule it is very homogenous, the only exception being that nodules sometimes show a coarser texture toward the center than toward the exterior of the nodule. One grey variety in particular is coarse grained. The marker fossil is *Orbitoides media*. There is considerable variation in the cortex because these nodules have been subjected to various kinds of secondary alteration. The cortex is calcareous, can be thick (up to 2 cm), thin (< 3 mm), or absent; its color ranges from dark grey to light beige; and it may be covered by iron concretions. The nodules are oblong, almond-shaped, or cylindrical, and range in size from a few tens of centimeters up to 1 m in diameter.

Chalcedony/millstone

Nodules and blocks of this variety are white, grey, brown, yellow, red, or purple. They often have voids in the form of poorly cemented bedding planes, small geode inclusions containing clay minerals, or calcite formations resembling cauliflower. It lacks calcareous cortex; the external surface is rough and bumpy with large pores. It occurs primarily in spherical boulders up to 50 cm in diameter, and continuous tabular beds, which are fragmented into angular blocks from a few centimeters to over 1 m in length. Millstone is opaque and has a coarse or moderately coarse texture, while chalcedony is translucent and has a finer texture, sometimes very fine. However, the distinction between millstone and chalcedony may be an artificial break in a continuum of variation in color, texture, and homogeneity. For this reason, and because both appear to have formed in an identical context, I lumped them in the same category.

Jasper and silicified wood

Jasper is a light to dark yellow, brown, black, or red chert. It is opaque, has a vitreous, waxy, or dull luster, and a very smooth texture that gives it a greasy feel. Some nodules are very homogenous, but others have voids, geode inclusions, or fissures. Puy d'Arnac jasper has fine, hair-like or dendritic black stains. Other varieties lack those black stains, but can have a variety of red, rust-colored, or black speckles and streaks. Jasper lacks calcareous cortex; the external surface consists of either a calcite crust or a thin, cavernous, convoluted mineral cortex. It can occur in large slabs, but those are rare due to the intensive use of this raw material at the few known occurrences, so it is usually found in small, angular fragments, which are often humanly modified.

It may be possible to distinguish sub-types of jasper. Most authors emphasize the jasper that occurs in Hettangian limestone, of which the best-known natural occurrence is at Puy d'Arnac, in Quercy southeast of Brive. Its appearance is distinct, and it cannot easily be confused with other opaque, yellow, fine-grained chert in the Perigord. However, most of the jasper in Caminade Est and Le Flageolet I appears very similar to a dark mustard-colored, opaque, fine-grained chert that Demars has pointed out to me in surface deposits on the plateau just south of Domme on the Bord plateau, in an area that also has abundant chalcedony. It is perhaps unfortunate that I neglected to distinguish these two varieties in the assemblages I analyzed. At La-Côte, besides a jasper that is very similar to the Domme outcrop, there is also another type that resembles silicified wood; Pelegrin (1986) already described this variety of jasper.

Fumelois chert

The most oft-cited attribute of this Turonian (early Senonian) chert is its indigo color. It occurs either as a solid or with fine, concentric bands of grey-white or grey-blue.

There is also a dark brown variety. It has a very fine texture, a shiny luster, and is very homogenous. The cortex is thin (< 3 mm), calcareous, and forms an irregular but distinct boundary with the chert. Nodules are oblong and less than 30 cm in length (Geneste 1985, Turq 1992). They are known for their highly predictable fracture.

Gavaudun chert

Morala (1983) first described a natural occurrence of this rare chert. It is opaque and ranges in color from ochre-yellow to *café au lait*, with very small orange flecks, veins, or mottles. It is composed of microorganisms, including bryozoans, rhynchonelles, tubular organisms, serpulides, sponge spicules, and fragments of lithothamnia (an alga). The latter permit the discrimination of Gavaudun chert from certain specimens of Bergeracois and others, to which it sometimes presents a close resemblance. Depending on the particular occurrence, the nodules may be from 5 to 15 cm in diameter, twisted, and have carbonaceous inclusions that impede flintknapping; they may be symmetrical, oval, and homogenous; or they may occur in plaquettes several centimeters in thickness and 25-30 cm long, with a thick calcareous cortex.

Mussidan chert

This chert is very similar to Bergeracois chert in color, texture, luster, homogeneity, and nodule size. However, it is less variable in color than Bergeracois. Unlike Bergeracois, Mussidan chert lacks concentric bands and *Orbitoïdes* fossils. It occurs in brown, beige, orange, or pink varieties, and ranges from opaque to translucent. Small (< 1 mm) microfossils are scattered throughout, expressed as tiny points of yellow, red, or yellow-orange color. In one variety, long, thin fossils occur in bundles up to 1 mm in length, giving this variety the name "packets of needles". The cortex is generally thin,

or has been removed through secondary alteration, being replaced by a thin, finely granular encrustation.

Jurassic chert

This is a mottled, opaque, grey or brown chert with a smooth texture and matte luster. It often shows mottles of different shades of grey. According to Demars (1982:61), there is a thin, calcareous cortex, but Turq (1992:216) claims that it lacks cortex altogether. The nodules are small to medium and relatively well-rounded. Some varieties contain microgeodes and phosphatic inclusions; all tend to have microfossils characteristics of the lagoon setting of the Middle Jurassic (Dogger era). There are numerous small clusters of occurrences throughout the region of Jurassic limestones (see Figure 4.1), each yielding a slightly different variety. For example, near Reilhac in northern Lot, there is a variety with a very fine texture, giving it an oily feel even when patinated. It is grey-blue, which sometimes has grey or black anthracite inclusions or lighter-colored traces of mycelium. It occurs in small nodules of a few centimeters in diameter, which often have fissures that are visible on the surface. According to Turq (1992:220), this chert is of high quality. On the right bank of the Dordogne at Puy d'Issould, there is another variety that occurs in burrow-shaped nodules up to 30 cm in diameter. It is solid grey or light grey, without mottles, sometimes with a light olive tint. Recrystallization has sometimes given it diffuse zones of grey or very dark grey. These are just two of the several varieties of Jurassic chert described by Turq (1992).

Porcelainite

The name derives from the even, shiny, bright white patina up to 1 mm thick that covers this chert. When broken, it reveals a dark chestnut-colored material that is translucent, very smooth, and very homogenous. The patina affects only the outer

surface, which gives any freshly broken surface a fresh appearance. It has no inclusions or voids. The external surface appears similar to that of chalcedony and jasper. No natural occurrences or unmodified nodules are known. For that reason, porcelainite is of unknown geologic provenience. Chadelle (1983) speculated that it may simply be highly patinated pieces of Senonian chert. Rigaud (1982) offered the same interpretation, but has also speculated that it may be yet another, undiscovered geologic formation (Rigaud, pers. comm.). However, I have observed that the interior of the bright white pieces of porcelainite, visible on pieces broken during excavation, is dark brown, fine-grained, and possibly translucent. Certain pieces from Le Flageolet I show a natural exterior surface that is identical to that of the Tertiary chert from the Bord plateau. Furthermore, this kind of patina is very different from the characteristic patina of black Senonian and beige Senonian (see below). Therefore, I speculate that porcelainite consists of highly patinated Tertiary chalcedony. Nevertheless, I retained it as a separate type because of the uncertainty of this proposition.

Pink speckled chert

I introduce this term to account for a variety of chert found in the La-Côte assemblage that I have not seen described in detail, although it was recognized by Pelegrin (1986) during his study of the La-Côte material. It is a fine-grained, smooth, pink chert that is evenly covered by dark orange or red inclusions, giving it a speckled appearance. Flakes thinner than about 4 mm are translucent. Gaussen (1980) noted that an occurrence of this chert was found in the area around Mussidan (on the Isle River downstream of La-Côte). Pelegrin (1986) speculated that it may represent a variety of either Bergeracois or beige Senonian. I retain it as a separate category because of this uncertainty about its geologic provenience.

Quartzite

Quartzite is coarse-grained compared to chert, but homogenous. The individual quartz grains are visible; they are opaque white crystals. In the Perigord, quartzite only occurs as river-smoothed cobbles, about 10-15 cm in length. The outer surface is smooth and white or orange. It fractures conchoidally, but the diagnostic features of conchoidal fracture are more difficult to recognize because of the coarse grain.

Basalt

Perigord basalt is coarse-grained compared to chert, but finer grained than quartzite, and homogenous. It is very dark grey or black, speckled with shiny inclusions of mica or other minerals. In the Perigord, it only occurs as river-smoothed cobbles of about 10-20 cm in length; their worn outer surface is dark grey. Like quartzite, basalt fractures conchoidally, and the diagnostic features of conchoidal fracture are more difficult to recognize than in chert.

Both quartzite and basalt originate in the igneous plateaus of the Massif Central (dark blue in Figure 4.1). Both are also found strewn along with gneiss, sandstone, granite, and chert in the cobble beaches of existing river beds, as well as in buried alluvial terraces dating as far back as oxygen isotope stage 9 (Turq 1992).

Unidentified chert

I recorded three sub-types of unidentified chert, according to the factors responsible for obscuring the diagnostic attributes: thermal alteration, alteration of the surface by patina, or simply the lack of diagnostic attributes. However, I now group these under a single heading because thermal alteration is relatively rare, and patina affects most of the unidentified pieces (as well as a large number of identified pieces) to varying degrees. Patina, as I use the term here, is a chemical alteration that usually

affects the first few micrometers of the object's surface, involving desilicification and replacement of silica by $CaCO_3$. Because of the karstic setting of the Perigord, patina is quite common. Individual artifacts display the full range of degrees of patination, from "absent" to "fully desilicified". Patination begins in the outer few microns of the object's surface, and can gradually work its way into the interior. Objects that have been completely desilicified are common in sites like La Micoque, which lies in a colluvial deposit encrusted with calcium carbonate, and they also occur at Caminade Est. Desilicified cherts are white or yellow, chalky, and friable, having lost all their original characteristics except morphology, which is preserved down to the smallest detail.

Because different raw materials acquire patina differently, the presence of heavy patina does not necessarily exclude identification of the raw material (P.-Y. Demars, pers. comm.). Senonian cherts generally begin with a pale white "netting" of patina that eventually turns to a uniform, light greyish-white. Unlike most other chert types, the patination of Senonian chert tends to start in one area, leaving other areas on the same piece untouched. Jasper gradually becomes more pale, without ever losing its yellow tint, even when totally desilicified. In Bergeracois chert, patination leads to a dimming of its originally bright colors, but the patina is never bright white, and even in advanced stages bands of color sometimes still can be distinguished. Thus, some identification is still possible, even when patina is present, and even when the development of patina is advanced. Nevertheless, patina often impedes identification.

**Geological distribution of raw material occurrences**

Geologic occurrences are well documented for almost all of the chert types in Table 4.1. Some types are very abundant in the Perigord (especially Senonian), while other types are only represented by a few occurrences (Fumelois chert, Gavaudun chert,

Mussidan chert, pink speckled chert) or by no occurrences (porcelainite). The most visible occurrences in the Perigord are primary: nodules of chert embedded in their parent rock (Figure 4.3). Senonian and Jurassic chert are known from primary sources throughout the Perigord, with the former being by far the most abundant and widely distributed.

There are also several kinds of secondary occurrences of chert in the Perigord (Geneste 1985). At the base of an eroding rock face containing chert nodules, there will usually be a talus containing both angular limestone rocks and chert nodules mixed with fine sediments. Over time, this talus builds into thick deposits, which Paleolithic stoneworkers may have exploited. On the plateaus, freeze-thaw and pedogenesis erode chert-rich limestone beds (Figure 4.4) and the nodules are incorporated into soils (Figure 4.5, 4.6) or roll downhill a few meters. This type of occurrence is very common and visible today, since plows tend to bring the chert to the surface, but the frequency of such occurrences before plows is unknown. Chert nodules from both of these kinds of occurrences may be washed into creeks, and from there into rivers, where they may accumulate along with other kinds of rock in gravel bars (Figure 4.7) and floodplain deposits (Figure 4.8). This process has continued for hundreds of thousands of years, and cherts can be found in buried alluvial terraces dating as far back as Oxygen Isotope Stage 9 (Turq 1992). When meandering rivers erode those ancient river terraces, the buried cobbles become exposed. In short, cliff talus, plateau soils, gravel bars, and ancient buried river terraces all furnish transported nodules, each in a different setting (Laville and Texier 1976; J.-M. Geneste, pers. comm.).

Figure 4.9 shows the distributions of most of the chert types in my taxonomy. To create this map, I compiled information from maps published by Demars (1982),

Geneste (1985), and Turq (1992). The map shows only the ranges in which certain types of chert occur; within those ranges, the densities of occurrences are highly variable. The distribution of chalcedony/millstone is particularly discontinuous. It clusters in two main areas: a band about 5-12 km wide running east to west just south of the Dordogne River, and an area with a radius of about 20 km centered near Brantôme on the Dronne River. Below, I explain how I estimated source distances from the available information, and how I estimated the natural availability of each raw material type.

**Methods**

Lithological taxonomy: application

Because my application of this taxonomy entailed an element of subjectivity, it is not possible to provide a precise description of the process of identifying the raw material types in archaeological assemblages. I learned to identify the major chert types through a brief tutelage with P.-Y. Demars, my experience excavating in the Dordogne, my extensive observations of artifacts in the collections I studied, and two days spent examining the *lithothèque* at the Service Régionale d'Archéologie in Bordeaux. I assigned each piece, excluding some in the < 1 g fraction from Le Flageolet I, to one of the types in the lithologic taxonomy, based on color, patterns, texture, luster, translucence, cortex, and presence of microfossils.

When I had serious doubts about a raw material's identity, I recorded it as "unidentified". For each assemblage, I identified every object weighing ≥ 1 g with the list in Table 4.1. I then computed the frequency of each raw material in each assemblage.

Natural availability of lithic raw materials

*Estimated source distance* I estimated the source distance of each raw material type in each assemblage based on the nearest known natural occurrence of that type, from maps and data presented by Demars (1982), Geneste (1985), and Turq (1992). I refer to this estimate as the minimum (estimated) source distance. This quantity is based on two main assumptions. First, I assume that the geographic distribution of occurrences of a given raw material type conforms closely with the past distribution of the same raw material type, even if some individual occurrences known today were unknown in the past, and if some occurrences known in the past are now hidden. Second, I assume equal probability of encounter for all occurrences within a given radius of a site, regardless of the topographic setting between site and occurrence. For example, I do not assume that people would have been more likely to exploit occurrences lying along the slopes of a river valley than occurrences lying on a plateau. There simply is not enough information about past landscape use to justify such an assumption. This is one way in which my treatment differs from that of Lucas (2000).

As I mentioned in Chapter 3, I gathered these data by plotting each site's location on maps provided by Geneste (1985) and Turq (1992), using an engineering scale to measure distances to the nearest mapped occurrence of each type, and converting the measurements to distances in kilometers. Geneste's maps are not sufficient to gather such data for the entire 50 km radius around each site (a figure that becomes important later). The area shown in those maps excludes much of the area west of La-Côte, and some of the area south of the Dordogne River. Because Turq's (1992) maps have better coverage for the occurrences that lie south of the Dordogne River, I used those maps to count occurrences in the area south of the Dordogne River, and Geneste's maps in the

area north of the Dordogne. My data on occurrence distances for Jurassic chert come from the maps presented by Demars (1982) and Turq (1992). In short, I measured occurrence distances using a combination of the maps presented in these three references, in effect treating them as a single data set.

*Primary v. secondary sources* In addition to the geographic range of primary sources, I also took into consideration the possibility that secondary deposits furnished at least some of the rocks used by Paleolithic stoneworkers. During field studies in the Perigord, I have found nodules of Senonian chert in river gravels less than 1 km from Le Moustier and Le Flageolet. Raw materials occur in formations bordering the Isle River less than 20 km upstream of La-Côte, making river transport toward the site a possibility. In these cases, I assigned a value of 1 km for estimated minimum source distance for the raw materials in question.

It would be of great interest to know exactly what kind of occurrence was the source of each raw material in a given assemblage. Chadelle (pers. comm.) and Lucas (2000) attempted to determine this through careful study of the original surface characteristics of cores, nodules, and cortical flakes, using a list of descriptive attributes for surface characteristics. Both found evidence supporting heavy reliance on secondary sources. I attempted a similar study, using the attributes listed in Table 4.2. This list is based on the observation that chert of limestone origin (Senonian and Jurassic) typically forms with a thick, calcareous cortex that is more dense and fine-grained than the surrounding matrix but distinct from the chert itself. Nodules pulled from a limestone outcrop or the talus at the base of such an outcrop typically have a coarse-grained cortex than is from 3 - 30 mm thick, which is rough to the touch. Nodules from plateau soils tend to show light weathering, which presumably rounds off

protuberances and sharp angles, and reduces the thickness of the cortex. Yet, nodules that I have observed in soils and near eroding limestone outcrops in the Perigord have surfaces that are still rough to the touch. Stream-rolled nodules show various degrees of alteration to the external surface, ranging from a thinning of the cortex, to bare spots where cortex has been eroded away, to nodules whose cortex has been eroded entirely. The exterior surface of most stream-rolled cobbles is smooth to the touch; old flake scars have a polish or a patina that is distinct from freshly fractured surfaces.

I used these observations to identify the attributes and attribute-states listed in Table 4.2, and then assembled the attribute-states into the cortex types shown in Table 4.3. The types in this list are intended to provide information about relative degrees of cortex weathering. The bumpy/rounded dichotomy describes the relative degree of angularity or roundedness in the sense used in Folk's (1974) particle morphology taxonomy. The rough/smooth dichotomy describes how the surface feels to the touch; smoothness is taken to indicate stream transport. The thickness of the cortex is unfortunately of little diagnostic value, since the thickness of cortex ranges widely among *in situ* nodules. However, very thick ($\geq$ 3 mm) cortex seems less likely to occur on pieces that have been extensively transported. The interpretations in Table 4.3 are based on these notions. In Table 4.3, "terrestrial transport" refers to the occurrence of nodules that have been eroded from the parent rock by dissolution of the matrix, freeze-thaw, or pedogenesis and transported by gravity and/or soil creep no more than a few meters from their original location.

All of the interpretations listed in this table are hypothetical. To my knowledge, the effects of various kinds of weathering on chert cortex have not been studied systematically. Thus, whatever patterns may arise in my data from the application of

these cortex types, those patterns do not confirm any given interpretation of source type. Rather, they suggest hypotheses that should be tested against other data. Nevertheless, in the case of smooth, eroded cortex, the interpretation of stream transport is clearly a strong one.

For each artifact showing some trace of the original nodule or cobble surface, I described that surface using the terms in Table 4.3. I did not do so for the La-Côte assemblage because I developed this descriptive terminology only after I had already studied that assemblage, and I was unable to study it a second time. After compiling the results for the remaining assemblages, I summarized the data by raw material type and by my interpretation of the cortex characteristics. I then compared these data with the estimated source distances and geographic distribution of each raw material type.

*Determining whether raw materials were gathered from primary or secondary sources* Tables 4.4-4.8 summarize the frequencies for objects with identifiable cortex, listing them by the corresponding interpretation (from Table 4.3). I discuss the results here because they affect the source distance estimates upon which I based subsequent analyses.

At Le Moustier, cortex suggests that most of the material was gathered from the nearby Vézère River. Acquisition at terrestrial secondary sources appears to account for 0-35% of the material (see Table 4.4). Beige Senonian chert shows a higher percentage under "limited terrestrial transport" than black Senonian chert. Primary occurrences of beige Senonian are known within 0.1 and 1.2 km of the site (see Table 3.3), whereas primary occurrences of black Senonian are no closer than 4.2 km. Weathered nodules from those terrestrial occurrences could account for at least some of the black and beige Senonian chert in the assemblage. The greater distance to *in situ*, soil, or talus

occurrences of black Senonian chert may account for the heavier reliance on stream gravels for that chert type compared to beige Senonian.

Some stream transport is indicated for all raw material types, but this does not mean they were all gathered locally. Senonian chert, chalcedony/millstone, basalt, and quartzite could all have been picked up from the Vézère, but if Bergeracois chert was gathered from stream gravels, they were gravels that lie at least 30 km west of Le Moustier.

The two pieces of possible Jurassic chert in Le Moustier (their attribution was made with some uncertainty) have rounded, smooth, thin cortex, suggesting stream transport. Could nodules of Jurassic chert have been washed into the stream gravels at the base of the cliff where Le Moustier sits? This is very unlikely. Two occurrences of Pleinsbachian era (Early Jurassic) chert within a few kilometers southwest of Brive that Demars (1982) mentions yield mainly *chaille*, a very poorly silicified chert, which Demars asserts was never used by Paleolithic inhabitants of the Brive basin. Furthermore, this *chaille* would have had to travel down a small stream and then about 45 km along the Vézère before reaching Le Moustier, a distance that this friable material might not survive. A more likely scenario is the washing of Dogger-age (Middle Jurassic) cherts from one of several occurrences south of Brive into the Dordogne River and their transport toward Limeuil, where the Dordogne River is joined by the Vézère River. There, they could have been picked up by people on their way to Le Moustier and carried toward the site, a distance of 18 km (as the crow flies) or 30 km (along the meandering river). However, this would require people to carry the cherts approximately the same distance as carrying them from their *in situ* occurrences. Therefore, I set the source distance for Jurassic chert at Le Moustier at 33 km.

In the assemblage from Caminade Est M3 (Table 4.5), the relative proportions of cortex types supporting the same two interpretations (limited terrestrial transport and stream transport) are basically reversed from their proportions in Le Moustier. This suggests a much heavier reliance on secondary sources in soils and talus near *in situ* limestone occurrences, and less reliance on stream gravels. This is not surprising, since the nearest large stream (the Dordogne) lies about 3 km from this site. A piece of Jurassic chert that I included in my technological analysis, as well as several dozen refit flakes that I did not include, came from one or more stream-worn cobbles. The Dordogne could have carried Jurassic chert most of the 17 km from the nearest occurrence, so I set the minimum source distance at 3 km (the distance to the Dordogne from Caminade). Jasper and chalcedony/millstone were probably not carried near to Caminade by stream because nearby sources lie high above the river on a plateau and away from streams. Therefore, I estimated the minimum source distance of each as equal to that of *in situ* occurrences. Basalt, quartzite, and black and beige Senonian chert could all have been gathered locally both from the river and from terrestrial secondary sources. Only Bergeracois must have been acquired non-locally.

The preceding comments also apply to Caminade Est, level G (Table 4.6), except that Jurassic chert does not occur in that assemblage, while Fumelois chert does. Like Bergeracois, Fumelois could have been gathered from either *in situ* occurrences or secondary occurrences, but both kinds of occurrences lie at about the same distance from this site. Cortex on both black and beige Senonian artifacts in level G indicates decreased reliance on terrestrial secondary sources and increased reliance on stream sources, relative to level M3. However, some of the difference might be accounted for by chance variation related to the small sample sizes in the level M3 assemblage: I

tabulated cortex types on nearly ten times as many objects from level G as from level M3. In level G, roughly two-thirds of the Senonian material of all varieties (black, beige, and indeterminate) seems to have been gathered from terrestrial secondary sources, and the remaining third from stream gravels.

Interestingly, four raw material types show noticeably higher frequencies of cortex indicating primary sources (the first two rows in Table 4.6). Summing the figures from those two rows gives 14% for Bergeracois chert, 45% for chalcedony/millstone (n = 12), 19% for jasper, and 30% for porcelainite. People seem to have gathered jasper and chalcedony/millstone mainly from sources on the Plateau de Bord, on the other side of the Dordogne River, but also gathered some from streams. Thus, I set the minimum source distance of both types at 1 km, the same as basalt, quartzite, black Senonian, and beige Senonian.

In levels XI and IX from Le Flageolet I, Jurassic chert is the only raw material type for which the estimate of minimum source distance would depend on my examination of cortex. Unfortunately, both levels yielded very few artifacts made of Jurassic chert, and none with sufficient amounts of cortex for identifying the characteristics of the occurrence. Thus, lacking any data that would allow me to assign a lower figure for the minimum source distance of this chert, I used the figure of 22 km, the distance to the nearest primary occurrences.

Black and beige Senonian chert, basalt, quartzite, jasper and chalcedony/ millstone all could have been gathered from either primary or secondary sources within 1-3 km of Le Flageolet. Primary and secondary occurrences of the four remaining raw materials—Bergeracois chert, Mussidan chert, Fumelois chert, and Gavaudun chert—lie at roughly equal distances to Le Flageolet. Thus, while cortex indicates that these

materials were gathered from a combination of primary and secondary sources, the transport distance would have been the same in either case.

The raw materials in Tables 4.7 and 4.8 show various kinds of cortex (except Fumelois chert, with a sample size of one), suggesting that people gathered each from a variety of occurrences types. It is interesting that level IX of Le Flageolet I shows a heavier reliance on stream transported cobbles than level XI. All varieties of Senonian chert in that assemblage show between 66% and 73% cortex indicating stream transport (last two rows in the table combined), and Bergeracois chert shows 76%. In level XI, those percents are 37%-58% for Senonian, and 25% for Bergeracois. I have no explanation for this difference between the two levels, although it appears to indicate some behavioral difference in landscape use. In contrast, the percent of chalcedony/millstone gathered from terrestrial sources appears to be equal in the two levels—about 70%.

These data clearly indicate that the exploitation of raw material sources in the past was rarely if ever limited to a single kind of occurrence. Even when people could have gathered (or did gather) cobbles of a given raw material type from nearby streams, they also exploited terrestrial sources. In several cases, a combination of primary sources and terrestrial secondary sources furnished the majority of a given raw material type. Pieces bearing stream-worn cortex are most common at Le Moustier, which seems to enjoy the easiest access to abundant river gravels, and rarest at Caminade Est, which has the most difficult access to river gravels. Therefore, my data lead me to draw conclusion that differs from those of other researchers in this area (Chadelle 1983, Lucas 2000, Turq 1992), who have concluded that raw material acquisition was done mostly or entirely at secondary sources, especially stream gravels. My data indicate that

the relative intensity with which people exploited different kinds of raw material sources depended strongly on the position of the site relative to primary sources and streams. It also probably depended on other factors affecting landscape use, such as the location of animal and plant resources, but the above data provide throw no light on that question.

*Occurrence densities* The different densities in which raw material outcrops are found must also be taken into account. As a proxy measure of these densities, I counted the occurrences plotted on both Geneste's (1985) and Turq's (1992) maps (using the former for the area north of the Dordogne River, and the latter for the area south of the Dordogne). For the Jurassic chert occurrences, I also relied on maps shown in Demars (1982). This yielded the totals shown in Table 4.9. Turq (1992:231-233) mentions ten or eleven known occurrences of Gavaudun chert, and "a few" of Fumelois chert. This list excludes several varieties recognized by Geneste (1985) and Turq (1992, 1999), all of which appear to be approximately as rare as Gavaudun and Fumelois. Altogether, about 1300 occurrences are documented by these studies. The figures should not be used as exact estimates of occurrence densities, because the sampling biases that might have affected the discovery of occurrences are unknown, and because of possible errors in tabulating the data from maps.

The sites I studied, of course, are located at various points on the maps. To obtain estimates of occurrence densities based on the same area around each site, I drew a circle corresponding to a 50 km radius around each site, and counted the number of known occurrences of each raw material type within those circles. I discuss the figures that resulted from these counts in more detail below.

The above occurrence densities do not include quartzite or basalt. These were certainly gathered from streams. Cobbles of basalt and quartzite are very common in

Perigord river gravels; their geologic sources lie over 70 km to the east in the highlands of the Massif Central; and their exterior surfaces are invariably smoothed and rounded by stream transport. Thus, the frequency of these rocks in streambeds best measures their occurrence density. In 1996, I conducted a systematic sampling of gravel composition in four riverbeds near Caminade Est, Le Flageolet, and Le Moustier, although I was unable to study the streambeds near La-Côte. In each riverbed, I conducted a separate sampling in one to three locations. I lay a 1 $m^2$ sampling unit upon the rocks in a dry gravel bar or on the stream bank (Figure 4.10), and broke apart each rock in the unit over 7 cm in its minimum dimension. I only examined loose rocks that could be picked up without excavating or pulling rocks out of the ground. Table 4.10 shows the results of this sampling. There is at least one set of sampling locations in close proximity to each of the sites except La-Côte; three of these are shown in Figure 4.11.

In Table 4.10, quartzite is by far the most common rock. Basalt took second place, and cherts were extremely rare. Discounting a few nodules of *chaille*, I found only four chert cobbles (0.7% of the total sample of 544 rocks), two of which belonged to black Senonian and two to beige Senonian.

*Estimating the natural availability of each raw material type* Table 4.11 lists the data that I used to estimate the natural availability of each raw material type for each site. I based these rankings on the three kinds of data I have just discussed: ranking by abundance in the sampled gravels, occurrence densities, and minimum source distance. Table 4.11 lists estimates of source distances for both primary (p) and secondary (s) occurrences; the figures I used to estimate natural availability are shown in plain face (based on the patterns of cortex characteristics, discussed above). To obtain an

estimate of the natural availability of each raw material type, I pooled the information in columns 3-5 of Table 4.11 and named the resulting variable Estimated Natural Availability (ENA).

I assigned a rank to each raw material type in each assemblage in the following manner. I first ranked the local raw material types according to their observed relative abundance in nearby river gravels. Based on the gravel survey data (Table 4.10), quartzite ranks first, basalt second, and cherts last. Among the cherts, I then ranked the local types in each assemblage by the number of occurrences within a 50 km radius of the site. Local types are those that certainly or probably could have been gathered from nearby stream gravels, or for which mapped occurrences exist within 12 km of the site.

Finally, I ranked the non-local cherts at each site by two criteria: first by estimated minimum source distance, then by the number of occurrences within a 50 km radius. Since this information was unavailable for indeterminate Senonian, porcelainite, and unidentified, I excluded those three types from the ENA ranks and from the analyses that depend on those ranks. These ranks are based on the assumption that source distance has a greater affect on the availability of each raw material type than the number of occurrences has. In order to gather rocks from a distant source, one would have had to travel a long way, no matter how many raw material occurrences were there. In contrast, a small number of known occurrences located within a short distance of one's base camp would be more accessible. This seems a reasonable assumption to make, although I know of no way of testing it. The last column in Table 4.11 lists the ranks that resulted from this process.

Hypothesis testing procedures

These ENA ranks are the data I compared against the quantity of each raw material type in each assemblage. I did this comparison in order to test the hypothesis that assemblage raw material composition reflects the natural availability of each rock. Carrying out these tests involved the following steps: In each assemblage, I summed the total weight of all objects within each raw material type, and ranked the raw material types by those sums. I term the resulting ranks "rank by weight". I then compared those ranks with the ranks by ENA, using Spearman's *rho*. The null hypothesis of the test is that of no correlation in the rankings.

**Results**

Raw material composition of the assemblages

Table 4.12 shows the frequencies of each raw material type in each assemblage, by total weight. The figures in the second column were obtained by summing the weights of all objects in each raw material type (excluding objects weighing less than 1 g). The figures in the last column are based on assumptions about the status of each raw material type at each site (local or non-local); they are the non-italicized figures in columns 5 and 6 of Table 4.11. In all cases, I assume that black Senonian chert, beige Senonian chert, quartzite, and basalt were gathered in local streambeds or other nearby secondary sources. This assumption is supported by observations of the erosion of cortex on the artifacts. Chalcedony/millstone was also locally obtained at Le Flageolet I, Caminade Est, and Le Moustier, but it was absent from La-Côte. Although indeterminate Senonian was excluded from the ENA ranks (see below), I include that category here because it consists of rocks that properly belong to either black or beige Senonian, which do not differ greatly in source distances. I exclude porcelainite and

unidentified raw material from the following analysis, however, because source distances could not be estimated for those types.

*Remarks* Tables 4.11 and 4.12 makes three things clear. First, locally available raw material types are much more abundant than the remainder of the raw material types in each assemblage. The total weight of the most abundant raw material type (always black Senonian) is several times that of the second most abundant type (beige Senonian, basalt, or Bergeracois) in most cases, with a rapid fall-off for the remainder of the types. Second, not all locally available raw material types occur in higher amounts than all non-local ones, despite large differences in the estimated source distances. For example, Bergeracois is more abundant that chalcedony/millstone in four of the five assemblages that have both, and Bergeracois is also more abundant that beige Senonian in La-Côte III. Third, the distributions of estimated source distance values are discontinuous, with most values clustering at 1 km, 2-6 km, or > 30 km.

Table 4.13 summarizes these data and categorizes all raw material types as either "local" or "non-local". Here, local raw material types are those for which the minimum source distances are ≤ 12 km; those from more distant sources are non-local. The table shows no clear relationship between the percentage of local materials and the assemblages' age, industrial identity, or geographic location.

Assemblage composition and the estimated natural availability of raw material types

Table 4.14 shows the results of the rank-order correlation tests. A test statistic that is positive and statistically significant ($\alpha$ = .05) would lead to rejection of the null hypothesis, and to acceptance of the idea that raw material use reflects the availability of raw materials and nothing else. Only the two assemblages from Le Flageolet I show significant test statistics, which are positive and high in both cases. Those two

assemblages are both Aurignacian, and are probably the youngest of the six assemblages.

The presence of quartzite and basalt cobbles in five of the assemblages is troublesome because these rocks may have had a different function from the cherts. If so, then it might be incorrect to rank them along with the cherts as if they represented the same class of artifacts. At least some of these coarser-grained cobbles were probably used as hammerstones. Furthermore, my technological analyses (to be presented later) show that their technological composition differs markedly from that of the cherts. In each assemblage, quartzite and basalt consist of a few flaked cobbles, a flake or two, and many chunks (fragments that cannot be oriented). These differences are statistically significant. The high frequency of quartzite and basalt chunks may result from the use of these materials in different activities, or from the greater difficulty in identifying the diagnostic attributes of conchoidal fracture in these granular materials. Without a detailed analysis of those artifacts, there is no way to discriminate between these possibilities.

I assigned new ranks to the raw materials in these five assemblages, excluding quartzite and basalt, and then repeated the rank-order correlation tests; Table 4.15 shows the results. The absolute value of the rank order correlation statistic is dramatically higher for Le Moustier, H8 and Caminade Est, G, and slightly higher for Caminade Est, M3 than in the previous test. It is slightly lower for both assemblages from Le Flageolet. However, only in the case of layer G from Caminade Est did the removal of basalt and quartzite cause a change in the statistical outcome of the tests. This assemblage shows a significant correlation in the two sets of ranks only when basalt and quartzite are excluded. Basalt and quartzite are the two most naturally

abundant raw material types at Caminade Est, but in level G they occur in lower frequencies than all identifiable chert types except Fumelois. This accounts for the difference in the outcome of the two tests.

In sum, the results suggest that raw material use in Le Flageolet I, XI and IX was a simple reflection of the natural availability of the raw material types. In Caminade Est, G the frequencies of the chert types does not differ significantly from their relative availability; only the frequencies of granular rocks do, but those were probably gathered in small numbers to be used as hammerstones. All three Aurignacian assemblages therefore show evidence that raw materials were collected on an encounter basis and as a function of the natural availability of each chert type. The raw material composition of Le Moustier H8, Caminade Est M3, and La-Côte III does not appear to result from such a straightforward behavioral pattern.

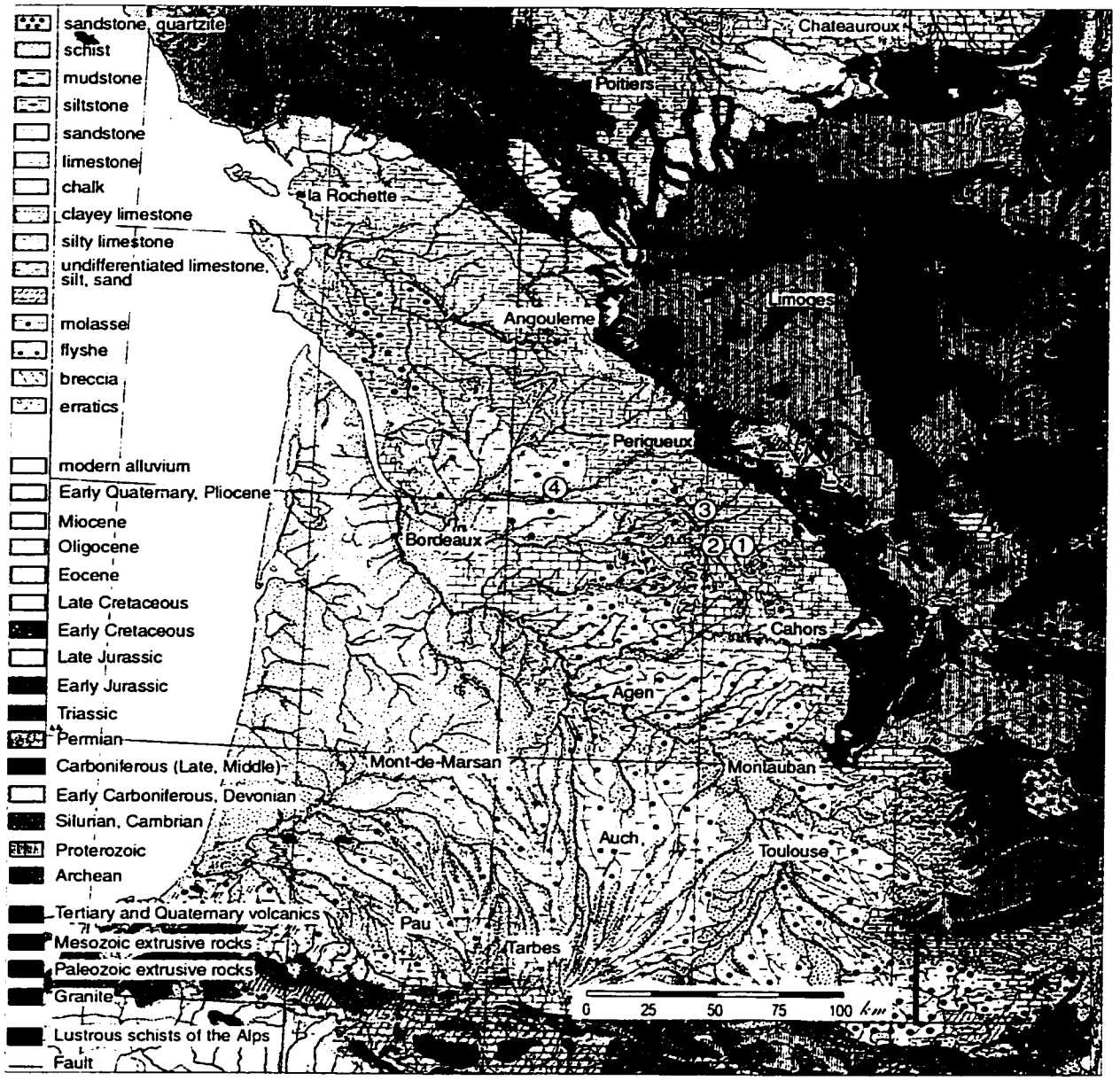
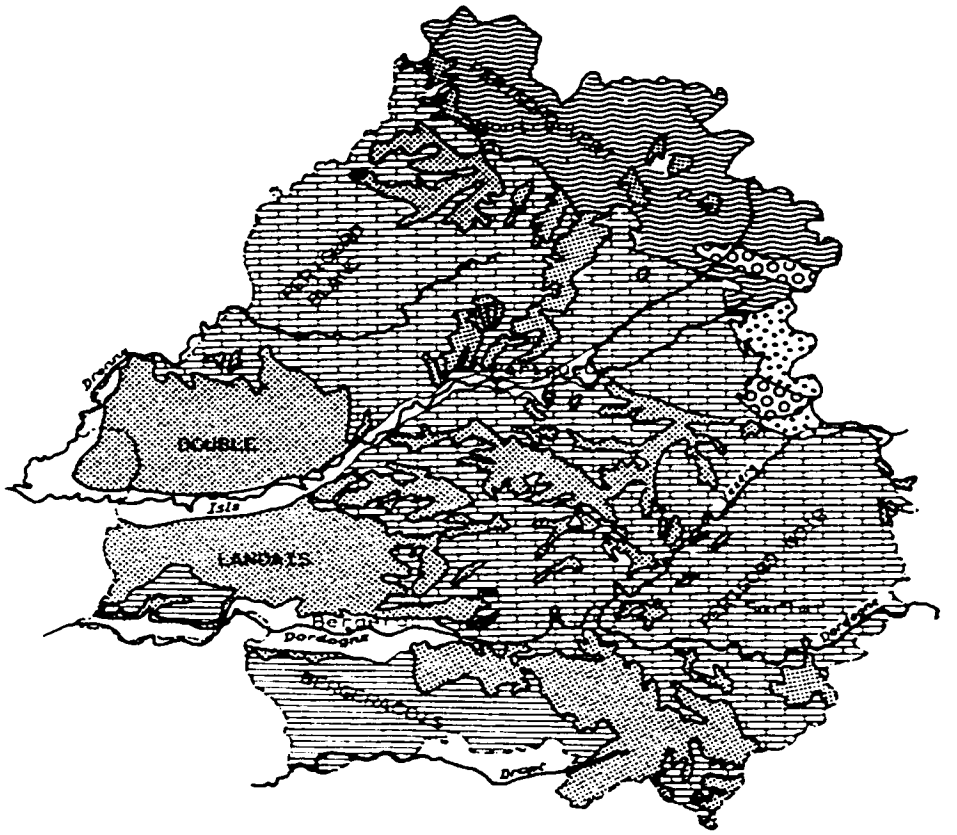



Figure 4.1 Map of rock formations in the Aquitaine and surrounding region. Modified after B.R.G.M. 1974. Sites: 1 = Caminade Est; 2 = Le Flageolet I; 3 = Le Moustier; 4 = La-Côte.




1 Alluvial terraces: recent or early Quaternary
2 Tertiary, marine or lacustrine
3 "Siderolithic" and "Perigord sands"
4 Jurassic, Late Cretaceous
5 Permian-Triassic
6 Early Cambrian, Ordivician
7 Crystalline base rock

Figure 4.2 Rock formations in the Dordogne. Modified after Laville and Texier (1976:37).

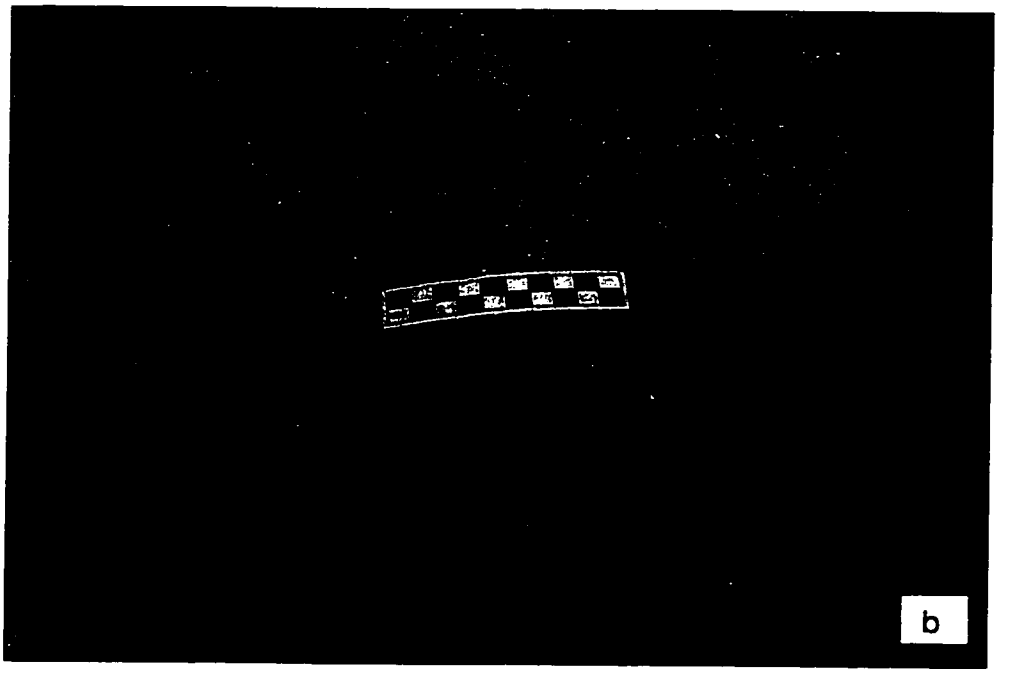



Figure 4.3 Outcrop (a) of black Senonian chert in limestone near Plazac (Dordogne), and close-up of nodule (b).

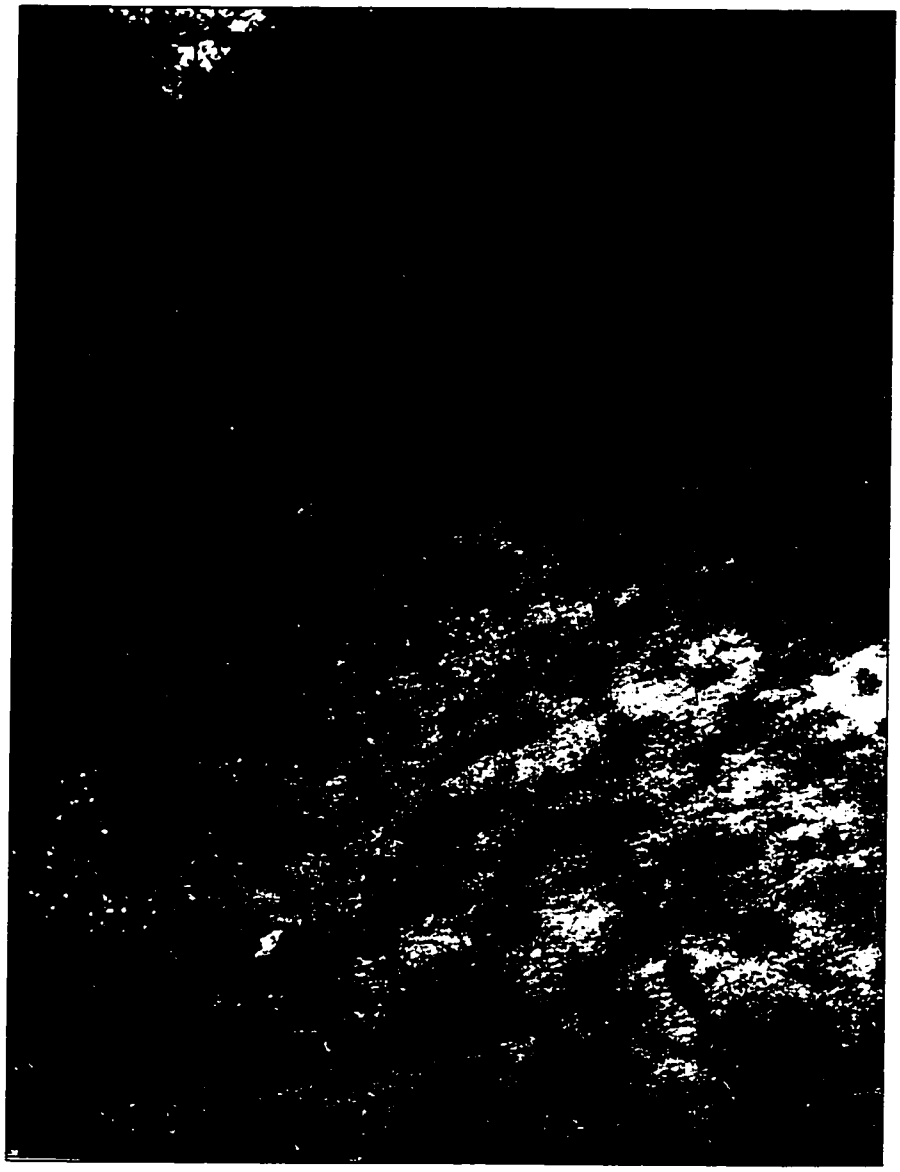


Figure 4.4 Eroding limestone outcrop at La Froumagie, Dordogne. Note nodules on ground's surface in foreground.

Figure 4.5 Nodules of Senonian chert between rows of maize at Le Grand Bonnet (Dordogne).

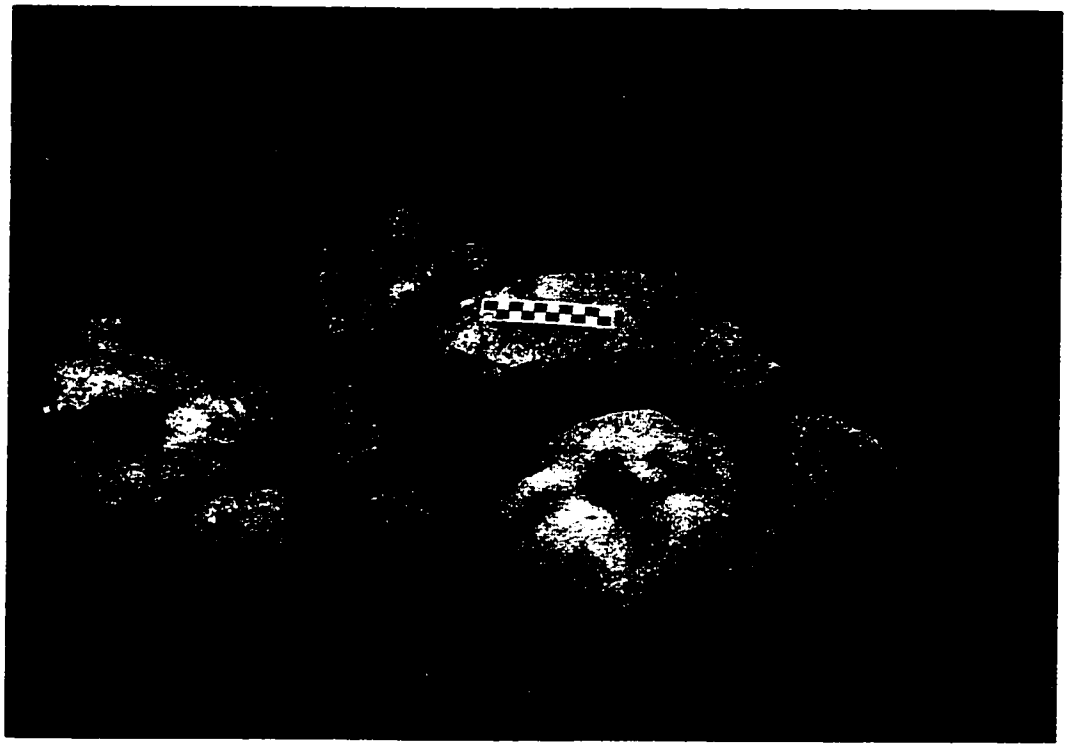


Figure 4.6 Nodules of chert collected from field at Le Grand Bonnet.

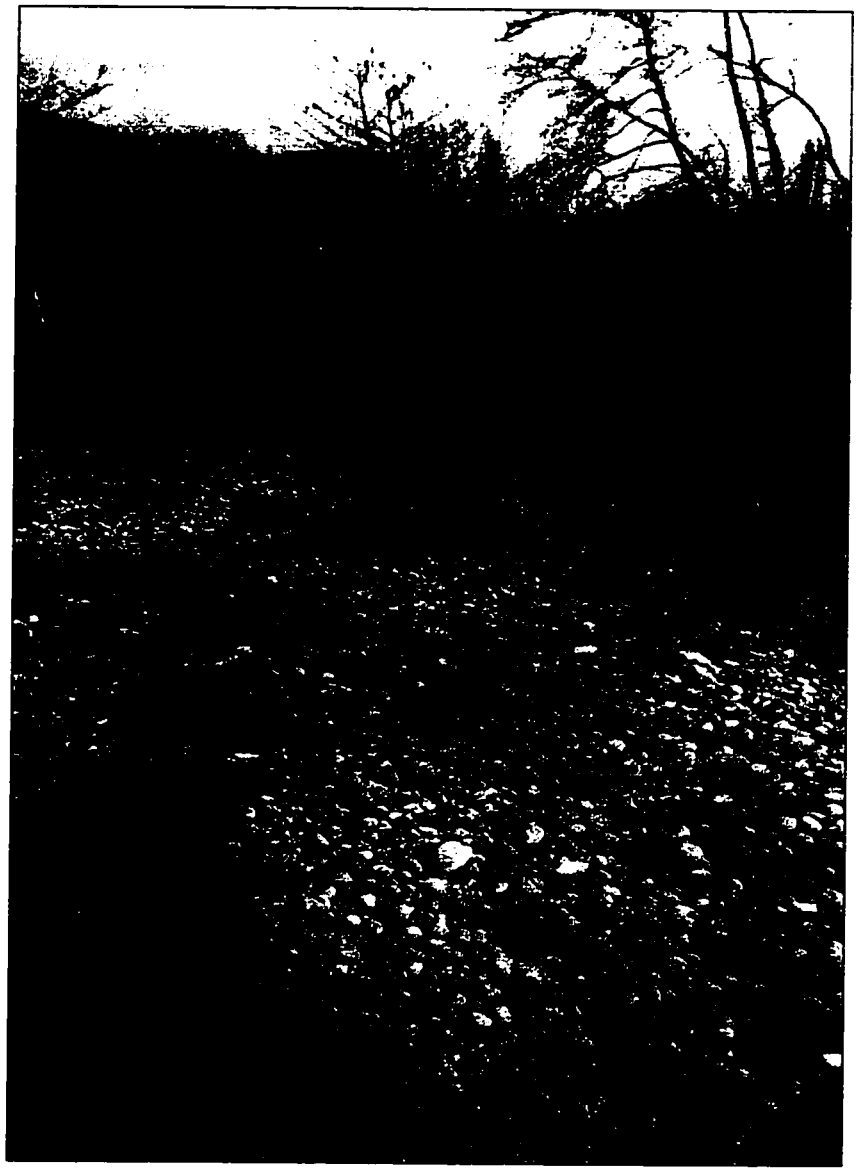


Figure 4.7 Gravel bar along the left bank of the Dordogne River at Goudou (Dordogne). The site of Le Flageolet I is approximately 2 km away on the other side of the valley.

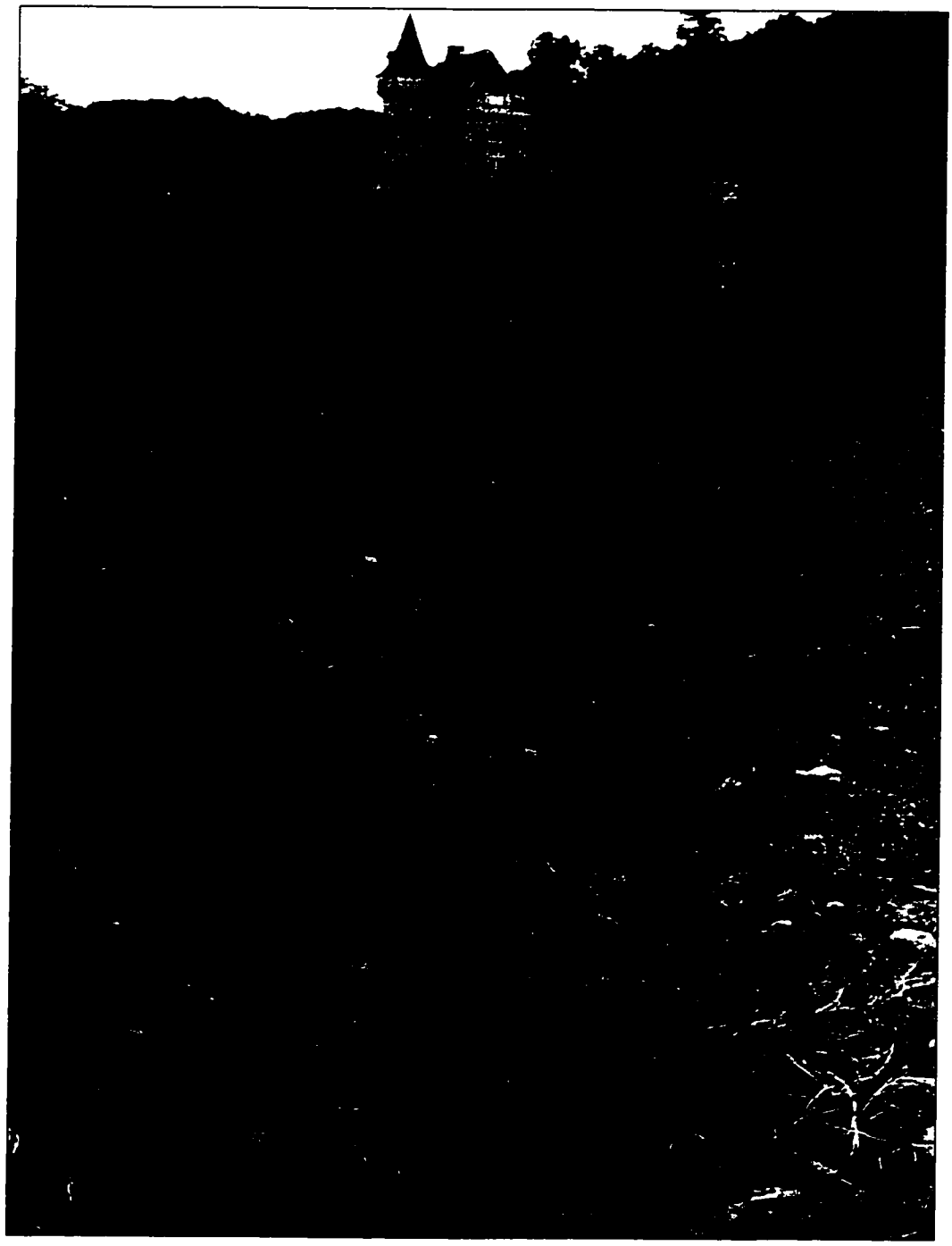


Figure 4.8 Cobbles of chert and quartzite in ploughed field on old terrace of the Vézère River, near Sergeac (Dordogne), where the Aurignacian site of Castanet lies, and about 4.5 km NE (as the crow flies) from Le Moustier. The river runs along the bluff beneath the Château de Belcayre.

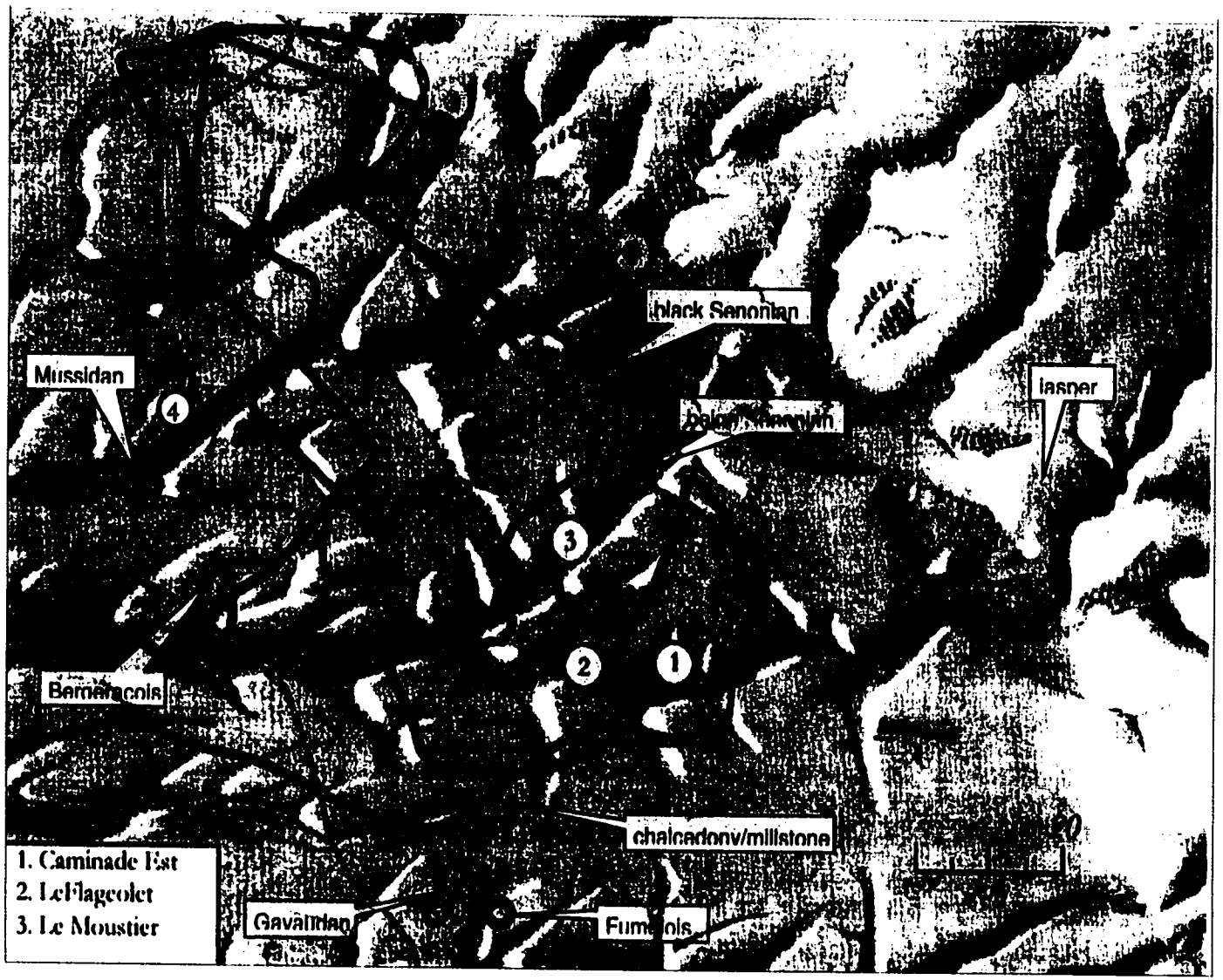
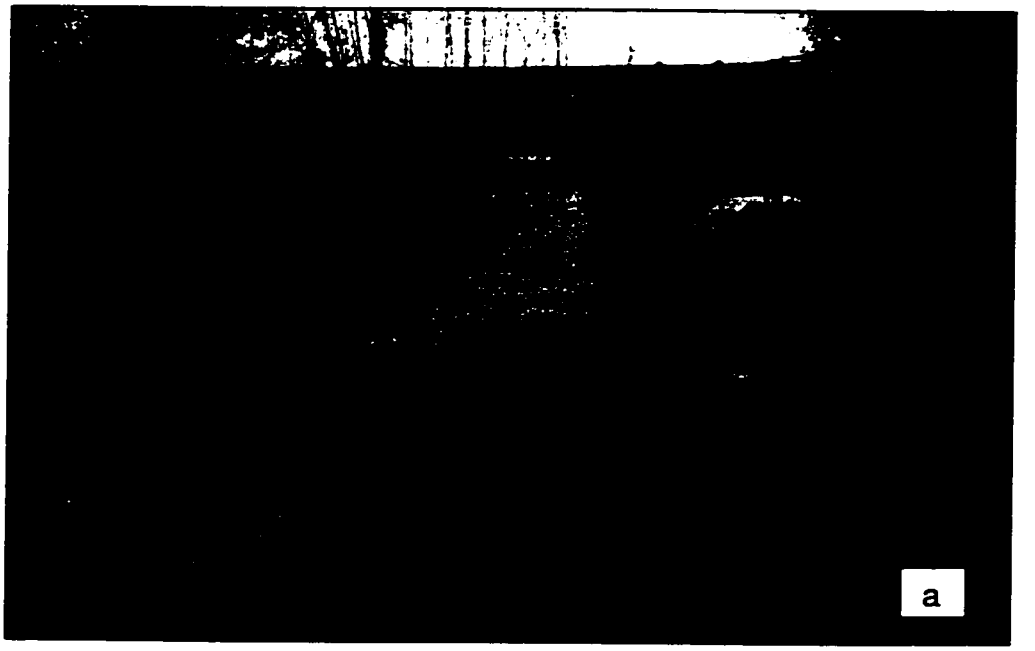



Figure 4.9 Map showing the geographic range of major chert types in the Perigord. Chert occurrences are not evenly distributed within each range.



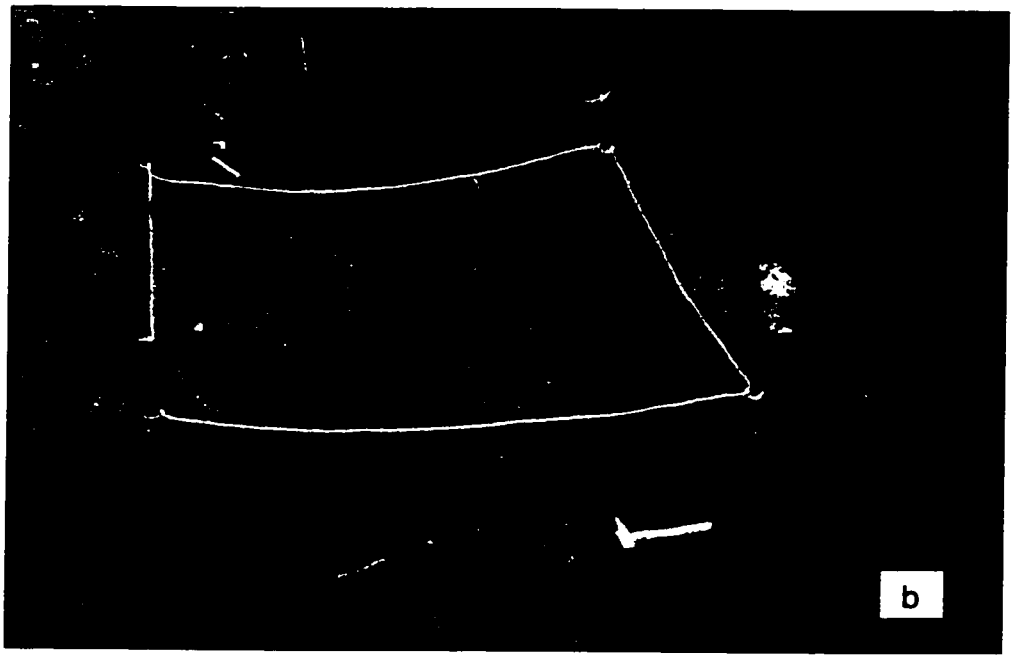




Figure 4.10 Gravel sampling at Le Moustier: (a) overview, looking to the east (upstream); (b) 1 $m^2$ sampling unit in gravel.

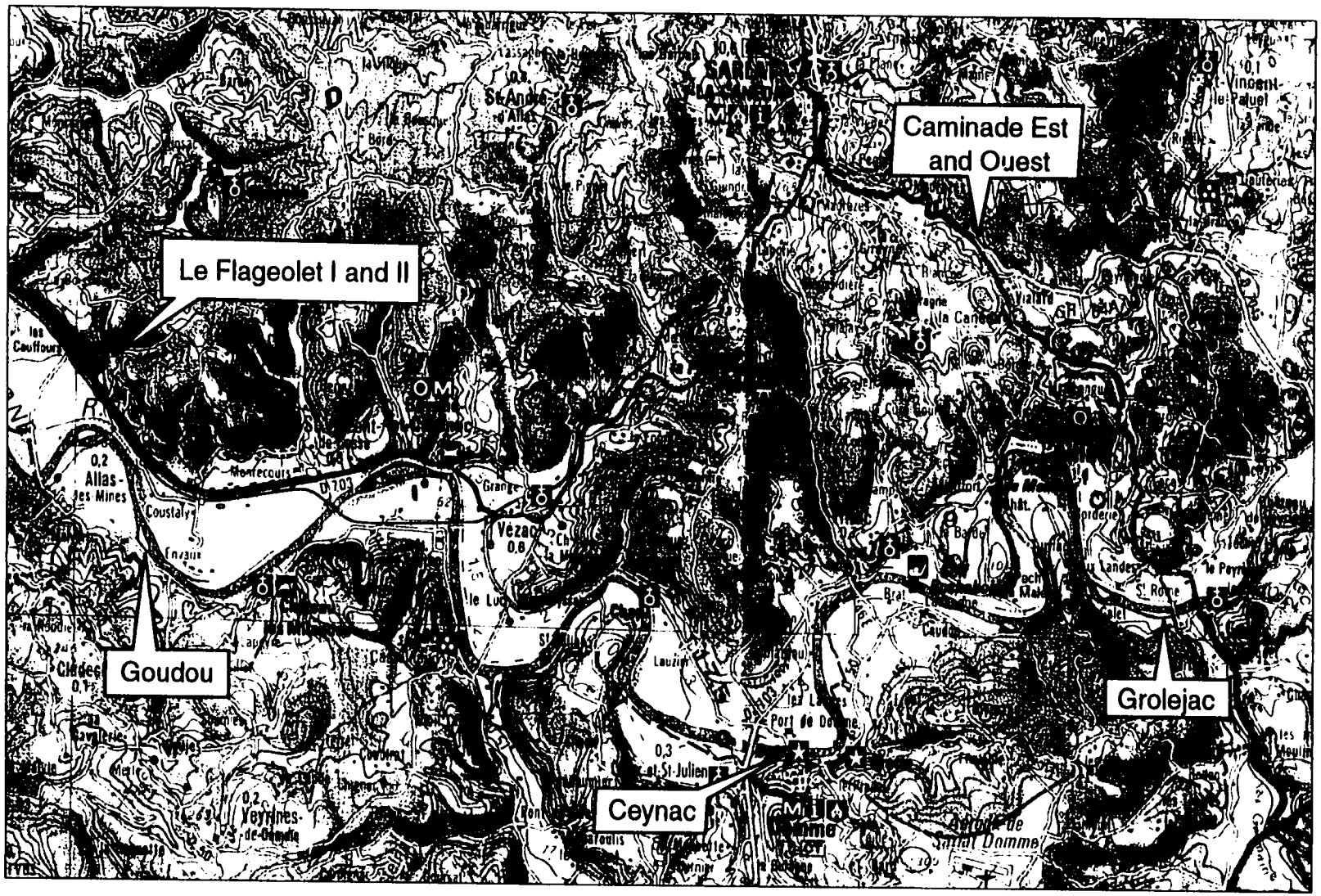



Figure 4.11 Location of river gravel sampling units. From I.G.N 1:100,000 map, Périgueux-Tulle.

Table 4.1 Siliceous raw materials in the assemblages studied here.

| NAME | AGE |
|---|---|
| Black Senonian chert | Coniancian, Santonian, and Campanian (Late Cretaceous) |
| Beige Senonian chert | Coniancian, Santonian, and Campanian (Late Cretaceous) |
| Senonian chert, indeterm. | Coniancian, Santonian, and Campanian (Late Cretaceous) |
| Bergeracois chert | Siderolithic (Tertiary) |
| Chalcedony/millstone | Tertiary |
| Jasper | Lias (Early Jurassic) and Tertiary |
| Fumelois chert | Turonian (Late Cretaceous) |
| Gavaudun chert | Coniacian (Late Cretaceous) |
| Mussidan chert | Siderolithic (Tertiary) |
| Jurassic chert | Jurassic |
| Pink speckled chert | Unknown |
| Porcelainite chert | Unknown, but probably Tertiary |
| Quartzite | Paleozoic |
| Basalt | Paleozoic |
| Unidentified | |

Table 4.2 Surface characteristics of Perigord cherts.

| Attribute | Attribute-state |
|---|---|
| Surface morphology | rounded |
| | bumpy |
| Feel | smooth |
| | rough |
| Thickness | thick (≥ 3 mm) |
| | thin (< 3 mm) |
| Miscellaneous | eroded areas |
| | totally eroded |
| | non-cortical exterior surface |

Table 4.3 Types of cortex (and other external surfaces of nodules and cobbles).

| Code | Description | Interpretation of cortex |
|---|---|---|
| 0 | no cortex | |
| 1 | bumpy, rough, thick | from primary source |
| 2 | bumpy, rough, thin | from primary source, or limited terrestrial transport |
| 3 | rounded, rough, thick | limited terrestrial transport |
| 4 | rounded, rough, thin | limited terrestrial transport |
| 5 | rough, thin, with eroded areas | terrestrial or stream transport |
| 6 | bumpy, smooth, thick | limited stream transport |
| 7 | bumpy, smooth, thin | limited stream transport |
| 8 | rounded, smooth, thick | limited stream transport |
| 9 | rounded, smooth, thin | extensive stream transport |
| 10 | thick, with eroded areas | extensive stream transport |
| 11 | smooth, thin, with eroded areas | extensive stream transport |
| 12 | totally eroded | extensive stream transport |
| 13 | non-cortical ext. surf | raw material lacking cortex |
| 14 | unidentified | |

Table 4.4 Frequencies of artifacts in each raw material type showing cortex suggesting different source types, based on study of cortex characteristics, Le Moustier, H8. Key to raw material codes: 1 = black Senonian chert; 2 = beige Senonian chert; 12 = indeterminate Senonian chert; 3 = Bergeracois chert; 9 = Jurassic chert; 19 = quartzite; 99 = unidentified.

| | Raw material code | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Interpretation | 1 | 2 | 12 | 3 | 9 | 19 | 99 | Total |
| primary source | 0.2% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.1% |
| primary source/ limited terrestrial transport | 0.2% | 0.0% | 3.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.3% |
| limited terrestrial transport | 23.4% | 34.9% | 18.2% | 25.0% | 0.0% | 0.0% | 34.5% | 25.5% |
| limited stream transport | 5.0% | 7.9% | 3.0% | 0.0% | 0.0% | 0.0% | 3.4% | 5.3% |
| extensive stream transport | 71.3% | 57.1% | 75.8% | 75.0% | 100.0% | 100.0% | 62.1% | 68.8% |
| Total | 100.0% | 100.0% | 100.0% | 100.0% | 100.0% | 100.0% | 100.0% | 100.0% |
| Sample size | 522 | 126 | 33 | 4 | 2 | 1 | 29 | 717 |

Table 4.5 Frequencies of artifacts in each raw material type showing cortex suggesting different source types, based o study of cortex characteristics, Caminade Est, M3. Key to raw material codes: 1 = black Senonian chert; 2 = beige Senonian chert; 12 = indeterminate Senonian chert; 5 = jasper; 9 = Jurassic chert; 97 = porcelainite; 99 = unidentified.

| | Raw material code | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Interpretation | 1 | 2 | 12 | 5 | 9 | 97 | 99 | Total |
| primary source | 1.4% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 3.1% | 1.2% |
| primary source/ limited terrestrial transport | 0.7% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 3.1% | 0.8% |
| limited terrestrial transport | 75.5% | 100.0% | 64.4% | 100.0% | 0.0% | 75.0% | 68.8% | 73.7% |
| limited stream transport | 2.1% | 0.0% | 2.2% | 0.0% | 0.0% | 0.0% | 0.0% | 1.6% |
| extensive stream transport | 20.3% | 0.0% | 33.3% | 0.0% | 100.0% | 25.0% | 25.0% | 22.6% |
| Total | 100.0% | 100.0% | 100.0% | 100.0% | 100.0% | 100.0% | 100.0% | 100.0% |
| Sample size | 143 | 12 | 45 | 2 | 1 | 8 | 32 | 243 |

Table 4.6 Frequencies of artifacts in each raw material type showing cortex suggesting different source types, based on study of cortex characteristics, Caminade Est, G. Key to raw material codes: 1 = black Senonian chert; 2 = beige Senonian chert; 12 = indeterminate Senonian chert; 3 = Bergeracois chert; 4 = chalcedony/millstone; 5 = jasper; 6 = Fumelois chert; 97 = porcelainite; 99 = unidentified.

| | Raw material code | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Interpretation | 1 | 2 | 12 | 3 | 4 | 5 | 6 | 97 | 99 | Total |
| primary source | 0.25% | 0.00% | 0.62% | 3.57% | 18.18% | 0.00% | 0.00% | 2.74% | 0.39% | 0.55% |
| primary source/ limited terrestrial transport | 0.50% | 0.44% | 0.62% | 10.71% | 27.27% | 19.44% | 0.00% | 27.40% | 3.09% | 2.60% |
| limited terrestrial transport | 62.90% | 65.33% | 62.47% | 67.86% | 36.36% | 41.67% | 71.43% | 56.16% | 62.74% | 62.40% |
| terrestrial or stream transport | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 1.37% | 0.39% | 0.14% |
| limited stream transport | 1.49% | 0.89% | 1.65% | 0.00% | 0.00% | 5.56% | 0.00% | 1.37% | 2.70% | 1.78% |
| extensive stream transport | 34.86% | 33.33% | 34.64% | 17.86% | 18.18% | 33.33% | 28.57% | 10.96% | 30.69% | 32.53% |
| Total | 100.00% | 100.00% | 100.00% | 100.00% | 100.00% | 100.00% | 100.00% | 100.00% | 100.00% | 100.00% |
| Sample size | 807 | 225 | 485 | 28 | 12 | 36 | 7 | 73 | 524 | 2197 |

Table 4.7 Frequencies of artifacts among cortex types and corresponding interpretation of source type, by raw material type; Le Flageolet I, XI. Key to raw material codes: 1 = black Senonian chert; 2 = beige Senonian chert; 12 = indeterminate Senonian chert; 3 = Bergeracois chert; 4 = chalcedony/millstone; 5 = jasper; 7 = Gavaudun chert; 99 = unidentified.

| | Raw material code | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Interpretation | 1 | 2 | 12 | 3 | 4 | 5 | 7 | 99 | Total |
| primary source | 0.4% | 0.0% | 0.7% | 0.0% | 12.5% | 0.0% | 0.0% | 0.5% | 0.5% |
| primary source/ limited terrestrial transport | 0.3% | 0.0% | 0.0% | 5.0% | 6.3% | 0.0% | 0.0% | 1.0% | 0.5% |
| limited terrestrial transport | 48.1% | 42.2% | 61.8% | 70.0% | 50.0% | 12.5% | 100.0% | 58.4% | 50.3% |
| terrestrial or stream transport | 0.6% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.3% |
| limited stream transport | 1.5% | 0.7% | 0.7% | 0.0% | 0.0% | 0.0% | 0.0% | 2.9% | 1.4% |
| extensive stream transport | 49.1% | 57.1% | 36.8% | 25.0% | 31.3% | 87.5% | 0.0% | 37.3% | 47.1% |
| Total | 100.0% | 100.0% | 100.0% | 100.0% | 100.0% | 100.0% | 100.0% | 100.0% | 100.0% |
| Sample size | 723 | 289 | 144 | 40 | 16 | 8 | 1 | 209 | 1430 |

Table 4.8 Frequencies of artifacts among cortex types and corresponding interpretation of source type, by raw material type; Le Flageolet I, IX. Key to raw material codes: 1 = black Senonian chert; 2 = beige Senonian chert; 12 = indeterminate Senonian chert; 3 = Bergeracois chert; 4 = chalcedony/millstone; 7 = Gavaudun chert; 97 = porcelainite; 99 = unidentified.

| | Raw Material Code | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Interpretation | 1 | 2 | 12 | 3 | 4 | 7 | 97 | 99 | Total |
| primary source | 0.0% | 0.0% | 1.2% | 0.0% | 0.0% | 0.0% | 0.0% | 0.6% | 0.2% |
| primary source/ limited terrestrial transport | 0.2% | 0.8% | 2.3% | 0.0% | 10.0% | 0.0% | 25.0% | 0.6% | 0.7% |
| limited terrestrial transport | 26.5% | 30.8% | 30.2% | 23.5% | 60.0% | 0.0% | 50.0% | 30.1% | 28.6% |
| terrestrial or stream transport | 0.2% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.1% |
| limited stream transport | 2.5% | 4.0% | 2.3% | 11.8% | 0.0% | 100.0% | 0.0% | 8.0% | 4.0% |
| extensive stream transport | 70.6% | 64.4% | 64.0% | 64.7% | 30.0% | 0.0% | 25.0% | 60.7% | 66.5% |
| Total | 100.0% | 100.0% | 100.0% | 100.0% | 100.0% | 100.0% | 100.0% | 100.0% | 100.0% |
| Sample size | 558 | 247 | 86 | 34 | 10 | 1 | 4 | 163 | 1103 |

Table 4.9 Inventory of occurrences of several raw material types in the Perigord, from data in Demars (1982), Geneste (1985) and Turq (1992).

| Raw material type | Number of occurrences in the Perigord |
|---|---|
| Beige Senonian chert | 615 |
| Black Senonian chert | 278 |
| chalcedony/millstone | 198 |
| jasper | 89 |
| Bergeracois chert | 71 |
| Jurassic chert | 20 |
| Fumelois chert | ≈12 |
| Gavaudun chert | ≈3 |
| Mussidan chert | 6 |
| pink speckled chert | unknown |
| porcelainite chert | unknown |

Table 4.10 Frequencies of rock types from systematic sampling in ten locations along four riverbanks. See text for explanation of locations and rock types. Mou = Le Moustier; Gou = Goudou; Cen = Cenac; Grol = Groléjac. See Figures 4.11 and 4.12 for locations. Each column represents a single 1 X 1 m sampling unit.

| Rock Type | Sample Location | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Mou 1 | Mou 2 | Mou 3 | Gou 1 | Gou 1 | Gou 3 | Cen 1 | Cen 2 | Cen 3 | Grol | Totals | % |
| quartzite | 6 | 5 | 5 | 49 | 43 | 49 | 56 | 34 | 43 | 33 | 323 | 59.4% |
| quartz | 18 | 8 | 1 | 9 | 1 | 10 | 8 | 3 | 3 | 4 | 65 | 11.9% |
| basalt | | | | 16 | 6 | 14 | 11 | 1 | 5 | 3 | 56 | 10.3% |
| shist | 11 | 2 | 2 | 8 | 5 | 7 | 5 | 2 | 2 | 6 | 50 | 9.2% |
| metamorphic | 4 | 1 | 3 | 7 | 5 | 1 | 5 | 2 | 2 | 1 | 31 | 5.7% |
| *chaille* chert | | | | | | 1 | | 1 | 3 | | 5 | 0.9% |
| limestone | | | | | | | 3 | 1 | | | 4 | 0.7% |
| unidentified non-chert | | | | 1 | 1 | 2 | | | | | 4 | 0.7% |
| sandstone | 1 | 1 | | | | | | | | | 2 | 0.4% |
| unidentified chert | | | | | | | 2 | | | | 2 | 0.4% |
| black Senonian chert | 1 | | | | | | | | | | 1 | 0.2% |
| beige Senonian chert | | | 1 | | | | | | | | 1 | 0.2% |
| Totals | 41 | 17 | 12 | 90 | 61 | 84 | 90 | 44 | 58 | 47 | 544 | 100% |

Table 4.11 Data used to determine Rank-by-ENA (Estimated Natural Availability) for raw material types, by assemblage. "Rank-gravel abundance", ranking of quartzite, basalt, and chert based on data in Table 4.3. "Occurrences within 50 km", number of occurrences counted within 50 km radius of site. "Est. min. source distance (km)", estimated minimum source distance, based on nearest known primary (p) or secondary (s) occurrence. In each row, the smaller of the two figures under "p" and "s" was used in figuring ENA ranks; figures that were not used are shown in italics. "Rank-ENA", within-assemblage rank by Estimated Natural Availability.

| Assemblage | Raw material type | Rank-gravel abundance | Occurrences within 50 km | Est. min. source distance (km) | | Rank-ENA |
|---|---|---|---|---|---|---|
| | | | | p | s | |
| Le Moustier, H8 | quartzite | 1 | - | *>70* | 1 | 1 |
| | basalt | 2 | - | *>70* | 1 | 2 |
| | beige Senonian | 3 | 594 | *1* | 1 | 3 |
| | black Senonian | 3 | 253 | *4* | 1 | 4 |
| | chalcedony/millstone | - | 141 | 4 | *?* | 5 |
| | Bergeracois | - | 71 | 33 | *>33* | 6 |
| | Jurassic | - | 8 | 31 | *?* | 7 |
| Caminade Est, M3 | quartzite | 1 | - | *>70* | 1 | 1 |
| | basalt | 2 | - | *>70* | 1 | 2 |
| | beige Senonian | 3 | 549 | *3* | 1 | 3 |
| | black Senonian | 3 | 179 | *1* | 1 | 4 |
| | chalcedony/millstone | - | 146 | *6* | 1 | 5 |
| | jasper | - | 47 | 4 | *?* | 6 |
| | Jurassic | - | 8 | 3 | *?* | 7 |
| | Bergeracois | - | 5 | 45 | *>45* | 8 |
| Caminade Est, G | quartzite | 1 | - | *>70* | 1 | 1 |
| | basalt | 2 | - | *>70* | 1 | 2 |
| | beige Senonian | 3 | 549 | *3* | 1 | 3 |
| | black Senonian | 3 | 179 | *1* | 1 | 4 |
| | chalcedony/millstone | - | 146 | *6* | 1 | 5 |
| | jasper | - | 47 | 4 | *?* | 6 |
| | Fumelois | - | 2 | 39 | *>39* | 7 |
| | Bergeracois | - | 5 | 45 | *>45* | 8 |
| La-Côte, III | beige Senonian | 1 | 263 | 3 | 1 | 1 |
| | black Senonian | 1 | 166 | *17* | 1 | 2 |
| | silicified wood | - | 12 | 2 | *1* | 3 |
| | jasper | - | 8 | 8 | *>8* | 4 |
| | pink translucent | - | 1 | 9 | *>9* | 5 |
| | Bergeracois | - | 71 | 19 | *>19* | 6 |

Table 4.11, continued.

| Assemblage | Raw material type | Rank-gravel abundance | Number of occurrences | Est. min. source distance (km) | | Rank-ENA |
|---|---|---|---|---|---|---|
| | | | | p | s | |
| Le Flageolet I, XI | quartzite | 1 | - | *>70* | 1 | 1 |
| | basalt | 2 | - | *>70* | 1 | 2 |
| | beige Senonian | 3 | 585 | *3* | 1 | 3 |
| | black Senonian | 3 | 231 | *2* | 1 | 4 |
| | chalcedony/millstone | - | 141 | *2* | 1 | 5 |
| | jasper | - | 45 | 1 | *?* | 6 |
| | Jurassic | - | 8 | 22 | *?* | 7 |
| | Bergeracois | - | 71 | 34 | *>34* | 8 |
| | Gavaudun | - | 12 | 33 | *>33* | 9 |
| | Mussidan | - | 6 | 58 | *>58* | 10 |
| Le Flageolet I, IX | quartzite | 1 | - | *>70* | 1 | 1 |
| | basalt | 2 | - | *>70* | 1 | 2 |
| | beige Senonian | 3 | 585 | *3* | 1 | 3 |
| | black Senonian | 3 | 231 | *2* | 1 | 4 |
| | chalcedony/millstone | - | 141 | *2* | 1 | 5 |
| | jasper | - | 45 | 1 | *?* | 6 |
| | Jurassic | - | 8 | 22 | *?* | 7 |
| | Bergeracois | - | 71 | 34 | *>34* | 8 |
| | Gavaudun | - | 12 | 33 | *>33* | 9 |
| | Fumelois | - | 2 | 31 | *>31* | 10 |

Table 4.12 Ranks of raw material type by ENA and ranks of raw material type by total weight in assemblage.

| Assemblage | Raw material type | Total Weight (kg) | Rank by Total Weight | Rank by ENA |
|---|---|---|---|---|
| Le Moustier, H8 | black Senonian | 12.987 | 1 | 4 |
| | beige Senonian | 3.782 | 2 | 3 |
| | Bergeracois | 0.149 | 3 | 6 |
| | quartz/quartzite | 0.080 | 4 | 1 |
| | Jurassic | 0.060 | 5 | 7 |
| | basalt | 0.027 | 6 | 2 |
| | chalcedony/millstone | 0.002 | 7 | 5 |
| | indet. Senonian | 0.827 | - | - |
| | unidentified | 0.684 | - | - |
| | Total | 18.598 | | |
| Caminade Est, M3 | black Senonian | 4.050 | 1 | 4 |
| | basalt | 1.013 | 2 | 2 |
| | Jurassic | 0.354 | 3 | 7 |
| | beige Senonian | 0.252 | 4 | 3 |
| | jasper | 0.078 | 5 | 6 |
| | quartz/quartzite | 0.063 | 6 | 1 |
| | Bergeracois | 0.010 | 7 | 8 |
| | chalcedony/millstone | 0.002 | 8 | 5 |
| | unidentified | 1.440 | - | |
| | indet. Senonian | 1.024 | - | |
| | porcelainite | 0.290 | - | |
| | Total | 8.577 | | |
| Caminade Est, G | black Senonian | 17.659 | 1 | 4 |
| | beige Senonian | 3.358 | 2 | 3 |
| | jasper | 1.242 | 3 | 6 |
| | chalcedony/millstone | 0.760 | 4 | 5 |
| | Bergeracois | 0.666 | 5 | 8 |
| | quartz/quartzite | 0.208 | 6 | 1 |
| | basalt | 0.188 | 7 | 2 |
| | Fumelois | 0.134 | 8 | 7 |
| | indet. Senonian | 8.286 | - | - |
| | unidentified | 6.022 | - | - |
| | porcelainite | 1.390 | - | - |
| | Total | 39.913 | | |
| La-Côte, III | black Senonian | 3.682 | 1 | 2 |
| | Bergeracois | 0.590 | 2 | 6 |
| | beige Senonian | 0.456 | 3 | 1 |
| | pink translucent | 0.086 | 4 | 5 |
| | petrified wood | 0.065 | 5 | 3 |
| | jasper | 0.035 | 6 | 4 |
| | indet. Senonian | 0.061 | - | - |
| | unidentified | 0.077 | - | - |
| | Total | 5.051 | | |

Table 4.12, continued.

| Assemblage | Raw material type | Total Weight (kg) | Rank by Total Weight | Rank by ENA |
|---|---|---|---|---|
| Le Flageolet I, XI | black Senonian | 13.195 | 1 | 4 |
| | beige Senonian | 5.428 | 2 | 3 |
| | basalt | 2.977 | 3 | 2 |
| | quartz/quartzite | 2.605 | 4 | 1 |
| | Bergeracois | 0.538 | 5 | 8 |
| | chalcedony/millstone | 0.299 | 6 | 5 |
| | jasper | 0.048 | 7 | 6 |
| | Mussidan | 0.037 | 8 | 10 |
| | Jurassic | 0.029 | 9 | 7 |
| | Gavaudun | 0.004 | 10 | 9 |
| | Unidentified | 2.033 | - | - |
| | indet. Senonian | 1.937 | - | - |
| | porcelainite | 0.042 | - | - |
| | Total | 29.173 | | |
| Le Flageolet I, IX | black Senonian | 27.945 | 1 | 4 |
| | beige Senonian | 7.619 | 2 | 3 |
| | quartz/quartzite | 4.902 | 3 | 1 |
| | basalt | 3.481 | 4 | 2 |
| | Bergeracois | 2.618 | 5 | 8 |
| | chalcedony/millstone | 0.351 | 6 | 5 |
| | jasper | 0.033 | 7 | 6 |
| | Gavaudun | 0.019 | 8 | 9 |
| | Fumelois | 0.014 | 9 | 10 |
| | Jurassic | 0.008 | 10 | 7 |
| | indet. Senonian | 5.354 | - | - |
| | Unidentified | 4.578 | - | - |
| | porcelainite | 0.210 | - | - |
| | Total | 57.132 | | |

Table 4.13 Percent of non-local raw material in each assemblage, by total weight. Non-local raw materials are defined as those occurring >12 km from the site.

| Assemblage | Lithic tradition | Approximate age bp | Non-local RM |
|---|---|---|---|
| La-Cote, III | Châtelperronian | 33,000-43,000 | 11.9% |
| Caminade Est, M3 | Mousterian (Ferrassie ) | 37,200-47,000 | 5.3% |
| Le Flageolet I, IX | Aurignacian I | 28,500 | 5.1% |
| Caminade Est, G | Aurignacian I | 37,200 | 2.5% |
| Le Flageolet I, XI | Aurignacian I | 33,400 | 2.2% |
| Le Moustier, H8 | Mousterian (MAT) | 42,500 | 1.2% |
| Grand total | | | 3.7% |

Table 4.14 Rank-order correlations (Spearman's rho) for raw material types ranked by Total Weight and by Estimated Natural Availability (ENA).

| Assemblage | rho | one-tailed significance |
|---|---|---|
| Le Moustier, H8 | 0.07 | $p > .25$ |
| Caminade Est, M3 | 0.26 | $p > .25$ |
| La-Côte, III | 0.14 | $p > .25$ |
| Caminade Est, G | 0.05 | $p > .25$ |
| Le Flageolet I, XI | 0.76 | $.01 > p > .005$ |
| Le Flageolet I, IX | 0.76 | $.01 > p > .005$ |

Table 4.15 Rank-order correlations for raw material types ranked by Total Weight and by Estimated Natural Availability (ENA), quartzite basalt omitted. Ranks were adjusted accordingly before the analysis was carried out.

| Assemblage | rho | one-tailed significance |
|---|---|---|
| Le Moustier, H8 | 0.60 | $.25 > p > .10$ |
| Caminade Est, M3 | 0.31 | $p > .25$ |
| La-Côte, III[1] | 0.14 | $p > .25$ |
| Caminade Est, G | 0.83 | $p = .05$ |
| Le Flageolet I, XI | 0.74 | $p = .025$ |
| Le Flageolet I, IX | 0.71 | $.05 > p > .025$ |

[1] Values for La-Côte, III are identical to those in Table 4.14 because the assemblage lacks quartzite and basalt.

# 5

# Assemblage Technological Composition

The optimal strategy for exploiting lithic raw materials in the Perigord during the Late Pleistocene was the one that achieved the most effective set of tools and weapons for the lowest cost. This strategy was the best possible fit between the needs of mobile foragers, the environmental state variables that constrain chipped stone technology and raw material use, and the behavioral variables that constrain raw material use. I do not presume to know how to determine what that optimal strategy was or whether it was ever used. However, to test the discontinuity hypothesis for RME, we only need to know how to evaluate the relative costs of different aspects of behavior. Efficiently managing the selection of raw materials is one way that can be achieved; efficiently consuming them is another.

Raw material consumption consists of turning raw materials into tools, using those tools, and repairing or renewing damaged ones. Getting from point A, a block of raw material, to point B, a tool, can be as simple as striking a few flakes from a cobble. However, was usually more complex; there were many points B for each point A in the Middle and Upper Paleolithic, and multiple pathways (methods) to each. The methods that achieved the lowest cost were those resulting in the highest number of useable blanks per unit of raw material, and using the highest proportion of blanks as tools. The most cost-effective strategies may not have been used, or may only have been applied to those raw materials that cost more to obtain or that permit the most efficient exploitation because of their higher level of fracture predictability. Thus, the

technological efficiency of an assemblage must be evaluated for each raw material type separately.

Here, I describe my efforts to evaluate technological efficiency with data on technological composition, measures of the intensity of use of blanks, and measures of core reduction intensity. Those efforts were not successful in every case, due to various factors that I discuss below. When the efficiency of a given manufacture method is not known, a close association between manufacture methods and highly predictable raw materials provides indirect evidence of technological organization. Technological efficiency can also be evaluated through an analysis of the partitioning of the manufacture process over space. All these ways of studying the relative technological efficiency of RME depend on the technological composition of each raw material type. Technological composition is the frequency distribution of artifacts within categories relating to chipped stone manufacture.

**Methods**

At the most basic level, all items belonging to the class "chipped stone artifact" fall into one of four broad categories: blank, chunk, flaked cobble, and raw or tested cobble (see Table 5.1). Blanks are flakes and blades, whether retouched or not. I also apply the term to fragments with enough bulb or ventral face remaining to establish they are broken blanks. The use of the term for retouched tools reflects the fact that an object that was initially "raw" was selected and retouched. A chunk is an object for which it cannot be determined whether there is a positive bulb of percussion or a ventral surface, which prevents being able to orient the object. Because chunks and raw/tested cobbles provide little information about manufacture methods or provisioning strategies, my analysis focuses on blanks and flaked cobbles. I described blanks using a

technological typology, and I described flaked cobbles, which I interpret as cores, using a set of descriptive variables and an experimental set of "core categories". For all artifacts, I recorded weight to the nearest .01 gram, presence/absence of retouch, and tool type, if retouched. Combining this information in various ways will allow me to address hypotheses concerning raw material provisioning and the conservation of raw material.

Blank typology

The typology is based on similar ones used by Chadelle (1983), Geneste (1985, 1988, 1990), Lucas (1995, 2000) and Turq (1992). I combined certain aspects of those typologies and added some new types. The first part of this blank typology is based on two dimensions: length/width ratio and the relative amount of dorsal cortex (or, cortex amount). I divide blanks into three general categories: blades are complete blanks whose length/width ratio is greater than 2.0; flakes are all other whole blanks; and fragments are blanks lacking either the proximal or distal extremity, or a portion of one or more sides, due to breakage. I applied the definition of blades strictly, using a ruler or calipers to make the distinction when it could not be determined by eye. Although a fragment could be either a flake or a blade by the strict definition, the object of this analysis is to infer core reduction methods, and therefore the important thing is the original dimensions of the blank before it was broken. When this could not be estimated, I recorded the blank as a fragment. An exception was made for blanks with a length:width ratio just under 2.0 that were missing one or both ends; these were recorded as blades.

The term "cortex" was applied to chalky cortex from chert nodules originating in limestone, as well as to non-chalky exterior surface that plainly preceded the human

modification of the artifact, such as river polish or mineral deposits. I made three distinctions based on Cortex Amount: 0 %, 1-49%, and 50-100%. Lacking any rapid means of measuring the cortex coverage on blanks, I made those distinctions qualitatively. Only blanks with no dorsal cortex anywhere except on the platform remnant were counted in the 0% category.

The combination of the six modes for these two dimensions (length:width ratio and cortex amount) creates nine types: 2a, 2b, 2c, 3a, 3b, 3c, 4a, 4b, and 4c (see Table 5.2). Most of the objects in each assemblage fall within one of these nine types.

The second part of the blank typology consists of categories whose relevance to manufacture methods is well established, but that are less systematically defined. These include Levallois flake (5a), Levallois blade (5b) Levallois point (5c), *éclat débordant* (5d), Kombewa flake (6), crested blank (7a), core rejuvenation tablet (7b), other rejuvenation blank (7c), and burin spall (7d). Except for 7c, these are all defined according to standard usage (e.g., Inizan *et al.* 1992). "Other rejuvenation blank" (7c) is defined as a blank that shows a portion of a striking platform along one edge or one side of its dorsal face, and part of a debitage surface along the other edge or side of the dorsal face. It is interpreted as a blank that was removed along the intersection between those two surfaces, presumably in order to rectify problems with the striking platform such as large spurs or hinges.

In addition to the 18 blank types, the technological typology also includes cobble/nodule (1a), prepared core (1b), reduced core (1c), and chunk (8). Type 1a is a cobble or nodule that lacks any reduction other than isolated flake scars, which were probably the result of testing for flaws. A prepared core is a core for which it can be deduced that little or no reduction has taken place other than the preparation of the

striking and debitage surfaces. A reduced core is one that shows evidence of blank production beyond initial decorticating and shaping.

I applied this typology to all blanks weighing ≥ 1 g, including material collected from screens (which was stored in bags labeled "*tamisage*"). Having done so for each assemblage, I then retrieved the cores (types 1b, 1c), and studied them with the core typology described below. I did not apply a separate typology to types 1a (nodules) or 8 (chunks) because I know of no useful way to describe those that would relate to the goals of this study. The codes for each type are for convenience only.

This technological typology helps to generate information about manufacture processes. Like other technological analysts (e.g., Bradley 1975, Chadelle 1983, Collins 1975, Geneste 1985, Lewarch and Bangs 1995), I assume that chipped stone manufacture is a linear process in general, although it can become non-linear in particular instances. Reduction always begins with a raw mass of material in some form, and proceeds to different sets of activities, which tend to follow one another sequentially. A raw block of material (nodule, cobble, or large flake) is first tested for macroflaws by the removal of one or two flakes, and then cortical flakes are removed while the striking platform is prepared. Cortical and semi-cortical flakes continue to be struck as platform preparation requires, and as irregularities are removed in order to shape the debitage surface. Once a striking surface/debitage surface pair has been created, the raw block of material has become a core. The products of these activities are cortical flakes, semi-cortical flakes, perhaps some chunks and very small flakes, and a core.

The next phase of manufacture involves removing blanks and maintaining core morphology. This may include many different actions. The initial blanks will generally have more cortex than later blanks, but the relationship between cortex coverage and

stage of reduction will depend more on changes in debitage surfaces than on the relative degree to which the core as a whole is reduced. If multiple debitage surfaces are used successively, then cortical and semi-cortical blanks may be produced even after many non-cortical ones have already been struck from the first debitage surface. Also included in the blank removal phase are platform rejuvenations, lateral and basal maintenance, and the preparation of additional striking platforms.

As blank production advances, the core shrinks, it loses cortex and the composition of the products gradually changes. Higher frequencies of cores (1c), cortical blanks (2a, 2b, 2c), crested flakes or blades (7a), core rejuvenations (7b, 7c) and chunks are most likely to signal the early phase of blank production/core maintenance. Relatively high frequencies of semi-cortical blanks (3a-3c), non-cortical blanks (4a-4c), Levallois blanks (5a-5d), and Kombewa flakes (6) are most likely to signal later stage blank production. However, the exact frequencies are unique for each episode of core reduction, and frequencies of any given product, such as cortical flakes, do not necessarily change continuously (for an example, see experimental data in Geneste, 1985).

As soon as blanks are struck, tools may be made. Tool manufacture, tool re-sharpening, and tool repair result in tools and small debris from retouch, such as burin spalls. Logically, this is the last stage of manufacture, but of course these actions could take place before a core has been completely reduced and before additional blank production. In my technological typology, only burin spalls (7d) furnish direct evidence of tool production, and they are very rare. The presence of retouched objects might result from either *in situ* tool production or from the import of tools. Other technological data may help to resolve that question.

*Derived variables* Based on the above variables, I derived five other variables: CTX (cortex amount), Object Type, Blank Type, WT_CLASS (weight class), and Retouch (presence/absence). Each of these variables was inferred from the data after the analysis was completed, so I refer to them as the "derived variables".

For the data that I recorded earliest (La-Côte III and part of Le Flageolet IX), CTX was not recorded separately. Luckily, I was able to infer that information from other data that were recorded. CTX is part of the definition of blank types 2a-4c: 2a, 2b and 2c were all counted as 0% cortex, 3a-3c as 1-49%, and 4a-4b as 50-100%. For the remaining blanks, I inferred the amount of cortex from other notes made during the analysis. For instance, I frequently recorded CTX in the "comments" section of the data entry form. For the remainder, an entry under "surface characteristics" indicates the presence of cortex, but not the amount. For the sake of simplicity, if the blank type was not one of those that is defined in part by cortex amount, and if an entry under surface characteristics indicated at least some cortex, I assumed CTX = 1-49%. This is a safe assumption because few Levallois flakes, Kombewa flakes, crested blades, core rejuvenations, or burin spalls have more than 50% dorsal cortex.

Object Type refers to whether the object is a core, flake, fragment, blade, or chunk. Blank Type is a typology of blanks, based on morphology. It has the following values: Ordinary flake (types 2a, 3a, and 4a), Ordinary blade (2c, 3c, 4c), Kombewa (6), Levallois (5a-5d), Crested blank (7a), Rejuvenation (7b, 7c), Burin spall (7d), and N/A ("not applicable"; applies to chunks, cores, and cobbles). CTX, Object Type and Blank Type apply only to blanks (types 2a to 7d in the technological typology). The WT_CLASS variable has five classes: $< 1.0$ g, 1.0– 4.9 g, 5.0 – 15.0 g, 15.0-29.9 g, and $\geq 30.0$ g. This way of partitioning the weight values yielded results similar or identical to

other ways that I experimented with. The variable Retouch is recorded as "retouched" for all the formal tools, and "unretouched" for all objects lacking retouch. Retouch is recorded for all objects, since even flaked cobbles and chunks were sometimes used to make tools.

Core descriptive categories

A core's flake scars and morphology provide a wealth of information about the methods used to strike blanks, about how striking platforms and debitage surfaces were maintained, and possible reasons why reduction ceased when it did (Inizan *et al.* 1992, Pelegrin 1986). I studied a sample of cores from five of the six assemblages in detail as part of my study of technological organization.

I studied all the cores from Caminade Est level M3, and most of those from Le Moustier, H8. I analyzed large samples of cores from levels XI and IX of Le Flageolet I, and level G of Caminade Est. However, when analyzing cores, I did not have access to La-Côte. Fortunately, Pelegrin (1986) performed a detailed description and interpretation of the cores in that assemblage; I relied upon those descriptions when attempting to infer manufacture processes. Nevertheless, I lack quantitative data on core attributes for the La-Côte cores. In the following discussion, references to cores in level III of La-Côte are based on Pelegrin's (1986) research. Table 5.3 shows the number of cores analyzed in each assemblage and compares those to the number of cores identified during the raw material/technological analysis that I had done previously.

The core analysis consisted of examining each core carefully, noting its features, and attempting to infer the organization of reduction as evidenced by the existing flake scars and morphology. I found there were groups of cores that were similar in morphology, intensity of reduction, and manufacture methods, which I refer to as "core

categories" (Table 5.4). These reveal the nature of the manufacture processes carried out, which can be compared to the results of my flake analysis. I view this as a first attempt to understand variation in core morphologies, and to sort out the causally relevant from the spurious variation. These core categories are an interpretive outcome of my analysis, rather than an *a priori* classification. Table 5.5 shows the observed frequencies and percentages of cores in each category, by assemblage.

The simplest core categories are 1A, simple blade core, and 1B, simple flake core (for examples, see Figure A.22 no. 2, A.40, A.41, and A.56 no. 2, in Appendix A). These are cores made on nodules or cobbles by the removal of one or two large cortical flakes to form a striking platform, and the removal of a small number of cortical and semi-cortical flakes. They have a single striking platform, are totally lacking in crests and debitage surface maintenance, and are minimally exploited.

The remaining categories are grouped according to the main blank type inferred from the flake scars on the cores' debitage surface: types 2A-11B are flake cores, and 12A-15 are blade cores. Within each group, the numbering of the categories represents a general progression from simple to more complex. Types 2A-2C are prepared flake cores. Type 2A (Figure A.23) has one striking platform, 2B (Figure A.1, A.14 no. 1) has 2 striking platforms oriented at right angles, and 2C (Figure A.42 no. 1) has two striking platforms, at opposite ends of the core and oriented at 180°. These three categories differ from 1B in having a more developed debitage, and in evidencing greater effort in the preparation of striking platforms. Unlike 1B, categories 2A-2C show the removal of some non-cortical blanks. However, they also lack crests and maintenance.

Core category 3, cuboid flake core, consists of a roughly cube-shaped block, generally very small (see Figure A.42, no. 2). Each of the six or so faces is generally flat

and created by the removal of only one or two large flakes. However, most of those faces were created prior to, and perhaps long prior to, the creation of the final debitage surface(s) and striking platform(s). There are usually only one or two striking platforms, and these were used to strike wide flakes terminating at the extreme end of the debitage surface. Since each flake scar intersects the surface opposite its own striking platform at a roughly 90° angle, striking platforms were maintained automatically. In addition, each debitage surface can also be used as a striking platform. There are at least two plausible interpretations of category 3: as cores specially prepared to yield small squarish flakes, or as exhausted cores that had initially been used with some other method.

Category 4A, globular core with multiple striking surfaces (striking platforms or crests), designates cores with a roughly spherical or globular shape and more than one striking surface (see Figure A.24). The striking surfaces show a minimum of investment, and they create debitage surfaces that intersect and overlap each other in complex ways. If there is any method in these cores, it is the opportunistic exploitation of available surfaces as striking surfaces, and of the volume of the core for blank production. Flake scars are much more common than blade scars in these cores. Category 4B is very similar, except that the shape of the object is blocky rather than globular, and there are only striking platforms, no crests. Like 4A, cores of category 4B lack any explicit organization and are probably the result of opportunistic exploitation of the available surfaces.

In a tablet-shaped flake core (category 5), one narrow edge of the "tablet" is squared off by the removal of short flakes. This surface is then used to strike much larger flakes from the wide face of the tablet (the same face that was used as a striking

platform in removing the small flakes from the edge). It is not clear whether both faces (narrow and wide) are debitage surfaces, or whether the narrow one is a striking platform and only the wide face is a debitage surface. I have not found any published examples of this core type, but there is at least one example in four of the assemblages.

Category 6, "Kombewa flake core" (Figure A.16), designates a blank with a prominent bulb, which was exploited for the production of a ventrally-struck flake (Tixier and Turq 1999). That flake, called the Kombewa flake, is distinguished by its possession of two bulbs of percussion and two ventral faces: one bulb results from the striking of the Kombewa flake, and the other is the bulb and ventral face of the blank that was used as a core. Turq (1992) has documented this technique in Quina Mousterian assemblages from the Lot region.

Category 7 is for cores that have either a tabular or a plano-convex shape; the debitage surface is on one narrow edge, instead of on one of the broad faces of the block (see Figure A.43, no. 3). When the block is plano-convex, the debitage surface is on a narrow face on a thick part of the block, between the two broad faces. These blocks seem to have functioned solely as cores for the removal of small, squarish or round flakes.

Category 8, prepared flake core on truncation, is represented by only two examples, both from Le Moustier, H8. These are thick flakes, the proximal end of which were truncated by steep flakes and then used as striking platforms.

Category 9, wedge-shaped core with striking platform and crest, consists of a small, thick object in which two wide faces converge at a narrow edge, which might be called a "crest" because of its shape, but is not necessarily a debitage crest as defined above. A third wide face, formed by the removal of one or two wide flakes, functioned as

the striking platform. The two wide faces were created in one of two ways. The striking of wide, thick flakes from the striking platform may have created them. In this case, the convexity left by these flake scars helped to create the narrow "crest". Alternatively, those faces may have been formed by the striking of flakes off the crest, to both sides; in that case, it is a true debitage crest. In both cases, the crest may have been created in order to strike a crested blank, or it may simply be the inevitable by-product of the striking of thick, short flakes on two adjacent surfaces. There is a rough similarity to the carinated or the muzzled endscraper. Typologically, however, these do not make good endscrapers because there are rarely any bladelet scars visible, and because the edge is not regular.

Category 10 has several sub-categories: 10A, disk core with bifacial debitage surface; 10B, plano/convex with one debitage surface on the convex face; 10D, plano/convex with one debitage surface on the plane face; and 10E, plano/convex with one debitage surface, made on a flake. Although I originally saw a similarity in these different sub-categories and assigned them all to "10" (they all involve centripetal debitage), I eventually came to realize that they do not all represent the same kind of manufacture method, despite the similarity in their shapes. Category 10A (Figures A.15, A.55 no. 2) designates disk shaped cores with two convex faces, and a crest forming the perimeter. The crest was used to strike flakes from both debitage surfaces. In some cases, one debitage surface was worked before turning the core around and working the other debitage surface, while in other cases the debitage alternated between the two faces. No debitage surface maintenance or striking surface rejuvenation was required, as both resulted automatically from normal debitage.

The plano/convex core categories (10B, 10D, 10E) have one flat (plane) face and one convex face. In 10B, the plane face is a striking platform that was used to strike blanks from the convex face. Apparently, this was accomplished without rejuvenation or maintenance; the stability of the convex shape of the debitage surface depended on the thickness of the flakes being struck. Some of these cores (e.g., Le Flageolet I, XI, C9-3125) were made on frost spalled flakes. In 10D, it is the plane face that was used as a debitage surface. While 10A, 10B, and 10D were made on cobbles or nodules, 10E was made on a thick flake. The plane face is the flake's dorsal surface, used as a striking platform to strike flakes centripetally from the ventral face of the core flake.

I observed two kinds of Levallois cores, both of which occurred only in Le Moustier, H8: categories 11A and 11B. The difference between the two is that only one face was used in 11A to strike the Levallois flake(s), while in 11B both faces were used alternately to strike Levallois flakes. Two of the 11B cores may not be Levallois by the strict definition (for an example, see Figure A.2). They have a discoidal shape and show the removal of a large flake from each of the two convex surfaces, but I was unable to determine whether the surface preparation that preceded the removal of those large flakes was centripetal. In any case, the method of flaking is similar or identical to the Levallois method.

Unlike all of the above, cores assigned to categories 12A-15 were mainly or exclusively used to strike blades. The essential factor in producing blades rather than flakes is the creation of a raised keel running longitudinally along the debitage surface of the core. There are many methods by which this can be accomplished. The simplest is represented by categories 12A-12B, blade cores without maintenance and with one (12A) or two striking platforms (12B). These are the blade analogue of category 1B.

They show a minimum of investment in the creation of the striking platform(s), a lack of debitage surface maintenance, and little debitage. The ability to strike blades from these cores apparently depended on the small radius of curvature of the nodules from which they were made. Striking one or more decortication flakes produced the necessary raised edges to serve as a keel for striking blades (Figures A.44, A.58).

A second method of producing blades involved creating a narrow edge between two wide, flat surfaces. This is represented by categories 13A and 13B, blade cores with maintenance and a narrow debitage surface (Figures A.22 no. 1, A.25, A.45, A.46, A.53, A.54, A.56, A.61 no. 9). Each of the two wide, flat surfaces is generally created by the removal of one or more large flakes, which were struck from one or sometimes two directions. I refer to these surfaces as lateral maintenance, because they each form one face of a relatively thin object; it is the long, narrow edge of this object that becomes the debitage surface, and the narrowness that guides the removal of blades. The debitage surface is only one or two blade scars wide. In some cases (e.g., D11.2166, Figure A.46 no.1), there are traces of debitage crest preparation on one or both surfaces adjacent to the debitage surface, with an axis of flaking perpendicular to the axis of the debitage surface.

One advantage to this method of blade production is that it potentially maximizes the amount of core volume that can be exploited. A second advantage is that little need be done to maintain the necessary morphology once the core is initially shaped, other than the removal of spurs and possibly some striking platform rejuvenation. Of course, the flakes that were struck to form the wide faces to either side of the blade debitage surface may themselves have been used as tools. However, those faces clearly define the width of the blade debitage surface, and this is what makes these cores distinctive.

The creation of those lateral faces also appears to be entirely anterior to the striking of blades from the debitage surface in every case. Figure A.60 no. 10 shows an example of a blade struck from this type of core.

Core categories 14A and 14B, blade cores with maintenance and a wide debitage surface (Figures A.17, A.26, A.27, A.28, A.59 no. 2), show a third blade production method, involving the creation of a single, wide face adjacent to the blade debitage surface, by lateral maintenance. This usually involved striking one or two large, wide flakes from some direction other than the direction of flaking on the debitage surface. The intersection between the blade debitage surface and this laterally maintained surface forms an angle of 90° or less, which helped to set up some of the blades. Unlike the 13A-13B cores, however, the debitage surface is relatively wide (more than two flake scars wide). The creation of the necessary raised surfaces to serve as potential blades presumably began with at the side adjacent to the laterally maintained surface. The removal of the first blade created another arris, which, when exploited, created another, and so on, until blades had been struck all the way around a wide debitage surface, which is convex in cross-section.

The last defined core category is 15: pyramidal blade core with one striking platform. There are only two examples in the analyzed sample, both from Caminade Est, G. The debitage was unidirectional, the blades were struck from nearly the entire perimeter of the striking platform, and the blade scars converge at a point at the distal end of the core. There was no lateral maintenance. Although debitage crests may have been used, neither of the category 15 cores I analyzed showed traces of crest preparation.

Categories 99A and 99B are cores for which I was unable to arrive at a clear interpretation of the methods used or the sequence of manufacture. Cores in category 99A (e.g., Figures A.47, A.48) are unidentified/indeterminate because of their complexity, and those in category 99B, because they were fragmentary.

Core variables: definitions

In addition to raw material, core category, and weight, I recorded seven other variables for each core: Origin, Blank Type, Debitage Surface Orientation, Debitage Surface Maintenance, Striking Surface Type, Cortex Amount, and Number of Striking Surfaces. Table 5.6 contains the possible values of each variable. Before defining those variables, I first define three additional terms on which a clear understanding of the others depends: blank, striking surface, and debitage surface.

Stone workers would have had a population of blanks from which to choose, whether they used them raw or retouched them. Differences between the retouched and unretouched blanks will be important to several aspects of my examination. In principle, any kind of blank could be retouched, and in the assemblages I examined, retouched objects include flakes, blades, and fragments of various sizes, with varying amounts of dorsal cortex, as well as flaked cobbles.

A striking surface is a relatively flat surface that intersects the proximal end of a flake scar on a second surface. It is interpreted as the surface that was struck repeatedly to create blanks on the second surface. A striking surface may be cortex, formed by the remnant of previous flake scars, or intentionally created by intentional removals. A striking *platform* is a relatively flat striking surface from which blanks have been struck at a relatively obtuse angle, between about 60° and 90° (Inizan *et al.* 1992). A striking *crest* is an intersection between the proximal edges of two debitage surfaces.

The striking surface in such a case is simply the edge of the opposing debitage surface. The interface between the two debitage surfaces is usually acute, forming an angle less than 60°. Cores that were reduced entirely using crests tend to be disc shaped.

A debitage surface is a surface from which flakes have been removed by the application of force to the edge of an adjacent striking surface. The presence of small, hinge-terminated flake scars allows discrimination between striking and debitage surfaces. Those small hinges result from platform preparation, failed attempts at flake removal, or the formation of multiple flakes from a single blow. Debitage surfaces usually have many more flake scars than striking surfaces have. The flake scars on a debitage surface overlap, resulting in a complex surface that is unlike the simpler, smoother striking surface. In addition, many debitage surfaces are adjacent to surfaces created by the removal of wide flakes or crests, which served to guide the removal of flakes and/or blades.

The above three terms enter into my definitions of the seven core descriptive variables (Table 5.6). Origin refers to the nature of the object that was used to create a core. Blank Type is the predominant kind of blanks struck from a core, as inferred from the negatives on the debitage surface(s). Cores having a roughly equal number of blade and flake negatives were recorded as "mixed". Striking Surface Type refers to whether the core possesses a striking platform, a crest, or both. Debitage Surface Orientation is the angular orientation of flake scars to one another on the debitage surface. Cores in which debitage took place from a crest usually have centripetal debitage surfaces; flakes were struck from both faces of the core, around the core's perimeter. Obviously, Levallois and discoidal cores often bear centripetal debitage surfaces as well.

Debitage Surface Maintenance is flaking that is done on surface adjacent to the debitage surface in order to create a morphology facilitating the removal of blanks. *Lateral maintenance* is flaking that is done to shape the sides of the core adjacent to a debitage surface. For example, one technique of blade reduction involves creating a long, narrow debitage surface by removing a wide flake on either side of the debitage surface. Those removals create a keel that guides the removal of blades. *Basal maintenance* is flaking that is done at the distal end of a debitage surface (the base of the core). Basal maintenance creates a morphology that facilitates the removal of products of a certain length, and helps avoid overpassed flakes and blades with a high radius of curvature, which are commonly produced by freehand percussion (Gallet 1998). Both lateral and basal maintenance can be recognized by the small number of flakes used to create the flat, maintained surfaces and by the fact that these surfaces were intersected by subsequent reduction on the debitage surface.

My term Debitage Crest (as opposed to striking surface crest) is what most call simply "crest". I follow the definition of (Inizan *et al.* 1992:84):

> A term which applies to the shaping or re-shaping of a core, for the debitage of blades or bladelets. This shaping is achieved by (usually bifacial) removals, creating a ridge which consists of two series of negative bulbs. This ridge will guide the debitage of the first blade, the crested blade. This will necessarily have a triangular cross-section, the removed line of the crest making up the two sides of its upper face.

As these authors also pointed out, cresting is only one of many ways to achieve the keel necessary for blade production. Others include lateral maintenance, the use of a naturally acute surface on the nodule, and the intersection of flake scars from previous core shaping removals.

Different combinations of the core attributes I recorded should reflect differences in manufacture methods. The choice of manufacture methods for each block of raw material may reflect part of a strategy for minimizing manufacture costs and/or maximizing the effectiveness of the blanks produced.

The remaining two core variables relate to core reduction intensity. The Number of Striking Surfaces is self-explanatory, but recording it sometimes involved a measure of subjectivity because the evidence remaining on cores is often obscured in part or in whole. Amount of Cortex is simply the relative amount of natural exterior surface remaining on the nodule or cobble, or on the blank if the core was made on a blank. In both cases, it is relative to the entire surface of the object. Core reduction intensity is the relative degree to which the core was exploited. A lightly exploited core has only a few removals, and those yielded partially cortical flakes or blades. An exhausted core has been used to the point where no further reduction can take place, either because it is too small or because the morphology has become unusable, and rejuvenation would remove so much material as to leave nothing left for additional reduction. Lightly reduced cores have only one striking surface, but cores that have been subjected to more intensive reduction might have remnants of multiple striking surfaces. The gradual removal of the object's cortex is a natural consequence of core reduction; lower amounts of cortex remaining on a core should result from more intense reduction.

Protocol

I analyzed the material one object at a time, and examined all the artifacts in a container (box, bag, or tray) before moving on to the next container. I identified the raw material (Table 4.1) of each object and weighed it on a digital balance to a precision of .01 grams. All objects weighing ≥ 1.0 g. were then submitted to the following analysis.

I first assigned the object a technological type from Table 5.2. Then I described the object according to a list of additional variables, depending on what sort of object it was. For flakes, fragments and blades, I described the amount of cortex (50-100%, 1-49%, or 0%) and the surface characteristics of the cortex (Table 4.3). For fragments, I described the location (proximal, distal, lateral, proximal and distal, other combination) and type of fragmentation (snap, hinge, hinge with languette, retouch, thermal fracture). For flakes, fragments, and blades still in possession of their proximal ends, I described the type of butt. I assigned each retouched object to a type from either Bordes' (1961) Lower/Middle Paleolithic type list or the Upper Paleolithic type list of Sonneville-Bordes and Perrot (1953-1956). I used the former type list for Le Moustier H8 and Caminade Est M3, and the latter for La-Côte III, Caminade Est G, and Le Flageolet I, IX and XI. I also noted the relative degree of patina formation (none, light, medium, heavy, desilicified). Finally, if there were any other interesting features of the object, I noted these under "comments". Although I did not make use of some of this information (location of fracture, type of fracture, butt type, tool type, or patina), I provide it, along with all other information I recorded, in the databases on the attached CD-ROM in case it would be useful to other researchers.

**Results**

All the data displays in this section are based on that fraction of each assemblage weighing ≥ 1 g. (see Table 5.7). The < 1 g. fraction is problematic, because of the high proportion of unidentifiable objects and the possibility of unequal collection of the small objects in at least some assemblages. The number of objects in the small fraction varies greatly, from 25 (Le Moustier, H8) to 5917 (Le Flageolet I, XI), but the total weight of that fraction only ranges from 13 g. (Le Moustier, H8) to 1,092 g

(Caminade Est, G). Therefore, the < 1 g. fraction constitutes only a small proportion of the mass of each assemblage, and is made up mostly of miniscule chips and fragments. Furthermore, the small fraction in some assemblages may not be a representative sample. The near absence of small remains in the Mousterian levels of Caminade Est is unexplained, especially given the large amount of small debris in the overlying Aurignacian levels. The collection I analyzed from Le Moustier was not collected with screens. In addition, I did not record sufficiently detailed information on raw material type in a large fraction of the small (< 1 g.) material in Le Flageolet I, level IX, because I weighed that material in lots by raw material type. Moreover, I found that the frequencies of chunks and unidentified raw material increased dramatically in objects weighing less than 1.2-1.0 grams. For all these reasons, I exclude the < 1.0 gram fraction from all the following analyses.

The charts and tables presented here are based on counts (the number of objects) rather than weight sums, with the exception of those in the section entitled "Blank portability". I present much of the data in the form of tables showing the cross-tabulation of frequencies and percentages for a given pair of variables. In most of these tables, I indicate both the "$G^2$" (likelihood ratio chi-square) statistics[1] for the test of association between the two variables, and the cell values that yielded significant standardized deviates. Cell values yielding significant positive standardized deviates are displayed in boldface, while those yielding significant negative standardized deviates are underlined.

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[1] The likelihood ratio statistic is based on maximum likelihood estimates, which is closely related to odds ratios. The underlying concept has to do with the odds that a given object will fall into a given cell, given the row and column totals.

Partitioning of the manufacture process

Because many Paleolithic assemblages show evidence that core preparation, core shaping and reduction, and tool making were done in different places depending on raw material source distance (see Chapter 2), we should expect to see evidence of the same phenomenon in the six assemblages studied here. What remains to be seen is whether the partitioning of the manufacture process was done differently at different times or by different groups of people. I am especially interested in knowing whether the strength of the association between manufacture partitioning and source distance varies between the assemblages, because this relates to technological efficiency.

The graphs in Figure 5.1 show the distribution of technological types in each assemblage. The frequencies of these types show significant variation among the assemblages. Below, I discuss the significance of this variation for manufacture processes. Figure 5.2 depicts the relative frequencies of blank types in each assemblage.

Tables 5.8-5.13 show the breakdown of technological types by raw material type in each assemblage, along with the $G^2$ statistics. The percentages shown in these tables are calculated based on the row totals. Figures associated with a significant, positive standardized deviate that have an expected value of $\geq 5$ are shown in boldface. Figures associated with a significant, negative standardized deviate that have an expected value of $\geq 5$ are underlined.

*Le Moustier, H8*

Several statistically significant standardized deviates resulted from the $G^2$ analysis, but almost all pertained to cells with expected values of one or less. As Table 5.8 shows, only one significant standardized deviate occurred in a cell with an expected

value of ≥ 5; it reveals a significantly high frequency of non-cortical flakes in unidentified raw material. This may signal an increased focus on later stage blank production, but since unidentified raw material probably combines many different kinds of material of unknown source distances, this information is not helpful. For this reason I generally ignore the unidentified raw material in each assemblage.

The technological composition of black Senonian chert is remarkably similar to that of beige Senonian. Table 5.8 strongly suggests that both were imported to the site as raw or tested cobbles (1a) from the nearby stream bed, and as partially prepared cores (1b), all of which were subsequently reduced. The absence of core rejuvenations (7b, 7c) in beige Senonian is unexpected, but the presence of cores (1c) and abundant cortical and semi-cortical blanks (2a-3c) clearly points to on-site core reduction. The other raw materials (excluding unidentified, which is of course not a lithological type) appear to have been brought to the site in the form of tools (Bergeracois) or blanks (chalcedony/millstone, Jurassic chert, basalt and quartzite). It is striking, with so much quartzite and basalt in the nearby streambed, that so little of it ended up in the assemblage.

*Caminade Est, level M3*

According to the $G^2$ result, level M3 of Caminade Est has statistically significant differences between RM Types in technological composition (see Table 5.9). However, although there were several significant standardized deviates, none occurred in a cell with an expected value of five or greater. The apparent differences between beige and black Senonian may suggest a difference in manufacture phases. Yet, despite the absence of beige Senonian cores, there are six cortical blanks and one core rejuvenation of this material. This suggests that the 14 objects of beige Senonian in the

assemblage may have been struck at Caminade Est from a core that was not recovered, possibly because it was carried away by people or by water (see Chapter 3). Black Senonian chert was reduced *in situ* from nodules or cobbles imported to the site, two of which were recovered as cores.

The single object listed for Jurassic chert under type 1c is not a core, but an elaborate refit, done by C. Normand and described in detail by Sonneville-Bordes (1990). It consists of several dozen blanks. The core's absence left a void in the interior of the refit (Figure A.18), which Sonneville-Bordes referred to as a "phantom core". Normally, this object would not have been counted as a core in my analysis and in Table 5.9. However, analyzing the flakes individually would have required disassembling the refit, thereby destroying something of scientific value. Ignoring the refit would have resulted in a loss of information about reduction processes in this assemblage. Therefore, I counted the entire refit as a single core. The refit flakes represent "a nodule of chert with an ancient yellow patina, with freeze-thaw damage in the interior, which was reduced *in situ*," (Sonneville-Bordes 1990:62, my translation). There were 28 "fragments" of this peculiar raw material and 57 "small retouch flakes that were found in the screen." The excavators found most of these within a very restricted area in the interior of a single meter-square, and within a vertical depth of 12 cm. The refit consists of a few dozen of the flakes and fragments, including three small blades. According to P. Y. Demars (cited by Sonneville-Bordes 1990), the block was a stream-rolled, tabular nodule of brown Jurassic chert. This supports a statement I made in Chapter 4, that the Dordogne River could have transported cobbles of Jurassic chert to locations near Caminade Est, a distance of at least 17 km.

Porcelainite is similar in technological composition to beige Senonian chert. It lacks cores and chunks, consisting entirely of blanks with varying amounts of cortex, two of which are retouched. There is a single rejuvenation flake (type 7c) made of each of these raw material types. Like beige Senonian, the porcelainite artifacts may have been imported as blanks, or they may have been struck from one or more cores that were subsequently exported.

The small sample size of Bergeracois, chalcedony/millstone, jasper, and quartzite, and the fact they are mostly represented by blanks, suggests these raw materials were all imported as blanks.

*La-Côte, level III*

Table 5.10 lists the technological composition of the Châtelperronian assemblage from La-Côte, broken down by raw material type. Judging by the presence of cores, the variety of debitage products, and the presence of tools (discussed below), most of the identifiable raw materials in this assemblage (black and beige Senonian, Bergeracois, and silicified wood) were clearly imported as blocks. Those were subsequently reduced, and tools were made on the products.

As with Caminade Est level M3, there is also an apparent difference between the black and beige varieties of Senonian chert. Both appear to have been brought to the site as nodules or cores, which were subsequently reduced *in situ* and discarded at the site. However, in beige Senonian chert, the relatively high frequencies of cortical blanks (types 2a and 2c) and the high number of chunks (type 8) suggests more late-stage blank production and less early-stage blank production, compared to black Senonian chert. In addition, beige Senonian has higher frequencies of flakes of all cortex amounts (2a, 3a, and 3c) and lower frequencies of blades (2c, 3c, 4c) than black Senonian.

Compared to both black and beige Senonian chert, Bergeracois chert appears to show increased core preparation and early-stage blank production. This pattern may result from a relative deficit in non-cortical blanks of Bergeracois due to the export of some of the blanks struck from the imported core(s). However, the small cell values warn against attaching much archaeological significance to the data on Bergeracois in this assemblage.

The 16 flakes of jasper could either have been imported as-is, or struck from a "walking core". A walking core is one that was prepared elsewhere and carried to the site, used to produce a few blanks, and subsequently exported from the site. While the core itself passed through the site temporarily, the blanks and chunks struck from it remained. Pink speckled chert was almost certainly imported as blanks, none of which were transformed into tools, unless the tools were exported.

*Caminade Est, level G*

Table 5.11 suggests that the raw materials differ in their technological composition, and that these differences may result in part from differences in the spatial partitioning of the manufacture process. The presence of cores and the relatively high frequencies of cortical blanks, non-cortical blanks, and chunks provide unambiguous evidence for the import and *in situ* reduction of several raw material types: black Senonian, beige Senonian, indeterminate Senonian, chalcedony/millstone, jasper, and porcelainite. However, there are subtle differences in technological composition between these materials, which suggest possible differences in manufacture phases or modes of transport.

For example, there are significant, positive standardized deviates under technological type 1c (cores) for both black Senonian and jasper. For black Senonian,

the large number of cores and the presence of all blank types and chunks provides unequivocal support for the import of nodules or cores and their reduction at the site, involving all phases of manufacture. In contrast, the high number of cores in jasper is anomalous, because that raw material type has fewer than expected numbers of cortical flakes (2a; observed = 2, expected = 9.3, std. dev. = -2.4) and cortical fragments (2b; observed = 0, expected = 4.1, std. dev. = -2.0). These two types would be expected in relatively high amounts if debitage was carried out at the rockshelter. Semi-cortical blanks also occur in small amounts. In contrast, jasper has a significantly high frequency of non-cortical flakes (4a). Other jasper artifacts include some chunks (8), a crested blade (7a), a core tablet (7b), and one "other rejuvenation" (7c). This evidence is consistent with a scenario in which jasper cores were decorticated somewhere else before being brought to Caminade. That hypothesis could also account for the technological composition of porcelainite, which is similar to that of jasper except for a lower percentage of cores.

The Bergeracois artifacts from level G of Caminade Est seem to have been imported as blanks, struck from a walking core, or both. The relatively high frequency of all types of blades (cortical, semi-cortical, and non-cortical) may result from a focus on blades rather than flakes during manufacture, as I discuss below.

Chalcedony/millstone presents another anomaly in that, despite the occurrence of two cores, there are very few blanks (only 14). This could mean that the blanks that were struck from these two cores were then exported. Alternatively, it could mean that the imported cores were not reduced very much at this site. A close examination of the cores made of chalcedony/millstone could resolve this question.

Fumelois consists only of 9 blanks, one of which is retouched. This suggests the importation of blanks and tools only, a plausible hypothesis given the estimated minimum source distance of 39 km.

Finally, the granular rocks (quartzite and basalt) consist almost entirely of chunks, with one cortical flake (2a) of quartzite. These chunks may be the by-products of the use of quartzite and basalt cobbles as hammerstones, which were discarded away from the site (or not collected by the excavators). It is possible that these raw materials were imported in the form of walking cores, but there are no tools made of quartzite or basalt. Whatever the manufacture phases represented by these two raw materials, they show a very different use from all varieties of chert.

*Le Flageolet I, level XI*

Table 5.12 shows the technological composition of each raw material in this Aurignacian assemblage. One of the clearest differences is in the presence or absence of technological types 1a-1c (cobbles, unworked cores, and worked cores): Senonian chert, quartzite, and basalt all have them, and the other raw materials all lack them. This is strong evidence that nodules or cobbles of Senonian chert, quartzite, and basalt were imported to the site before being reduced. For Senonian, this inference is strengthened by the presence of almost all technological types. It is also strengthened by the frequencies of cortical blanks (2a-2c) in black Senonian, beige Senonian, and intermediate Senonian, which tend to be close to the overall frequencies in the assemblage. The other chert types have lower frequencies of cortical blanks. For example, in Bergeracois, the standardized deviates for 2a, 2b, and 2c are –2.14, -1.16, and –1.22, respectively.

For the granular rocks, *in situ* reduction is not indicated. Although there are raw or tested cobbles and prepared cores of quartzite and basalt, neither material is represented by many blanks; both consist almost entirely of chunks. In addition, there are no tools in this assemblage made of quartzite or basalt. This is not the pattern one would expect if these raw materials were used to manufacture tools, even if those tools were subsequently exported. It is more likely that these materials were used as hammerstones rather than cores. Judging by the prominence of bulbs, presence of bruising on striking surfaces and crushing on flake butts, it appears that most of the chert in this assemblage was reduced using hard hammer percussion, perhaps with basalt and quartzite cobbles. However, I lack the data that would permit a definitive interpretation of the function of the granular rocks.

The remaining chert types fall into two groups. Bergeracois, chalcedony/millstone and jasper are all present in frequencies of 14 or greater, are represented by at least 6 technological types, and have some blanks belonging to the cortical (2a-2c), semi-cortical (3a-3c), and non-cortical (4a-4c) groups. As I discuss below, Bergeracois and jasper have significantly high retouch frequencies, while chalcedony/millstone has only one tool. These raw materials were probably imported in the form of flakes, retouched or not. However, the possibility of walking cores cannot be excluded for Bergeracois and chalcedony/millstone, since they have chunks, crested blanks, and core rejuvenation blanks, all of which signal core maintenance activities.

There are 12 or fewer objects in each of the remaining RM types: Gavaudun, Mussidan, Jurassic, and porcelainite. Each is represented by three or fewer technological types and lacks objects with cortex. It seems safe to infer that these raw materials were imported in the form of blanks, some of which may have been retouched,

and that they were not reduced on site. The possibility that the technological composition of these three raw materials is spurious because of their small sample sizes is lessened by the pattern of standardized deviates, which automatically take sample sizes into consideration.

In sum, the raw material types in level XI fall into three or four groups. The first group, represented by black, beige, and indeterminate Senonian chert, was clearly imported to Le Flageolet in the form of either nodules, cobbles, or prepared cores, on which all phases of manufacture were subsequently carried out including tool production. Quartzite and basalt were also locally obtained as nodules, but were probably used as hammerstones instead of cores. Bergeracois and chalcedony/millstone were probably imported as blanks and tools, but may have been struck from walking cores, which were then carried elsewhere. The few objects of jasper, Gavaudun, Mussidan, Jurassic, and porcelainite were imported as unretouched and/or retouched blanks, with no reduction occurring on-site.

*Le Flageolet I, level IX*

Table 5.13 clearly shows that all varieties of Senonian were imported as cobbles, prepared cores, and possibly worked cores, and that all phases of reduction including tool production were done on-site during the time that level IX was deposited.

The technological composition of Bergeracois shows broad similarities to that of black Senonian and beige Senonian. This, and the presence of four Bergeracois cores, shows that it was also imported in the form of prepared cores, with reduction occurring on-site. However, non-cortical fragments (4b; observed = 44; expected = 26.9; std. dev. = 3.3) and non-cortical blades (4c; observed = 39; expected = 22.6; std. dev. = 3.5) have higher than expected frequencies. This suggests either that the imported Bergeracois

cores had already been shorn of much of their cortex and worked, or that cores were made on thick flakes rather than raw nodules. Because Bergeracois often occurs naturally in the form of boulders, it is reasonable to speculate that very large flakes struck from boulders, rather than small nodules, were used as cores (Geneste, pers. comm.). If so, then fewer cortical and semi-cortical flakes would result from the reduction of Bergeracois than from the reduction of cherts imported as raw nodules. Unfortunately, I did not analyze the four Bergeracois cores from this assemblage in detail, so this hypothesis cannot be tested without additional analysis.

The granular rocks (quartzite and basalt) are more difficult to interpret. Each is represented by at least three kinds of blanks, including cortical, semi-cortical, and non-cortical kinds, and there is one tool made of each. Perhaps the two raw cobbles of quartzite and the one cobble of basalt were used as hammerstones, while blanks and tools of each raw material were imported for use as tools.

Based on the data in Table 5.13, it appears that chalcedony/millstone and porcelainite, like Senonian and Bergeracois, were imported in the form of nodules or cores, and that all phases of reduction were carried out. However, chalcedony/millstone and porcelainite were imported to level IX of Le Flageolet I in much smaller amounts than Senonian and Bergeracois.

Jasper, Fumelois, Gavaudun, and Jurassic lack cobbles, cores, and chunks. These materials all occur in frequencies of eight or less. All have at least one retouched blank. If a random sample of technological products had been imported, then the most probable type of blank would be cortical, semi-cortical, or non-cortical flakes (2a, 3a, 4a), based on likelihood ratios. Instead, the blanks of these raw materials mostly consist of

fragments and blades, including one core reduction tablet (Table 5.13). Thus, these four raw materials were clearly imported in the form of blanks, retouched or not.

*Summary*

Table 5.14 shows a summary of the above interpretations concerning manufacture location and mode of transport. Each column in the table represents the interpretation of transport primarily in the form listed in the column heading (cobbles or nodules, cores, walking cores, and blanks or tools), with all subsequent reduction being done on that kind of object.

Manufacture methods

To infer the manufacture methods (i.e., methods of blank production) in each assemblage, I studied the frequencies of technological types, the frequencies of blank types, and descriptions of cores.

*Le Moustier, H8.*

Figure 5.1 shows the percentages of each technological type among the 1074 objects weighing ≥ 1 g (this excludes only 24 objects). Most of the assemblage consists of cortical, partially-cortical, and non-cortical flakes (2a, 3a, and 4a, respectively). The dominance of flakes over fragments and blades at each level of dorsal cortex is very clear. Figure 5.2 shows that the 1022 blanks are dominated by ordinary flakes.

In addition to eighteen Levallois flakes, one Levallois blade, and one Levallois point, there are two other kinds of flakes in Le Moustier, H8 that suggest Levallois was an important core reduction method. There are 64 *éclats débordants* (which are grouped with Levallois flakes in Figure 5.2), and the similarity among these is remarkable. The shape is roughly that of an isosceles triangle, with the flaking axis offset by 20°-30° from the axis of symmetry of the triangle (Figures A.7 and A.11). In

about two-thirds of the cases, the triangle is tilted to the left of the flaking axis (with the blank in standard orientation); in the remainder, the triangle is tilted to the right of the flaking axis. The base of the triangle is the thickest part of the flake, and consists of a wide, flat surface, formed by a single flake scar. The dorsal face of the flake is formed by two large flake scars, struck from the surface that forms the base of the triangle, converging toward the apex of the triangle, which is the thinnest part of the flake. Thus, the base of the triangle appears to be a remnant of a former striking platform, which is the reason for calling these flakes *éclats débordants*. However, the high degree of regularity in these 64 flakes, as well as the fact that several are retouched, suggests specialized manufacture. These flakes may have been struck from Levallois cores, but I am unable to reconstruct the nature of the cores and the manufacture method used to produce them.

There also are 17 crested blanks in Le Moustier, H8, and these also show a remarkable degree of uniformity in their shape. They tend to be elongated flakes, with a crest running along the long axis (proximal to distal), which is offset somewhat from the center line (see Figures A.4 no. 2; A.6 no. 4; A.7 no. 1). The sagittal cross-section of these flakes is an asymmetrical triangle. The dorsal face on either side of the crest was formed by striking two or three large flakes from the crest downward; the distal ends of the crest's flake scars were truncated by the removal of the flake from its core. The place of these flakes in a reduction sequence is difficult to judge. They might have come from some kind of crested flake core, analogous to a crested blade core, or they may have been struck along the edges of Levallois cores, where the trimmed edge intersects the debitage surface, to rejuvenate the striking platform of a discoidal or Levallois core.

Unfortunately, the 24 cores I studied from this assemblage do little to resolve the nature of these flakes because most of them are small and seemingly exhausted. As Table 5.6 shows, these are fairly evenly distributed over 14 core categories. They are all flake cores, with very few blade or bladelet scars. One, belonging to category 8, shows a peculiar mode of debitage. The proximal end of a thick flake was truncated by a strong blow, and the flat surface that resulted was used as a striking platform for the removal of small flakes from the edges and ventral face of the flake/core.

Table 5.7 shows that most of the 24 analyzed cores in Le Moustier, H8 were made on nodules or cobbles, but a large number were made on flakes. The reduction is clearly dominated by flake debitage: only one core has any blade removals. Most are unifacial cores with a linear debitage surface, although seven have centripetal debitage surfaces. There is almost no debitage surface maintenance.

*Discussion* The vast majority of blanks are ordinary flakes that show no evidence of a particular reduction method. These could just as easily been struck during the edge trimming or decortication phase of a Levallois core as from the discoidal debitage surface of a plano-convex core. The blades in this assemblage could easily have been produced in the course of a flake-oriented production, and there is no reason to suspect that systematic blade production was carried out.

However, based on the cores, at least four different flake production methods appear to have been used at Le Moustier. One involves removing just enough cortex from the core to make one or two striking platform/debitage surface pairs. A second method involved the creation of a plano-convex core by the removal of all cortex and by trimming; the plane face then became a large striking platform for debitage on the convex face. At least one kind of Levallois debitage was also carried out, possibly

involving a specialized production of *éclats débordants*. The fourth flake production method is represented by only one example; it is the exploitation of a thick flake as a core for making small flakes, from a striking platform made by truncating the proximal end of the flake. Four other cores are difficult to interpret, and may represent still other blank production methods.

*Caminade Est, M3*

Figure 5.1 shows that level M3 from Caminade Est is dominated by partially-cortical flakes (3a) and non-cortical flakes (4a). In each category of dorsal cortex, flakes are far more abundant than either fragments or blades. The vast majority of blanks are ordinary flakes (Figure 5.2). Blades are more common than Levallois flakes, and rejuvenations and crested blanks are comparatively rare. In each category of dorsal cortex (2a-2c = 50-100%, 3a-3c = 1-49%, and 4a-4c = 0%), there are many more flakes than blades, and in the first and third categories there are more blades than fragments. Moreover, the frequency of blades rises steadily as the percentage of dorsal cortex decreases; this can be seen by comparing the bars for 2c, 3c, and 4c in Figure 5.1.

Some Levallois debitage was done, as witnessed by the presence of Levallois flakes, blades, and points. An excellent example of a Levallois point, retouched as a sidescraper, is shown in Figure A.19 no. 1. One large flake shows evidence of a bi-directional Levallois blade reduction sequence (Figure A.19 no. 2). This flake was either an accident that removed the entire debitage surface and substantial portions of a striking platform from the core, or a large core rejuvenation. Nevertheless, Levallois blanks are less common in this assemblage than in level H8 of Le Moustier.

There are five cores in Caminade Est, M3 (Table 5.6). The origin (kind of object on which the cores are made) of most of the cores is unknown (see Table 5.7). Flake

and blade debitage are both represented. Most of the cores have striking platforms and linear debitage surfaces, but one has a crest with centripetal debitage surfaces. Only two of the five show debitage surface maintenance, but these include both lateral and basal maintenance.

Each of the five cores differs significantly from the others. B9.523 (Figure A.14 no. 1) is a small, squared object, belonging to category 2B, that could have originated as a cobble or as a thick flake; it is of indeterminate Senonian chert. There is one debitage surface, on which flakes from two separate striking platforms intersect at a 90° angle. Each of the core's six sides consists of a remnant of a formerly large, wide flake scar. This seems to be an exhausted core, exploited to the maximum and abandoned because of its small volume.

B10.488 (Figure A.15) is a small discoidal core with debitage on both faces (category 10A), made of black Senonian chert. Some debitage originated from a flat striking platform at one thick edge of the core, but most of it originated from the crest defining the intersection of the two debitage surfaces along approximately three-fifths of its perimeter. One of these debitage surfaces is somewhat convex, while the other is flat and consists mainly of two relatively wide flake scars. There are five bladelet flake scars at one end of the convex debitage surface (d). Y10.3 (Figure A.16) is a thick, cortical flake of unknown raw material, which turned white from a considerable development of patina. A relatively large Kombewa flake was struck from its ventral surface, originating at the flake's wide butt. There are other removals along one edge, forming a short crest, but the Kombewa flake seems to have been the only potential tool blank struck from this core.

Figure A.17 shows a simple blade core with one striking platform and a cortical back (category 14A), made on a nodule of black Senonian chert. The distal end of the core's debitage surface is truncated by steep flake scars, resulting in an angle of contact with the core's distal back of approximately 90°. This may represent an attempt to maintain a flat debitage surface using basal maintenance.

The remaining "core" is really the elaborate refit I mentioned earlier. The absence of much material from the interior of the refit suggests to me that a usable core may have been carried away from the site. I assigned this refit to core category 4B (blocky flake core with multiple striking platforms).

*La-Côte, level III*

As seen in Figure 5.1, semi-cortical blanks (3a-3c) are more common than cortical blanks (2a-2c) in the La-Côte assemblage, but less common than non-cortical blanks (4a-4c). Among cortical blanks, flakes are dominant over blades, but blades rise in frequency with decreasing levels of cortex faster than do flakes, so that blades are nearly twice as frequent among non-cortical blanks. Figure 5.2 shows the percentages of blank types. They are almost all ordinary flakes and blades, with only two crested blanks[2] and 12 rejuvenation flakes. Ordinary flakes (2a, 3a, 4a) are marginally more frequent than ordinary blades (2c, 3c, 4c) overall.

The following description is based on Pelegrin (1986:477-492). Of the fourteen cores, three are small, fragmented cobbles that show very little debitage, which I identified as technological type 1a, raw or tested nodule. The remaining eleven cores show organized debitage. One (B0.132) shows a striking platform, totally renewed (by

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[2] Pelegrin (1986) reported finding 17 crested blades in this assemblage.

rejuvenation flaking) once and partially renewed several times. This core's debitage surface was destroyed by one last flake removal, which was an overpassed flake that removed most of a striking platform at the other end of the core. In addition, Pelegrin was able to refit a series of flakes and blades in the same raw distinctive raw material, which he believes may belong to the same sequence of debitage, but which lack the intermediate object(s) that would permit the refit to be attached to the core. The reduction sequence consisted of a the removal of a wide, cortical flake that left a large flat surface; the use of that flat surface to strike a one-sided crest; the removal of the crest as a crested blade; and the removal of several other small blades.

Core A0.61 is a crested blade core with a single prepared striking platform, from which removals were struck on a wide debitage surface. Remnants of transverse flakes to either side of the debitage surface show that crests were prepared during the early stage of debitage. A series of small flakes near the distal part of one debitage surface may be the result of basal maintenance. This core was made on a small, rolled cobble.

Core B0.20 was also made on a small rolled cobble, or a fragment of one. Flakes were struck on two wide, flat debitage surfaces from a single striking platform. The striking platform is very flat, and could be either a natural fracture or the result of complete platform rejuvenation. The last few removals were "blade-like flakes" according to Pelegrin. This core (like A0.61) appears to have been exhausted.

Cores A1.54, C1.30, and C-1.11 are bi-directional blade cores with opposed striking platforms. Each was probably made on a stream rolled nodule, although A1.54 may have been made on a thick flake. Generally, the striking platforms show signs of previous rejuvenations, and two of the cores show traces of crest preparation. The crested blades may have been removed at the beginning or in the middle of the debitage

sequence. C1.30 appears not to have yielded many flakes or blades, while C-1.11 was practically exhausted.

There are two cores clearly made on thick flakes: D3.14 and A0.55. Each has two opposed striking platforms oriented at 180°. D3.14 shows debitage on the core's edge and dorsal face. One of its striking platforms was made by inverse truncation removals, and the other was rejuvenated by a burin-like blow across the distal end of the flake, before a small, flat blade was struck off it. A0.55 shows debitage on the flake core's edge and ventral face. One of its striking platforms is perfectly smooth, while the other was rejuvenated by the removal of small flakes. Pelegrin speculated that one of the removals from this core would have made an appropriate blank for a Châtelperron point; the several Châtelperron points in the assemblage tend to be made on flat blades.

In addition to these cores, Pelegrin reconstructed the debitage sequences of three other cores with refitting. Like the above cores, these show the importance of crested blades and platform rejuvenations, as well as the creation of new striking platforms during reduction. One (C0.146) consisted of a fragmented core made on a thick cortical flake, and 12 blanks, including a crested blade, a flake from the making of the crested blade, and two core rejuvenation tablets (see Figure A.35). One blade from this core was retouched into a Châtelperronian point.

In addition to these cores, Pelegrin also refit several individual pairs of flakes. Among these was a pair of core tablets, fitting one on top of the other. The edge of the upper tablet, the first to be struck from the core, hangs far over the edge of the lower tablet. This shows how the debitage surface retreated as debitage progressed (see Figure A.37, no. 7).

*Discussion* There are several key features about debitage in the level III assemblage that Pelegrin brought to light with his study of the cores, refits, and crested blades. Most of the debitage began with the creation of a wide, flat surface by the removal of a large flake from a stream rolled nodule or a thick flake. This surface served as one of the two sides of the eventual crested blade. It was used to strike the short, transverse flakes that form the one-sided crest, which initiated the debitage sequence. Afterward, debitage usually moved in the direction of the large, flat surface, possibly signaling a preference for laminar products that are rather wide, flat, and relatively thin. When the debitage surface became too flat from the removal of blades, it was "taken in" again by the removal of wide flakes, which re-created the keel that is necessary for blade debitage. Although many of the cores have two opposed striking platforms, it is not clear whether debitage was the principal function of both, or whether one of the striking platforms was used principally to rejuvenate the debitage surface. At any rate, Pelegrin (1986:505) believed that the evidence, especially the refit of core A-1.16 (Figure A.34), supported the idea of "a true intention to make blades." In addition, his morphological analysis of blanks led him to suggest that there was a marked selection of certain types of blanks for certain types of tools. For example, long, heavy blades were selected for endscrapers, while thinner, flat blades were reserved for Châtelperronian points.

An interesting footnote to this summary of Pelegrin's (1986) analysis has to do with the typological analysis of Gaussen and Texier (1974), the site's excavators. Of the five objects they labeled burins, Pelegrin accepted only two. One of the objects he rejected as a burin was A-1.16: a core that formed the heart of one of his refits. Based

on its morphology, Gaussen and Texier had concluded that this object was a busked burin. Based on the refit (Figure A.34), Pelegrin showed that it is a bladelet core.

*Caminade Est, level G*

Figure 5.1 shows that every technological category except the four Levallois types (5a-5d) is represented, although in widely varying frequencies. Frequencies of flakes, fragments, and blades rise with decreasing amounts of dorsal cortex. Non-cortical blanks (4a-4c) are dominant over semi-cortical (3a-3b) and cortical (2a-2c) blanks. In addition, while cortical flakes (2a) are more abundant than cortical fragments and cortical blades (2b and 2c, respectively), non-cortical blades (4c) are more abundant than non-cortical fragments and flakes (4b and 4a).

As Table 5.6 shows, the 78 analyzed cores are distributed over a large number of core categories, including flake as well as blade cores. The largest single frequency is 15 (19%), for blade cores with lateral maintenance and wide debitage surfaces (category 14A). For level G of Caminade Est, Table 5.7 shows strong tendencies toward cores made on nodules rather than flakes, the use of striking platforms rather than crests, and (consequently) linear debitage surfaces rather than centripetal ones. There are more blade cores than flake cores, but the difference is not large, and several cores have roughly equal numbers of blade scars and flake scars.

A few examples will show the range of manufacture methods among the cores in Caminade Est, G. Figure A.22 (no. 2) shows one of the two cores belonging to category 1B, C3.187. This core is made on a small nodule of very dense, smooth, hard, grey chert with pinkish mottles and a very thin, smooth, rounded cortex. The color and mottling resemble Jurassic chert, but I classed the raw material as "unidentified" due to uncertainty. There is one striking platform, made by the removal of a single, wide flake.

The platform was probably rejuvenated at least twice, as evidenced by remnants of previous flake scars that represent previous stages of the same striking platform. There is essentially one debitage surface, showing a series of wide flakes on two adjacent faces (views b and c) whose lateral edges meet at an acute angle. There is also a single flake scar on one side of this debitage surface, originating at the opposite end of the core, which was subsequently truncated by a blow across the base of the core (b). That blow may represent basal maintenance or a second debitage surface, but it and the flake scar it truncated probably both represent the removal of cortex. The curvature of the cortical back of this core, and the presence of cortex on both sides, indicate that the small nodule was not reduced very intensively.

Core number C8.843 (Figure A.23) is slightly more complex, suggesting it was exploited more intensively. This is a small object, made on a nodule of black Senonian chert, with two striking platforms and no maintenance. I categorized this core as 2B: prepared flake core, two striking platforms at 90°. One debitage surface occupies two intersecting faces, visible in views (a) and (b) in Figure A.23. At least four blanks, two of which may have been blades, were struck on this debitage surface from the striking platform in (d). A second, much smaller striking platform (not shown) was used to strike at least three or four overlapping blanks, which are visible in (c). The distal end of that debitage surface intersects one side of the first debitage surface. The remaining surfaces on this cores are undoubtedly remnants of previous debitage surfaces and striking platforms, and the core probably survived several phases as striking platforms were created, exploited, then removed during subsequent core maintenance or debitage.

Figure A.24 shows one of the two globular cores (category 4A) from Caminade Est, G: C10.88. There is one very clear striking platform (b), associated with the debitage surface in view a. There is also a crest (right-hand side of view c), from which some small flakes were struck to one side, and two larger, rectangular flakes on the other side (d). The core seems to have ample volume for the production of additional blanks; it may have been abandoned because of the difficulty in maintaining viable striking surfaces.

Categories 12A-12B, prepared blade cores without maintenance, show that not all blade debitage is complex. C7.607 is a small core, weighing 45 grams, which could have originated with a thick flake or a cobble/nodule; there is cortex remaining on two sides. It has one striking platform created by the removal of a wide flake, which was used to strike three or four short blades. The resulting debitage surface was then used as a striking surface for the removal of at least two blades on an adjacent surface.

Core number B7.95 (Figure A.22 no. 1) is an example of category 13A: blade core with lateral maintenance and a narrow striking surface. The two views in this illustration show the two flat surfaces (one is actually rather convex). The narrow blade debitage surface is at the left-hand side of view (a) in the figure, and at the right-hand side of view (b). Core D7.116 (Figure A.25) is another example. In that figure, the blade debitage surface is visible in (b). This appears to be made on a flat cobble, made flatter by lateral maintenance in order to set up the narrow debitage surface.

Most of the blade cores in Caminade Est, G belong to core category 14A-14B: blade core with maintenance and a wide striking surface. C9.404 (Figure A.26 no. 1) is an excellent example of the single-striking platform type (14A). Another example is C8.803 (Figure A.30 no. 13), which is also a muzzled endscraper. Examples with two

striking platforms include C6.116 (Figure A.26 no. 2), A-10.181 (Figure A.27 no. 1), D7.92 (Figure A.27 no. 2), and C6.164 (Figure A.28). In D7.92, all the cortex has been removed from the back of the core, and the lateral maintenance consists of a single wide bladelet flake scar, on the left-hand side of view (a).

*Discussion* This assemblage shows several methods of flake production. Many are variations on a basic theme: the removal of some cortex, the creation of a striking platform with a few blows, and the production of blanks along a simple debitage surface with no crest. The cores differ mainly in the level of investment in creating debitage surfaces, the types of blanks removed, the number of striking platforms, and the degree of exploitation. There is nearly continuous variation from simple, little-exploited cores to more complex and more intensively reduced ones. There are at least two flake production methods, represented by simple flake cores and globular or blocky cores. In addition, there are at least four blade production methods, represented by simple cores with no maintenance, cores with lateral maintenance and a narrow debitage surface, cores with lateral maintenance and a wide debitage surface, and pyramidal cores. Many nodules and/or cobbles were brought to the site and reduced there. They were not all reduced to the same extent; some appear to have been abandoned before they were completely exhausted.

*Le Flageolet I, level XI*

Figure 5.1 shows the technological composition of level XI from Le Flageolet I. Within each category of cortex amount among flakes (2a-2c, 3a-3c, 4a-4c), flakes are much more abundant than fragments and blades. Fragments and blades increase with decreasing amounts of cortex (that is, 2b<3b<4b and 2c<3c<4c). However, there are roughly equal numbers of semi-cortical flakes (3a) and non-cortical flakes (4a). The

pattern resembles level H8 of Le Moustier. Figure 5.2 shows the percentages of blank types among flakes. Ordinary flakes are by far the most abundant, followed by fragments, ordinary blades, and rejuvenation flakes in that order.

Of the 51 cores I analyzed, 75% are flake and 25% blade cores (not counting those assigned to categories 99A and 99B, unidentified; see Table 5.6). Most of the flake cores fall into category 1B, simple flake core. All but one of the nine blade cores fall into categories 13A or 13B, which are defined by lateral maintenance and a narrow debitage surface. Several of these bear a striking morphological similarity to carinated and muzzled endscrapers and busked burins. Most of the cores in level XI were made on nodules or cobbles, and almost all have striking platforms rather than crests, with linear debitage surfaces (see Table 5.7). Most of the cores are not very complex; only 24% have any kind of debitage surface maintenance.

Figure A.41 no. 2 shows an example of a category 1B core (D10.2639). This is a water-worn cobble of black Senonian chert, with smooth cortex, eroded in spots. The block contains large inclusions of calcareous, cortex-like matter, which commonly occurs in this raw material type. One edge of the block was squared off by a series of thin cortical flakes, which exposed some of the calcareous inclusions. This wide, relatively flat surface was then used to strike several short cortical and semi-cortical flakes from one edge. A series of small hinge-terminated flakes at the base of the core may signal an attempt at decortication or the unfinished preparation of a second striking platform.

Figure A.42 no. 1 shows an example of category 2C (core D10.2190). This odd little core may have been made on a nodule or a thick flake. It has a wide cortical back (only partly visible in the figure) and a tiny remnant of cortex on the opposite edge, but the original nature of the block is impossible to ascertain. Small, narrow striking

platforms were prepared at each end of the block (right and left in each view of the figure) by the removal of a few small flakes. A few wide flakes, about as large as one could remove from such a small core, were struck from both striking platforms. From one striking platform (left-hand side of view a), two flakes were struck on one face, and a third on the other face of the core. On one face, the two flakes were preceded by a relatively large flake that was struck in a transverse direction, across the distal end of the debitage surface (a). This represents either a remnant of a debitage surface from a now-missing striking platform, or lateral maintenance of the existing debitage surface. The other striking platform was only used to strike one very wide flake from one face of the core. This core is probably the exhausted remnant of a long series of reduction, the traces of which have been removed by these last, wide scars.

Core number C9.3489 (Figure A.42 no. 2) is a good example of category 3. The figure shows three of the six flat faces. Most of these were flattened by the removal of only one or two wide flakes. The last removals, the flake scars of which are seen in view (a), were struck from the striking platform in (c). I infer that this core was made on a small, roughly spherical nodule, based on the location of cortex remaining on the block. Its small size is not, therefore, the consequence of a high core reduction intensity. Rather, the stoneworker seems to have chosen a blank production method appropriate to the size and shape of the nodule.

Figure A.43 no. 1 shows a schematic sketch of a category 4B core from level XI, number D11.10001. There are four striking platforms on this cube- or tablet-shaped block, which originated as a cobble or a nodule of black Senonian chert and still shows remnants of its thin, rounded cortex. The principal striking platform, SP 1, was formed by the removal of one wide flake, the scar of which (not shown) covers about 60% of one

face of the block. The distal end of that flake scar is concave because of a pronounced undulation. At least six or seven flakes were struck from SP 1 along a flat debitage surface, most of them running all the way to its distal end (view b). Exactly opposite this striking platform, and at the distal end of the first debitage surface, are several small, hinged flake scars. These may have served as basal maintenance for debitage surface 1, to prevent the flakes from becoming curved distally. Two or three flakes were struck from the surface created by that basal maintenance, toward striking platform 1, but that surface was probably not a striking platform. At the end of the block opposite debitage surface 1 is a second striking platform, SP 2, which was used to strike three long flakes (view a) down the side of the block in the direction of debitage surface 1. One side of this debitage surface was then used as third striking platform, for the removal of a few small flakes on the surface that supports SP 1. Most of the flakes struck from this core were nearly as long as the width or length of the block. This core is not pretty, but it shows evidence of organized debitage in the creation of wide, flat surfaces by careful flake removals, the basal maintenance of debitage surface 1, and the use of one flat debitage surface as a striking platform.

Core B-1.500 (schematically illustrated in A.43 no. 2) is one of the two cores belonging to category 7 in this assemblage. This is a frost spall, the ventral face of which shows the characteristic rough surface of cryoclastic weathering. The flake is thick along one edge and thin along the other, which gives it a triangular cross-section. The thick edge became the first debitage surface. Small, short flakes were removed along the entire length of that edge from a cortical surface. A second debitage surface along the distal end of the cryoclastic flake was created when a series of small, hackley flakes were struck from the ventral face. The other core belonging to category 7 in level

XI (D11.2661; Figure A.43 no. 3) was made on a flake. The use of narrow edges to remove small, thumbnail-shaped flakes is a recurrent theme in this assemblage.

Core C9.3464 (not shown) is a type 10B core. Its origin is unclear, because there is no original external surface remaining. It has a plano-convex shape, the plane face of which was maintained by the removal of both blades and flakes (there are 7 main scars remaining). Between episodes of maintenance, this surface was being used as a striking platform for a convex, centripetal debitage surface. Most of those flakes terminated at the center of the convex face, which is its highest point, and which resulted in a tortoise-core shape. This object closely resembles the discoidal cores often found in Mousterian assemblages.

Many of the cores I examined from level XI show systematic blade production. Number C7.1774 (Figure A.44) shows how the stoneworker took advantage of the cylindrical shape of a long nodule of black Senonian chert to strike several long blades. The striking platform for the blades was created with three or four main flake removals; the distal ends of two of these removals extend far down the cortical back of the core, but the striking platform intersects the debitage surface at nearly a right angle. There is a very wide, deep flake scar on a surface to one side of the blade debitage surface, but this does not appear to constitute lateral maintenance, since it did not affect the blades that were struck. At the end of the core opposite the first striking platform is a second striking platform, created by three small flake scars, from which four square flakes were struck on a face adjacent to the distal end of the blade debitage surface. This may represent some form of basal maintenance, or an independent debitage surface.

D11.2382 is a very similar core (Figure A.45), but it differs in that lateral maintenance was used to shape the debitage surface. This core was made on a very

small, cigar-shaped nodule of black Senonian chert, on which a small amount of smooth cortex remains. There are two striking platforms. SP 1 was made by the removal of a single flake, which created an acute angle with the debitage surface. Several long bladelets were struck down this debitage surface, which is bordered by a cortical surface on one side and a wide, flat flake scar on the other. The latter was clearly removed in order to create a constricted debitage surface. The distal end of debitage surface 1 was subsequently truncated by the creation of a second striking platform. SP 2 was made with two or three small flakes, and was used to strike one long blade down the side of the core opposite debitage surface 1.

Core D11.2166 is a blade core with a laterally-maintained, narrow debitage surface (Figure A.46 no. 1). Above, I mentioned this core as one of two bearing a marked similarity to some of the busked burins from level XI. The striking platform (a) was created by the removal of several small flakes, struck mostly from one side. Each of the two wide, flat faces (b, d) bordering the debitage surface (c) was created by the removal of several wide flakes, and possibly also by remnants of wide flake scars from an earlier stage in this core's reduction. During an early stage of bladelet production, a crest was created; three distal remnants of the negatives of flakes used to make that crest are visible in view (d). After the removal of the crested blade, several other blades were struck, but the third or fourth hinged without attaining the distal end of the debitage surface. The striking platform was renewed at least once by small flakes struck from the proximal end of the debitage surface. If this object were identified as a busked burin, the intersection between the striking platform and debitage surface would be the tool's bit. However, this would make it difficult to understand why the flat face of the bit (the core's striking platform) was prepared by flaking, and why, after the removal of several blades,

that surface was renewed by a few additional small flakes. It is also difficult to understand why a crested blade would need to be struck, if the goal was simply to create a working edge for a tool. Therefore, it seems most likely that the main function of this object was as a core for striking long, thin bladelets, and that most of the flaking was done either in the preparation of the striking platform, the creation of the crested blade, or maintenance of the debitage surface.

Figure A.61, no. 9 shows a very similar core with tool-like morphology, B10.2276. The stoneworker thinned a flake of black Senonian chert with a series of short removals on one side (b) and by a single, wide flake on the other side (d). This resulted in the constricted debitage surface in (c). At an early stage in the debitage of bladelets from this debitage surface, a crest was fashioned and removed as a crested blade; the distal remnants of the crest preparation flakes can be seen on either side. The striking platform (a) is smooth, and was probably formed when the core flake or pebble was much larger. The striking platform was rejuvenated at least once by the removal of two small flakes, struck from the proximal end of the debitage surface. Typologically, this object is a busked burin, but it was clearly used as a bladelet core.

D10.2348 is a small core, made on a nodule of black Senonian chert, on which both bladelet and flake scars are visible (Figure A.46 no. 2). Each debitage surface is two bladelet scars wide. From the debitage surface in view d of Figure A.46, a few flakes were struck, which helped to narrow the width of the core and to create a relatively narrow surface from which two additional bladelets were then removed. Thus, this is a type 13B core, in which the two striking platforms originate at the same location but are oriented at 90° to each other.

Figures A.47 and A.48 show two examples of core category 99A, indeterminate.

*Le Flageolet I, level IX*

Figure 5.1 shows that flakes, fragments, and blades all increase with decreasing amounts of cortex (e.g., 2a<3a<4a) in this assemblage. Flakes (2a, 3a, and 4a) are much more abundant than fragments, and fragments (2b, 3b, 2b) are more abundant than blades (2c, 3c, 4c). Other kinds of flakes are exceedingly rare, although there are significant quantities of core rejuvenation blanks (7b, 7c). Chunks (type 8) are surprisingly abundant, making up 12% of the assemblage, which is more than any other technological type except semi-cortical and non-cortical flakes. Figure 5.2 shows the percentages of blank types. This assemblage is closely similar to level XI from the same site.

Level IX has more cores than any of the other assemblages, and they are distributed over more core categories. Excluding 99A and 99B, eighteen kinds of cores are represented in the assemblage (Table 5.6). Fifty-four of the 115 analyzed cores are flake cores, 36 are blade cores, and 15 are indeterminate. The single most abundant category is 13A, blade core with maintenance and a narrow debitage surface with one striking platform. Table 5.7 shows that most of the cores are made on nodules, although some are made on flakes and a few on frost spalls. Flake blanks are in the majority, but there are also many debitage surfaces showing blades or a mixture of blank types. Striking platforms are the rule, crests the exception. There is some centripetal debitage, but most debitage was linear. Lateral maintenance occurs on about one quarter of the cores, and most of those are type 13B; but most cores have no debitage surface maintenance.

Figure A.52 shows a core of type 1B (B-1.290) made on a rounded nodule of indeterminate Senonian, a dark reddish-brown chert with chalcedony inclusions and a

black zone in the center of the nodule. One end of the nodule was truncated by the removal of about three large cortical flakes, creating a fairly flat striking platform, which was then used to strike three long flakes, all cortical or semi-cortical. A few small flake scars at the base of the nodule may represent an abandoned effort to create a second striking platform. Core C2.178 (Figure A.56 no. 2), also of type 1B, was made on a small, rounded nodule of beige Senonian chert. The removal of one relatively large and two or three small, cortical flakes created the single striking platform (a). From this striking platform, at least one cortical flake was struck. That flake scar was then used to strike two (or more) transverse cortical flakes, across the face of the nodule, in order to create the debitage surface. About one dozen small flakes were then struck off that debitage surface, without apparent platform rejuvenation. A pair of cortical flakes from the base of the core may represent an attempt to remove additional cortex and/or to create a second striking platform, which was never used.

C-1.679, in Figure A.57, is a good example of core category 4A, globular with multiple striking platforms and crests. At first glance this core does not appear to show any organized debitage, but on closer inspection there does seem to have been a method to the madness. There are four debitage surfaces, one associated with a striking platform, the other three with crests. The former is shown in (a), and its striking platform was created by the removal of a wide flake, which has a pronounced undulation that created a rather marked depression. Above this depression there is a sharp ridge—the heavy line in (b). Just below that line is a series of relatively small flake scars, which initiate at a crest and terminate at the dark line of the ridge. The crest is the striking surface for debitage surface 2. On the opposite side of the crest, at least three larger flakes were struck (d). Apparently, the latter were struck first, then the smaller flakes

whose scars are visible in the bottom half of view (b). On the right-hand side of (b) is a pair of flake scars that were struck from a second crest, whose profile forms the right-hand edge of the drawing. The scars on the other side of this crest can be seen in the left-hand side of (c). The distal ends of those scars intersect a third crest, which was used to strike the larger flake scars in (c). Two of those are also visible in the right-hand side of (d).

Figure A.55 shows two cores that are unique among all the six assemblages: C2.160 and D6.2084. Both are made on flakes of black Senonian. In C2.160, most of the ventral face is still visible. Five flakes were struck from the ventral face, at its proximal end and around half the perimeter of the flake. An equal number was struck from the dorsal face, in a series extending from the proximal end along one side of the flake. A few small flakes were also struck form the opposite side. Very little of the ventral face of D6.2084 is still visible because both faces have extensive removals. In this case, the crest was used alternately to strike several flakes from the core flake's ventral face (a), then its dorsal face (b). I placed both these cores in category 10A, disk core with a bifacial debitage surface (i.e., a crest).

B1.385 (not shown) is another core made on a flake, belonging to core category 10B. The flake was very thick, and the flakes were struck from its dorsal face around most if its perimeter, using the ventral face of the core flake as a striking platform. Another example is B5.409 (also not shown), which has a small amount of cortex remaining, may have been made on cobble or a thick flake. The debitage surface is probably a remnant of a flake scar that was large and flat. A long series of short flakes was removed along approximately half the perimeter of the striking platform. On the

other side of the core, a pair of overlapping flake scars may represent a second debitage surface, or some kind of debitage surface maintenance.

Figure A.58 shows a very clear example of category 12B, albeit an atypical one. This core (D9.2351) was made on a nodule of black Senonian flint. The main striking platform (a) consists of a single large flake scar. Judging by the curvature of the compression rings on that scar relative to the size of the remaining surface, the debitage surface has probably been used extensively, and this removed much of the initial striking platform. Blades were struck down the length of the nodule, along a wide, curved debitage surface that shows no maintenance (b). The distal end of this debitage surface was subsequently used as a striking platform for the removal of several blades (c). Both debitage surfaces have several small, hinged flake scars that result either from gentle flaking to remove spurs or from failed attempts to detach blades.

In my discussion of level XI, I noted the great similarity between some examples of category 13A cores and certain tool types. Figure A.56 no. 1 shows an excellent example from level IX (B10.2773), made from a small, flat cobble of beige Senonian chert. A cortical blade was struck along an end of the pebble to create a striking platform (a). Three or four flakes were then struck in a direction perpendicular to the eventual debitage surface, in order to create a flat surface on one of the sides of the pebble (c). This flaking must have created an acute angle, along which blades were then struck. The scars from the last two blades are visible on the right-hand side of view (b). However, blade debitage was not limited to that narrow face, but extended partway around the cobble, onto the flat, cortical face adjacent to it. Whether the blades removed there resulted from lateral maintenance or blade debitage *per se* is hard to say. Although this object is clearly a core, its morphology is similar to that of many carinated

endscrapers. A very similar core is shown by the sketch in Figure A.53 (B11.1776). The striking platform of this core was rejuvenated at least once by striking on the proximal end of the debitage surface.

A5.497 is a good example of category 14A, blade core with maintenance, wide debitage surface, and one striking platform. This core (Figure A.59, no. 2) was made on a nodule of indeterminate Senonian, and still has cortex over more than half its surface. The striking platform (a) was created by one large removal, which was subsequently rejuvenated by several smaller removals. A wide, flat surface (b) was created by striking a large flake, creating the keel that was then used to initiate blade production. However, the debitage surface (c) was not constricted by any lateral maintenance on the other side. The laterally-maintained side was flaked several times. Blade production ended after a series of hinge-terminated removals prohibited further blade debitage. The core would still have been useable with modest rejuvenation of the striking platform, but that was never done.

There are several flakes in the assemblage that represent either rejuvenations of the bits of carinated endscrapers or busked burins, or rejuvenations of the debitage surfaces of small bladelet cores. Several of these are shown in Figures A.61 and A.62.No. 1 in Figure A.61 is especially striking. The removal of this flake would have created a wide, flat surface to one side of the surface with bladelet scars, as well as renewing that bladelet surface, and so it probably represents lateral maintenance and/or debitage surface rejuvenation from a core of category 13A. Interestingly, the butt of this flake shows that it was carefully prepared before the flake was struck. I assigned it to technological type 7c, "other rejuvenation flake".

Association between manufacture methods and raw material type

The preceding analysis has shown that various methods of blank production are represented in each assemblage. If certain manufacture methods are associated with a narrow range of raw material types, and if those raw material types represent a particular source distance, range of fracture properties, or level of natural availability, this could be evidence of raw material conservation.

I applied likelihood-ratio chi-square ($G^2$) to cross-tabulations of Raw Material type with Blank Type (Tables 5.15-5.20), Core Category (Tables 5.21-5.25), and five core descriptive variables (Table 5.26) to determine the presence of statistically significant associations. Percentages shown in Tables 5.15-5.20 are calculated based on the row totals. In all the tables presented in this section, cells associated with significant, positive standardized deviates and with expected values of $\geq 5$ are shown in bold. Cells associated with significant, negative standardized deviates and with expected values of $\geq 5$ are shown underlined. All the results are based only on the objects weighing $\geq 1$ gram.

In general, there are very few significant test results in these tables, both in terms of $G^2$ statistics and in terms of significant standardized deviates for particular cells. This has much to do with the small sample sizes that result when the data are partitioned into two variables, each of which is further partitioned into several values. Blank composition is an exception: each assemblage except level M3 of Caminade Est shows a significant association. Yet, even among cases where relatively large sample sizes remained after this partitioning, a lack of statistically significant variation is the rule. For this reason, I briefly summarize all the data rather than presenting a detailed, assemblage-by-assemblage discussion.

*Blank composition*

In each assemblage, black, beige, and indeterminate Senonian chert together make up a large majority of the blanks. In five of the six assemblages, these three raw materials have a very similar blank composition. The similarity is somewhat less marked in one of the five, level M3 of Caminade Est, where they differ in the presence/absence of Levallois products. In that Mousterian assemblage, the beige variety lacks Levallois products, but the black and indeterminate varieties have them in frequencies of 9% and 11%, respectively (Table 5.16). However, there are only 14 examples of beige Senonian in that assemblage. La-Côte III is the only assemblage where there is a measurable difference between beige and black Senonian in technological composition (see Table 5.17). In that assemblage, the beige variety has significantly more flakes and fewer blades than black Senonian and other raw materials.

Bergeracois also shows significant variation in blank composition. This chert is more laminar (i.e., has a higher proportion of blades) than other raw materials in the three Aurignacian assemblages, significantly so in level G of Caminade Est (Table 5.18) and level IX of Le Flageolet I (Table 5.20). This is not true of level H8 of Le Moustier, which has only 4 Bergeracois blanks, or Caminade Est M3, which has only one. It is also not true in La-Côte level III, where the frequency of blades for Bergeracois falls in between the frequencies for other raw materials. Interestingly, level III of La-Côte is the most laminar of the six assemblages, both in having a larger proportion of blades among all blanks and in having a higher proportion of blade cores.

*Core composition*

In level H8 of Le Moustier, that three of the five beige Senonian cores belong to category 2C (Table 5.21) may indicate a preferred use of this raw material for that kind

of core, on which flakes were struck from opposed striking platforms with no maintenance. Although there is a significant, positive standardized deviate (2.99) associated with this cell of the table, the low expected value (0.6) warns against attaching any significance to the figure.

Since I did not examine the 13 cores in the La-Côte assemblage in detail, I am unable to test for associations between RM Type and core category or core descriptive variables. However, the small number of cores and their raw material composition suggest that it would be difficult to establish statistically significant associations. Moreover, according to Pelegrin (1986:515), his data on the raw material composition of the tool types "do not permit us, it seems, to speak here of the differential exploitation of raw materials."

There is no statistically significant evidence of associations between RM Type and Core Category in any of the remaining assemblages. In each case, the $G^2$ statistic for the association is insignificant, and in no case are there significant standardized deviates for cells with expected values of five or greater.

*Core descriptive variables*

There are no significant associations between Raw Material Type and any of the five core descriptive variables in any assemblage (Table 5.26).

Core reduction intensity

If provisioning strategies included efforts to conserve more costly raw materials, this might have resulted in more intense exploitation of the cores made from those raw materials. Two ways in which this might be seen are 1) decreased amounts of cortex, from increased decortication and reduction; and 2) increased numbers of striking surfaces (platforms or crests). Each kind of evidence would be revealed in significant

associations between RM Type and the core descriptive variable in question (Cortex Amount or Number of Striking Surfaces).

I first looked for these associations in the entire data set as a whole (excluding La-Côte). For the first comparison, Cortex Amount was divided into three values: 0%, <50%, and > 50% (Table 5.27). The $G^2$ statistic is 30.29, which is significant (df = 40, $p$ = .005). However, there were no significant standardized deviates for any cell in which the expected value was equal to or greater than 5. The only raw material types with substantial numbers of cores are the three varieties of Senonian chert (black, beige, and indeterminate). In each of those raw material types, most cores have <50% cortex, followed by roughly equal numbers with 0% and with >50% cortex. The significant $G^2$ result may result largely from the comparatively high frequency of cores with 0% cortex, and absence of cores with > 50% cortex, in unidentified raw material. If so, then this result reflects nothing more than the dependence between my ability to identify RM Type and the presence of cortex (some cortex attributes are diagnostic of chert types).

In testing for an association between RM Type and Number of Striking Surfaces (No_SS), I excluded Jurassic chert, for which there was only the "phantom core" from level M3 of Caminade Est, and collapsed the remaining raw material types into five categories, due to the sparseness of the data table (Table 5.28). I also partitioned No_SS into three values: 1 striking surface, 2-3 striking surfaces, and >3 striking surfaces. This test yielded an insignificant statistic ($G^2$ = 6.69, df = 8, $p$ = .57).

I then compared the same pairs of variables among cores in each of these five assemblages individually. Most did not produce a significant likelihood ratio chi-square. Here, I discuss only the three comparisons that did produce a significant result. Table 5.29 shows the cross-tabulation of RM Type with Number of Striking Surfaces for the 24

analyzed cores from level H8 of Le Moustier. Most black Senonian cores have only one striking surface, while most beige Senonian cores have two. Thus, beige Senonian seems somewhat more intensively exploited in this assemblage.

Table 5.30 shows the cross-tabulation of RM Type and Cortex Amount among the 78 analyzed cores from Caminade Est, level G. The significant $G^2$ statistic seems to have resulted from the higher frequencies of non-cortical cores among jasper, chalcedony/millstone, and unidentified raw materials, compared with black, beige, and indeterminate Senonian. However, chalcedony/millstone and jasper cores are very rare, which reduces the statistical significance of their frequencies, while cores made of unidentified raw materials are of uncertain archaeological significance.

Table 5.31 shows the cross-tabulation of RM Type and Cortex Amount among the 115 analyzed cores from level IX of Le Flageolet I. As with level G of Caminade Est, the three varieties of Senonian chert have roughly similar proportions of cores in each cortex category. The $G^2$ statistic seems strongly influenced by the fact that all six unidentified cores had no cortex, which may have resulted from the increased difficulty in identifying raw material types when no cortex is present.

Blank portability and distance/attrition

In this section, I examine the hypotheses concerning blank weights outlined in Chapter 2, following the procedure described by flow chart in Figure 2.4. In computing the average weights of local and non-local blanks (retouched or unretouched), I included all blank types except burin spall (type 7d) and N/A ("not applicable": technological types 1a, 1b, 1c, and 8). I excluded burin spalls because many of them weigh less than 1 gram; including them would necessitate also including other blanks weighing less than a gram, which I have already stated is problematic. I included all raw materials except

those for which no information on minimum source distances was available (porcelainite, pink speckled chert, and unidentified). Because I am unsure whether jasper was obtained from local sources, non-local sources, or a mixture of the two, I either treated it as a separate value in addition to "local" and "non-local" or omitted it from the analysis, as noted below. I excluded objects made of quartzite and basalt because of uncertainty about their function. In all cases, I excluded blanks weighing less than 1 gram.

In order to formulate clear empirical expectations about the blank portability and distance/attrition hypotheses, one must first establish whether retouched objects ("tools") are larger than, the same size as, or smaller than unretouched objects ("raw blanks"). Table 5.32 shows a comparison of the mean weights of tools and raw blanks in each assemblage. Tools and raw blanks are statistically indistinguishable only in level G of Caminade Est, and as I discuss below, that result is spurious. Once the source of that error has been accounted for, tools are quite larger than raw blanks on average, in all the assemblages. Thus, in each assemblage where the distance/attrition hypothesis can be tested, it would be supported by data showing a size differential between tools and raw blanks that is smaller among non-local raw materials than among local ones.

An initial examination of the data suggested that blank weights vary significantly according to blank type, raw material type, and the presence/absence of retouch. Therefore, I present the data in three-way tables partitioned according to the values of those three variables. Each of these tables can be used to address the first three questions in Figure 2.4: 1) Are non-local blanks smaller than local blanks? 2) Is there a difference in size between tools and raw blanks? and, 3) Is the difference in size between tools and raw blanks larger among local than among non-local raw materials? The fourth question—Do local and non-local blanks (retouched or not) have a similar

technological composition? —must be addressed separately, and I do so only where appropriate.

I carried out ANOVA on these data from each assemblage in order to determine statistically significant associations. When jasper was present, I performed the analysis with and without jasper. Table 5.33 shows the results of the ANOVA results for all assemblages except level M3 of Caminade Est. Although I present the data for Caminade Est, level M3 in Table 5.35, that assemblage contained too few data for a meaningful analysis, with only two blanks of non-local raw material.

*Le Moustier H8*

Table 5.34 suggests that non-local blanks are larger than local blanks in this Mousterian assemblage, and the ANOVA results support this impression. This relationship does not seem to depend on whether the blank is retouched. However, the sample sizes for non-local blanks are very low: there are only six artifacts made of non-local raw materials in the assemblage, consisting of two Bergeracois tools, two raw blanks of Bergeracois, and two raw blanks of Jurassic chert. In contrast, there are 962 blanks made of local raw materials. Thus, although these results fail to support either the blank portability or the distance/attrition hypotheses, this does not necessarily mean that those behaviors were not practiced by the occupants of Le Moustier.

*La-Côte III*

La-Côte differs from the other sites examined here in the distribution of raw material sources. At the other sites, the minimum estimated source distances of raw materials cluster at around 1 km and over 20 km, with very few in between. At La-Côte, the estimated source distances cluster at three values: 1 km, 8-9 km, and 19 km. To see whether there are any measurable effects of source distance on blank weights, I

initially examined the data with the variable RM Distance divided into three levels: local, which includes Senonian chert and silicified wood, both available within 1-2 km; intermediate, which includes jasper and pink speckled chert, available at 8-9 km; and non-local, which includes only Bergeracois, available at 19 km.

The data in Table 5.36 do not suggest the presence of any single pattern. Generally, local blanks are larger than those from intermediate and non-local sources. However, there are important exceptions. For example, retouched ordinary flakes of jasper (obtained from sources approximately 8-9 km away) are larger than those of indeterminate Senonian chert (obtained from sources 1-2 km away); and unretouched blades of pink speckled chert (n = 4) are larger than those of black Senonian, beige Senonian, and silicified wood.

I first computed the ANOVA statistics based on this tripartite division (local, intermediate, and non-local). The first set of results for La-Côte III in Table 5.33 (marked with an asterisk) are from this analysis. Although my examination of Table 5.36 suggested that local blanks were significantly larger than both intermediate and non-local blanks, the ANOVA results show no statistically significant effects of either RM Distance or Retouch on the mean weights.

"Intermediate" blanks are more similar to non-local blanks than to local blanks. This suggests that any effect that source distance might have on provisioning behaviors would be similar for the intermediate and non-local raw materials, and different for local ones. Thus, I grouped the intermediate with the non-local raw materials, and carried out a second ANOVA. The results are shown in Table 5.33 (no asterisk). In this instance, non-local blanks are significantly smaller than local blanks. This fits the pattern found by Demars in the Brive area data.

Moving to the second question in Figure 2.4, in every Raw Material Type/Blank Type pair there is an apparent difference in size between tools and raw blanks. However, the data do not point to any overall pattern. There are nine cases in Table 5.36 where both tools and raw blanks are present for a given raw material and blank type. Of those, four cases show differences in size (between tools and raw blanks) of > 2.0 grams, while the remaining five cases show smaller differences. Of the four with the largest differences, tools are larger in two cases and raw blanks in the other two cases. Of the five cases with smaller differences, tools are larger in three cases. In one of the remaining cases (ordinary blades made of black Senonian chert), the difference is marginal and probably not statistically significant. Perhaps this lack of any clear pattern is what led to the insignificant statistics for the effect "retouch" in the two-way ANOVA (see Table 5.33).

I nevertheless felt that the data did not permit a simple "No" to the question, "Is there a difference in size between tools and raw blanks?" Table 5.37 shows that tools are (on average) about twice as large as raw blanks among local raw materials, while tools are slightly smaller than raw blanks among non-local raw materials. This pattern suggests a positive answer to the question, Is the difference in size between tools and raw blanks larger among local than among non-local raw materials? This pattern could result from retouch, use, and repair so intense as to drive the sizes of tools below the sizes of raw blanks, which may initially have been smaller than the tools. This, in turn, supports the distance attrition hypothesis.

Nevertheless, I am not willing to commit to that hypothesis just yet. For one thing, it is intriguing that non-local blanks are generally smaller than local ones, whether retouched or not. Table 5.37 raises the question, Were non-local blanks smaller initially

(that is, at the time they were struck from cores) than local ones were? The fact that raw blanks of non-local rocks are somewhat smaller than raw blanks of local rocks suggests that this was the case. If so, then the pattern might be explained by a smaller size of nodules or cobbles among non-local raw materials, or by efforts to increase blank portability by striking smaller blanks or selecting smaller blanks from the blank pool.

In order to test this last possibility, I compared the technological composition of local and non-local blanks (Table 5.38). Overall, blanks from the two source distances are closely similar in their technological composition. Only a few differences are apparent, including the lack of fragments (2b, 3b, 4b) among non-local blanks, and the relatively higher percentages of both cortical blades (2c) and non-cortical flakes (4a) in local blanks. The Pearson's chi-square for this table is insignificant, while the likelihood-ratio statistic is significant at the .05 level. However, both results must be treated with caution because of the large number of cells with expected values less than 5. This is insufficient evidence of a significant difference in technological composition. Therefore, I conclude that the smaller size of non-local blanks most likely results from a combination of two factors: non-local materials were struck from smaller blocks; and those blanks experienced size attrition due to retouching, use, and resharpening to a greater extent than local blanks did.

There is a discrepancy in these data that must be explained before that last explanation is accepted. As I stated earlier, Table 5.37 suggests that for non-local raw materials, tools were slightly smaller than raw blanks. However, Table 5.36 shows that, in all three non-local raw materials occurring as both tools and raw blanks (the shaded cells), the tools are *larger* than the raw blanks. The reason for the difference that the mean weights in Table 5.36 were calculated on the basis of all blanks within each

category (local/retouched, local/unretouched, etc.). The mean weight of unretouched non-local blanks in that table (5.2 g) includes the large values for unretouched blanks (ordinary flakes and ordinary blades) of pink speckled chert and unretouched ordinary flakes of Bergeracois. Since the variables Raw Material Type and Blank Type are known to affect blank weights, blank weights should only be compared within each combination of a Raw Material Type and a Blank Type. When we do so by restricting our comparisons to the three shaded cells in Table 5.36, it is clear that tools are larger than raw blanks within individual blank types. This is true of both non-local and local raw materials. Furthermore, the difference in size between tools and raw blanks is smaller among non-local materials than local materials. For example, (a - b) > (c - d). Thus, the distance/attrition hypothesis is still supported.

*Caminade Est G*

While there is great variation in mean blank weights between raw material types and blank types in this early Aurignacian assemblage, Table 5.39 does not suggest that non-local blanks are consistently smaller than local blanks. However, there are at least three intriguing exceptions. First, tools made of porcelainite are larger than tools made of three local raw materials, especially among ordinary flakes: indeterminate Senonian, chalcedony/millstone, and black Senonian. Second, tools and raw blanks of Fumelois chert are larger than those of most other raw materials. Third, blades made of Bergeracois, whether retouched or not, are larger than blades of all other raw materials. There are so few Fumelois objects (nine) that their mean sizes are probably unreliable estimators. While there are many porcelainite objects in the assemblage (n = 146), the source of this material is unknown. Therefore, of the three exceptions, Bergeracois is the only one that has the potential to suggest raw material conservation behaviors. Yet,

the pattern is the opposite of what would be expected under either the distance/attrition hypothesis or the blank portability hypothesis.

Nevertheless, I calculated the ANOVA statistics, with the RM Distance variable partitioned into three values: local, non-local, and jasper. The results (not shown) suggest that RM Distance and Retouch both had significant effects on mean blank weights, but that the interaction term was insignificant.

There are about one-third again as many blanks made of jasper as there are of raw materials securely attributed to non-local sources (Bergeracois and Fumelois). Jasper blanks are significantly smaller than both local and non-local blanks, whether retouched and unretouched objects are considered together or separately. Unfortunately, my examination of the material did not make it clear whether this jasper was obtained from nearby sources or more distant ones. This makes it difficult to interpret these results.

In order to obtain a more interpretable set of results, I eliminated jasper from the analysis. Table 5.33 shows the resulting ANOVA results. These suggest that, while tools are larger than raw blanks, this is equally true of both local and non-local raw materials. This result differs from Demars' findings, and it does not support the blank portability hypothesis.

The ANOVA results seem to contradict the results of t-tests comparing mean weights of retouched and unretouched blanks in each assemblage (Table 5.32). Level G of Caminade Est is the only assemblage lacking a significant difference in size between tools and raw blanks. However, the apparent contradiction can be explained by the fact that blank weights vary by RM Type and by Blank Type in this assemblage (Table 5.39). When all values of those variables are pooled, as they were in the t-test,

the variation among blank types and raw material types overrides that between tools and raw blanks. Yet, of the 21 cases in Table 5.39 where the mean weights of retouched and unretouched objects can be compared for a given RM Type/Blank Type combination, only one shows tools weighing less than raw blanks. The exception is ordinary flakes made of chalcedony/millstone, of which there are only nine in the assemblage. Moreover, the figures in the table suggest that the difference in size between tools and raw blanks is generally quite large.

I performed a two-way Model I ANOVA with some of the raw data on which Table 5.39 is based in order to determine the statistical significance of this pattern. Because there are only some RM Type/Blank Type combinations for which a comparison of retouched and unretouched mean weights is possible, the ANOVA analysis was done on a set of 1882 cases that included black Senonian, indeterminate Senonian, Bergeracois, jasper, and porcelainite; and that included only ordinary flakes, ordinary blades, and fragments. The analysis compared Retouch and RM Type as independent variables, with weight as the dependent variable. The results (Table 5.40) clearly support the hypothesis of a consistent difference in mean weights between tools and raw blanks. They also reaffirm that this difference is not affected by RM Type. This only becomes apparent when variation between blank types and raw materials is accounted for.

In short, while tools are larger than raw blanks in this assemblage, imported blanks (whether retouched or not) are not smaller than blanks made locally. In some cases, such as blade tools, imported ones (Bergeracois) are larger. Therefore, there is no evidence of efforts to improve blank portability, nor of greater attrition of non-local blanks.

*Le Flageolet I, level XI*

Table 5.41 shows the mean blank weights by Blank Type, Retouch, and Raw Material Type in this Aurignacian assemblage. The only non-local raw material with sufficient sample sizes for comparative purposes is Bergeracois chert. Each cell in the table showing data for Gavaudun (abbreviated Gav.), Mussidan (Muss.), and Jurassic (Juras.) is based on a sample size of one. In contrast, there are 97 Bergeracois blanks altogether. Unfortunately, the source distances of Jasper (Jasp.) and porcelainite (porcel) are unknown. Therefore, the only relevant comparison that can be done is that between Bergeracois and all the local cherts.

The 51 Bergeracois ordinary flakes, which are all unretouched, are somewhat lighter than ordinary flakes of the local raw materials. The same is true of Bergeracois fragments, especially those that are retouched. Yet, when it comes to blades, the values for Bergeracois fall among those for the local cherts; they are especially similar to beige Senonian. This implies that the answer to the question, "Are non-local blanks smaller than local blanks?", depends on Blank Type. To address this issue, I turned to the analysis of variance.

I performed two separate ANOVA analyses. The first was done on a data set including jasper, and resulted in the first set of figures for Le Flageolet I level XI shown in Table 5.33 (marked with an asterisk). These results, along with examination of the cross-tabulated data, suggest that tools are significantly heavier, and that this is equally true of local, non-local, and jasper blanks. The interaction term is insignificant. Jasper blanks are somewhat smaller than non-local blanks, and significantly smaller than local ones. This is true whether we look at retouched blanks only, unretouched blanks only, or retouched and unretouched blanks combined (see Figure 5.3).

Because there are only 12 blanks made of jasper in this assemblage, and because the source of this jasper has not been determined, I performed a second ANOVA excluding the data on jasper blanks. The second set of figures for level XI of Le Flageolet I in Table 5.33 (no asterisk) resulted from this analysis. These show that both RM Distance and Retouch have significant effects on blank weights. Blanks made of local raw materials are larger than imported blanks, and tools are larger than raw blanks. The lack of a significant interaction term indicates that those effects are independent.

The next question is whether the difference in size between tools and raw blanks is larger for local or non-local blanks. If it is larger for local blanks, the distance/attrition hypothesis would be supported. Table 5.42 suggests that the question might be answered in the affirmative, but with important reservations. The difference in size is 12.5 g – 7.0 g = 5.5 g for local raw materials, and 9.4 g – 4.6 g = 4.8 g for non-local raw materials. Is this difference significant? Probably not; we should expect the latter figure to be slightly smaller simply because the magnitude of the difference will scale with the magnitude of the mean weight values, which are smaller for non-local raw materials. The smaller size differential for non-local raw materials might be the result of higher attrition due to more intense retouching, use, and repair of non-local blanks, but if so, the difference in use and retouching intensity is not great.

Even so, that explanation seems more likely than the blank portability hypothesis. The difference between local and non-local raw materials (5.5 g – 4.8 g = 0.7 g) seems too small to be a significant factor in the economy of Paleolithic hunter-gatherers. Still, it is prudent to test the blank portability hypothesis by comparing the blank composition of local raw materials to that of non-local raw materials. This can be done by looking at Table 5.43, which shows the data and the result of a $G^2$ test, which is significant. Non-

local blanks have lower percentages of several cortical and semi-cortical types (2a, 2b, 2c, 3a), and higher percentages of non-cortical types (4a-4c). Standardized deviates (not shown) indicate that the differences are statistically significant for cortical flakes (2a), semi-cortical fragments (3a), non-cortical fragments (4b), and non-cortical blades (4c).

This pattern is consistent with the hypothesis that blanks made of non-local raw materials are a non-random sample of some initial blank population, a sample biased in favor of blanks with less cortex. Smaller blanks were selected from the blank population available at off-site locations, perhaps in order to increase their portability. This selection resulted in smaller blanks with less cortex. Moreover, the reduction in blank size that resulted when non-local raw materials were used and repaired during transport did not greatly exceed that resulting from the in-place use and repair of blanks made from local raw materials. Nevertheless, it seems prudent to temper this conclusion with the observation that whatever behaviors may have helped created the pattern seen in the data, the treatment of non-local raw materials was not greatly different from that of local raw materials.

*Le Flageolet I, level IX*

In this late Aurignacian assemblage, there are three raw materials of unknown provenience: jasper, porcelainite, and unidentified. For that reason, and because of the low sample size of jasper (n = 2), I excluded all three from the following analyses. I also excluded basalt and quartzite because of the likelihood that they were used as hammerstones rather than cores. Table 5.44 combines the data for each non-local raw material type other than Bergeracois chert (Gavaudun, Jurassic, and Fumelois) into a single column, because the estimated minimum source distances for these three are

roughly similar (see Table 4.11), and because sample sizes are very low for all three (between 2 and 6; see Table 5.13). Even after combining these data, the sample size is prohibitively small for comparative purposes. Thus, Bergeracois is the only raw material in the assemblage that is definitely non-local and statistically representative (n = 270 blanks). Therefore, any statistically detectable differences between local and non-local blanks in this assemblage must be due to a difference between Bergeracois and Senonian chert. There is also another aspect of Bergeracois in this assemblage that makes it unique: although obtained from sources that lie at least 34 km away, it was imported wholly or largely in the form of prepared cores (see above). For these reasons, efforts to increase blank portability could not have had a significant effect on the weights of blanks.

Nevertheless, for consistency, I addressed the question, "Are non-local blanks smaller than local blanks?" by comparing Bergeracois with local raw materials (Table 5.44). The answer appears to depend on Blank Type and on Retouch. Bergeracois flakes are somewhat smaller than flakes of Senonian when retouched, while Bergeracois blades are much larger than blades of local raw materials when retouched. Both are nearly identical to Senonian blanks of the same type when unretouched. For fragments, there is no clear difference between Bergeracois and local raw materials except chalcedony/millstone, fragments of which are larger.

All three varieties of Senonian chert occur in very similar blank sizes within each Blank Type, and within either retouched or unretouched objects. In addition, Senonian chert is far more abundant than chalcedony/millstone, for which there are only 34 blanks. For these reasons, I did a comparison of Senonian chert, all three varieties grouped, with Bergeracois chert (Table 5.45). In general, there is a close resemblance in the

blank sizes of the two raw materials, within any given Blank Type/Retouch combination. This suggests a lack of any significant difference in core reduction intensity, core reduction method, or degree of blank selection. It is particularly striking that, while there are large differences in size between tools and raw blanks within each raw material type, the mean weights of raw blanks are nearly identical for each blank type. There is one figure, however, that stands out in this table: the value of 8.3 g for retouched ordinary blades made of Senonian. This is less than half the value for retouched ordinary blades made of Bergeracois. It results in a large difference in size between blade and flake tools among Senonian, whereas blade and flake tools are essentially the same size among Bergeracois.

Without further analysis, it is not clear what caused this difference. However, I would offer two hypothetical explanations. Senonian blade tools may have been retouched more intensively than Bergeracois blade tools, resulting in a more marked attrition in size. This hypothesis does not agree with the view of Demars (1996) that blade tools, especially those made of Bergeracois, were conserved more than flake tools. Alternatively, there may have been a more intense focus on the production of large blades from Bergeracois than from Senonian. That hypothesis does agree with Demars, as well as Chadelle (1983), both of whom found evidence that Bergeracois was especially favored for blades. Both hypotheses may be testable, but not with data that I have provided here.

Table 5.33 shows the results of the ANOVA comparing the effects of RM Distance (local, non-local) and Retouch (retouched, unretouched) on weight among 4130 blanks. These results are in good agreement with the above impressions, based on my examination of the cross-tabulated data. They indicate that while tools are

significantly larger than raw blanks in this assemblage, this is equally true of local and non-local raw materials. Furthermore, the effect of retouch on blank weight is independent of RM Distance. I see no evidence of either distance/attrition or efforts to increase blank portability in this assemblage.

Retouch intensity

Closely related to the issue of blank conservation is that of retouch intensity. Retouch intensity is the proportion of blanks retouched, out of all that were struck from a given core or out of a given raw material type. Increased raw material conservation should result in increased retouch intensity, especially in non-local raw materials and/or raw materials that fracture more predictably. The relationship between retouch intensity and Raw Material Type should be significantly stronger in later assemblages, if the discontinuity hypothesis is correct.

For locally reduced raw materials, the ratio of retouched to unretouched blanks measures retouch intensity. In contrast, the retouch intensity of non-local raw materials cannot be measured directly, because is unlikely that the entire population of blanks struck from cores of non-local raw materials was transported to the site where they were found. In level XI of Le Flageolet, for example, there was a clear selection of smaller blanks for transport. This means that the size of the initial population of blanks from the reduction of non-local raw materials is unknown, and so therefore is the ratio of retouched to unretouched objects. In all likelihood, the observed ratio of retouched to unretouched blanks exaggerates the true retouch intensity of non-local raw materials.

Tables 5.46 and 5.47 show the frequencies of retouched objects in level H8 of Le Moustier and level M3 of Caminade Est, respectively (based on all objects weighing $\geq 1$ gram, of course). The insignificant $G^2$ statistics for both may be related to the low

sample sizes of non-local raw materials in these assemblages. It could also reflect a true absence of differential retouch intensity as a method of conserving raw material.

For level G of Caminade Est, Table 5.48 shows clear differences in retouch frequency between raw material types. In this table, figures in boldface indicate significant positive standardized deviates, while underlined figures indicate significant negative standardized deviates. The highest values occur in one non-local raw material (Bergeracois) and two for which source distances are unknown (jasper and porcelainite). Beige Senonian was not retouched at all, even though locally available and relatively well represented in the assemblage. The high retouch frequency in Bergeracois may result from more intense retouching. If so, these data are consistent with Demars' (1996) observation that Bergeracois was preferred for the manufacture of blade tools. Alternatively, a high retouch frequency may result from the preferential transport of technological products tending to be retouched the most, and not from a higher retouch intensity. I refer to this preferential transport as transport bias.

One way to resolve this question is to test the following null hypothesis:

> $H_0$: The proportion of retouched objects in the raw material in question is equal to the proportion of retouched objects in the assemblage as a whole, given the technological composition of that raw material in the assemblage and the proportions of retouched objects in each technological type.

Typically, the retouched blanks in an assemblage do not resemble a simple random sample of blanks. Close examination of the six assemblages revealed that tools tend to be made on large semi- or non-cortical blanks, and in some cases, blades are more likely than flakes to be retouched. These patterns result in significant associations between Retouch Frequency and various technological variables, such as Cortex

Amount, Object Type, Blank Type, or Weight Class. At the same time, as the above examination has shown, there are significant differences between raw materials in frequencies of technological types and blank types.

These relationships can be exploited to test the above null hypothesis for raw materials showing significantly high retouch frequencies. If those frequencies arise solely because of the chance co-occurrence of two kinds of associations—that is, if they represent a spurious association—then two conditions should obtain. First, there should be a significant association between RM Type and the technological variable that is also associated with retouch frequency. Second, when we examine the association between RM Type and Retouch Frequency by levels of the variable in question, the significant associations should disappear.

The first row of Table 5.49 shows a significant association between RM Type and Retouch in level G of Caminade Est. The second row shows that there is also a significant association between RM Type and Technological Type. Table 5.11 shows that Bergeracois is high in blades, jasper is high in cobbles, and porcelainite is low in cobbles (in terms of significant standardized deviates). When we control for levels of the variable Object Type, there is a significant $G^2$ result at three of the levels. Among blades, the association between RM Type and Retouch produced standardized deviates of 3.40 for Bergeracois, 3.07 for jasper, and 5.17 for porcelainite. This indicates that these raw material types have significantly higher retouch frequencies than the others both overall and among blades.

Table 5.49 also shows significant $G^2$ statistics for the association between RM Type and Cortex Amount, and between Retouch and Cortex Amount. Table 5.50 shows the cross-tabulation of frequencies and percentages for RM Type and Cortex Amount.

In this table, "N/A" refers to objects that cannot be assigned a dorsal cortex value: technological types 1a-1c and 8. Five raw material types including jasper, Bergeracois, and porcelainite have more objects with 0% dorsal cortex, and fewer with 50-100% cortex, than the remaining raw materials. Coupled with the fact that Cortex Amount and Retouch are significantly associated, this might suggest that the higher retouch frequencies in jasper, Bergeracois, and porcelainite are due simply to the higher frequencies of non-cortical blanks and lower frequencies of cortical blanks in those raw materials. However, Table 5.49 shows significant associations between RM Type and Retouch at each level of Cortex Amount except N/A.

Finally, Table 5.51 shows the $G^2$ statistics for RM Type and Weight Class. Bergeracois has significantly fewer objects weighing 1.0-4.9 g, and significantly more objects weighing 15.0-29.9 g (observed = 12, expected = 4.8, std. deviate = 3.29). The $G^2$ statistics are significant for every level of the variable Weight Class (Table 5.49).

These analyses demonstrate that the higher frequencies of retouch in jasper, Bergeracois, and porcelainite are not due simply to the higher frequencies of certain blank types (defined in terms of Object Type, CTX, or WT_CLASS) that these raw materials have. These raw materials are retouched more than others, regardless of the technological composition of each raw material type. This suggests that the high retouch frequencies of these raw materials are independent of any transport bias that may have affected their technological composition.

In level III of La-Côte, there is a significant association between Retouch Frequency and RM Type (Table 5.52). However, despite wide variation in the frequencies of retouch among the various raw material types, the only significant standardized deviate is a negative one for beige Senonian and "Retouched". The dearth

of significant standardized deviates may result from the low sample sizes of all raw material types except black Senonian.

Table 5.53 provides one clue to this puzzle. It shows that technological type 2a (non-cortical flake) is retouched significantly less than other types. Non-cortical blades (4c) have significantly more tools and fewer raw blanks. As Table 5.10 shows, beige Senonian has more non-cortical flakes than either black Senonian or Bergeracois, but is deficient in non-cortical blades. This may in part explain the lack of retouch in beige Senonian.

Is the association between RM Type and Retouch Frequency real or spurious? The summary of $G^2$ results for variable pairs in Table 5.54 suggests that it is spurious. RM Type and Retouch Frequency are both significantly associated with Object Type. However, when we examine the relationship between RM Type and Retouch Frequency at the individual levels of Object Type, the only significant association occurs among flakes. A similar situation obtains when we consider the variable Cortex Amount. That variable has a significant association with both RM Type and Retouch Frequency, but there is no significant association with Retouch Frequency at the individual levels of Cortex Amount. The association between Retouch Frequency and Weight Class is not significant.

Taken together, these observations suggest that the apparent association between RM Type and Retouch Frequency results from a transport bias among some raw material types that led to higher frequencies of the types of blanks that tend to be retouched most frequently. Table 5.55 supports this hypothesis: it shows a significantly high frequency of non-cortical blanks in jasper, which has a higher retouch frequency than any other raw material (although that frequency is not statistically significant; see

Table 5.52). There also may have been a transport bias resulting in lower frequencies of non-cortical blades in beige Senonian (Table 5.10), which has a significantly low retouch frequency.

Turning to level XI of Le Flageolet I, Table 5.56 shows the cross-tabulation of frequencies and percentages for RM Type and Retouch. Retouch frequencies are high for Bergeracois, jasper, Mussidan, Jurassic, and porcelainite, significantly so for Bergeracois. All these raw materials appear, by their technological compositions (Table 5.12), to have been reduced off-site. Thus, a transport bias could have affected retouch frequencies in these raw materials.

Table 5.57 shows that in the assemblage as a whole, non-cortical fragments (4b), non-cortical blades (4c), and core reduction tablets (7b) were retouched more than other blank types, significantly so in the case of types 4b and 4c. Do raw materials with higher retouch frequencies also have higher frequencies of these technological types? Table 5.12 shows that Bergeracois, Mussidan, Jurassic, and porcelainite do have significantly more non-cortical blades (4c) than other raw materials. Porcelainite is also high in non-cortical fragments (type 4b). Bergeracois is low in cortical flakes (2a), which are retouched somewhat less than other technological types. In addition, chalcedony/millstone, which is significantly high in non-cortical flakes, has a low retouch frequency. This suggests a transport bias may have contributed to a false impression that these raw materials were retouched more intensively than local raw materials in level XI of Le Flageolet I.

I examined this question more closely by analyzing the relationships between RM Type, Retouch Frequency, and each of three additional variables: Object Type, Cortex Amount, and Weight Class. Table 5.58 shows the summary of associations between the

various variable pairs. Object Type, Cortex Amount, and Weight Class all show significant associations with both Retouch Frequency and RM Type. For each of the three variables, if the association between RM Type and Retouch Frequency is real, then that association should hold at each level of the variable.

In the case of Object Type, there is a significant association between RM Type and Retouch Frequency among fragments, blades, and chunks, but not among flakes or cobbles. Fragments and blades tend strongly to be retouched, and flakes and chunks tend strongly not to be retouched in this assemblage (Table 5.59). Chunks of all raw materials were retouched in uniformly low frequencies. Blades and fragments were retouched in high frequencies among all raw materials, while flakes were retouched in frequencies that differed from one raw material to the next. Therefore, if transport bias affected retouch frequencies, its effect would be largest among blades and fragments, and this might lower the $G^2$ values in those levels of Object Type. Yet, the $G^2$ values are significant for blades and fragments. Thus, the higher retouch frequencies of Bergeracois, jasper, Mussidan, Jurassic, and porcelainite probably reflects a true retouch bias in those raw materials, and not simply a transport bias in favor of blades and fragments.

There is a significant association between RM Type and Cortex Amount only among non-cortical blanks and objects assigned to "N/A" (cobbles, cores, and chunks). Those raw materials with higher retouch frequencies overall (Bergeracois, jasper, Mussidan, Jurassic, and porcelainite) also have higher than average percentages of non-cortical blanks; the difference is significant for Bergeracois (Table 5.60). Non-cortical fragments and blades have significantly high retouch frequencies among all technological types (Table 5.57). Therefore, the lack of significant associations between

RM Type and Retouch among cortical and semi-cortical blanks may be at least partly a function of the low retouch frequencies in those categories overall, and the significant association at the 0% cortex level may reflect the higher overall retouch frequencies of types 4b and 4c. Nevertheless, the evidence is not entirely clear.

Table 5.61 shows significant associations between RM Type and Retouch Frequency across all Weight Class levels except the largest, ≥ 30 g, in level XI of Le Flageolet I. If the raw material types with the highest retouch frequencies had significantly fewer objects in that weight class, then the higher retouch frequencies would appear spurious. That is not the pattern that emerges from Table 5.61: the frequency of objects weighing ≥ 30 in Bergeracois is statistically identical to the frequencies in other raw materials.

These observations show that the higher frequencies of retouched objects in Bergeracois, jasper, Mussidan, Jurassic, and porcelainite are at least partly the function of a true retouch bias in favor of those raw materials, even when the technological composition and blank composition in each raw material are accounted for. Differential transport may have biased the technological composition of each raw material, and it may account for some of the variation in retouch frequencies among raw material types and among cortex categories. However, those biases would not fully explain the significant differences in Retouch Frequency.

Turning to the late Aurignacian assemblage from level IX of Le Flageolet I, Table 5.62 shows the frequencies of retouched and unretouched objects in each raw material. The four non-local raw materials, along with jasper, have higher retouch frequencies than the other raw materials, although the figure is significant only in the case of Bergeracois (which also happens to have the largest sample size among those five). A

comparison of Table 5.13 with Tables 5.62 and 5.63, and examination of the standardized deviates (not shown) associated with cells of those tables, suggests that these results may only be an artifact of the technological composition of each raw material type. The most frequently retouched raw materials happen to have high frequencies of some of the most frequently retouched blank types, and the least frequently retouched raw materials happen to have high frequencies of the least frequently retouched blank types. For example, black and beige Senonian chert, which were retouched with the same frequency as the overall assemblage frequency (13%), have relatively high frequencies of semi-cortical and non-cortical flakes, two types that are retouched in significantly low frequencies. Black Senonian has significantly few non-cortical fragments, a type that was retouched with a significantly high frequency.

I compared the $G^2$ results from the associations of RM Type and Retouch Frequency with those from the associations of RM Type and a third variable (Object Type, Cortex Amount, or Weight Class), along with the results from the associations of Retouch Frequency and that third variable by levels of the variable. Table 5.64 summarizes the associations between these various variable pairs for level IX. In each case, the association between RM Type and the variable in question is significant. Each of those variables also shows a significant association with retouch. In addition, Bergeracois chert, which is the only raw material with a significantly high retouch frequency, also has high frequencies of kinds of objects most likely to be retouched (non-corticial fragments and blades; see Table 5.13 or Tables 5.65 and 5.66). Yet, the associations between RM Type and Retouch Frequency are also significant at each level of the variable in question, except for "Cobble" under Object Type. This is not the expected result if the RM-Retouch associations were simply artifacts of the blank

composition of each raw material type. Thus, I conclude that the high percentage of tools among Bergeracois chert reflects a greater retouch intensity. In addition, the lower retouch frequencies for quartzite and basalt resulted from a bias against blanks of those raw materials for tool making in level IX of Le Flageolet I.

Blank:core ratios

Core reduction intensity relates to raw material conservation, because it measures the proportion of material that was fashioned into potential tools. For each raw material that was reduced *in situ*, the ratio of blanks to cores indicates core reduction intensity, in part. For a material reduced elsewhere and imported to the site, the ratio of blanks to cores gives an indication of the form of transport only. Comparing the blank:core ratios for raw materials reduced *in situ*, as determined from the above analyses of cores and technological composition, should help determine whether source distance, natural availability, or fracture properties contributed to variation in core reduction intensity.

Obviously, this comparison can only be carried out for raw materials that were apparently reduced at each site. As Tables 5.8-5.13 show, this leaves only three assemblages for which an inter-raw material blank:core ratio analysis is appropriate: level G of Caminade Est (early Aurignacian), level III of La-Côte, (Châtelperronian), and level IX of Le Flageolet I (late Aurignacian). In calculating blank:core ratios, I counted technological types 1a (cobble/nodule), 1b (prepared core), and 1c (reduced core) as "cores", since each represents a block of material that was transported, whether reduced or not. I counted types 2a-7d as blanks.

In level G of Caminade Est, jasper is the only raw material that is not certainly of local origin and that is represented by at least one core. Unfortunately, this jasper may

have been obtained from local, intermediate, or distant sources. A significantly higher blank:core ratio in jasper than in Senonian chert or chalcedony/millstone might indicate a non-local origin for the jasper. Table 5.67 shows blank:core ratios for each raw material that has cores in Caminade Est level G. The position of jasper, which is intermediate between the Senonian cherts on the one hand and chalcedony/millstone on the other hand, does not suggest that jasper was reduced more intensively than local cherts. The large range of values among local cherts (black Senonian, beige Senonian, indeterminate Senonian, and chalcedony/millstone) suggests either that core reduction intensity ranges widely, or that there are factors other than source distance that may have affected blank:core ratios, such as fracture properties or transport bias.

In level III of La-Côte, cores are present among black and beige Senonian chert, silicified wood, and Bergeracois chert (Table 5.68). The first three are locally available, while the last is only available from distances of 19 km or more. Although there is wide variation in the blank:core ratios of the local stones, the blank:core ratio of Bergeracois is smaller than those of all three.

In level IX from Le Flageolet I, Bergeracois chert has the highest blank:core ratio (Table 5.69). There is wide variation in values among the remaining raw material types, all of which are local, with the possible exception of porcelainite, the geologic provenience of which is unknown.

**Summary of results**

The assemblages all have certain traits in common. In each, local Senonian chert is far more abundant than other raw material types, and black Senonian is more abundant than the beige variety (despite the higher natural abundance of the latter). Black Senonian chert was always imported in the form of raw blocks, and all phases of

reduction are represented. Generally, the kinds of objects imported represent successively more advanced phases of reduction for progressively more distant raw material occurrences, although there are important exceptions. In all cases, the raw materials with the most distant occurrences were imported as blanks, retouched or not. In spite of my clear intention to base my conclusions on statistical analyses involving comparisons of local with non-local raw materials, each assemblage insisted on having such small amounts of non-local raw materials as to make many such comparisons difficult or impossible. This severely constrained the number of analyses that could be done successfully, and led to some uncertainty even when patterns seemed to emerge. In most cases, it was not possible to compare core attributes or blank:core ratios because cores of non-local raw material were rare or absent. Apart from these similarities, the assemblages differ in many ways.

The assemblage from level H8 of Le Moustier was more dominated by local black and beige Senonian than most. The few artifacts made of other raw materials were imported as blanks, some of which were retouched. Most blanks are flakes, and these are mostly ordinary flakes, although there are significant numbers of Levallois products, *éclats débordants*, and crested blanks. This, and the lack of blade production methods on the 24 analyzed cores, shows a strong focus on flake production, which was done with various methods including Levallois. It was not possible to identify significant patterns of association between Raw Material Type and blank composition, core categories, retouch frequency, or blank:core ratios, probably because of the extremely low frequency of all raw materials other than Senonian chert. Nor was it possible to test the blank portability and distance/attrition hypotheses. However, it was possible to show that beige Senonian cores have a significantly higher number of striking surfaces

(usually two) than black Senonian cores (usually one), indicating that the former may have been exploited more intensively.

Level M3 of Caminade Est was also very dominated by local Senonian chert. Black Senonian was reduced in situ from raw blocks of material; the few blanks of beige Senonian and porcelainite were probably struck from cores that were not recovered; a well-rounded river cobble of Jurassic chert was reduced in situ; while chalcedony/millstone, Bergeracois, jasper, and quartzite were all imported as blanks and/or tools. Various methods were used to produce flakes, blades, and Levallois blanks, with a strong focus on ordinary flakes. There are more blades and fewer Levallois products than in level H8 from Le Moustier. As in the latter assemblage, small sample sizes make comparisons between raw material types difficult, and make it impossible to examine most kinds of evidence on differential RME. The only significant result is the absence of Levallois blanks among beige Senonian, compared with frequencies of 9-11% in blanks of black and indeterminate Senonian.

The lone Châtelperronian assemblage examined, level III of La-Côte, is distinct from all the other assemblages in several ways. Its blank composition and core attributes show a narrow focus on the production of relatively small blades. Black and beige Senonian, Bergeracois, and silicified wood were imported in the form of raw blocks, which were reduced, and tools were made on the blanks produced. Technological composition suggests that black Senonian may have been reduced more intensively than beige Senonian or Bergeracois. Jasper blanks were probably struck from a walking core, while pink speckled chert was imported in the form of blanks. Unlike the five other assemblages, La-Côte III shows a distinct difference between black and beige Senonian in blank composition, with beige Senonian being less laminar.

Bergeracois is about as laminar as all other raw materials (except beige Senonian), which differs from Demars' (1994) conclusion about Bergeracois and blade technology. Beige Senonian blanks were retouched the least, and jasper blanks the most, but this is a side-effect of technological composition: non-cortical blades, which are retouched significantly more than other blank types, are significantly rare in beige Senonian but abundant in jasper. The distance/attrition hypothesis is supported for jasper and Bergeracois, meaning that tools of these raw materials shrunk during transport because of continual use and repair, and that this phenomenon was absent or much less pronounced in local raw materials. There is wide variation in the blank:core ratios of raw material types, with Bergeracois (a non-local type) having the lowest ratio. This seems to suggest that Bergeracois was used less efficiently than other raw materials, which are cheaper to acquire.

In level G of Caminade Est, raw materials differ in how the manufacture process was partitioned over space. Some of the differences relate to differences in source distance, wherein the materials occurring further away from Caminade were introduced in progressively more reduced forms. Other differences are harder to explain, such as the significantly high frequency of cores in jasper, relative to the products of early phase reduction, which are all but absent in jasper. Basalt and quartzite are represented almost entirely by chunks, suggesting a markedly different pattern of use from the cherts. Blades were produced somewhat more frequently than flakes, significantly so in the case of Bergeracois. Several methods were used to strike flakes and blades. There is some evidence of greater core reduction intensity (inferred from Cortex Amount) for jasper and chalcedony/millstone than with Senonian chert, but low sample sizes prevent definitive conclusions. Data on blank weights show that tools are larger than raw blanks,

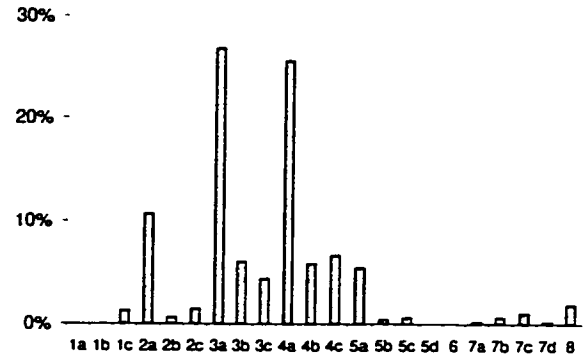
but the difference is similar for all raw material types (when Blank Type is controlled). Thus, there is no evidence of raw material conservation relating to either blank portability or curation during transport (distance/attrition). However, there is evidence of raw material conservation through increased retouch intensity for three raw materials: Bergeracois (non-local), jasper, and porcelainite (both of unknown source distances). Blank:core ratios vary widely but provide no conclusive evidence on technological efficiency because of an absence of cores for any raw material that was definitely acquired from non-local sources.

There are four patterns relating to the spatial partitioning of manufacture in level XI from Le Flageolet I: (1) Senonian chert of both types was imported as raw blocks and reduced in situ; (2) Bergeracois and chalcedony/millstone were imported as blanks or struck from walking cores; (3) jasper, Gavaudun, Mussidan, Jurassic, and porcelainite were imported as blanks, some of which were retouched; (4) quartzite and basalt were imported as cobbles, which were probably used as hammerstones. The differences relate partly to source distances, and partly to unknown factors. Most of the analyzed cores were used primarily to strike flakes, and these flake cores show a variety of blank production methods with an emphasis on simple, relatively non-intensive reduction. Flakes are far more abundant than blades, and most are ordinary flakes; Levallois and Kombewa are absent. In contrast, nine of the ten blade cores were relatively complex ones showing efforts to create a long, narrow debitage surface (or two) constricted by wide adjacent surfaces. Bergeracois has a somewhat higher frequency of blade blanks, but the difference is not significant. There are no cores made of non-local raw materials. Non-local blanks brought to the site were a biased sample of the original blank pool, resulting from a selection for smaller blanks with little cortex. Furthermore, non-local

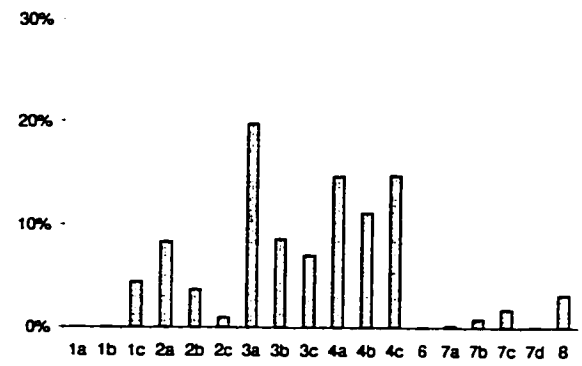
blanks show somewhat greater size attrition from use and repair than local blanks do. Both of these patterns are evidence for raw material conservation. Three non-local raw materials—Bergeracois, Mussidan, and Jurassic—and two of unknown source locations—jasper, porcelainite—have significantly higher retouch frequencies than other raw materials, and this is at least partly due to raw material conservation.

In level IX from Le Flageolet I, there are three patterns of reduction; (1) black and beige Senonian (local), Bergeracois (non-local), chalcedony/millstone (local), and porcelainite (unknown distance) were all imported as nodules or cores, albeit in very different quantities, and were reduced in situ; (2) Jasper, Fumelois, and Jurassic (all non-local) were imported as blanks and/or tools in small amounts; (3) quartzite and basalt were imported as cobbles and probably used as hammerstones, although there are some blanks and one tool of each, indicating some deliberate blank production. This assemblage and La-Côte are the only in which Bergeracois was imported as raw blocks or cores rather than blanks. The overall technological composition of the assemblage is very similar to that of level XI, indicating that all phases of reduction were carried out and that blank production was oriented more towards flakes than blades. The cores show a variety of production methods, including small blade cores with lateral maintenance and narrow debitage surfaces. As in level G of Caminade Est, Bergeracois is significantly more laminar than other raw material types. Perhaps because Bergeracois was imported mainly or wholly in the form of raw blocks, there is no evidence supporting either the blank portability or distance/attrition hypotheses. There is one interesting difference in blank weights: retouched blades of Senonian are much smaller than retouched flakes of Senonian or Bergeracois. Unfortunately, there is insufficient data to explain this anomaly. Despite this lack of evidence for increased technological efficiency

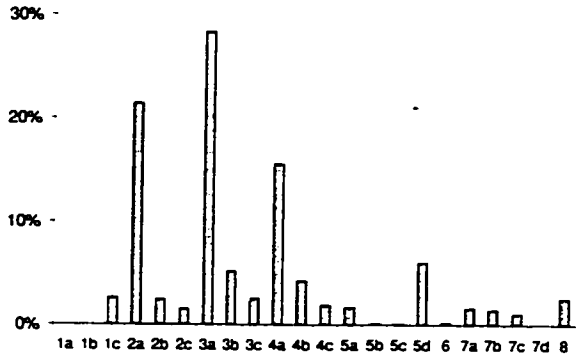
in the use of Bergeracois, there is one kind of evidence for such an increase in the significantly higher retouch frequency among Bergeracois blanks. This may well be related to fracture properties rather than to acquisition costs.



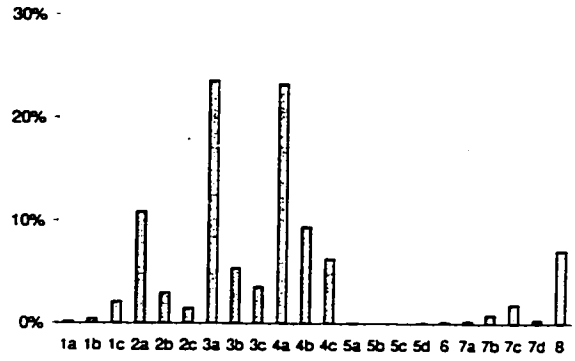

Caminade Est, M3 (n = 477)



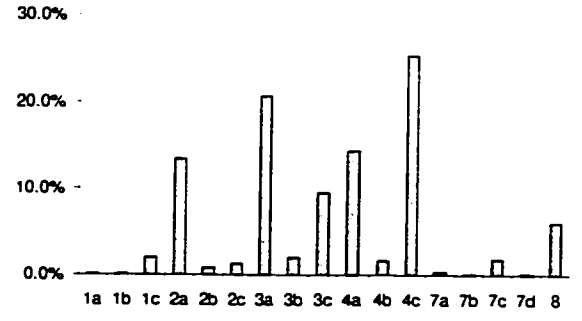

Caminade Est, G (n = 3084)



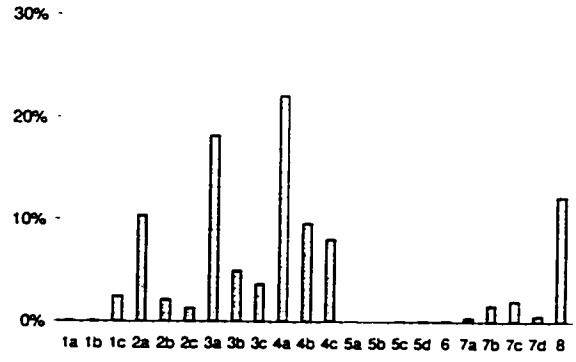

Le Moustier, H8 (n = 1074)




Le Flageolet I, XI (n = 2751)

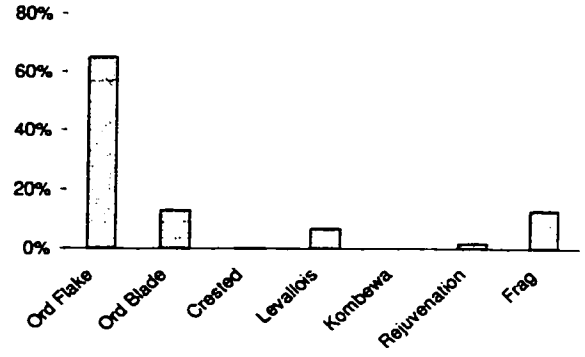



La Côte, III (n = 610)

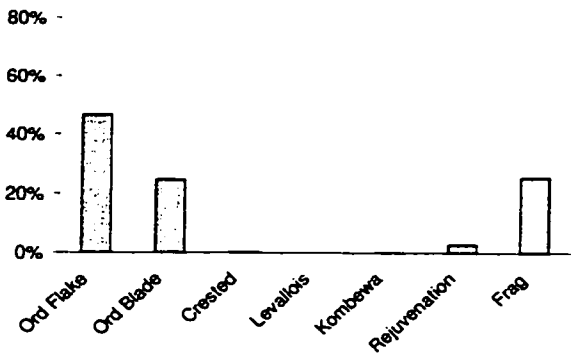



Le Flageolet I, IX (n = 5967)

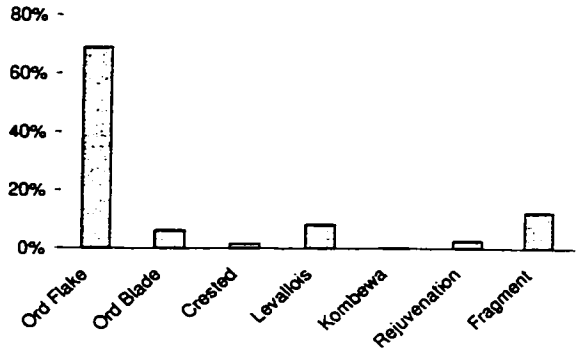
Figure 5.1 Technological composition of the assemblages.



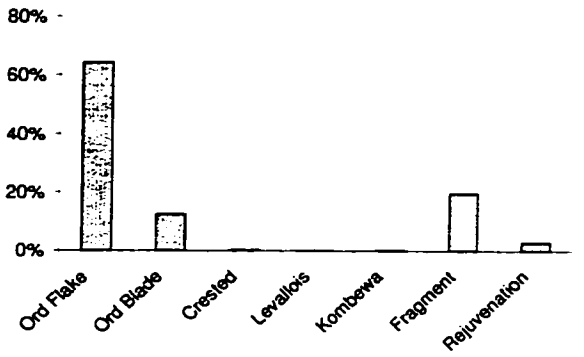

Caminade Est, M3



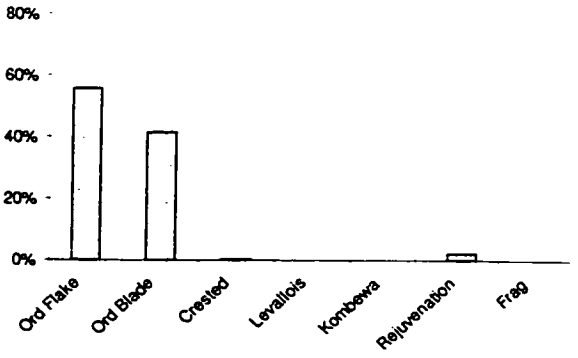

Caminade Est, G



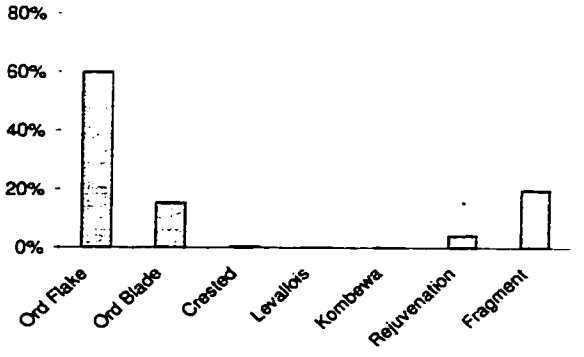

Le Moustier, H8




Le Flageolet I, XI




La Côte, III




Le Flageolet I, IX

Figure 5.2 Blank composition of each assemblage.

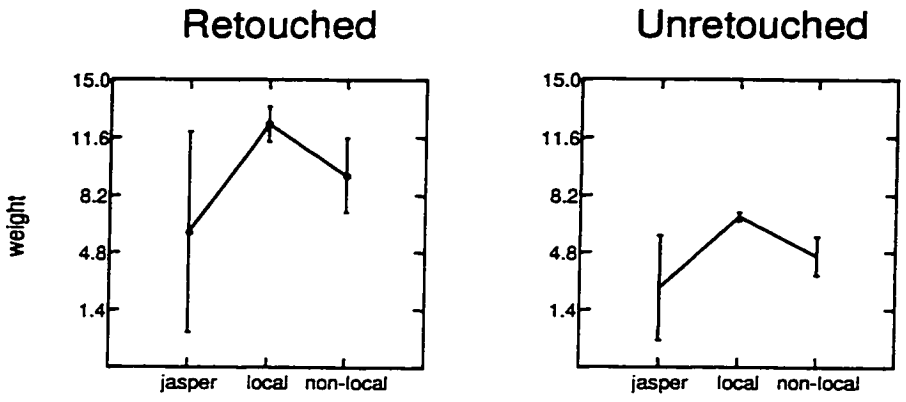



Figure 5.3 Le Flageolet I, XI. Mean weights (g) of jasper, local, and non-local raw materials, retouched and unretouched.

Table 5.1 Chipped stone artifacts

| Object Class | Defining attributes |
|---|---|
| Cobble/nodule | No ventral face, no flake scars |
| Flaked cobble | No ventral face, and one or more flake scars |
| Blank | One ventral face, with or without flake scars |
| Chunk | Cannot be determined whether it has a ventral face, either because of alteration after manufacture, non-recognizable fracture, etc. One or more flake scars. |

Table 5.2 Technological typology.

| Code | Description |
|---|---|
| 1a | Cobble or nodule, raw or tested |
| 1b | Prepared core, unworked |
| 1c | Worked core |
| 2a | Flake, 50-100% dorsal cortex |
| 2b | Fragment, 50-100% dorsal cortex |
| 2c | Blade, 50-100% dorsal cortex |
| 3a | Flake, 1-49% dorsal cortex |
| 3b | Fragment, 1-49% dorsal cortex |
| 3c | Blade, 1-49% dorsal cortex |
| 4a | Flake, 0% dorsal cortex |
| 4b | Fragment, 0% dorsal cortex |
| 4c | Blade, 0% dorsal cortex |
| 5a | Levallois flake |
| 5b | Levallois blade |
| 5c | Levallois point |
| 5d | Éclat débordant |
| 6 | Kombewa flake |
| 7a | Partially or fully crested blank (blade or flake) |
| 7b | Core rejuvenation tablet |
| 7c | Other rejuvenation blank |
| 7d | Burin spall |
| 8 | Chunk |

Table 5.3 Inventory of cores by assemblage.

| Site | Level | Number of cores | Number analyzed | Percentage analyzed |
|---|---|---|---|---|
| Le Moustier | H8 | 27 | 24 | 89% |
| Caminade Est | M3 | 5 | 5 | 100% |
| Caminade Est | G | 138 | 78 | 57% |
| La Côte | III | 14 | 0 | 0% |
| Le Flageolet I | XI | 68 | 51 | 75% |
| Le Flageolet I | IX | 152 | 115 | 76% |
| Total | | 404 | 273 | 68% |

Table 5.4 Description of core categories. SP = striking platform, DS = debitage surface.

| Code | Description | Primary Products |
|---|---|---|
| 1A | Simple blade core, 1 SP | blades |
| 1B | Simple flake core, 1 SP | flakes |
| 2A | Prepared flake, 1 SP | flakes |
| 2B | Prepared flake, 2 SPs, oriented at 90° | flakes |
| 2C | Prepared flake, 2 SPs oriented at 180° | flakes |
| 3 | Cuboid flake core, with several | flakes |
| 4A | Globular w/multiple SPs and/or crests | flakes |
| 4B | Blocky core w/multiple SPs | flakes |
| 5 | Flake tablet | flakes |
| 6 | Kombewa flake core | flakes |
| 7 | Flake DS on narrow face | flakes |
| 8 | Prepared flake core on truncated flake | flakes |
| 9 | Wedge-shaped core w/SP and crest | flakes |
| 10A | Discoidal w/crest, bifacial DS | flakes |
| 10B | Plano-convex, 1 DS, on convex face | flakes |
| 10D | Plano-convex, 1 DS, on plane face | flakes |
| 10E | Plano-convex, 1 DS, made on a flake | flakes |
| 11A | Levallois, unifacial removals | flakes |
| 11B | Levallois, bifacial removals | flakes |
| 12A | Blade core without maintenance, 1 SP | blades/bladelets |
| 12B | Blade core without maintenance, 2 SP | blades/bladelets |
| 13A | Blade core w/maintenance, 1SP, narrow DS (1-2 flake scars wide) | blades/bladelets |
| 13B | Blade core w/maintenance, 2 SP, narrow DS (1-2 flake scars wide) | blades/bladelets |
| 14A | Blade core w/maintenance, 1SP, wide DS (> 2 flake scars wide) | blades |
| 14B | Blade core w/maintenance, 2 SPs, wide DS (> 2 flake scars wide) | blades |
| 15 | Blade core, pyramidal, 1 SP | blades |
| 99A | Indeterminate, complex | flakes |
| 99B | Indeterminate, fragmented | flakes or blades |

Table 5.5 Observed frequencies and percentages of cores in each core category, by assemblage.

| Core Category | Le Moustier, H8 | | Caminade Est, M3 | | Caminade Est, G | | Le Flageolet I, XI | | Le Flageolet I, IX | | Grand Total | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1A: Simple blade core, 1 SP | | | | | 4 | 5% | | | 2 | 2% | 6 | 2% |
| 1B: Simple flake core, 1 SP | 2 | 8% | | | 2 | 3% | 9 | 18% | 8 | 7% | 21 | 8% |
| 2A: Prepared flake, 1 SP | 3 | 13% | | | 10 | 13% | 3 | 6% | 9 | 7% | 25 | 9% |
| 2B: Prepared flake, 2 SPs at 90° | 2 | 8% | 1 | 20% | 6 | 8% | 2 | 4% | 3 | 3% | 13 | 5% |
| 2C: Prepared flake, 2 SPs at 180° | 3 | 13% | | | 2 | 3% | 2 | 4% | | | 7 | 3% |
| 3: Cuboid Flake | 2 | 8% | | | 1 | 1% | 3 | 6% | 7 | 6% | 13 | 5% |
| 4A: Globular w/multiple SP/crest | | | | | 2 | 3% | 3 | 6% | 2 | 2% | 7 | 3% |
| 4B: Blocky w/multiple SP | | | 1 | 20% | 2 | 3% | 4 | 8% | 2 | 2% | 9 | 3% |
| 5: Flake tablet | | | | | 1 | 1% | | | 2 | 2% | 3 | 1% |
| 6: Kombewa flake core | | | 1 | 20% | | | | | 1 | 1% | 2 | 1% |
| 7: Flake DS on narrow face | 1 | 4% | | | | | 1 | 2% | 3 | 3% | 5 | 2% |
| 8: Prep Flake DS on truncated flake | 2 | 8% | | | | | | | | | 2 | 1% |
| 9: Wedge shaped w/SP and crest | | | | | | | | | 1 | 1% | 1 | 0% |
| 10A: Discoidal, crest, bifacial DS | | | 1 | 20% | 1 | 1% | 3 | 6% | 3 | 3% | 8 | 3% |
| 10B: Plano/convex, 1 DS convex face | 2 | 8% | | | | | 5 | 10% | 10 | 9% | 17 | 6% |
| 10D: Plano/convex, 1 DS plane face | 1 | 4% | | | | | | | | | 1 | 0% |
| 10E: Plano/convex, 1 DS on flake | 1 | 4% | | | | | | | 1 | 1% | 2 | 1% |
| 11A: Levallois, unifacial | 1 | 4% | | | | | | | | | 1 | 0% |
| 11B: Levallois, bifacial | 3 | 12% | | | | | | | | | 3 | 1% |
| 12A: Blade core w/o maintenance, 1 SP | | | | | 4 | 5% | | | | | 4 | 1% |
| 12B: Blade core w/o maintenance, 2 SP | | | | | 2 | 3% | 1 | 2% | 2 | 2% | 5 | 2% |
| 13A: Blade w/maintenance, 1SP narrow | | | | | 6 | 8% | 5 | 10% | 21 | 18% | 32 | 12% |
| 13B: Blade w/maintenance, 2SP narrow | | | | | 1 | 1% | 3 | 6% | 6 | 5% | 10 | 4% |
| 14A: Blade w/maintenance, 1SP wide | | | 1 | 20% | 15 | 19% | | | 5 | 4% | 21 | 8% |
| 14B: Blade w/maintenance, 2SP wide | | | | | 9 | 12% | | | 2 | 2% | 11 | 4% |
| 15: Blade, pyramidal, 1SP | | | | | 2 | 3% | | | | | 2 | 1% |
| 99A: Indeterminate, complex | 1 | 4% | | | 5 | 6% | 5 | 10% | 10 | 9% | 21 | 8% |
| 99B: Indeterminate, fragmented | | | | | 3 | 4% | 1 | 2% | 15 | 13% | 19 | 7% |
| Grand Total | 24 | 100% | 5 | 100% | 78 | 100% | 50 | 100% | 115 | 100% | 271 | 100% |

Table 5.6 Core variables: frequencies and percentages for each assemblage.

| | Moust. H8 | | Cam Est M3 | | Cam Est G | | Flag XI | | Flag IX | |
|---|---|---|---|---|---|---|---|---|---|---|
| *Origin* | Total | % | Total | % | Total | % | Total | % | Total | % |
| Frost spall | | | | | | | 2 | 3.9% | 3 | 2.6% |
| Flake | 6 | 25.0% | 1 | 20.0% | 3 | 3.8% | 6 | 11.8% | 14 | 12.2% |
| Nodule | 9 | 37.5% | 1 | 20.0% | 60 | 76.9% | 35 | 68.6% | 64 | 55.7% |
| Unknown | 9 | 37.5% | 3 | 60.0% | 15 | 19.2% | 8 | 15.7% | 34 | 29.6% |
| Total | 24 | | 5 | | 78 | | 51 | | 115 | |
| *Blanks* | | | | | | | | | | |
| Flake | 23 | 95.8% | 3 | 60.0% | 31 | 39.7% | 35 | 68.6% | 51 | 44.3% |
| Blade | | | 1 | 20.0% | 37 | 47.4% | 8 | 15.7% | 30 | 26.1% |
| Mix | 1 | 4.2% | 1 | 20.0% | 7 | 9.0% | 8 | 15.7% | 30 | 26.1% |
| Unknown | | | | | 3 | 3.8% | | | 4 | 3.5% |
| Total | 24 | | 5 | | 78 | | 51 | | 115 | |
| *Strik. surf. type* | | | | | | | | | | |
| SP | 22 | 91.7% | 4 | 80.0% | 67 | 85.9% | 46 | 90.2% | 99 | 86.1% |
| Crest | 2 | 8.3% | 1 | 20.0% | 1 | 1.3% | 1 | 2.0% | 4 | 3.5% |
| Mix | | | | | 2 | 2.6% | 2 | 3.9% | 7 | 6.1% |
| Unknown | | | | | 8 | 10.3% | 2 | 3.9% | 5 | 4.3% |
| Total | 24 | | 5 | | 78 | | 51 | | 115 | |
| *DS orientation* | | | | | | | | | | |
| Linear | 15 | 62.5% | 4 | 80.0% | 70 | 89.7% | 47 | 92.2% | 96 | 83.5% |
| Centripetal | 7 | 29.2% | 1 | 20.0% | 1 | 1.3% | 2 | 3.9% | 10 | 8.7% |
| Mix | | | | | | | | | 3 | 2.6% |
| Unknown | 2 | 8.3% | | | 7 | 9.0% | 2 | 3.9% | 6 | 5.2% |
| Total | 24 | | 5 | | 78 | | 51 | | 115 | |
| *Maintenance* | | | | | | | | | | |
| Absent | 21 | 87.5% | 3 | 60.0% | 40 | 51.3% | 37 | 72.5% | 73 | 63.5% |
| Lateral | | | | | 25 | 32.1% | 8 | 15.7% | 27 | 23.5% |
| Basal | 1 | 4.2% | 1 | 20.0% | 3 | 3.8% | 3 | 5.9% | 3 | 2.6% |
| Both | | | 1 | 20.0% | 3 | 3.8% | 1 | 2.0% | 4 | 3.5% |
| Unknown | 2 | 8.3% | | | 7 | 9.0% | 2 | 3.9% | 8 | 7.0% |
| Total | 24 | | 5 | | 78 | | 51 | | 115 | |

Table 5.7 Total count and weight of each assemblage.

| Site | Level | N[1] | Total weight[2] | n[3] | Sub-total weight[4] |
|---|---|---|---|---|---|
| Le Moustier | H8 | 1099 | 18.611 | 1074 | 18.598 |
| Caminade Est | M3 | 830 | 8.672 | 477 | 8.577 |
| La Côte | III | 1245 | 5.297 | 610 | 5.051 |
| Caminade Est | G | 5779 | 41.005 | 3084 | 39.913 |
| Le Flageolet I | XI | 8668 | 30.171 | 2751 | 29.173 |
| Le Flageolet I | IX | [5]6840 | 57.604 | 5967 | 57.132 |

[1] N = total number of lithic objects in assemblage.

[2] Total weight = weight (kg) of all objects counted in N.

[3] n = number of lithic objects weighing ≥ 1 g; all results in this paper are based on this fraction of each assemblage.

[4] Sub-total weight = weight (kg) of all objects counted in n.

[5] Some screening material from Le Flageolet I, level IX was not counted in this total.

Table 5.8 Le Moustier, level H8: cross-tabulation of observed frequencies and percentages for Raw Material Type (RM Type) and Technological Type. ESD = Estimated Source Distance, in kilometers. $G^2$ = 122.3, df = 144, $p$ = .002.

| | Technological Type | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| RM Type (ESD) | 1c | 2a | 2b | 2c | 3a | 3b | 3c | 4a | 4b | 4c | 5a | 5b | 5c | 5d | 6 | 7a | 7b | 7c | 8 | Grand Total |
| Senonian, black | 22 | 169 | 17 | 11 | 218 | 40 | 19 | 109 | 28 | 14 | 13 | 1 | 1 | 47 | 1 | 14 | 13 | 10 | 14 | 761 |
| (1) | 3% | 22% | 2% | 1% | 29% | 5% | 2% | 14% | 4% | 2% | 2% | 0% | 0% | 6% | 0% | 2% | 2% | 1% | 2% | 100% |
| Senonian, beige | 5 | 40 | 5 | 3 | 55 | 14 | 5 | 31 | 8 | 4 | 5 | | | 10 | | 1 | | | 1 | 187 |
| (1) | 3% | 21% | 3% | 2% | 29% | 7% | 3% | 17% | 4% | 2% | 3% | | | 5% | | 1% | | | 1% | 100% |
| Senonian, indet. | 1 | 9 | 3 | 1 | 16 | | 2 | 9 | 6 | | | | | 4 | 1 | 2 | 1 | 1 | 2 | 58 |
| (1) | 2% | 16% | 5% | 2% | 28% | | 3% | 16% | 10% | | | | | 7% | 2% | 3% | 2% | 2% | 3% | 100% |
| chalc./millstone | | | | | | | | | | 1 | | | | | | | | | | 1 |
| (1) | | | | | | | | | | 100% | | | | | | | | | | 100% |
| quartzite | | | | 1 | | | | | | | | | | | | | | | 1 | 2 |
| (1) | | | | 50% | | | | | | | | | | | | | | | 50% | 100% |
| basalt | | | | | | | | | | | | | | | | | | | 1 | 1 |
| (1) | | | | | | | | | | | | | | | | | | | 100% | 100% |
| Jurassic | | 1 | | | 1 | | | | | | | | | | | | | | | 2 |
| (31) | | 50% | | | 50% | | | | | | | | | | | | | | | 100% |
| Bergeracois | | 1 | | | 2 | | 1 | | | | | | | | | | | | | 4 |
| (33) | | 25% | | | 50% | | 25% | | | | | | | | | | | | | 100% |
| unidentified | | 10 | 1 | | 12 | 1 | | 18 | 3 | 1 | | | | 3 | | | 1 | | 8 | 58 |
| (-) | | 17% | 2% | | 21% | 2% | | 31% | 5% | 2% | | | | 5% | | | 2% | | 14% | 100% |
| Total | 28 | 230 | 26 | 16 | 304 | 55 | 27 | 167 | 45 | 20 | 18 | 1 | 1 | 64 | 2 | 17 | 15 | 11 | 27 | 1074 |
| | 0% | 17% | 2% | 0% | 21% | 2% | 0% | 31% | 5% | 2% | 0% | 0% | 0% | 5% | 0% | 0% | 2% | 0% | 14% | |

Table 5.9 Caminade Est, M3: cross-tabulation of observed frequencies and percentages for Raw Material Type (RM Type) and Technological Type (Tech). ESD = Estimated Source Distance, in kilometers. $G^2 = 127.6$, df = 170, $p = .005$.

| | Technological Type | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| RM Type (ESD) | 1c | 2a | 2b | 2c | 3a | 3b | 3c | 4a | 4b | 4c | 5a | 5b | 5c | 7a | 7b | 7c | 7d | 8 | Grand Total |
| Senonian, black | 2 | 26 | 2 | 2 | 82 | 22 | 12 | 83 | 17 | 24 | 18 | 2 | 3 | 1 | 3 | 3 | 1 | 3 | 306 |
| (1) | 1% | 8% | 1% | 1% | 27% | 7% | 4% | 27% | 6% | 8% | 6% | 1% | 1% | 0% | 1% | 1% | 0% | 1% | 100% |
| Senonian, beige | | 6 | | 1 | 3 | | 1 | 2 | | | | | | | | 1 | | | 14 |
| (1) | | 43% | | 7% | 21% | | 7% | 14% | | | | | | | | 7% | | | 100% |
| Senonian, indet. | 1 | 5 | | 3 | 22 | 4 | 5 | 18 | 4 | 2 | 7 | | | | | | | 1 | 72 |
| (1) | 1% | 7% | | 4% | 31% | 6% | 7% | 25% | 6% | 3% | 10% | | | | | | | 1% | 100% |
| chalced./millstone | | | | | 1 | | | | | | | | | | | | | | 1 |
| (1) | | | | | 100% | | | | | | | | | | | | | | 100% |
| quartzite | | | | | | | | | | 1 | | | | | | | | 2 | 3 |
| (1) | | | | | | | | | | 33% | | | | | | | | 67% | 100% |
| basalt | 1 | | | | | | | | | | | | | | | | | 1 | 2 |
| (1) | 50% | | | | | | | | | | | | | | | | | 50% | 100% |
| jasper | | | | | 2 | | | | | 1 | | | | | | | | | 3 |
| (4) | | | | | 67% | | | | | 33% | | | | | | | | | 100% |
| Jurassic | 1 | | | | | | | | | | | | | | | | | | 1 |
| (1) | 100% | | | | | | | | | | | | | | | | | | 100% |
| Bergeracois | | | | | | | | | 1 | | | | | | | | | | 1 |
| (45) | | | | | | | | | 100% | | | | | | | | | | 100% |
| porcelainite | | 3 | | | 3 | | | 2 | | | 1 | | | | | 1 | | | 10 |
| (-) | | 30% | | | 30% | | | 20% | | | 10% | | | | | 10% | | | 100% |
| unidentified | 1 | 11 | 1 | 1 | 15 | 3 | 3 | 17 | 6 | 4 | | | | | | | | 2 | 64 |
| (-) | 2% | 17% | 2% | 2% | 23% | 5% | 5% | 27% | 9% | 6% | | | | | | | | 3% | 100% |
| Total Count | 6 | 51 | 3 | 7 | 128 | 29 | 21 | 122 | 28 | 32 | 26 | 2 | 3 | 1 | 3 | 5 | 1 | 9 | 477 |
| | 1% | 11% | 1% | 1% | 27% | 6% | 4% | 26% | 6% | 7% | 5% | 0% | 1% | 0% | 1% | 1% | 0% | 2% | |

Table 5.10 La Côte, III: cross-tabulation of observed frequencies and percentages for Raw Material Type (RM Type) and Technological Type (Tech). ESD = Estimated Source Distance, in kilometers. $G^2 = 132.0$, df = 112, $p = .000$.

| | Technological Type | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| RM Type (ESD) | 1a | 1b | 1c | 2a | 2b | 2c | 3a | 3b | 3c | 4a | 4b | 4c | 7a | 7b | 7c | 7d | 8 | Total |
| Senonian, black | 1 | | 7 | 49 | 5 | 4 | 90 | 12 | 46 | 54 | 8 | 120 | 1 | 1 | 8 | 1 | 24 | 431 |
| (1) | (0%) | | (2%) | (11%) | (1%) | (1%) | (21%) | (3%) | (11%) | (13%) | (2%) | (28%) | (0%) | (0%) | (2%) | (0%) | (6%) | (100%) |
| Senonian, beige | | | 1 | 10 | | 1 | 14 | | 2 | 9 | | 5 | | | | | 7 | 49 |
| (1) | | | (2%) | (20%) | | (2%) | (29%) | | (4%) | (18%) | | (10%) | | | | | (14%) | (100%) |
| Senonian, indet. | | | | 2 | | | 5 | | | 1 | 1 | | | | | | | 9 |
| (1) | | | | (22%) | | | (56%) | | | (11%) | (11%) | | | | | | | (100%) |
| silicified wood | | | 1 | 4 | | | 1 | | 3 | | | 4 | 1 | | | | | 14 |
| (2) | | | (7%) | (29%) | | | (7%) | | (21%) | | | (29%) | (7%) | | | | | (100%) |
| jasper | | | | 1 | | | 2 | | | 6 | | 6 | | | 1 | | | 16 |
| (8) | | | | (6%) | | | (13%) | | | (38%) | | (38%) | | | (6%) | | | (100%) |
| pink speckled | | | | | | | 4 | | 3 | 4 | | 1 | | | | | | 12 |
| (9) | | | | | | | (33%) | | (25%) | (33%) | | (8%) | | | | | | (100%) |
| Bergeracois | | 1 | 3 | 10 | | 3 | 9 | | 4 | 9 | | 13 | | | 2 | | 2 | 56 |
| (19) | | (2%) | (5%) | (18%) | | (5%) | (16%) | | (7%) | (16%) | | (23%) | | | (4%) | | (4%) | (100%) |
| unidentified | | | | 6 | | | 1 | | | 5 | 1 | 6 | | | | | 4 | 23 |
| (-) | | | | (26%) | | | (4%) | | (0%) | (22%) | (4%) | (26%) | | | | | (17%) | (100%) |
| Total | 1 | 1 | 12 | 82 | 5 | 8 | 126 | 12 | 58 | 88 | 10 | 155 | 2 | 1 | 11 | 1 | 37 | 610 |
| | (0%) | (0%) | (2%) | (13%) | (1%) | (1%) | (21%) | (2%) | (10%) | (14%) | (2%) | (25%) | (0%) | (0%) | (2%) | (0%) | (6%) | (100%) |

Table 5.11 Caminade Est, G: cross-tabulation of observed frequencies and percentages for Raw Material Type (RM Type) and Technological Type. ESD = Estimated Source Distance, in kilometers. $G^2 = 346.7$, df = 170, $p$ = .000.

| | Technological Type | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| RM Type (ESD) | 1a | 1b | 1c | 2a | 2b | 2c | 3a | 3b | 3c | 4a | 4b | 4c | 6 | 7a | 7b | 7c | 7d | 8 | Total |
| Senonian, black | | 1 | **66** | 100 | 34 | 6 | 237 | 103 | 88 | 165 | 125 | 173 | | 3 | 14 | 19 | 1 | 31 | 1166 |
| (1) | | (0%) | **(6%)** | (9%) | (3%) | (1%) | (20%) | (9%) | (8%) | (14%) | (11%) | (15%) | | (0%) | (1%) | (2%) | (0%) | (3%) | (100%) |
| Senonian, beige | | | 8 | 27 | 5 | 5 | **71** | 21 | 23 | 32 | 21 | 34 | | | 2 | 5 | | 8 | 262 |
| (1) | | | (3%) | (10%) | (2%) | (2%) | **(27%)** | (8%) | (9%) | (12%) | (8%) | (13%) | | | (1%) | (2%) | | (3%) | (100%) |
| Senonian, indet. | | | 34 | 60 | 28 | 5 | **153** | 68 | 42 | 80 | 58 | 75 | | 1 | 4 | 15 | 1 | 7 | 631 |
| (1) | | | (5%) | (10%) | (4%) | (1%) | **(24%)** | (11%) | (7%) | (13%) | (9%) | (12%) | | (0%) | (1%) | (2%) | (0%) | (1%) | (100%) |
| chalced./millstone | | | 2 | 2 | | | 4 | | | 3 | | 2 | | | | | | 3 | 16 |
| (1) | | | (13%) | (13%) | | | (25%) | | | (19%) | | (13%) | | | | | | (19%) | (100%) |
| quartzite | | | | 1 | | | | | | | | | | | | | | 4 | 5 |
| (1) | | | | (20%) | | | | | | | | | | | | | | (80%) | (100%) |
| basalt | | | | | | | | | | | | | | | | | | 6 | 6 |
| (1) | | | | | | | | | | | | | | | | | | (100%) | (100%) |
| jasper | | | **10** | 2 | | 1 | 15 | 5 | 3 | **27** | 17 | 22 | | 1 | 1 | 1 | | 6 | 111 |
| (4) | | | **(9%)** | (2%) | | (1%) | (14%) | (5%) | (3%) | **(24%)** | (15%) | (20%) | | (1%) | (1%) | (1%) | | (5%) | (100%) |
| Fumelois | | | | 1 | | | 3 | 2 | | 3 | | | | | | | | | 9 |
| (39) | | | | (11%) | | | (33%) | (22%) | | (33%) | | | | | | | | | (100%) |
| Bergeracois | | | | 2 | | 3 | 4 | 6 | 6 | 9 | 3 | **19** | | | 2 | | | 1 | 55 |
| (45) | | | | (4%) | | (5%) | (7%) | (11%) | (11%) | (16%) | (5%) | **(35%)** | | | (4%) | | | (2%) | (100%) |
| porcelainite | | | 1 | 5 | 3 | | 24 | 8 | 9 | 25 | **33** | 31 | | | 1 | 7 | | 8 | 155 |
| (-) | | | (1%) | (3%) | (2%) | | (15%) | (5%) | (6%) | (16%) | **(21%)** | (20%) | | | (1%) | (5%) | (0%) | (5%) | (100%) |
| unidentified | 2 | | 16 | 58 | **44** | 10 | 99 | 54 | 46 | 111 | 89 | 102 | 1 | 1 | 2 | 8 | 1 | 24 | 668 |
| (-) | (0%) | | (2%) | (9%) | **(7%)** | (1%) | (15%) | (8%) | (7%) | (17%) | (13%) | (15%) | (0%) | (0%) | (0%) | (1%) | (0%) | (4%) | (100%) |
| Total | 2 | 1 | 137 | 258 | 114 | 30 | 610 | 267 | 217 | 455 | 346 | 458 | 1 | 6 | 26 | 55 | 3 | 98 | 3084 |
| | (0%) | (0%) | (4%) | (8%) | (4%) | (1%) | (20%) | (9%) | (7%) | (15%) | (11%) | (15%) | (0%) | (0%) | (1%) | (2%) | (0%) | (3%) | (100%) |

Table 5.12 Le Flageolet I, XI: cross-tabulation of observed frequencies and percentages for Raw Material Type (RM Type) and Technological Type. ESD = Estimated Source Distance, in kilometers. $G^2 = 800.9$, df = 228, $p = .000$.

| | Technological Type | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| RM Type (ESD) | 1a | 1b | 1c | 2a | 2b | 2c | 3a | 3b | 3c | 4a | 4b | 4c | 5a | 5d | 6 | 7a | 7b | 7c | 7d | 8 | Total |
| Senonian, black | 1 | 3 | 38 | 168 | 49 | 18 | 341 | 72 | 47 | 330 | 116 | 72 | 1 | 1 | 1 | 3 | 13 | 34 | 3 | 37 | 1348 |
| (1) | (0%) | (0%) | (3%) | (12%) | (4%) | (1%) | (25%) | (5%) | (3%) | (24%) | (9%) | (5%) | (0%) | (0%) | (0%) | (0%) | (1%) | (3%) | (0%) | (3%) | (100%) |
| Senonian, beige | 1 | 1 | 11 | 61 | 8 | 12 | 145 | 28 | 26 | 91 | 31 | 27 | | | | 1 | 3 | 6 | | 12 | 464 |
| (1) | (0%) | (0%) | (2%) | (13%) | (2%) | (3%) | (31%) | (6%) | (6%) | (20%) | (7%) | (6%) | | | | (0%) | (1%) | (1%) | | (3%) | (100%) |
| Senonian, indet. | | | 5 | 23 | 6 | 1 | 67 | 13 | 7 | 56 | 32 | 14 | | | 1 | | 2 | 4 | 2 | 13 | 246 |
| (1) | | | (2%) | (9%) | (2%) | (0%) | (27%) | (5%) | (3%) | (23%) | (13%) | (6%) | | | (0%) | | (1%) | (2%) | (1%) | (5%) | (100%) |
| chalc./millstone | | | | 2 | | | 11 | 1 | | 16 | 2 | 2 | | | | | 1 | | | 1 | 36 |
| (1) | | | | (6%) | | | (31%) | (3%) | | (44%) | (6%) | (6%) | | | | | (3%) | | | (3%) | (100%) |
| jasper | | | | 1 | 2 | | 2 | | 1 | 6 | | 2 | | | | | | | | | 14 |
| ( 1) | | | | (7%) | (14%) | | (14%) | | (7%) | (43%) | | (14%) | | | | | | | | | (100%) |
| quartzite | 1 | 3 | | 0 | | | 0 | | | 2 | 1 | | | | | | | | | 51 | 58 |
| (1) | (2%) | (5%) | | (0%) | | | (0%) | | | (3%) | (2%) | | | | | | | | | (88%) | (100%) |
| basalt | 1 | 4 | | 0 | | | 1 | | | 0 | 0 | 1 | | | | | | | | 42 | 49 |
| (1) | (2%) | (8%) | | (0%) | | | (2%) | | | (0%) | (0%) | (2%) | | | | | | | | (86%) | (100%) |
| Jurassic | | | | | | | | | | | 1 | 1 | | | | | | | | | 2 |
| (22) | | | | | | | | | | | (50%) | (50%) | | | | | | | | | (100%) |
| Gavaudun | | | | | | | | | 1 | | 1 | | | | | | | | | | 2 |
| (33) | | | | | | | | | (50%) | | (50%) | | | | | | | | | | (100%) |
| Bergeracois | | | | 4 | 1 | | 18 | 7 | 4 | 29 | 15 | 14 | | | 1 | 1 | 2 | 1 | 2 | 3 | 102 |
| (34) | | | | (4%) | (1%) | | (18%) | (7%) | (4%) | (28%) | (15%) | (14%) | | | (1%) | (1%) | (2%) | (1%) | (2%) | (3%) | (100%) |
| Mussidan | | | | | | | | | | | 1 | 1 | | | | | | | | | 2 |
| (58) | | | | | | | | | | | (50%) | (50%) | | | | | | | | | (100%) |
| porcelainite | | | | | | | | | | 4 | 5 | 3 | | | | | | | | | 12 |
| (-) | | | | | | | | | | (33%) | (42%) | (25%) | | | | | | | | | (100%) |
| unidentified | 1 | | 3 | 41 | 15 | 9 | 65 | 26 | 12 | 107 | 54 | 35 | | | 1 | 1 | 2 | 5 | 3 | 36 | 416 |
| (-) | (0%) | | (1%) | (10%) | (4%) | (2%) | (16%) | (6%) | (3%) | (26%) | (13%) | (8%) | | | (0%) | (0%) | (0%) | (1%) | (1%) | (9%) | (100%) |
| Total | 5 | 11 | 57 | 300 | 81 | 40 | 650 | 147 | 98 | 641 | 259 | 172 | 1 | 1 | 4 | 6 | 23 | 50 | 10 | 195 | 2751 |
| | (0%) | (0%) | (2%) | (11%) | (3%) | (1%) | (24%) | (5%) | (4%) | (23%) | (9%) | (6%) | (0%) | (0%) | (0%) | (0%) | (1%) | (2%) | (0%) | (7%) | (100%) |

Table 5.13 Le Flageolet I, IX: cross-tabulation of observed frequencies and percentages for Raw Material Type (RM Type) and Technological Type. ESD = Estimated Source Distance, in kilometers. G2 = 1887.0, df = 228, $p$ = .000.

| | Technological Type | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| RM Type (ESD) | 1a | 1b | 1c | 2a | 2b | 2c | 3a | 3b | 3c | 4a | 4b | 4c | 5c | 5d | 6 | 7a | 7b | 7c | 7d | 8 | Total |
| Senonian, black | 1 | 5 | **89** | 332 | 60 | 45 | **629** | 133 | 108 | **713** | 243 | 235 | 1 | | 2 | 15 | **61** | 71 | 11 | 185 | 2939 |
| (1) | (0%) | (0%) | **(3%)** | (11%) | (2%) | (2%) | **(21%)** | (5%) | (4%) | **(24%)** | (8%) | (8%) | (0%) | | | (1%) | **(2%)** | (2%) | (0%) | (6%) | (100%) |
| Senonian, beige | | 1 | 18 | 81 | **28** | 13 | **209** | 55 | **52** | 186 | 76 | 76 | | 2 | | 3 | 17 | 18 | 6 | 38 | 879 |
| (1) | | (0%) | (2%) | (9%) | **(3%)** | (1%) | **(24%)** | (6%) | **(6%)** | (21%) | (9%) | (9%) | | (0%) | | (0%) | (2%) | (2%) | (1%) | (4%) | (100%) |
| Senonian, indet. | | | **19** | 46 | 6 | 5 | 70 | **30** | 13 | 79 | **52** | 38 | | | | | 9 | 10 | 4 | 22 | 403 |
| (1) | | | **(5%)** | (11%) | (1%) | (1%) | (17%) | **(7%)** | (3%) | (20%) | **(13%)** | (9%) | | | | | (2%) | (2%) | (1%) | (5%) | (100%) |
| chalc./millstone | | | 2 | 2 | 1 | | 6 | 4 | | 11 | 3 | 4 | | | | 1 | 1 | | 1 | 1 | 37 |
| (1) | | | (5%) | (5%) | (3%) | | (16%) | (11%) | | (30%) | (8%) | (11%) | | | | (3%) | (3%) | | (3%) | (3%) | (100%) |
| jasper | | | | | 1 | | 1 | 1 | | | 4 | 1 | | | | | | | | | 8 |
| (1) | | | | | (13%) | | (13%) | (13%) | | | (50%) | (13%) | | | | | | | | | (100%) |
| quartzite | 2 | | | 3 | | 1 | 5 | 0 | 0 | 2 | 0 | 0 | | | | | | | | **213** | 226 |
| (1) | (1%) | | | (1%) | | (0%) | (2%) | (0%) | (0%) | (1%) | (0%) | (0%) | | | | | | | | **(94%)** | (100%) |
| basalt | 1 | | | 2 | | | 5 | 0 | 0 | 17 | 0 | 0 | | | | | | | | **144** | 169 |
| (1) | (1%) | | | (1%) | | | (3%) | (0%) | (0%) | (10%) | (0%) | (0%) | | | | | | | | **(85%)** | (100%) |
| Jurassic | | | | | | | | | | | 1 | 1 | | | | | | | 1 | | 3 |
| (22) | | | | | | | | | | | (33%) | (33%) | | | | | | | (33%) | | (100%) |
| Fumelois | | | | | | | 1 | | | | 1 | 3 | | | | | 1 | | | | 6 |
| (31) | | | | | | | (17%) | | | | (17%) | (50%) | | | | | (17%) | | | | (100%) |
| Gavaudun | | | | | | | | 1 | | 1 | | | | | | | | | | | 2 |
| (33) | | | | | | | | (50%) | | (50%) | | | | | | | | | | | (100%) |
| Bergeracois | | | 4 | 21 | 3 | 7 | 38 | 18 | 11 | 74 | **44** | **39** | | | | 1 | 3 | 6 | 5 | 6 | 280 |
| (34) | | | (1%) | (8%) | (1%) | (3%) | (14%) | (6%) | (4%) | (26%) | **(16%)** | **(14%)** | | | | (0%) | (1%) | (2%) | (2%) | (2%) | (100%) |
| porcelainite | | | 1 | 6 | 2 | | 6 | 4 | 1 | 9 | 3 | 5 | | | | | | 1 | | 4 | 42 |
| (-) | | | (2%) | (14%) | (5%) | | (14%) | (10%) | (2%) | (21%) | (7%) | (12%) | | | | | | (2%) | | (10%) | (100%) |
| unidentified | | | 13 | **126** | 26 | 6 | 117 | 51 | 34 | 229 | **146** | 79 | | | | 3 | 3 | 16 | 5 | 119 | 973 |
| (-) | | | (1%) | **(13%)** | (3%) | (1%) | (12%) | (5%) | (3%) | (24%) | **(15%)** | (8%) | | | | (0%) | (0%) | (2%) | (1%) | (12%) | (100%) |
| Total | 4 | 6 | 146 | 619 | 127 | 77 | 1087 | 297 | 219 | 1321 | 573 | 481 | 1 | 2 | 2 | 23 | 95 | 122 | 33 | 732 | 5967 |
| | (0%) | (0%) | (2%) | (10%) | (2%) | (1%) | (18%) | (5%) | (4%) | (22%) | (10%) | (8%) | (0%) | (0%) | (0%) | (0%) | (2%) | (2%) | (1%) | (12%) | (100%) |

Table 5.14 Summary of interpretations concerning manufacture location/mode of transport for each raw material type, by assemblage. Most RM type names are abbreviated. ESD = minimum estimated source distance. Question marks indicate unknown ESDs. RM types in italics indicate greater uncertainty concerning the interpretation.

| Assemblage | 1 = cobbles/nodules | | 2 = cores | | 3 = walking cores | | 4 = blanks/ tools | |
|---|---|---|---|---|---|---|---|---|
| | RM | ESD | RM | ESD | RM | ESD | RM | ESD |
| Le Moustier, H8 | black Sen | 1 | | | | | Bergerac | 33 |
| | beige Sen | 1 | | | | | chalc/mill | 4 |
| | | | | | | | Jurassic | 31 |
| | | | | | | | quartzite | 1 |
| | | | | | | | basalt | 1 |
| Caminade Est, M3 | black Sen | 1 | | | *beige Sen* | 1 | *beige Sen* | 1 |
| | basalt | 1 | | | porcelain | ? | chalc/mill | 1 |
| | | | | | Jurassic | 17 | quartzite | 1 |
| | | | | | | | jasper | 4-42 |
| | | | | | | | Bergerac | 45 |
| Caminade Est, G | black Sen | 1 | chalc/mill | 1 | *Bergerac* | 45 | quartzite | 1 |
| | beige Sen | 1 | *jasper* | 4-42 | | | basalt | 1 |
| | | | *porcelain* | ? | | | Fumelois | 39 |
| | | | | | | | Jurassic | 17 |
| | | | | | | | Bergerac | 45 |
| La Côte, III | black Sen | 1 | *silic wood* | 2 | *jasper* | 8 | *jasper* | 8 |
| | beige Sen | 1 | | | | | pink speck | 9 |
| | Bergerac | 19 | | | | | | |
| | silic wood | 2 | | | | | | |
| Le Flageolet I, XI | black Sen | 1 | | | *Bergerac* | 34 | chalc/mill | 1 |
| | beige Sen | 1 | | | *chalc/mill* | 1 | jasper | 1-48 |
| | quartzite | 1 | | | | | Jurassic | 22 |
| | basalt | 1 | | | | | Gavaudun | 33 |
| | | | | | | | Bergerac | 34 |
| | | | | | | | Mussidan | 58 |
| | | | | | | | porcelain | ? |
| Le Flageolet I, IX | black Sen | 1 | | | | | *quartzite* | 1 |
| | beige Sen | 1 | | | | | *basalt* | 1 |
| | chalc/mill | 1 | | | | | jasper | 1-48 |
| | quartzite | 1 | | | | | Jurassic | 22 |
| | basalt | 1 | | | | | Fumelois | 31 |
| | porcelain | ? | | | | | Gavaudun | 33 |
| | Bergerac | 34 | | | | | | |

Table 5.15 Le Moustier, H8: cross-tabulation of observed frequencies and percentages for Raw Material Type and Blank Type for blanks weighing ≥ 1 g. Two Kombewa flakes are omitted from this table.

| Raw Material | Ordinary Flake | | Ordinary Blade | | Levallois | | Crested | | Rejuvenation | | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Senonian, black | 499 | (78%) | 44 | (7%) | 62 | (10%) | 14 | (2%) | 23 | (4%) | 643 |
| Senonian, beige | 126 | (82%) | 12 | (8%) | 15 | (10%) | 1 | (1%) | | (0%) | 154 |
| Senonian, indet. | 34 | (74%) | 3 | (7%) | 4 | (9%) | 2 | (4%) | 2 | (4%) | 46 |
| Bergeracois | 3 | (75%) | 1 | (25%) | | (0%) | | (0%) | | (0%) | 4 |
| chalc./millstone | | (0%) | 1 | (100%) | | (0%) | | (0%) | | (0%) | 1 |
| Jurassic | 2 | (100%) | | (0%) | | (0%) | | (0%) | | (0%) | 2 |
| quartzite | | (0%) | 1 | (100%) | | (0%) | | (0%) | | (0%) | 1 |
| unidentified | 40 | (89%) | 1 | (2%) | 3 | (7%) | | (0%) | 1 | (2%) | 45 |
| Total | 704 | (79%) | 63 | (7%) | 84 | (9%) | 17 | (2%) | 26 | (3%) | 896 |

$G^2 = 36.28$, df = 35, $p = 0.04$

Table 5.16 Caminade Est, M3: cross-tabulation of observed frequencies and percentages for Raw Material Type and Blank Type.

| Raw Material | Ordinary Flake | | Ordinary Blade | | Levallois | | Crested | | Rejuvenation | | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Senonian, black | 191 | (74%) | 38 | (15%) | 23 | (9%) | 1 | (0%) | 6 | (2%) | 259 |
| Senonian, beige | 11 | (79%) | 2 | (14%) | | (0%) | | (0%) | 1 | (7%) | 14 |
| Senonian, indet. | 45 | (73%) | 10 | (16%) | 7 | (11%) | | (0%) | | (0%) | 62 |
| chalc./millstone | 1 | (100%) | | (0%) | | (0%) | | (0%) | | (0%) | 1 |
| jasper | 2 | (67%) | 1 | (33%) | | (0%) | | (0%) | | (0%) | 3 |
| quartzite | | (0%) | 1 | (100%) | | (0%) | | (0%) | | (0%) | 1 |
| porcelainite | 8 | (80%) | | (0%) | 1 | (10%) | | (0%) | 1 | (10%) | 10 |
| unidentified | 43 | (84%) | 8 | (16%) | | (0%) | | (0%) | | (0%) | 51 |
| Total | 301 | (75%) | 60 | (15%) | 31 | (8%) | 1 | (0%) | 8 | (2%) | 401 |

$G^2 = 28.95$, df = 28, $p = .08$

Table 5.17 La Côte, III: cross-tabulation of observed frequencies and percentages for Raw Material Type and Blank Type for blanks weighing ≥ 1 g.

| Raw Material | Ordinary Flake | | Ordinary Blade | | Levallois | | Crested | | Rejuvenation | | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Senonian, black | 193 | (52%) | 170 | (46%) | | (0%) | 1 | (0%) | 9 | (2%) | 373 |
| Senonian, beige | [a]**33** | **(80%)** | [b]8 | (20%) | | (0%) | | (0%) | | (0%) | 41 |
| Senonian, indet. | 8 | (100%) | | (0%) | | (0%) | | (0%) | | (0%) | 8 |
| Bergeracois | 28 | (56%) | 20 | (40%) | | (0%) | | (0%) | 2 | (4%) | 50 |
| jasper | 9 | (56%) | 6 | (38%) | | (0%) | | (0%) | 1 | (6%) | 16 |
| petrified wood | 5 | (38%) | 7 | (54%) | | (0%) | 1 | (8%) | | (0%) | 13 |
| pink speckled | 8 | (67%) | 4 | (33%) | | (0%) | | (0%) | | (0%) | 12 |
| unidentified | 12 | (67%) | 6 | (33%) | | (0%) | | (0%) | | (0%) | 18 |
| Total | 296 | (56%) | 221 | (42%) | 0 | (0%) | 2 | (0%) | 12 | (2%) | 531 |

$G^2 = 34.65$, df = 21, $p = .00$

[a] Expected count = 22.9, std. dev. = 2.21.

[b] Expected count = 17.1, std. dev. = -2.19

Table 5.18 Caminade Est, G: cross-tabulation of observed frequencies and percentages for Raw Material Type and Blank Type.

| Raw Material | Ordinary Flake | | Ordinary Blade | | Levallois | | Crested | | Rejuvenation | | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Senonian, black | 503 | (62%) | 267 | (33%) | | (0%) | 3 | (0%) | 33 | (4%) | 806 |
| Senonian, beige | 130 | (65%) | 62 | (31%) | | (0%) | | (0%) | 7 | (4%) | 199 |
| Senonian, indet. | 293 | (67%) | 122 | (28%) | | (0%) | 1 | (0%) | 19 | (4%) | 435 |
| Bergeracois | [a]15 | (33%) | [b]**28** | **(62%)** | | (0%) | | (0%) | 2 | (4%) | 45 |
| chalc./millstone | 9 | (82%) | 2 | (18%) | | (0%) | | (0%) | | (0%) | 11 |
| jasper | 44 | (60%) | 26 | (36%) | | (0%) | 1 | (1%) | 2 | (3%) | 73 |
| Fumelois | 7 | (100%) | | (0%) | | (0%) | | (0%) | | (0%) | 7 |
| quartzite | 1 | (100%) | | (0%) | | (0%) | | (0%) | | (0%) | 1 |
| porcelainite | 54 | (53%) | 40 | (39%) | | (0%) | | (0%) | 8 | (8%) | 102 |
| unidentified | 268 | (61%) | 158 | (36%) | | (0%) | 1 | (0%) | 10 | (2%) | 438 |
| Total | 1324 | (63%) | 705 | (33%) | 0 | (0%) | 6 | (0%) | 81 | (4%) | 2117 |

$G^2 = 50.37$, df = 36, $p = .00$

[a] Expected count = 28.1, std. dev. = -2.48.

[b] Expected count = 15.0, std. dev. = 3.36.

Table 5.19 Le Flageolet I, XI: cross-tabulation of observed frequencies and percentages for Raw Material Type and Blank Type. Four Kombewa flakes are omitted from this table.

| Raw Material | Ordinary Flake | | Ordinary Blade | | Levallois Blank | | Crested Blank | | Rejuvenation Blank | | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Senonian, black | 840 | (82%) | 137 | (13%) | 2 | (0%) | 3 | (0%) | 47 | (5%) | 1030 |
| Senonian, beige | 297 | (80%) | 65 | (17%) | | (0%) | 1 | (0%) | 9 | (2%) | 372 |
| Senonian, indet. | 146 | (83%) | 22 | (13%) | | (0%) | | (0%) | 6 | (3%) | 175 |
| Bergeracois | 51 | (69%) | 18 | (24%) | | (0%) | 1 | (1%) | 3 | (4%) | 74 |
| chalc./millstone | 29 | (91%) | 2 | (6%) | | (0%) | | (0%) | 1 | (3%) | 32 |
| jasper | 9 | (75%) | 3 | (25%) | | (0%) | | (0%) | | (0%) | 12 |
| Gavaudun | | (0%) | 1 | (100%) | | (0%) | | (0%) | | (0%) | 1 |
| Mussidan | | (0%) | 1 | (100%) | | (0%) | | (0%) | | (0%) | 1 |
| Jurassic | | (0%) | 1 | (100%) | | (0%) | | (0%) | | (0%) | 1 |
| quartzite | 2 | (100%) | | (0%) | | (0%) | | (0%) | | (0%) | 2 |
| basalt | 1 | (50%) | 1 | (50%) | | (0%) | | (0%) | | (0%) | 2 |
| porcelainite | 4 | (57%) | 3 | (43%) | | (0%) | | (0%) | | (0%) | 7 |
| unidentified | 213 | (77%) | 56 | (20%) | | (0%) | 1 | (0%) | 7 | (3%) | 278 |
| Total | 1592 | (80%) | 310 | (16%) | 2 | (0%) | 6 | (0%) | 73 | (4%) | 1987 |

$G^2 = 51.25$, df = 60, $p = .03$

Table 5.20 Le Flageolet I, IX: cross-tabulation of observed frequencies and percentages for Raw Material Type and Blank Type. Two Kombewa flakes (both made of black Senonian) are omitted from this table.

| Raw Material | Ordinary Flake | | Ordinary Blade | | Levallois Blank | | Crested Blank | | Rejuvenation Blank | | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Senonian, black | 1679 | (76%) | 388 | (18%) | 1 | (0%) | 15 | (1%) | 132 | (6%) | 2217 |
| Senonian, beige | 476 | (72%) | 141 | (21%) | 2 | (0%) | 3 | (0%) | 35 | (5%) | 657 |
| Senonian, Indet. | 195 | (72%) | 56 | (21%) | | (0%) | | (0%) | 19 | (7%) | 270 |
| Bergeracois | 133 | (67%) | [a]**57** | **(29%)** | | (0%) | 1 | (1%) | 9 | (5%) | 200 |
| chalc./millstone | 21 | (78%) | 4 | (15%) | | (0%) | 1 | (4%) | 1 | (4%) | 27 |
| jasper | 1 | (50%) | 1 | (50%) | | (0%) | | (0%) | | (0%) | 2 |
| Gavaudun | 1 | (20%) | 3 | (60%) | | (0%) | | (0%) | 1 | (20%) | 5 |
| Fumelois | 1 | (100%) | | (0%) | | (0%) | | (0%) | | (0%) | 1 |
| Jurassic | | (0%) | 1 | (100%) | | (0%) | | (0%) | | (0%) | 1 |
| quartzite | 10 | (91%) | 1 | (9%) | | (0%) | | (0%) | | (0%) | 11 |
| basalt | 24 | (100%) | | (0%) | | (0%) | | (0%) | | (0%) | 24 |
| porcelainite | 21 | (75%) | 6 | (21%) | | (0%) | | (0%) | 1 | (4%) | 28 |
| unidentified | 472 | (77%) | 120 | (20%) | | (0%) | 3 | (0%) | 19 | (3%) | 614 |
| Total | 3034 | (75%) | 778 | (19%) | 3 | (0%) | 23 | (1%) | 217 | (5%) | 4057 |

$G^2 = 68.55$, df = 60, $p = .00$

[a] Expected count = 38.4, std. dev. = 3.01

Table 5.21 Le Moustier, H8: cross-tabulation of observed frequencies for Raw Material Type and Core Category. See Table 5.5 for explanation of core descriptive categories. Raw material types: 1 = black Senonian; 2 = beige Senonian; 12 = indeterminate Senonian.

| | *Raw Material Type* | | | |
|---|---|---|---|---|
| *Core Category* | 1 | 2 | 12 | Total |
| 1B: Simple flake | 2 | | | 2 |
| 2A: Prep flake, 1SP | 3 | | | 3 |
| 2B: Prep flake, 2SP-90 | 2 | | | 2 |
| 2C: Prep flake, 2SP-180 | | 3 | | 3 |
| 3: Cuboid flake | 2 | | | 2 |
| 8: Prep flake on truncation | 2 | | | 2 |
| 9: flake DS on narrow face | 1 | | | 1 |
| 10B: Pl/cvx, 1 DS | 1 | 1 | | 2 |
| 10D: Pl/cvx, 1 DS | 1 | | | 1 |
| 10E: Pl/cvx, 1 DS on flake | 1 | | | 1 |
| 11A: Classic Lev, uniface | 1 | | | 1 |
| 11B: Class Lev biface | 1 | 1 | 1 | 3 |
| 99A: Indet, complex | 1 | | | 1 |
| Total | 18 | 5 | 1 | 24 |

$G^2 = 26.9$, df = 26, $p = .055$

Table 5.22 Caminade Est, M3: cross-tabulation of observed frequencies for Raw Material Type and Core Category. Raw material types: 1 = black Senonian; 9 = Jurassic; 12 = indeterminate Senonian; 99 = unidentified.

| | *Raw Material Type* | | | | |
|---|---|---|---|---|---|
| *Core Category* | 1 | 9 | 12 | 99 | Total |
| 2B: Prep Fk, 2SP-90 | | | 1 | | 1 |
| 4B: Blocky w/multiple SP | | 1 | | | 1 |
| 6:Kombewa flake core | | | | 1 | 1 |
| 10A: Disk, bifacial DS | 1 | | | | 1 |
| 14A: Blade w/maint., 1 wide SP | 1 | | | | 1 |
| Total | 2 | 1 | 1 | 1 | 5 |

$G^2 = 13.3$, df = 12, $p = 1.000$

Table 5.23 Caminade Est, G: cross-tabulation of observed frequencies for Raw Material Type and Core Category. Raw material types: 1 = black Senonian; 2 = beige Senonian; 12 = indeterminate Senonian; 4 = chalcedony/millstone; 5 = jasper; 99 = unidentified.

| | *Raw Material Type* | | | | | | |
|---|---|---|---|---|---|---|---|
| *Core Category* | 1 | 2 | 12 | 4 | 5 | 99 | Total |
| 1A: Simple blade | 3 | | 1 | | | | 4 |
| 1B: Simple flake | 1 | | | | | 1 | 2 |
| 2A: Prep flake, 1 SP | 8 | | 1 | | | 1 | 10 |
| 2B: Prep flake, 2 SP-90 | 5 | 1 | | | | | 6 |
| 2C: Prep flake, 2 SP-180 | 1 | | | | | 1 | 2 |
| 3: Cuboid flake | 1 | | | | | | 1 |
| 4A: Globular w/mult sp/crests | | | 2 | | | | 2 |
| 4B: Blocky w/mult SP | 1 | | 1 | | | | 2 |
| 5: flake tablet 2 SP 90 | | | | 1 | | | 1 |
| 10A: Disk, bifacial DS | 1 | | | | | | 1 |
| 12A: Blade w/o maint 1 SP | 2 | | 2 | | | | 4 |
| 12B: Blade w/o maint 2 SP | | | 2 | | | | 2 |
| 13A: Blade w/maint, 1 SP narrow | 4 | | | | | 2 | 6 |
| 13B: Blade w/maint, 2 SP narrow | 1 | | | | | | 1 |
| 14A: Blade w/maint, wide 1 SP | 7 | 2 | 5 | | 1 | | 15 |
| 14B: Blade w/maint, wide 2 SP | 6 | | 2 | | | 1 | 9 |
| 15:Blade Pyramid, 1 SP | 2 | | | | | | 2 |
| 99A: Indet, complex | 2 | | 1 | | 2 | | 5 |
| 99B: Indet, fragmented | 3 | | | | | | 3 |
| Total | 48 | 3 | 17 | 1 | 3 | 6 | 78 |

$G^2 = 71.9$, df = 90, $p = .107$

Table 5.24 Le Flageolet I, XI: cross-tabulation of observed frequencies for Raw Material Type and Core Category. Raw material types: 1 = black Senonian; 2 = beige Senonian; 12 = indeterminate Senonian; 99 = unidentified.

| | *Raw Material Type* | | | | |
|---|---|---|---|---|---|
| *Core Category* | 1 | 2 | 12 | 99 | Total |
| 1B: Simple flake | 7 | 2 | | | 9 |
| 2A: Prep flake, 1 SP | 2 | | 1 | | 3 |
| 2B: Prep flake, 2 SP-90 | 1 | | 1 | | 2 |
| 2C: Prep flake, 2 SP-180 | 2 | | | | 2 |
| 3: Cuboid flake | 2 | 1 | | | 3 |
| 4A: Globular w/mult. SP/crests | 1 | 1 | 1 | | 3 |
| 4B: Blocky w/mult. SP | 4 | 1 | | | 5 |
| 7: Flake DS on narrow face | 1 | | | | 1 |
| 10A: Disk, bifacial DS | 2 | 1 | | | 3 |
| 10B: Plano/cvx, 1 DS | 3 | 1 | | 1 | 5 |
| 12B: Blade w/o maint. 2 SP | 1 | | | | 1 |
| 13A: Blade w/maint., 1 SP narrow | 4 | | 1 | | 5 |
| 13B: Blade w/maint., 2 SP narrow | 2 | | | 1 | 3 |
| 99A: Indet., complex | 5 | | | | 5 |
| 99B: Indet., fragmented | | 1 | | | 1 |
| Total | 37 | 8 | 4 | 2 | 51 |

$G^2$ =33.0, df = 42, $p$ = 0.653

Table 5.25 Le Flageolet I, IX: cross-tabulation of observed frequencies for Raw Material Type and Core Category. Raw material types: 1 = black Senonian; 2 = beige Senonian; 12 = indeterminate Senonian; 4 = chalcedony/millstone; 97 = porcelainite; 99 = unidentified.

| | *Raw Material Type* | | | | | | |
|---|---|---|---|---|---|---|---|
| *Core Category* | 1 | 2 | 12 | 4 | 97 | 99 | Total |
| 1A: Simple blade | 1 | | | 1 | | | 2 |
| 1B: Simple flake | 3 | 1 | 4 | | | | 8 |
| 2A: Prep flake, 1 SP | 5 | 3 | 1 | | | | 9 |
| 2B: Prep flake, 2 SP-90 | 2 | | 1 | | | | 3 |
| 3: Cuboid flake | 6 | 1 | | | | | 7 |
| 4A: Globular w/multiple SPs/crests | 1 | | 1 | | | | 2 |
| 4B: Blocky w/multiple SP | 1 | | 1 | | | | 2 |
| 5: flake tablet 2 SP 90 | 1 | | | | | 1 | 2 |
| 6: Kombewa flake core | 1 | | | | | | 1 |
| 7: Flake DS on narrow face | 2 | | 1 | | | | 3 |
| 9A: Wedge w/crest | 1 | | | | | | 1 |
| 9B: Wedge w/SP and crest | 1 | | | | | | 1 |
| 10A: Disk, bifacial DS | 2 | | 1 | | | | 3 |
| 10B: Plano/convex, 1 DS | 6 | 1 | 1 | | | 2 | 10 |
| 10E: Plano/convex, 1 DS on flake | 1 | | | | | | 1 |
| 12B: Blade w/o maint 2 SP | 2 | | | | | | 2 |
| 13A: Blade w/maint, 1 SP narrow | 15 | 4 | 1 | | 1 | | 21 |
| 13B: Blade w/maint, 2 SP narrow | 5 | | 1 | | | | 6 |
| 14A: Blade w/maint, wide 1 SP | 3 | 1 | 1 | | | | 5 |
| 14B: Blade w/maint, wide 2 SP | 2 | | | | | | 2 |
| 99A: Indeterminate, complex | 8 | 1 | | | | | 9 |
| 99B: Indeterminate, fragmented | 8 | 3 | | 1 | | 3 | 15 |
| Total | 77 | 15 | 14 | 2 | 1 | 6 | 115 |

$G^2 = 69.0$, df = 110, $p = .754$

Table 5.26 Tests of association between Raw Material Type (RM) and core descriptive variables.

| *Assemblage* Terms: RM and... | $G^2$ | df | *p* | n |
|---|---|---|---|---|
| *Le Moustier, H8* | | | | |
| Origin | 0.1 | 1 | 1.00 | [a]15 |
| Blank Type | 0.6 | 2 | 1.00 | 24 |
| Maintenance | 0.7 | 2 | 1.00 | [a]22 |
| SS Type | 1.2 | 2 | 0.67 | 24 |
| DS Orientation | 2.6 | 2 | 0.51 | [a]22 |
| *Caminade Est, M3* | | | | |
| Origin | 2.8 | 1 | 0.50 | [a]2 |
| Blank Type | 5.5 | 4 | 1.00 | [b]4 |
| Maintenance | 5.5 | 4 | 1.00 | [b]4 |
| SS Type | 1.7 | 2 | 1.00 | [b]4 |
| DS Orientation | 1.7 | 2 | 1.00 | [b]4 |
| *Caminade Est, G* | | | | |
| Origin | 3.9 | 10 | 0.97 | 78 |
| Blank Type | 8.5 | 10 | 0.69 | [a]75 |
| Maintenance | 12.1 | 20 | 0.89 | 78 |
| SS Type | 12.3 | 15 | 0.27 | 78 |
| DS Orientation | 4.4 | 10 | 0.76 | 78 |
| *Le Flageolet I, XI* | | | | |
| Origin | 5.3 | 6 | 0.49 | [a]43 |
| Blank Type | 5.2 | 6 | 0.73 | 51 |
| Maintenance | 11.8 | 9 | 0.12 | [a]49 |
| SS Type | 2.3 | 6 | 0.65 | [a]49 |
| DS Orientation | 4.9 | 3 | 0.14 | [a]49 |
| *Le Flageolet I, IX* | | | | |
| Origin | 3.6 | 8 | 0.92 | [a]81 |
| Blank Type | 13.7 | 10 | 0.25 | [a]111 |
| Maintenance | 8.6 | 15 | 0.85 | [a]107 |
| SS Type | 12.5 | 10 | 0.12 | [a]110 |
| DS Orientation | 9.4 | 10 | 0.31 | [a]109 |

[a] Excludes cases with missing data.

[b] Excludes the "phantom" core.

Table 5.27 Association between Raw Material Type and Cortex Amount among the 272 analyzed cores.

| Raw Material | 0% | <50% | >50% | Total |
|---|---|---|---|---|
| Senonian, black | 32 | 123 | 27 | 182 |
| Senonian, beige | 5 | 20 | 6 | 31 |
| Senonian, indeterminate | 7 | 24 | 5 | 36 |
| chalcedony/millstone | 1 | 1 | 1 | 3 |
| jasper | 2 | 1 | | 3 |
| Jurassic | | | 1 | 1 |
| porcelainite | 1 | | | 1 |
| unidentified | 10 | 5 | | 15 |
| Grand Total | 58 | 174 | 40 | 272 |

Table 5.28 Cross-tabulated frequencies of Raw Material Type and Number of Striking Surfaces among the 272 analyzed cores.

| Raw Material Type | 1 | 2-3 | >3 | Total |
|---|---|---|---|---|
| Senonian, black | 110 | 59 | 5 | 174 |
| Senonian, beige | 17 | 13 | | 30 |
| chalcedony, jasper, and porcelainite | 4 | 3 | | 7 |
| Senonian, indeterminate | 20 | 14 | 3 | 37 |
| unidentified | 9 | 6 | | 15 |
| Grand Total | 160 | 95 | 8 | 263 |

Table 5.29 Level H8 of Le Moustier: cross-tabulated frequencies of Raw Material Type and Number of Striking Surfaces among cores.

| Raw Material Type | 1 | 2 | 3 | Total |
|---|---|---|---|---|
| Senonian, black | 14 | 3 | 1 | 18 |
| Senonian, beige | 1 | 4 | | 5 |
| Senonian, indeterminate | | 1 | | 1 |
| Grand Total | 15 | 8 | 1 | 24 |

$G^2 = 7.68$, df = 2, $p = .015$

Table 5.30 Level G of Caminade Est: cross-tabulated frequencies of Raw Material Type and Cortex Amount among cores.

| Raw Material Type | 0% | <50% | >50% | Total |
|---|---|---|---|---|
| Senonian, black | 4 | 38 | 6 | 48 |
| Senonian, beige | | 2 | 1 | 3 |
| Senonian, indeterminate | 2 | 14 | 1 | 17 |
| chalcedony/millstone | 1 | | | 1 |
| jasper | 2 | 1 | | 3 |
| unidentified | 3 | 3 | | 6 |
| Grand Total | 12 | 58 | 8 | 78 |

$G^2 = 17.52$, df = 10, $p = 0.045$

Table 5.31 Level IX of Le Flageolet I: cross-tabulated frequencies of Raw Material Type and Cortex Amount among cores.

| Raw Material Type | 0% | <50% | >50% | Total |
|---|---|---|---|---|
| Senonian, black | 20 | 47 | 10 | 77 |
| Senonian, beige | 3 | 8 | 4 | 15 |
| Senonian, indeterminate | 3 | 7 | 4 | 14 |
| chalcedony/millstone | | 1 | 1 | 2 |
| porcelainite | 1 | | | 1 |
| unidentified | 6 | | | 6 |
| Grand Total | 33 | 63 | 19 | 115 |

$G^2 = 23.46$, df = 10, $p = .008$

Table 5.32 Mean weight (wt.) and standard deviation (SD) of weight, for retouched and unretouched blanks in each assemblage, with t-test results.

| *Assemblage* | Retouch | Mean wt. | SD wt. | n | *p* |
|---|---|---|---|---|---|
| *Le Moustier, H8* | retouched | 23.1 | 16.5 | 103 | << 0.00 |
| | unretouched | 15.6 | 17.5 | 916 | |
| *Caminade Est, M3* | retouched | 25.2 | 23.1 | 155 | << 0.00 |
| | unretouched | 9.2 | 23.2 | 306 | |
| *La Cote, III* | retouched | 12.5 | 25.4 | 81 | 0.03 |
| | unretouched | 6.2 | 9.9 | 477 | |
| *Caminade Est, G* | retouched | 16.0 | 15.8 | 264 | 0.44 |
| | unretouched | 7.3 | 12.4 | 2579 | |
| *Le Flageolet I, XI* | retouched | 11.5 | 11.1 | 148 | << 0.00 |
| | unretouched | 6.4 | 9.7 | 2325 | |
| *Le Flageolet I, IX* | retouched | 14.1 | 16.3 | 757 | << 0.00 |
| | unretouched | 5.8 | 10.8 | 4289 | |

Table 5.33 ANOVA, comparing effects of Retouch (retouched, unretouched), RM Distance (local, non-local), and interaction term on mean blank weights.

| **Assemblage** Source | Sum-of-Squares | df | Mean-Square | F-ratio | *p* |
|---|---|---|---|---|---|
| **Le Moustier H8** | | | | | |
| RM Distance | 1877.51 | 1 | 1877.51 | 6.29 | 0.012 |
| Retouch | 906.02 | 1 | 906.02 | 3.04 | 0.082 |
| RM Dist.*Retouch | 194.95 | 1 | 194.95 | 0.65 | 0.419 |
| Error | 287823.12 | 964 | 298.57 | | |
| **La Côte III*** | | | | | |
| RM Distance | 942.59 | 2 | 471.29 | 2.59 | 0.076 |
| Retouch | 29.14 | 1 | 29.14 | 0.16 | 0.689 |
| RM Dist.*Retouch | 525.50 | 2 | 262.75 | 1.44 | 0.237 |
| Error | 97035.02 | 533 | 182.05 | | |
| **La Côte III** | | | | | |
| RM Distance | 915.88 | 1 | 915.88 | 5.05 | 0.025 |
| Retouch | 216.21 | 1 | 216.21 | 1.19 | 0.275 |
| RM Dist.*Retouch | 533.96 | 1 | 533.96 | 2.94 | 0.087 |
| Error | 97061.74 | 535 | 181.42 | | |
| **Caminade Est G** | | | | | |
| RM Distance | 218.87 | 1 | 218.87 | 1.23 | 0.267 |
| Retouch | 5110.46 | 1 | 5110.46 | 28.73 | 0.000 |
| RM Dist.*Retouch | 169.95 | 1 | 169.95 | 0.96 | 0.328 |
| Error | 350789.37 | 1972 | 177.89 | | |
| **Le Flageolet I, XI*** | | | | | |
| RM Distance | 644.90 | 2 | 322.45 | 3.06 | 0.047 |
| Retouch | 376.82 | 1 | 376.82 | 3.57 | 0.059 |
| RM Dist.*Retouch | 17.06 | 2 | 8.53 | 0.08 | 0.922 |
| Error | 219196.39 | 2077 | 105.54 | | |
| **Le Flageolet I, XI** | | | | | |
| RM Distance | 422.76 | 1 | 422.76 | 3.98 | 0.046 |
| Retouch | 1556.95 | 1 | 1556.95 | 14.67 | 0.000 |
| RM Dist.*Retouch | 7.22 | 1 | 7.22 | 0.07 | 0.794 |
| Error | 219121.65 | 2065 | 106.11 | | |
| **Le Flageolet I, IX** | | | | | |
| RM Distance | 18.80 | 1 | 18.80 | 0.12 | 0.726 |
| Retouch | 16443.00 | 1 | 16443.00 | 107.3 | 0.000 |
| RM Dist.*Retouch | 1.83 | 1 | 1.83 | 0.01 | 0.913 |
| Error | 632160.96 | 4126 | 153.21 | | |

Table 5.34 Le Moustier, level H8. Mean blank weights (in grams), by Blank Type, Retouch, and Raw Material Type.

| Blank Type | Retouch | Raw Material Type | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | *Local* | | | | *Non-local* | | |
| | | black Senon. | beige Senon. | indet. Senon. | chalc./ millst. | Berg. | Juras. | Grand Total |
| ordinary flake | retouched | 25.2 | 19.1 | 6.3 | | 45.0 | | 23.5 |
| | unretouched | 15.0 | 20.0 | 14.1 | | 26.9 | 30.0 | 16.0 |
| ordinary blade | retouched | 38.3 | 14.1 | | | 50.3 | | 30.7 |
| | unretouched | 11.6 | 13.2 | 13.5 | 2.1 | | | 11.8 |
| fragment | retouched | 11.2 | 15.0 | | | | | 11.7 |
| | unretouched | 9.8 | 8.5 | 9.4 | | | | 9.5 |
| Levallois | retouched | 28.4 | 25.5 | | | | | 27.3 |
| | unretouched | 24.9 | 24.8 | 9.8 | | | | 24.0 |
| crested | retouched | 44.5 | | | | | | 44.5 |
| | unretouched | 33.2 | 33.7 | 29.2 | | | | 32.8 |
| rejuvenation | retouched | 20.2 | | | | | | 20.2 |
| | unretouched | 10.3 | | 14.3 | | | | 10.6 |
| Kombewa | retouched | | | | | | | |
| | unretouched | 4.3 | | 22.5 | | | | 13.4 |

Table 5.35 Caminade Est, level M3. Mean blank weights (in grams), by Blank Type, Retouch, and Raw Material Type.

| Blank Type | Retouch | Raw Material Type | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | *Local* | | | | *Unknown* | | *Non-local* | |
| | | black Senon. | beige Senon. | indet. Senon. | chalc./m illst. | Jasp. | porcel. | Bergerac. | Grand Total |
| ordinary flake | retouched | 26.5 | 51.8 | 30.3 | | 36.8 | 7.0 | | 27.7 |
| | unretouched | 6.9 | 13.5 | 6.9 | 2.4 | | 17.7 | | 7.6 |
| ordinary blade | retouched | 17.6 | 22.7 | 12.5 | | | | | 17.4 |
| | unretouched | 4.5 | 2.8 | 3.8 | | 4.9 | | | 4.2 |
| fragment | retouched | 19.2 | | 19.3 | | | | 10.1 | 18.7 |
| | unretouched | 2.9 | | 5.0 | | | | | 3.1 |
| Levallois | retouched | 22.0 | | 20.4 | | | | | 21.9 |
| | unretouched | 30.3 | | 12.7 | | | 28.3 | | 24.6 |
| crested | retouched | | | | | | | | |
| | unretouched | 6.5 | | | | | | | 6.5 |
| rejuvenation | retouched | | 39.2 | | | | 131.0 | | 85.1 |
| | unretouched | 4.0 | | | | | | | 4.0 |

Table 5.36 La-Côte level III. Mean blank weights (in grams), by Blank Type, Retouch, and Raw Material Type. For explanation of shading and superscripts, see text.

| Blank Type | Retouch | Raw Material Type | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | *Local* | | | | *Intermediate* | | *Non-local* | |
| | | black Senon. | beige Senon. | indet. Senon. | silicified wood | Jasp. | pink speck. | Bergerac. | Grand Total |
| ordinary flake | retouched | 35.4[a] | | 2.6 | | 3.2[c] | | | 32.4 |
| | unretouched | 7.6[b] | 10.7 | 8.1 | 2.7 | 2.7[d] | 6.3 | 6.5 | 7.6 |
| ordinary blade | retouched | 4.4 | 2.4 | | 2.9 | 1.8 | | 4.8 | 4.2 |
| | unretouched | 4.5 | 4.6 | | 3.8 | 1.3 | 8.9 | 3.6 | 4.4 |
| fragment | retouched | 14.4 | | | | | | | 14.4 |
| | unretouched | 7.3 | | 1.8 | | | | | 7.0 |
| crested | retouched | | | | 6.0 | | | | 6.0 |
| | unretouched | 10.1 | | | | | | | 10.1 |
| rejuvenation | retouched | | | | | | | | |
| | unretouched | 5.4 | | | | 1.1 | | 6.7 | 5.3 |

Table 5.37 La-Côte level III: mean weights (g) for local and non-local blanks, retouched and unretouched.

| RM Distance | Retouched | Unretouched | Grand Mean |
|---|---|---|---|
| local | 13.7 | 6.6 | 7.7 |
| non-local | 3.6 | 5.2 | 5.0 |
| Grand Mean | 12.6 | 6.4 | 7.3 |

Table 5.38 La-Côte, level III: technological composition of local and non-local blanks.

| Technological type | Local | | Non-local | |
|---|---|---|---|---|
| 2a: cortical flake | 65 | 14.1% | 11 | 14.1% |
| 2b: cortical fragment | 5 | 1.1% | | |
| 2c: cortical blade | 5 | 1.1% | 3 | 3.8% |
| 3a: semi-cortical flake | 110 | 23.9% | 15 | 19.2% |
| 3b: semi-cortical fragment | 12 | 2.6% | | |
| 3c: semi-cortical blade | 51 | 11.1% | 7 | 9.0% |
| 4a: non-cortical flake | 64 | 13.9% | 19 | 24.4% |
| 4b: non-cortical fragment | 9 | 2.0% | | |
| 4c: non-cortical blade | 129 | 28.0% | 20 | 25.6% |
| 7a: crested blank | 2 | 0.4% | | |
| 7b: core rejuvenation tablet | 1 | 0.2% | | |
| 7c: other core rejuvenation | 8 | 1.7% | 3 | 3.8% |
| Grand Total | 461 | 100.0% | 78 | 100.0% |

Table 5.39 Caminade Est, level G. Mean blank weights (in grams), by Blank Type, Retouch, and Raw Material Type.

| Blank Type | Retouch | Raw Material Type | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | *Local* | | | | *Non-local* | | *Unknown* | | |
| | | black Senon. | beige Senon. | indet. Senon. | chalc./ millst. | Berg. | Fumel. | jasper | porcel. | Grand Total |
| ordinary flake | retouched | 22.9 | | 18.8 | 11.2 | 14.7 | 38.5 | 22.8 | 33.0 | 22.1 |
| | unretouched | 11.4 | 11.4 | 11.3 | 21.0 | 8.4 | 13.2 | 4.6 | 9.2 | 11.0 |
| ordinary blade | retouched | 9.9 | | 11.2 | | 21.0 | | 6.4 | 12.3 | 11.7 |
| | unretouched | 4.1 | 4.8 | 3.7 | 1.8 | 7.7 | | 3.1 | 3.0 | 4.1 |
| fragment | retouched | 16.2 | | 17.7 | | 15.7 | | 16.9 | 19.9 | 17.2 |
| | unretouched | 3.8 | 4.5 | 3.4 | | 3.5 | 8.5 | 2.2 | 2.1 | 3.6 |
| crested | retouched | 17.8 | | | | | | | | 17.8 |
| | unretouched | 4.7 | | 4.0 | | | | 12.9 | | 6.6 |
| rejuvenation | retouched | 22.5 | | | | 21.9 | | 7.8 | | 18.7 |
| | unretouched | 11.3 | 14.8 | 5.2 | | 1.2 | | 1.6 | 12.8 | 9.8 |

Table 5.40 Caminade Est, level G. Analysis of variance comparing effects of retouch (retouched, unretouched) and Raw Material Type (black Senonian, indeterminate Senonian, jasper, porcelainite, Bergeracois) on weights of blanks.

| Source | Sum-of-Squares | df | Mean-Square | F-ratio | *p* |
|---|---|---|---|---|---|
| Raw material | 1018.34 | 4 | 254.59 | 1.52 | 0.194 |
| Retouch | 10201.52 | 1 | 10201.52 | 60.90 | 0.000 |
| Raw mat.*Retouch | 203.47 | 4 | 50.87 | 0.30 | 0.876 |
| Error | 313581.27 | 1872 | 167.51 | | |

Table 5.41 Le Flageolet I, level XI. Mean blank weights (in grams), by Blank Type, Retouch, and Raw Material Type.

| Blank Type | Retouch | Raw Material Type | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | *Local* | | | | *Non-local* | | | | *Unknown* | | |
| | | black Senon. | beige Senon. | indet. Senon. | chalc./ millst. | Berg. | Gav. | Muss. | Juras. | Jasp. | porcel | Grand Total |
| ordinary flake | retouched | 15.9 | 13.0 | 6.6 | | | | | | 11.2 | | 13.8 |
| | unretouched | 7.7 | 8.1 | 7.2 | 8.3 | 5.2 | | | | 2.6 | 1.9 | 7.6 |
| ordinary blade | retouched | 8.6 | 9.7 | 2.4 | 13.3 | 9.3 | | 14.2 | 22.4 | 1.5 | 4.5 | 9.0 |
| | unretouched | 4.0 | 4.6 | 3.2 | 4.0 | 4.2 | 2.1 | | | 2.1 | 2.1 | 4.1 |
| fragment | retouched | 12.9 | 12.9 | 14.5 | | 6.4 | | 22.7 | 6.5 | 5.5 | 9.0 | 12.2 |
| | unretouched | 5.5 | 4.8 | 3.9 | 5.5 | 3.6 | 2.0 | | | 5.1 | 1.9 | 5.0 |
| Levallois | retouched | | | | | | | | | | | |
| | unretouched | 27.3 | | | | | | | | | | 27.3 |
| crested | retouched | | | | | 1.2 | | | | | | 1.2 |
| | unretouched | 11.1 | 1.2 | | | | | | | | | 8.6 |
| rejuvenation | retouched | 13.7 | | | | 9.2 | | | | | | 12.0 |
| | unretouched | 7.5 | 9.5 | 16.4 | 22.5 | | | | | | | 9.0 |
| Kombewa | retouched | | | | | | | | | | | |
| | unretouched | 1.8 | | 2.4 | | 3.6 | | | | | | 2.6 |

Table 5.42 Le Flageolet I, level XI: mean weight (in grams) and count of blanks partitioned by raw material source distance (RM) and presence/absence of retouch.

| | Retouched | | Unretouched | | Grand Total | |
|---|---|---|---|---|---|---|
| RM | mean wt. | count | mean wt. | count | mean wt. | count |
| local | 12.5 | (103) | 7.0 | (1863) | 7.2 | (1966) |
| non-local | 9.4 | (22) | 4.6 | (81) | 5.7 | (103) |
| jasper | 6.1 | (3) | 2.7 | (11) | 3.4 | (14) |
| Grand Total | 11.8 | (128) | 6.8 | (1955) | 7.1 | (2083) |

Table 5.43 Le Flageolet I, level XI: technological composition of blanks made of local and non-local raw materials.

| Technological type | Local | | Non-local | |
|---|---|---|---|---|
| 2a: cortical flake | 254 | 12.9% | 4 | 3.9% |
| 2b: cortical fragment | 63 | 3.2% | 1 | 1.0% |
| 2c: cortical blade | 31 | 1.6% | | |
| 3a: semi-cortical flake | 564 | 28.7% | 18 | 17.5% |
| 3b: semi-cortical fragment | 114 | 5.8% | 7 | 6.8% |
| 3c: semi-cortical blade | 80 | 4.1% | 5 | 4.9% |
| 4a: non-cortical flake | 493 | 25.1% | 29 | 28.2% |
| 4b: non-cortical fragment | 181 | 9.2% | 18 | 17.5% |
| 4c: non-cortical blade | 115 | 5.8% | 16 | 15.5% |
| 5a: Levallois flake | 1 | 0.1% | | |
| 5d: éclat débordant | 1 | 0.1% | | |
| 6: Kombewa flake | 2 | 0.1% | 1 | 1.0% |
| 7a: crested blank | 4 | 0.2% | 1 | 1.0% |
| 7b: core rejuvenation tablet | 19 | 1.0% | 2 | 1.9% |
| 7c: other core rejuvenation | 44 | 2.2% | 1 | 1.0% |
| Grand Total | 1966 | 100.0% | 103 | 100.0% |

$G^2$ =41.4, df = 14, $p$ = .000

Table 5.44 Le Flageolet I, level IX. Mean blank weights (in grams), by Blank Type, Retouch, and Raw Material Type.

| Blank Type | Retouch | Raw Material Type | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | *Local* | | | | *Non-local* | | *Unknown* | | |
| | | black Senon. | beige Senon. | indet. Senon. | chalc./ millst. | Berg. | other | Jasp. | porcel | Grand Total |
| ordinary flake | retouched | 20.3 | 23.4 | 23.9 | | 17.6 | | | | 20.7 |
| | unretouched | 7.2 | 6.9 | 6.1 | 6.5 | 6.9 | 4.5 | 3.0 | 5.0 | 7.0 |
| ordinary blade | retouched | 8.9 | 5.5 | 9.9 | 3.4 | 17.4 | 2.9 | | 8.4 | 9.9 |
| | unretouched | 3.6 | 4.1 | 4.1 | 1.0 | 3.4 | 1.8 | 2.0 | 5.9 | 3.8 |
| fragment | retouched | 13.0 | 16.7 | 9.6 | 16.2 | 12.0 | 6.9 | 7.6 | 8.3 | 13.0 |
| | unretouched | 4.4 | 3.2 | 3.5 | 10.0 | 4.7 | 2.4 | 1.7 | 1.7 | 4.0 |
| Levallois | retouched | | 7.8 | | | | | | | 7.8 |
| | unretouched | 6.1 | 18.2 | | | | | | | 12.2 |
| crested | retouched | 17.1 | 9.8 | | | | | | | 14.7 |
| | unretouched | 3.5 | 5.8 | | 6.2 | 4.0 | | | | 4.0 |
| rejuvenation | retouched | 14.5 | 7.3 | | | 12.0 | | | | 13.0 |
| | unretouched | 5.7 | 8.5 | 9.6 | 1.1 | 7.2 | 5.1 | | 8.2 | 6.7 |
| Kombewa | retouched | 25.6 | | | | | | | | 25.6 |
| | unretouched | 2.1 | | | | | | | | 2.1 |

Table 5.45 Le Flageolet I, level IX. Mean weight (g) of blanks, retouched and unretouched, by Blank Type, Senonian compared to Bergeracois. Total Count: total number of objects on which grand means are based.

| *Blank Type* | | *Senonian* | *Bergeracois* | *Grand mean* | *Total Count* |
|---|---|---|---|---|---|
| ordinary flake | Retouched | 21.1 | 17.6 | 20.7 | 202 |
| | Unretouched | 7.1 | 6.9 | 7.1 | 2276 |
| ordinary blade | Retouched | 8.3 | 17.4 | 10.2 | 142 |
| | Unretouched | 3.8 | 3.4 | 3.8 | 500 |
| fragment | Retouched | 13.3 | 12.0 | 13.1 | 258 |
| | Unretouched | 4.0 | 4.7 | 4.0 | 490 |
| rejuvenation | Retouched | 13.1 | 12.0 | 13.0 | 27 |
| | Unretouched | 6.7 | 7.2 | 6.7 | 168 |
| crested | Retouched | 14.7 | | 14.7 | 3 |
| | Unretouched | 3.8 | 4.0 | 3.8 | 16 |
| Levallois | Retouched | 7.8 | | 7.8 | 1 |
| | Unretouched | 12.2 | | 12.2 | 2 |
| Kombewa | Retouched | 25.6 | | 25.6 | 1 |
| | Unretouched | 2.1 | | 2.1 | 1 |
| Grand mean | | 7.4 | 9.2 | 7.5 | |
| Total Count | | 3822 | 265 | | 4087 |

Table 5.46 Le Moustier, H8: cross-tabulation of observed frequencies and percentages for Raw Material Type and Retouch.

| Raw Material Type | Retouched | | Unretouched | | Total |
|---|---|---|---|---|---|
| Local | | | | | |
| Senonian, black | 73 | (10%) | 688 | (90%) | 761 |
| Senonian, beige | 24 | (13%) | 163 | (87%) | 187 |
| Senonian, indeterm. | 3 | (5%) | 55 | (95%) | 58 |
| chalced./millstone | | | 1 | (100%) | 1 |
| quartzite | | | 2 | (100%) | 2 |
| basalt | | | 1 | (100%) | 1 |
| Non-local | | | | | |
| Bergeracois | 2 | (50%) | 2 | (50%) | 4 |
| Jurassic | | | 2 | (100%) | 2 |
| Unknown distance | | | | | |
| unidentified | 4 | (7%) | 54 | (93%) | 58 |
| Total | 106 | (10%) | 968 | (90%) | 1074 |

$G^2 = 9.5$, df = 8, p = 0.208

Table 5.47 Caminade Est, M3: cross-tabulation of observed frequencies and percentages for Raw Material Type and Retouch.

| RM Type | Retouched | | Unretouched | | Total |
|---|---|---|---|---|---|
| Local | | | | | |
| Senonian, black | 100 | (33%) | 206 | (67%) | 306 |
| Senonian, beige | 3 | (21%) | 11 | (79%) | 14 |
| Senonian, indeterm. | 24 | (33%) | 48 | (67%) | 72 |
| chalcedony/millstone | | | 1 | (100%) | 1 |
| quartzite | | | 3 | (100%) | 3 |
| basalt | | | 2 | (100%) | 2 |
| Non-local | | | | | |
| Bergeracois | 1 | (100%) | | | 1 |
| Jurassic | | | 1 | (100%) | 1 |
| Unknown distance | | | | | |
| jasper | 2 | (67%) | 1 | (33%) | 3 |
| porcelainite | 2 | (20%) | 8 | (80%) | 10 |
| unidentified | 23 | (36%) | 41 | (64%) | 64 |
| Total | 155 | (32%) | 322 | (68%) | 477 |

$G^2 = 11.2$, df = 10, $p = 0.506$

Table 5.48 Caminade Est, G: cross-tabulation of observed frequencies and percentages for Raw Material Type and Retouch.

| Raw Material Type | Retouched | | Unretouched | | Total |
|---|---|---|---|---|---|
| Local | | | | | |
| Senonian, black | 100 | (9%) | 1066 | (91%) | 1166 |
| Senonian, beige | [a]0 | (0%) | 262 | (100%) | 262 |
| Senonian, indeterm. | 53 | (8%) | 578 | (92%) | 631 |
| chalcedony/millstone | 1 | (6%) | 15 | (94%) | 16 |
| quartzite | | | 5 | (100%) | 5 |
| basalt | | | 6 | (100%) | 6 |
| Non-local | | | | | |
| Bergeracois | [b]**20** | **(36%)** | [f]35 | (64%) | 55 |
| Fumelois | 1 | (11%) | 8 | (89%) | 9 |
| Unknown distance | | | | | |
| jasper | [c]**26** | **(23%)** | 85 | (77%) | 111 |
| porcelainite | [d]**33** | **(21%)** | 122 | (79%) | 155 |
| unidentified | [e]42 | (6%) | 626 | (94%) | 668 |
| Total | 276 | (9%) | 2808 | (91%) | 3084 |

$G^2 = 131.5$, df = 10, $p = .000$

[a] Expected count = 23.4, standardized deviate = -4.84.

[b] Expected count = 4.9, standardized deviate = 6.80.

[c] Expected count = 9.9, standardized deviate = 5.10.

[d] Expected count = 13.9, standardized deviate = 5.14.

[e] Expected count = 59.8, standardized deviate = -2.30.

[f] Expected count = 50.1, standardized deviate = -2.13.

Table 5.49 Caminade Est, G: summary of associations between variable pairs. Raw Mat = Raw Material Type; Techno = Technological Type; WTCL = Weight Class. Values of Retouch variable: retouched, unretouched.

| Interaction Term | $G^2$ | df | *p* | n |
|---|---|---|---|---|
| Raw Mat * Retouch | 131.5 | 10 | 0.000 | 3084 |
| Raw Mat * Techno | 346.7 | 170 | 0.000 | 3084 |
| Retouch * Techno | 118.8 | 17 | 0.000 | 3084 |
| Raw Mat * Object Type | 175.6 | 40 | 0.000 | 3084 |
| Retouch * Object type | 104.5 | 4 | 0.000 | 3084 |
| Raw Mat * Retouch, at levels of Object Type: | | | | |
| flake | 28.9 | 9 | 0.000 | 1405 |
| fragment | 43.3 | 7 | 0.000 | 727 |
| blade | 70.7 | 7 | 0.000 | 715 |
| chunk | 4.7 | 9 | 0.739 | 98 |
| core | 8.8 | 6 | 0.141 | 139 |
| | | | | |
| Raw Mat * CTX | 178.6 | 30 | 0.000 | 3084 |
| Retouch * CTX | 17.8 | 3 | 0.000 | 3084 |
| Raw Mat * Retouch, at levels of CTX: | | | | |
| 0% | 61.5 | 8 | 0.000 | 1313 |
| 1 – 49% | 53.3 | 8 | 0.000 | 1133 |
| 50 – 100% | 22.0 | 9 | 0.004 | 402 |
| N/A | 8.6 | 9 | 0.477 | 236 |
| | | | | |
| Raw Mat * WTCL | 85.2 | 30 | 0.000 | 3084 |
| Retouch * WTCL | 183.4 | 3 | 0.000 | 3084 |
| Raw Mat * Retouch, at levels of WTCL : | | | | |
| 1.0 – 4.9 g | 42.4 | 8 | 0.000 | 1811 |
| 5.0 – 14.9 g | 50.1 | 10 | 0.000 | 686 |
| 15.0 – 29.9 g | 28.5 | 7 | 0.000 | 269 |
| ≥ 30.0 g | 42.7 | 10 | 0.000 | 318 |

Table 5.50 Caminade Est, G: cross-tabulation of observed frequencies and percentages for Raw Material Type and Cortex Amount.

| Raw Material Type | 0 % | 1-49 % | 50-100 % | N/A | Total |
|---|---|---|---|---|---|
| Senonian, black | 484 (42%) | 445 (38%) | 140 (12%) | 97 (8%) | 1166 |
| Senonian, beige | **90 (34%)** | **119 (45%)** | 37 (14%) | 16 (6%) | 262 |
| Senonian, indeterm. | 224 (35%) | 274 (43%) | 93 (15%) | 40 (6%) | 631 |
| Bergeracois | **33 (60%)** | 16 (29%) | 5 (9%) | 1 (2%) | 55 |
| chalcedony/millstone | 5 (31%) | 4 (25%) | 2 (13%) | 5 (31%) | 16 |
| jasper | **67 (60%)** | 25 (23%) | **3 (3%)** | **16 (14%)** | 111 |
| Fumelois | 3 (33%) | 5 (56%) | 1 (11%) | | 9 |
| quartzite | | | 1 (20%) | 4 (80%) | 5 |
| basalt | | | | 6 (100%) | 6 |
| porcelainite | **96 (62%)** | 42 (27%) | 8 (5%) | 9 (6%) | 155 |
| unidentified | 311 (47%) | 203 (30%) | **112 (17%)** | 42 (6%) | 668 |
| Total | 1313 (43%) | 1133 (37%) | 402 (13%) | 236 (8%) | 3084 |

$G^2 = 178.6$, df = 30, $p = .000$

Table 5.51 Caminade Est, G: cross-tabulation of observed frequencies and percentages for Raw Material Type and Weight Class.

| Raw Material | 1.0 – 4.9 g | 5.0 – 14.9 g | 15.0 – 29.9 g | ≥ 30 g | Total |
|---|---|---|---|---|---|
| Senonian, black | 654 (56%) | 271 (23%) | 104 (9%) | 137 (12%) | 1166 |
| Senonian, beige | 149 (57%) | 67 (26%) | 22 (8%) | 24 (9%) | 262 |
| Senonian, indeterm. | 354 (56%) | 147 (23%) | 61 (10%) | 69 (11%) | 631 |
| Bergeracois | 21 (38%) | 16 (29%) | 12 (22%) | 6 (11%) | 55 |
| chalcedony/millstone | 9 (56%) | 4 (25%) | | 3 (19%) | 16 |
| jasper | 67 (60%) | 25 (23%) | 7 (6%) | 12 (11%) | 111 |
| Fumelois | 4 (44%) | 3 (33%) | | 2 (22%) | 9 |
| quartzite | | 1 (20%) | 2 (40%) | 2 (40%) | 5 |
| basalt | | 2 (33%) | | 4 (67%) | 6 |
| porcelainite | 97 (63%) | 32 (21%) | 13 (8%) | 13 (8%) | 155 |
| unidentified | **456 (68%)** | 118 (18%) | 48 (7%) | 46 (7%) | 668 |
| Total | 1811 (59%) | 686 (22%) | 269 (9%) | 318 (10%) | 3084 |

$G^2 = 85.2$, df = 30, $p = .000$

Table 5.52 La Côte, III: cross-tabulation of observed frequencies and percentages for Raw Material Type and Retouch.

| Raw Material Type | Retouched | | Unretouched | | Total |
|---|---|---|---|---|---|
| Local | | | | | |
| Senonian, black | 67 | (16%) | 364 | (84%) | 431 |
| Senonian, beige | 1 | [a](2%) | 48 | (98%) | 49 |
| Senonian, indeterm. | 1 | (11%) | 8 | (89%) | 9 |
| silicified wood | 3 | (21%) | 11 | (79%) | 14 |
| Intermediate | | | | | |
| jasper | 4 | (25%) | 12 | (75%) | 16 |
| pink translucent | | | 12 | (100%) | 12 |
| Non-local | | | | | |
| Bergeracois | 5 | (9%) | 51 | (91%) | 56 |
| Unknown distance | | | | | |
| Unidentified | 3 | (13%) | 20 | (87%) | 23 |
| Total | 84 | (14%) | 526 | (86%) | 61 |

$G^2$= 16.4, df = 7, $p$ = .02

[a] Expected count = 6.8, std. dev. = -2.21.

Table 5.53 La Côte, level III: cross-tabulation of observed frequencies and percentages for Retouch and Technological Type (Tech).

| Tech | Retouched | | Unretouched | | Total |
|---|---|---|---|---|---|
| *Cobbles, cores* | | | | | |
| 1a | | | 1 | (100%) | 1 |
| 1b | | | 1 | (100%) | 1 |
| 1c | | | 12 | (100%) | 12 |
| *Cortical blanks* | | | | | |
| 2a | 4 | (5%) | 78 | (95%) | 82 |
| 2b | 1 | (20%) | 4 | (80%) | 5 |
| 2c | 1 | (13%) | 7 | (88%) | 8 |
| *Semi-cortical blanks* | | | | | |
| 3a | 12 | (10%) | 114 | (90%) | 126 |
| 3b | 3 | (25%) | 9 | (75%) | 12 |
| 3c | 6 | (10%) | 52 | (90%) | 58 |
| *Non-cortical blanks* | | | | | |
| 4a | 6 | (7%) | 82 | (93%) | 88 |
| 4b | | | 10 | (100%) | 10 |
| 4c | **47** | **(30%)** | 108 | (70%) | 155 |
| *Crests & rejuvenations* | | | | | |
| 7a | 1 | (50%) | 1 | (50%) | 2 |
| 7b | | | 1 | (100%) | 1 |
| 7c | | | 11 | (100%) | 11 |
| *Burin spalls* | | | | | |
| 7d | | | 1 | (100%) | 1 |
| *Chunks* | | | | | |
| 8 | 3 | (8%) | 34 | (92%) | 37 |
| Total | 84 | (14%) | 526 | (86%) | 610 |

Table 5.54 La Côte, level III: summary of associations between various variable pairs. Raw Mat = Raw Material Type; Techno = Technological Type; WTCL = Weight Class. Values of Retouch: retouched, unretouched.

| Interaction Term | $G^2$ | df | *p* | n |
|---|---|---|---|---|
| Raw Mat * Retouch | 16.4 | 7 | 0.026 | 610 |
| Raw Mat * Object Type | 62.1 | 28 | 0.002 | 610 |
| Retouch * Object Type | 34.9 | 3 | 0.000 | 610 |
| Raw Mat * Retouch, at levels of Object Type: | | | | |
| flake | 15.6 | 7 | 0.021 | 307 |
| fragment | 0.7 | 2 | 1.000 | 27 |
| blade | 5.7 | 6 | 0.588 | 225 |
| chunk | 2.6 | 3 | 0.665 | 37 |
| core | - | - | - | 0 |
| Raw Mat * CTX | 49.9 | 21 | 0.001 | 610 |
| Retouch * CTX | 19.5 | 3 | 0.000 | 610 |
| Raw Mat * Retouch, at levels of CTX: | | | | |
| 0% | 9.7 | 7 | 0.274 | 264 |
| 1 – 49% | 11.0 | 7 | 0.117 | 200 |
| 50 – 100% | 6.2 | 6 | 0.320 | 95 |
| N/A | 3.4 | 4 | 0.355 | 51 |
| Raw Mat * WTCL | 29.6 | 21 | 0.158 | 610 |
| Retouch * WTCL | 3.7 | 3 | 0.299 | 610 |
| Raw Mat * Retouch, at levels of WTCL: | | | | |
| 1.0 – 4.9 g | 7.4 | 7 | 0.485 | 269 |
| 5.0 – 14.9 g | 7.5 | 7 | 0.388 | 386 |
| 15.0 – 29.9 g | 7.2 | 6 | 0.376 | 233 |
| ≥ 30.0 g | 5.3 | 2 | 0.147 | 186 |

Table 5.55 La Côte, III: cross-tabulation of observed frequencies and percentages for Raw Material Type and Cortex Amount.

| Raw Material Type | 0 % | 1-49 % | 50-100 % | N/A | Total |
|---|---|---|---|---|---|
| Senonian, black | 189 (44%) | 152 (35%) | 58 (13%) | 32 (7%) | 431 |
| Senonian, beige | 14 (29%) | 16 (33%) | 11 (22%) | [c]8 (16%) | 49 |
| Senonian, indeterm. | 2 (22%) | 5 (56%) | 2 (22%) | | 9 |
| Bergeracois | 24 (43%) | 13 (23%) | 13 (23%) | 6 (11%) | 56 |
| jasper | [a]**13 (81%)** | 2 (13%) | 1 (6%) | | 16 |
| silicified wood | 5 (36%) | 4 (29%) | 4 (29%) | 1 (7%) | 14 |
| pink translucent | 5 (42%) | 7 (58%) | | | 12 |
| unidentified | 12 (52%) | [b]1 (4%) | 6 (26%) | 4 (17%) | 23 |
| Total | 264 (43%) | 200 (33%) | 95 (16%) | 51 (8%) | 610 |

$G^2 = 49.9$, df = 21, $p = .001$

[a] Expected count = 6.9, standardized deviate = 2.31.

[b] Expected count = 7.5, standardized deviate = -2.38.

[c] Expected count = 4.1, standardized deviate = 1.92.

Table 5.56 Le Flageolet I, XI: cross-tabulation of observed frequencies and percentages for Raw Material Type and Retouch.

| Raw Material Type | Retouched | | Unretouched | | Total |
|---|---|---|---|---|---|
| Local | | | | | |
| Senonian, black | 82 | (6%) | 1266 | (94%) | 1348 |
| Senonian, beige | 17 | (4%) | 447 | (96%) | 464 |
| Senonian, indeterm. | 8 | (3%) | 238 | (97%) | 246 |
| chalcedony/millstone | 1 | (3%) | 35 | (97%) | 36 |
| quartzite | | | 58 | (100%) | 58 |
| basalt | | | 49 | (100%) | 49 |
| Non-local | | | | | |
| Bergeracois | [a]**19** | **(19%)** | 83 | (81%) | 102 |
| Gavaudun | | | 2 | (100%) | 2 |
| Mussidan | 2 | (100%) | | | 2 |
| Jurassic | 2 | (100%) | | | 2 |
| Unknown distance | | | | | |
| jasper | 3 | (21%) | 11 | (79%) | 14 |
| porcelainite | 4 | (33%) | 8 | (67%) | 12 |
| unidentified | 19 | (5%) | 397 | (95%) | 416 |
| Total | 157 | (6%) | 2594 | (94%) | 2751 |

$G^2 = 78.2$, df = 12, $p = .000$

[a] Expected count = 5.8, standardized deviate = 5.46.

Table 5.57 Le Flageolet I, XI: cross-tabulation of observed frequencies and percentages for Retouch and Technological Type (Tech). $G^2 = 181.7$, df = 19, $p = .000$.

| Tech | Retouched | | Unretouched | | Total |
|---|---|---|---|---|---|
| *Cobbles and cores* | | | | | |
| 1a | | | 5 | (100%) | 5 |
| 1b | | | 11 | (100%) | 11 |
| 1c | 1 | (2%) | 56 | (98%) | 57 |
| *Cortical blanks* | | | | | |
| 2a | 5 | (2%) | 295 | (98%) | 300 |
| 2b | 9 | (11%) | 72 | (89%) | 81 |
| 2c | 4 | (10%) | 36 | (90%) | 40 |
| *Semi-cortical blanks* | | | | | |
| 3a | 11 | (2%) | 639 | (98%) | 650 |
| 3b | 12 | (8%) | 135 | (92%) | 147 |
| 3c | 3 | (3%) | 95 | (97%) | 98 |
| *Non-cortical blanks* | | | | | |
| 4a | 11 | (2%) | 630 | (98%) | 641 |
| 4b | **53** | **(20%)** | 206 | (80%) | 259 |
| 4c | **31** | **(18%)** | 141 | (82%) | 172 |
| *Specialized blanks* | | | | | |
| 5a | | | 1 | (100%) | 1 |
| 5d | | | 1 | (100%) | 1 |
| 6 | | | 4 | (100%) | 4 |
| *Crests & rejuvenations* | | | | | |
| 7a | 1 | (17%) | 5 | (83%) | 6 |
| 7b | 4 | (17%) | 19 | (83%) | 23 |
| 7c | 4 | (8%) | 46 | (92%) | 50 |
| *Burin spalls* | | | | | |
| 7d | 1 | (10%) | 9 | (90%) | 10 |
| *Chunks* | | | | | |
| 8 | 7 | (4%) | 188 | (96%) | 195 |
| Total | 157 | (6%) | 2594 | (94%) | 2751 |

Table 5.58 Le Flageolet I, XI: summary of associations between variable pairs. Raw mat = Raw Material Type; Techno = Technological Type; WTCL = Weight Class. Values of Retouch variable: retouched, unretouched.

| Interaction Term | $G^2$ | df | *p* | n |
|---|---|---|---|---|
| Raw mat * Retouch | 78.2 | 12 | 0.000 | 2751 |
| Raw mat * Techno | 800.9 | 228 | 0.000 | 2751 |
| Retouch * Techno | 181.7 | 19 | 0.000 | 2751 |
| Raw mat * Object type | 618.3 | 48 | 0.000 | 2751 |
| Retouch * Object type | 148.8 | 4 | 0.000 | 2751 |
| Raw mat * Retouch, at levels of Object type: | | | | |
| Flake | 5.1 | 9 | 0.830 | 1660 |
| Fragment | 23.8 | 11 | 0.013 | 487 |
| Blade | 41.0 | 11 | 0.000 | 337 |
| Chunk | 18.1 | 7 | 0.012 | 195 |
| Cobble | 6.0 | 5 | 0.302 | 72 |
| Raw mat * CTX | 590.1 | 36 | 0.000 | 2751 |
| Retouch * CTX | 40.0 | 3 | 0.000 | 2751 |
| Raw mat * Retouch, at levels of CTX: | | | | |
| 0% | 50.2 | 12 | 0.000 | 1129 |
| 1 – 49% | 3.3 | 8 | 0.917 | 933 |
| 50 – 100% | 6.4 | 6 | 0.379 | 422 |
| N/A | 15.0 | 7 | 0.036 | 267 |
| Raw mat * WTCL | 181.4 | 36 | 0.000 | 2751 |
| Retouch * WTCL | 77.5 | 3 | 0.000 | 2751 |
| Raw mat * Retouch, at levels of WTCL : | | | | |
| 1.0 – 4.9 g | 23.4 | 10 | 0.009 | 1685 |
| 5.0 – 14.9 g | 36.3 | 11 | 0.000 | 213 |
| 15.0 – 29.9 g | 27.9 | 10 | 0.002 | 686 |
| ≥ 30.0 g | 7.2 | 7 | 0.408 | 167 |

Table 5.59 Le Flageolet I, XI: cross-tabulation of observed frequencies and percentages for Retouch and Object Type.

| Object Type | Retouched | | Unretouched | | Grand Total | |
|---|---|---|---|---|---|---|
| flake | 38 | (1.8%) | 2117 | (98.2%) | 2155 | (100.0%) |
| fragment | **135** | **(18.7%)** | 588 | (81.3%) | 723 | (100.0%) |
| blade | **71** | **(13.1%)** | 470 | (86.9%) | 541 | (100.0%) |
| chunk | 8 | (2.9%) | 265 | (97.1%) | 273 | (100.0%) |
| cobble/core | 1 | (1.4%) | 68 | (98.6%) | 69 | (100.0%) |
| Total | 253 | (6.7%) | 3508 | (93.3%) | 3761 | (100.0%) |

$G^2 = 148.8$, df = 4, $p = .000$

Table 5.60 Le Flageolet I, XI: cross-tabulation of observed frequencies and percentages for Raw Material Type and Cortex Amount.

| Raw Material Type | 0 % | | 1-49 % | | 50-100 % | | N/A | | Total |
|---|---|---|---|---|---|---|---|---|---|
| Senonian, black | 549 | (41%) | 486 | (36%) | **235** | **(17%)** | 78 | (6%) | 1348 |
| Senonian, beige | 156 | (34%) | **202** | **(44%)** | 81 | (17%) | 25 | (5%) | 464 |
| Senonian, indeterm. | 107 | (43%) | 90 | (37%) | 31 | (13%) | 18 | (7%) | 246 |
| Bergeracois | **64** | **(63%)** | 30 | (29%) | 5 | (5%) | 3 | (3%) | 102 |
| chalcedony/millstone | 20 | (56%) | 13 | (36%) | 2 | (6%) | 1 | (3%) | 36 |
| jasper | 8 | (57%) | 3 | (21%) | 3 | (21%) | | | 14 |
| Gavaudun | 1 | (50%) | 1 | (50%) | | | | | 2 |
| Mussidan | 2 | (100%) | | | | | | | 2 |
| Jurassic | 2 | (100%) | | | | | | | 2 |
| quartzite | 3 | (5%) | 0 | (0%) | 0 | (0%) | **55** | **(95%)** | 58 |
| basalt | 1 | (2%) | 1 | (2%) | 0 | (0%) | [a]47 | (96%) | 49 |
| porcelainite | [b]12 | (100%) | | | | | | | 12 |
| unidentified | **204** | **(49%)** | 107 | (26%) | 65 | (16%) | 40 | (10%) | 416 |
| Total | 1129 | (41%) | 933 | (34%) | 422 | (15%) | 267 | (10%) | 2751 |

$G^2 = 590.1$, df = 36, $p = .000$

[a] Expected count = 4.8, std. deviate = 19.37.

[b] Expected count = 4.9; std. deviate = 3.19.

Table 5.61 Le Flageolet I, XI: cross-tabulation of observed frequencies and percentages for Raw Material Type and Weight Class.

| Raw Material Type | 1.0 – 4.9 g | | 5.0 – 14.9 g | | 15.0 – 29.9 g | | ≥ 30 g | | Total |
|---|---|---|---|---|---|---|---|---|---|
| Senonian, black | 760 | (56%) | 383 | (28%) | 122 | (9%) | 83 | (6%) | 1348 |
| Senonian, beige | 280 | (60%) | 115 | (25%) | 44 | (9%) | 25 | (5%) | 464 |
| Senonian, indeterm. | 163 | (66%) | 56 | (23%) | 14 | (6%) | 13 | (5%) | 246 |
| Bergeracois | 71 | (70%) | 23 | (23%) | 6 | (6%) | 2 | (2%) | 102 |
| chalced./millstone. | 17 | (47%) | 13 | (36%) | 5 | (14%) | 1 | (3%) | 36 |
| Jasper | 10 | (71%) | 4 | (29%) | | | | | 14 |
| Gavaudun | 2 | (100%) | | | | | | | 2 |
| Mussidan | | | 1 | (50%) | 1 | (50%) | | | 2 |
| Jurassic | | | 1 | (50%) | 1 | (50%) | | | 2 |
| quartzite | 28 | (48%) | 8 | (14%) | 5 | (9%) | 17 | (29%) | 58 |
| basalt | 19 | (39%) | 10 | (20%) | 3 | (6%) | 17 | (35%) | 49 |
| porcelainite | 10 | (83%) | 1 | (8%) | 1 | (8%) | | | 12 |
| unidentified | 325 | (78%) | 71 | (17%) | 11 | (3%) | 9 | (2%) | 416 |
| Total | 1685 | (61%) | 686 | (25%) | 213 | (8%) | 167 | (6%) | 2751 |

$G^2 = 181.4$, df = 36, $p = .000$

Table 5.62 Le Flageolet I, IX: cross-tabulation of observed frequencies and percentages for Raw Material Type and Retouch.

| Raw Material Type | Retouched | | Unretouched | | Total |
|---|---|---|---|---|---|
| Local | | | | | |
| Senonian, black | 391 | (13%) | 2548 | (87%) | 2939 |
| Senonian, beige | 111 | (13%) | 768 | (87%) | 879 |
| Senonian, indeterm. | 65 | (16%) | 338 | (84%) | 403 |
| chalcedony/millstone | 6 | (16%) | 31 | (84%) | 37 |
| quartzite | [b]1 | (0%) | [e]**225** | **(100%)** | 226 |
| basalt | [c]1 | (1%) | 168 | (99%) | 169 |
| Non-local | | | | | |
| Bergeracois | [a]**94** | **(34%)** | [d]186 | (66%) | 280 |
| Fumelois | 1 | (17%) | 5 | (83%) | 6 |
| Gavaudun | 1 | (50%) | 1 | (50%) | 2 |
| Jurassic | 2 | (67%) | 1 | (33%) | 3 |
| Unknown distance | | | | | |
| jasper | 3 | (38%) | 5 | (63%) | 8 |
| porcelainite | 5 | (12%) | 37 | (88%) | 42 |
| unidentified | 109 | (11%) | 864 | (89%) | 973 |
| Total | 790 | (13%) | 5177 | (87%) | 5967 |

$G^2 = 186.4$, df = 12, $p = .000$

[a] Expected count = 37.1, standardized deviate = 9.35.

[b] Expected count = 29.9, standardized deviate = -5.29.

[c] Expected count = 22.3, standardized deviate = -4.52.

[d] Expected count = 242.9, standardized deviate = -3.65.

[e] Expected count = 196.1, standardized deviate = 2.07.

Table 5.63 Le Flageolet I, IX: cross-tabulation of observed frequencies and percentages for Retouch and Technological Type (Tech). With $G^2$ statistics and standardized deviates (std. dev.) for selected cells.

| Tech | Retouched | | Unretouched | | Total |
|---|---|---|---|---|---|
| *Cobbles, cores:* | | | | | |
| 1a | | | 4 | (100%) | 4 |
| 1b | | | 6 | (100%) | 6 |
| 1c | 20 | (14%) | 126 | (86%) | 146 |
| *Cortical blanks:* | | | | | |
| 2a | 39 | (6%) | 580 | (94%) | 619 |
| 2b | **25** | **(20%)** | 102 | (80%) | 127 |
| 2c | 10 | (13%) | 67 | (87%) | 77 |
| *Semi-cortical blanks:* | | | | | |
| 3a | 84 | (8%) | [c]1003 | (92%) | 1087 |
| 3b | **94** | **(32%)** | 203 | (68%) | 297 |
| 3c | 27 | (12%) | 192 | (88%) | 219 |
| *Non-cortical blanks:* | | | | | |
| 4a | 94 | (7%) | **1227** | **(93%)** | 1321 |
| 4b | [a]**220** | **(38%)** | 353 | (62%) | 573 |
| 4c | **131** | **(27%)** | 350 | (73%) | 481 |
| *Special blanks:* | | | | | |
| 5c | | | 1 | (100%) | 1 |
| 5d | 1 | (50%) | 1 | (50%) | 2 |
| 6 | 1 | (50%) | 1 | (50%) | 2 |
| *Crests & rejuvenations:* | | | | | |
| 7a | 3 | (13%) | 20 | (87%) | 23 |
| 7b | 15 | (16%) | 80 | (84%) | 95 |
| 7c | 13 | (11%) | 109 | (89%) | 122 |
| *Burin spalls:* | | | | | |
| 7d | 1 | (3%) | 32 | (97%) | 33 |
| *Chunks:* | | | | | |
| 8 | [b]12 | (2%) | **720** | **(98%)** | 732 |
| Total | 790 | (13%) | 5177 | (87%) | 5967 |

$G^2 = 621.2$, df = 19, $p = .000$

[a] Expected count = 75.9, std. dev. = 16.55.

[b] Expected count = 96.9, std. dev. = -8.63.

[c] Expected count = 943.1, std. dev. = 1.95

Table 5.64 Le Flageolet I, IX: summary of associations between various variable pairs. Raw Mat = Raw Material Type; Techno = Technological Type; Cortex = amount dorsal cortex; WTCL = Weight Class. Values of Retouch variable: retouched, unretouched.

| Interaction Term | $G^2$ | df | *p* | n |
|---|---|---|---|---|
| Raw Mat * Retouch | 186.4 | 12 | 0.000 | 5967 |
| Raw Mat * Techno | 1887.0 | 228 | 0.000 | 5967 |
| Retouch * Techno | 621.6 | 19 | 0.000 | 5967 |
| Raw Mat * Object Type | 1663.0 | 48 | 0.000 | 5967 |
| Retouch * Object Type | 557.1 | 4 | 0.000 | 5967 |
| Raw Mat * Retouch, at levels of Object Type: | | | | |
| Flake | 44.9 | 12 | 0.000 | 3230 |
| Fragment | 38.9 | 10 | 0.000 | 1000 |
| Blade | 35.2 | 10 | 0.000 | 860 |
| Chunk | 19.3 | 8 | 0.013 | 733 |
| Cobble | 2.3 | 6 | 0.917 | 144 |
| | | | | |
| Raw Mat * CTX | 1441.0 | 36 | 0.000 | 5697 |
| Retouch * CTX | 168.7 | 4 | 0.000 | 5697 |
| Raw Mat * Retouch, at levels of CTX: | | | | |
| 0% | 82.0 | 12 | 0.000 | 2538 |
| 1 – 49% | 27.0 | 12 | 0.008 | 1722 |
| 50 – 100% | 21.8 | 10 | 0.016 | 823 |
| N/A | 36.0 | 8 | 0.000 | 882 |
| | | | | |
| Raw Mat * WTCL | 189.6 | 36 | 0.000 | 5697 |
| Retouch * WTCL | 477.9 | 3 | 0.000 | 5967 |
| Raw Mat * Retouch, at levels of WTCL : | | | | |
| 1.0 – 4.9 g | 59.8 | 12 | 0.000 | 3799 |
| 5.0 – 14.9 g | 86.7 | 10 | 0.000 | 1375 |
| 15.0 – 29.9 g | 49.9 | 9 | 0.000 | 455 |
| ≥ 30.0 g | 39.2 | 7 | 0.000 | 338 |

Table 5.65 Le Flageolet I, IX: cross-tabulation of observed frequencies and percentages for Raw Material Type and Object Type. With $G^2$ statistics and standardized deviates (std. dev.) for selected cells (extreme values).

| Raw Material | Flake | | Fragment | | Blade | | Chunk | | Cobble | | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Local | | | | | | | | | | | |
| Senonian, black | [c]**1797** | **(61%)** | 438 | (15%) | 431 | (15%) | [e]186 | (6%) | 87 | (3%) | 2939 |
| Senonian, beige | 509 | (58%) | 159 | (18%) | **154** | **(18%)** | 38 | (4%) | 19 | (2%) | 879 |
| Senonian, indeterm. | 212 | (53%) | **88** | **(22%)** | 62 | (15%) | 22 | (5%) | **19** | **(5%)** | 403 |
| chalc./millstone | 23 | (62%) | 8 | (22%) | 5 | (14%) | 1 | (3%) | | | 37 |
| quartzite | [d]10 | (4%) | 0 | (0%) | 1 | (<1%) | [a]**213** | **(94%)** | 2 | (1%) | 226 |
| basalt | [f]24 | (14%) | 0 | (0%) | 0 | (0%) | [b]**144** | **(85%)** | 1 | (1%) | 169 |
| Non-local | | | | | | | | | | | |
| Bergeracois | 142 | (51%) | **65** | **(23%)** | **63** | **(23%)** | 6 | (2%) | 4 | (1%) | 280 |
| Fumelois | 2 | (33%) | 1 | (17%) | 3 | (50%) | | | | | 6 |
| Gavaudun | 1 | (50%) | 1 | (50%) | | | | | | | 2 |
| Jurassic | | | 1 | (33%) | 2 | (67%) | | | | | 3 |
| Unknown provenience: | | | | | | | | | | | |
| jasper | 1 | (13%) | 6 | (75%) | 1 | (13%) | | | | | 8 |
| porcelainite | 21 | (50%) | 10 | (24%) | 7 | (17%) | 4 | (10%) | | | 42 |
| unidentified | 488 | (50%) | **223** | **(23%)** | 131 | (13%) | 119 | (12%) | 12 | (1%) | 973 |
| Total | 3230 | (54%) | 1000 | (17%) | 860 | (14%) | 733 | (12%) | 144 | (2%) | 5967 |

$G^2$ = 1663.0, df = 48, $p$ = .000

[a] Expected count = 27.8, std. dev. = 35.16.

[b] Expected count = 20.8, std. dev. = 27.05.

[c] Expected count = 1590.9, std. dev. = 5.17.

[d] Expected count = 122.3, std. dev. = -10.16

[e] Expected count = 361.0, std. dev. = -9.21.

[f] Expected count = 91.5, std. dev. = -7.06.

Table 5.66 Le Flageolet I, IX: cross-tabulation of observed frequencies and percentages for Raw Material Type and Cortex Amount.

| Raw Material | 0 % | | 1-49 % | | 50-100 % | | N/A | | Total |
|---|---|---|---|---|---|---|---|---|---|
| Senonian, black | 1285 | (44%) | **938** | **(32%)** | 437 | (15%) | 278 | (9%) | 2938 |
| Senonian, beige | 361 | (41%) | **338** | **(38%)** | 122 | (14%) | 57 | (6%) | 878 |
| Senonian, indet. | 184 | (46%) | 121 | (30%) | 57 | (14%) | 41 | (10%) | 403 |
| Bergeracois | **163** | **(58%)** | 76 | (27%) | 31 | (11%) | 10 | (4%) | 280 |
| chalced./millstone | 19 | (51%) | 14 | (38%) | 3 | (8%) | 1 | (3%) | 37 |
| jasper | 5 | (63%) | 2 | (25%) | 1 | (13%) | | | 8 |
| Fumelois | 5 | (83%) | 1 | (17%) | | | | | 6 |
| Gavaudun | 1 | (50%) | 1 | (50%) | | | | | 2 |
| Jurassic | 2 | (67%) | 1 | (33%) | | | | | 3 |
| quartzite | 2 | (1%) | 5 | (2%) | 4 | (2%) | **215** | **(95%)** | 226 |
| basalt | 17 | (10%) | 5 | (3%) | 2 | (1%) | **145** | **(86%)** | 169 |
| porcelainite | 19 | (45%) | 11 | (26%) | 8 | (19%) | 4 | (10%) | 42 |
| unidentified | **475** | **(49%)** | 209 | (21%) | **158** | **(16%)** | 131 | (13%) | 973 |
| Total | 2538 | (43%) | 1722 | (29%) | 823 | (14%) | 882 | (15%) | 5965 |

$G^2 = 1441.0$, df = 36, $p = .000$

Table 5.67 Counts of blanks and cores, and blank:core ratios, in level G of Caminade Est.

| Raw Material Type | Blanks | Cores | Blank:Core |
|---|---|---|---|
| Local | | | |
| Senonian, black | 1068 | 67 | 15.9 |
| Senonian, beige | 246 | 8 | 30.8 |
| Senonian, indeterm. | 11 | 2 | 17.4 |
| chalcedony/millstone | 95 | 10 | 5.5 |
| Unknown distance | | | |
| jasper | 590 | 34 | 9.5 |
| porcelainite | 146 | 1 | 146.0 |
| unidentified | 43 | 5 | 8.6 |
| Grand Total | 2199 | 127 | 17.3 |

Table 5.68 Level III of La-Côte: counts of blanks and cores, and blank:core ratios.

| Raw Material Type | Blanks | Cores | Blank:Core |
|---|---|---|---|
| Local | | | |
| Senonian, black | 726 | 8 | 90.8 |
| Senonian, beige | 58 | 1 | 58.0 |
| silicified wood | 34 | 1 | 34.0 |
| Non-local | | | |
| Bergeracois | 67 | 4 | 16.8 |
| Grand Total | 885 | 14 | 63.2 |

Table 5.69 Level IX of Le Flageolet I: counts of blanks and cores, and blank:core ratios.

| Raw Material Type | Blanks | Cores | Blank:Core |
|---|---|---|---|
| Local | | | |
| Senonian, black | 2659 | 95 | 28.0 |
| Senonian, beige | 822 | 19 | 43.3 |
| Senonian, indeterminate | 362 | 19 | 19.1 |
| chalcedony/millstone | 34 | 2 | 17.0 |
| Non-local | | | |
| Bergeracois | 270 | 4 | 67.5 |
| Unknown distance | | | |
| porcelainite | 37 | 1 | 37.0 |
| Grand Total | 4184 | 140 | 29.9 |

# 6

# Fracture Properties of Lithic Raw Materials

The previous chapters were written under the assumption that some lithic raw materials have fracture properties that allow increased technological efficiency, especially when strategies for acquiring and consuming those raw materials maximize the effect. In this chapter, I examine that assumption more closely.

The material properties that allow increased technological efficiency are those that tend to lower manufacture costs or improve tool performance. Pinpointing these requires considering the problems that stone workers and tool users must solve. As I noted earlier, examining the effects of different raw materials on the costs and benefits of tool performance is beyond the scope of this work; thus, I consider raw material properties in relation to manufacture costs but not tool performance.

The rock materials used as tool stone used in the past "must have been rather easy to chip and relatively hard, tough, and fine-grained," (Goodman1944: 418). Crabtree (1967:9) stressed, in addition, ease of chipping, or "the amount of resistance to the necessary force required for detaching a flake." This is an empirical property that I term flaking strength. Below, this concept is described in relation to experimental results. In addition to flaking strength, Crabtree also cited the importance of predictable fracture: "When one is able to control the four dimensions—thickness, width, length and curve—when removing a flake, he can then produce almost any tool he may need," (*op. cit.* p. 8). The ability to control flake size and morphology is what I have termed fracture predictability. This, too, is an empirical property that is described by phenomena

observed during flaking experiments. Later, I give a specific definition of fracture predictability, and relate this property to some experimental results.

Experiments in flintknapping indicate that both flaking strength and fracture predictability are highly relevant to lithic technology at the scale of individual flintknapping episodes, in that they affect the ease of flaking and one's success in making a desired product. Unfortunately, raw material fracture properties are often described using an ordinal scale of measurement with two or three categories, such as when raw material is identified as either "good quality" or "poor quality," which terms are, moreover, rarely defined (e.g., Andrefsky 1994; but see Brantingham *et al.* 2000 for a more refined approach). In reality, there is significant variation in fracture properties between rocks belonging to a single stone type, as shown by results described below. Fracture properties should be measured using interval or ratio scales of measurement.

Flaking strength and fracture predictability also affect the costs of stone tool production on a longer time scale. The production of tools from rocks with high flaking strength requires more energy than that required if weaker rocks are used, and the increased energy required could become significant in some adaptive contexts. The production of tools from rocks that flake less predictably increases cost, because it decreases the amount of useful product that can be obtained from a given quantity of raw material, compared with more predictable rocks. This effect will be enhanced when the raw material has a high acquisition cost. As an extreme example, a rock transported a long distance that crumbles into useless chunks and shatter would result in a total loss.

The previous two chapters examined evidence for the choice of raw materials and strategies for managing their consumption efficiently. By adding data on the fracture

properties of the raw materials observed in the six assemblages, I will be able to provide a more complete characterization of the relative costs of lithic raw material exploitation (RME) in each assemblage. This requires measuring the flaking strength and fracture predictability of the various material types, and measuring the inherent variability of these properties. A brief summary of theories of rock fracture mechanics will provide the necessary background for understanding how these properties can be measured, and the sources of variation in each property.

**Fracture of brittle rock**

Brittle solids fracture in various ways. During chipped stone manufacture, rocks like chert and basalt usually experience "Mode I fracture" in which the two surfaces of an internal crack are pulled apart by tension. Conchiodal fracture is a kind of Mode I fracture that leads to the development of a Hertzian cone of fracture, whereby the fracture plane develops in such a way as to produce the characteristic shell-like appearance on the faces of the broken rock. Archaeologists are mainly interested in a very narrow set of conditions: conchoidal fracture on the edge of a core, usually made of microcrystalline or cryptocrystalline siliceous rock such as chert, flint, basalt, or quartzite—tool stone. The purpose of the following discussion is to review the application of fracture mechanics theory to this context as a way of setting the stage for the presentation of experimental work on the fracture properties of Perigordian tool stone.

Variation between rocks in the factors that affect the *initiation* of crack growth determines the flaking strength and fracture predictability of a given rock. Tool stone materials are brittle/elastic solids that are isotropic (their elastic properties are the same in all directions). Griffith (1921, 1924) developed the first theory that allowed prediction

of fracture initiation in such materials, based on the concept of energy balance. Irwin (1958, cited in Jaeger and Cook 1976) developed an independent approach called the fracture stress approach, which has been shown to be compatible with the Griffith approach (Whittaker et al. 1992). Both approaches begin with the concepts stress, strain, elasticity, and brittleness.

Stress, strain, elasticity, brittleness

When force is applied to the surface of a rock, the rock changes shape slightly. The applied force, or load, is called stress ($\sigma$); its technical definition is "force per unit area," (Whittaker *et al.* 1992:15). The change in shape is called strain ($\varepsilon$), and can be expressed as the displacement of points within the body. Until stress reaches the point where fracture begins to occur, displacement is approximately linearly related to the applied force (Jaeger and Cook 1976), and the amount of displacement is equal to the work done on the body. If the load is removed, strain energy is converted into kinetic energy and does the work of moving the displaced points back to their original positions. In glass and glass-like materials, dislocations are very hard to move because of the dense packing of molecules, the complex structure, the high strength of the molecular bonds, and the high frequency of impurities and precipitates (A. Franklin pers. comm.).

When struck with a hammer, a rock experiences compressive, tensile, and shear stresses along multiple axes. Tool stone has much greater strength under compressive and shear stresses than they have under tensile stresses. Thus, under the conditions that normally prevail during flintknapping, fracture is due to tensile stress associated with compressive loading (Cotterell and Kamminga 1979, 1987).

The strength of a rock depends on how it behaves while a load is being applied. A graphical technique is often used to model this behavior, by plotting stress against

strain (Figure 6.1). For solids in general, there are three main regions under the stress/strain curve, each of which defines a distinct kind of behavior. In Figure 6.1a, AB is the elastic region; BC is the ductile region; and CD is the brittle region (Jaeger and Cook 1976). If the applied stress is relieved while the curve is still in the elastic region, the rock returns to its original shape. For perfectly elastic solids, the stress/strain curve will follow the same path each time the same load is applied, if the load is relieved before the curve reaches point C. The shape of the $\sigma/\varepsilon$ curve in the AB region defines the elasticity of the rock, which is designated by E, Young's modulus. If the applied load is sufficient to cause some permanent deformation, but the material retains most of its ability to resist stress, then the material exhibits ductility. Of course, the ductile region of most rocks is so small that it can be effectively ignored. Once the applied stress exceeds the rock's strength, the rock typically transitions rapidly from elastic to brittle behavior and fails catastrophically, or fractures. The brittleness of the material is described by the slope of the $\sigma/\varepsilon$ curve in the brittle region.

Fracture mechanics of rock

According to Jaeger and Cook (1976), failure is the continuous process during which a rock steadily deteriorates. Some rocks sustain some brittle failure, or fracture, without losing their ability to resist stress; others experience catastrophic failure immediately after fracture occurs. In the latter case "failure" and "fracture" are synonymous. This is generally true of rocks used as tool stone, which typically behave as shown in Figure 6.1b. The point along the stress/strain curve at which such a rock fails is called fracture strength (Jaeger and Cook 1976, Lawn 1993). This corresponds to point C in Figure 6.1a.

A mathematical technique for modeling the failure of brittle-elastic solids (glass, ceramics, rock, composites, and metals) was first proposed by Griffith (1921, 1924). The impetus for the theory was to explain why the measured strength of such materials is far below its calculated strength. Strength is calculated using an energy function for inter-atomic bonds (Davidge 1979), because it is a function of the amount of stress necessary to break the weakest inter-atomic bonds (Luedtke 1992). However, the measured tensile strength of glass is at least ten times lower than its theoretical tensile strength.

The Griffith theory explains the occurrence of crack initiation in terms of an energy balance and the effects of minute cracks on it. A body subjected to surface forces is in its equilibrium state when the potential energy stored within the body is at a minimum (Davidge 1979). As a load is applied, strain energy builds up within the body, increasing the total potential energy. To cause fracture, the potential energy must exceed the energy of the molecular bonds that hold the particles of the body together (atomic cohesion and adhesion). Griffith proposed that the surface of glass is permeated with microscopic cracks, which are variously termed flaws, Griffith cracks, or microcracks; these have since been observed in rock (Lawn 1993). During the application of stress to a body of rock, these microcracks act as stress concentrators, allowing local build-ups of stain energy far above the level of the global applied stress. These localized spikes in strain energy more easily overcome the molecular cohesive and adhesive forces, and a favorably oriented crack begins to lengthen. This is the onset of crack initiation.

One application of Griffith theory is to predict the conditions under which crack initiation will occur. Under a given set of test conditions, whenever a component of

stress is increased until failure occurs, the magnitude of the applied stress at failure defines the strength of the material under those conditions (Davidge 1979, Jaeger and Cook 1976). (In the case of chipped stone manufacture, I would suggest that we are usually interested in tensile strength under oblique, uniaxial, dynamic impact loading, although that term is rather unwieldy.) In measuring the fracture strength of a material, the problem is to develop a "criterion of failure" as a predictor for crack initiation under a given set of conditions. Griffith developed such a criterion for the case of an elliptical hole in the center of an infinite plate that is subjected to uniaxial tension, and this criterion is most pertinent in the present context.

The Griffith criterion depends on the notions of strain energy, surface energy, total potential energy, the work done on the body by strain energy, and strain energy release. Surface energy is an effect of molecular cohesion and adhesion, which pull atoms together. Those atoms that form the outermost layer and that are exposed at a free surface, such as the surface of an opening crack, are pulled into the material more strongly because of the absence of atoms on one side. Elastic strain energy is the potential energy stored in the strained part of the rock as points are displaced due to stress. Some strain energy is present in the body before an outside stress is applied; the application of such stress increases the total strain energy. When a crack begins to extend, some strain energy at the crack tip is released. Some of this energy is expended in doing the work of extending the crack, and some does the work of returning displaced points around the crack back to their original locations as the strained material relaxes. Simultaneously, surface energy is added to the system by the creation of new crack surface. The total energy of the cracked plate is a function of all these components (Whittaker et al. 1992). The strain energy release rate is the change in

total energy divided by the change in crack length. The higher the material's elasticity, the lower its strain energy release rate.

Griffith energy balance theory basically postulates that a microcrack will begin to extend when the total potential energy of the body is at equilibrium, which occurs when the surface energy associated with the crack is balanced by the strain energy at the crack tip. In other words,

$$\frac{\delta U}{\delta a} = \frac{\delta W}{\delta a}$$

where U is the potential energy in the body, which is composed of the elastic strain energy and the energy of the applied stress; *a* is one-half the length of the crack; and W is the work done on lengthening the crack. The left-hand term is equal to G, strain energy release rate; the right-hand term is equal to R, resistance to crack initiation (Wittaker et al. 1992). R is also equal to surface tension or molecular cohesion (Lawn 1993). According to Lawn (1993), many workers assume that R is a constant, and that $G = G_C$, where $G_C$ is the critical value of G at which crack initiation occurs (http://www.engr.utk.edu/~cmc/528/chapter1/sec5.htm). The critical value is:

$$G_C = 2E\gamma_{eff}$$

where E is Young's modulus (the elastic modulus, which is stress divided by strain) and $\gamma_{eff}$ is the effective intrinsic surface energy of the body (Whittaker et al. 1992). However, Lawn (1993) cites the following as an additional condition for crack initiation: $dG/dC > 0$. That is, the change in strain energy release rate divided by the change in crack length must be greater than zero. These two conditions lead to crack initiation.

The Griffith energy balance theory is able to explain stable crack propagation, where the system remains at equilibrium. However, conchoidal fracture is unstable, in the sense that failure equals fracture, causing the material to lose its ability to resist

stress. It is also "unstable in that, with increasing crack length, the decrease in stored elastic energy exceeds the increase in the surface energy. Therefore, the crack propagates spontaneously without limit, resulting in complete failure, any excess elastic energy being transformed into the kinetic energy of the moving crack," (Tite et al. 2001:303). Mott (1948, cited in Lawn 1993) noted that the Griffith energy balance theory failed to account for unstable crack propagation. Mott's solution was to add a new term to the total energy system, $U_K$, the kinetic energy from the movement of material on either side of the crack as the crack passes. This term is equal to the difference between G and $R_0$ over the change in crack length:

$$G - R_0 = dU_K/dc \text{ (Lawn 1993).}$$

That is, when the crack driving force (G) exceeds the crack resistance energy ($R_0$), the excess energy translates into the kinetic energy of the moving crack, and this is what propagates the crack until the material separates into two or more pieces.

One of the assumptions of the Griffith approach is that the crack extends in its own plane. However, cracks often extend in a plane oriented differently from the crack plane. This led Griffith to propose some elements that led to an alternative approach termed the fracture stress approach, which in turn furnished the foundation for linear elastic fracture mechanics (Whittaker 1992). A key concept of these approaches is that the major factor determining the onset of crack initiation is the intensity of the local stress field in the vicinity of the crack tip. This is known as $K_I$, the stress intensity factor. This contrasts with the Griffith energy balance approach, which deals with global phenomena. The most basic and general expression of stress intensity is

$$\sigma_i = K_I/(2\pi a)^{1/2} \; f(\theta)$$

where $\sigma_j$ is the local tensile stress along the j axis for a crack with its tip at the polar coordinates (0,0), *a* is one-half the crack length, and $\theta$ is the angle between the crack plane and the plane of $\sigma_j$ (Egan 1975, Lawn 1993, Whittaker et al. 1993). Thus, $K_I$ varies for different stresses, which have different geometries. For example, for tensile stress in the x axis in Mode I fracture,

$$\sigma_{xx} = K_I/(2\pi a)^{1/2} \cos(\theta/2)[1-\sin(\theta/2)\sin(3\theta/2)] .$$

$K_I$ is also dependent on the loading conditions and the crack configuration. In the case of an infinite plate with a crack of length 2*a* in the center, to which a uniform tension $\sigma$ is applied,

$$K_I = \sigma(\pi a)^{1/2} .$$

A crack in a body will propagate when $K_I$ is equal to $K_{IC}$, the Mode I fracture toughness of the material. $K_{IC}$ is considered a material constant; it is equivalent to $T_0$, the "intrinsic toughness" (Lawn 1993:61). Intrinsic toughness is defined as

$$T_0 = (E'R_o)½,$$

where $R_o$ is the "intrinsic work rate per unit area" (Lawn 1993:40). $K_{IC}$ has also been shown to be equivalent to $G_C$, and the equivalence of those two terms forms the basis for linear elastic fracture mechanics (Whittaker et al. 1992).

From the above it follows that $G_C = 2E\gamma_{eff} = K_{IC} = T_0 = (E'R_o)½$. $K_{IC}$ can also be expressed as $Y\sigma(\pi a)^{1/2}$, where Y is a dimensionless parameter that depends on the specimen size and shape and crack geometry (http://filebox.vt.edu/users/jekim7/termpro.htm).

The relationship between fracture strength and fracture toughness depends more on semantics than on any precise mathematical relation. The concept of strength existed many years before the work of Griffith, when it was thought that any material had

an intrinsic strength value and that this value was adequately described by a well-defined stress limit. The work of Griffith and others showed that this was not the case; instead, material strength varied depending on the type of load applied, the geometry of loading, the geometry of the test specimen, and other factors (Lawn 1993). This work, and the subsequent development of the field of fracture mechanics, led to the development of the concept "fracture toughness". The above discussion makes clear that fracture strength pertains to the magnitude of the global applied stress, while fracture toughness pertains to the magnitude of stress intensity in the immediate vicinity of the crack tip.

Strength and toughness emerge from various physical aspects of stone, some of which are common to both fracture properties. According to Luedtke (1992:88), the strength of rocks is affected by mineralogy, grain size, interlocking of grains, cracks and pores, and the presence/absence of water. The mineralogy of chert is dominated by $SiO_2$, but minute quantities of other elements may affect the rock's strength (Alan Franklin pers. comm. 1994). The strength of the rock is also affected by the strength of the crystal bonds, the cement between grains, and any filling material in voids and cracks. The tighter the bond between grains, the stronger the rock. Strength increases as microcrack length decreases, so rocks with larger microcracks are weaker. Because many microcracks in rocks correspond to grain boundaries, strength generally correlates inversely with grain size, although some coarse-grained rocks have a structure that inhibits crack propagation. Microcracks in rock are minute, lenticular microstructural defects that result from lithologic processes and weathering (Lawn and Marshall 1979). Their orientation within a given rock mass is usually assumed to be approximately random. They exist both along grain boundaries and within grains. Most cherts contain

about 1% water (Luedtke 1992:89), which tends to weaken the material by creating a bond that is less strong than the $SiO_2$ bond.

Fracture toughness, on the other hand, is a function of crack length (*a*), the orientation ($\theta$) of stresses relative to the crack plane, elasticity (E), and the global applied stress ($\sigma_A$). "In most rocks, voids, open cracks, and closed cracks of different and often random orientations are present," (Jaeger and Cook 1976:333). There is no reason to presuppose a tendency for microcracks to have any preferred orientation in chert, basalt, or quartzite; they are probably oriented approximately randomly, so that fracture is equally likely from loads applied in any direction, for a given test configuration. Thus, for a given applied stress and a given test configuration, variation in fracture toughness between different rocks must be a function of the material's elasticity and the frequency distribution of microcrack lengths. Mineralogy, grain size, interlocking of grains, and pores affect elasticity. Thus, fracture strength and fracture toughness are closely related. Measuring them, however, requires different tests.

*Crack propagation*

The direction and length of the crack path are determined by the relationship between the geometry of stresses and strains and the shape of the rock nucleus or core. Striking a nodule of chert in the middle may produce an incipient cone of percussion (Bordes 1969a), but flaking only occurs when a) the point of impact is near the edge of the core, b) the edge has an angle of about 90° or less, and c) the cone of percussion intersects the debitage surface of the core very near to the point of impact. Under these conditions, the normal mode of fracture is Hertzian after the German physicist who discovered this phenomenon (Speth 1972).

Using a special "photoelastic" technique (involving polarized light and high-speed photography), Faulkner (1972) produced images of the stress field in pieces of obsidian during loading and flaking. His work showed that the distribution of the stress field changes dramatically within microseconds after the crack propagation phase begins. This results from the asymmetry of the situation, whereby the incipient Hertzian cone intercepts the outside surface of the core. The developing circular crack is inhibited there, causing a build-up of tensile stress on the opposite side of the cone. In addition, when the trajectory of the indenter is obliquely to the striking surface, rather than perpendicular to it, compressive stress increases near the edge of the core, while tensile stress increases in the area away from the edge (Cotterall and Kamminga 1987). The crack path also changes quasi-abruptly soon after crack initiation. This crack path is determined largely by the geometry of the stresses in the rock and by the rock's stiffness (Cotterell and Kamminga 1987). The advancing crack path follows the axis of maximum tensile stress.

The size and shape of the flake that ultimately results is also affected by the location of the initial crack relative to the edge of the nucleus. When all other conditions (such as load, hammer type, and hammer shape) are equal, differences in crack location result in differences in butt size and flake size. Experimental data (Pelcin 1997) show clearly that the further the crack develops from the edge, the larger the resulting flake, regardless of the shape of the core's debitage surface. This raises the question of what causes variation in crack location.

Close observation of test specimens from the experiments I describe below suggests that cracks rarely initiate directly under the point of impact. More usually, the crack can be seen to initiate at a small distance (on the order of 1.0 mm) away from the

point of impact. Moreover, the exact location varies from one test to another. In addition, many hard-hammer flakes I studied in the Paleolithic collections show, on the ventral face near the butt, two or more incipient cones of percussion. The bulb of the flake will appear to be emanating from only one of the several incipient cones, or will appear to be the coalescence of several of them into a single fracture front. This suggests that multiple cracks often initiate simultaneously in neighboring locations near the point of impact. This suggests, in turn, that the exact location of crack initiation, and thus flake size, must be partly a function of the lengths, density, and distribution of microcracks in the material. The more variable these microcrack properties, the greater the variation in locus of initiation and, consequently, flake size. This variation gives rise to unpredictability to flaking.

**Measuring flaking strength, fracture predictability**

Two strategies for measuring the fracture properties of rocks are feasible. The first is to use tests specifically designed to measure isolated fracture properties, such as fracture toughness, uniaxial compressive strength, etc. For instance, fracture toughness can be calculated from the compliance, or load-point displacement per unit load, of a cracked plate under tension (Andreev 1995, Whittaker *et al.* 1992). The advantages of using such techniques is they have already been fully developed by materials scientists and engineers, and they yield unambiguous results with regard to the property being studied. The disadvantage is that the relevance of the measured values to variation in chipped stone technology would be difficult to establish, particularly since fracture predictability is affected by a combination of rock physical properties in ways that are not fully understood.

The second method is to design a test that mimics the flaking situation in flintknapping and observe the effects of load and material type on flaking strength and fracture predictability. Flintknapping itself is not a good choice, because it does not provide adequate control over the several parameters that affect the outcome of tests, and thus does not allow one to isolate the effects of any one parameter (Luedtke 1992; McCutcheon 1997; Pelcin 1996). Much better are the controlled testing techniques developed most recently by McCutcheon (1997) and Pelcin (1996), which do permit relatively good isolation of individual effects. The advantage of this method is that the results are clearly relevant to chipped stone technology. The disadvantages are that, despite excellent work by Pelcin and McCutcheon, the techniques still need adjustment; and that the exact physical basis of variation in test results may be difficult to isolate, since various rock physical properties together affect the outcomes of these tests. Nevertheless, I chose this strategy because the relevance of a method to chipped stone technology is more critical than the exact physical mechanism responsible for differences in the flaking properties of stone.

The test apparatus must produce Hertzian fracture. The experimental design should include a specimen of standard geometry possessing at least one edge with an angle of 90° or less to which a dynamic load is applied, such that the potential Hertzian cone will intersect the edge of the piece. It should also include controls on all other factors in order to minimize potential masking or confounding effects from other variables.

Each instance of applying a load to a specimen, or trial, will provide two kinds of information: whether the specimen fractured, and if so, the size of the resulting flake. The flaking strength of a given rock will be recorded in a manner closely similar to

Crabtree's definition of "ease of chipping" (see above): the minimum amount of force needed to break the rock. Fracture predictability will be recorded as the regularity of the relationship between applied load and probability of failure, and of the relationship between applied load and flake size. The manner in which both will be recorded is specific to the testing apparatus and protocol, and will be outlined more fully once those have been described.

A brief review of previous applications of this approach will serve to illustrate the challenges that must be overcome, and will help explain the reasons why I chose the machine employed by McCutcheon, but used a rather different protocol.

Previous studies of rock physical properties and flake formation in archaeology

Goodman (1944) used a Paige impact tester, which consists of a hammer attached to a spring. One places the test specimen under the hammer, pulls back the hammer, and lets go. Toughness is estimated by the minimum hammer height needed to produce a flake. Since velocity increases as the square of drop height, the measurement that is read at the time of fracture is converted by taking its square root. Goodman performed several repetitions of each measurement and then took the mean of the square roots of the measurements. She found some correlation between the ranking produced by these results and the rankings produced by her tests of hardness and resiliency on the same materials, but cautioned that her small sample sizes limited the extent to which her results could be generalized. The obvious disadvantage of this technique is its low precision.

Bonnichsen (1977) designed a more elaborate machine, which had a set of two vertical guide rails and a stabilizing support. These guide rails had been inserted through a pair of holes in a metal bar, so that the bar could slide along the rails. Above

the metal bar was a lock mechanism with a release button, permitting the bar to be suspended from a given height and then dropped. One end of the bar extended out and away from the rails, and held a steel collar in which indenters of various materials were clamped. Directly below the indenter, at ground level, was a vice holding the test specimen, made of either plate glass or obsidian. The operation of this device involved clamping a specimen in place, locking the metal bar at a pre-determined height, and then releasing it like a guillotine blade. Out of 720 trials, only a little over 100 of the test specimens broke. Bonnichsen was interested in replicating the actual flintknapping situation as closely as possible; accordingly, he tested the effects of different indenter materials, different specimen edge angles and positions, and different locations of impact. His results are difficult to apply because of his small sample sizes, the use of an incomplete and misleading theory of rock fracture mechanics (based on the behavior of P and S waves), and the limitations of his statistical approach.

Pelcin (1996) and Dibble and Pelcin (1995) developed a new method, with the ultimate goal of better understanding all the extrinsic factors that affect flake size and shape. They used a pair of machines, one of which is simply a more precise version of the Paige impact tester. However, instead of a steel hammer, various indenter materials were used, and release of the indenter arm was controlled with an electromagnet. The other machine consists of a T-shaped tower, from which steel ball bearings of various sizes could be suspended with an electromagnet, and then dropped by shutting off the electromagnet. The indenters and ball bearings were dropped onto glass "cores", machined to specified sizes and shapes and clamped into a vice. Dibble and Pelcin varied the sizes of ball bearing (using 45 g, 224g, and 535 g ball bearings), the drop

heights, the edge angles of the test specimens, the presence or absence of a bevel on the edge of the test specimens, and the morphology of the test specimens.

In this situation, indenter mass and velocity jointly determine the energy of the blow:

$$KE = mgh,$$

where KE = kinetic energy, $m$ = mass, $g$ = acceleration of gravity, and $h$ = drop height (Giancoli 1991). When an indenter is dropped onto the specimen, $m$ is equal to indenter mass, and $gh$ is equal to indenter velocity. Indenter mass times indenter velocity equals load. Pelcin (1996), and Dibble and Pelcin (1995) relied on a similar, but technically identical notion, momentum, which is equal to hammer mass times the square of hammer velocity.

Based on these experiments, Dibble and Pelcin (1995) concluded that hammer mass and hammer velocity had negligible effect on flake mass. To reach that conclusion, they examined the distribution of flake mass values along a second variable, platform thickness (defined as in Figure 6.2), for several different series of tests. Each series of tests differed in the mass of the ball bearing, the drop height of the ball bearing, and the exterior platform angle of the glass core. When different combinations of hammer mass and velocity were used to produce an identical momentum, or load (smaller balls dropped from higher positions, or larger balls from lower positions), Dibble and Pelcin found that the resulting flake mass values were statistically identical.

When they compared different series of data produced using different loads, but on cores with the same edge angle, they found a significant, positive relationship between flake platform thickness and flake mass. That is, flake mass appeared to increase as a function of platform thickness. Figure 6.3 illustrates how this occurs.

Moreover, they claim that "even when overall momentum is varied to... a considerable degree, flake mass is still largely determined by exterior platform angle and platform thickness alone," (Dibble and Pelcin 1995:432), and not by hammer mass or velocity. This last was based on an interpretation of data such as those shown in Figure 6.4; where two data series (represented by triangles and circles), each produced using a different momentum (by dropping a 225 g ball from two different heights), are compared for cores of different edge angles. According to these authors, on cores with a given edge angle (55°, 65°, or 75°), there is no appreciable difference in the distribution of flake mass values between tests done at different loads. Yet in each case, platform thickness does appear to have a significant effect on flake mass.

If this conclusion is true, it has important implications for the testing protocol that I should use for measuring the fracture properties of cherts. However, I interpret data such as those in Figure 6.4 differently. It is clear that Dibble and Pelcin (1995:430) believe platform thickness is controlled by the point of impact of the hammer: "In essence, [platform thickness] is the thickness of the flake at the point of percussion..." (and see Figure 6.3). This concept is the reason for treating platform thickness as an independent variable, against which flake mass was compared as the dependent variable.

Platform thickness and exterior platform angle can be used to predict flake mass, as elegantly shown by Pelcin (1997), and as Dibble and Pelcin argued, the ability to do so has important implications for the study of prehistoric technology. However, flake mass may not be a simple function of the hammer's point of impact. That point cannot be perfectly controlled by the knapper; it can only be approximately controlled in direct percussion. Moreover, the locus of crack initiation is beyond human control. The variation in platform thickness that can be seen in Dibble and Pelcin's graphs must

therefore result from a combination of the imprecision involved in aiming a ball bearing at a point on a core, and the variation in crack initiation loci that results from inherent variation in the microcrack properties of glass.

This would be a trivial point, if Dibble and Pelcin's problematic assumption about the point of crack initiation had not led to a second problem. Because they believed that platform thickness is entirely under the control of the experimenter (or knapper), they presented their data with that variable arrayed along the horizontal axis. Dibble and Pelcin (1995) did note that there was "some separation" between the different series, Yet, they dismissed the effect on flake mass as insignificant, compared with the "effect" of platform thickness, although the effect is more pronounced at higher values of exterior platform angle (EPA). However, if we remove the horizontal axis of their graphs, and examine only the flake mass data, a different picture emerges. I collected the raw data from their Figure 7 (shown in Figure 6.4) using Grab It!™ version 1.5 (Datatrend Software 1998); re-calculated the loads according to the equation KE = $mgh$; and drew new plots for each of the plots in their figure. These new plots (Figure 6.5) show the flake weights for each of the two data series (done at loads of 0.75 J and 2.76 J, corresponding to the two momentums), with data from cores of different EPAs shown in separate plots. Figure 6.5 also shows the mean value for each set of values.

There are appreciable differences in the distribution of flake mass values resulting from different hammer mass and/or velocity values. Mean flake weights are statistically indistinguishable for the data done on cores with EPA = 55° (Figure 6.5 (a)). When EPA = 65°, the mean flake weight is significantly higher at the higher load, although the difference is not statistically significant. When EPA = 75°, the mean flake weight is significantly higher at the higher load and the difference is significant (Table

6.1). This suggests that momentum (or load) has a significant effect on flake mass in cores with an EPA of 75° or greater, and that the effect becomes stronger with increasing EPA values. Dibble and Pelcin (1995) did not recognize this because they treated platform thickness as an input variable. As my reanalysis of their data shows, platform thickness and flake mass are effects of the locus of crack initiation.

McCutcheon (1997) also pursued experiments concerning the fracture properties of chert, using a slightly different machine. His experiments were part of a multi-facetted examination of the mechanisms responsible for the observed effects of heat treatment on the physical properties of chert. His "modified pendulum impact tester with steel indenter" is the very same machine that I used in all my experiments. The pendulum impact tester, or PIT, is supported by a steel frame. Two steel bands are suspended from widely separated points on horizontal bar at the top of the frame. A cylindrical steel billet is attached to the other end of the bands; the bands and billet swing freely, acting as a pendulum. The indenter can be swiveled to any vertical height up to 54 cm; when released, it swings down and strikes the edge of a square specimen clamped into a vice at the base of the frame. Load is proportional to the drop height. I provide a more detailed description of the PIT below.

The goal of McCutcheon's study was (1997) to determine whether and in what way heat-treatment affects fracture toughness and predictability, and to elucidate the underlying physical mechanism of such effects. His testing protocol for the PIT was developed in view of that goal, and the results were integrated with those of other tests, such as thermogravimetric analysis of chert specimens and fracture toughness tests using a Vicker's microindentation hardness tester. I limit my discussion to the design

and results of his PIT analyses, and analyze his protocol to see how it might be improved.

For each specimen, he ran multiple tests at each of several drop heights. McCutcheon measured fracture toughness as the "mean failure load". This quantity was calculated in the following way: He summed the drop heights for all the tests that resulted in a failure (for a given rock), and then divided by the total number of failures. He provided the following example: "A sample [i.e., specimens cut from one rock] could fail 10 times, once at 0.12, twice at 0.14, three times at 0.16, twice at 0.18, once at 0.20, and once at 0.22 Pa," (McCutcheon 1997:144)[1]. Adding 0.12 + 0.14 + 0.14 . . . + 0.22, and dividing by 10 yields the "average failure load" of 0.166. For each rock, he carried out between one and five tests (usually three) at each of several loads. He generated such data for unheated as well as heated specimens from the same rock. Seven of the 12 rocks he tested showed a lower average failure load for the heated than for the unheated specimens, which he determined using t-tests.

McCutcheon used two techniques to estimate fracture predictability and test the hypothesis that heated specimens have a more predictable fracture than unheated specimens. First, he compared the standard error (SE) of average failure load for the heated specimens with the SE of the unheated specimens from each rock. Nine of the 12 rocks showed a decrease in SE of average failure load in the heated specimens compared to the unheated specimens (although in one of the nine cases, the difference in SE was only 0.001).

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[1] McCutcheon mistook drop heights in cm for load in units of Pascals–Pa. However, that mistake had no effect on his results, since drop height is directly proportional to load.

The second technique involved testing whether the amount of material removed during failure increases with load. "If heating increases the predictability of amount of material removed, a stronger relationship for heated than unheated samples would be expected between these two variables," (McCutcheon 1997:151). To obtain the data, he weighed each test specimen before and after the test; "amount of material removed" is equivalent to flake mass, based on the assumption that weight loss is due to the removal of a flake. He first observed the distribution of Weight Loss values over loads, for unheated and heated specimens. Unfortunately, the sample sizes were too small to generate meaningful patterns, but McCutcheon did suggest that heated specimens tended to show more weight loss. He then compared the mean Weight Loss for heated and unheated specimens from each rock using a t-test. However, only three of the 12 rocks showed a significant test statistic. Grouping all data from the 12 rocks produced a significant Student's *t* value, but as he noted, this obscures significant variation among the rocks. Based on earlier analyses that suggested the distribution of failures over loads is non-normal, he chose to compare Fail Load and Weight Loss for both heated and unheated specimens, the basic idea being that in predictable rocks, Weight Loss should increase as Load increases. Of these tests, only three were significant at the .05 significance level. McCutcheon's main conclusion from these tests was that heating sometimes reduces fracture toughness improves fracture predictability, but not in every case.

McCutcheon's multifaceted approach to dissecting the causal mechanisms behind apparent changes in the appearance and fracture behavior of heated chert is unique, interesting, and potentially very powerful. His work goes farther than any of the others that I have reviewed in providing a basis for the present study. However, there is

at least one serious problem with his approach, stemming from the way that he computed average Fail Load. This quantity is the basis for several of his significance tests. In order to be valid, any comparison of the average Fail Load must be based on an identical test procedure: the loads tested and the number of tests at each load must be the same. McCutcheon (1997:148) stated, "I have tested 12 specimens [rocks]. Each of these specimens were tested in an identical manner with the same number of measurements for both unheated and heated samples." However, examination of the indenter data in his Appendix E plainly shows that this is not the case. For example, Table 6.2 shows the loads tested and number of tests at each load for the heated and unheated samples from the rock labeled PC 032. The average failure load that McCutcheon calculated for each set of results is strongly affected by the number of tests at each load and the loads tested.

However, McCutcheon (1997) made some crucial observations. He noted that each test must be done on a new specimen, since tests may cause incipient cracks without fracturing the specimen. He also made the significant discovery that the distribution of "fails" and "non-fails" was not discrete. Instead, when he did multiple trials (tests) at each of several different loads, the proportion of fails differed from one load to the next. Moreover, the proportion of fails did not clearly rise with increasing loads, as common sense and the Griffith theory lead us to believe it should. This suggests that the test results are not related to a single cause, such as fracture toughness, but are affected by more than one rock physical property, as suspected. The problems I identified in McCutcheon's protocol can be solved by determining how the results should be quantified so that they relate to flaking strength and fracture predictability, and by

establishing how results from different series of tests can be compared statistically. I discuss the ways in which I dealt with these issues below.

All of these studies represent significant advances in our understanding of the processes of the fracture strength of rocks used as raw materials by prehistoric stone workers. These studies provide a secure starting place for the present study. Yet, the testing protocols of these studies do not permit sufficient estimates of flaking strength or fracture predictability. In addition, the crucial factors in developing such estimates involve more than simply using an appropriate piece of equipment. They also include a) a strong foundation in current theories of fracture mechanics and flake formation, b) an appropriate research design, and c) appropriate and powerful methods for analyzing and interpreting the data produced. Below, I describe an approach to testing the fracture properties of siliceous rocks that goes further toward meeting these requirements.

**Measurement protocol: the Pendulum Impact Tester**

Physical description of the pendulum impact tester

The pendulum impact tester (PIT) permits dynamic loading with a steel indenter of specimens on the order of 0.5 cm in thickness, at loads of up to 1.0 J. It consists of a 60-cm tall steel frame supported by two heavy steel "feet" and supporting struts (Figure 6.6). At the top is a bar that can be raised or lowered by turning an adjusting wheel. At each end of the bar is a small tab. Over each tab is inserted a brass collar, to which is attached a thin steel band 5 mm wide and ca. 0.1 mm thick. The two bands are brought together at their lower ends and screwed to a cylindrical steel indenter billet. The result is a V-shaped pendulum that can swing freely; the billet is at the base of the "V". Extending away from the top bar of the PIT is a horizontal strut that supports a graded arc, which sweeps down and in toward the base of the impact tester. This arc is marked

off by notches, which represent the vertical drop heights of the billet; each notch is engraved with the corresponding vertical drop height (Figure 6.7). (In its downward swing, the pendulum's trajectory has two components: vertical and horizontal. However, the energy of the impact with the specimen is solely dependent on the vertical component: *h* of the KE equation). Drop heights range from 0.02 m to 0.54 m. Load is calculated with the values shown in Table 6.3. If the desired load is higher than what can be achieved by setting the billet at the highest notch, a steel collar can be inserted over the billet's rear, which adds enough mass to attain a load of 1.053 J (Table 6.4). Attached to this graded arc is a clamp, which can be set at any of the notches. At the base of the PIT, just below the spot where the billet rests when not in use, is a vice made out of a v-shaped piece of aluminum, a small aluminum strip, and two C-clamps. The inside of the vice is padded with a thin layer of cardboard of the type used in the boxes that rolls of 35-mm film are sold in.

To use the PIT, a square specimen is clamped into the vice at a angle of 50° from the horizontal, with one of its broad surfaces facing the pendulum (Figure 6.8). The height of the pendulum is adjusted so that, when released, the billet will strike the specimen at the desired point. This is done by turning the adjusting wheel, which raises and lowers the bar supporting the pendulum, along with the graded arc. The pendulum is then pulled up and back, and attached to the clamp on the graded arc at the desired drop height. This is done by means of a toothpick, which, held by the clamp, is inserted into a hole at the bottom of the billet. To release the pendulum, one squeezes two small bars that act as a tweezers; this releases the toothpick, which falls away, and this in turn releases the billet, which swings downward and strikes the specimen.

The front of the billet is semi-circular in section. There is a small bevel at the base, which presents a flat, lens-shaped surface approximately 5.5 mm long and 1.2 mm high. This bevel is the surface that contacts the specimen at impact. At contact, the small beveled tip of the billet is flush with the surface of the specimen, so that the total area of contact is equal to the surface area of the bevel, which is approximately 4.8 $mm^2$.

The impact is elastic (Giancoli 1991) in that the front of the indenter bounces up as the pendulum continues its forward movement. In effect, the billet "jumps" over the specimen after striking it, and continues its swing for some distance, albeit with less energy. It must be stopped by hand in order to prevent it swinging back down and striking the specimen a second time.

The drop height is read from the graded arc (Figure 6.7), and can be converted into the load in Joules (J) with the kinetic energy equation (Table 6.4). The quantity that is more relevant to the stress/strain curve of the specimen when it is indented is the amount of stress, which is equal to the load divided by the area of contact. However, the area of contact is constant throughout all the tests, so either the load (KE at the base of the pendulum's swing) or the drop height can be used to measure the amount of force in the impact. I present all findings in terms of load measured in Joules.

Sample preparation

I tested specimens from 23 rocks, which I collected in the Perigord. The sample collection procedure is described below in a separate section. After recording the weight of the rocks, I slabbed each with a Ray Tech 10" slab and trim saw, which uses a diamond- or corundum-embedded blade and oil lubricant. After first slabbing the rock into long, rectangular "rods", I then slabbed off individual square "tiles", each of which is

5 mm thick and 15-20 mm long on each side (Figure 6.9). These tiles are the test specimens.

The number of tiles one can obtain depends on the size of the rock. The experimental design I used requires at least 15 usable tiles. Initially, I was concerned about the possibility that rocks might exhibit anisotropy, such that elastic properties, and thus the apparent fracture strength, would vary depending on which way the rock was oriented. If so, the probability of failure and size of flake might be somewhat dependent on the original orientation of each piece of rock before being slabbed into tiles. I was also concerned about the possibility that different parts of a rock's body would differ in grain size or composition, and that this would lead to differences in the results. Therefore, I attempted to document the exact location of each tile within the rock, and its orientation. However, testing failed to reveal any evidence of isotropy or heterogeneity of fracture properties. In addition, the recording system was time consuming and imprecise, so I discontinued using it. I did nevertheless make an effort to randomize the loads that are applied with respect to the (original) positions within the rock of the tested tile edges, in order to avoid any accidental correspondence between the loads tested and unobserved differences among the tiles.

The oil lubricant from the slab saw coats each tile, and this must be removed with soapy water. An unfortunate artifact of the slabbing is that many cubes have a small angular projection at one corner. These projections would not affect the test results, but they make it impossible to insert the tile in the vice of the PIT machine. In addition, the saw blade sometimes leaves visible tool marks on the face of the tile, which can affect its seating within the vice. In these cases, I removed the projection or smoothed the

rough tile face with a lap polisher, using 120 grit sand paper and water as a lubricant. I then left the tiles to air-dry.

I marked each tile with a unique number, which includes the ID number of the rock and a serial number for the tile. Following the lead of McCutcheon, I drew a straight line in pencil about 6 mm below each edge of the tile, to serve as a guide when clamping the tile in the vice, so that it would have the same amount of material exposed above the vice. I also marked, in pencil, a line 2mm below the edge, to serve as a "target" for aiming the indenter billet. However, after many hundreds of trials, I found it possible to achieve precise alignment of the tiles in the vice and a precise targeting of the tile's edges without drawing those lines. It is also possible to measure, with calipers, the height of the specimen above the vice where it is held. In addition, because the billet leaves a streak on the face of the tiles, it is possible to measure the exact point of impact in relation to the edge of the tile. I measured these parameters, along with several others, for a large number of trials in order to determine whether variation in each parameter affected the outcomes of the tests; I describe the results below.

Recording data

Each instance of striking the specimen with the indenter is called a "trial". In order for a trial to be considered valid, several conditions must be met. The tile must be clamped into the vice tightly so that it does not move. Any breakage that occurs must be located in the portion of the tile protruding above the vice; breakage within the vice is due to secondary stresses induced by the sides of the vice when the specimen is improperly seated. The billet must strike the edge of the specimen solidly at least 1.0 mm below its edge. Occasionally the indenter billet will simply graze the edge of the specimen because the billet was set too high or the specimen was seated at the wrong

angle in the vice. In such cases, the trial is not counted. Only when all these conditions is the trial considered valid and the data recorded.

There are three possible outcomes for a valid trial. The indenter may cause no damage to the specimen, resulting in a non-failure (NF). The indenter may remove a chip from the edge of the specimen at the spot where it was struck. This is called a failure (F). The specimen may also snap rather than flaking. In that case, the failure is due to bending, which in some cases may be facilitated by the presence of weathering planes or zones cemented by other minerals such as $CaCO_3$ inside the material. Whatever the result, it is recorded in a notebook or computer file.

The flakes are difficult to collect because they fly at great speed away from the PIT machine. The data from the testing comes from measuring the weight loss of the tile that results from impact, rather than weighing the flakes. Whenever using the PIT, I carry out the tests on 4-6 tiles at a time. This set of tiles is called the "group". Before each set of trials, I weigh each of the tiles in the group on a Sartorius balance to a precision of 0.0001 g, repeating the weight measurement 3-6 times. I also weigh a tile that is never tested, which I refer to as the "control". I used the same control tile for all trials. The necessity of having a control will become clear shortly. Testing consists of placing the first tile from the group in the vice and letting the pendulum drop from the desired height, pulling it out and placing the second tile in the vice, running that trial, and so on until all the tiles in the group have been tested. Then all the tiles in the group are weighed again, along with the control tile, with the same number of repetitions as the initial set of weights.

Each tile is tested more than once, but in a separate location each time. The same location is never tested more than once, regardless of whether it results in a

failure. This helps to avoid changes in the probability of failure due to the creation of crack nucleation centers that do not develop into fractures. McCutcheon (1997) tested each tile four times: once on each edge, and only on one face of the tile. I followed that example, but when I had difficulty getting large enough sample sizes because of the small sizes of some rocks, I resorted to turning the tile around and impacting the four edges again, on the opposite face. Eventually, I also tested two or even three locations on the same face and same edge of the cube.

Any danger that each trial might be affected by the outcome of previous trials on the same tile is minimized by the small scale of the tests: the flakes are rarely wider than 6 mm, and are often less than 1 mm wide. Stress decreases as the inverse square of the distance from the impact point (Lawn and Marshall 1979). In order to test for the possible effects of previous indents on the probability of failure for subsequent indents in neighboring locations on the same tile, MCutcheon (1997) showed a table in which he displayed the load and result (Failure or Non-failure) for each of the four "cube-sides" of five tiles. As he noted, if the probabilities of failure in subsequent trials were affected by previous indents on the same tile face, then the lowest frequency of failure should occur during the first trial, and the highest frequency, during the last trial on each tile. The data he presented in that table fail to show any such relationship, and he concluded "the initial impact tests did not affect the subsequent tests on a particular cube," (p. 146).

In order to test for the same effect in my data, I carried out likelihood-ratio chi-square tests of Test Result (failure, no-failure) against Trial Order (1, 2, 3, or 4). I confined the test to tiles in which the same load was applied to all sides, or in which no trial was done at a significantly higher load than subsequent trials. This was in order to avoid the potentially confounding effect that might result when the later trials were done

at significantly higher loads, which might also affect the probability of failure. For these tests, I summed the data from tiles of the same rock. If the earlier trials on a tile cause microcrack extension and consequently affected the probability of failure in subsequent trials on the same tile face, then the lowest number of failures should be with the trials that were first in the series, and the highest number of failures should occur with the trials that were last (fourth) in the series. I carried these tests out on the pooled data from each of 7 rocks (see Table 6.5), and none showed a significant test statistic.

I also took a tile and indented it three times on each side of each face, for a total of 24 trials, all at the same load. I then examined the results to see whether there was a trend toward increasing fail frequency with increasingly high order trials. I then repeated this experiment on a second tile (in both cases, there was one invalid trial, resulting in 23 trials for each tile). In neither case do the results suggest the presence of any such effect (see Table 6.6). In trials from the tile "12A 13", there is a decidedly higher number of failures among the first 12 trials (9/12) than among the last 11 trials (4/11). It just so happens that the edge angles on each of the four sides of the first face of the tile tend to be slightly higher than those on each of the four sides of the second face of the tile. The difference is between approximately 1.5° and 2.6°. This may have caused the difference. In any case, I conclude that my results agree with those of McCutcheon (1997): in these test conditions, the probability of failure associated with each trial is independent of the number of trials previously carried out on the same tile. Nevertheless, out of prudence I avoided placing two trials closer than 5 mm from each other on the same tile side and face. I avoided doing trials in close proximity, preferring to do only one trial per tile side and face, except when scarcity of material required me to do multiple trials per side/face in order to achieve the desired sample sizes.

Determining the occurrence of a failure and resulting weight loss

For each trial, the data recorded consist of the following: 1) weight of the tile before the trial, 2) weight of the tile after the trial, and 3) observed result (F/NF). In addition, each trial is associated with the weight of the control trial before and after the trial. Observed results are not always reliable. Even though I inspected the edge of each tile immediately before and immediately after impact with a hand lens, tiny chips from the indent can be difficult to distinguish from preexisting chips along the edge of the tile that are an artifact of slabbing. The former are generally thin and feather-terminated, whereas the latter generally resemble bending flake scars or have step terminations. Nevertheless, the two can be difficult to distinguish when very small. Therefore, I turned to paired-sample t-tests in order to determine the occurrence of a failure.

The necessity of using paired sample t-tests arises from the fact that balance readings vary slightly over time. Some of this variation is simply the measurement error of the machine, which accounts for differences of approximately 0.1 mg. However, there is also variation on the order of 1.0 mg that I have observed over the course of a single day, and measurements (of the control tile) vary as much as 10.0 mg from day to day. This variation is probably tied to diurnal variation in temperature, atmospheric pressure, or humidity. Since I generally completed all trials on each tile during a four to six-hour period, most of the diurnal variation is of little consequence. Nevertheless, there is often important variation in balance readings occurring on the scale of minutes. Since the magnitude of the tiles' chips overlaps considerably with this measurement error, both Type I errors (failure to correctly identify a true fracture) and Type II errors (mistaken identification of a fracture when none occurred) are possible. Without any way to control

for this error variation in the balance readings, it would be difficult to distinguish spurious instances of weight loss from true ones.

My initial solution to this problem was to use paired-sample t-tests. The paired sample t-test consists of a comparison of the difference between the "before" and "after" weights of the test tile with the before and after weights of the control tile. In each case, this quantity is $D$ = difference between before and after weights. If the balance varied in some way during the 5-10 minutes that it took to run the tests—that is, between the time the before weights were recorded and the after weights were recorded—then $D$ will not be equal to 0.0000. For example, Figure 6.10 shows the variation in the $D$ values of a control tile ($D_{control}$) and of test tiles ($D_{test}$) cut from a single rock, over a two-day period. Each data point represents an individual weight measurement. In this example, I did six measurements for each before- and after-trial weight; thus, each cluster of six data points represents a single trial. The large, positive values of $D$ for the test tiles represent failures resulting from impact.

How large of a difference between $D_{control}$ and $D_{test}$ is required before we can say that a failure occurred in the test tile? I used the Student's $t$ distribution to test the hypothesis that $|D_{test}| \leq |D_{control}|$. This is a one-tailed test: the case $D_{test} > D_{control}$ could only be due to random variation balance readings because the control tile does not lose weight. If $|D_{test}| < |D_{control}|$, then the observed weight loss of the test tile must be due to something other than measurement error, that is, to the detachment of a flake. I set the alpha value at .05. Running these tests was facilitated by the use of a Visual Basic program that I wrote, called Cube Cruncher. This program does the following:

- pairs each set of test weights with the appropriate control weights,
- calculates $D_{test}$ and $D_{control}$,

- runs the paired sample t-test,
- determines whether the result indicates failure (F) or non-failure (NF),
- sets the weight loss of each NF at 0.0000 and the weight loss of each F as equal to $D_{test}$-$D_{control}$,
- draws a scatterplot showing the relationship between Weight Loss and Load,
- calculates the median and mean Weight Loss for all trials at each Load,
- and draws a column chart showing median Weight Loss per Load with an error bar.

Eventually, I discovered that the paired sample t-test did not eliminate all instances of Type I error. Ideally, the result determined through visual inspection of the tile's edge after the trial should be the same as that determined with the paired-sample t-test. While there is some uncertainty in the results determined by visual inspection, this could not account for the high percentage of disagreement between the two sets of results. Table 6.7 shows an example, in which there was a 27% frequency of Type I errors (20 cases in which observed result = F, but t-test result indicates no failure) and a 26% frequency of Type II errors (19 cases in which observed result = NF, but t-test result indicates failure). This poor performance forced me to consider alternative techniques of distinguishing failures from non-failures. Doing so led me to take a closer look at the small chips that form on the tiles during impact in order to discover why the t-test faired poorly.

Pelcin (1996) demonstrated that a significant positive correlation exists between flake length and flake mass, when flake shape is constant. (He controlled flake shape by using test specimens with the same morphology and keeping the parameters of the test the same). That such a relationship exists is no surprise and agrees perfectly with

the current understanding of rock fracture mechanics and flake formation. One way to ascertain the reliability of the paired-sample t-test for determining failures is to measure the lengths of each flake scar from a series of tests, and compare this to the weight loss value determined with the t distribution. In the case of a Type I error, there should be a flake scar with a measurable length even though weight loss was recorded as 0.0000. (In all cases of Type I or Type II error, only very small flakes were involved).

I measured the flake scars from failures determined by visual inspection of tiles from three rocks, using a Nikon measuring microscope, resulting in sample sizes of 34, 31, and 50. Figure 6.11, which plots the data from all three rocks, show a clear positive correlation between flake length and flake mass (again, flake mass is estimated by Weight Loss). However, this relationship is less clear in the lower left-hand portion of the graph. With very short flakes, the t-test often failed to identify the failure, resulting in a weight loss of 0.00 mg. This suggests that, for each rock, there is a region in which the paired-sample t-test is unreliable for identifying failures. In this region, the t-test is inconsistent in identifying true failures. Observed results and results determined by t-tests agree when flakes are larger than about 1.5 mg, which happens to correspond to a flake scar of about 1.5 mm in length. This is the threshold between the reliable and unreliable regions of the Load/Weight loss scatterplot.

Measuring the flake scar length after each trial is very time-consuming and would be impractical as a routine technique for determining the occurrence of failures. Therefore, I used the value 1.5 mg as a threshold for identifying true weight loss values, and integrated this value into the Cube Cruncher program. For all the PIT results, a

failure is identified as a trial in which $D_{test} - D_{control} \geq 1.5$ mg[2]. Unfortunately, this procedure deletes some valid data points where weight loss < 1.5 mg. However, the fact that this allows me to eliminate many Type I and Type II errors makes this a reasonable price to pay. Of course, if the PIT machine were capable of conducting the tests at a higher range of loads (and upon a correspondingly larger test specimen), then the error variance of the balance would be much smaller than the magnitude of weight loss values, and this issue would not have to be addressed. I chose the PIT because this is the apparatus that was available; I could not have known that identifying failures reliably would become a difficult issue.

Control of test parameters

In McCutcheon's (1997) discussion of the PIT apparatus, he noted the necessity of ascertaining adequate control of test parameters. In order to support the claim that the experimental approach is better than the flintknapping approach, a claim made by both McCutcheon and Pelcin, it is minimally necessary to demonstrate that the critical test parameters are either better controlled or more easily measured with the test apparatus than they are in the flintknapping context.

I examined my data for potential influence of uncontrolled variation in various test parameters. Certain parameters do no vary because they are fixed: 1) horizontal adjustment of the apparatus, 2) angle of blow, 3) shape of the indenter, and 4) mass of the indenter. The horizontal adjustment of the apparatus is indicated by bubble levels.

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[2] The actual procedure is the following: each of the "after" weights of the control tile is subtracted from the corresponding "before" weight for the control tile. This produces a number of "weight change" values equal to the number of repetitions of the measurement. The same procedure is then carried out on the test tile's before and after weights. Then, each control weight change value is subtracted from the corresponding test weight change value, resulting in a set of "difference" values. If the mean difference value is greater than 1.49 mg, then the trial is assigned a value of "F" and the weight loss for the trial is equal to "mean diff". Otherwise, the trial is assigned "NF" and weight loss = 0.00 mg.

As long as the vice is not adjusted, the tiles are all held at the same angle from the horizontal, which results in a uniform angle of blow (which happens to be 50°). Since the same steel indenter billet was used for all trials, the indenter shape is also constant. The mass of the indenter billet is 136.5 g. The mass of the indenter only changed when I added a brass ring (weighing 62.5 g) to the billet in order to increase the maximum load; doing so is equivalent to raising the billet to a greater height without the ring. Load is the one test parameter that I deliberately varied. As mentioned previously, I measured load as the KE of the billet at the base of its swing (where it strikes the specimen) using the equation KE = $mgh$, where $m$ is the mass of the indenter billet in grams (plus the mass of the brass ring, if one was used), $g$ is the acceleration of gravity (9.8 m/s$^2$), and $h$ is the drop height in meters, which is read directly from the graded arc of the PIT.

Other test parameters are not fixed and must be controlled: length of tile side ("LENGTH"), thickness of tile ("THICKNESS"), edge angle of tile at the impact location ("ANGLE"), distance between tile edge and point of impact ("PI"), and amount of tile exposed above the vice ("HEIGHT") (see Figures 6.12-6.14). In most problems in rock fracture mechanics, the size of the specimen in question is considered to have a significant effect on its strength (Jaeger and Cook 1976, Whittaker *et al.* 1992). This is because the elasticity of the material (Young's modulus), and thus the strain energy stored when the load is applied before crack initiation, are strongly affected by the volume of the body to which stresses are applied. The amount of strain energy within the rock body depends on the density of the material and the volume of the rock body. Thus, fracture mechanics theory provides a compelling reason to expect a significant correlation between tile size in the PIT experiments and the frequency of failure. Both

LENGTH and THICKNESS partially measure tile size, and so these parameters might be correlated with Fail Rate, Weight Loss, or both.

THICKNESS and HEIGHT may also influence the probability of failure by affecting the effective elasticity of the tile. Variation in ANGLE should have an effect because edge angle is strongly correlated with flake mass (Pelcin 1997). Variation in PI could affect flake mass (and therefore Weight Loss), because it probably has a strong effect on the location of crack initiation, which should always be in the vicinity of the point of impact even if it is not equal to it.

For a large number of tiles and trials, I measured LENGTH, THICKNESS, PI and HEIGHT with calipers to a precision of 0.01 mm, repeating each measurement at least three times. I measured ANGLE with a goniometer (or plane protractor) to a precision of 1°. For each of these five parameters, I compared their values for all trials on tiles from a given rock, and examined the hypothesis of no difference between the fails and no fails using a t-test. In order to determine if the weight loss (of failures) was correlated with each parameter, I simply examined the scatter plot of Weight Loss against the parameter in question (all trials included). I carried these exploratory analyses out on data from several rocks.

Tables 6.8-6.12 compare means and other statistics of each parameter for failures and non-failures. The following abbreviations are used in the tables: "RM type", raw material type from Table 4.1; "F mean", mean value of the parameter, for all trials that resulted in failure (F); "F sd", standard deviation of the parameter for all F trials; "F n", number of F trials; "NF mean", mean of the parameter for all trials that resulted in no failure (NF); "NF sd", standard deviation for same; "NF n", number of non-failure trials; "CI overlap", whether or not the 95% confidence intervals for mean values of the

parameter for F trials and NF trials overlap. The larger of the two mean values in each case is displayed in boldface.

In these five tables, there is a strong pattern of no difference in the mean value of the parameter between failures and non-failures. However, in each table, there happens to be one case where the mean values for failures and non-failures appear to differ. These cases are probably due to chance correlations between test parameters. For example, in Table 6.9, 10A is the only rock to show a significant difference between failures and non-failures in the mean tile side thickness. However, as Figure 6.16 shows, thinner tile sides happen to have been tested at higher loads, on average. This accidental bias probably accounts for the apparent relationship between tile side thickness and Fail Rate. Another example is rock 9A in Table 6.12, for which failures have a significantly higher edge angle than the non-failures. This goes against expectations, since if there were any correlation between edge angle and Fail Rate, lower angles should fail more often. However, the mean angle of fails for 9A was calculated on the basis of only two trials. Thus, the apparently significant result is probably spurious; more data need to be compiled to ascertain whether this is this case.

In sum, each significant difference in the mean value of a parameter between fails and non-fails appears to result from chance biases in the parameter. As a whole, the data in Tables 6.8-6.12 strongly indicate that each of the extrinsic parameters of the PIT apparatus is controlled within a sufficiently narrow range so as to prevent any influence on the Fail Rate and Weight Loss data. I did not collect such data for every trial or for every rock tested. Instead, based on the above data, I assumed that additional testing could be done without any danger that uncontrolled variation in test parameters would affect the results of the tests. To make sure that this was the case, I

maintained test parameters within the ranges defined by the confidence intervals based on the data in Tables 6.8-6.12; these ranges are displayed in Table 6.13.

The same issue can also be evaluated with regard to weight loss values; that is, was uncontrolled variation in these five test parameters great enough to effect systematic differences in weight loss values, which would be erroneously interpreted as resulting from variation in the mechanical properties of the tiles? I addressed this question by examining scatterplots in which each weight loss value (including non-failures) was arrayed against the parameter in question. There is not enough space to reproduce all 80 graphs that I examined; Figures 6.19-6.23 show representative examples of the results of these analyses. In no case did the data suggest the presence of a spurious effect from chance biases in a test parameter.

These analyses demonstrate that each parameter has no effect on either the probability of failure or the weight loss resulting from a failure, when that parameter is kept within a narrow range of values. Therefore, in agreement with McCutcheon, I conclude that the PIT apparatus provides adequate control over all critical test parameters.

Relevance to fracture properties

In principle, flaking strength could be measured by the lowest load at which flaking occurs, but examination of McCutcheon's (1997) results revealed that this load is practically zero in many cases, and that failure behavior at higher loads was not predicted by this quantity. Instead, I measured flaking strength by the proportion of fails at individual loads. By testing specimens from different rocks at the same or similar loads, and attaining sufficient sample sizes for a statistically valid comparison, I was able to compare the proportion, which I term Fail Rate per Load, between rocks. Lower

values reflect greater difficulty in obtaining flakes. In principle, it should also be possible to do trials at progressively higher loads until all tested specimens fail; the load at which this occurs is the Minimum 100% Fail Load. Higher values should obtain for rocks that are harder to flake. In practice, this quantity was impossible to obtain in most cases because the PIT did not permit testing sufficiently high loads, as I describe below.

One way to define fracture predictability is the propensity of a material to produce a flake when just the right amount of force is applied. This property will be described by the frequency distribution of fails along the range of loads tested. A stone worker has to consider a range of parameters in addition to applied load, such as the shape of the platform, the shape of the surface from which the flake will be struck, the nature of the hammer, and so on. In the experiments described below, all parameters other than load were held constant. The Fail Rate Predictability of the material will be correlated with the degree to which the Fail Rate increases steadily with increasing loads.

The shapes of flakes produced here should be similar, because the shapes of the test specimens are controlled. The ability to produce a flake of the desired size, and to control the size of a flake by varying the applied force, can be measured in terms of the relationship between flake size and load. This component of fracture predictability is what I term Flake Size Predictability. It will be a function of the degree to which flake sizes increase with increasing loads. Below, I explain that the weight loss of a specimen that fails is used as a surrogate for flake size. Thus, the correlation or association between weight loss and load should provide a measure of Flake Size Predictability.

Experimental design and sample sizes needed

The data generated by the PIT will be used to measure the four rock fracture properties that I defined above: Fail Rate per Load, Minimum 100% Fail Rate, Fail Rate

Predictability, and Flake Size Predictability. Each rock belongs to one of the lithologic types in Table 4.1. I hoped that the fracture property values generated by the PIT analyses for each rock would be similar for all rocks of the same type. However, since I could not be sure of such an outcome, I did the analysis on a rock by rock basis. Thus, the rock is the unit of comparison upon which the interpretations of these data will be based.

For each rock, I carried out the tests at several loads. From the first tests to the last, I experimented with different experimental designs. Each experimental design consists of the set of loads (or drop heights) to be tested, and the sample size at each load. The size of the rock limited the number of tiles that could be made, which in turn determined the number of trials possible. Even when doing more than four trials per tile, the sample size achieved (the total number of trials at all loads) was sometimes smaller than desired.

Planning the experimental design for each rock consisted in determining the distribution of trials over loads. In earlier tests, I attempted to distribute those trials evenly over the widest possible range of loads. Eventually, two factors led me to modify that approach. First, it became clear that higher sample sizes were needed at lower loads because the fail rates at lower loads are lower. The sample size issue is more critical when estimating mean Weight Loss at each load, because that variable is calculated on the basis of the fails only. Thus, if one does 15 trials from a drop height of .34 cm, but there are only two fails, the mean weight loss for that drop height may not be reliable, and it may be necessary to quadruple the number of trials to obtain eight fails. Second, as the testing progressed, it became clear that both Fail Rate and Weight Loss tend to correlate with Load, and that the relationship is roughly linear. Therefore, it

seemed more important to examine this relationship, and this can be done with data from only four or five loads instead of 10 or 12. My changing ideas about these issues resulted in variation in the experimental designs.

There are various ways one could approach the issue of minimum required sample size for sufficient precision in the estimation of the four variables. McCutcheon (1997:224) attempted to address that issue in the following manner: "The standard error (SE) of mean failure load and amount of material removed for each specimen was plotted against the number of failures observed for each specimen to assess whether making three measurements at each load was structuring the precisions around these mean values." The underlying reasoning of that approach seems to be that a dependency between the precision of the estimate (of either parameter: Average Failure Load or Weight Loss) would result in a correlation between standard error and sample size. McCutcheon plotted the SE of the estimate of average failure load against sample size (number of trials at all loads, combined), and calculated Kendall's tau for the rank-order correlation of the two variables. He chose tau instead of a parametric statistic because K-S tests of the data suggested that they were not normally distributed. However, this technique would seem more relevant to the question of whether SE of average failure load is a function of total sample size, rather than of the sample size at each load, especially since the latter was essentially a constant throughout all his tests. In addition, comparing the average failure load of different rocks is invalid because the loads tested varied from rock to rock, and therefore it is also invalid to compare the SE of average failure load.

McCutcheon (1997:26) also seems to have erred when he stated that "only a weak relationship for SE of failure load and number of failures observed and from this I

can conclude that measuring only three cube sides per impact load has negligible effects on only those four specimens with less than six failures observed." For the correlation of (Average) Failure Load with Number of Failures he reported a Kendall's tau of -0.5335, with a *p*-value of <0.001. This indicates a significant negative correlation between Failure Load and Number of Failures, which is supported by the scatterplot McCutcheon presented of those two variables for the 24 cases. For the comparison of Weight Loss with Number of Failures, he reported a tau of 0.0688 ($p = 0.651$), and concluded that "the number of measurements made at each impact load has very little affect on the precision around mean weight loss values observed." This statement is difficult to evaluate because McCutcheon did not indicate how Weight Loss was calculated. As a result of these problems, it is difficult to be as optimistic as McCutcheon was about the sufficiency of his sample sizes.

I approached the issue differently. I calculated confidence intervals for each Fail Rate value (Fail Rate is the proportion of trials resulting in fails, at a given load). Because Fail Rate is a binomial variable, I calculated the confidence intervals based on the binomial distribution according to the formulae in Zar (1984). A lack of overlap in the confidence intervals of the Fail Rate values of two rocks (at a given load) is taken to indicate that the rocks differ in fracture toughness.

I estimated Fail Rate Predictability of each rock as a function of the strength of the relationship between Fail Rate and Load, using simple linear regression with Fail Rate as the dependent variable and Load as the independent variable. If Fail Rate increases as a function of Load, as it should when the rock has a predictable fail rate, then it should be possible to obtain a significant regression statistic with acceptable residuals.

I encountered a problem when attempting to measure Minimum 100% Fail Load: only a few rocks yielded a fail rate of 100% at any load. Therefore, I attempted to estimate Minimum 100% Fail Load by predicting the load at which Fail Rate will equal 100%, using the regression equation from the simple linear regression of Fail Rate on Load. Predictably, this proved a poor way to estimate the variable because it requires extrapolation for values that lie outside the data for which the equation was calculated.

There are two techniques with which Flake Size Predictability potentially could be estimated. The first is to regress Weight Loss over Load, using the weight loss value from each trial as a separate data point. In a predictable rock, those values should rise as a function of Load. I calculated such regressions for each rock tested. The second technique uses the variance in weight loss at a given load: the larger the spread in individual weight loss values at each load, the more variable flake size is, and the less predictable the rock is with regard to flake sizes. I chose the coefficient of variation (CV) of weight loss (per load) as the basis of comparison, because it is the only measure of variance that accounts for differences in magnitude of the test statistic from one case to the next (Sokal and Rohlf 1995). This is important when comparing the amount of variation in Weight Loss at low and high loads, because the magnitude of variation increases dramatically as Load increases. I attempted to apply both techniques as estimates of Flake Size Predictability.

Sample collection

I collected most of the samples for fracture properties testing in June 1994. Pierre-Yves Demars led me to ten different raw material occurrences in the Perigord. In August of 1994, I relied upon the map coordinates published by Demars (1982) to find an additional dozen occurrences. Jean-Philippe Rigaud directed me to another

occurrence (La Malartrie) near La Roque Gageac along the Dordogne River, Christophe Griggio provided a nodule of Mussidan chert, and Jean-Guillaume Bordes provided a nodule of Bergeracois chert. In 1996, during the same trip in which I sampled river gravels to study their lithologic composition, I also collected two nodules of flint, two of quartzite, and two of basalt from some of those gravels. During various other trips to France between 1994 and 1999, I collected a few additional samples. Altogether, I collected over 110 rocks. These include almost the entire range of material types in Table 4.1; they do not include Gavaudan chert, Fumelois chert, pink speckled chert, or porcelainite.

At each occurrence where I collected rocks, I selected two or three samples, avoiding small ones and those with frost damage. I have tested more than one sample from certain occurrences, as well as rocks of the same type but from different occurrences. Thus, the composition of my sample allows me to determine the degree of similarity in physical properties of rocks from the same occurrence, as well as the amount of variation in rocks of the same type from different locations.

Summary: rock fracture mechanics, PIT tests, and empirical expectations

In sum, my experiments are designed to measure four properties: 1) Fail Rate per Load, 2) Minimum 100% Fail Load, 3) Fail Rate Predictability, and 4) Flake Size Predictability. I have attempted to show that these terms are grounded in theories of rock fracture mechanics and flake formation, and that they relate directly to the flaking strength and fracture predictability of lithic raw materials. Furthermore, these four properties affect the manufacture cost of stone tools and the performance characteristics of at least some kinds of tools in some circumstances. I have not attempted to specify exactly how variation of these properties among a set of lithic raw materials should relate

to variation in the raw material and technological composition of assemblages. I only stipulate that the strength of the association between these rock properties and assemblage raw material composition is a measure of technological efficiency.

I tested that expectation by describing the raw material and technological composition of the six assemblages, on the one hand, and by generating data on the fracture properties of rocks belonging to the same lithological categories as those found in the assemblages, on the other hand. Unfortunately, the physical properties of the archaeological specimens cannot be tested because of the destructive nature of the work, the small size of the artifacts relative to the sample size requirements of the tests, and the probability that patina and weathering changed the physical properties of the artifacts as they lay buried. The only viable option is to test geologic specimens that are the same lithological types as the archaeologically observed specimens.

**Results**

Description of sampled occurrences

For each of the twenty-three rocks, Table 6.14 lists an ID number, the name of the *lieu-dit* nearest the occurrence, the raw material type to which the rock belongs, the geologic age of the limestone from which the rock derives, the Lambert coordinates of the occurrence, the ID number assigned to the occurrence by Demars (1982), the nature of the occurrence, and the weight of the rock before sample preparation. The ID numbers are arbitrary numbers that refer to the occurrence (e.g., 10 = occurrence of jasper at Puy d'Arnac). Individual rocks from the same occurrence are indicated by letters (10A, 10B, etc.). Although I collected rocks from nearly thirty occurrences, I only tested rocks from 14 of those. A *lieu-dit* is the smallest geographic unit in France; *lieu-dits* are marked on topographic maps in the Institut Géographique National (IGN) orange

series (1:50,000) and blue series (1:25,000). Many of the occurrences I list here are also listed in Demars (1982); in those cases, I list the geologic age of the occurrence as he reported it and the ID number he gave. The figures under "Map No." in Table 6.14 designate maps in the IGN orange series. Demars (1982) listed all map locations with Lambert coordinates (Zone III)[3]. One of the tested rocks (26) was given to me and I lack precise provenience for it. However, that rock is a typical piece of Bergeracois chert, and it certainly originated in the small region around Bergerac where that raw material type is found. The letters in parentheses under the column "Nature of occurrence" refer to whether the rock was pulled from a primary (p) or secondary (s) occurrence. Primary occurrences are those where the rock is found embedded in the limestone matrix; all others are secondary occurrences.

*Senonian chert*

*Occurrence 1: La Froumagie* This occurrence is 4 km NW of Montignac, near Lascaux cave. It consists of several outcrops (numbered here from I – VII; see map, Figure 6.24) on either side of a road following a small creek that feeds into the Vézère River. The road and creek pass through a shallow valley that is about 150-300 m wide. In the embankment of a private drive (leading to a cluster of houses called La Froumagie) SW of the main road, nodules can be found embedded in soil. Nearby and on the other side of the road, a diversion of the creek (associated with a second driveway) resulted in the accumulation of a large number of nodules, many of which show some erosion of cortex, in and around the creek bed. About 200 m NW of that spot, there is an open field bordered on one side by the road, and on the other by a low

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[3] Lambert coordinates are in units of kilometers. The lower left corner of the Lambert grid is its point of origin; thus, the numbers rise from west to east and from south to north.

limestone outcrop, which has a small rockshelter. Nodules are found in-situ in the eroding limestone (Figure 4.4), as well as in the field, where they were transported after eroding out of the limestone. Further along the road (to the NW), where it curves sharply to the right and rises a steep incline, the limestone exposed by the road cut has the same chert in both tabular and nodule form. At the top of the incline there is a large pile of nodules, collected and deposited there by a farmer. All of these outcrops apparently belong to the same Santonian (Senonian) formation. There are two varieties, black and dark brown. I tested two black nodules from the limestone outcrop: 1B and 1C. Both are black Senonian.

*Occurrence 2: Le Grand Bonnet* The small road that runs past La Froumagie eventually meets with departmental road D31, about 3 km SW of Thenon. Turning left on D 31, and then almost immediately left again, on a small road marked "Plazac", one arrives quickly at the next occurrence. This area has many small hills steeply dissected by small creeks. The road descends between two of these hills, each of which is cleared and tilled. At the time of my last visit in 1999, one was partly planted in maize (Figure 4.5), while the other lay fallow. On each hill, there are many nodules of chert (Figure 4.6). On one hill they are beige, and on the other, dark greyish brown. The nodules are highly irregular in shape, range from approximately 0.5 – 4.0 kg, and have a thick, coarse cortex. I tested two beige nodules (2A and 2C).

*Occurrence 6: La Rouquette* This occurrence is a bed of nodules in the limestone that was excavated for the Les Eyzies-Perigord railroad. It is less than a kilometer SW of the town of Les Eyzies. Leaving Les Eyzies to the north on departmental road D 47, after passing the Cro-Magnon rockshelter and crossing the bridge over the Vézère, one turns south onto a small road that passes by a campground

and follows the railroad. At La Rouquette, one turns left on another small road that crosses a bridge over the railroad. Nodules of fine black Senonian chert can be found in the limestone and in the soil that has developed on top of it, just north of the bridge.

*Occurrence 11: Limeuil* This is a small medieval town on the north shore of the Dordogne at the confluence of that river and the Vézère. Departmental road *D* 31 skirts the southern edge of the town, passing by a small park at the water's edge. I collected two well-rounded cobbles of beige Senonian chert (11A and 11A') from the abundant river gravels, rich in chert, that lie here. Both had thin, rolled cortex. One was poorly lithified and had a crumbly fracture.

*Occurrence 12: Badefols-sur-Dordogne* This is the name of a small cluster of buildings on departmental road *D* 29, which passes between Lalinde and Le Buisson-de-Cadouin. The raw material occurrence is a high limestone rock face, exposed when the rock was blasted during road construction. There are numerous large nodules of black Senonian chert in the rock face and in the rubble at its base. The nodules are fine-grained, uniform, and have a thick, chalky cortex. Many show zones of dark grey, which however have the same fine texture as the black zones. These, like the chert from La Roquette, bear a close resemblance to classic English chalk flint. I tested two nearly identical nodules that I picked up from rubble at the base of the exposure (Figure 6.24).

*Occurrence 14: La Malartrie* Half a kilometer west of La Roque-Gageac along the right bank of the Dordogne, on the outside edge of a large bend in the river, there is a cluster of houses called La Malartrie. Here, the river is at an elevation of 64 m amsl. The houses are situated at the base of the steep southern slope of the Sarladais plateau. The elevation attains 198 m just 200 m northwest of the riverbed. This ridge forms a narrow spit extending southwest from the Sarladais plateau north of the

Dordogne valley, and between two stretches of floodplain where ancient river meanders cut into the limestone. At an elevation of about 130 m, and about 100 m from the road, rises a small rockshelter. Scattered here, and in exposed banks of limestone along the slope below the rock face, are a few small nodules of brown Senonian chert. Most have been smashed by flintknappers, but I was able to obtain three nodules, of which I tested the largest (14B).

*Tertiary chert: chalcedony, millstone, jasper*

*Occurrence 9: Graudemagne* This is a very large occurrence that lies 5 km to the E-NE of Domme, and 1.2 km W-SW of Groléjac. It lies on a dissected plateau approximately 260 m amsl, and about 200 m above the Dordogne River, the banks of which lie about a kilometer north of Graudemagne. The easiest approach is to take one of the small, tortuous roads that join D 704 at Groléjac. The occurrence is just off the paved road, in a thickly wooded area with little underbrush but with a thick ground cover of leaves and moss.

There are two kinds of chert here. One is a reddish-purple chalcedony, in the form of large, spherical nodules that range in diameter from about 30 to 50 cm (Figure 6.25). These lie on the surface, covered in moss. Many nodules are visible in the 1-m. high road cut of an old farm road (Figure 6.26). They have a cortex that is quite different from the cortex of Senonian chert: it consists of a thin, hard, mineral coating, and the exterior surface of the nodules is convoluted and bumpy. The other kind of chert is dark yellowish-brown jasper, of which nodules are unfortunately rare. It is opaque, the color is solid, and the texture is medium. In one nodule that I tested (9D), the solid yellowish-brown matrix was separated into hexagon shapes by a web-like system of colorless veins of chalcedony, resembling mudcracks. Jasper nodules are only about 10 cm in

diameter here, and have irregular shapes. I tested samples from two chalcedony nodules (9A and 9D), and two very small jasper nodules (9E and 9G). This occurrence is an exposure of epigenetic chert that formed during the Tertiary, possibly in a shallow lake. The chalcedony and jasper may be part of the same episode of silicification. The cortex of the material is similar, but the color, transparency, and patterns of the two raw material types are quite distinct.

Graudemagne is not only the site of a large natural occurrence of chert, but also a large cluster of artifacts. During a visit to this place in 1999 with Jay Franklin and Loic Daulny, we found many carinated endscrapers, burins, and a large blade core in jasper on the ground, where we left them. The tools are made of both kinds of raw material found here. I have conducted no systematic investigations of the cultural resources here, and to my knowledge no such investigations have been carried out. Fortunately, the artifact clusters are fairly well hidden, and I saw no signs of clandestine digs.

*Occurrence 10: Puy d'Arnac* This is one of only a handful of occurrences containing jasper-like chert associated with Hettangian (late Jurassic) limestones, east of Dordogne in the NW-SE trending formations that border the crystalline plateaus of the Massif Central. Puy d'Arnac lies about 40 km east of Caminade Est, 22 km SE of Brive and about 4 km NE of the site of La-Chapelle-Aux-Saints. The jasper that occurs in this area is distinctive in appearance. Most of it is very smooth, fine-grained, and opaque. At Puy d'Arnac, the jasper is lemon yellow or mustard yellow, and much of it has thin, black, squiggly lines from traces of manganese. It occurs in small nodules with a thin, hard, reddish brown cortex, a calcitic covering, or no cortex at all. The nodules often have veins of quartz and small voids, which sometimes contain calcite crystals or reddish clay.

Demars (1982:76) described the occurrence thusly:

> ... a remnant butte about 4 km long and a few hundred meters wide, south of Puy d'Arnac, oriented in a north-south direction. [The butte] lies on Triassic sandstone.... Its summit is partially covered by a [post-Hettangian] formation. The jasper-like chert is found in abundance in the slope deposits, mixed with quartz cobbles. The chert seems to belong to a clayey bed near the summit of the butte.
>
> The blocks are of many sizes, up to 50 cm in diameter. They are generally inappropriate for flintknapping, like at the other occurrences [of Hettangian jasper]. There are, however, blocks of good quality, which are generally small. This occurrence is very important. All the varieties of jasper-like chert used in the Brive basin during the Upper Paleolithic are found here, notably a mottled jasper-like chert that is absent in the other occurrences.... Unless an occurrence is found in closer proximity that is equally well stocked with jasper-like chert (which very improbable), it seems reasonable to suppose that the Upper Paleolithic inhabitants of Brive gathered their jasper-like chert here, as well as at the occurrence at Bout de La Côte.

Demars considered this chert to be of Hettangian age, based on the geologic age of the limestone with which it is associated. However, as I explained in Chapter 4, it may be an epigentic chert that formed during the Tertiary.

*Occurrence 18: Lac de Couffé* A plateau rises south of the two large meanders of the Dordogne near Limeuil; south of Belvès, this plateau attains an elevation of nearly 300 m amsl The small Couze River dissects this plateau, flowing west before turning northwest to drain into the Dordogne. The area of the plateau between the Dordogne and the Couze is called the Fôret de La Bessède, and it is here that the Lac de Couffé occurrence is found, at an elevation of 230 m. Between Belvès and Cadouin, departmental road D 54 runs through a mixed deciduous-conifer forest. In the ditch along the road are very large, angular nodules of white and yellow millstone, buried by about a half-meter of soil. This chert is very similar to chalcedony, differing mainly in being opaque rather than translucent, and having zones of coarse grain. It has no

cortex, and the blocks are full of large voids. I found one nodule that was nearly 50 cm long, but most were smaller.

*Occurrence 21: Aérodrome de Sarlat-Domme* This small landing strip occupies a large, flat area on the plateau SE of Domme, which overlooks the Dordogne valley to the north. A small road runs past the landing strip; to the east, this road connects with D 704 (which runs north to Groléjac and south to Gourdon). The road intersects another small road just east of the landing strip. Near this intersection, in a ditch at the side of the road, I found many large angular blocks of millstone, which are very similar to the material from occurrence 18. I tested a sample from one large block: 21D. In a slough or old quarry pit about 1 km south of this location, I found many large oblong and spherical boulders of the same raw material, some of which were over 75 cm in diameter.

*Bergeracois and Mussidan chert*

*Occurrence 13: Creysse* The small town of Creysse lies about 1.5 km east of Bergerac, on a small plateau overlooking the Dordogne valley from the north, in the heart of the area where Bergeracois chert abounds. I tested two large flakes of Bergeracois that I collected from a pasture near the chateau at Creysse (13A and 13B). These have the typical hard, dark grey cortex of Bergeracois. Both nodules are light brown with a series of distinct, multicolored concentric bands in dark brown, red, yellow, grey, and white. The grain is very fine, but near the center of the nodules it becomes coarser. The non-cortical surfaces were weathered, but it was not possible to determine if these were frost spalls or man-made flakes that had lain on the surface for several years. This area is notorious for the intensity with which local flintknappers, both amateurs and commercially successful professionals, have collected and hoarded

Bergeracois chert. Formerly, large nodules of this raw material were found all over the area. Today, very little of it remains exposed on the surface (J. Pelegrin, pers. comm.). The position of these two nodules in a pasture close to a road does not inspire confidence that this was their primordial location. However, these nodules, as well as rock 26, are indisputably typical Bergeracois chert.

*Occurrence 29: Mussidan* The town of Mussidan lies on the Isle River about 25 km N-NW of Bergerac. The site of La Côte lies upstream of Mussidan, about 8.5 km as the crow flies. National road 89 runs through the town on the way to Périgueux; a bridge connects that road to D 709, which runs north toward Ribérac. About 100 m east of that bridge, N 89 skirts the base of the steep northern slope of a plateau that rises to an elevation of 127 m, southeast of Mussidan. I climbed the wooded slope here.

Crews had been clearing the forest with saws and fire, and in one such clearing I found three large, oblong boulders, about one meter long (Figure 6.27). Another person had recently knocked some massive flakes from one of the boulders. I took one of the large flakes, which lacked evidence of thermal alteration. The material is homogeneous, yellow-brown or yellow- orange, fined-grained, and lacks voids and inclusions. The cortex is thick, hard, dark grey, and calcareous. Farther up the slope, near its summit, I found another large boulder covered in moss and ivy. The interior was homogeneous and fine-grained, with concentric zones of dark grey and brown.

*Quartzite*

*Occurrence 28: Goudou* This location is the same in which I conducted a systematic sampling of the lithologic composition of river gravels. It lies approximately 2.5 km south of the site of Le Flageolet, on the left bank of the Dordogne in a relatively straight stretch of river between two large meanders. At this spot there are several large

islands made up of gravels, on which some small trees and large shrubs have grown (Figure 4.7). I tested one well-rounded quartzite cobble from this location. These appendices appear at the back of this dissertation, and are also recorded on the CD-ROM.

Pendulum Indenter Tests

The raw data from all 3313 valid trials from the PIT analyses, as well as the Cube Cruncher program with which I calculated weight loss values and drew charts summarizing the results, are recorded on a CD-ROM attached to the inside back cover. Appendix B shows a series of three charts for each rock: a scatterplot with the individual weight loss values from each valid trail, a chart showing Median Weight Loss values per load, and a column chart showing Fail Rate per load. Appendix C lists the number of valid trials, number of failures, and the fail rate at each load for each rock. Appendix D lists descriptive statistics derived from the weight loss values at each load for each rock.

*Fail Rate per Load*

At any given load, tougher rocks will have a lower fail rate than weaker rocks. Had I carried out the PIT tests at the same set of loads with each rock, it would be simple to make comparisons between rocks. However, as Appendices D and E make clear, the loads I tested differ from rock to rock. These differences reflect the progressive development of my ideas about the most appropriate experimental design, but they add an unnecessary complication to the inter-rock comparisons.

The basic solution is to choose a single load or set of loads for the comparisons. Unfortunately, for most loads, there are many rocks that were not tested. However, the magnitude of the difference between a load of, for example, 0.401 J and 0.455 J is small. Furthermore, the results tend to be very similar for trials done at similar loads on

tiles from a single rock, and different from loads that are much higher or much lower. For example, results at loads of 0.401 and 0.455 are generally different from the results at loads of 0.669 and 0.722, for a single rock. Therefore, I grouped the data from similar loads in order to be able to include more rocks in the comparisons. By grouping the results of all trials carried out at loads of 0.401, .428, and 0.455 into a single category ("Load = 0.40-0.46), I was able to include 21 rocks, which is more than I would have been able to include if I had treated each of the three loads separately. In similar fashion, I grouped all trials carried out at loads of 0.535, 0.562, and 0.589 J into a single category: "Load = 0.54-0.59", and I grouped all trials at loads of 0.669 and 0.722 J into the category "Load = 0.67-0.72". This gives three load categories with relatively good separation, which will serve as the basis of comparisons.

Figures 6.28-6.31 show the fail rates for each rock at loads of 0.40-0.46, 0.54-0.59, 0.67-0.72, and 1.06 J, respectively, excluding any rocks for which no data exist at the given load. In these figures, the error bars are binomial confidence intervals. The confidence intervals are based on the binomial distribution because a fail rate is simply a function of the two possible outcomes of a valid trial: failure or non-failure. In the figures, the rocks are color-coded according to raw material type.

The error bars tend to be large relative to the distribution of Fail Rate values. These fail rates were calculated on the basis of sample sizes (number of trials) ranging from 6 to 75, and there is an inverse correlation between sample size and the width of the error bars. For example, there were only 6 trials at Load = 0.40-0.46 for rock 9E, and it has the largest error bar in Figure 6.28. However, even those values that were based on the largest sample sizes nevertheless have error bars spanning a length of nearly 0.20 along the vertical axis (corresponding to a range of 20% in fail rates). This is

large relative to the range of Fail Rate values (from 0.12 to 0.67). This indicates the minimum sample size for an acceptably low variance, or an acceptably narrow confidence interval (of say, 0.10 in Fail Rate) is probably very high indeed. A sample size of 75 (for rock 6B in the load range of 0.54-0.59, Figure 6.29) is apparently not sufficient to achieve a confidence interval of that size.

It is also notable while Fail Rate generally increases with Load, it does so slowly relative to the range of loads shown here.

Another important aspect of these results is that if we were to rank the rocks by fail rates at each load, the rankings would change from load to load. For example, rock 11A' ranks 17 of 22 at Load = 0.40-0.46 J, 6 of 22 at Load = 0.54-0.59 J, and 21 of 23 at Load = 0.67-0.72 J. The fail rates of many rocks show the same kind of instability from one load range to the next. The basis of this phenomenon can be seen in the Fail Rate/Load charts in Appendix B. For some rocks (especially 10A, 13A, and 29), Fail Rate increases steadily with increasing loads. For others (e.g., 11A', 14B, 18B) there is no recognizable pattern in fail rate.

Is there no pattern in Fail Rate because the rocks are inherently unpredictable in terms of fail rate, or because the sample sizes in my data are insufficient? Deciphering the meaning of the results will depend in part on the answer to this question. However, that question cannot be answered until I have discussed the issue of Fail Rate Predictability, so I leave it unanswered for the time being.

Another question that arises is, given that I carried out the tests at several different loads, at which load, loads, or load range should the comparison of fail rates be carried out in order to determine the ranking of the rocks by fracture toughness? This question, too, must be set aside until I have discussed the issue of Fail Rate

Predictability, because the answer will depend on the answer to the above question. If the rocks with unpatterned results are that way because they are inherently unpredictable, then all loads (or load ranges) should be equally valid for comparing the fail rates of different rocks. This is true for the predictable as well as the unpredictable rocks. However, if the lack of patterning in the data for some rocks is the result of insufficient sample sizes, then the inter-rock comparisons must be carried out only at the load or load range with the largest sample sizes, in order to minimize the potential effects of sample size on the results. In short, I cannot fully address the issue of fracture toughness as measured by fail rates until I have discussed Fail Rate Predictability. For reasons that will become clear shortly, I shall also postpone my discussion of Minimum 100% Fail Rate.

*Fail Rate Predictability*

In a predictable rock, there should be a significant, positive correlation between Fail Rate and Load. Such a relationship is apparent in Figure B.30 but not in B.33. I used simple linear regression in order to evaluate whether the relationship was significant, for each rock. I restricted the analysis to fail rates based on a sample size of ten or more trials, and for which Fail Rate > 0.00. The latter restriction is necessary because the expectation is that Fail Rate increases with load within the load ranges where failure occurs.

The initial results were significant at the .05 level only in eight cases out of twenty-three. However, when I removed two outliers from the data for rock 1C and re-calculated the regression, the results I obtained were significant. With the inclusion of that rock, outliers removed, there are nine rocks for which the regressions indicate a significant relationship between Fail Rate and Load. The results of these nine

regressions are shown in Tables 6.15 and 6.16. Figures 6.32-6.44 show the best-fit lines and residuals for each of the nine rocks.

If a moderately higher significance level were chosen for this test, then up to three additional rocks might also be considered to have predictable fail rates: 9D (chalcedony from Graudemagne), 21D (millstone from Aérodrome de Sarlat-Domme), and 9G (jasper from Graudemagne). The regression statistics for those rocks are shown in Table 6.16, and the best-fit lines and residual plots are shown in Figures 6.42-6.44. The first two rocks, both of which belong to the chalcedony/millstone raw material type, are good candidates for rocks with predictable fail rates. The third (9G, jasper) might also be but is unfortunately limited by the small sample size: there are only three loads for which 5 or more trials resulted in failure. If that restriction were loosened, results from the fourth load tested (1.06 J) could be included, and the percentage (fail rate = 29%) would fall close to the best-fit line. However, all three rocks must be considered possible candidates only, because of a lack of any strong reason to adopt different statistical criteria for them than for the remaining rocks. Additional trials might help achieve more reliable estimates of Fail Rate, and thus lead to a higher degree of confidence in accepting these results, but unfortunately there are few or no remaining tiles of each rock.

The twenty-three tested rocks can be divided into three groups: nine in which Fail Rate is predictable at statistically significant level; three which may have predictable fail rates, but for which that cannot be determined with confidence; and twelve in which Fail Rate is unpredictable. There is at least one rock with predictable fail rates in every raw material type tested except chalcedony/millstone (if we discount the results of the second group). For most of the rock types, there is only one rock that showed a

predictable fail rate, but four of the five black Senonian rocks appear predictable (see Table 6.17).

*Minimum 100% Fail Load*

In principle, the regression formulae listed in Table 6.16 could be used to predict the load at which a fail rate of 1.00 will occur. Minimum 100% Fail Load is an intuitively appealing concept: the higher it is, the harder one must strike the rock in order to produce a flake. To obtain estimates of Minimum 100% Fail Load, I solved each of the nine regression equations in Table 6.16 for x = 1.00. The results are shown in Table 6.18.

Of course, these Minimum 100% Fail Load estimates could be inaccurate, because they all lie beyond the range of data that were entered into the regression equation. They would only be accurate if the linear relationship identified by the regression statistics continued to be linear at higher loads, but I lack data that would allow me to evaluate whether that is the case. Therefore, it would be invalid to base any estimate of rock fracture toughness on these data. However, I do believe that the minimum 100% fail load values are suggestive.

Figure 6.45 shows the superimposed best-fit lines for the nine rocks with significant Fail Rate/Load regression equations. These lines reveal the relationship that exists between the slope of the Fail Rate/Load regression equation and the consistency of rankings by Fail Rate at different load ranges. Earlier, I mentioned that fail rates at a given load may not be useful as estimates of fracture toughness, because of inconsistencies in the rankings of rocks by Fail Rate at different load ranges. Figure 6.45 suggests what the ranking of these nine rocks would be at any given load (of course, observed values differ from the predicted values, on which the best-fit lines are

based, but the example serves for the purposes of illustration). Those rankings would clearly differ at loads of 0.20 J and 0.60 J, for example. In a sense, the rankings are unstable within the displayed region as we move along the x-axis. The differing slopes of the best-fit lines probably explain why the rankings of rocks by Fail Rate change from load to load. However, at the right-hand side of the figure, the ranking of the rocks by Fail Rate closely corresponds to their slopes. This suggests that the ranks by Fail Rate at the highest load shown here would differ little from the ranks if they were done at a much higher load. In other words, the rankings should become more stable at loads higher than about 0.70 J, if the relationship between the two variables is linear at those higher loads.

As a check on the reliability of the rankings by Fail Rate, I compared the ranking of the nine rocks by Minimum 100% Fail Load with the ranking by Fail Rate in the load range 0.67-0.72 J. There is a small degree of dependency between these two sets of data, because the Fail Rate at 0.67-0.72 includes some of the data that were used in the regression analyses, and therefore, to estimate Minimum 100% Fail Load. However, this dependency is probably slight, and is overridden by the effect of slope. Hence Fail Rate at Load = 0.67-0.72 and Minimum 100% Fail Load are largely independent measures of fracture toughness. A correlation in the rankings of the nine rocks by the two measures would strengthen our confidence in the reliability of both measures.

Since Minimum 100% Fail Load increases but Fail Rate decreases as fracture toughness increases, I used inverse ranks for the latter variable (e.g., the lowest fail rate received the highest rank). Table 6.19 shows the data and the Spearman's rank-order correlation coefficient, which is positive and highly significant. This helps to answer a question I posed earlier: at which load, loads, or load range should the comparison of fail

rates be carried out in order to determine the ranking of the rocks by fracture toughness? Table 6.18 suggests that the highest load range usually tested (0.67-0.72 J) is the most reliable.

An additional analysis supports this conclusion. First, I ranked the rocks by Fail Rate at each of the load ranges defined above (0.40-0.46 J, 0.54-0.59 J, and 0.67-0.72 J). Then, I calculated Spearman's rho for two pairs of rankings: 0.40-0.46/0.54-0.59, and 0.54-0.59/0.67-0.72. Table 6.20 shows the results; rho is significant for the second rank-order comparison, but not the first. This suggests that rocks tend to change ranks less at higher loads, which is another indication that Fail Rates are more reliable (as a measure of fracture toughness) at the highest loads tested. Therefore, I shall use the data represented in Figure 6.30 (Fail Rate at Load = 0.67-0.72) as a measure of fracture toughness. Unfortunately, Minimum 100% Fail Load cannot be used as a valid measure of fracture toughness, at least not without additional data that would permit us to determine whether the Fail Rate/Load relationship is linear at higher loads than those I show here.

*Flake Size Predictability*

I used two different methods to estimate Flake Size Predictability from the weight loss values of each rock: simple linear regression and the coefficient of variation of Weight Loss. Initially, I expected Weight Loss to increase in a linear fashion with Load. I also expected that the strength of this relationship would be an appropriate measure of the Flake Size Predictability of each rock. At the completion of the analysis, I tested these ideas by calculating simple linear regression for each rock, using all the valid failures across all loads, with Weight Loss as the dependent variable and Load as the independent variable. However, in no case did a significant result obtain. (For that

reason, I do not report the results.) Why are these results so different from my initial expectations?

A careful look at the raw data scatterplots in Appendix B (e.g., Figures B.1, B.4, B.7, and so on) suggests an answer. There are three patterns that characterize nearly all of these plots: 1) increase in maximum value with increasing load; 2) uniformity in the minimum values, which are near zero at all loads; and 3) heteroscedasticity—unequal scatter, or "inequality of variances among samples," (Sokal and Rohlf 1995:97). The first pattern suggests partial confirmation of the expectation: in general, higher weight loss values result at higher loads. And to some degree, this pattern is also seen in the "median weight loss per load" plots (e.g., Figures B.2, B.5, B.8, etc.). As load increases, median weight loss values tend to increase. However, the median weight loss values do not line up along a straight line. Figure B.17 shows an excellent example. There, the median weight loss values increase in orderly fashion with increasing loads—until we arrive at the last value, at the maximum load of 1.06 J, which is as low as those at the median weight loss at the lowest load tested. Uneven sample sizes might explain some of the anomalies in the data, but not this one: there were 11 trials at 1.06 J, and 16 trials at 0.72 J. This suggests one of two possibilities: either there is an unrecognized source of spurious variation in some aspect of the PIT apparatus, or a large degree of unpredictability is an inherent property of these rocks. It is not clear which of these is the most likely.

The anomalous median weight loss values, however, pose less of a problem to regression analyses than the problem of heteroscedasticity. Heteroscedasticity is represented by the marked tendency for weight loss values to cluster near zero in the raw data scatterplots, while maximum values range widely. Those plots exaggerate the

problem because they show all the data, including non-failures. However, even when we consider only the failures—the data entered into the regressions—the problem remains. Compare Figures B.13 and 6.47, for example. Figure B.13 shows the weight loss values for each trial of rock 6B, while Figure 6.46 shows the weight loss values of the failures only. At several loads, the data points tend to cluster near the low end of the range. This tendency characterizes the data from each rock. I do not know why this is the case.

One hypothesis is that it results, in part, from the relationship between platform thickness and the volume of the resulting flake. When the exterior platform angle is large (approaching 90°), small differences in the position of the point of crack initiation may result in relatively large differences in flake thickness and mass due to the geometrical configuration of the surfaces of the flake-to-be.

Another hypothesis is that chert possesses an inherently high degree of variation in flake mass. This would be plausible if there were large variations in the homogeneity of the distribution of microcrack lengths and of microcracks themselves within the body of the rock. Such variation could result in an inherent imprecision in the point of crack initiation, even if the location of impact relative to the edge of the specimen were perfectly controlled. Variation in the distribution of microcrack properties would result in variation in the location of crack initiation and therefore in flake mass, even if the point of impact and specimen geometry were identical in each trial.

I do not know which of these two hypotheses is more likely, or whether they are both wrong. What is clear is that simple linear regression is not a valid method for characterizing the Weight Loss/Load relationship in this data set. That method assumes that the data are normally distributed along both axes, which is clearly not the case here.

Moreover, I lack any theoretical model from fracture mechanics that would indicate a different mathematical curve-fitting technique, or a meaningful data transform that might produce significant regressions.

As an alternative to regression, I turned to the coefficient of variation (V) of weight loss per load as a possible solution. Unlike other measures of the spread of data, V accounts for differences in the magnitude of variation between separate measurements. The scatterplots in Appendix B show why this is important: weight loss values become dramatically more widely dispersed as load increases. Because I did not apply the same experimental design to each rock, the between-rock comparisons will necessarily involve data generated at different loads. Thus, any comparison of the variance in weight loss from different loads might be confounded by the effects of load on the variance. The coefficient of variation provides an excellent solution to this problem.

The coefficient of variation of weight loss ($V_{wt}$) is easily related to rock fracture predictability. Since the parameters of the PIT tests that could affect the results are controlled, variation in weight loss, as measured by $V_{wt}$, must be due to variation in the microcrack properties of the rocks. Furthermore, $V_{wt}$ should be the same for the trials carried out at different loads in the same rock. That is, changing the load should not change the relative amount of variation in weight loss, because there is no reason to expect Load and Flake Size Predictability to interact in any systematic way. Crack propagation happens in the same way at small and large loads. Thus, we should be able to compare the $V_{wt}$ from any load on one rock with the $V_{wt}$ from any load on a different rock.

Unfortunately, things do not always turn out as expected. The individual $V_{wt}$ values for each load (for each rock) are listed in the last column of Appendix D. There are a few rocks where $V_{wt}$ changes little from load to load, regardless of sample size, but in most cases the values are highly variable. In some cases, this variation seems related to sample sizes (numbers of failures). Figure 6.47 shows the relationship between $V_{wt}$ and sample size. The largest range in $V_{wt}$ values occurs at sample sizes of two or three; as sample size increases, the range in $V_{wt}$ values narrows. This is perfectly logical from a statistical point of view. However, the magnitude of $V_{wt}$ does not appear to be tied to the absolute values of the loads. Figure 6.48 shows the relationship between $V_{wt}$ and Load. The range of $V_{wt}$ values is similar across the entire range of loads, although $V_{wt}$ values less than 40 only occur at loads of less than 0.60 J. I conclude that $V_{wt}$ is independent of Load. Most of the variation in $V_{wt}$ values appears to result from differences in the intrinsic fracture properties of rocks and from sample size differences, and not from variation in load.

I therefore calculated a global $V_{wt}$ value for each rock, using the weight loss values from all loads combined. I calculated these values based on the global mean for all N weight loss values from all failures and the standard deviation of that mean. Table 6.21 shows these data. In this table, the sample size of each rock (N) is equal to the sum of the figures under "No. fails" in Appendix D. Calculating $V_{wt}$ this way should improve the reliability of the statistic as a measure of flake size predictability because it results in much larger sample sizes. Figure 6.49 shows the global $V_{wt}$ values plotted against sample size (number of failures). Those values are largely unaffected by sample size.

Figure 6.50 shows the global $V_{wt}$ values plotted against RM Type. This figure suggests that different RM types have different amounts of variation in flake size. It is clear that the $V_{wt}$ values for black Senonian and beige Senonian are both higher and more widely distributed than the $V_{wt}$ values for all other rock types. Because Mussidan chert and quartzite each have a sample size of one rock, I refrain from placing too much significance on their $V_{wt}$ values. However, it is clear that black and beige Senonian show a tendency toward higher $V_{wt}$ values than Bergeracois, chalcedony/millstone, and jasper. Beige Senonian has the highest $V_{wt}$ values, and therefore, the lowest flake size predictability. For black Senonian, there is a clear separation between the two lowest values and the three highest ones. At first glance, this might suggest that different varieties of black Senonian, from different outcrops, possess distinctly different fracture properties. However, this is clearly not the case, because each of the two rocks from occurrence 12 (Badefols-sur-Dordogne) would then fall into different groups, as would each of the two rocks from occurrence 1 (La Froumagie), and that would make little sense. Instead, the spread of the data within the black Senonian category shows that the magnitude of variation in flake size predictability is larger in black Senonian than in Bergeracois, chalcedony/millstone, or jasper.

**Summary and explanation of results**

The above experiments were designed to measure four properties: 1) Fail Rate per Load, 2) Minimum 100% Fail Load, 3) Fail Rate Predictability, and 4) Flake Size Predictability. They only measured the last two properties reliably. The experiments do not measure Fail Rate per Load consistently, possibly due to the small sample sizes generated, compared with high inherent variation in the rocks. For many rocks, fail rates

change unpredictably from one load range to the next, whereas they were expected to either stay the same, or to rise gradually with increasing loads.

Closely related to this is the failure of the results to yield reliable estimates of Minimum 100% Fail Load. My attempt to generate such estimates depended on regression analysis, based on the idea that fail rate should rise predictably with increasing loads. They did so only in nine of the 23 rocks tested. Moreover, because of the size of the test apparatus, the range of loads usually did not extend into the region where (presumably) failure would occur in 100% of the trials. Therefore, using regression equations to predict Minimum 100% Fail Load required extrapolating beyond the data, which is of questionable validity. For this reason, the predicted Minimum 100% Fail Loads in Table 6.18 are suggestive only. Even so, those figures do not cluster according to raw material type. This may reflect the fact that those figures were predicted using an invalid method, or they may reflect a high inherent variation in the material tested. Unfortunately, there are no other data that would permit a resolution of this dilemma. Such data could only come from additional tests, conducted at loads extending into the range where failure occurs in 100% of the trials. In sum, these experiments yielded no estimates of fracture toughness or fracture strength for rocks.

The PIT experiments do give an accurate, albeit simplistic, picture of Fail Rate Predictability. Fail Rate increases predictably with increasing loads in nine cases. Either the remaining 14 rocks have such a high inherent variation in microcrack properties that crack initiation cannot be predicted accurately, or the data I generated for those rocks are insufficient for making such predictions accurately. If the latter is true, this may result from the relatively small sample sizes, or the relatively narrow range of loads tested. Yet, while sample sizes vary from rock to rock, the loads tested covered a

similar or identical range for each, and there are no systematic differences in sample size between rock types. Therefore, the statistically significant results that were obtained for nine rocks appear to signify a real difference in fracture predictability between those and the other 14 rocks.

Each raw material type has a different proportion of rocks with predictable fail rates (Table 6.17). The single nodule of Mussidan chert and the quartzite cobble each had a predictable fail rate, determined by the occurrence of a significant $R^2$ for the regression of Fail Rate on Load. More suggestive is the high proportion for black Senonian chert (four of five), and the low proportion (one of five) for beige Senonian chert. This suggests that, although beige Senonian is by far the most abundant raw material type in the Perigord, it is much harder to find nodules of beige Senonian with predictable fracture than nodules of black Senonian with predictable fracture.

The PIT experiments gave coherent results on Flake Size Predictability. These indicate systematic differences in the range of variation within each raw material type, as well as differences between raw material types in mean flake size predictability. The range of variation is highest among beige Senonian, high among black Senonian, and uniformly low among all other raw material types tested. Also, mean $V_{wt}$ values, which indicate the overall level of flake size predictability for each rock type, are highest for beige Senonian, lower for black Senonian, and lower still for chalcedony/millstone, Bergeracois, jasper, Mussidan, and quartzite. $V_{wt}$ values for the latter five rock types are statistically indistinguishable (although, again, those for Mussidan chert and quartzite are each based on a sample size of one).

The results of the two kinds of measures (Fail Rate Predictability and Flake Size Predictability) both indicate differences between black and beige Senonian. They

indicate that the beige variety is less predictable than the black in two ways: in having a lower predictability of fracture, and lower flake size predictability. In contrast, the two measures gave differing results for chalcedony/millstone. This material lacks predictable fracture, but does have high flake size predictability. This means that one can produce flakes of the desired size and shape; the problem lies in getting the material to flake when one wants it to.

With these results, we can now re-examine the results of the raw material and technological analyses of the six assemblages to test the idea that variation in raw material fracture properties affected raw material acquisition and use in the past.

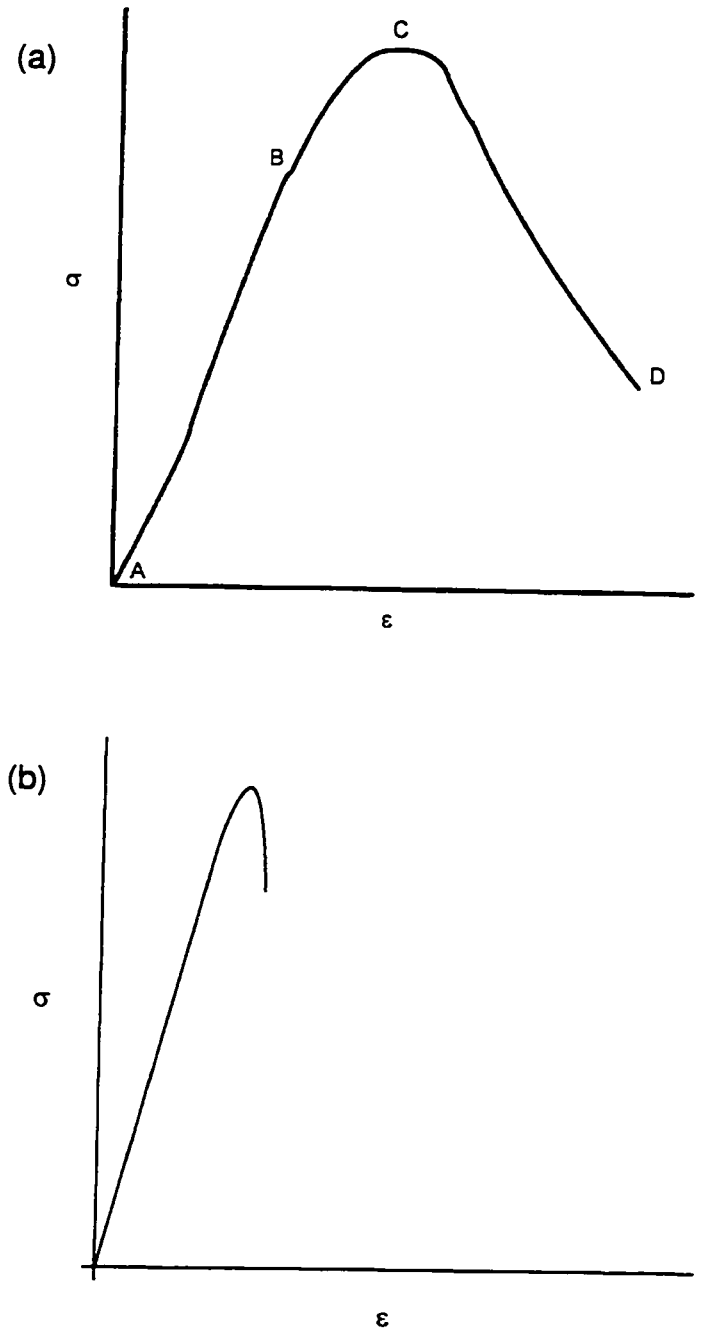



Figure 6.1 Ideal stress strain curves: (a), complete stress/strain curve for rock (after Jaeger and Cook 1976, Figure 4.2.2; (b), stress/strain curve typical of brittle rock.

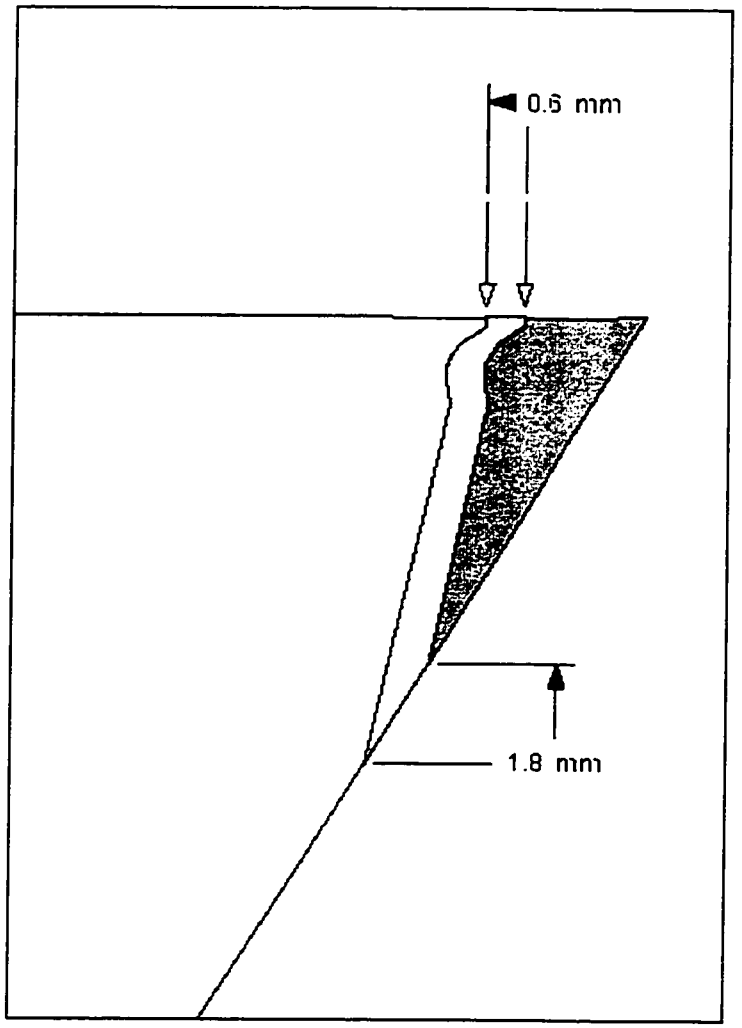



Figure 6.2 Effect of increasing butt thickness (or platform thickness) on flake length.

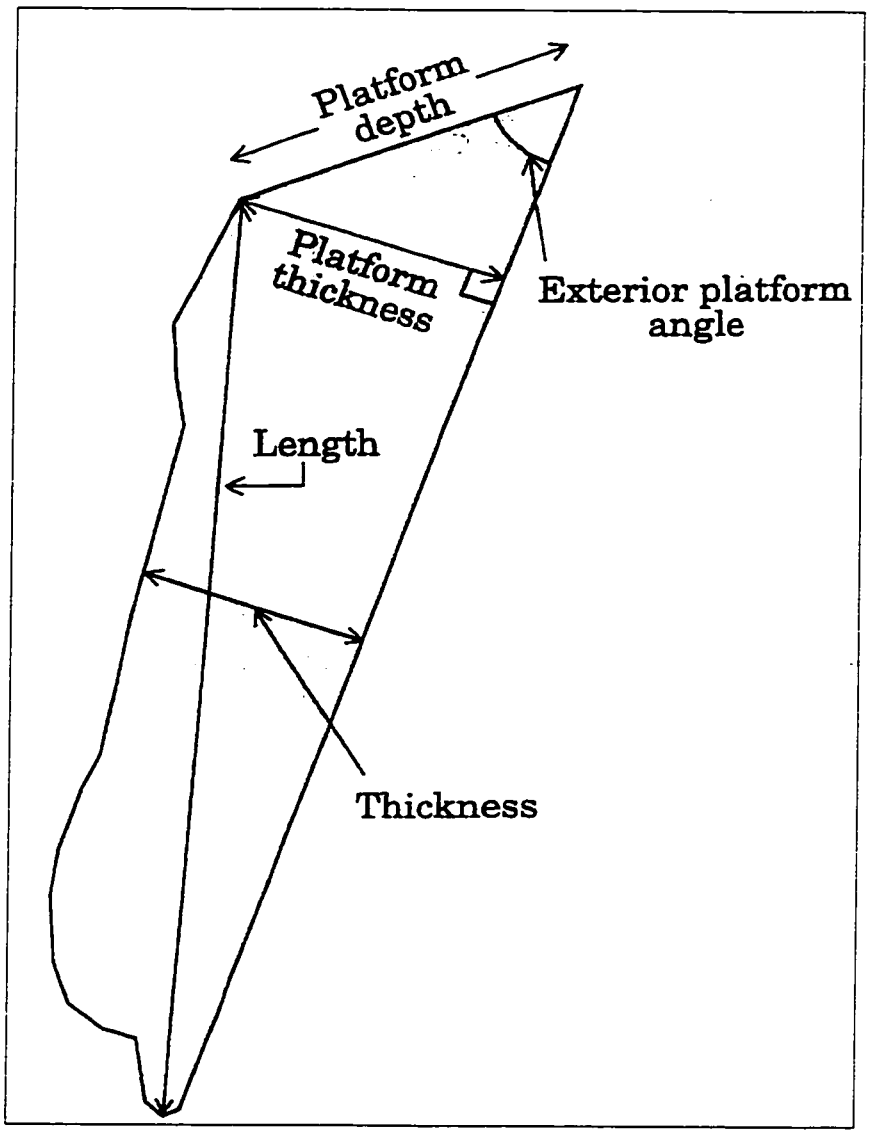



Figure 6.3 Definition of platform thickness. From Dibble and Pelcin (1995).

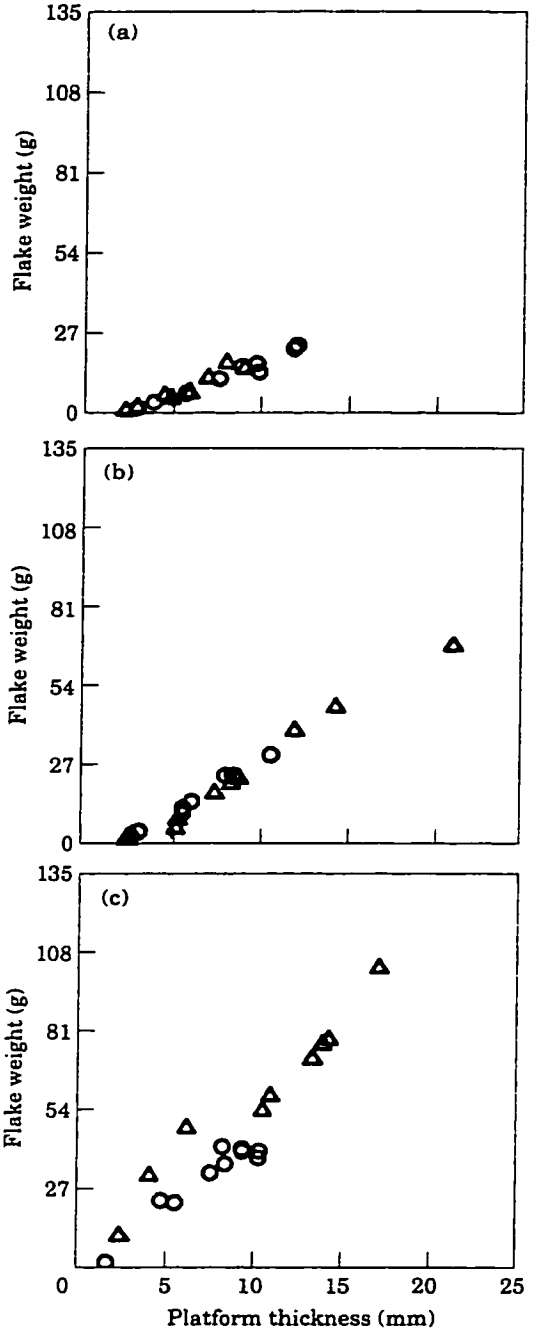



Figure 6.4 "Effect" of platform thickness on flake mass, for a 225 g ball bearing dropped from different heights: ○, 0.34 m; △, 1.25 m. Exterior platform angle: (a) 55°; (b) 65°; (c) 75°. From Dibble and Pelcin (1995, Figure 7).

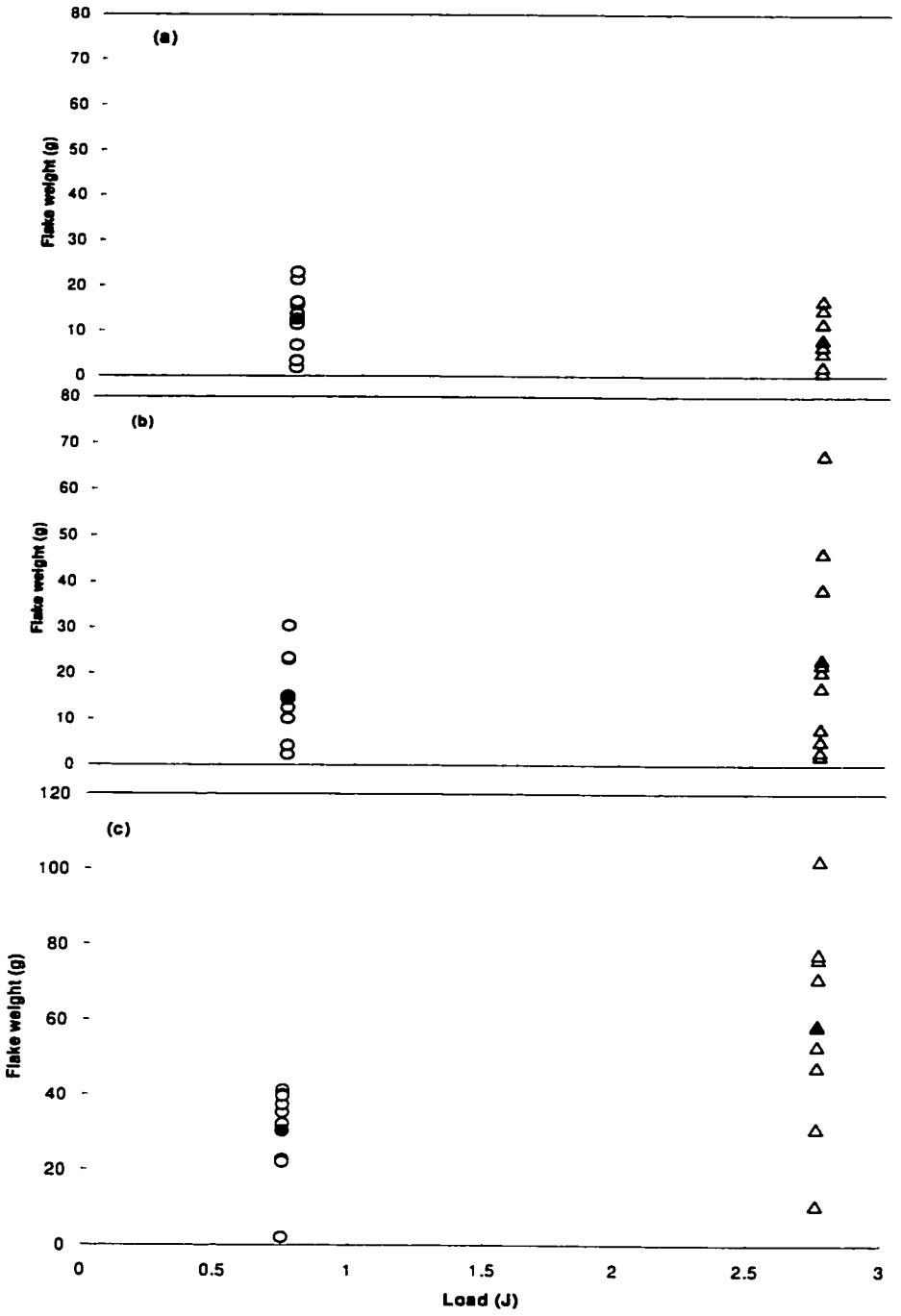



Figure 6.5 Data from Dibble and Pelcin's (1995) Figure 7, re-plotted as flake weight v. load, for the 225 g ball dropped from two different heights, corresponding to two different loads: ▪, 0.75 J; ▪, 2.76 J. Exterior platform angle: (a) 55°; (b) 65°; (c) 75°. Filled shapes are mean values.

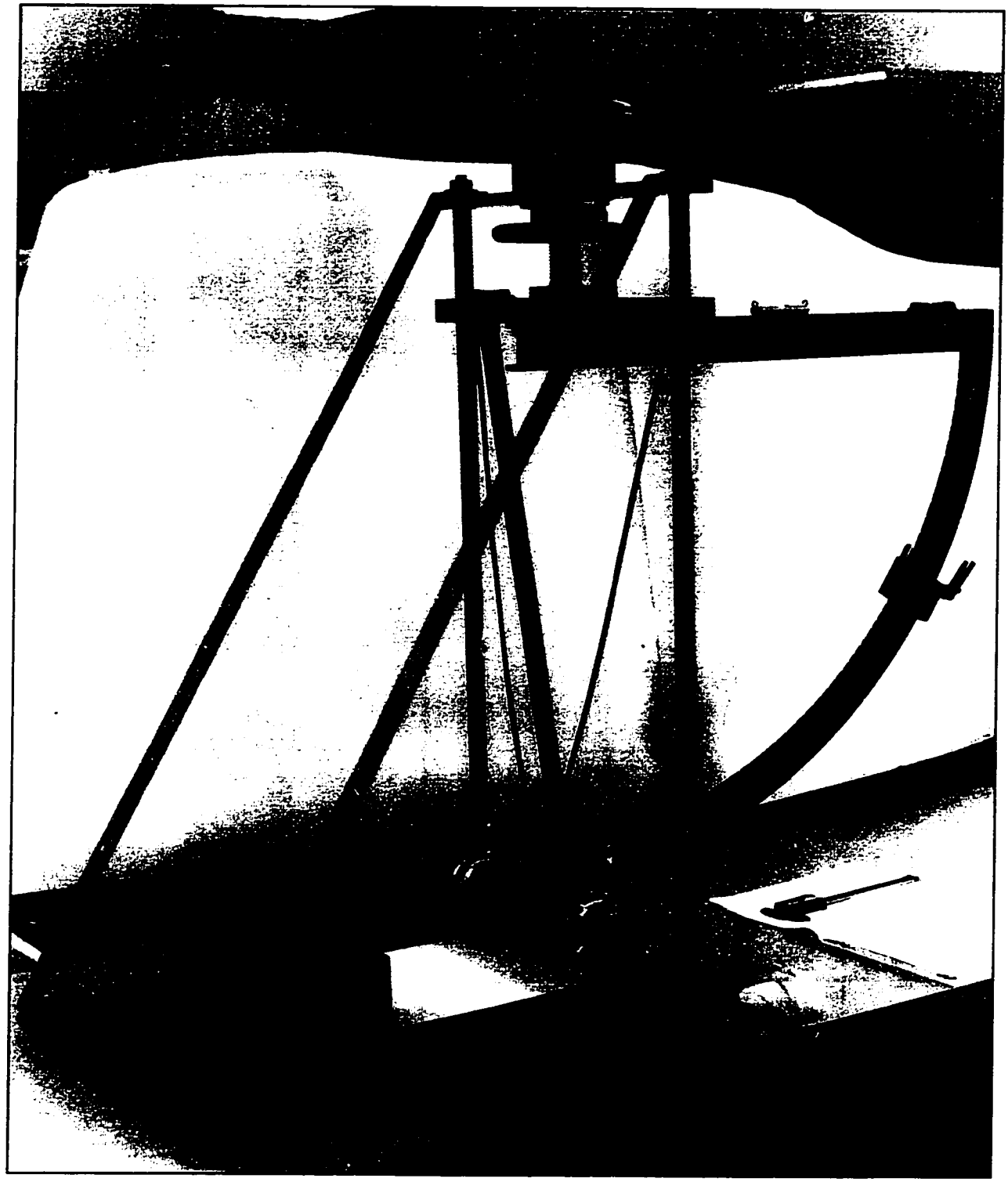


Figure 6.6 Pendulum impact tester (PIT).

Figure 6.7 Indenter billet in ready position.

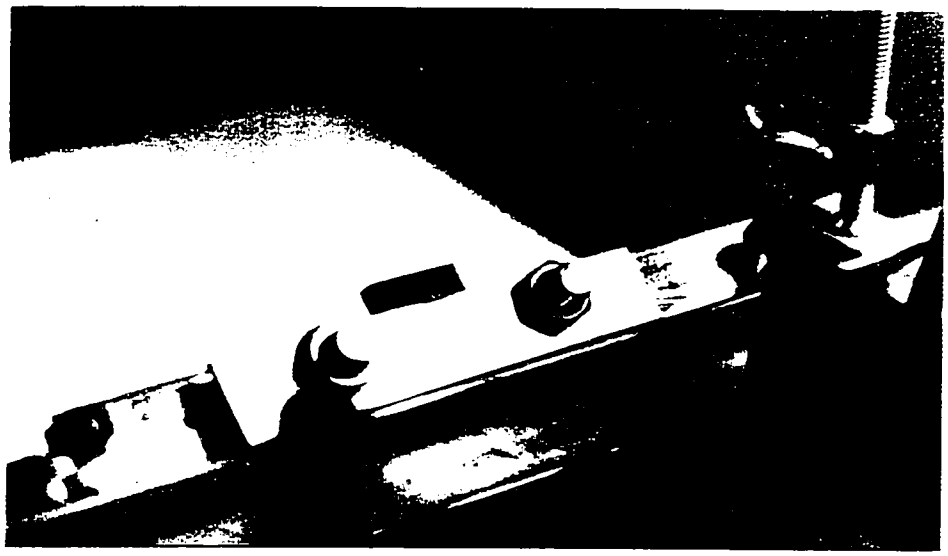


Figure 6.8 Tile in vice.

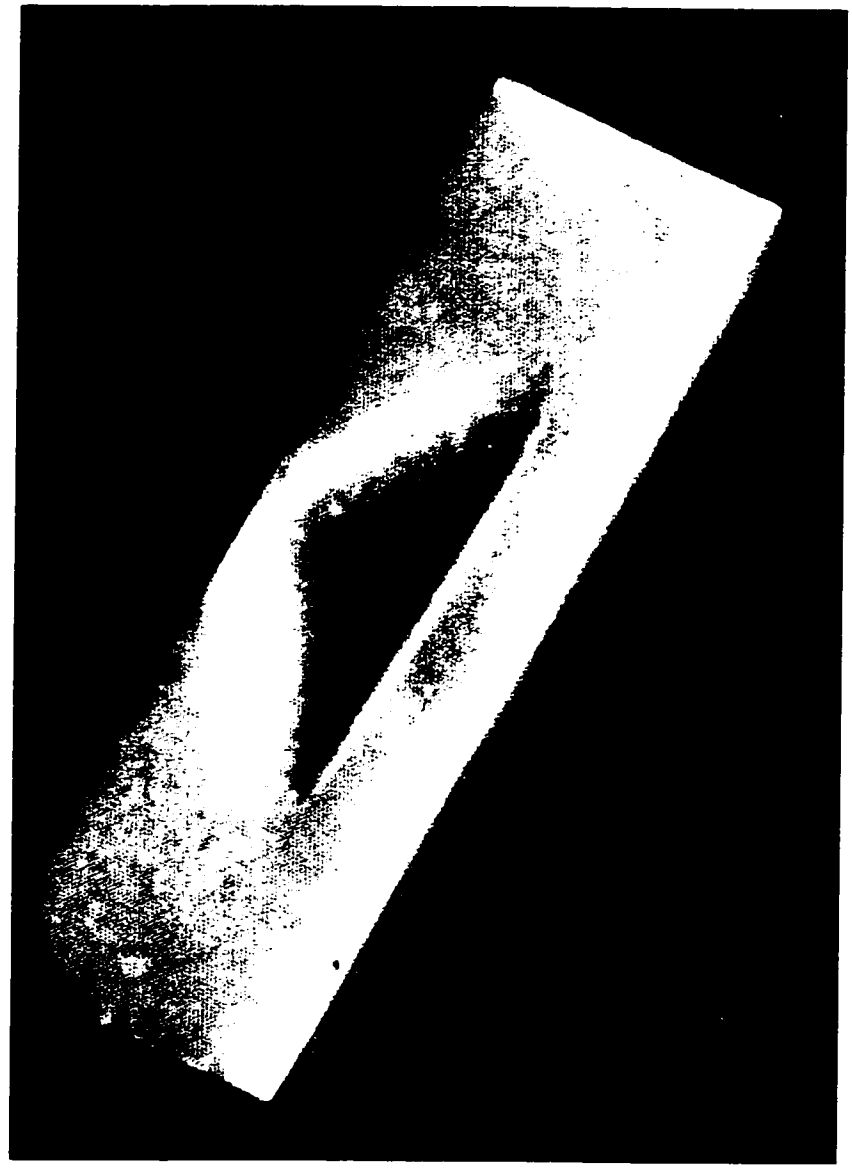


Figure 6.9 Tile of chalcedony/millstone, showing flake scar resulting from PIT tests.

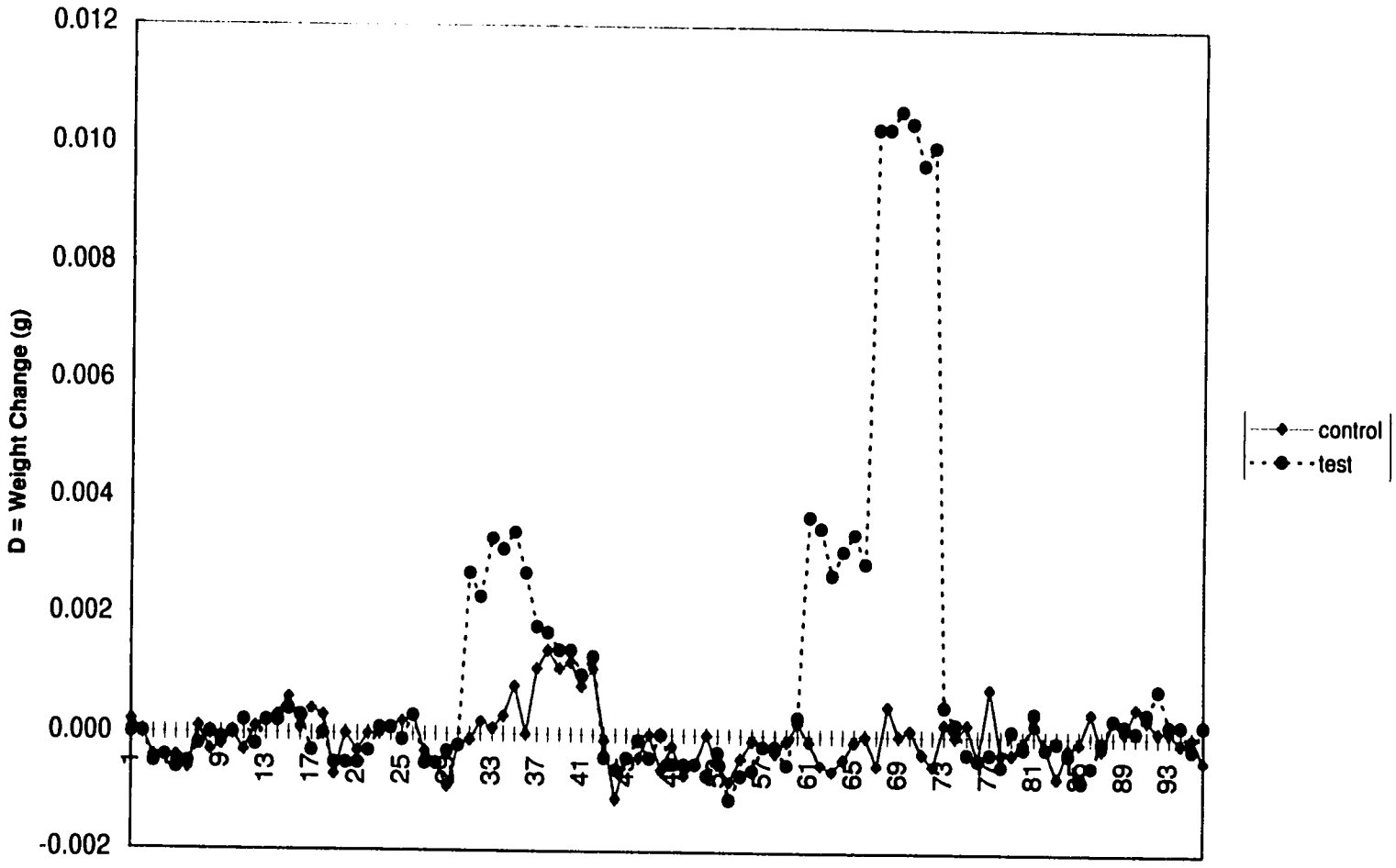



Figure 6.10 Variation in the *D* values of a control tile of test tiles cut from a single rock, over a two-day period. Each trial is represented by a set of six weights for each tile. There are three fails recorded in this sequence.

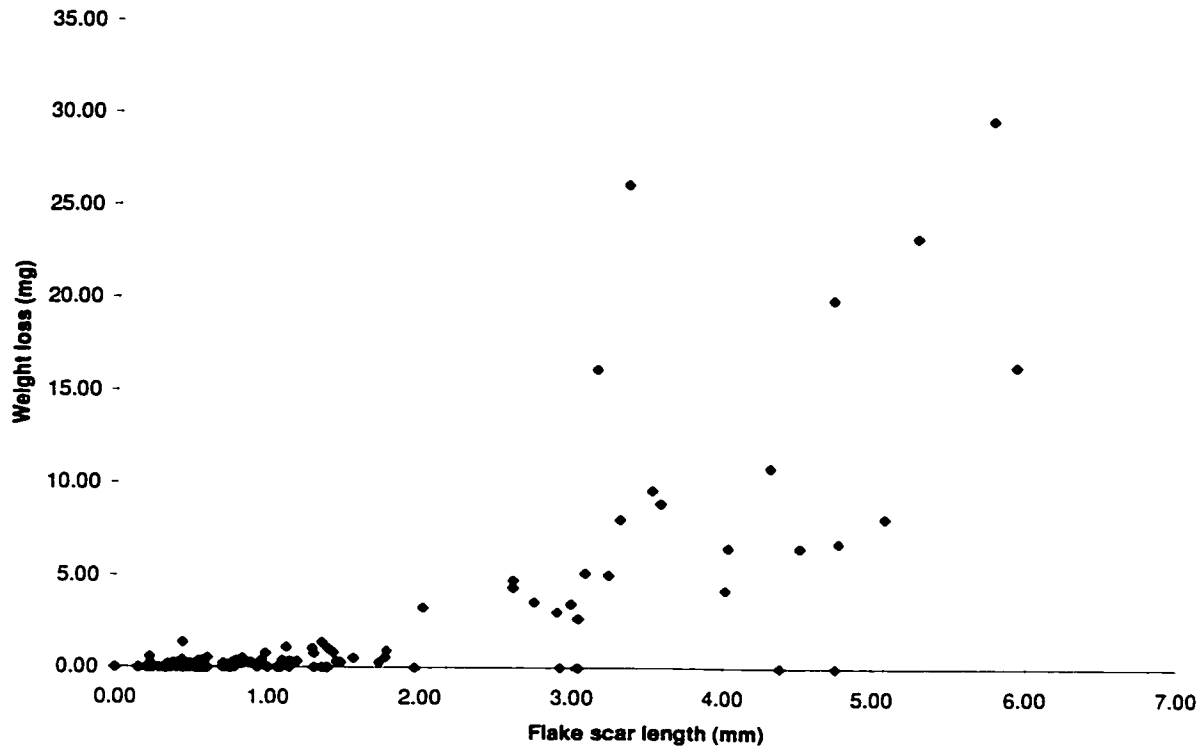



Figure 6.11 Plot of flake mass against length of flake scar.

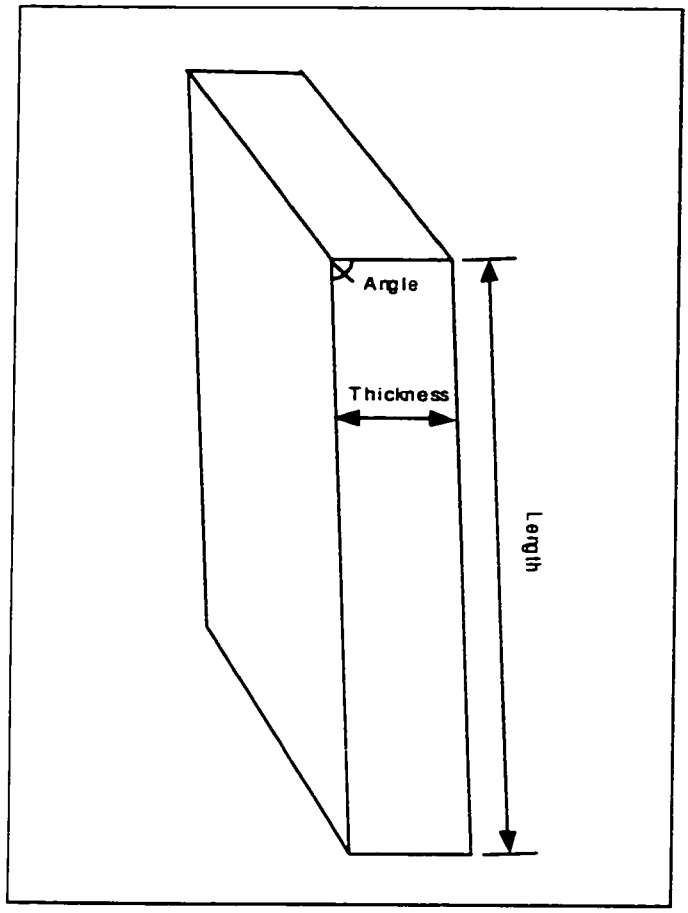



Figure 6.12 Tile side length, thickness, and angle.

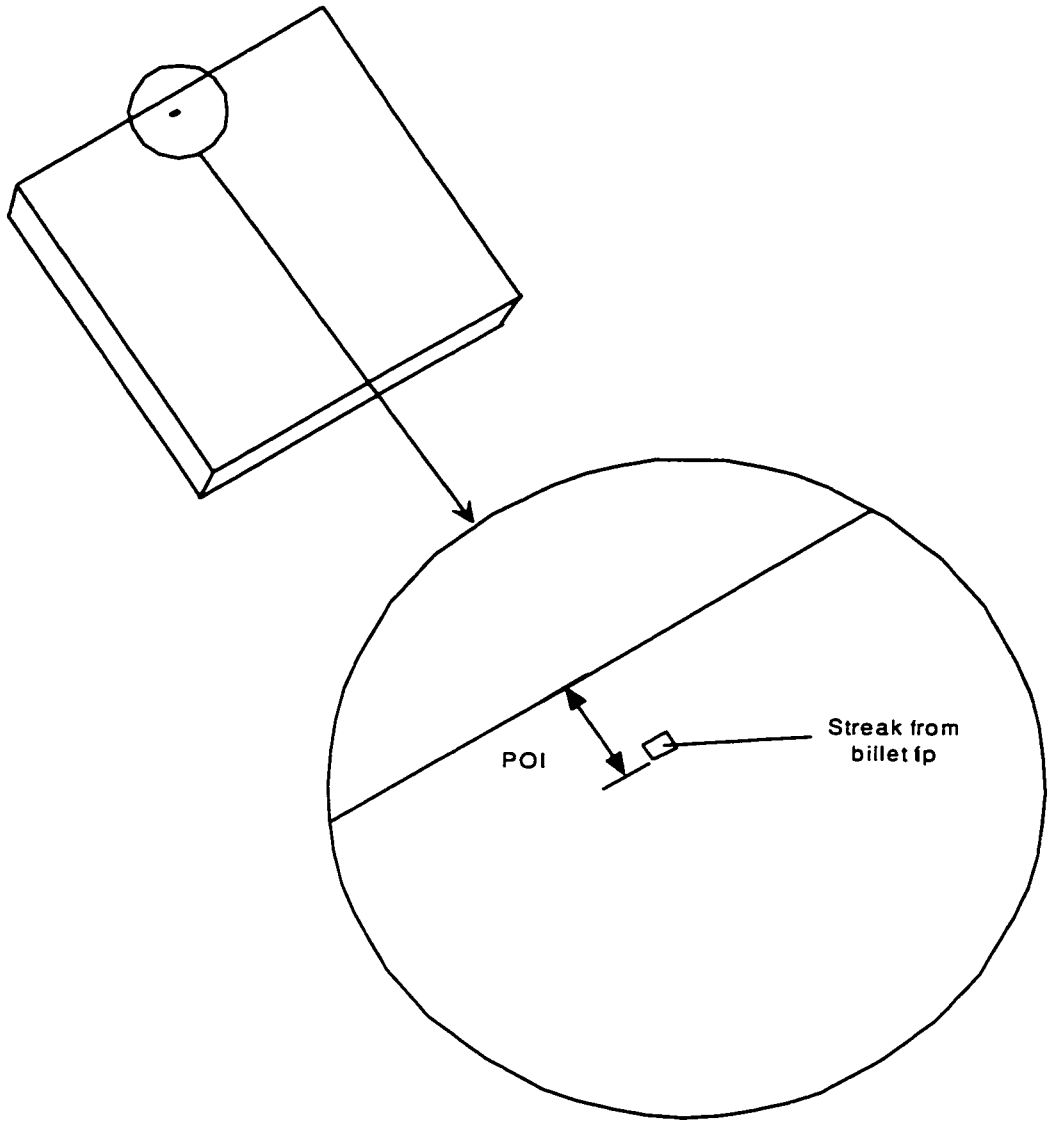



Figure 6.13 Point of impact (POI).

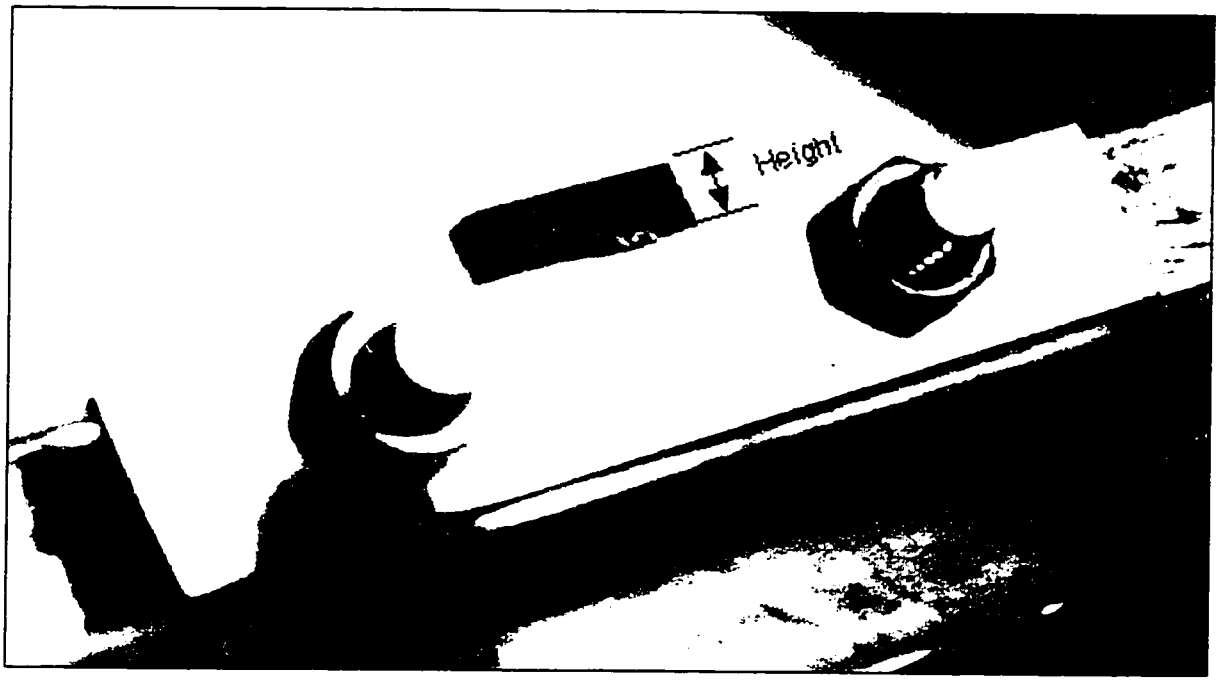



Figure 6.14 Detail from Figure 6.8 showing how Height is defined on a tile clamped into the PIT vice.

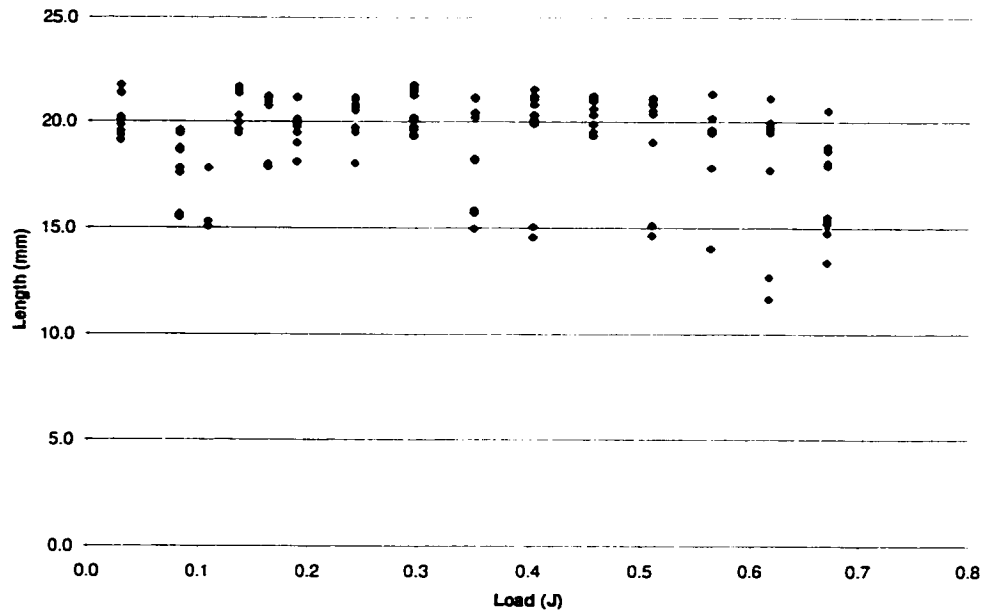



Figure 6.15 Lengths of tiles for all trials against load, rock 11A (cobble of beige Senonian collected at Limeuil).

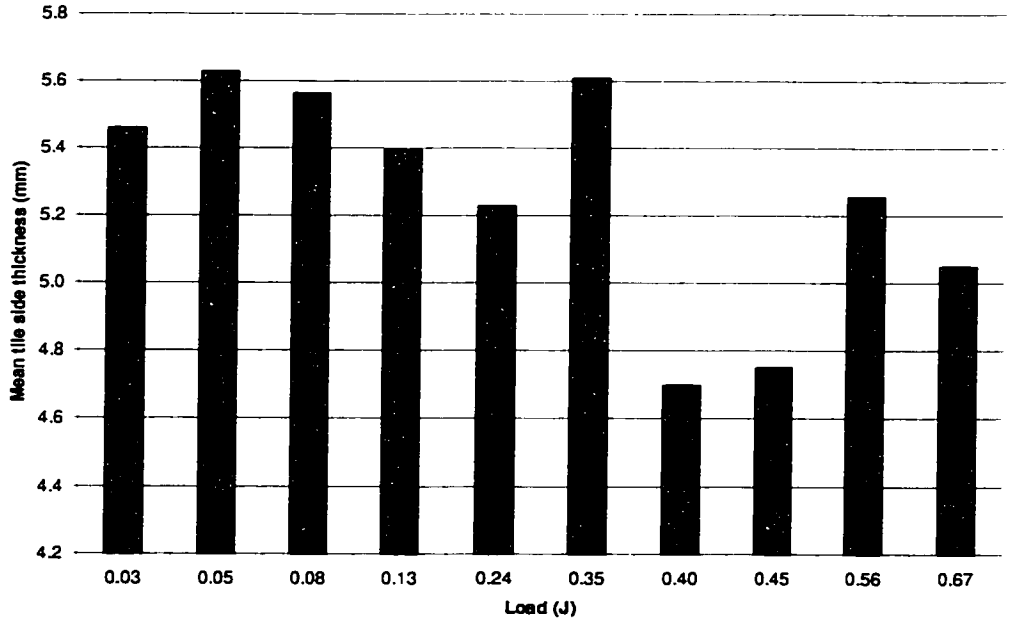



Figure 6.16 Mean thickness of tiles at each load tested, rock 10A (jasper from Puy d'Arnac).

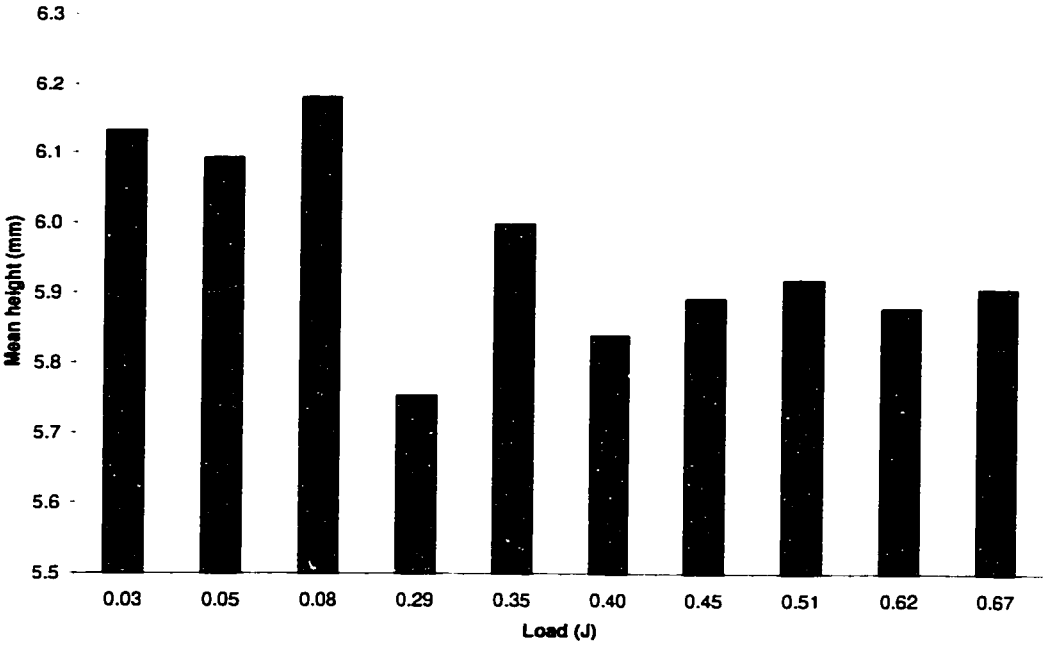



Figure 6.17 Mean HEIGHT of tested tiles at each load, rock 1B (nodule of black Senonian from a road cut at la Froumagie).

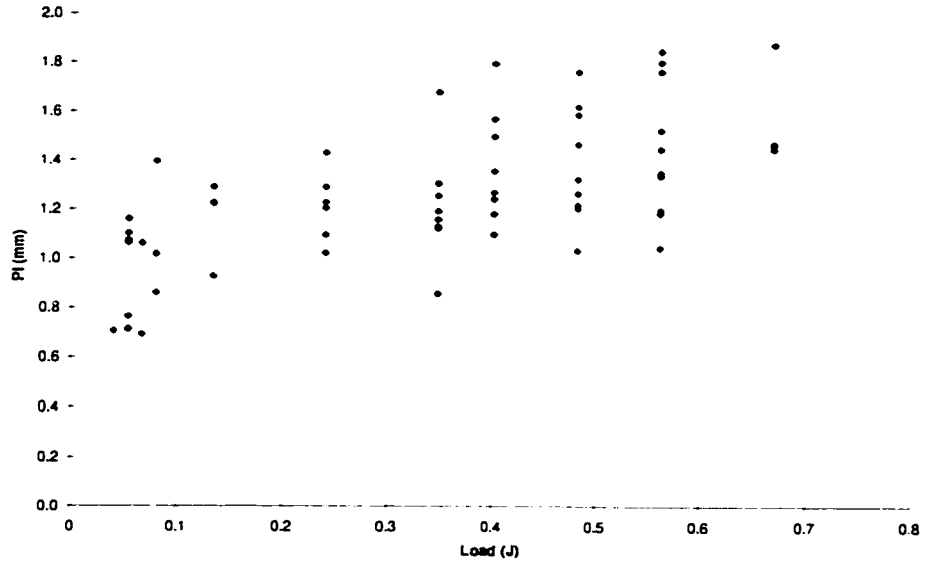



Figure 6.18 PI per trial, by load, rock 12A' (nodule of black Senonian from road cut at Badefols-sur-Dordogne).

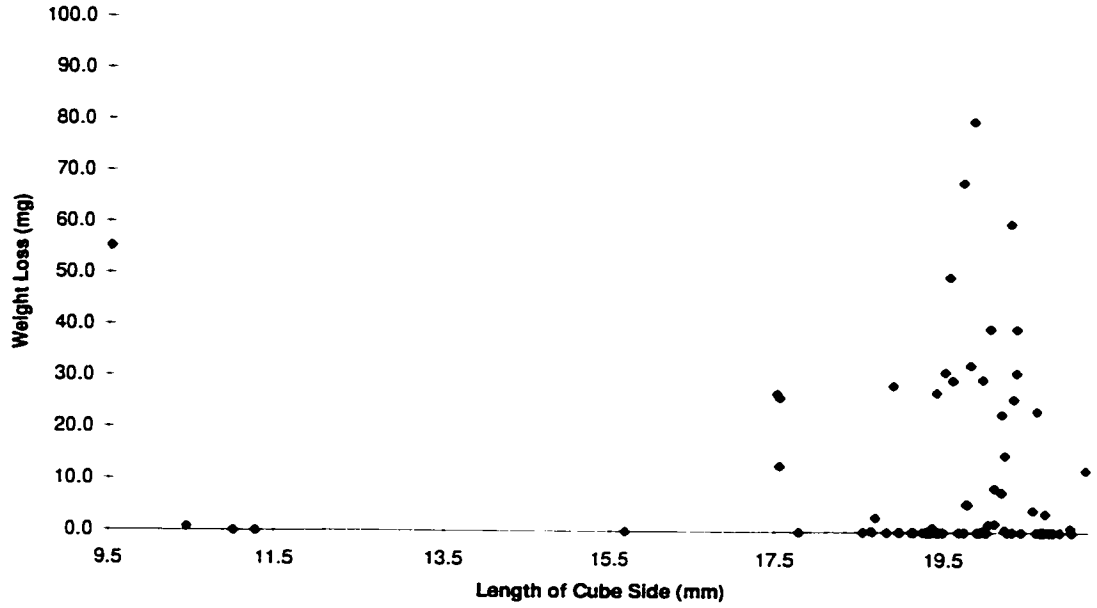



Figure 6.19 Scatterplot of LENGTH against WTL for rock 10A.

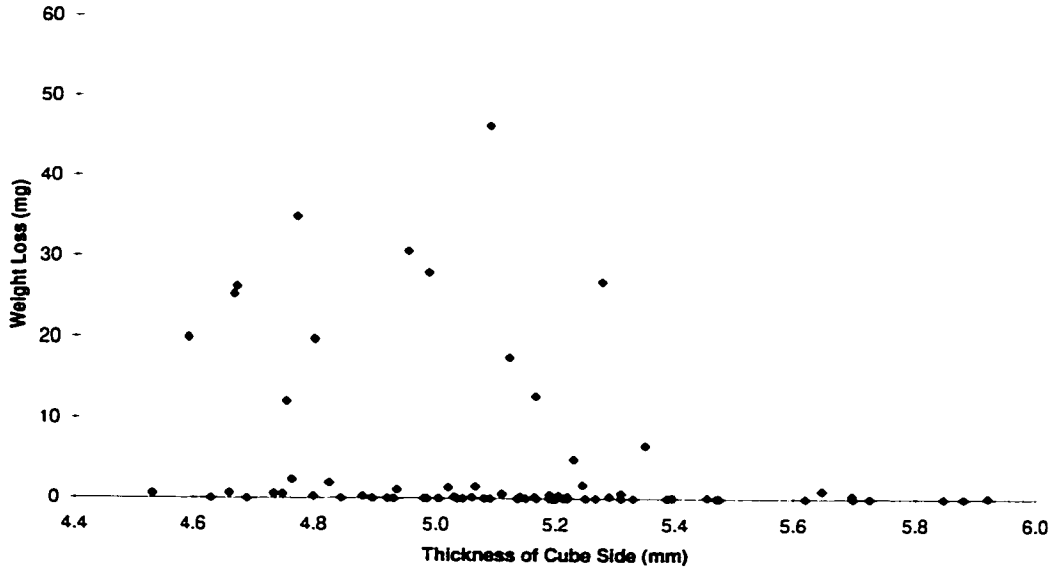



Figure 6.20 Scatterplot of THICKNESS against WTL for rock 13B.

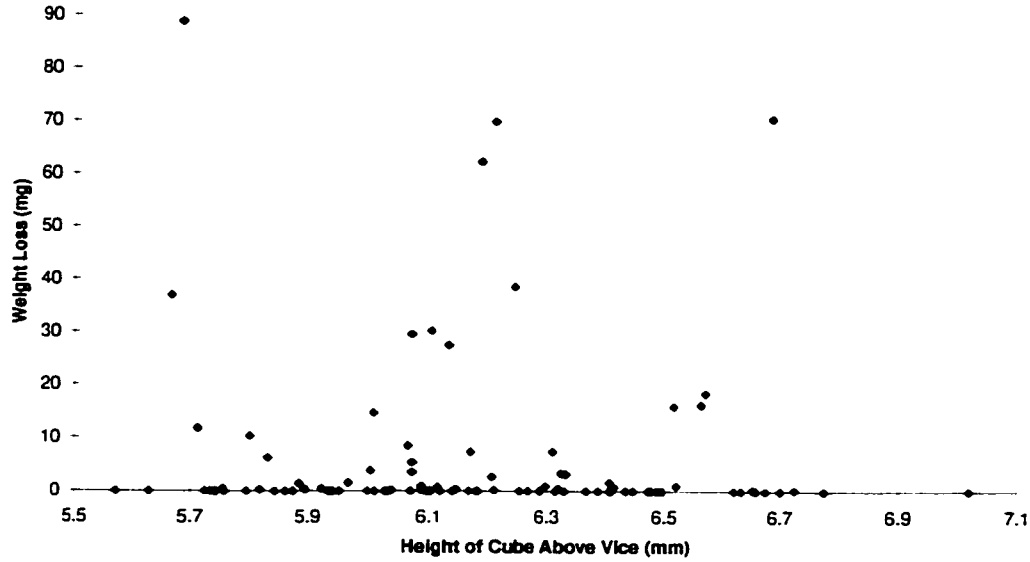



Figure 6.21 Scatterplot of HEIGHT against WTL for rock 1C.

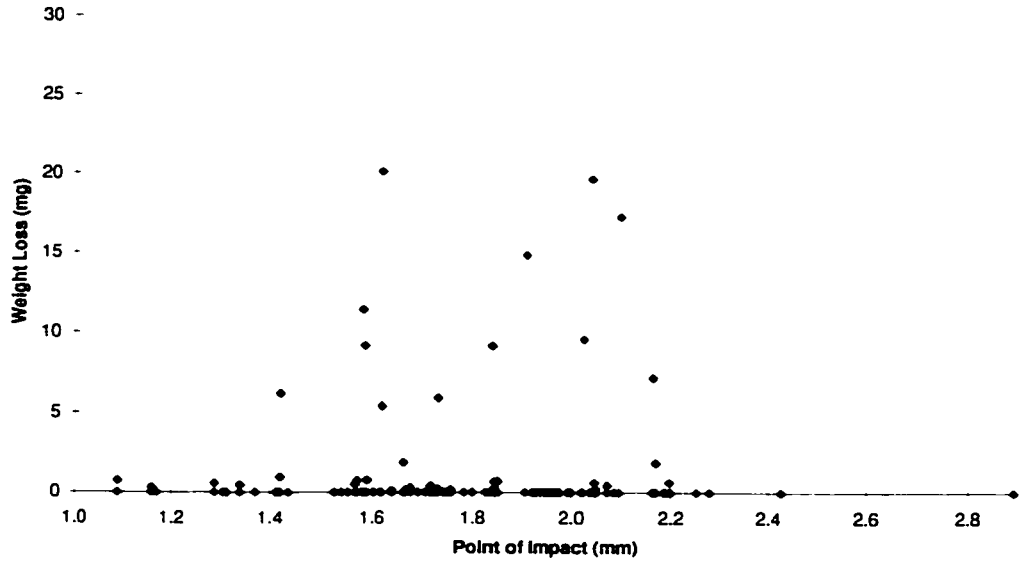



Figure 6.22 Scatterplot of PI against WTL for rock 18B.

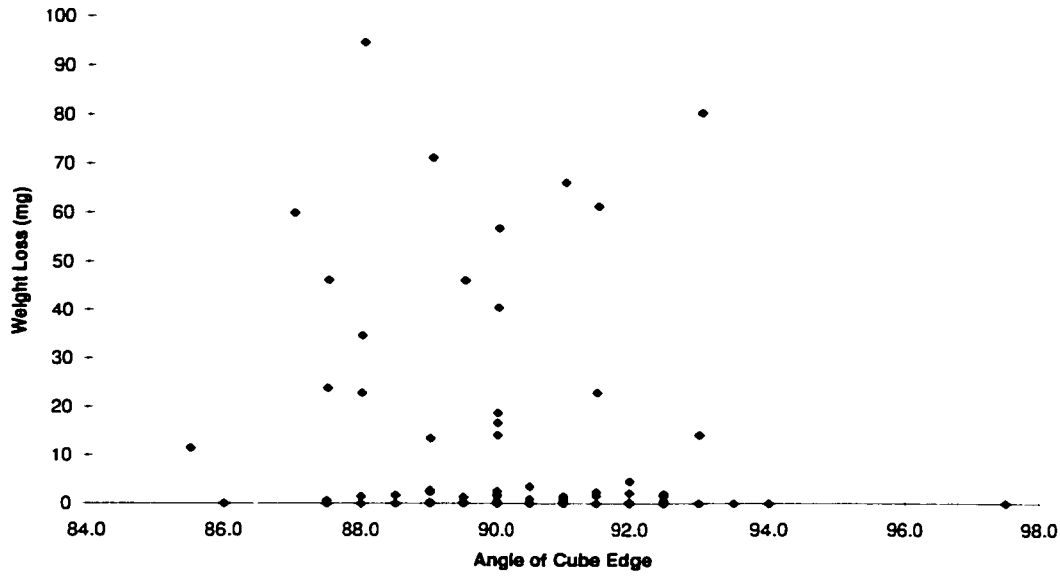



Figure 6.23 Scatterplot of ANGLE against WTL for rock 1B.

Figure 6.24 Nodules of Senonian chert exposed in chalky limestone in road cut, Badefols-sur-Dordogne.

Figure 6.25 Boulder of chalcedony covered in moss, Graudemagne. Scale bar: 10 cm.

Figure 6.26 Exposed bank along farming road with nodules of chalcedony at Graudemagne.

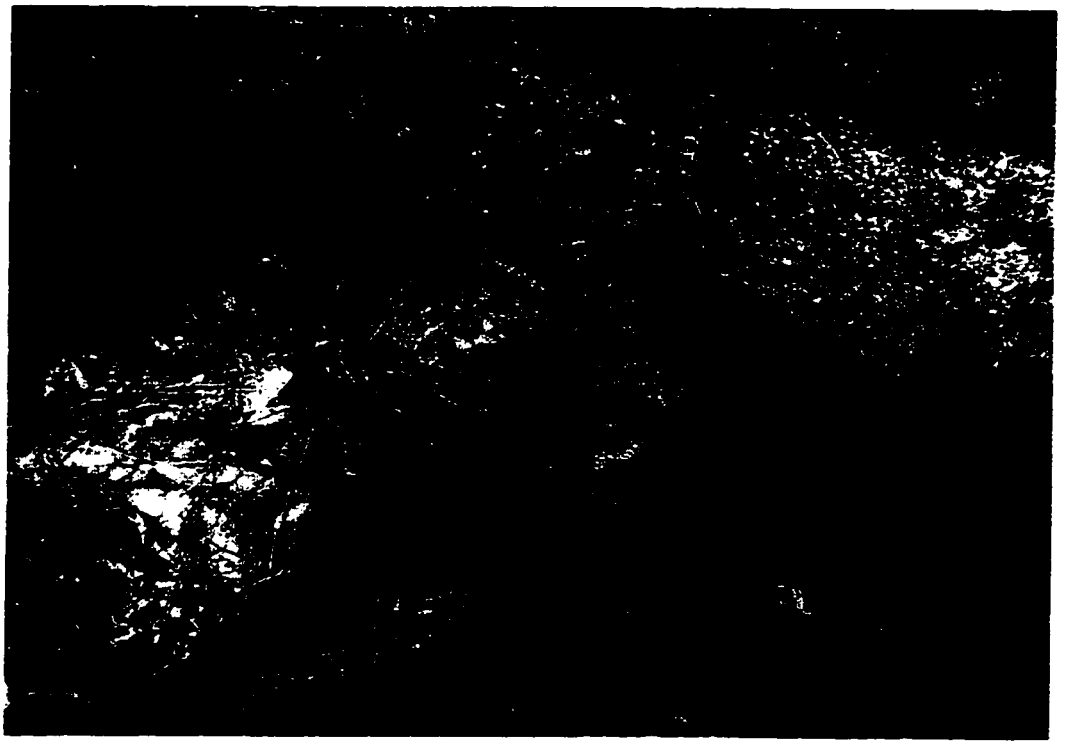


Figure 6.27 Large boulder of chert near top of bluff at Mussidan. Ivy leaves give relative scale.

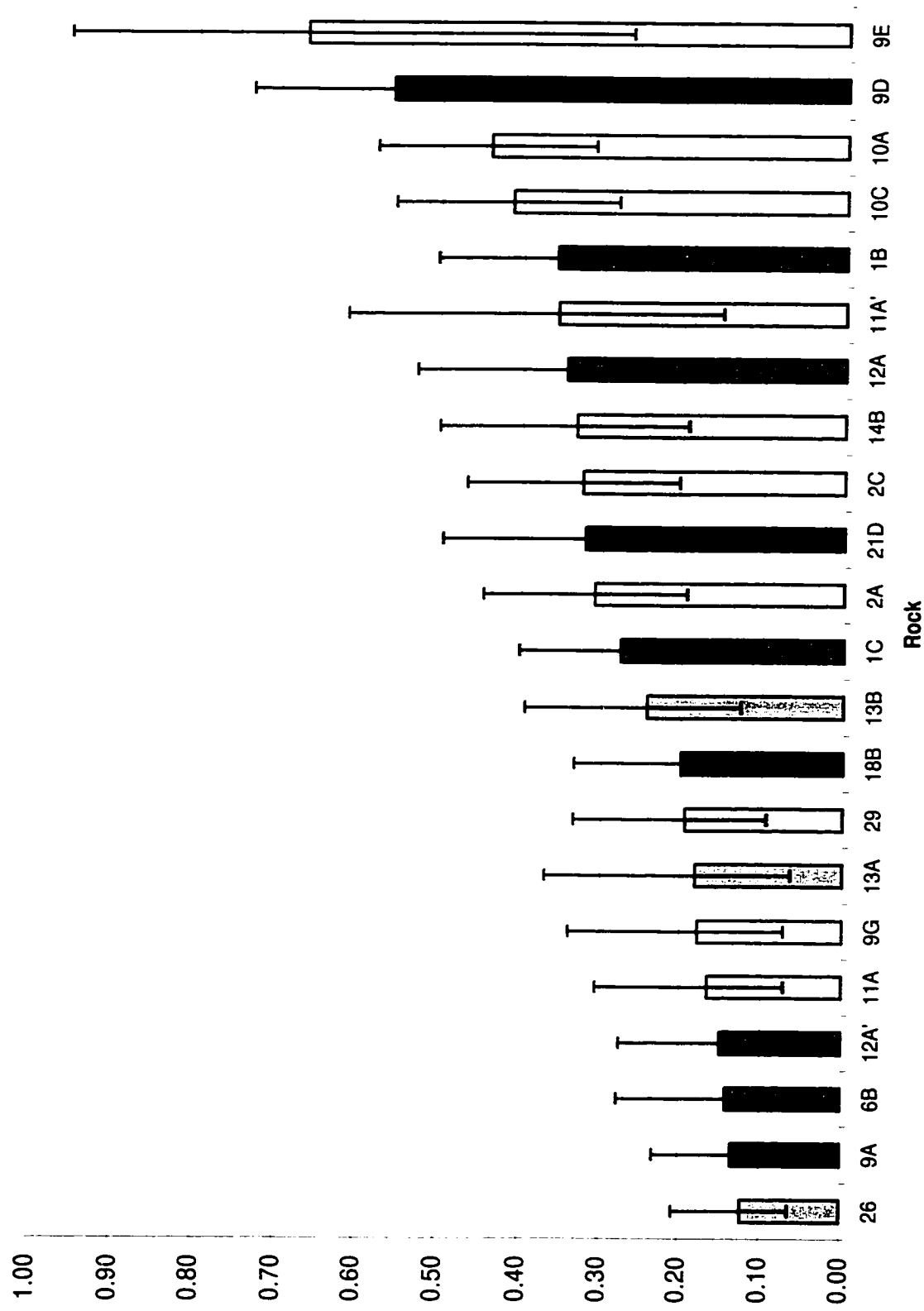



Figure 6.28 Fail Rate for twenty-two rocks from trials carried out at Load = 0.40-0.46 J.

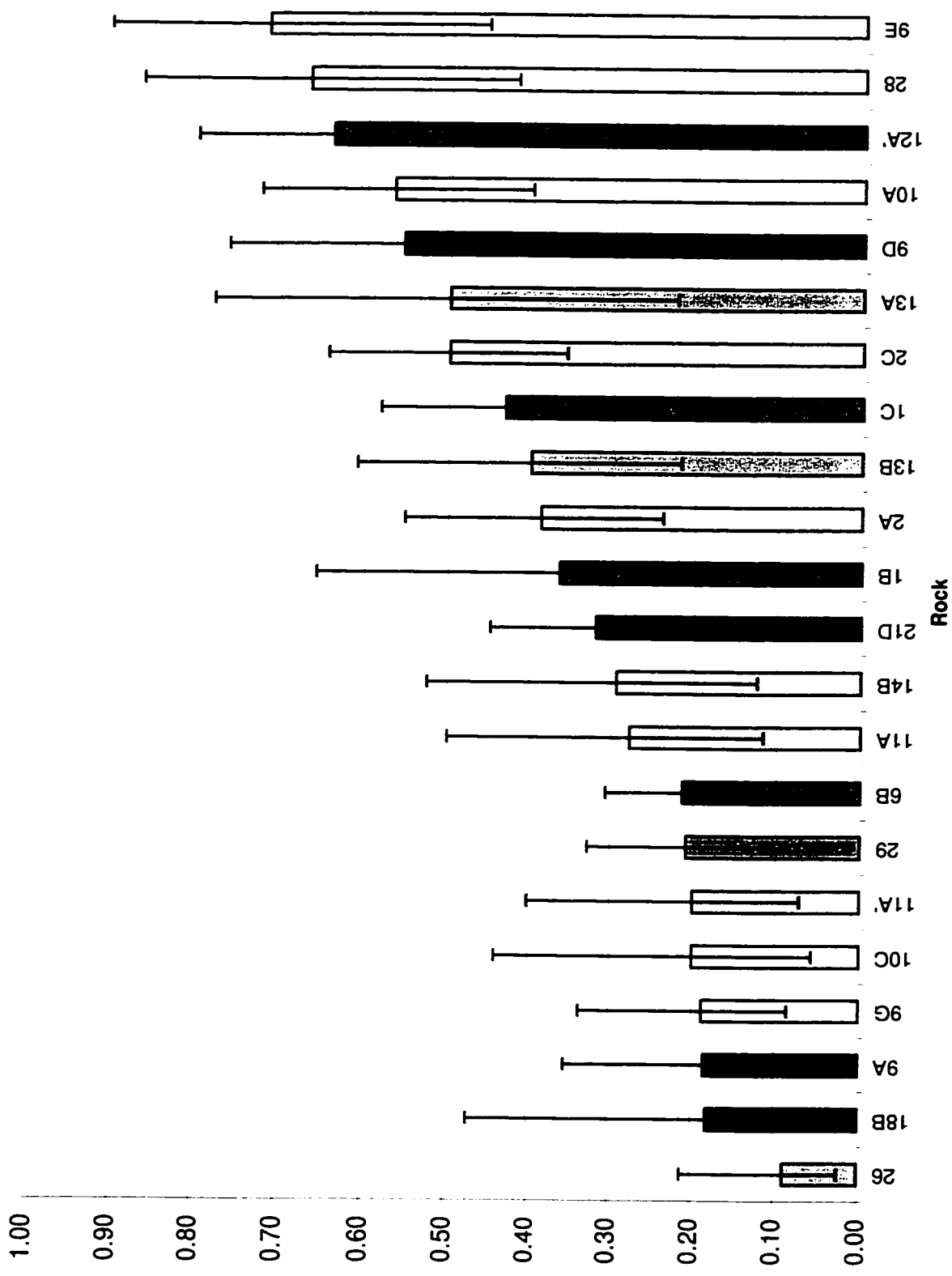



Figure 6.29 Fail Rate for twenty-two rocks from trials carried out at Load = 0.54-0.59 J.

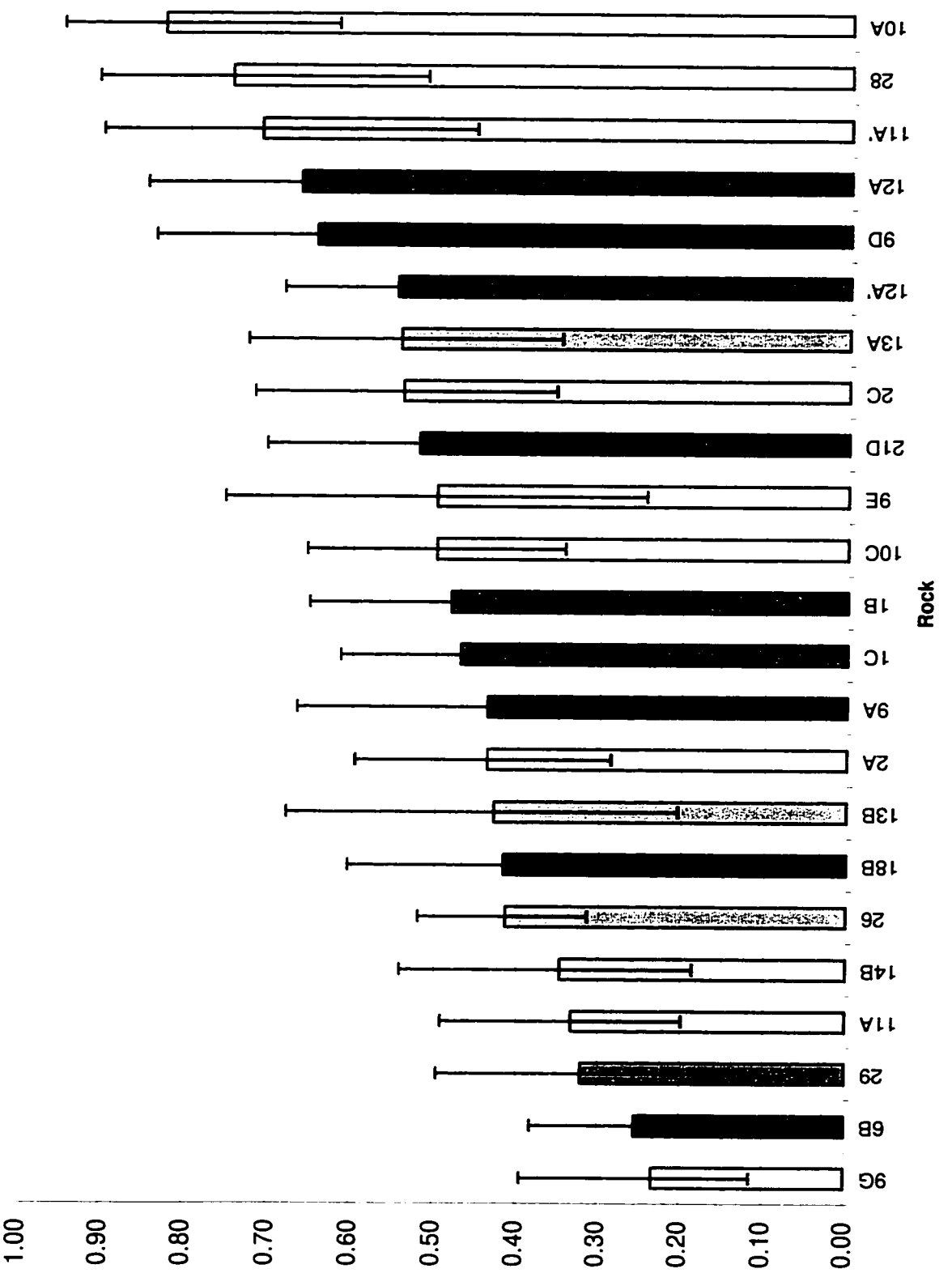



Figure 6.30 Fail Rate for twenty-three rocks from trials carried out at Load = 0.67-0.72 J.

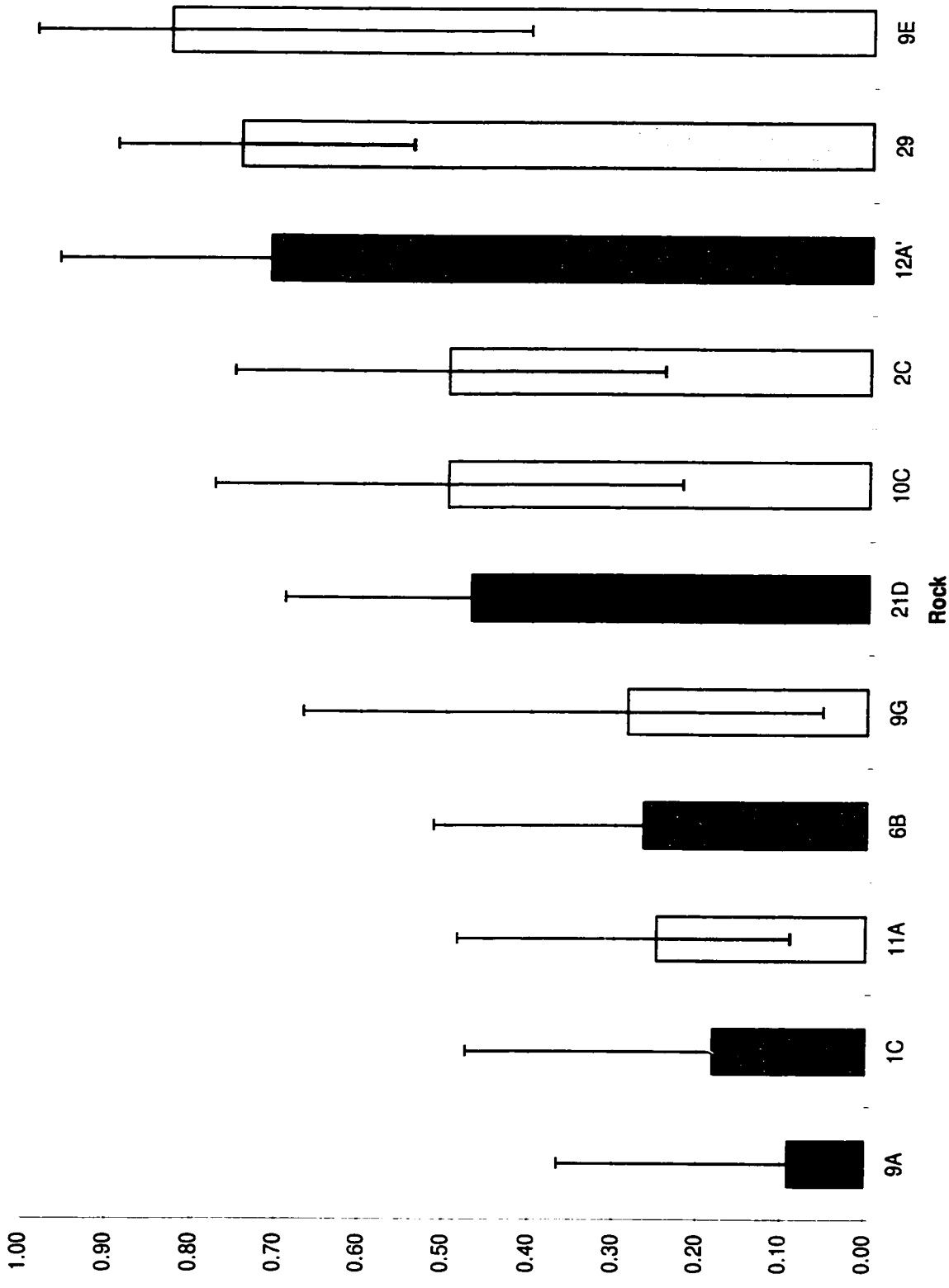
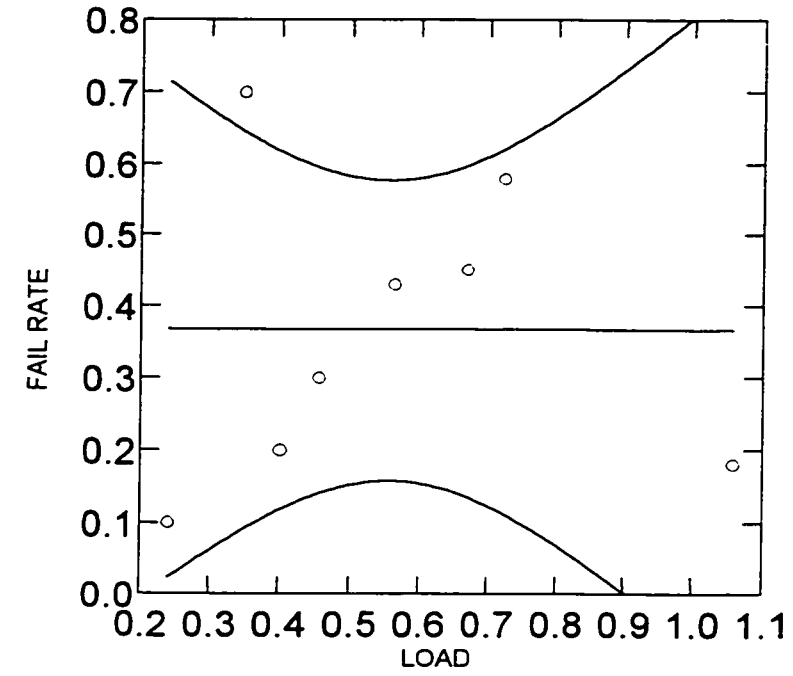
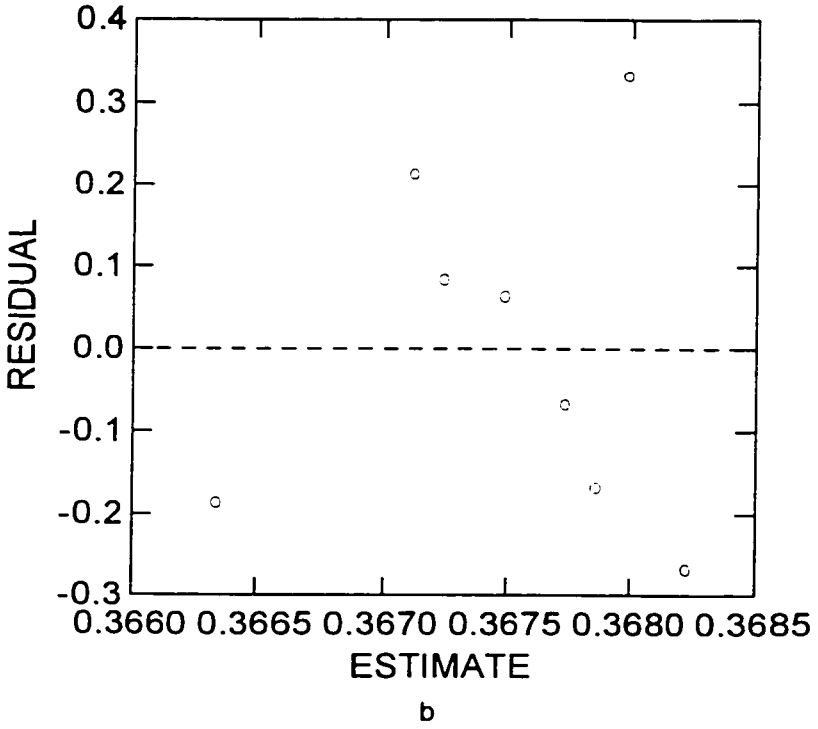



Figure 6.31 Fail Rate for eleven rocks from trials carried out at Load = 1.06 J.




a




b

Figure 6.32 Best-fit line with 90% confidence ellipse (a), and plot of residuals against expected values (b) for rock 1C (black Senonian).

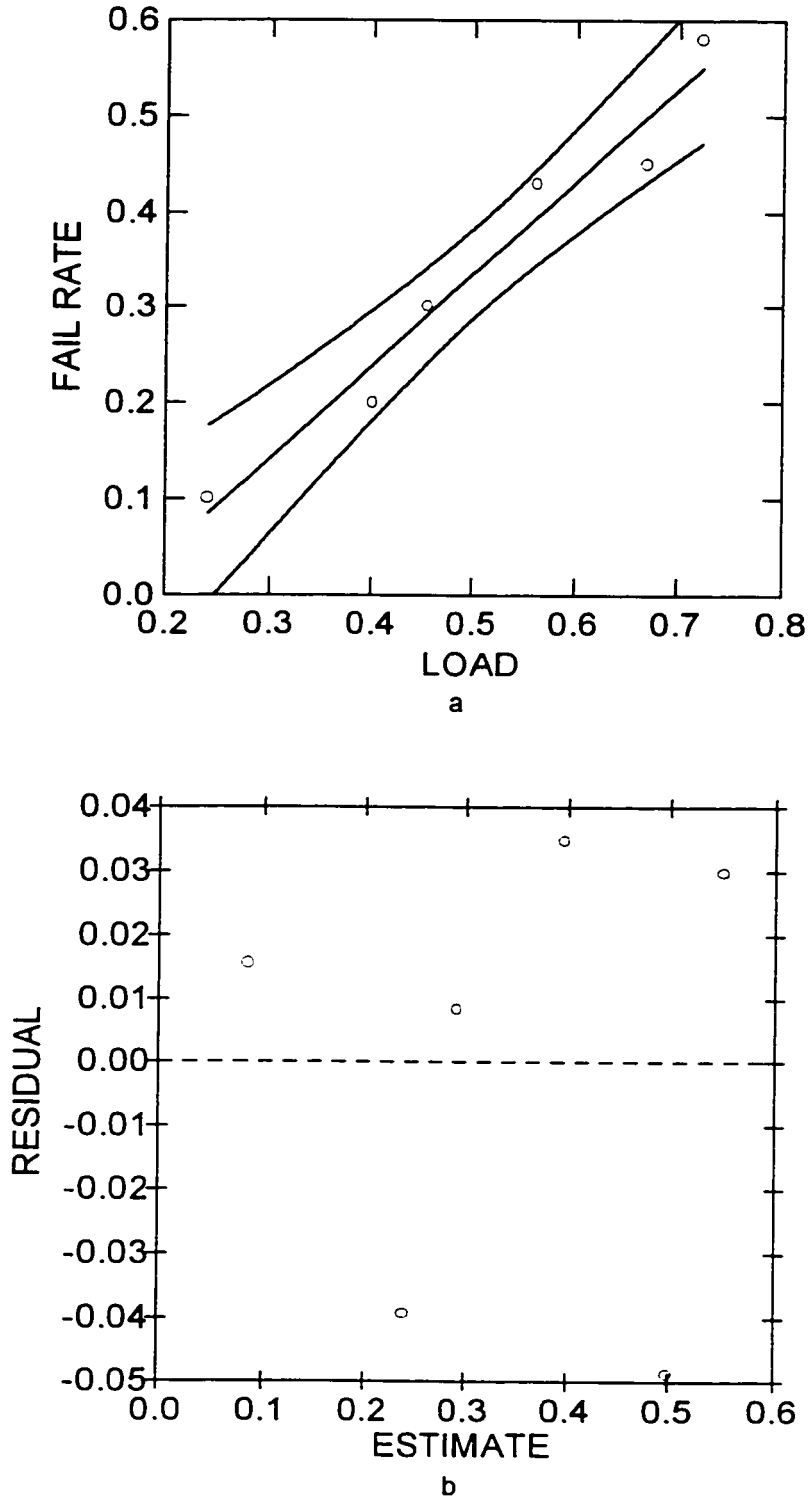



Figure 6.33 Best-fit line with 90% confidence ellipse (a), and plot of residuals against expected values (b) for rock 1C (black Senonian), two outliners removed.

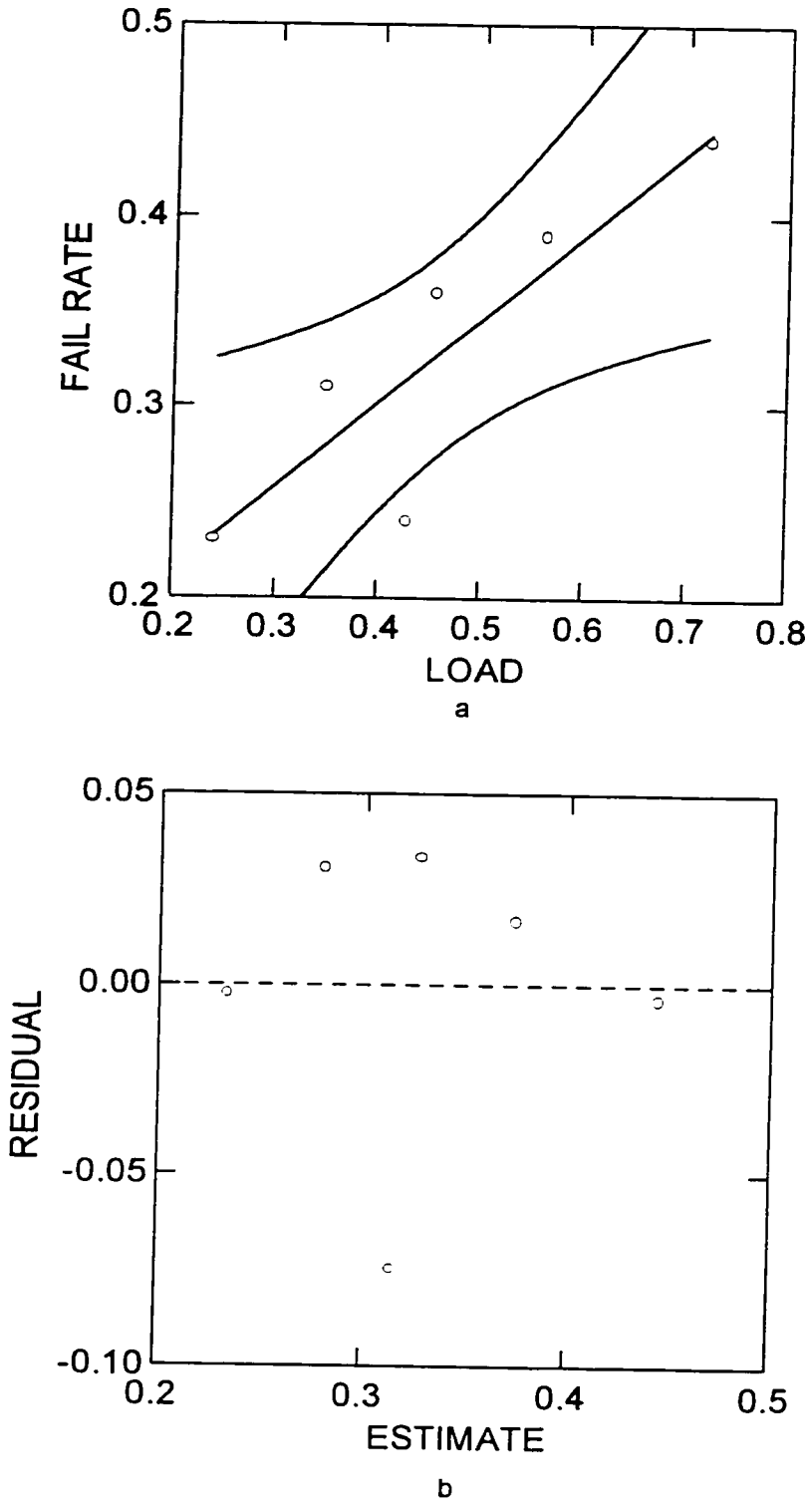
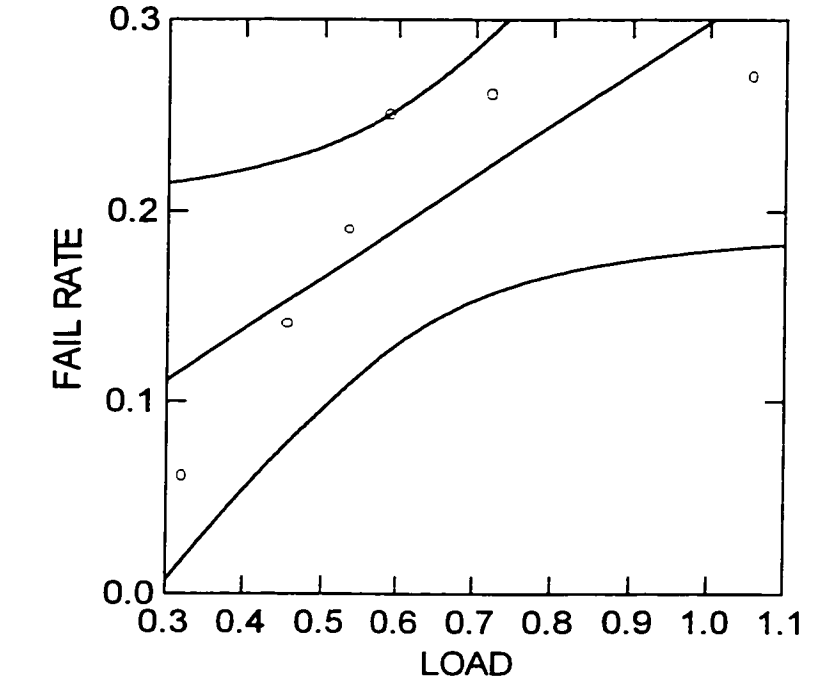
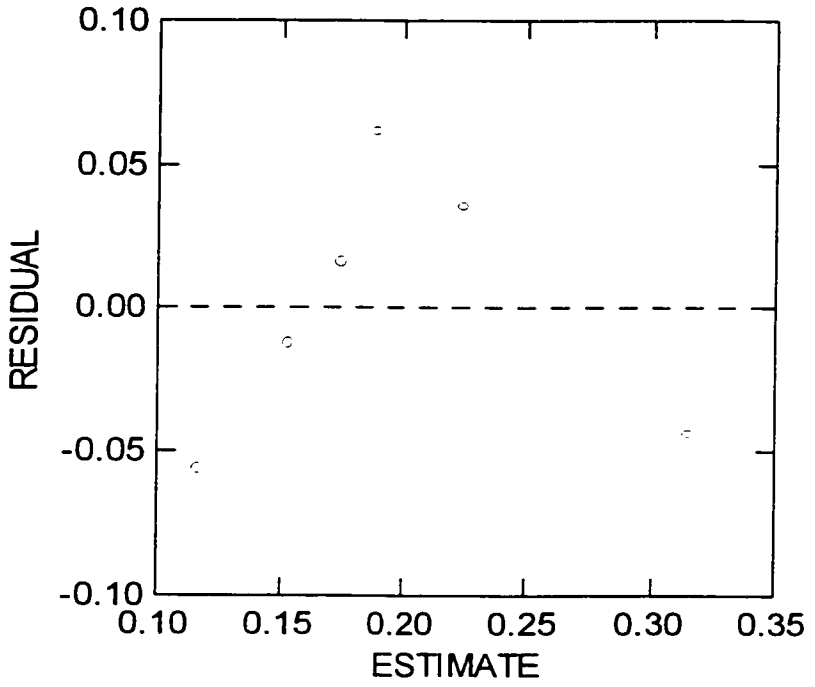



Figure 6.34 Best-fit line with 90% confidence ellipse (a), and plot of residuals against expected values (b) for rock 2A (beige Senonian).

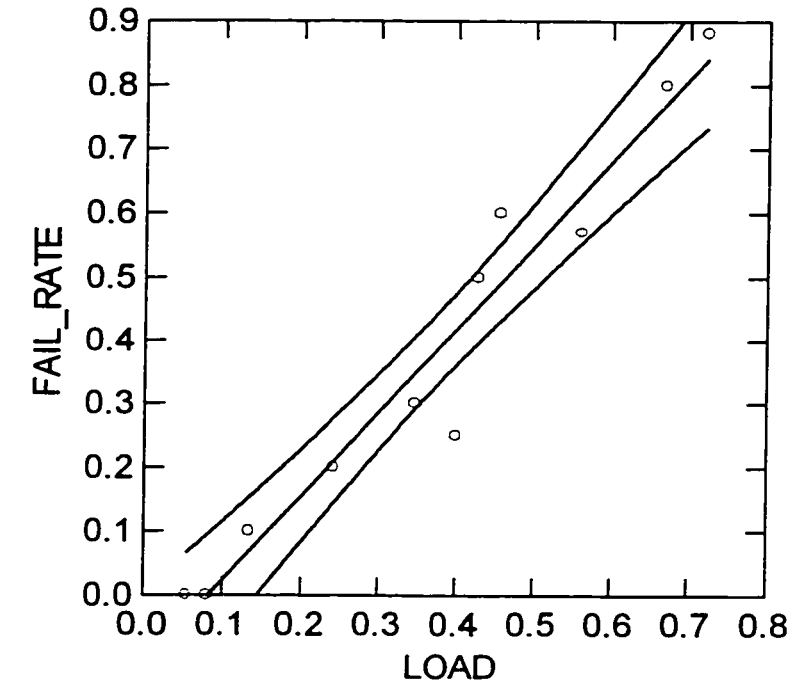



a

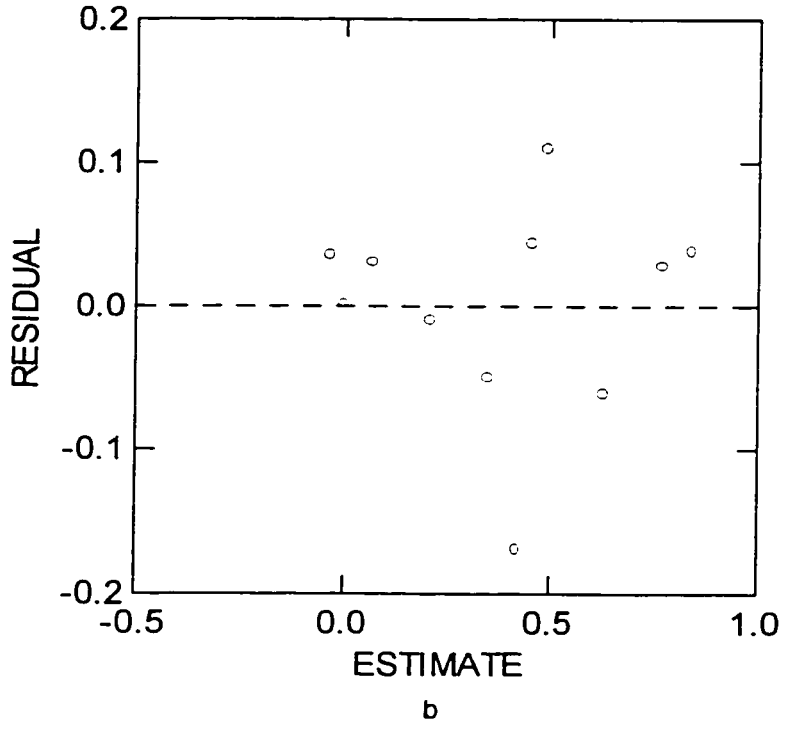



b

Figure 6.35 Best-fit line with 90% confidence ellipse (a), and plot of residuals against expected values (b) for rock 6B (black Senonian).




a




b

Figure 6.36 Best-fit line with 90% confidence ellipse (a), and plot of residuals against expected values (b) for rock 10A (Puy d'Arnac jasper).

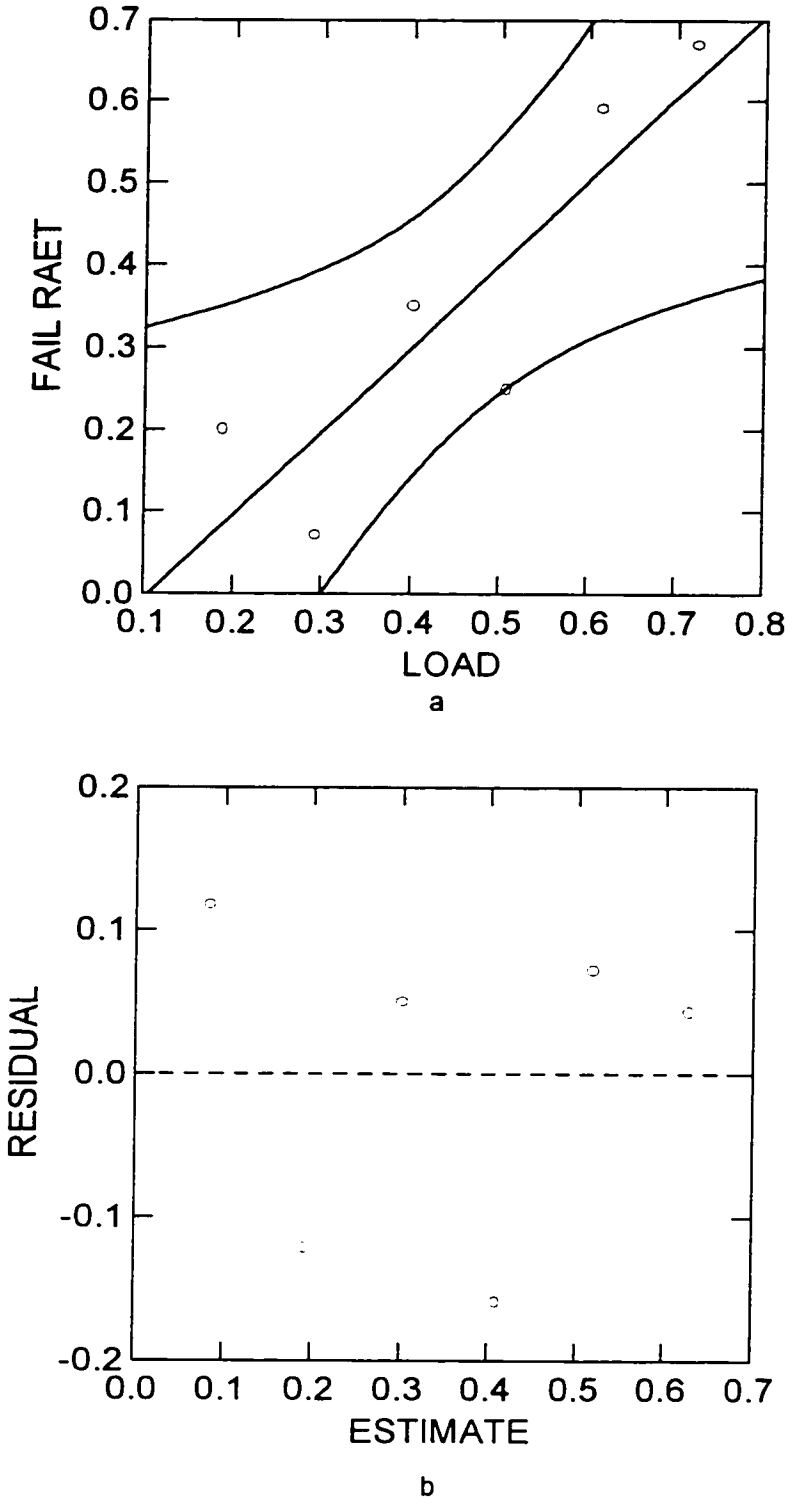



Figure 6.37 Best-fit line with 90% confidence ellipse (a), and plot of residuals against expected values (b) for rock 12A (black Senonian).

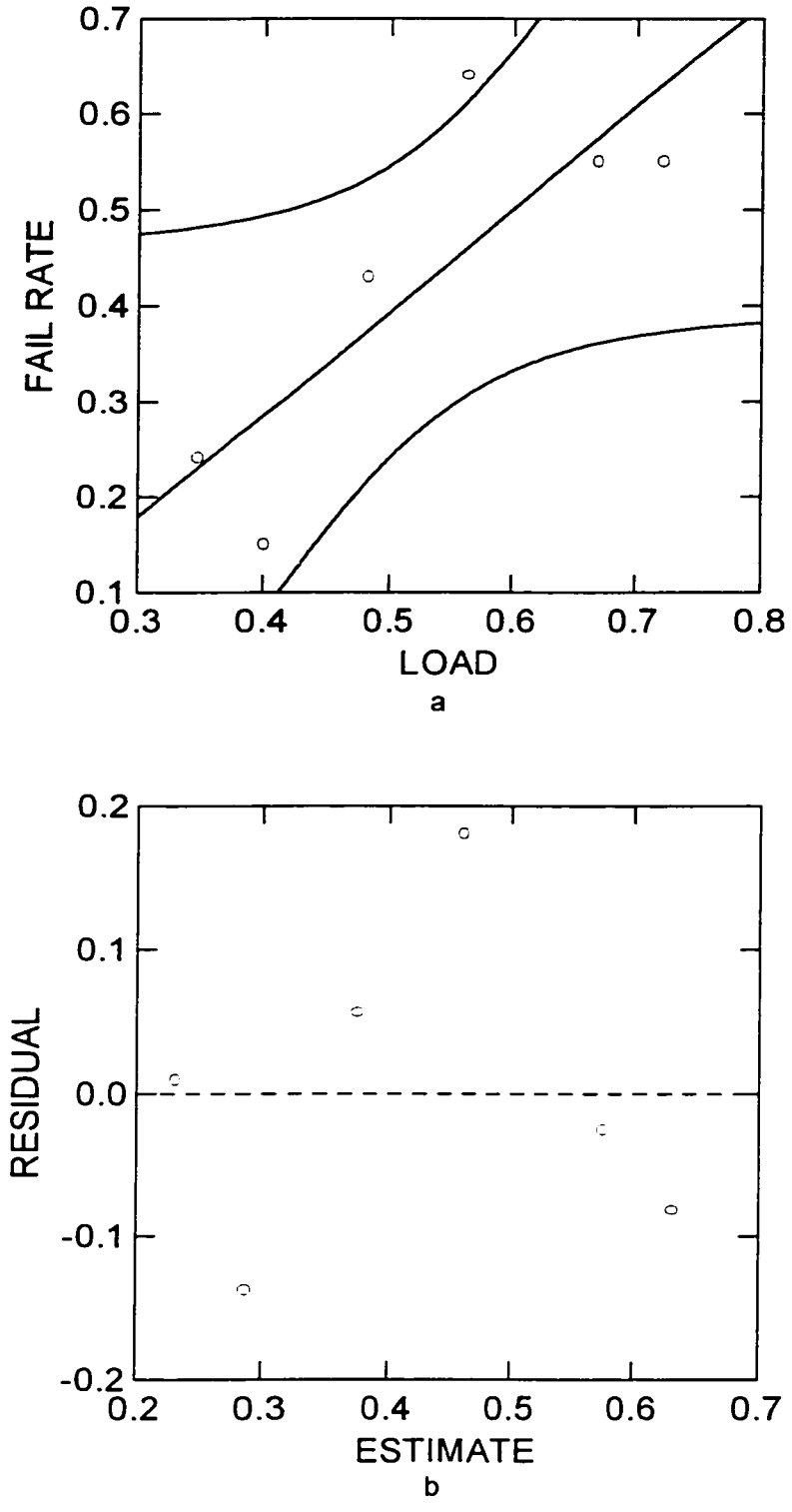



Figure 6.38 Best-fit line with 90% confidence ellipse (a), and plot of residuals against expected values (b) for rock 12A' (black Senonian).

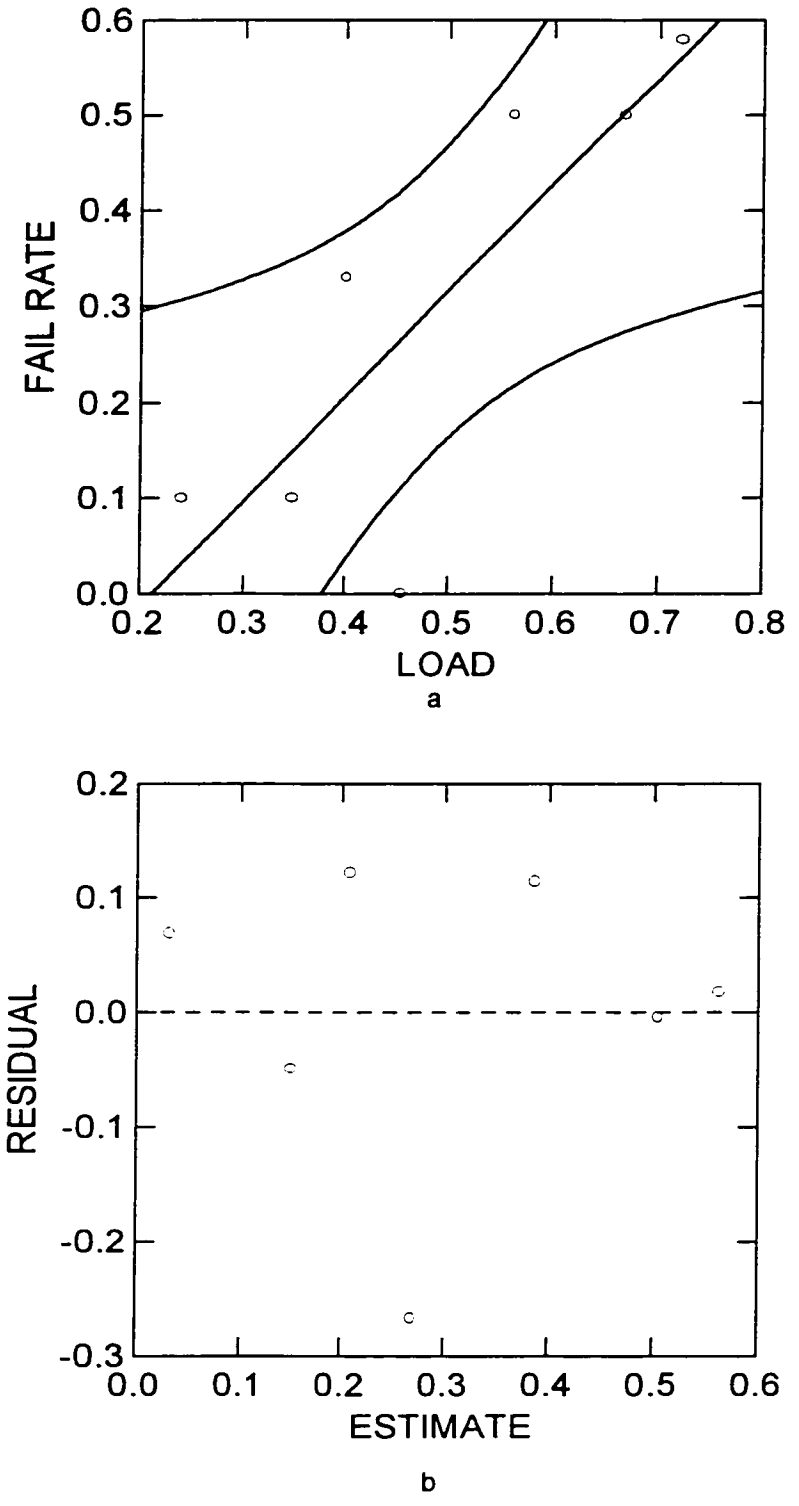



Figure 6.39 Best-fit line with 90% confidence ellipse (a), and plot of residuals against expected values (b) for rock 13A (Bergeracois chert).

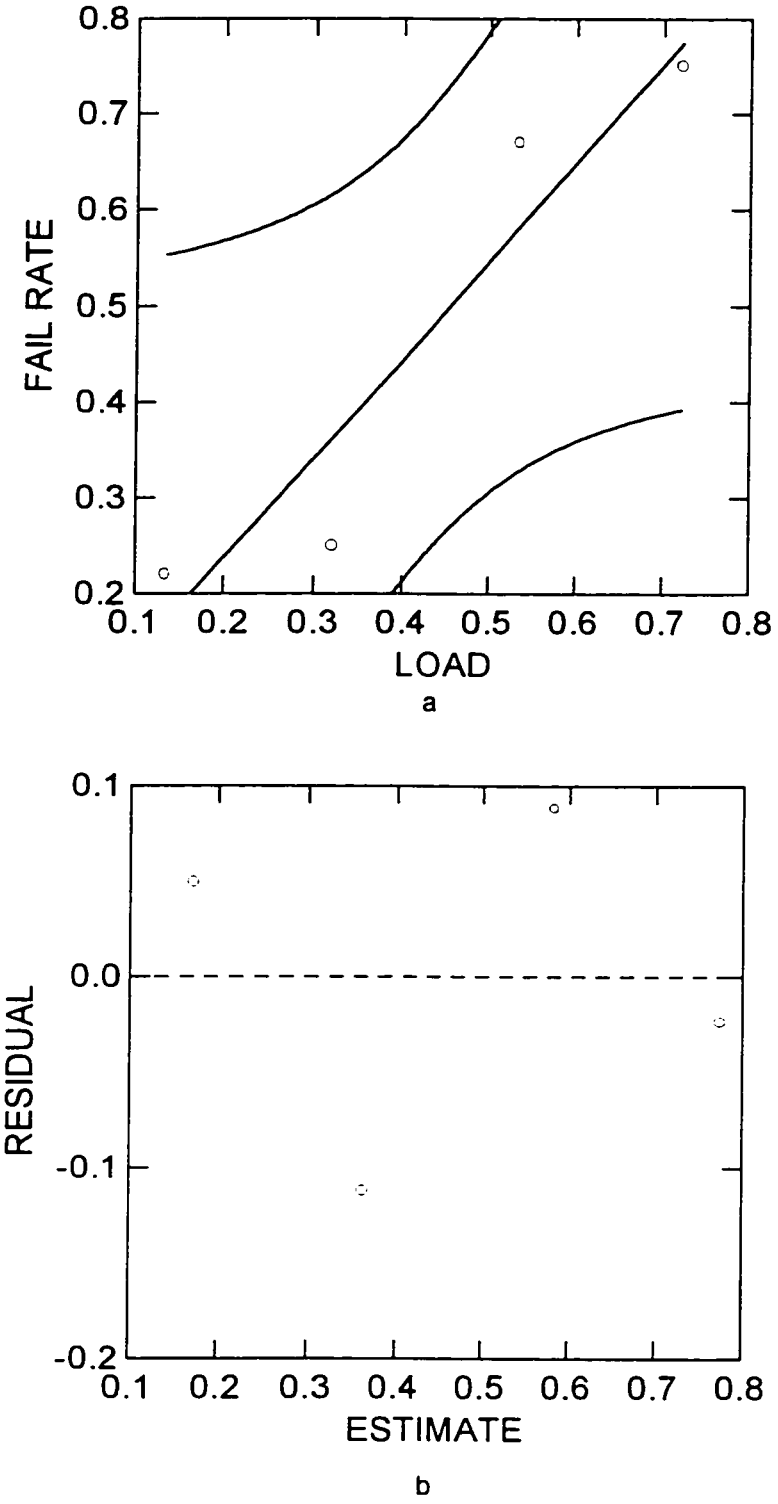



Figure 6.40 Best-fit line with 90% confidence ellipse (a), and plot of residuals against expected values (b) for rock 28 (Mussidan chert).

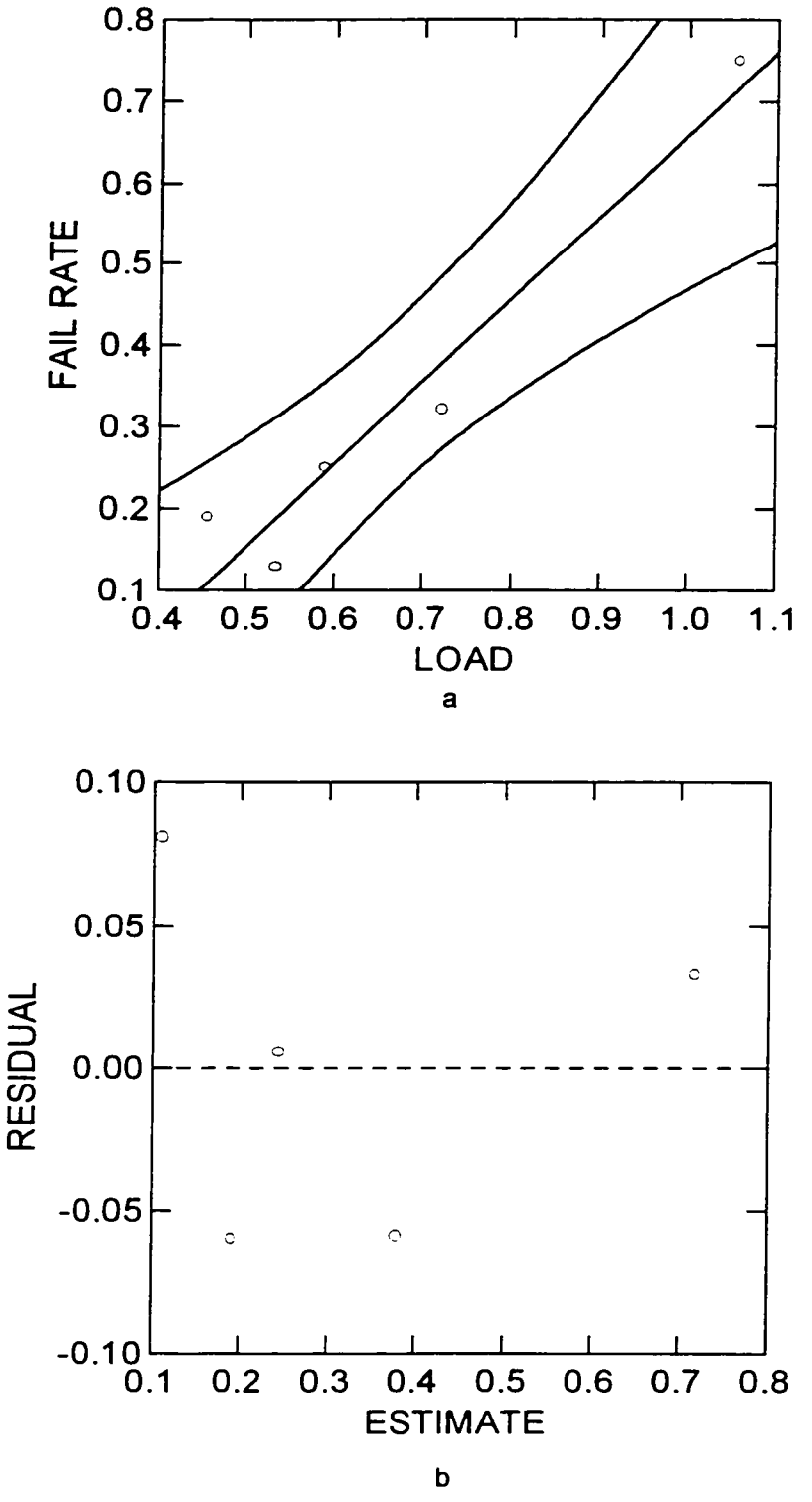



Figure 6.41 Best-fit line with 90% confidence ellipse (a), and plot of residuals against expected values (b) for rock 29 (quartzite).

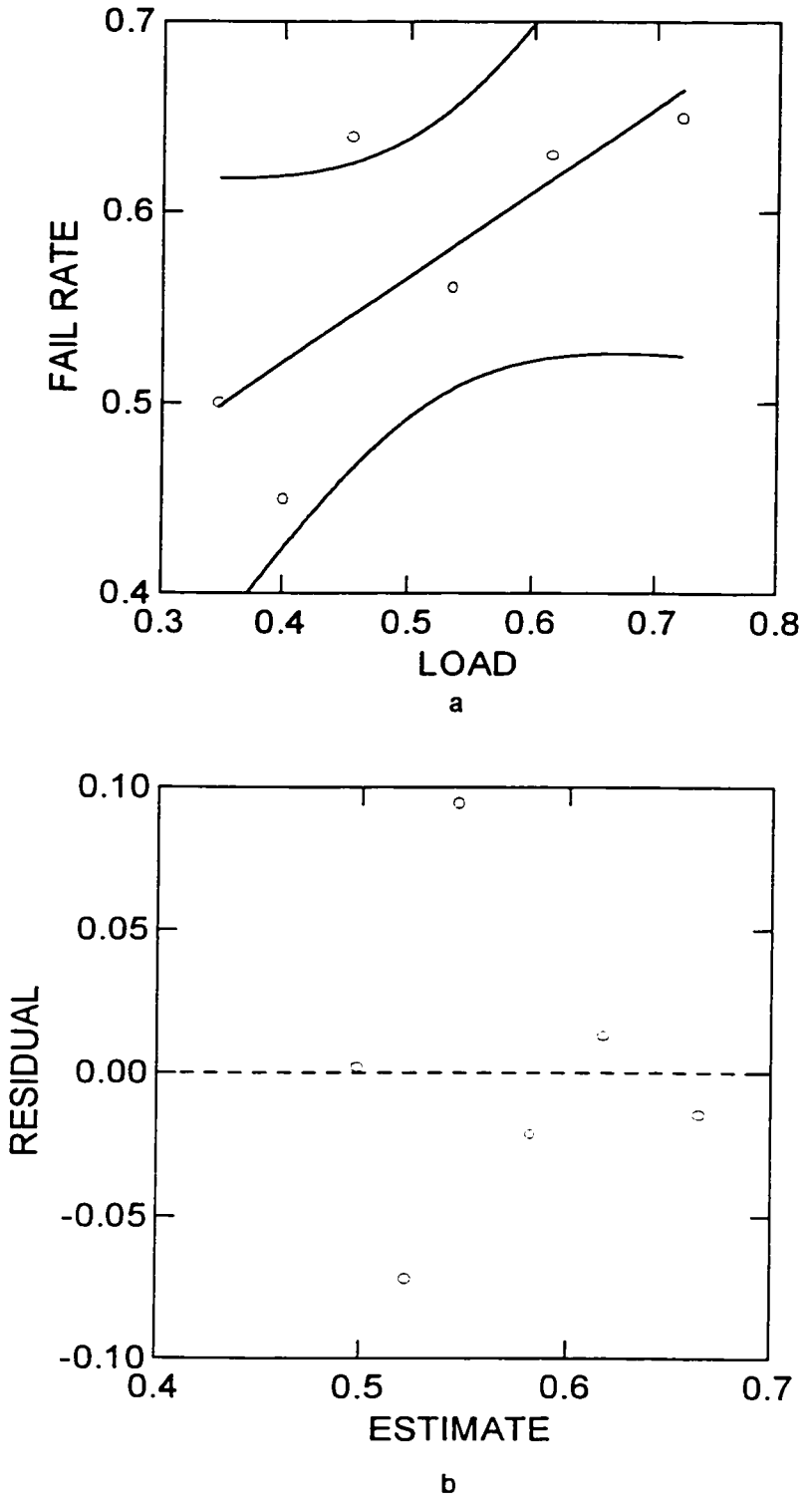



Figure 6.42 Best-fit line with 90% confidence ellipse (a), and plot of residuals against expected values (b) for rock 9D (chalcedony from Graudemagne).

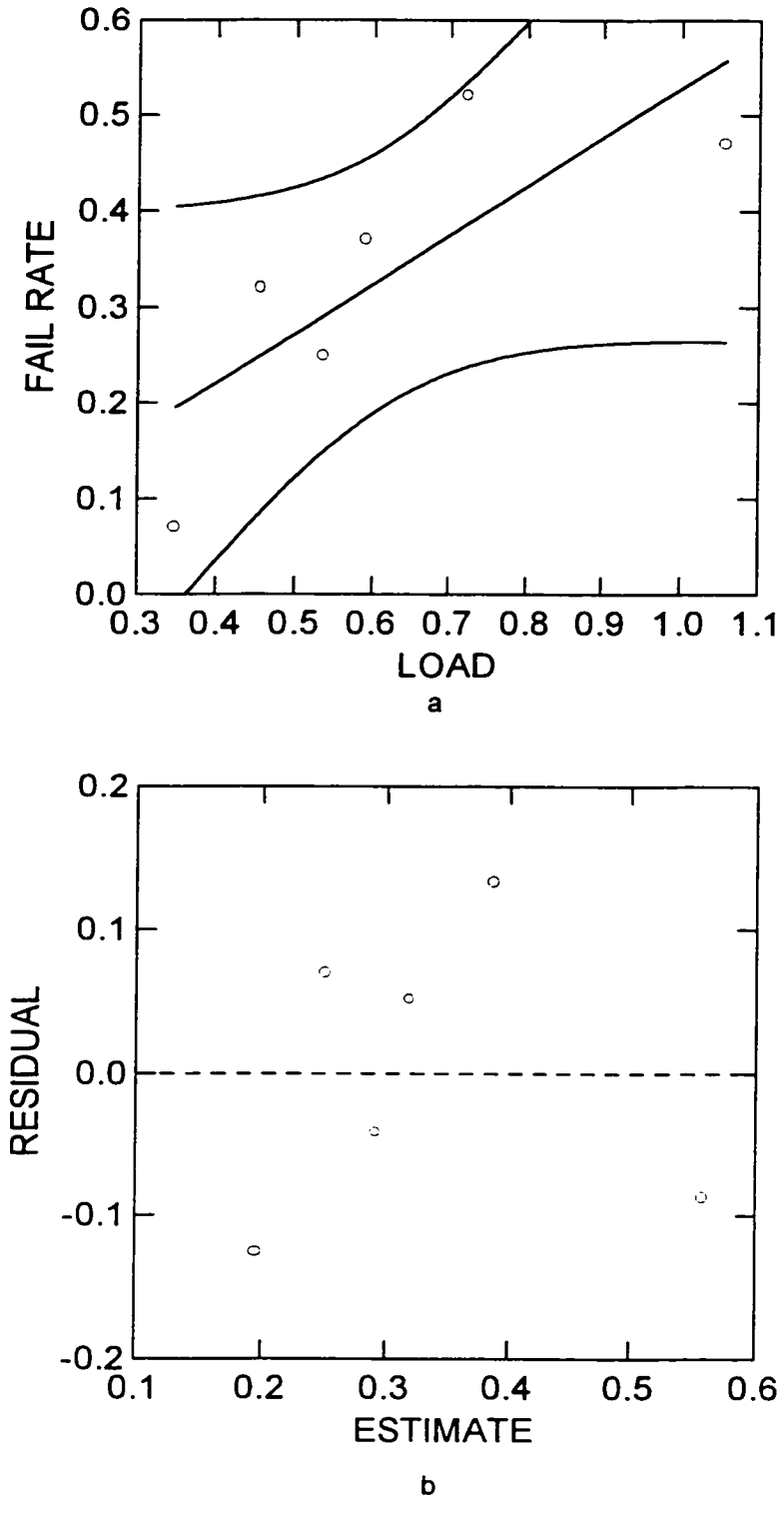
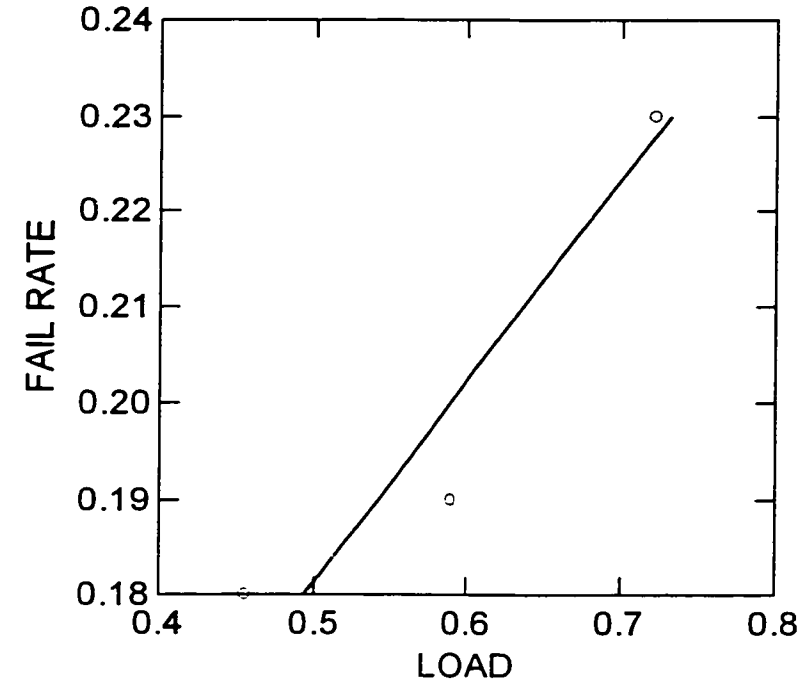
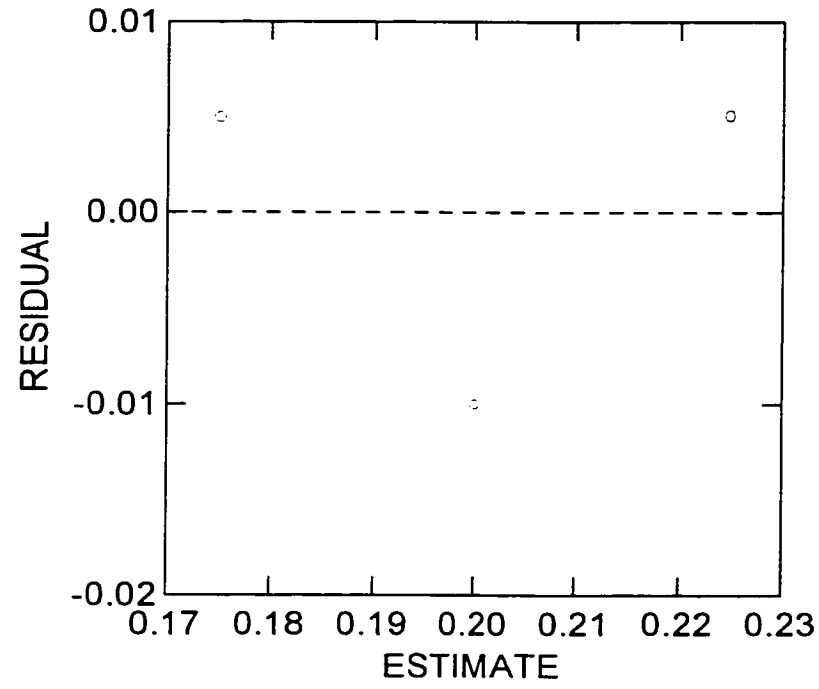



Figure 6.43 Best-fit line with 90% confidence ellipse (a), and plot of residuals against expected values (b) for rock 21D (millstone from Aérodrome de Sarlat-Domme).




a




b

Figure 6.44 Best-fit line with 90% confidence ellipse (a), and plot of residuals against expected values (b) for rock 9G (jasper from Graudemagne).

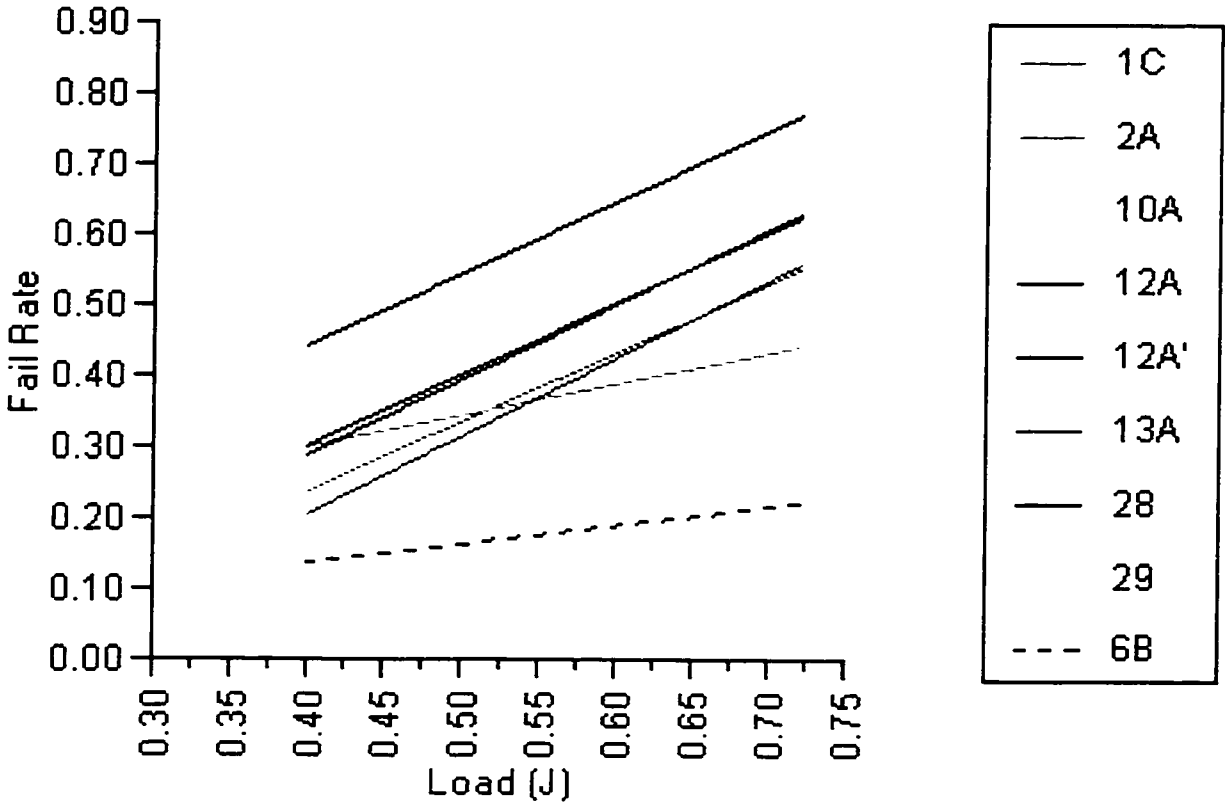



Figure 6.45 Superimposed best-fit lines for the nine rocks with significant Fail Rate/Load regression equations.

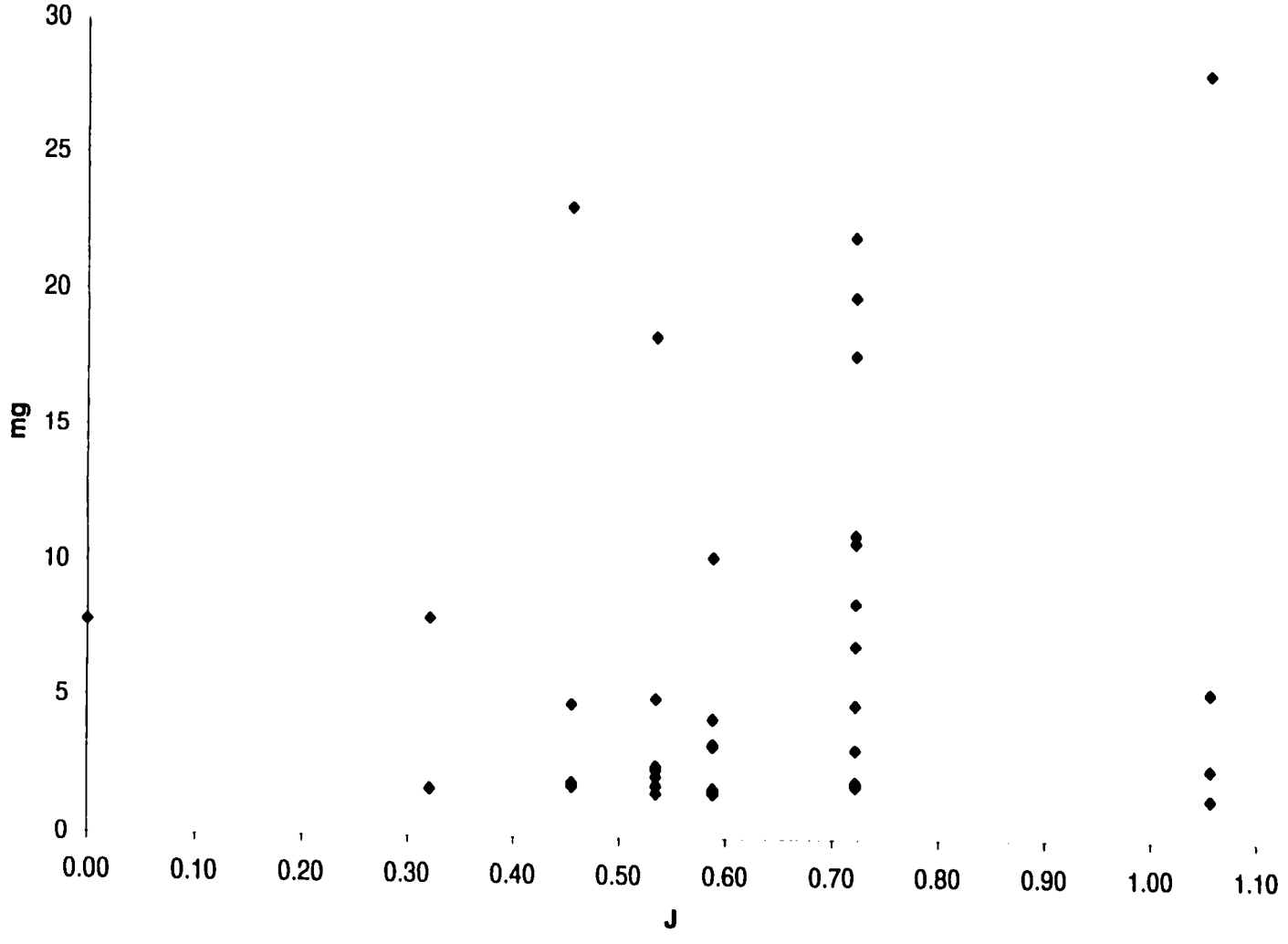



Figure 6.46 Raw weight loss data for rock 6B (black Senonian), excluding the non-failures.

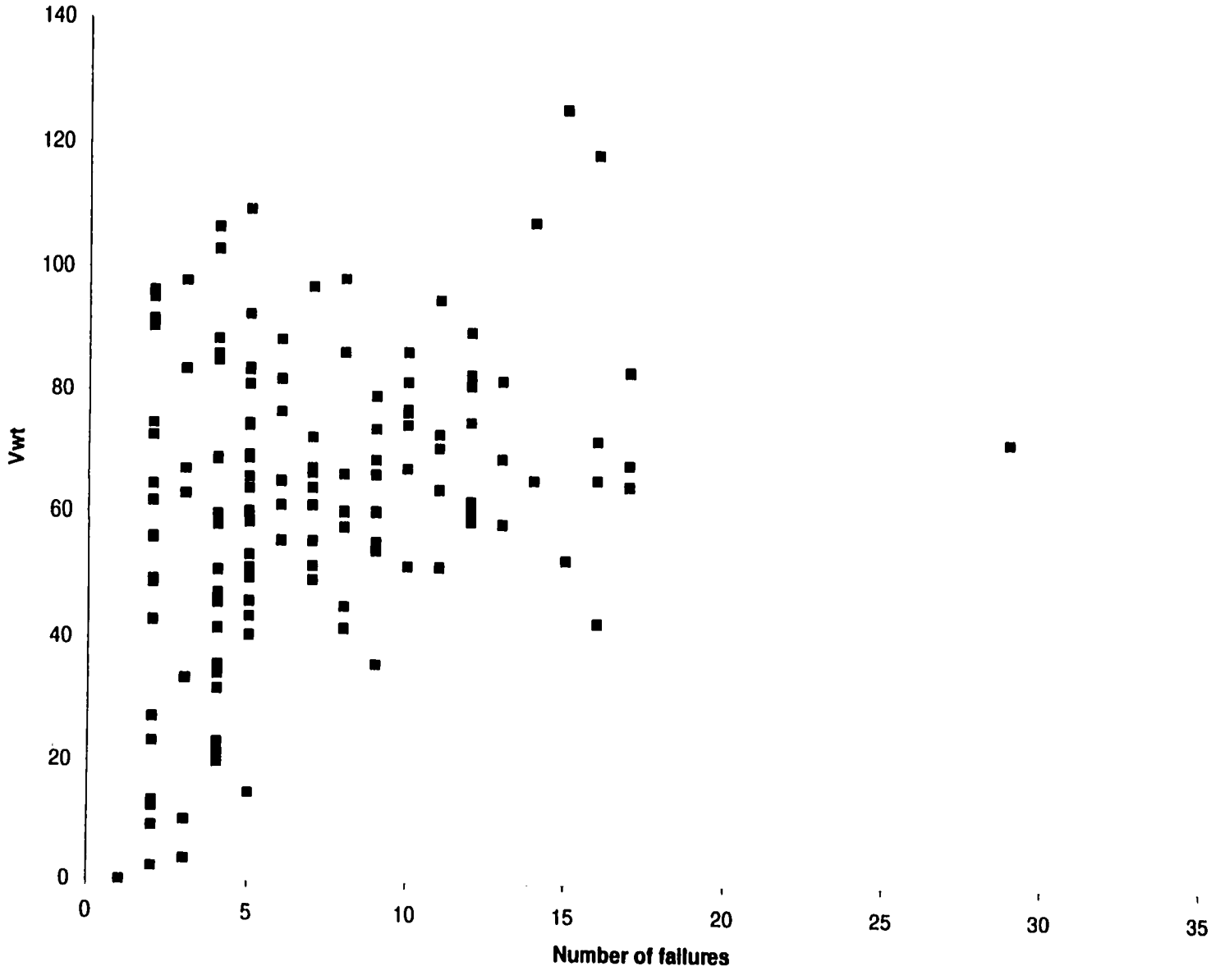



Figure 6.47 $V_{wt}$ values for loads with different sample sizes, from various rocks. Each point represents the value for all trials done at a given load on tiles from a single rock.

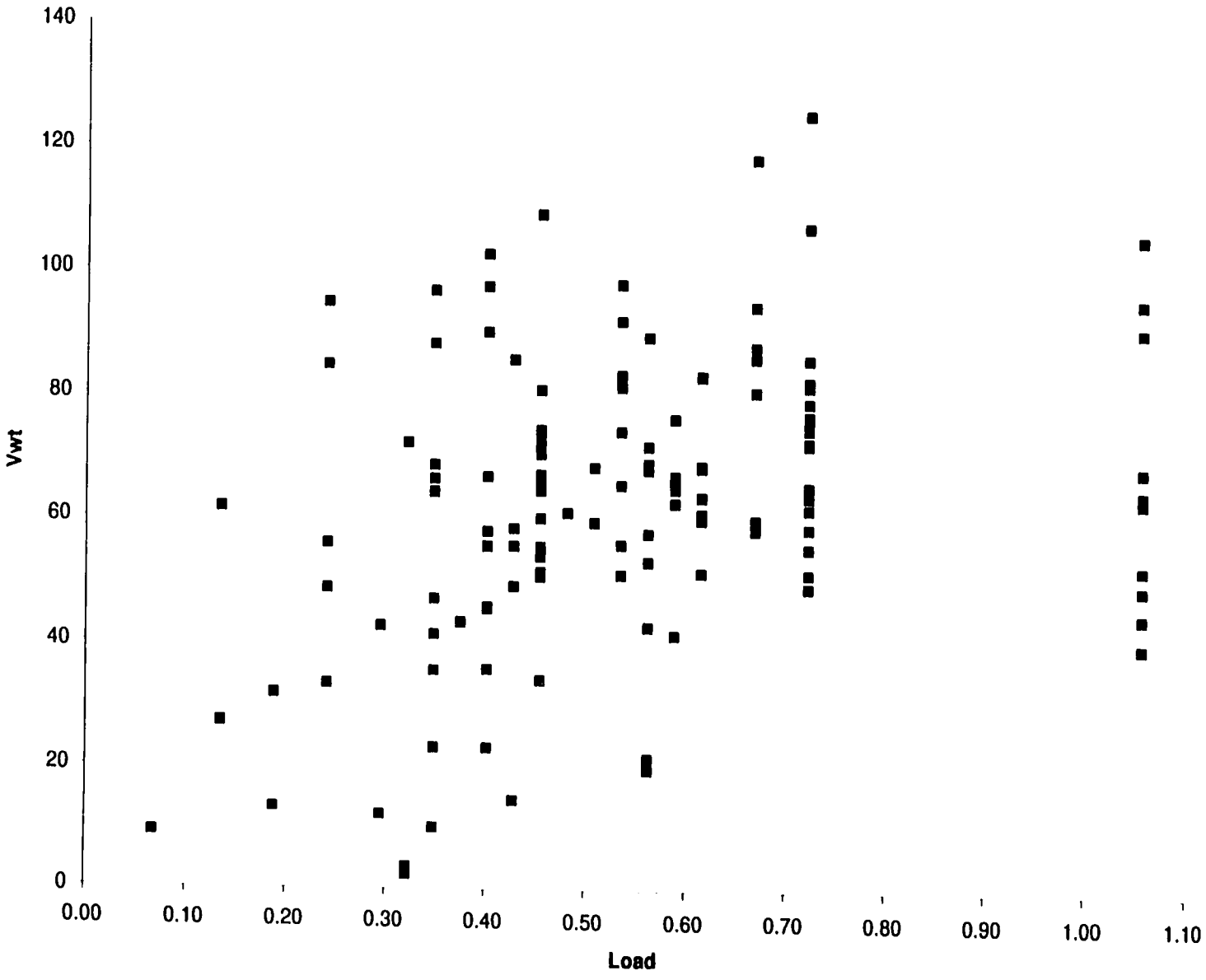



Figure 6.48 $V_{wt}$ values at different loads. Each point represents the value for all trials at the given load, for a given rock. These are the same data as in Figure 6.50, plotted by load instead of by sample size.

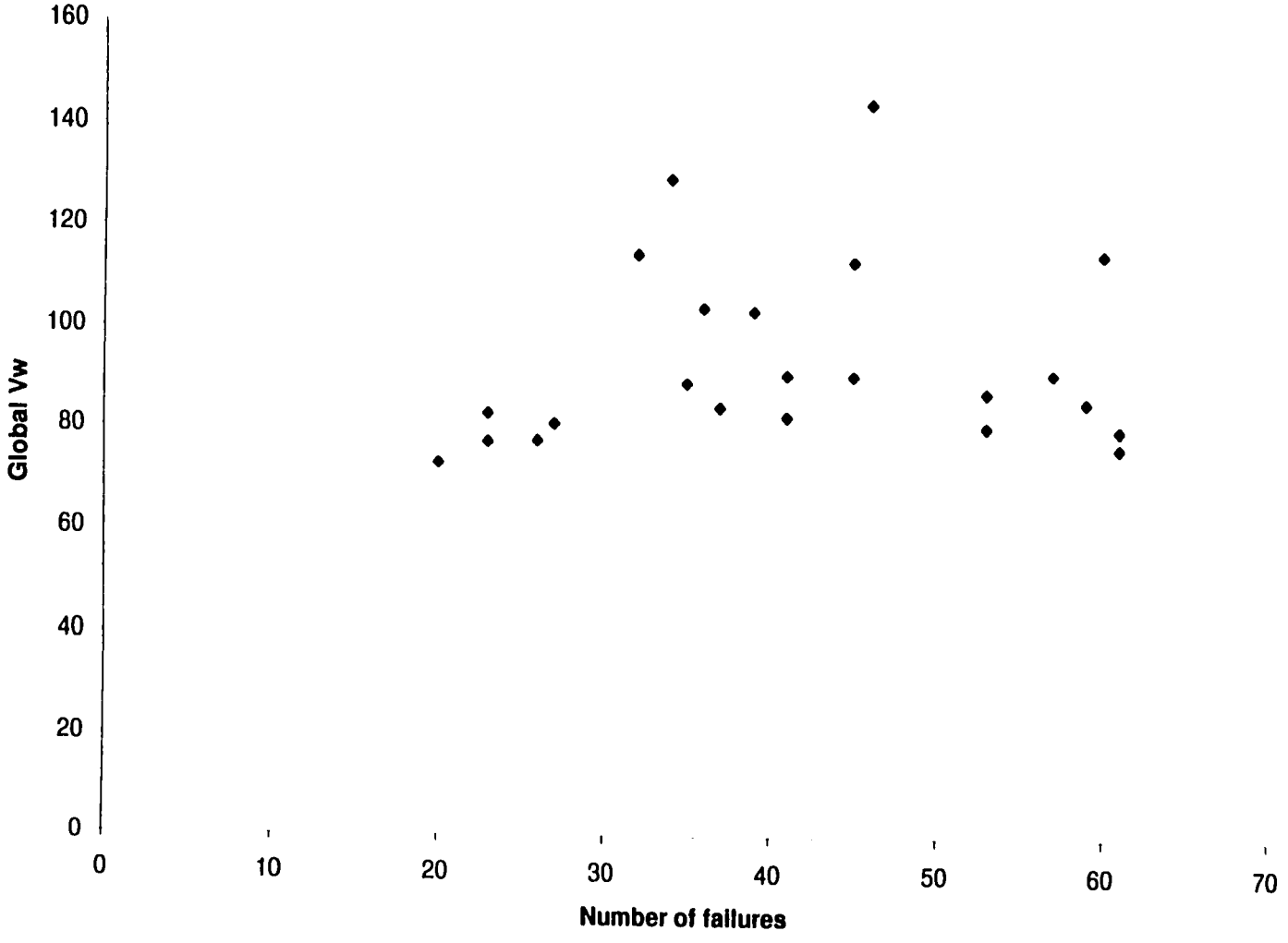



Figure 6.49 Global $V_{wt}$ values (i.e., one value for all trials from each rock), by number of failures.

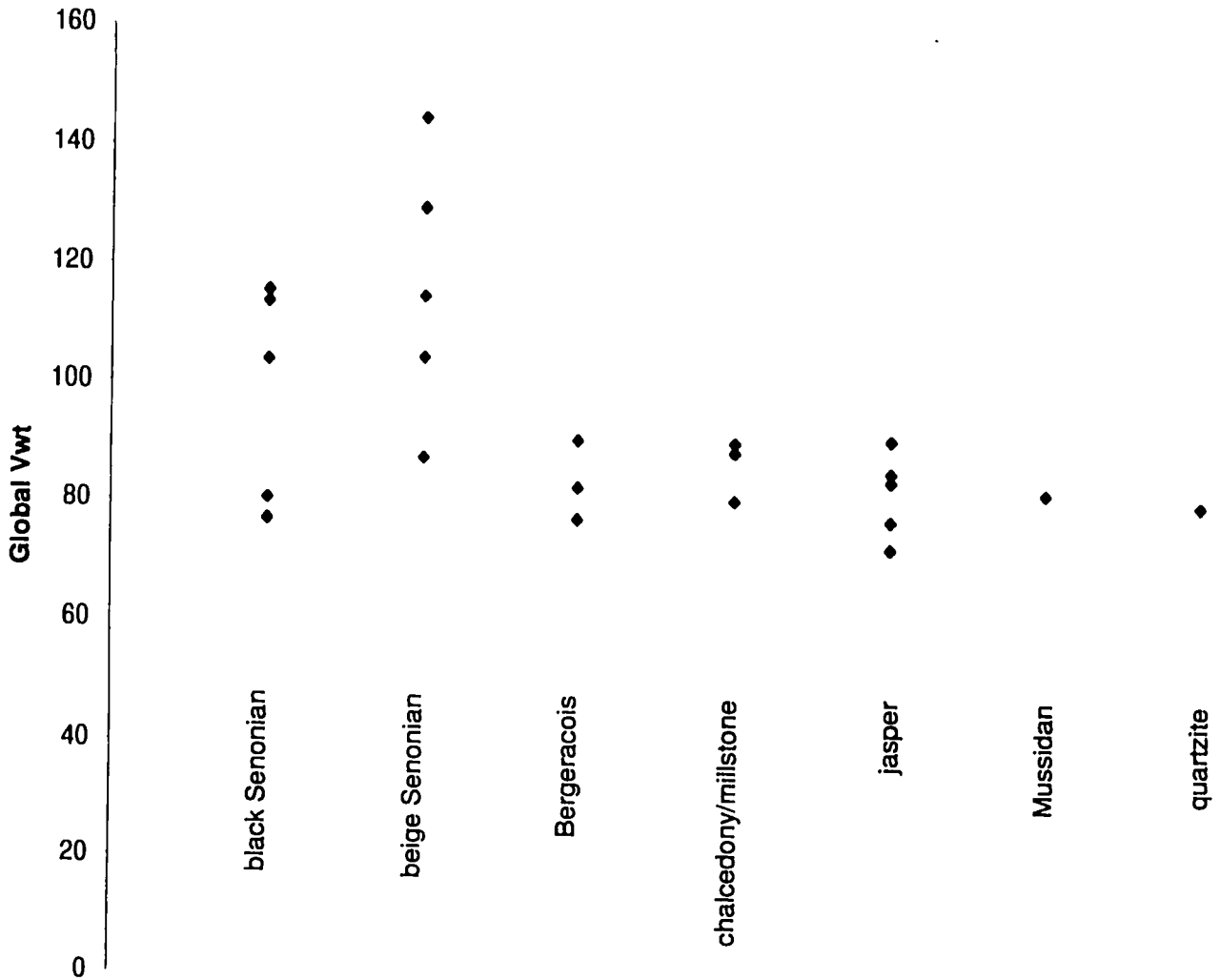



Figure 6.50 Global $V_{wt}$ values by raw material type.

Table 6.1 Results of testing the null hypothesis $\mu_1 = \mu_2$, for flake weight data from Dibble and Pelcin (1995), Table 7. EPA = Exterior platform angle of tested cores. Columns 2 and 3 show mean flake weights ($\bar{x}$) for trials at loads of 0.75 J and 2.76 J, respectively. $t_{calc}$, calculated $t$ value for the difference between columns 2 and 3, based on Welch's approximate t, which accounts for differences in sample variances; $t_{05(2),\upsilon}$ : tabled $t$ value for two-tailed test with $\alpha = .05$ and $\upsilon$ calculated according to Zar (1984:131).

| EPA | $\bar{x}$, 0.75 J | $\bar{x}$, 2.76 J | $t_{calc}$ | $t_{05(2),\upsilon}$ |
|---|---|---|---|---|
| 55° | 12.68 g | 8.28 g | 1.369 | 2.145 |
| 65° | 15.07 g | 23.18 g | 1.062 | 2.262 |
| 75° | 30.26 g | 58.91 g | 2.860 | 1.062 |

Table 6.2 Data used by McCutcheon (1997) to calculate "average fail load" for heated and unheated specimens; this example is for the rock labeled "Pop Ck 2X2 032".

| | Heated specimens | | | Unheated specimens | | |
|---|---|---|---|---|---|---|
| Drop Height (m) | F | NF | Total | F | NF | Total |
| 0.02 | 3 | 0 | 3 | | | |
| 0.04 | 3 | 0 | 3 | | | |
| 0.06 | 1 | 2 | 3 | | | |
| 0.08 | 3 | 0 | 3 | 0 | 3 | 3 |
| 0.10 | 2 | 1 | 3 | 0 | 3 | 3 |
| 0.12 | 2 | 1 | 3 | 3 | 0 | 3 |
| 0.14 | 2 | 1 | 3 | 2 | 1 | 3 |
| 0.16 | 2 | 1 | 3 | 0 | 2 | 2 |
| 0.18 | | | | 1 | 3 | 4 |
| 0.20 | | | | 3 | 2 | 5 |
| 0.22 | | | | 2 | 3 | 5 |
| 0.23 | | | | 1 | 1 | 2 |
| 0.24 | | | | 3 | 0 | 3 |
| 0.26 | | | | 2 | 1 | 3 |
| 0.28 | | | | 2 | 1 | 3 |
| 0.30 | | | | 2 | 0 | 2 |
| Total | 18 | 6 | 24 | 21 | 20 | 41 |
| "Avg. failure load" | .084 | | | .214 | | |

Table 6.3 Values for the kinetic energy equation, KE = $mgh$.

| Terms of the equation | Values |
|---|---|
| $m_p$ = mass of pendulum | 0.1365 kg |
| $g$ = acceleration of gravity | 9.8 m/s$^2$ |
| $m_p * g$ | 1.3375 |
| $m_{br}$ = mass of brass ring attachment | 0.0625 kg |
| $m_{p+br}$ = mass of pendulum with brass ring attached | 0.1990 |
| $m_{p+br} * g$ | 1.9503 |

Table 6.4 Load at selected drop heights of the PIT.

| Drop height (h) | Load = KE = $m_p*gh$ | Load with brass ring attached = KE = $m_{p+br}*gh$ |
|---|---|---|
| 0.02 m (lowest setting) | 0.027 J | 0.039 J |
| 0.12 m | 0.1605 | 0.234 J |
| 0.24 m | 0.321 J | 0.468 J |
| 0.40 m | 0.535 J | 0.780 J |
| 0.54 m (highest setting) | 0.722 J | 1.053 J |

Table 6.5 Cross-tabulation of Trial Order (per tile) and Observed Result from PIT tests, with likelihood-ratio chi-square test results, for selected tiles and selected rocks.

| Trial order (on tile face) | Total no. of observed fails | Total no. of observed non-fails | Grand total | LR chi-square and exact p-value (df = 3) |
|---|---|---|---|---|
| Rock: 12A' (black Senonian) | | | | $G^2 = 0.3113$ $p = 1.000$ |
| 1 | 4 | 7 | 11 | |
| 2 | 4 | 7 | 11 | |
| 3 | 3 | 8 | 11 | |
| 4 | 4 | 7 | 11 | |
| | 15 | 29 | 44 | |
| Rock: 10A (jasper) | | | | $G^2 = 0.1720$ $p = .2114$ |
| 1 | 2 | 6 | 8 | |
| 2 | 4 | 5 | 9 | |
| 3 | 5 | 4 | 9 | |
| 4 | 1 | 8 | 9 | |
| | 12 | 23 | 35 | |
| Rock: 10C (jasper) | | | | $G^2 = 6.911$ $p = 0.0961$ |
| 1 | 7 | 5 | 12 | |
| 2 | 6 | 6 | 12 | |
| 3 | 6 | 6 | 12 | |
| 4 | 1 | 9 | 10 | |
| | 20 | 26 | 46 | |
| Rock: 9A (chalcedony) | | | | $G^2 = 0.6002$ $p = 1.000$ |
| 1 | 2 | 6 | 8 | |
| 2 | 2 | 6 | 8 | |
| 3 | 2 | 6 | 8 | |
| 4 | 1 | 7 | 8 | |
| | 7 | 20 | 32 | |
| Rock: 13B (Bergeracois silex) | | | | $G^2 = 3.231$ $p = .4676$ |
| 1 | 1 | 7 | 8 | |
| 2 | 2 | 8 | 10 | |
| 3 | 1 | 4 | 5 | |
| 4 | 2 | 1 | 3 | |
| | 6 | 20 | 26 | |

Table 6.5, continued.

| Trial order (on tile face) | Total no. of observed fails | Total no. of observed non-fails | Grand total | LR chi-square and exact p-value (df = 3) |
|---|---|---|---|---|
| Rock: 2C (beige Senonian) | | | | $G^2 = 3.231$<br>$p = .4676$ |
| 1 | 1 | 2 | 3 | |
| 2 | 1 | 3 | 4 | |
| 3 | 3 | 2 | 5 | |
| 4 | 1 | 3 | 4 | |
| 5 | | 1 | 1 | |
| Grand Total | 6 | 11 | 17 | |
| Rock: 1B (black Senonian) | | | | $G^2 = 3.536$<br>$p = 0.3323$ |
| 1 | 9 | 19 | 28 | |
| 2 | 6 | 23 | 29 | |
| 3 | 13 | 17 | 30 | |
| 4 | 6 | 12 | 18 | |
| Grand Total | 34 | 71 | 105 | |

Table 6.6 Observed PIT results (F/NF) for multiple trials on each of two tiles.

| Trial (first to last) | Observed results | |
|---|---|---|
| Tile number: | 9A 25 | 12A 13 |
| 1 | NF | F |
| 2 | F | F |
| 3 | F | NF |
| 4 | NF | F |
| 5 | F | F |
| 6 | F | F |
| 7 | F | F |
| 8 | F | F |
| 9 | F | NF |
| 10 | NF | F |
| 11 | F | F |
| 12 | F | NF |
| 13 | F | NF |
| 14 | NF | NF |
| 15 | F | F |
| 16 | F | - |
| 17 | NF | NF |
| 18 | NF | F |
| 19 | NF | NF |
| 20 | - | F |
| 21 | F | NF |
| 22 | F | NF |
| 23 | F | NF |
| 24 | NF | F |

Table 6.7 Comparison of observed PIT results and results determined by t-tests for 125 trials from one rock (#9A, chalcedony/millstone).

| | observed result | | |
|---|---|---|---|
| t-test result | F | NF | Total |
| F | 55 | 19 | 74 |
| NF | 20 | 31 | 51 |
| Total | 75 | 50 | 125 |

Table 6.8 Mean, standard deviation (sd), and sample size (n) for tile side length, for trials resulting in failure (F) versus trials resulting in non-failure (NF). "CI overlap": whether confidence intervals of F mean and NF mean overlap.

| Rock | RM type | F mean | F sd | F n | NF mean | NF sd | NF n | CI overlap |
|---|---|---|---|---|---|---|---|---|
| 1C | RM 1 | **20.37** | 0.32 | 47 | 20.14 | 0.38 | 53 | yes |
| 12A' | RM 1 | **20.26** | 0.20 | 44 | 19.78 | 0.32 | 59 | yes |
| 12A | RM 1 | **19.44** | 0.67 | 52 | 19.09 | 0.93 | 43 | yes |
| 1B | RM 1 | 19.18 | 0.41 | 66 | **19.33** | 0.34 | 86 | yes |
| 2A | RM 2 | **19.06** | 0.78 | 28 | 18.45 | 1.45 | 16 | yes |
| 11A | RM 2 | 18.45 | 0.69 | 41 | **19.57** | 0.40 | 98 | no |
| 11A' | RM 2 | 17.41 | 1.44 | 20 | **18.09** | 1.00 | 34 | yes |
| 13A | RM 3 | 17.06 | 0.31 | 45 | **17.32** | 0.33 | 55 | yes |
| 13B | RM 3 | **14.35** | 0.55 | 10 | 14.43 | 0.38 | 25 | yes |
| 10A | RM 5 | **19.27** | 0.72 | 40 | 19.21 | 0.75 | 35 | yes |

Table 6.9 Mean, standard deviation (sd), and sample size (n) for tile side thickness, for trials resulting in failure (F) versus trials resulting in non-failure (NF). "CI overlap", whether confidence intervals of F mean and NF mean overlap.

| Rock | RM type | F mean | F sd | F n | NF mean | NF sd | NF n | CI overlap |
|---|---|---|---|---|---|---|---|---|
| 12A | RM 1 | **5.27** | 0.13 | 54 | 5.15 | 0.11 | 41 | yes |
| 1C | RM 1 | **5.24** | 0.11 | 30 | 5.15 | 0.09 | 44 | yes |
| 12A' | RM 1 | **5.14** | 0.12 | 45 | 5.07 | 0.09 | 65 | yes |
| 1B | RM 1 | **4.98** | 0.12 | 51 | 4.97 | 0.12 | 57 | yes |
| 11A' | RM 2 | **5.23** | 0.34 | 21 | 5.19 | 0.25 | 35 | yes |
| 2A | RM 2 | **5.18** | 0.07 | 28 | 5.11 | 0.07 | 20 | yes |
| 11A | RM 2 | **5.16** | 0.19 | 41 | 5.11 | 0.07 | 98 | yes |
| 13A | RM 3 | 5.09 | 0.10 | 42 | **5.12** | 0.10 | 58 | yes |
| 13B | RM 3 | 5.04 | 0.10 | 42 | **5.20** | 0.10 | 36 | yes |
| 10A | RM 5 | 5.03 | 0.19 | 31 | **5.46** | 0.22 | 28 | no |

Table 6.10 Mean, standard deviation (sd), and sample size (n) for tile side heights (height of tile's upper edge above vice, in mm), for trials resulting in failure (F) versus trials resulting in non-failure (NF). "CI overlap", whether confidence intervals of F mean and NF mean overlap.

| Rock | RM type | F mean | F sd | F n | NF mean | NF sd | NF n | CI overlap |
|---|---|---|---|---|---|---|---|---|
| 1C | RM 1 | 6.16 | 0.08 | 47 | **6.19** | 0.09 | 53 | yes |
| 12A' | RM 1 | 6.09 | 0.06 | 44 | **6.11** | 0.07 | 58 | yes |
| 1B | RM 1 | 5.88 | 0.07 | 29 | **6.07** | 0.08 | 36 | no |
| 11A' | RM 2 | 5.89 | 0.13 | 12 | **6.01** | 0.10 | 22 | yes |
| 13A | RM 3 | **6.16** | 0.07 | 38 | 6.09 | 0.08 | 53 | yes |
| 13B | RM 3 | **6.05** | 0.09 | 44 | 6.03 | 0.12 | 40 | yes |
| 9A | RM 4 | **6.66** | 0.08 | 6 | 6.61 | 0.13 | 14 | yes |
| 10A | RM 5 | **5.99** | 0.09 | 45 | 5.96 | 0.05 | 57 | yes |

Table 6.11 Mean, standard deviation (sd), and sample size (n) for point of impact (PI = distance between point of impact and upper tile edge, in mm), for trials resulting in failure (F) versus trials resulting in non-failure (NF). "CI overlap", whether confidence intervals of F mean and NF mean overlap.

| Rock | RM type | F mean | F sd | F n | NF mean | NF sd | NF n | CI overlap |
|---|---|---|---|---|---|---|---|---|
| 12A | RM 1 | **1.84** | 0.13 | 6 | 1.80 | 0.11 | 17 | yes |
| 12A' | RM 1 | **1.36** | 0.09 | 38 | 1.13 | 0.09 | 24 | no |
| 14B | RM 2 | **1.76** | 0.11 | 40 | 1.74 | 0.13 | 30 | yes |
| 13B | RM 3 | **1.78** | 0.11 | 31 | 1.71 | 0.18 | 13 | yes |
| 26 | RM 3 | 1.45 | 0.13 | 32 | **1.66** | 0.13 | 38 | yes |
| 18B | RM 4 | 1.73 | 0.09 | 35 | **1.83** | 0.09 | 47 | yes |
| 9D | RM 4 | 1.73 | 0.06 | 64 | **1.80** | 0.11 | 30 | yes |

Table 6.12 Mean, standard deviation (sd), and sample size (n) for tile edge angles, for trials resulting in failure (F) versus trials resulting in non-failure (NF). "CI overlap", whether confidence intervals of F mean and NF mean overlap.

| Rock | RM type | F mean | F sd | F n | NF mean | NF sd | NF n | CI overlap |
|---|---|---|---|---|---|---|---|---|
| 10C | RM 5 | 89.97 | 0.54 | 43 | **90.15** | 0.53 | 39 | yes |
| 12A' | RM 1 | 90.01 | 0.41 | 28 | **90.56** | 0.24 | 50 | yes |
| 1B | RM 1 | 90.00 | 0.42 | 55 | **90.04** | 0.48 | 57 | yes |
| 2A | RM 2 | **90.33** | 0.61 | 30 | 89.78 | 0.54 | 18 | yes |
| 9A | RM 4 | **91.75** | 0.49 | 2 | 90.02 | 0.69 | 22 | no |

Table 6.13 Specifications for PIT test parameters. All valid trials reported here meet these parameters.

| Parameter | Acceptable range |
|---|---|
| tile side length | 13-20 mm |
| tile side thickness | 4.6-5.6 mm |
| height of tile edge above vice | 5.7-6.4 mm |
| point of impact (position below tile edge) | 0.9-2.1 mm |
| tile edge angle | 88° - 92° |

Table 6.14 Rocks tested with the pendulum impact tester.

| ID | lieu-dit | RM | Age | ID number (Demars 1982) | Map No. | Lambert coordinates | | Nature of occurrence | Weight (kg) |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | E | N | | |
| 1B | la Froumagie | 1 | Santonian | KH 39 | 1935 | 504.5 | 3310.9 | road cut (rockface) (p) | >2.3 |
| 1C | la Froumagie | 1 | Santonian | KH 39 | 1935 | 504.5 | 3310.9 | road cut (rockface) (p) | 1.67 |
| 2A | Grand Bonnet | 2 | Santonian | KG 78 | 1935 | 498.4 | 3313.6 | field (s) | 2.22 |
| 2C | Grand Bonnet | 2 | Santonian | KG 78 | 1935 | 498.4 | 3313.6 | field (s) | 2.76 |
| 6B | la Rouquette | 1 | Coniacian | - | 1936 | 495.1 | 3293.4 | railway cut (rockface) (p) | 0.63 |
| 9A | Graudemagne | 4 | Tertiary | MH 3 | 2037 | 516.2 | 3279.9 | uncleared forest, road cut (s) | >2.3 |
| 9D | Graudemagne | 4 | Tertiary | MH 3 | 2037 | 516.2 | 3279.9 | uncleared forest, road cut (s) | 0.73 |
| 9E | Graudemagne | 5 | Tertiary | MH 3 | 2037 | 516.2 | 3279.9 | uncleared forest, road cut (s) | 0.17 |
| 9G | Graudemagne | 5 | Tertiary | MH 3 | 2037 | 516.2 | 3279.9 | uncleared forest, road cut (s) | 0.34 |
| 10A | Puy d'Arnac | 5 | Tertiary | KI 4 | 2135 | 555.9 | 3302.4 | cleared forest (s) | 1.17 |
| 10C | Puy d'Arnac | 5 | Tertiary | KI 4 | 2135 | 555.9 | 3302.4 | cleared forest (s) | 0.33 |
| 11A | Limeuil | 2 | Senonian | - | 1936 | 485.6 | 3287.8 | river gravel (s) | 1.41 |
| 11A' | Limeuil | 2 | Senonian | - | 1936 | 485.6 | 3287.8 | river gravel (s) | 0.46 |
| 12A | Badefols-sur-Dordogne | 1 | Campanian | LG 86 | 1936 | 477.9 | 3283.8 | road cut (rockface) (p) | 1.33 |
| 12A' | Badefols-sur-Dordogne | 1 | Campanian | LG 86 | 1936 | 477.9 | 3283.8 | road cut (rockface) (p) | 1.85 |
| 13A | Creysse | 3 | Tertiary | - | 1836 | 459.0 | 3285.8 | pasture (s) | >2.3 |
| 13B | Creysse | 3 | Tertiary | - | 1836 | 459.0 | 3285.8 | pasture (s) | 0.35 |
| 14B | la Malartrie | 2 | Coniacian | - | 2036 | 507.6 | 3281.2 | natural rockface (p) | 2.37 |
| 18B | Lac de Couffé | 4 | Tertiary | MG 5 | 1937 | 487.8 | 3278.1 | field (s) | >2.3 |
| 21D | Aérodrome de Sarlat | 4 | Tertiary | - | 2037 | 514.7 | 3277.7 | ditch/road bank (s) | 1.75 |
| 26 | - | 3 | Tertiary | - | - | - | | - | 0.74 |
| 28 | Goudou | 19 | - | - | 2036 | 501.6 | 3281.6 | river gravel (s) | 0.58 |
| 29 | Mussidan | 8 | Tertiary | - | 1835 | 445.2 | 3305.9 | forested hillside (s) | 0.96 |

Table 6.15 Analysis of variance from simple linear regressions of fail rate on load for twelve rocks tested with the PIT.

1C-black Senonian

| | Sum-of-Squares | df | Mean-Square | F-ratio | *p* |
|---|---|---|---|---|---|
| Regression | 0.000 | 1 | 0.000 | 0.000 | 0.995 |
| Residual | 0.306 | 6 | 0.051 | | |

1C, minus two outliers

| | Sum-of-Squares | df | Mean-Square | F-ratio | *p* |
|---|---|---|---|---|---|
| Regression | 0.150 | 1 | 0.150 | 94.679 | 0.001 |
| Residual | 0.006 | 4 | 0.002 | | |

6B- black Senonian

| | Sum-of-Squares | df | Mean-Square | F-ratio | *p* |
|---|---|---|---|---|---|
| Regression | 0.024 | 1 | 0.024 | 8.859 | 0.041 |
| Residual | 0.011 | 4 | 0.003 | | |

12A-black Senonian

| | Sum-of-Squares | df | Mean-Square | F-ratio | *p* |
|---|---|---|---|---|---|
| Regression | 0.207 | 1 | 0.207 | 13.088 | 0.022 |
| Residual | 0.063 | 4 | 0.016 | | |

12A'-black Senonian

| | Sum-of-Squares | df | Mean-Square | F-ratio | *p* |
|---|---|---|---|---|---|
| Regression | 0.126 | 1 | 0.126 | 8.138 | 0.046 |
| Residual | 0.062 | 4 | 0.015 | | |

2A- beige Senonian

| | Sum-of-Squares | df | Mean-Square | F-ratio | *p* |
|---|---|---|---|---|---|
| Regression | 0.027 | 1 | 0.027 | 13.727 | 0.021 |
| Residual | 0.008 | 4 | 0.002 | | |

13A-Bergeracois

| | Sum-of-Squares | df | Mean-Square | F-ratio | *p* |
|---|---|---|---|---|---|
| Regression | 0.222 | 1 | 0.222 | 10.381 | 0.023 |
| Residual | 0.107 | 5 | 0.021 | | |

Table 6.15, continued

10A-Puy d'Arnac jasper

| | Sum-of-Squares | df | Mean-Square | F-ratio | *p* |
|---|---|---|---|---|---|
| Regression | 0.349 | 1 | 0.349 | 41.831 | 0.001 |
| Residual | 0.050 | 6 | 0.008 | | |

28-Mussidan

| | Sum-of-Squares | df | Mean-Square | F-ratio | *p* |
|---|---|---|---|---|---|
| Regression | 0.206 | 1 | 0.206 | 17.598 | 0.052 |
| Residual | 0.023 | 2 | 0.012 | | |

9D-chalcedony

| | Sum-of-Squares | df | Mean-Square | F-ratio | *p* |
|---|---|---|---|---|---|
| Regression | 0.019 | 1 | 0.019 | 5.223 | 0.084 |
| Residual | 0.015 | 4 | 0.004 | | |

21D- millstone

| | Sum-of-Squares | df | Mean-Square | F-ratio | *p* |
|---|---|---|---|---|---|
| Regression | 0.081 | 1 | 0.081 | 6.413 | 0.064 |
| Residual | 0.050 | 4 | 0.013 | | |

9G- Graudemagne jasper

| | Sum-of-Squares | df | Mean-Square | F-ratio | *p* |
|---|---|---|---|---|---|
| Regression | 0.001 | 1 | 0.001 | 8.218 | 0.214 |
| Residual | 0.001 | 1 | 0.000 | | |

Table 6.16 Regression formulae and correlation statistics for selected rocks, based on regression of Fail Rate against Load. Formula predicts fail rate (y) at a given load (x). Raw material (RM) types: 1 = black Senonian; 2 = beige Senonian; 3 = Bergeracois; 5 = jasper; 8 = Mussidan; 19 = quartzite.

| Rock | RM type | n | Formula | Multiple R | adj. $R^2$ |
|---|---|---|---|---|---|
| 1C* | 1 | 6 | y = (0.968)x – 0.149 | .980 | .949 |
| 2A | 2 | 6 | y = (0.440)x + 0.126 | .880 | .718 |
| 6B | 1 | 6 | y = (0.269)x + 0.030 | .830 | .689 |
| 10A | 5 | 8 | y = (1.319)x – 0.119 | .935 | .854 |
| 12A | 1 | 6 | y = (1.017)x – 0.107 | .875 | .707 |
| 12A' | 1 | 6 | y = (1.072)x – 0.142 | .819 | .588 |
| 13A | 3 | 7 | y = (1.104)x – 0.235 | .822 | .610 |
| 28 | 19 | 4 | y = (1.025)x + 0.034 | .948 | .847 |
| 29 | 8 | 5 | y = (1.010)x - 0.350 | .939 | .919 |

* 1C results after the deletion of two outliers.

Table 6.17 Fail Rate Predictability. Frequencies and percents of rocks within each raw material type that showed a significant $R^2$ when Fail Rate is regressed against Load.

| Rock type | No. rocks tested | No. with statistically significant $R^2$ | Percent |
|---|---|---|---|
| black Senonian | 5 | 4 | 80% |
| beige Senonian | 5 | 1 | 20% |
| Bergeracois | 3 | 1 | 33% |
| chalced./millstone | 4 | 0 | 0% |
| jasper | 4 | 1 | 25% |
| Mussidan | 1 | 1 | 100% |
| quartzite | 1 | 1 | 100% |

Table 6.18 Minimum 100% Fail Load for nine rocks with significant regression statistics when Fail Rate is regressed against Load.

| Rock | RM Type | Minimum 100% Fail Load |
|---|---|---|
| 6B | black Senonian | 3.606 J |
| 2A | beige Senonian | 1.986 J |
| 29 | Mussidan | 1.337 J |
| 1C* | black Senonian | 1.187 J |
| 13A | Bergeracois | 1.119 J |
| 12A | black Senonian | 1.088 J |
| 12A' | black Senonian | 1.065 J |
| 28 | quartzite | 0.942 J |
| 10A | jasper | 0.848 J |

* Two outliers were excluded from 1C.

Table 6.19 Rankings of nine rocks by Minimum 100% Fail Load and inverse ranking by Fail Rate at Load = .67-.72, with Spearman's rank-order correlation statistic.

| Rock | Minimum 100% Fail Load | Rank | Fail Rate at Load = .67-.72 | Inverse Rank |
|---|---|---|---|---|
| 6B | 3.606 | 1 | 0.26 | 1 |
| 2A | 1.986 | 2 | 0.44 | 3 |
| 29 | 1.337 | 3 | 0.32 | 2 |
| 1C | 1.187 | 4 | 0.47 | 4 |
| 13A | 1.119 | 5 | 0.54 | 5 |
| 12A | 1.088 | 6 | 0.67 | 7 |
| 12A' | 1.065 | 7 | 0.55 | 6 |
| 28 | 0.942 | 8 | 0.75 | 8 |
| 10A | 0.848 | 9 | 0.83 | 9 |

rho = 0.952, $p$ = .002

Table 6.20 Spearman's rank-order correlation coefficients for comparisons of rock ranks by Fail Rate (FR), for trials carried out at different load ranges.

| Comparison | n | rho | $p$ |
|---|---|---|---|
| Rank by FR at Load = 0.40-0.46 J and Rank by FR at Load = 0.54-0.59 J | 21 | 0.428 | $.10 > p > .05$ |
| Rank by FR at Load = 0.54-0.59 J and Rank by FR at Load = 0.67-0.72 J | 22 | 0.584 | $.01 > p > .005$ |

Table 6.21 Global mean weight loss (WL), global standard error on weight Loss ($S_x$ WL), and global coefficient of variation ($V_{wt}$) for all weight loss values at all loads combined, for each rock tested. N = total number of trials, all loads combined.

| Rock | Raw Material Type | N | Global Mean WL | Global $S_x$ WL | Global $V_{wt}$ |
|---|---|---|---|---|---|
| 1B | black Senonian | 61 | 21.66 | 17.45 | 80.58 |
| 1C | black Senonian | 60 | 27.72 | 32.06 | 115.65 |
| 6B | black Senonian | 39 | 6.04 | 6.28 | 103.85 |
| 12A | black Senonian | 45 | 15.37 | 17.49 | 113.80 |
| 12A' | black Senonian | 61 | 30.37 | 23.37 | 76.96 |
| 2A | beige Senonian | 46 | 20.03 | 29.02 | 144.91 |
| 2C | beige Senonian | 53 | 22.30 | 19.55 | 87.70 |
| 11A | beige Senonian | 34 | 13.37 | 17.36 | 129.89 |
| 11A' | beige Senonian | 32 | 17.38 | 19.98 | 114.92 |
| 14B | beige Senonian | 36 | 18.72 | 19.57 | 104.50 |
| 9A | chalcedony/millstone | 35 | 11.50 | 10.26 | 89.21 |
| 9D | chalcedony/millstone | 53 | 16.52 | 13.37 | 80.91 |
| 18B | chalcedony/millstone | 37 | 19.61 | 16.57 | 84.46 |
| 21D | chalcedony/millstone | 45 | 9.26 | 8.41 | 90.83 |
| 9E | jasper | 26 | 30.08 | 23.38 | 77.72 |
| 9G | jasper | 20 | 8.93 | 6.53 | 73.14 |
| 10A | jasper | 57 | 33.37 | 30.55 | 91.54 |
| 10C | jasper | 59 | 26.75 | 23.01 | 86.00 |
| 13A | Bergeracois | 23 | 14.77 | 12.25 | 82.92 |
| 13B | Bergeracois | 23 | 14.55 | 11.27 | 77.47 |
| 26 | Bergeracois | 41 | 15.35 | 13.96 | 90.96 |
| 28 | quartzite | 27 | 7.99 | 6.48 | 81.03 |
| 29 | Mussidan | 41 | 26.11 | 21.60 | 82.70 |

# 7

# Discussion

In this chapter, I first briefly compare the results for each assemblage with the predictions of the discontinuity hypothesis, as I outlined them on pp. 77-78. I discuss the many issues that arose during the course of this study, most of which were unforeseen. I also discuss how each issue may have affected my ability to document and interpret variation in raw material use during the period 40-30 kya in France, as a prelude to my exposition of the major conclusions.

**Results: comparison with predictions**

Le Moustier, level H8

The raw material composition of this assemblage does not support a "random walk" model of tool stone acquisition. Black Senonian, Bergeracois, and Jurassic chert are more abundant in the assemblage, while beige Senonian, chalcedony/millstone, quartzite, and basalt are less abundant, than would be expected under such a model. In part, this may result from a heavier reliance on stream gravels rather than primary occurrences, as indicated by the study of cortex attributes. It also appears to be related to fracture properties: black Senonian is far more abundant in assemblages than beige Senonian or chalcedony/millstone, and it is also more predictable. A strategy of minimizing acquisition cost was followed, both in the focus on nearby gravel sources as well as in the rarity or absence of highly predictable non-local raw materials (Bergeracois and Jurassic chert). Because of the highly skewed raw material composition, the partitioning of manufacture phases over space was difficult to study, but it does appear to follow the general pattern in which local rocks were imported as raw blocks, and non-

locals were imported as blanks and/or tools. The skewed raw material distribution also made most of the other predictions difficult to test.

The only evidence of a possible association between manufacture methods and raw materials is the fact that three of the five beige Senonian cores belong to core category 2C, simple flake core with two opposed striking platforms. In Chapter 5, I observed that most beige Senonian cores have two striking surfaces, while most black Senonian cores have only one. I inferred that beige Senonian cores may have been reduced more intensively. However, it is also true that beige Senonian cores weigh more than black Senonian cores. Table 7.1 shows this: the mean weight of the three 2C cores is two to three times as high as that of most black Senonian cores. The three largest cores in the assemblage, all of which weigh over 100 g, are made of beige Senonian chert. It is unlikely that this reflects any difference in the natural sizes of nodules or cobbles, because both black and beige Senonian cherts occur in a very similar size range in the Perigord. This strongly suggests that cores made of beige Senonian were reduced less intensively than those made of black Senonian; I now believe that the number of striking surfaces is a poor measure of core reduction intensity, and I discuss this below.

In sum, there is modest evidence for raw material conservation in this assemblage. That black Senonian dominates the assemblage, even though terrestrial occurrences of that material are about 3 km further away than terrestrial sources of beige Senonian, indicates a preference for the more predictable black variety. The same factor may account for the apparently lower level of core reduction intensity in beige Senonian cores. Finally, the rarity of chalcedony/millstone in the assemblage indicates that the low fail rate predictability of that material precluded its routine use. It is

quite likely that black Senonian, beige Senonian, and chalcedony/millstone were available to the inhabitants of Le Moustier at nearby gravel beds in roughly similar quantities. Thus, it appears that the raw material and technological composition of this assemblage was mostly affected by fracture predictability rather than by source distance or occurrence densities, and that the portability and utility of transported blanks played very small roles or none at all.

Caminade Est, level M3

All six assemblages studied here are dominated by black Senonian chert, with beige Senonian taking a distant second place (by count), but this assemblage represents the extreme, with 306 artifacts of black Senonian and only 14 of beige Senonian (not counting artifacts weighing < 1 g). The raw material composition of this assemblage does not support a "random walk" model of tool stone acquisition. Black Senonian, Jurassic, and jasper are more abundant, while beige Senonian, quartzite, and chalcedony/millstone are less abundant (on a rank order scale) than would be expected under such a model. Basalt and Bergeracois chert are approximately as abundant as predicted under the random walk model.

As expected, the technological composition of raw material types suggests that the manufacture process was partitioned over space. Only basalt, black Senonian, and indeterminate Senonian chert (all local) were imported as cobbles or nodules and reduced at the site. Of two basalt artifacts, one is a chunk and the other is a flaked cobble. The cobble may have been used as a tool or a core; the blanks or retouch flakes struck from it were not recovered. One stream-rolled nodule of Jurassic chert, probably from the nearby Dordogne River, was also brought to the site and reduced, although the core was not recovered. Judging by their technological compositions,

beige Senonian (local) and porcelainite (unknown source) artifacts were also struck from cores that were subsequently carried away. Bergeracois, (non-local) was imported as blanks, retouched or not, as was jasper, which may or may not be non-local. However, two local raw materials—chalcedony/millstone and quartzite—were also imported as tools and/or raw blanks, which indicates that some factor other than acquisition cost was driving the mode of transport.

The low frequencies of beige Senonian and chalcedony/millstone may be related to their comparatively low fracture predictability. However, there is a large range of fracture properties among Senonian nodules, so predictable nodules of the beige variety might have been available in small amounts. Perhaps the walking core was one such nodule, which was conserved and carried along as a hedge against the difficulty of finding predictable nodules of that material. If predictable nodules of beige Senonian were rare, one would expect beige Senonian cores to show more intense reduction than black Senonian cores. Unfortunately, no beige Senonian cores were recovered.

There is no strong evidence of a link between manufacture methods and raw material types. Beige Senonian may have been avoided for Levallois reduction, because there were Levallois blanks made of black Senonian, indeterminate Senonian, and porcelainite, but not of beige Senonian. However, this could also be a sample size effect.

Low sample sizes or missing data also precluded any meaningful statistical analyses of core reduction intensity including blank:core ratios, or blank conservation. The association between RM Type and Retouch Frequency is insignificant, but this too may reflect sample size problems. On the other hand, the retouch frequency of beige

Senonian (21%) is much lower than that of black Senonian (33%), and this may reflect an avoidance of the former raw material for tool making.

In short, there are two kinds of evidence providing moderate support for the hypothesis of raw material conservation in this assemblage. That manufacture location/transport modes are different for different materials may represent an effort to conserve energy or raw material. The facts that beige Senonian and chalcedony/millstone were not imported as nodules or cores, were not used for Levallois flakes, and were retouched in lower frequencies is consistent with a form of raw material conservation in which less predictable materials were avoided. However, the low sample sizes of these raw material types limits the confidence we may have in these inferences.

La-Côte, level III

Because this site lies very close to the Isle River, and because there are only eight known terrestrial raw material occurrences within a 5 km radius, much of the raw material was probably acquired from alluvial gravels, except for Mussidan chert and pink speckled chert (available 8-9 km downstream) and Bergeracois (≥19 km away). The raw material composition of this assemblage does not support a "random walk" model of tool stone acquisition. Black Senonian, Bergeracois, and pink speckled chert are more abundant, while beige Senonian, silicified wood, and jasper are less abundant, than would be expected under such a model. One effect of this is to raise acquisition costs. Those costs were raised further by importing nodules, rather than blanks, of black and beige Senonian, silicified wood, and Bergeracois chert.

This assemblage shows a clear specialization in blade tools. Most of the flakes in the assemblage are probably by-products of blade manufacture resulting from nodule

decortication, core shaping, debitage surface maintenance, and striking platform rejuvenation. That there are more flakes and fewer blades made of beige Senonian compared to other raw material types indicates that manufacture methods did depend to some extent on raw material characteristics. However, Bergeracois is not more laminar than other raw materials in spite of its low $V_{wt}$ (coefficient of variation in weight loss, the measure of flake size predictability). Jasper has the highest frequency of non-cortical blades, but that probably reflects a transport bias.

Blanks made of non-local raw materials are smaller than those made of local raw materials. This appears to have resulted from two factors: non-local blanks were struck from cores that were smaller than cores of local raw materials, and the transported blanks, while not size-sorted, did experience size attrition from retouch and use during transport. This indicates that a moderate level of blank conservation was practiced, which slightly favored more portable blanks.

There are large differences in the retouch frequencies of different raw materials, and the association between RM Type and Retouch is significant. However, this proved to be an artifact of the technological composition of each raw material and the tendency of some technological types to be retouched more than others. It does not reflect an effort to conserve more costly or more predictable raw materials by retouching more blanks. However, the very low retouch frequency in beige Senonian may reflect an avoidance of that material for tool making, possibly because of its unpredictable fracture.

Finally, even though Bergeracois was obtained from the most distant sources, it has a smaller blank:core ratio than black Senonian, beige Senonian, or silicified wood. Given my other results, this does not conform to the expectation based on optimality theory, that more costly raw materials would be exploited more efficiently. However,

there are factors other than raw material conservation that may affect blank:core ratios, which I discuss below.

In short, the evidence for raw material conservation is slight in this assemblage. For unknown reasons, Bergeracois chert was not exploited more intensively at this site than local raw materials. However, blanks of Bergeracois do appear to have been conserved during transport by reuse and repair, resulting in considerable size attrition. There may also have been other conserving behaviors that are difficult or impossible to discover because of preservation factors, such as the relatively small size of the assemblage and the incompleteness of its recovery.

Caminade Est, level G

The raw material composition of this assemblage agrees with a random walk model of lithic raw material provisioning if basalt and quartzite are ignored. Those raw materials were essentially ignored here because their function, although unknown, was probably very different from that of the cherts. As far as chert, the raw material composition agrees with the random encounter model, with one exception: the high frequency of black Senonian compared with beige Senonian. This is undoubtedly related to the lower predictability of beige Senonian chert.

In general, the patterns of manufacture location and transport mode conform to expectations. Almost all local raw materials were imported as either raw nodules/cobbles or as prepared cores, and reduced at the site, while non-local raw materials were imported as tools and/or raw blanks.

Although there is a large range of blank production methods in the assemblage, there was a substantial focus on blade blanks. Furthermore, Bergeracois is significantly more laminar than other raw materials, with twice the percentage of ordinary blades.

Jasper and porcelainite are slightly more laminar than Senonian, but they occur in numbers too small to trigger significant standardized deviates.

There is some indication that cores of chalcedony/millstone and jasper were reduced with greater intensity than those of Senonian cherts. However, because of low sample sizes, this can not be established with any confidence.

There is no evidence of blank conservation through either blank portability or distance/attrition. Tools weigh more than raw blanks, but this is true of all raw material types to roughly the same degree. Moreover, non-local blanks tend to weigh more, not less, than local ones. However, there is evidence of raw material conservation in the form of more intense retouching among blanks of certain raw materials. Bergeracois (non-local), jasper, and porcelainite (both of unknown source distance) are all retouched in frequencies two to six times as high as black Senonian, indeterminate Senonian, and chalcedony/millstone. This is a real reflection of increased retouch intensity, and not an effect of any transport bias. Surprisingly, there are no tools made of beige Senonian, and it is difficult to attribute this to sample size effects, because there are far more artifacts of this material than of Bergeracois, jasper, or porcelainite. The increased retouch intensity of the latter three material types may be related to higher acquisition cost resulting from longer source distances, lower manufacture cost resulting from greater fracture predictability, or both.

Because there are no raw materials that are clearly non-local and that are represented by at least one core, I could not use blank:core ratios to measure differential core reduction intensity in this assemblage. However, it is interesting that the least predictable raw material, beige Senonian, has a higher blank:core ratio than black

Senonian, chalcedony/millstone, or jasper. The very high blank:core ratio for porcelainite (146:1) must be treated with caution because it is based on only one core.

Le Flageolet I, level XI

Raw materials were obtained from a variety of geomorphologic settings, but mostly from either terrestrial secondary sources or alluvial gravels. The raw material composition of the assemblage does not differ significantly from the pattern that would result from a random walk model of acquisition. However, the technological composition of the different raw materials suggests that manufacture mode and mode of transport were affected by both source distances and fracture properties. Cobbles and nodules of black, beige, and indeterminate Senonian were imported and reduced entirely on-site. The same is true of basalt and quartzite, but those were almost certainly used as hammerstones rather than for tool making. Bergeracois and chalcedony/millstone were imported as blanks and walking cores. The remaining raw materials (jasper, Fumelois, Mussidan, Jurassic, and porcelainite) were imported entirely in the form of blanks, which may or may not have been retouched before arriving at the rockshelter. These patterns conform to expectations based on estimated source distances, except for chalcedony/millstone. The technological composition of that material suggests extensive field processing before transport, probably as a way to minimize the cost incurred by transporting material that would eventually go unused to due the material's low fail rate predictability.

Bergeracois is more laminar than other raw materials, which may reflect a strategy for taking advantage of its low $V_{wt}$. It also has a much higher retouch frequency than Senonian chert and chalcedony/millstone. The higher retouch frequency of Bergeracois seems to be partly a function of higher retouch intensity, and partly of a

transport bias favoring non-cortical fragments and blades. Jasper and porcelainite are retouched in even higher frequencies, although those are not statistically significant. Interestingly, there are no tools made of ordinary flakes of Bergeracois—the tools are made of blades, crested blades, fragments, and rejuvenation flakes.

There is some evidence for efforts to improve the portability of Bergeracois blanks. At the location(s) where cores were reduced, there was a selection of blanks for transport, resulting in a population of blanks at Le Flageolet I that tend to be somewhat smaller and less cortical than locally-produced Senonian blanks. During transport, the Bergeracois blanks were retouched, used, and probably repaired, resulting in size attrition somewhat greater than the attrition that occurred with blanks of local raw materials. These behaviors may result from efforts to conserve a predictable and relatively costly raw material, although they did not result in a very large difference in the sizes of Bergeracois and Senonian blanks.

It was not possible to examine the effects of source distance on core reduction intensity because all cores belong to either Senonian chert or unidentified raw material. For the same reason, blank:core ratios were not examined.

Le Flageolet I, level IX

The raw material composition of this assemblage agrees with a random walk model of acquisition. As with the level XI assemblage, cobbles and nodules of chert were obtained from a variety of geomorphological settings, but here the balance was tipped in favor of alluvial gravels. These account for between 64% and 70% of cortex-possessing objects of black Senonian, beige Senonian, indeterminate Senonian, and Bergeracois. These are the only raw materials for which more than 30 pieces with cortex were available. Senonian (black, beige and indeterminate), chalcedony/millstone,

porcelainite, and Bergeracois were all imported as cobbles and/or nodules, which were reduced on site. Some of the Bergeracois may have arrived in the form of decorticated or prepared cores also. Cobbles of quartzite and basalt were also brought to this site, but probably for use as hammerstones rather than for making tools. The remaining raw materials—jasper, Fumelois, Gavaudun, and Jurassic—were imported as blanks and/or tools. The one major anomaly is the presence of four Bergeracois cores, which were transported a distance of at least 34 km.

There is a somewhat stronger focus on blade production here than in level XI of Le Flageolet I, but less than in either level G of Caminade Est or level III of La-Côte. Most of the blade cores belong to categories 13A and 13B (laterally-maintained, narrow debitage surfaces, often with crests). Bergeracois chert is significantly more laminar than other raw materials. This is the only clear evidence in any of the assemblages of an association between raw material types and core reduction methods. However, there are no significant associations between raw material types and either core categories or core descriptive variables, and there are no differences in core reduction intensity between raw material types.

Bergeracois chert is also retouched in higher frequencies than other raw materials, and this is not due to any transport bias. This probably reflects raw material conservation through increased use of a more costly and somewhat more predictable raw material.

The assemblage lacks clear evidence of raw material conservation through efforts to increase blank portability, or in the form of blank attrition resulting from conservation during transport. However, there is an interesting difference between Senonian and Bergeracois blanks. Tools made on ordinary blades of Senonian chert

are much smaller than tools made on other blank types, and less than tools made on Bergeracois blades. This could be attributed to one of two possible causes. 1) There was a deliberate effort to manufacture unusually large blades of Bergeracois, but not large blades of Senonian chert. 2) The tools made of Senonian blades were retouched and used with much greater intensity than tools made of Bergeracois blades, resulting in greater size attrition. Neither hypothesis can be tested without additional data.

Finally, there is evidence of the conservation of Bergeracois chert through more intense core reduction. That raw material has the highest blank:core ratio, roughly one-third higher than that of beige Senonian and more than twice as high as that of black Senonian.

Bergeracois chert differs in many ways from other raw materials in several assemblages, but the evidence that it was treated differently, and that this resulted from efforts to increase technological efficiency, is strongest in this assemblage. The greater laminarity, higher retouch frequency, and higher blank:core ratio of Bergeracois cannot be an artifact of transport bias because this material was imported as nodules and/or cobbles. At La-Côte, the most laminar of all six assemblages, nodules of Bergeracois were also imported but this material was not more laminar, more intensively retouched, or more highly conserved than other raw materials. Although I made efforts to discriminate between spurious and real associations between RM Type and various technological variables, the possibility of a transport bias affecting the technological composition of non-local raw materials cannot be totally ruled out in the absence of total recovery of those materials. Nevertheless, the evidence from level IX of Le Flageolet clearly indicates that Bergeracois was conserved more intensively than other raw materials.

**Evaluation of research strategy**

At the beginning of this dissertation, I laid out a general strategy for deriving testable hypotheses for the discontinuity hypothesis for RME, based on principles of evolutionary ecology. Here, I review the way in which I did so, and evaluate the overall success of the effort. I reserve discussion of how the hypothesis testing outcomes relate to the discontinuity hypothesis and the Middle to Upper Paleolithic transition for the next chapter.

Fundamental to my strategy was a demonstration that many aspects of lithic raw material exploitation have adaptive significance. If they do not, then we would expect RME to be opportunistic, and we would not expect strategies for decreasing overall costs or for raising technological efficiency. Such efforts require planning and organization, and sometimes involve short-term expenditures in order to lower long-term costs. An example is expending increased energy to acquire non-local raw materials in order to reap the benefit of their more desirable fracture properties. Without adaptive pressure for improved technological efficiency, this extra planning, organization, and long-term budgeting of time and energy would not have been favored by natural selection.

To the extent that sample sizes allow, several of the results show significant departures from the simplest, most opportunistic strategy. First, that non-local raw materials were acquired at all shows some technological organization. Whether these materials were imported directly to the site without field processing or consumption, as was done with Bergeracois in La-Côte and level XI of Le Flageolet I, or were consumed as people moved away from the sources, they were carried further than the local raw

materials in each assemblage. Therefore, non-local raw materials represent increased cost.

That raw material was imported to each site in different states of consumption (whole nodules, prepared cores, walking cores, blanks/tools), and that the degree of prior processing and consumption depended on source distance, may mean different things depending on what the circumstances were. To a degree, this pattern may result simply from the gradual consumption of raw materials across several residence moves, so that transport distance correlates with technological composition. This is probably the case with level G of Caminade Est. However, the rest of the assemblages all show at least one significant departure from this pattern. In levels H8 of Le Moustier, M3 of Caminade Est, and XI of Le Flageolet I, local materials such as chalcedony/millstone, beige Senonian, and quartzite were imported as blanks, despite the short transport distance. This pattern probably reflects the importance of fracture predictability on REM efficiency. The higher cost of materials with lower predictability (higher $V_{wt}$ values) results from the large amount of waste that is generated for each successful blank. Once a useable blank has been struck, low fracture predictability is less constraining. Therefore, the loss in utility that occurs when a block of material is reduced is much less for these materials than it would be for more predictable materials, and the trade-off between utility and portability is less important. The groups represented by these three assemblages took advantage of this situation by reducing materials like beige Senonian and chalcedony/millstone at the acquisition site, then transporting blanks.

Levels III of La-Côte and IX of Le Flageolet I show the import of raw blocks of Bergeracois, even though that material was acquired from sources ≥19 km and ≥34 km away, respectively. This may suggest that the decrease in manufacture costs that

resulted from the higher fracture predictability of this material offset the increase in acquisition cost.

There is additional evidence of the adaptive value of RME strategies, related to the fracture properties of various raw materials. The low Flake Size Predictability (high $V_{wt}$) of beige Senonian chert probably accounts for several findings: low frequencies of this chert in all assemblages compared to black Senonian chert, which is less abundant in the region; the less intense reduction of beige Senonian cores relative to black Senonian in level H8 of Le Moustier; the low blade frequencies in beige Senonian in La-Côte, the most laminar of all the assemblages; and the significantly low retouch frequencies of beige Senonian in levels M3 of Caminade Est and III of La-Côte, as well as the total absence of beige Senonian tools in level G of Caminade Est. Similarly, the low Fail Rate Predictability of chalcedony/millstone probably accounts for its very low frequencies in all the assemblages except La-Côte, where the absence of this material is probably due to its absence from the surrounding area. The high Flake Size Predictability of Bergeracois accounts for the higher than expected frequencies of this material in several assemblages, the high frequencies of blades in Bergeracois relative to other materials in the three Aurignacian assemblages, the higher retouch frequencies among Bergeracois blanks in the three Aurignacian assemblages, and the evidence in favor of the blank portability hypothesis for Bergeracois in levels IX and IX from Le Flageolet I.

In short, each assemblage shows some evidence that RME strategies have adaptive significance. Furthermore, each assemblage shows a unique combination of RME strategies. This may reflect changes in the adaptive consequences of different

aspects of RME throughout the Middle to Upper Paleolithic transition, or an adaptive differential between two competing populations.

Another part of the general strategy for this research has been the development of a model of RME, and the use of that model to derive testable hypotheses that are consistent with the discontinuity hypothesis but not the continuity hypothesis. The model that I developed in Chapter 2 is qualitative, but it served its purpose. It addresses three important problems that Paleolithic foragers faced: how far to travel for raw material, how much energy to spend on acquiring high-quality raw material, and how much energy to invest in curation and other raw material conservation measures. The model indicates how different elements of an RME strategy contribute to overall technological efficiency, by providing relative indications of the cost of each element.

The predictions of the discontinuity hypothesis for raw material exploitation are that technological efficiency, measured in the ways listed on pp. 77-78, would be lower for one set of assemblages, and that this set would consist of the oldest assemblages. Specifically, evidence consistent with the discontinuity hypothesis would include:

1. a decrease in the association between the estimated natural availability (ENA) and the quantity of each raw material type (in the assemblage) over time;
2. an increase in the acquisition of more costly raw materials only when those materials have higher fracture predictability;
3. an increase in the strength of association between the partitioning of manufacture and various environmental variables, such as source distance;
4. an increase in the strength of association between manufacture methods and the fracture properties of raw materials;

5. an increase in the degree to which more costly raw materials and raw materials with unusual fracture properties were curated, by increasing the portability of blanks, consuming non-local blanks more intensively, or reducing cores more intensively.

If the evidence presented in the previous chapters demonstrates that these changes occurred during the period 40,000-30,000 BP, then the replacement-and-discontinuity models are supported, because that evidence would show an archaeological discontinuity associated with a set of adaptively significant behaviors. It would not support the continuity model, because while that model does not preclude behavioral change, it does preclude the temporal correlation of significant behavioral changes with the time of the Neandertal/*H. s. sapiens* transition.

In sum, I feel that the strategy I proposed at the beginning of this dissertation has been followed successfully. This raises the obvious question, Do the results support the discontinuity hypothesis? I address that question in the next chapter. In the remainder of this chapter, I consider some of the assumptions on which my approach is based because these may affect my ability to address the basic research question.

**Assumptions**

Archaeological research depends on many assumptions. When one or more of the assumptions turns out to be wrong, the results of the study may not bear a predictable relationship to the expected outcome. For instance, one may not have measured what he believed himself to be measuring. In theory, therefore, it is important to examine and evaluate each assumption. However, in practice, it is usually impossible to evaluate them all. Many assumptions serve the necessities of defining the problem and formulating hypotheses, regardless of their ultimate truth value. I employed a

number of simplifying assumptions, and it is neither desirable nor possible to evaluate the truth of each assumption.

For example, I chose to carry out this study on assemblages that had been excavated and curated rather than to excavate sites, for obvious reasons. Consequently, the chronological and behavioral resolution of the inferences I make are limited by the resolution of each assemblage, which is in turn limited by the excavation techniques that were in use by Paleolithic archaeologists in France between 1955 and 1983. Furthermore, the possibility that natural processes affected the assemblages after they were deposited cannot be eliminated. However, the strength of the archaeological patterns that I have exposed would seem to exclude natural processes as a cause based on parsimony.

*Assumptions germane to evolutionary theory*

The theoretical approach of this study entails several other assumptions. I stated in Chapter 2 that this study is based on ecological theory. This theory assumes that the growth of a given foraging group is constrained by the energy available for reproduction and survival, and that variation in available energy is largely dependent on technology and behavioral variation, within a given environment. Because it is grounded in Darwinian theory, this theory also assumes that there is variation in human behavior; that much of this variation is passed from person to person by learning; and that some of this variation is fitness affecting. It assumes further that economic activities such as raw material provisioning entail fitness affecting behavioral variation; that there is a wide range of variation in these behaviors among foragers; and that different foraging adaptations in any environment can be arrayed along a continuum of adaptedness, from maladaptive to optimal.

I do not consider it either necessary or possible to evaluate the truth of these assumptions. Some have been shown to be true (albeit in studies concerning phenomena that are more tightly controlled by genetic variation), while others have not. They all serve the purpose of defining a context and a set of terms with which to formulate a research problem, and with which to construct testable hypotheses. The success of this project is related to the truth of these assumptions, but not necessarily in a direct way.

*Energy spent on raw material acquisition*

Several other assumptions employed here should be evaluated. In order to construct testable hypotheses, any approach based on ecological theory must designate variables to be measured, measurement scales, and units of measurement. The behavioral variables I chose to measure consist mainly of assemblage raw material composition, manufacture methods, blank conservation, and core reduction intensity. Calling these things variables is a simplification; the last two were actually inferences based on frequency distributions of other variables (such as retouch frequency, mean blank weights, blank:core ratios, etc.), and on analyses of the relationships between variables. The measurement scales and units differ in each case, but each variable relates to energy in some way.

In the case of raw material composition, I attempted to derive a measure of the extent to which the energy spent on raw material provisioning exceeded the minimum amount of energy necessary to acquire tool stone. I construed the minimum energy expenditure as that required in a random model of raw material acquisition, expressed in terms of a ranking by Estimated Natural Availability (ENA). If raw material assemblage composition diverged significantly from that model, I reasoned, then people must have

spent additional energy in order to acquire certain raw material types that they would not stumble across very often without trying. However, as I noted above, there is at least one alternative explanation for an acquisition pattern that differs from a random walk model. People may have exploited food resources in ways that did not lead to a random path over the landscape, while exploiting lithic raw materials opportunistically in the process. This might lead to a non-random raw material assemblage composition even though the minimum was spent on acquiring tool stone, given the mobility associated with subsistence foraging. These two ways of producing a non-random raw material composition can be discriminated when there is evidence that raw material composition was affected by factors affecting acquisition cost, manufacture cost, or tool performance characteristics.

Strangely, those assemblages showing a statistically non-random acquisition pattern (Le Moustier H8, Caminade Est M3, and La-Côte III) do not show a preferred exploitation of the most predictable raw materials. They do show a preference of black Senonian over beige Senonian despite the greater natural abundance of the latter. However, in these assemblages I found no evidence that jasper, Mussidan, Bergeracois, or quartzite (the most predictable materials) were conserved through the conservation of blanks, a higher retouch frequency, or a more intense exploitation of cores. Yet, there is evidence that raw material fracture properties affected raw material composition. This does not suggest a random raw material acquisition embedded within a non-random foraging pattern.

On the other hand, the only assemblages that do show convincing evidence for the conservation of more predictable tool stone (namely, Bergeracois) are those where raw material composition is consistent with a random model of acquisition (level G of

Caminade Est and levels XI and IX of Le Flageolet I). The strongest evidence of this kind of conservation is in Level IX of Le Flageolet I. This pattern suggests that energy was conserved during raw material acquisition by minimizing search times. Such a strategy could lower the probability of finding the most predictable raw materials. Yet, within the range of raw materials so acquired, people apparently practiced some raw material conservation, and this affected retouch frequencies, blank composition, blank weights, and core reduction intensity.

Thus, the pattern did not conform to expectations in any assemblage. This implies that, although both acquisition patterns and associations between raw material type and technological or blank composition are related to technological efficiency, there are other factors involved, which this study did not examine. Thus, the answer lies not in the incorrectness of the assumptions I employed, but probably with a failure to account for all possible avenues of energy flow in the raw material provisioning system.

*Assumptions about the past lithological landscape*

I assumed that the known distribution and density of each raw material type is representative of its distribution and density in the distant past (between 27,000 BP and 42,000 BP). I based this on the fact that all these lithic raw materials derive from geologic formations that are very stable in their spatial distributions and depth. The formations have not changed location, and the rivers that eroded nodules and transport them have not changed course in the past 42,000 years (or more), even if erosion and other geomorphological processes have affected the uppermost surface of each formation.

Nevertheless, the known distribution of occurrences may not faithfully represent the distribution of available occurrences in the past. For one thing, primary occurrences

may not have been used as raw material sources in the past. As Demars (1982) and Chadelle (1983) have pointed out, nodules of chert are very difficult to extract from their limestone matrix without metal tools. Digging nodules of chert out of limestone would rarely have been worth the trouble if chert was widely available in secondary occurrences. In addition, the known distribution of secondary occurrences is largely a function of modern construction and agricultural activities (Chadelle 1983, Dibble 1991). The occurrence that we find in a ditch today may have been deeply buried by soil, loess, colluvium, or alluvium in the past. On the other hand, some sources used in the past may lie hidden under vegetation or Holocene sediments.

This leads to a consideration of the factors that would have been responsible for exposing chert occurrences during the Pleistocene. One can only speculate, but it seems likely that several factors would have come into play, including snow cover, cryoturbation, vegetation, pedogenesis, stream courses, and stream load (Chadelle 1993, Straus 1991, Turq 1992). Given the fact that both the Massif Central and Pyrenees were glaciated, it seems likely that the meandering rivers that head in those mountains (Lot, Dordogne, Vézère, Isle, Garonne) would have had sections of braided stream during glacial periods. They would have been capable of carrying a much higher gravel load, since spring melts would have brought large floods. These rivers would have carried cobbles of chert, basalt, and quartzite further downstream than they do today, in effect widening the distribution of each raw material type. Turq (1992, 1999) made an admirable effort to understand better the past distribution of alluvial occurrences by compiling cartographic information on ancient river terraces, but this topic needs additional research.

For the time being, estimates of source distances applied to archaeological assemblages, and assumptions about the densities of various raw material types, must be based on current knowledge of Pleistocene geomorphology and its effects on the distribution of chert nodules and stream cobbles in various microenvironments. I see no reason to be concerned about the way in which I constructed ENA values. Limiting the analysis to an ordinal level of measurement should make the method robust to errors in the estimates of occurrence densities and source distances. With more detailed information about the past distribution of sources, it may become possible to carry out this analysis at a more informative scale of measurement.

*Estimated source distances*

Another assumption I employed is that raw material acquisition, manufacture, and conservation would depend in part on the distance over which each material was transported from its source. In as much as the minimum estimated source distance (ESD) was part of estimated natural availability (ENA), I have already evaluated this assumption. However, there are other aspects of my analysis that were affected by ESDs, such as my expectations about the technological composition of each assemblage, and I have not yet evaluated this relationship.

In general, the results of this study are similar to patterns identified by Chadelle (1983), Geneste (1985) and Turq (1992): transport mode and manufacture location tend strongly to vary with ESD. Nevertheless, no assemblage shows a perfect correlation between ESD and raw material frequencies. If a high correlation had existed in Le Flageolet I, for example, then the frequencies of Mussidan and Fumelois would be nearly equal to the frequencies of Bergeracois, and all would be about thirty times less abundant than black Senonian, beige Senonian, quartzite, basalt, or

chalcedony/millstone. The frequencies of Mussidan and pink speckled chert in La-Côte would also be almost exactly intermediate between those of Bergeracois and the local raw materials. Instead, each assemblage shows departures from perfect correlation between ESD and any of the variables that might be expected to vary in a regular way with ESD: frequency, transport mode, retouch frequency, blank attrition, blank size, or any of the measures of core reduction intensity (blank composition, cortex amount on cores, number of striking surfaces, or blank:core ratios). This raises the question of what other factors besides source distance affected these variables.

As I argued above, these factors must include the abundance of the material in stream gravels and the number of terrestrial occurrences. In Chapter 5, I implied that earlier studies of raw material provisioning may have failed to account for these two factors sufficiently. As a solution to that problem, I developed a method for doing so, and I believe that combining ESD with measures of occurrence densities yielded a more realistic model of acquisition. However, there is at least one difficulty with my approach: it provides no way to distinguish the individual effects that each environmental factor may have on various measures of raw material provisioning. For example, was Fumelois rare at Caminade Est because the sources are further than most other raw materials found in the level G assemblage, or because of the rarity of occurrences? I have not answered that question, and see no way of doing so.

Like ESD and occurrence densities, fracture predictability also may affect raw material composition and other variables. Unlike those geographic factors, however, the effects of fracture predictability can be distinguished. Low fracture predictability appears to explain the rarity of beige Senonian relative to black Senonian in each assemblage, the low frequency of beige Senonian tools in at least one assemblage, and the rarity of

chalcedony/millstone in five of the assemblages. Other patterns remain to be explained, such as the higher frequency of Bergeracois than other distant raw materials. This may be related to fracture properties, but my PIT analyses, which did not include all the raw material types observed in these six assemblages, suggest that jasper, quartzite, and Mussidan chert are all equally as predictable as Bergeracois. Mussidan chert lies further from most of the sites (except La-Côte) than Bergeracois, and this may help explain its lower frequencies. Occurrences of Mussidan are also less naturally abundant than those of Bergeracois, and this probably affected raw material composition as well. Occurrences of Gavaudun and Fumelois chert are especially rare, and although I have no data on the fracture properties of those rocks, they are reputed to have highly predictable fracture. Perhaps their low ENA explains their rarity in these assemblages.

With additional lines of evidence, it might be possible to go further in reconstructing the factors affecting raw material provisioning. One piece of missing information that greatly hampers the ability to do so is the lack of knowledge about group mobility patterns for this period. We do not know how often people changed residences, the size of the landscape each group exploited, or the paths they traveled. Having this information would help evaluate such problems as the low ratio of Fumelois and Gavaudun to Bergeracois. This kind of knowledge can only come with increasingly detailed and theoretically-informed studies of faunal exploitation, seasonality, and the chronological duration of each assemblage.

Artifact identification and measurement of variables

Clearly, this success of this project would be affected by errors resulting from misidentifications of artifact classes, or by the inaccurate or incomplete measurement of variables. If there were independent phenomena with known relationships to the

phenomena described here, then it would be possible to do a comparison and quantitatively assess the precision and accuracy of my methods. Of course, there are no such phenomena that can be independently measured. For instance, the application of trace element studies to identifying lithologic types would not be practical as a test of raw material identifications based on macroscopic criteria (Demars 1985). Nevertheless, there are a number of known factors that do permit a partial evaluation of how accurately identifications and measurements were made.

*Identifying RM Types: problems*

The amount of uncertainty in identified lithic raw materials found in archaeological assemblages is larger than that in identifying other kinds of artifacts (tool types or bones, to name two examples). That uncertainty has never been quantified. Generally, variation in the physical characteristics of lithic raw materials clusters in distinct patterns corresponding to chert from a certain geological formation. The lithologic types in Table 4.1 represent such clusters. However, there is also substantial variation in the physical properties of these stones that does not cluster so clearly, or that is not unique to a single formation. For example, some nodules of Mussidan chert appear very similar to some nodules of Bergeracois chert. Some beige Senonian nodules have colored bands, making them very similar to many Bergeracois nodules. This resulted when the Senonian nodules were eroded from their mother rock, transported, and deposited in moist, mineral-rich karstic cavities identical to those in which Bergeracois chert formed (Turq 1992). Jasper-like chert from Senonian formations can be very similar to Tertiary jasper on the Bord Plateau. The breakage of nodules into very small pieces by Paleolithic stoneworkers and their subsequent desilicification in the deposits have made identification even more difficult.

This gives rise to two issues that affect the reliability of tabulated raw material type frequencies as estimates of the true frequencies. First is the issue of how much confidence we may have in the frequencies of raw material types that are tabulated in any given assemblage. This depends in large part on the inherent distinctiveness of each raw material type. In my experience, nodules belonging to the different types in Table 4.1 are generally very distinct: the space where the attributes of different types "overlap" is smaller than the spaces occupied solely by each given type. Thus, the tabulated frequencies will be accurate estimates of the relative percentages of each raw material type, given sufficient expertise on the part of the analyst.

In contrast, the precision of those estimates is unknown because we lack any standard against which to compare our tabulations. One might obtain an estimate of that precision by tabulating the raw material frequencies in an assemblage many times, in order to obtain a mean and variance for the frequency of each raw material type. Those statistics could then be used to examine statistical differences between frequencies of different raw material types, and to generate estimates of precision. However, doing a sufficient number of repetitions to obtain statistically significant results would dramatically increase the time required to do the lengthy analysis presented here. This is one reason why I relied primarily on $\chi^2$ and $G^2$ to test patterns of association in cross-tabulated data: these methods do not require estimates of the variance of each frequency as an estimate.

The second issue is how conservative to be in drawing the line between identifiable and unidentifiable raw materials. Clearly, the more conservative one is, the smaller the chance of mistaken attributions (type I errors). Yet, increased conservatism also results in a higher frequency of unidentified pieces and, therefore, fewer data with

which to make meaningful comparisons. Because of the subjectivity inherent in this kind of analysis, there are no explicit criteria, and there is no clear point beyond which a piece must be left in the "unidentified" category. Undoubtedly, the differences in frequencies in that category in my data on Le Flageolet I, levels IX and XI, and Lucas' (2000) frequencies for the same assemblages are due to differences in how each of us drew the line between identifiable and unidentifiable.

*Adequacy of lithological taxonomy*

The effectiveness of the lithological taxonomy used here is largely dependent on whether the raw material types are each internally homogeneous but distinct from the other types with regard to each of the factors that were expected to affect raw material provisioning: source distance, occurrence density/natural availability, flaking strength, and fracture predictability. I have already addressed the first two factors, and here I address the second two. For the research design to work, three criteria should be met: 1) the PIT analyses should provide reliable estimates of each fracture property; 2) each specimen of each raw material type should yield results similar to those of the other specimens belonging to the same raw material type; and 3) there should be clear separation in the results between each type.

The first criterion was not met in the case of Minimum 100% Fail Rate. This can largely be attributed to the relatively low loads that the PIT is capable of testing. An apparatus capable of testing loads two to five times higher than those tested here should permit an accurate assessment of Minimum 100% Fail Rates for each rock (the minimum load at which failure occurs in every trial).

In the case of Fail Rate at each given load, the results were problematic but not necessarily unreliable. The problem lies in the inconsistency in Fail Rate values from

load to load, which followed no clear pattern in all but the nine rocks where I was able to obtain a significant regression equation. This inconsistency may reflect high variability, or it may be a sign of inadequate sample sizes. This is a problem that I address in greater detail below. Even if these results are reliable, they do not permit a grouping by raw material type. Thus, it is not possible to compare flaking strength values for each of the lithologic types. The same is true for Fail Rate Predictability.

Flake Size Predictability was reliably measured, did yield consistent results for each rock type tested, and does permit some separation between rock types. I have confidence in the reliability of these results as a measure of flake size predictability because of the large sample sizes that resulted from combining weight loss values from all loads, and because there is no indication that $V_{wt}$ is affected by the load at which the tests were carried out. Figure 6.50 makes it plain that specimens belonging to each raw material type differ in flake size predictability. The separation between rock types is fairly poor. Yet, black and beige Senonian tend to be much less predictable than Bergeracois, chalcedony/millstone, and jasper, and perhaps less predictable than Mussidan and quartzite as well. The range of values is much smaller for Bergeracois, chalcedony/millstone, and jasper than for the Senonian rocks, and this suggests that not only do the first three have a greater flake size predictability than Senonian, but that there is less variation in this property from one rock to the next and from one raw material occurrence to the next within the same raw material type. Of the two varieties of Senonian, black is somewhat more predictable than beige, contra Larick (1986).

It would not be exactly accurate to say that Senonian rocks are less predictable than the other raw material types, on the basis of Figure 6.50. One could find, and I obviously have found, examples from each raw material type that are approximately

equal in their flake size predictability. It would be more accurate to state that in a random sample of rocks from occurrences of each type, the proportion of rocks with $V_{wt}$ values less than 90 would be much higher in Bergeracois, chalcedony, millstone, and jasper (and possibly in Mussidan and quartzite as well) than in black or beige Senonian. Thus, the results of the fracture predictability tests are just sufficient to permit the testing of hypotheses about raw material provisioning.

Even so, there is a problem in that the lithogical taxonomy is based on macroscopic properties such as color, patterns, luster, and texture, instead of on fracture properties. Had the fracture properties tests resulted in clusters of values corresponding exactly to the lithological types in Table 4.1, then that taxonomy would be perfect for the purposes at hand. Because this did not happen, the taxonomy must be reassessed by pairing a detailed analysis of variation in macroscopic rock properties with the results of fracture properties tests. This kind of study should be pursued in the future. The goal would be to find clusters of macroscopic properties that correspond to distinct fracture properties.

Finally, my study suffers from the failure to analyze the fracture properties of every raw material type found in the assemblages. Clearly, this is impossible in the case of porcelainite, but it would be possible to test pink speckled chert, Fumelois, Gavaudun, and basalt. It will also be very interesting to collect jasper from several additional sources, carry out a large number of fracture properties experiments, and discover whether there are distinct clusters of values corresponding to different varieties of jasper. This should be done in concert with the macroscopic properties analysis to permit a more appropriate identification of jasper varieties in the archaeological assemblages.

This will permit a much better understanding than I currently have of the results I obtained for jasper.

*Reliability of PIT results*

Closely related to these issues is whether the pendulum indenter tests (PIT) yielded reliable results. There are two potential sources of systematic error that may have affected those results. The first source is the PIT apparatus itself, and the testing protocol. If either introduced an undetected bias, then variation due to that bias might have been mistaken for variation arising from the elasticity and microcrack properties of the rocks. I discussed several ways in which such a bias might occur in Chapter 6, each of which was tied to a given test parameter: tile side thickness, tile side length, height of the top edge of the tile above the vice, angle of tested edge, and distance between the point of impact and the upper edge of the tile. I carried out extensive measurements of each parameter, and found no convincing evidence of a systematic bias.

However, there is an additional kind of bias that I did not recognize until the PIT analyses were nearly completed. Because the indenter billet is made of steel, and the hardness of steel (5.5 on the Mohs scale) is lower than that of chert, the impact that occurs during each trial must have some effect on the indenter billet tip. The fact that each impact leaves a metallic streak on the tile's face is a clue that I unfortunately did not recognize until most of the trials had been done. When I realized that the billet's tip may have worn and thus changed shape during the course of the trials, I examined it under a binocular microscope. The tip of the billet was scarred and grooved and showed much evidence of wear. Because of the shape of the tip, this wear would, over time, widen the surface that comes into contact with the tile. I did additional trials, then

observed the tip under the microscope again, and found that it had changed shape slightly.

In theory, the area of contact between billet tip and tile would grow with increasing wear. Fail rates would decrease because the increase in contact area would effectively lower the applied stress (force per unit area). However, in practice, the contact area probably fluctuates but does not grow, at least not in a linear fashion. The reason is that the flat surface of the tip does not arrive at the bottom of the pendulum's swing perfectly flush with the face of the tested tile; at least, it does not do so every time. Instead, it sometimes strikes the tile while still inclined slightly from the plane of the tile. When that happens, the area of contact is smaller than predicted, and it also wears, producing a very slight bevel. Thus, although wear can enlarge the contact area, it can also create a bevel that decreases the effective contact area. The angle of the billet is not perfectly controlled, so it must vary slightly from one trial to the next. This variation is due to changes in the angle of the billet (relative to the horizontal), which occur as the screws that fasten the pendulum's bands to the billet loosen slightly and have to be retightened. Therefore, the changes in billet tip size, and consequently in the area of contact, would probably fluctuate rather than steadily accumulate. The effect on the trials would essentially amount to random errors in applied load.

It would be very interesting to do additional trials while monitoring the exact shape and size of the billet tip. Because that has not been done, I am unable to quantify any possible effect that variation in contact area may have had on my results. Hopefully, whatever the effect may have been, it was effectively randomized across trials and across rocks. In all but a few cases, the tiles from each rock were tested at different times, with intervals of days, weeks, months, or years in between. Nevertheless, a

better-designed apparatus will be used in future tests. The ideal billet would probably be a sphere, like the ball bearings used by Pelcin (1997).

This second possible source of systematic error is sample size. Sample size differences could have affected each of the two base measures the PIT generated: fail rates and weight loss. The apparent inconsistency in fail rates from one load to the next in several of the rocks probably reflects a high inherent variability, possibly due to a heterogeneous distribution of microcracks and microcrack lengths within the rock body. If so, then larger sample sizes may be needed for reliable estimates of fail rates. Would larger sample sizes result in more predictable fail rates? Stated differently, are the unpredictable variations in Fail Rate from load to load an accurate reflection of the rocks' true variability, or are they mostly an artifact of the sample sizes on which my estimates of Fail Rate are based?

This question can be addressed in part by estimating the required sample sizes in order to achieve a given minimum detectable effect (MDE; Zar 1984). For the purpose of measuring Fail Rate at a Given Load as an estimate of flaking strength, the desired MDE will be expressed as a statistical difference in the Fail Rates of two rocks at a given load. I have attempted to distinguish between the fail rates of different rocks using histograms with confidence intervals (Figures 6.28-6.31). Thus, the problem can be modeled as one of reducing the width of the confidence intervals until the fail rates of rocks that are truly different have non-overlapping confidence intervals. Of course, there may be rocks the fail rates of which are truly indistinguishable, and their confidence intervals should overlap. The goal is to find the point at which the data faithfully represent those similarities as well as the real differences.

Figure 7.1 shows a plot of the widths of binomial confidence intervals for fail rates against sample size for all 23 tested rocks, for trials at loads within the range 0.40-0.45 J. Figure 7.2 shows a plot of the same data for trials within the range 0.69-0.72. Both plots show that increasing sample size also increases the likelihood that different rocks will have statistically distinguishable fail rates. However, sample sizes of about 50 or larger may be required just to shrink confidence intervals to a width of 20% in Fail Rate. Most of the nodules I tested were smaller than 2 kg, and yielded a limited number of tiles that, with the protocol I used, was too small to achieve a sample size that large at any load except in rare instances. Achieving adequate sample sizes might require taking all the measures I listed above (reducing the number of loads tested, increasing the number of trials per tile, etc.). Yet, a glance at Figure 6.28-6.31 will show that decreasing confidence interval widths to 20%, while generally helpful, may not be sufficient to permit one to distinguish rocks that have truly different fail rates. Thus, even in the best of circumstances, the high variability in the occurrence of failures leads to disappointingly large confidence intervals.

The same general question can be asked of the weight loss values: is the documented variation in weight loss a true reflection of inherent variability, or does it also reflect the relatively small sample sizes? On the one hand, calculating weight loss should be more susceptible to sample size problems because it based on only the trials resulting in failures (and thus, weight loss). On the other hand, the behavior of median weight loss was more predictable—it generally increased with increasing loads, despite the problem of heteroscedasticty. Even so, the coefficient of variation in weight loss ($V_{wt}$) values are higher than expected. Would increasing sample sizes decrease these values, leading one to infer greater flake size predictability?

This question can be addressed by assessing the effect of increased sample sizes on the variance (or confidence intervals) associated with median weight loss values. The minimum sample size required in order to reduce confidence interval size as low as reasonably achievable is that at which additional increases in sample size have little effect on variance. I wrote a bootstrap re-sampling program that uses simulation to estimate the increase in sample size that would be required for each rock at selected loads. The simulations are based on the existing sample size, median weight loss, and standard deviation (around the median weight loss).

The data used in each simulation are the n weight loss values at a given load for a given rock. Those values are replicated many times in order to produce a data set of 1000 values. For example, if n = 8, then the data set is replicated 125 times. The program begins by taking one random sample of 3 from this data set, with which it calculates a median and standard deviation. In this way, it simulates a simple random sample with replacement. It repeats this step 1000 times, then calculates the mean of the 1000 medians and the mean standard deviation (i.e., standard error). The standard error is then used to compute a confidence interval, based on $df = n - 1$ and $\alpha = .05$. This process is then repeated at sample sizes of 5, 7, 9, and so on up to the desired maximum sample size (which can be greater than the actual sample size of the sample). Thus, for each sample size, there will be a median weight loss and a confidence interval. The results are displayed in a chart showing the change in median and variance (confidence interval width) with increasing sample sizes.

Figure 7.3 shows the progressive decrease in variance, expressed as half confidence intervals, with increasing sample sizes at four loads, for rock 14B (beige Senonian from la Malartrie). The figure suggests that variance would continue to

decrease even at sample sizes larger than 20 or 30. It also suggests that it takes longer for the relationship between variance and sample size to stabilize at higher loads. After having done over 2300 trials, I estimated the need for additional trials at various loads for each rock based on these simulations. I then did as many additional trials as possible, given the number of tiles remaining that had not yet been tested on all four sides. After about 900 additional trials, I ceased all PIT work and recomputed all relevant statistics for each rock. Although there were measurable decreases in variance in many cases, the overall improvement resulting from increased trials was less than expected. This suggests that the computer simulations produced overly optimistic results, and that attaining variances low enough for an MDE of, say, 5%, would require a very large number of failures. Because the number of failures is only a fraction of the number of trials, this suggests a very large number of trials will generally be called for, perhaps more than 100 trials per load. Lower sample sizes would be required at higher loads.

What this suggests is that the sample sizes on which I based estimates of fail rate and median weight loss are generally smaller than desirable. The results of the statistical analyses of these values may be suspect, and the behavior of both fail rate and weight loss would probably appear more predictable if sample sizes were increased. However, this could not be achieved in most cases, because most of the tested rocks were ground into the maximum number of tiles that could be obtained, and each tile was tested as many times as its size would allow. Many tiles broke in the process, or contained areas with calcareous inclusions or voids, so that fewer trials could be done than was possible on better tiles. Future work on additional rock samples, however,

could benefit from efforts to increase sample sizes beyond what I was able to achieve here.

In sum, the inconsistency in the results probably reflects low sample sizes and also a truly high level of variability in the fracture behavior of these rocks. The rocks are inherently variable due to variation in microcrack probabilities, but larger sample sizes would improve the precision with which that variability could be measured. Nevertheless, in the data set as a whole, variance is not a simple function of sample size. Some rocks show a very predictable increase in median weight loss values with increasing loads despite relatively few trials, while others show no such predictable relationship despite a large number of trials. For this reason, I believe that the differences I observed between rocks, and between rock types, are mostly caused by real differences in fracture properties.

*Measuring variation in technology*

The same general statements I made about the precision and accuracy of the lithological taxonomy could also be applied to the technological typology. However, here the problem is not one of identification—the types are not difficult to distinguish, aside from the potential inaccuracy of my subjective approach to discriminating the percentage of dorsal cortex on blanks. The more difficult issue is whether the typology appropriately measures technological variation. That is, if raw material characteristics (source distance, ENA, or fracture properties) affected manufacture methods or other aspects of raw material use, would the frequency distributions of my technological types show it?

The lack of evidence that different raw materials were treated differently during manufacture, with the exception of high Bergeracois laminarity in all three Aurignacian assemblages, does not necessarily mean that all raw materials were treated the same

way. In part, this is a missing evidence problem: the absence of cores of most non-local raw materials, and the very small sample sizes of those materials, greatly hamper my ability to identify manufacture methods. However, it is also possible that the blank types simply do not discriminate dimensions of morphological variation that were affected by variation in manufacture methods. I made few distinctions between kinds of flakes or blades in order to expedite the analysis. Had I made more distinctions, as Pelegrin (1986) did with blade shapes, it is possible I might have discovered technological variation that corresponds to variation in raw material characteristics. All I can offer at this point is the admission that such patterns may lie undiscovered in the data I have presented here, and may remain undiscovered until the artifacts are described with a different or more detailed technological typology. Typologies are essentially hypotheses about relationships between variables, which are tested by comparing empirical distributions against theoretical ones. The results presented in Chapter 5 suggest that some tinkering with the technological typology might be fruitful.

The core categories could probably also benefit from tinkering. Because the categories lack definitions that are completely mutually exclusive, there is some overlap between them. Like any set of categories (such as the Paleolithic tool typologies), the most useful result of this one lies in the general relationships that it describes. My core categories show a general sequence from simple to complex, and a steady progression in the levels of investment in core reduction. They also give a general idea of the manufacture methods used to produce blanks.

The similarity between some cores in different categories and the small size of some of them suggests that many may passed through more than one category during their lives, especially those in category 3 (cuboid flake core), 4A-4B (globular and blocky

cores with multiple striking platforms/crests), and 15 (pyramidal blade core). A core weighing 30 g. is the final end-product of a process that may have started out with a 3-kg. nodule. A small core with squarish flake scars may be the end result of heavy reduction on a crested blade core or a Levallois point core. Only refitting could provide a definitive answer to that question, but refitting was not a practical solution in this case because it was usually impossible to combine objects from different excavation units without losing their provenience information.

Certain core categories have a morphology that is very similar to certain tool forms. Consider, for example, the bladelet core in Figure A.56 no. 1 (Le Flageolet I, IX, B10-2773). I assigned this core to category 13A. It was made on a small, relatively flat cobble. Its striking platform was created by the removal of one long, semi-cortical blade or flake across the end of the cobble (view a). Both of the wide faces of the cobble have been flattened by the removal of several blades and flakes; on one side (b), these were struck from the striking platform; on the other side (d), they were struck from the incipient debitage surface and perpendicular to that debitage surface. These removals created a narrow, constricted surface running the length of the cobble, and this became the debitage surface (not clearly shown), which was used to remove several long bladelets. This core bears a close similarity to the muzzled endscraper from Le Flageolet, I, IX in Figure A.66 (no. 8). This tool was manufactured using the same steps that were followed in reducing the 13A core: creation of a striking platform on one end of a small, flattish nodule; creation of a long, constricted surface by the removal of flakes and blades from two opposite faces; and use of that constricted surface as a debitage surface for the long blades or bladelets. There are also similarities with other thick

endscrapers in Figures A.30 and A.66, although most of those were probably made on thick flakes instead of small cobbles.

Another interesting comparison is with the object in Figure A.61 no. 9 (Le Flageolet I, IX, B10-2276). Though classed as a busked burin by the excavator, it shows the very same morphologial features that define my core category 13A. It even shows traces from the preparation of a debitage crest, in the form of a distal remnant of a flake (in view b) that was clearly struck from the bladelet debitage surface (c). Other bladelet cores in this assemblage closely resemble this object, including the traces of crest preparation, especially catalogue numbers C10-2582 and B2-264 , both classed as tool type 11, and C11-1587 and D11-2166, both classed as tool type 31.

These comparisons support the notion that the distinction between tool and core is not straightforward, or even, is a false dichotomy. They agree with recent work (Hays and Lucas 1999; Lucas 2000) showing that carinated endscrapers, carinated burins, and busked burins in many Aurignacian assemblages were used as specialized bladelet cores rather than as tools.

*Sample size problems*

Insufficient sample sizes have caused problems throughout this study. The very small sample sizes of most non-local raw material types in each assemblage made it difficult or impossible to provide confident interpretations about manufacture methods, blank conservation, or core conservation for those raw materials. I attempted to lessen the effects of this problem by relying extensively on chi-square analyses, which automatically take sample sizes into consideration when computing expected values, but this test is limited by the rule of thumb requirement of an expected value of $\geq 5$ for each cell (Sokal and Rohlf 1995). The only other solution is to merge data from different

columns and/or different rows of the contingency table. I refrained from doing so in all but a few cases because it was important to know if each raw material had distinctive characteristics that might have affected raw material provisioning. However, because many raw material types yielded similar values of flake size predictability, it would be appropriate to merge those data and re-calculate the $G^2$ values.

The answer to low sample sizes in the PIT analyses is simple: do more tests. Because I have demonstrated that many trials can be carried out on a single tile without autocorrelation effects, it is clear that many trials that can be done on a given rock specimen. In addition, my measure of flake size predictability does not require data from a large number of loads; a reliable slope can be calculated on data from only five or six loads. Doing so increases the number of trials that can be done at each load (for a given number of tiles), and this is the critical factor, especially in measuring fail rates at low loads. A machine capable of testing loads higher than 1.0 J would also increase the fail rates overall, and thus the number of failures at each load. This, in turn, would increase the sample size available for estimating flake size predictability. All of these steps would be relatively simple to carry out.

Of course, the results I generated are also limited by the small number of rocks tested (n = 23). It is not clear whether this constitutes a representative sample of the rock types. As I stressed in Chapter 4, siliceous raw materials are very abundant in the Perigord. They are also highly variable, and most of the raw material types originate in geologic formations that are widely distributed across the land's surface. There may be millions of exposed nodules of chert, quartzite, and basalt in this region. Obtaining a truly representative sample of such a large population might require collecting and testing thousands of rocks, something that is clearly beyond the scope of this project.

From that perspective, 23 rocks seems a small sample indeed. At best, then, this should be considered a pilot project for a future study that will be carried out with more resources.

*Core reduction intensity*

Core reduction intensity is another aspect of raw material conservation. I attempted to measure core reduction intensity with three separate measures: amount of cortex remaining on cores, number of striking surfaces, and blank:core ratios. I found no convincing evidence of inter-raw material differences with the first two measures. Partly, this is a result of the limitation imposed by the absence of cores made of non-local raw materials in each assemblage. However, it may also indicate that neither measure bears the kind of relationship to core reduction intensity that I initially expected it to. The amount of cortex remaining on a core would change as debitage surfaces expanded, new debitage surfaces were opened up, or striking platforms were extensively rejuvenated. However, the continued reduction of a single debitage surface might have no or little effect on cortex. Also, a core that was totally decorticated before any reduction took place might present an exaggerated impression of the amount of reduction.

The number of striking surfaces might also bear little relationship to core reduction intensity. I had supposed that this number would increase with increasing core reduction. However, most of the cores with multiple striking surfaces in these assemblages were large, blocky or globular cores, and the number of striking surfaces appears to be a function of core morphology rather than a measure of increasing core reduction intensity. On the other hand, when a core has been reduced to an extreme

degree, it may only be possible to create a single striking platform, or existing platforms may be removed as debitage proceeds.

Blank:core ratios are probably a good measure of core reduction intensity because removing blanks is reduction, by definition. Yet, this measure is probably very sensitive to the number of cores present. If one or two reduced cores were carried elsewhere, or were not recovered during excavation, then the blank:core ratio of that raw material would be inflated. This is a real concern with La-Côte level III, because the assemblage is known to have been partially destroyed before excavation, and with Le Moustier level H8, because the excavation covered a very small horizontal area of the site. It might also be a concern in level M3 of Caminade Est, if stream erosion destroyed a substantial portion of the Mousterian deposits. The excavator's analysis (Laville and Sonneville-Bordes 1970) suggests that this is a possibility.

**Assessing the fit between expectations and results**

At the time I began my analyses, I believed that the raw material and technological composition of each assemblage, and the relationships between environmental parameters and behavioral variables, would show some degree of raw material conservation. This would take several forms, I thought. Frequencies of each raw material type would decline with increasing source distances, although this pattern would also be strongly affected by raw materials with very distinct fracture properties. For instance, highly predictable raw materials would occur in higher frequencies than predicted by source distance alone, and very tough or unpredictable materials, in much lower frequencies. This expectation was clearly met, although there are exceptions.

I expected that source distances and occurrence densities would have a combined effect on raw material composition. In general, the results meet this

expectation. This shows that basing expectations about raw material composition on a combined factor such as estimated natural availability (ENA) is more realistic than basing them on estimated source distances alone. I overcame the difficulty of comparing assemblages in different lithologic settings by figuring ENA for each site and using a rank-order correlation test.

I expected manufacture methods to vary with ENA and/or fracture properties. This expectation was generally not met; as I explained above, this might result from either methodological shortcomings or low sample sizes, or both. However, it was met in the case of Bergeracois in the three Aurignacian assemblages, where this material was more laminar (had higher frequencies of blades) than other materials, and was also retouched more intensively. This agrees well with Demars' (1989, 1994) model. On the other hand, the failure of La-Côte III, the most laminar of the assemblages, to show any evidence of increased laminarity or raw material conservation in Bergeracois does not agree with that model.

I also expected source distance, occurrence densities, and fracture properties to have noticeable effects on manufacture methods, the spatial partitioning of manufacture, core reduction intensity, and retouch frequency. This expectation was met with mixed results. One surprise was that fracture properties affected the spatial partitioning of manufacture more strongly than source distance did in the case of chalcedony/millstone. This illustrates just how strong the influence of fracture predictability was on acquisition strategies.

In Chapter 1, I argued that the replacement scenario is not fully supported. Nevertheless, if there were chronological trends in lithic raw material provisioning among the six assemblages, that would lend credibility to the replacement scenario. If the

replacement scenario is correct, then relationships between environmental variables (ESD, ENA, fracture properties) and behavioral variables should have either grown increasingly strong over time, or should have changed within a short period of time, resulting in clear differences between the earlier and later assemblages.

Table 7.2 summarizes in a very simple fashion the strength of relationships between Raw Material Type and six behavioral dimensions in each assemblage: acquisition patterns, transport mode, manufacture methods, blank curation, retouch frequency, and core conservation. Obviously, some of these dimensions are based on more than one kind of analysis. Blank curation is based on whether there is evidence for either the blank portability hypothesis or the distance/attrition hypothesis. Core conservation is based on blank:core ratios, frequencies of cores with different amounts of cortex, and differences in the number of striking surfaces. The table is intended only as a heuristic sketch of overall patterns.

Three of the dimensions show no evidence of a temporal trend. All six assemblages have relatively strong evidence that manufacture location and/or mode of transport depended on either source distance or natural availability. Where the pattern differs from what would be expected if source distance/ENA alone determined raw material frequency, the difference can be attributed to fracture predictability. Only two assemblages show any evidence in favor of raw material conservation in terms of blank portability or distance attrition of blanks; one of those (La-Côte) is of unknown age, while the other (level XI of Le Flageolet I) is approximately 33,000-34,000 years old. The assemblages that show evidence for raw material conservation through careful management of cores are dispersed throughout the age range of the assemblages.

However, the variables with which I attempted to measure core reduction intensity are problematic, as I discussed above.

The remaining three dimensions do show temporal trends, although I am taking some liberty in stating that, as the ages of level M3 of Caminade Est and level III of La-Côte are unknown and the age of each remaining assemblage is only an estimate based on one or more chronometric dates. Only in the two Mousterian assemblages and single Châtelperronian assemblage is there evidence that raw material acquisition was not solely dependent on raw material distances and distributions in the landscape. In those three assemblages, fracture properties strongly influenced acquisition patterns. These three assemblages also lack compelling evidence that manufacture methods varied by raw material type. In level III of La-Côte, there is evidence for an effect on manufacture methods, but it is slight: it consists of a higher frequency of flakes and lower frequency of blades among beige Senonian. In all three Aurignacian assemblages, there is evidence for a relationship between manufacture methods and raw material types, signaled by significantly higher frequencies of blades in Bergeracois. The Mousterian and Châtelperronian assemblages also differ in their absence of any evidence for maximizing the utility of non-local raw materials by increasing the retouch intensity of blanks of those materials. In level G of Caminade Est and both levels of Le Flageolet, Bergeracois was retouched in higher frequencies than other raw materials. Other non-local raw materials may also have been retouched more intensively but sample sizes were too small to say so with confidence.

This evidence suggests that a concern with raw material fracture properties was a constant throughout the 15,000-year period represented by these assemblages, but that there was a shift in strategies of provisioning. In what are probably the three earliest

assemblages, raw material fracture properties affected how people used the landscape. People avoided some raw materials that were abundantly available nearby because those materials had relatively unpredictable fracture, and put more energy into acquiring other raw materials that were only available at a distance because of their relatively predictable fracture. Even when two materials were nearly equal in abundance and availability (beige and black Senonian), that with the more predictable fracture was used much more heavily. However, once more costly or more predictable materials were incorporated into the mobile tool kit and/or brought back to a camp, they were not treated differently from any other raw material.

At some time between 42,000 BP and about 34,000 BP, this pattern changed in my sample of assemblages. People probably acquired raw materials in the course of their usual foraging runs, and did not go out of their way for tool stone, regardless of its fracture predictability. Yet, when a material became incorporated into their raw material supply, acquisition cost and/or fracture properties affected how it was treated. Bergeracois was exploited somewhat more intensively for blades as opposed to flakes. Moreover, there was some effort to conserve non-local blanks either through improving their portability or by exploiting the blank pool more intensively.

In sum, there is convincing evidence of a shift in raw material provisioning patterns. This shift does appear to have occurred sometime between the end of the Mousterian and the beginning of the Aurignacian. However, this does not mean that this shift was a simple linear process. There are many differences between all of the assemblages, resulting from differences in raw material provisioning about which we can only speculate.

There are several aspects of this study that call for additional work. All the methods I used to describe variation in technology could be improved. The technological typology should be modified to include greater logical consistency and more specific blank types. Although costly in time and money, metrical data should be gathered as well, to provide a more fine-grained database. The list of core categories, which was intended to be provisional, also should be modified after additional morphological analysis of cores. Another goal for future research is to search for possible relationships between the macroscopic characteristics of raw material types and their fracture properties, in order to construct a more relevant lithologic typology. The PIT protocol also could be improved, including a better apparatus and changes in experimental design to allow larger sample sizes and a better discrimination between fails and non-fails. All these changes will help develop and improve the research program that was so powerfully set in motion by Demars, Chadelle, Geneste, Rigaud, Turq, and others for studying lithic raw material provisioning among Paleolithic hunter-gatherers.

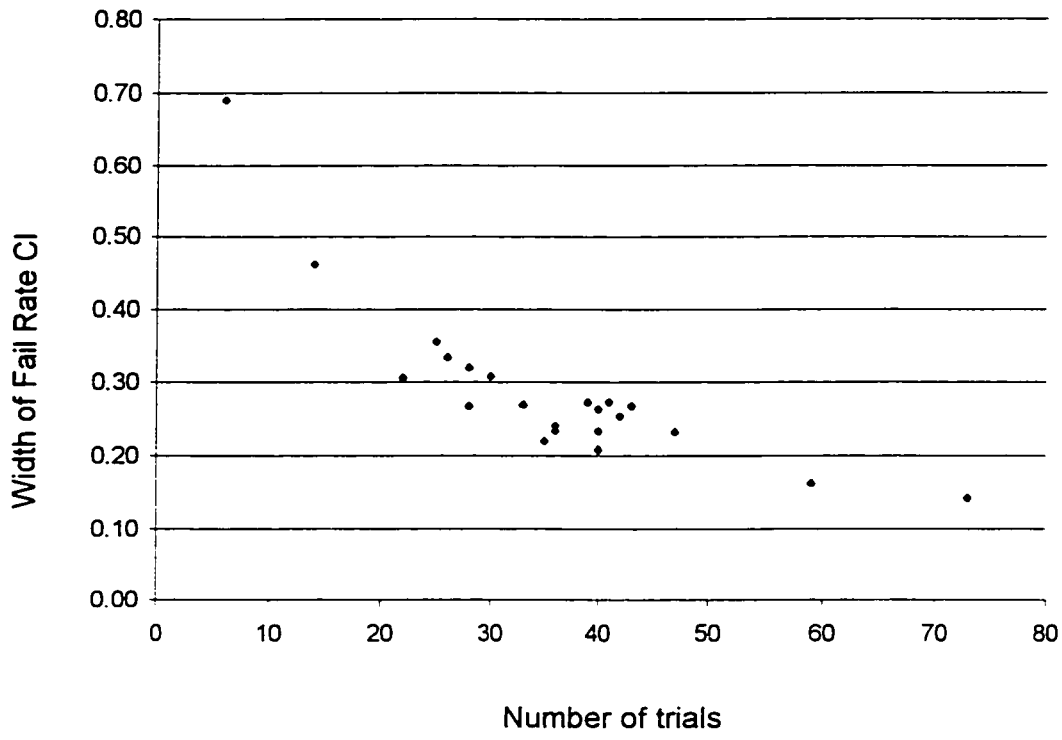



Figure 7.1 Fail Rate confidence intervals plotted against sample size (number of trials) at loads between 0.40 and 0.45 J, combined, for 23 rocks.

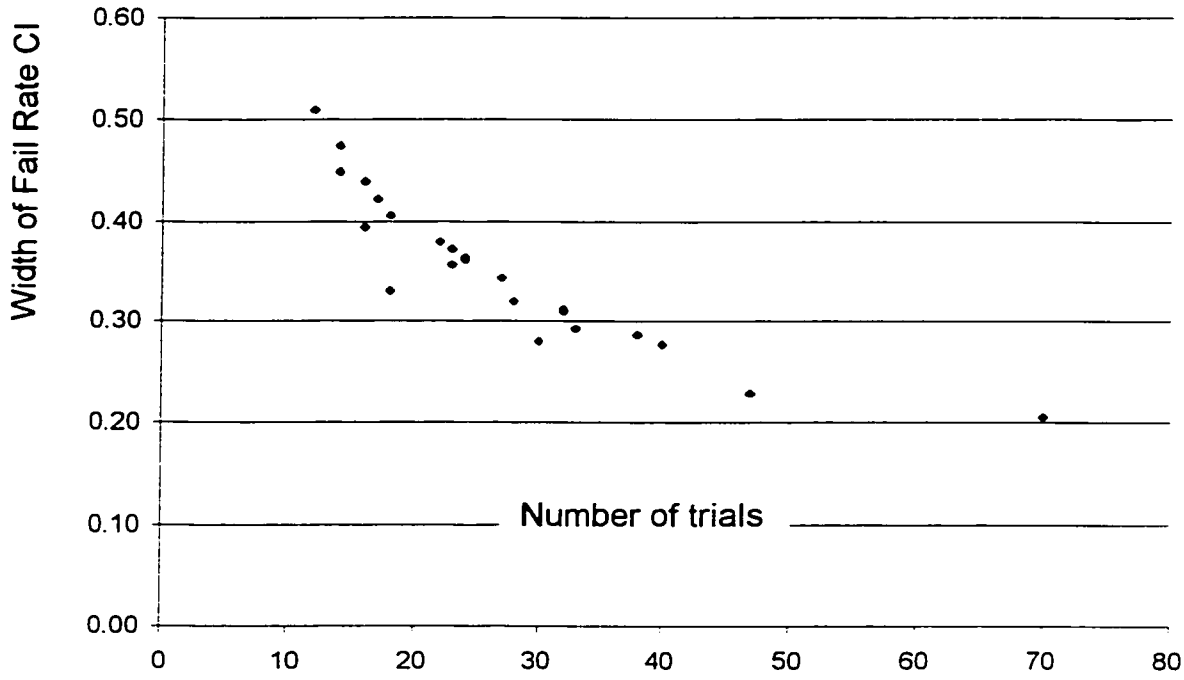



Figure 7.2 Fail Rate confidence intervals plotted against sample size (number of trials) at loads between 0.69 and 0.72 J, combined, for 23 rocks.

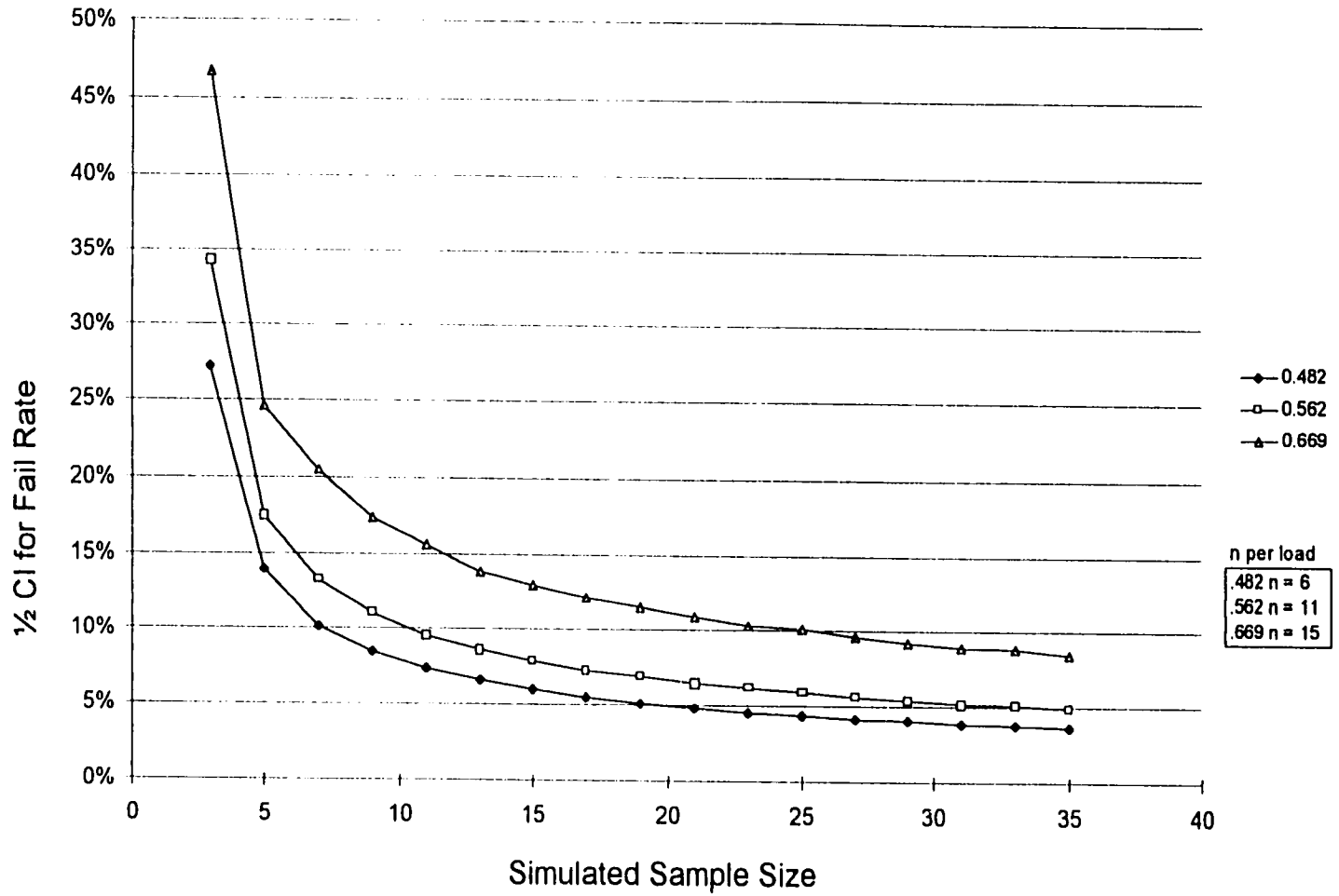



Figure 7.3 Fail Rate half confidence interval for 17 simulated sample sizes, based on data from three loads for rock 12A' (black Senonian chert from Badefols-sur-Dordogne). "n per load" = size of actual sample from which simulated samples were drawn.

Table 7.1 Le Moustier, H8. Individual or mean weights (in grams) of cores in each category, by raw material type.

| Core Category | black Senon | | beige Senon | | indet. Senon | | Total |
|---|---|---|---|---|---|---|---|
| | mean wt | n | mean wt | n | mean wt | n | |
| 1B: Simple flake | 66.5 | 2 | | | | | 66.5 |
| 2A: Prep Fk, 1 SP | 57.0 | 3 | | | | | 57.0 |
| 2B: Prep Fk, 2 SP-90 | 43.8 | 2 | | | | | 43.8 |
| 2C: Prep Fk, 2 SP-180 | | | 96.3 | 3 | | | 96.3 |
| 3: Cuboid Fk | 77.1 | 2 | | | | | 77.1 |
| 7: Fk DS on narrow face | 27.4 | 1 | | | | | 27.4 |
| 8: Prep Fk on trunc FK | 38.7 | 2 | | | | | 38.7 |
| 10B: Pl/cvx, 1 DS | 18.7 | 1 | 59.2 | 1 | | | 39.0 |
| 10D: Pl/cvx, 1 DS plane face | 63.7 | 1 | | | | | 63.7 |
| 10E: Pl/cvx, 1 DS on Flk | 33.8 | 1 | | | | | 33.8 |
| 11A: Classic Lev, uniface | 44.4 | 1 | | | | | 44.4 |
| 11B: Class Lev biface | | | | | 79.3 | 1 | 79.3 |
| 11B: Lev-like, biface | 65.7 | 1 | 112.3 | 1 | | | 89.0 |
| 99A: Indet, complex | 39.9 | 1 | | | | | 39.9 |

Table 7.2 Simplified summary of the strength of evidence for a relationship between Raw Material Type (RM) and five behavioral variables. Acquisition = non-random acquisition patterns; transport mode = relationship between RM and manufacture location/mode of transport (i.e., spatial partitioning of manufacture); manufacture methods = relationship between RM and manufacture methods; blank curation = support for the blank portability or distance/attrition hypotheses; retouch frequency = associations between retouch frequency and raw material types; core conservation = core reduction intensity, blank:core ratios. H = high, M = moderate, L = low.

| *Assemblage* | *acquisition* | *transport mode* | *manufacture methods* | *blank curation* | *retouch frequency* | *core conservation* |
|---|---|---|---|---|---|---|
| Le Moustier H8 | H | H | L | L | L | M |
| Caminade Est M3 | H | H | L | L | L | L |
| La-Côte III | H | H | L | M | L | L |
| Caminade Est G | L | H | H | L | H | M |
| Le Flageolet I, XI | L | H | M | M | H | L |
| Le Flageolet I, IX | L | H | H | L | H | M |

# 8

# Raw Material Exploitation and the Middle to Upper Paleolithic Transition

Do the results of this study demonstrate that a discontinuity in lithic raw material exploitation (RME) occurred in the Perigord between 40,000 BP and 30,000 BP? They do reveal intriguing differences between the two Mousterian assemblages, which are older than 37,000 years, and the three Aurignacian assemblages, which are younger than that. These differences indicate that changes in raw material exploitation began happening sometime between 42,500 BP (the approximate age of level H8 from Le Moustier) and 37,200 BP (the age of level G from Caminade Est), and this supports the discontinuity hypothesis. Yet, it does not support it as strongly as might be expected if an immigrant population of Aurignacian people, possessing a distinct adaptive advantage over the resident population of Mousterian people, swept into Europe and rapidly replaced them. Differences between the two sets of assemblages were not evident until the results of complex statistical analyses were carefully picked over. If the two populations were as distinct, culturally and technologically, as some supporters of replacement and discontinuity (e.g., Klein 2000, McBrearty and Brooks 2000, Tattersall and Schwartz 1999) claim they were, then why are the differences in RME strategies not more obvious? Why, for example, is there no sudden, large jump in the distances over which raw materials were acquired, or in the proportions of materials with high fracture predictability like Bergeracois, Mussidan, and jasper?

I do not know the answer to that, but the evidence suggests that the environmental variables that constrained RME before 42,000 BP continued to do so after that time. The people who made Aurignacian artifacts had to cope with those constraints just as the people who made Mousterian artifacts did. Yet, they were not required to invent a completely new solution to the problem of maintaining a supply of adequate raw material. For example, they continued to manage the problem of transporting raw materials by field processing and by partitioning the manufacture process in such a way as to generally reduce acquisition costs without overly compromising the utility of the raw material packages. They also continued to rely primarily on local raw materials, including stream gravels as well as terrestrial outcrops.

If the differences between these earlier and later assemblages are less striking than expected, then this is fully consistent with the notion that groups of people making Mousterian artifacts competed with those making Aurignacian artifacts. As I stated earlier, competition—an essential component of the discontinuity hypothesis—occurs between organisms or groups of organisms whose adaptations are similar; hence their mutual need for a given resource. Perhaps, then, certain formulations of the human revolution model go too far in attempting to contrast Neandertals with "modern humans", or the Middle with the Upper Paleolithic. Exaggerated contrasts may fit with some preconceived notion of how uneven social contests play out, such as those by which non-industrial peoples all over the world have been driven into extinction or assimilation during the past 500 years, but the Middle to Upper Paleolithic transition does not resemble those situations (Zilhão and d'Errico 1999). All Paleolithic groups who inhabited Europe during Oxygen Isotope Stage 3 lived by hunting and gathering, followed wild animal herds, and made tools by breaking rocks. There were probably

fewer technological differences among mid-latitude Paleolithic groups throughout Europe than there were between those groups and the more complex societies that developed nearly everywhere during the Holocene.

Nevertheless, it is still clear that the earlier assemblages differ from the later ones in my study. This difference may suggest that the differences in RME that I documented resulted in an adaptive differential large enough to help ensure the success of the allochthonous population and the failure of the autochthonous one. The precise way in which the economical differences between the RME strategy of the Mousterian assemblages and that of the Aurignacian assemblages led to an adaptive differential is difficult to know. That the creators of both Aurignacian assemblages from Le Flageolet I were carrying around raw blocks of Bergeracois that they collected at least 34 km away may be a clue. They left four cores in the level IX assemblage, and several by-products of early phase manufacture from a walking core in the level XI assemblage. If this strategy raised technological efficiency, it must have done so by reducing cost or by increasing tool efficiency in excess of the amount needed to offset the increased acquisition cost. The higher flake size predictability of Bergeracois may have contributed to such a reduction in cost. Of course, this material may also have improved the efficiency of tool use, although my analysis would not show it. This costly strategy of transporting nodules long distances was not seen in level G from Caminade Est, which is 1,000-8,000 years older than level XI from Le Flageolet I and 5,000-10,000 years older than level IX. Thus, this change toward a more costly acquisition strategy post-dates the earliest Aurignacian in the Perigord by a long time.

My results from the Châtelperronian assemblage from La-Côte are difficult to integrate within the above conclusions because the age of that assemblage is unknown.

It is almost certainly older than level IX of Le Flageolet I and younger than level H8 of Le Moustier, but it could have been made at virtually any time in between. If Zilhão and d'Errico (1999) are correct in assigning the Châtelperronian to the period before 38,000 BP, then level III of La-Côte is older than all three Aurignacian assemblages. However, their argument is controversial (see Mellars 1999, 2000). Even if consensus eventually emerges concerning the correctness of radiocarbon dates from Châtelperronian levels elsewhere, the level from La-Côte will never be dated because the site was destroyed.

Nevertheless, the evidence on RME in this assemblage is important. The stoneworkers who created that assemblage evidently used a strategy that resembles the two Mousterian assemblages in some ways, but resembled the three Aurignacian assemblages in other ways. As in the Mousterian ones, raw material composition was not a simple function of raw material natural availability in and around the middle Isle valley. The raw material composition of the assemblage may have been driven by the fracture predictability of the various materials, because Bergeracois is among those materials occurring in larger than expected amounts, and beige Senonian is among those occurring in smaller than expected amounts, under the model of random collection. Yet, jasper is less abundant than expected, despite the apparently high flake size predictability of that material (see Figure 6.50). Perhaps jasper was used less because fail rate predictability is relatively low (see Table 6.17), or because of its apparently lower strength (Tables 6.18 and 6.19), which might have made blank production easier but increased the wear rates of tools. As for other materials found in larger amounts (pink specked chert) or smaller amounts (silicified wood) than expected, there are no data on fracture properties. Of course, factors other than fracture properties also may have influenced acquisition strategies in this assemblage.

The La-Côte assemblage shows evidence that non-local blanks experienced considerable attrition during transport, like the Aurignacian assemblage in level XI of Le Flageolet I. This represents raw material curation, in that tools were used and repaired rather than being discarded as soon as they became worn. However, such behavior represents just the minimal investment in curating tools. Unlike the three Aurignacian assemblages, La-Côte shows no evidence of differential retouch frequency depending on raw material costs or fracture properties. It also differs from those assemblages in lacking a correlation between blade manufacture and Bergeracois use, although this is the most laminar assemblage of the six.

Overall, the RME strategies represented in this Châtelperronian assemblage seem to give it greater affinities to the two Mousterian assemblages than to the three Aurignacian ones. Moreover, the Châtelperronian and Mousterian assemblages are generally more similar to one another in RME strategies than the three Aurignacian assemblages are among themselves (see Table 7.2). Given the long span of time represented by the latter, this could be an indication that some long-term changes began to be set in motion during the Middle to Upper Paleolithic transition. Such changes might be indicated by the apparent trends in Table 7.2: shifts toward a more opportunistic acquisition strategy, a tighter articulation between the functional demands of blade manufacture and the fracture predictability of certain raw materials, and more efficient consumption through increased retouch frequencies of raw materials that are more costly or have more predictable fracture.

This last point raises the question of how large a difference is required before we can say that the data represent an archaeological discontinuity, instead of a gradual change. Supporters of the discontinuity hypothesis sometimes paint a picture of great

contrasts. What is generally missing is a clear exposition of tolerance limits for judging differences, beyond which any further decrease in similarity supports the model. For instance, Mellars (1996: 400-401) stated that the "earlier stages of the Aurignacian in Europe provide explicit evidence for radical changes in at least five or six separate aspects of behaviour [including] the technology ... of stone tool production... and the emergence of greatly expanded networks for the distribution of ... high-quality raw materials." Supporters of this idea have provided no clear guidelines for assessing the fit between such statements and detailed data on stone tool technology or raw material provisioning, such as those I have presented here. For this reason, I believe the data presented here can not be used to assess the ultimate truth of the replacement scenario. Furthermore, I believe the problem lies not with these data, but with the absence of any effort to develop specific empirical expectations for raw material provisioning based on the replacement scenario. While I attempted to do so in a general way, I did not develop tolerance limits that could be used for testing the replacement scenario. Such will have to await improvements in the specificity and empirical relevance of that model.

The analyses I have presented here can not fully answer an important question about the replacement scenario: If an interaction of allochthonous and autochthonous populations created competition for resources, and if that competition raised the adaptive cost of technological inefficiency, then how long did this effect last? Presumably, it would only have lasted as long as the two groups were in competition. Once competition was removed—perhaps by the disappearance of the less successful population—then natural selection on technological efficiency should have dwindled. If so, heightened technological efficiency would be temporally correlated with the period of interaction between these two putative groups. To test this hypothesis, one would need

to apply the same analyses I have carried out on a series of Middle Paleolithic assemblages pre-dating 40,000 BP, a series of Upper Paleolithic assemblages post-dating 30,000 BP, and a third series of assemblages dating to the time of the alleged population interaction. In addition, it would be interesting to consider how lithic RME might have evolved after the putative autochthonous population were gone. In population genetics, when selective pressure is removed, genetic variation increases (Levins 1968). Perhaps an analogous process took place among Aurignacian populations after 30,000 BP, leading to greater heterogeneity in RME. Then again, competitive pressure may not have been lifted when the Mousterian population vanished; some proponents of replacement have suggested that the allochthonous population was large, larger than the resident Mousterian population. If so, competition may have been there to stay.

A related question is whether the changes I have documented in RME have anything to do with the putative Middle to Upper Paleolithic transition. Given the length of time represented by these six assemblages—10,000 to 15,000 years—the occurrence of some modest changes in technology and behavior is not surprising. If we were to sample six Mousterian assemblages from a similar length of time before 40,000 BP, or six Upper Paleolithic assemblages from a similar length of time after 30,000 BP, we might expect to see changes of similar magnitude in lithic raw material exploitation. If RME were related to environmental change, then this suggestion would become even more compelling. The climatic record shows many dramatic oscillations during Oxygen Isotope Stage 3, suggesting that environmental changes between 61,000 BP and 29,000 BP were frequent, rapid, and of large magnitude (Burjachs and Julià 1996, Guiot *et al.* 1993, Jouzel *et al.* 1989). The trends I have documented in RME between 42,000 BP

and 27,000 BP may be related to those changes rather than to the technological and typological differences between Mousterian and Aurignacian or the biological transition from Neandertals to *H. s. sapiens*. If so, then those trends are neither the cause nor the result of an adaptive differential between two competing populations.

In this vein, it is interesting to note that there are no cases in Europe of interstratification between Mousterian and Aurignacian industries. Of course, a large body of chronometric dates for these two cultural traditions indicates concurrence on regional and continental scales. Nevertheless, the complete absence of interstratification is inconsistent with the premise that two groups existed in the same places at the same times, and this is incongruous with the tenet that Mousterian and Aurignacian groups interacted, a tenet that is central to the human revolution, long African development, Neandertal acculturation, and Neandertal invention models (see Chapter 1). The idea that people belonging to these two cultural complexes never saw one another is, therefore, tenable. Whatever the Mousterian represents—a group of people, a technocomplex, a species—if it vanished before the Aurignacian arrived, then the differences I have documented here could not be related to change. Instead, they would only signal differences between two unrelated cultural entities. Whether this idea has any merit at all depends on how one interprets existing chronometric dates, and the weight one attaches to problems related to calibrating radiocarbon ages between 40,000 BP and 30,000 BP (Pettit 1999). Until these chronological problems are resolved, it seems worthwhile to entertain the possibility that variation in RME strategies are related to environmental change, and unrelated to cultural interaction or ecological competition.

Unfortunately, it is difficult to predict how climatic change or environmental change might affect RME in the Perigord, or for that matter in any setting in the remote

past. The environmental variables that I examined here are essentially independent of environmental change. There are some environmental changes that could affect the availability of lithic raw materials, such as the sediment loads of streams and migrating stream channels (which could bury some occurrences and expose new ones). As noted previously (e.g., Chadelle 1983, Straus 1991, Turq 1992), other environmental changes might affect the visibility of raw material occurrences, such as the amount of vegetation cover or depth of snow. However, changes in streams are unlikely to have resulted in marked increases or decreases in the availability of raw material occurrences in the Perigord. Changes in the visibility of occurrences might have an effect in the very short term, but seem unlikely to affect long-term RME because users of lithic raw material would accumulate knowledge of their environment.

If environmental change did affect RME, then it was probably through its effects on the foraging economy and on mobility patterns. Blades (2001) suggested the following set of relationships for the Perigord in late Stage 3: In colder, more open environments, human subsistence is relatively more specialized and groups are more mobile as they pursue migrating game herds. Warmer, more wooded environments favor smaller populations of less mobile game, which in turn favors increased diet breadth among human hunters and lower mobility. Blades' data do not fully address this model, but the model does suggest how environmental change might affect lithic RME. Higher mobility, defined as more frequent residential moves (and consequently lower residence times), would result in more energy being expended on travel, leaving less available for other activities. Thus, increased mobility may lead to less time devoted to raw material procurement. In addition, decreased residence times would decrease opportunities to explore the environment around the residence site, and search times

(for raw material) would have a higher cost. Yet, higher mobility would also lead to more travel, and consequently an increased frequency of chance encounters with raw material occurrences. In short, higher mobility would favor a more opportunistic strategy of raw material acquisition, or at least, one in which the probability that a given occurrence would be exploited is a direct function of its proximity to travel routes. Higher mobility would disfavor any strategy that required devoting time specifically to the search for raw material. At the same time, higher mobility might increase the relative cost of carrying raw material, which might favor increased raw material conservation.

Of course, this is all speculative, but it suggests a possible explanation for the apparent shift to a strategy of more opportunistic raw material acquisition and increased blank conservation after 38,000 BP. The shift may be the result of an increase in residential mobility, which in turn is tied to a trend toward colder, more open environments. Whether it is realistic to expect these relationships could be evaluated by studying the ethnographic record of mobile hunter-gatherers in cold temperate and sub-arctic environments. Whether this explanation works for the period in question here could be tested with data concerning two areas: paleonenvironments and mobility. At Le Flageolet I, faunal data from level XI indicate a cold, open steppe environment; fauna from level IX indicate a slight warming and an increase in woodland animals (Delpech et al. 2000). The lithic assemblages from both levels suggest an opportunistic raw material acquisition strategy and increased blank conservation (higher retouch frequencies). What remains to be seen is whether faunal data for 37,000 BP also support this kind of environment, and whether the environment was more wooded during the times represented by La-Côte III, Le Moustier H8, and Caminade Est M3. Also needed is a measure of residential mobility that is independent of both faunal data and lithic raw

material composition. Unfortunately, since these assemblages are composed entirely of bones and stones, such a measure will be difficult to find.

The ever-expanding literature on the Middle to Upper Paleolithic transition in Europe has great value. However, the tendency in that literature to treat this issue as a global one has led to the tacit expectation that the answer to the big questions will be found in grand summaries of data from all over the continent, or all over the world. Vast databases have been painstakingly summarized, but the big questions remain unanswered. Worse, the issue continually becomes more complicated. In part, this is a natural by-product of the advance of any discipline: things get more complex before they become easier to understand. Yet, some of the confusion could probably be avoided by focusing on what was happening between 40,000 BP and 30,000 BP in individual neighborhoods, rather than by looking at the whole country, so to speak. By doing so here, I have clarified which issues most need to be addressed for understanding lithic raw material exploitation in the Perigord, and the kind of data that will be required to address those issues. We need to ascertain whether there was competition leading to increased selection for technological efficiency. We need a measure of residential mobility that is independent of the data we use to reconstruct technological efficiency. We need models that specify in clear archaeological terms what we should expect to see in lithic assemblages when groups become more mobile or less mobile. And we need better information on the magnitude of the changes that nearly everyone agrees were happening for a few thousand years or more. Of course, while accomplishing these things, future archaeologists will only raise additional issues, and these will have to be addressed. Doing so will bring us ever closer to figuring out what happened in Europe between the end of the Middle Paleolithic and beginning of the Upper Paleolithic, and

explaining why it did. If this dissertation has brought us a step closer to that goal, then it has been worth the effort.

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# Appendix A

This appendix contains illustrations of some of the artifacts in each of the six assemblages. Some of the illustrations are reprinted from other sources, as noted in the captions. Kay Bennet drew a few of them, and I sketched a few others. The bulk of them were drawn by Sylvain Pasty.

The scales are not the same throughout, partly due to space limitations, and partly to the diverse sources from which the illustrations came.

The purpose of the drawings is two-fold: to illustrate specific points that are discussed in the text, and to allow the reader to see what the objects look like, so that he can make his own interpretations. I specifically avoided showing only attractive tools, and included many objects that do not appear in any textbook. The hope is that this more faithfully represents the true character of the assemblages. Even so, such a small sample of illustrations provides only a narrow glimpse at the assemblages.

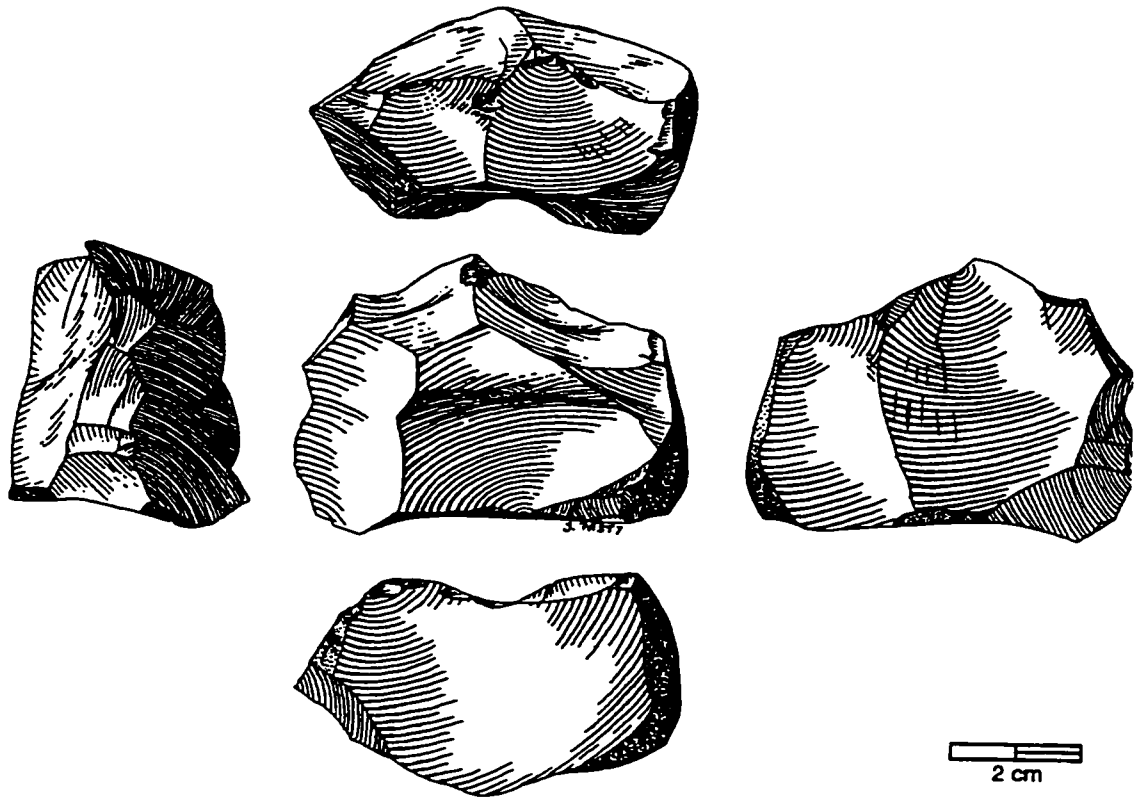



Figure A.1 Le Moustier, H8. Catalogue number 1096, prepared flake core with two striking platforms (core category 2B), in beige Senonian silex

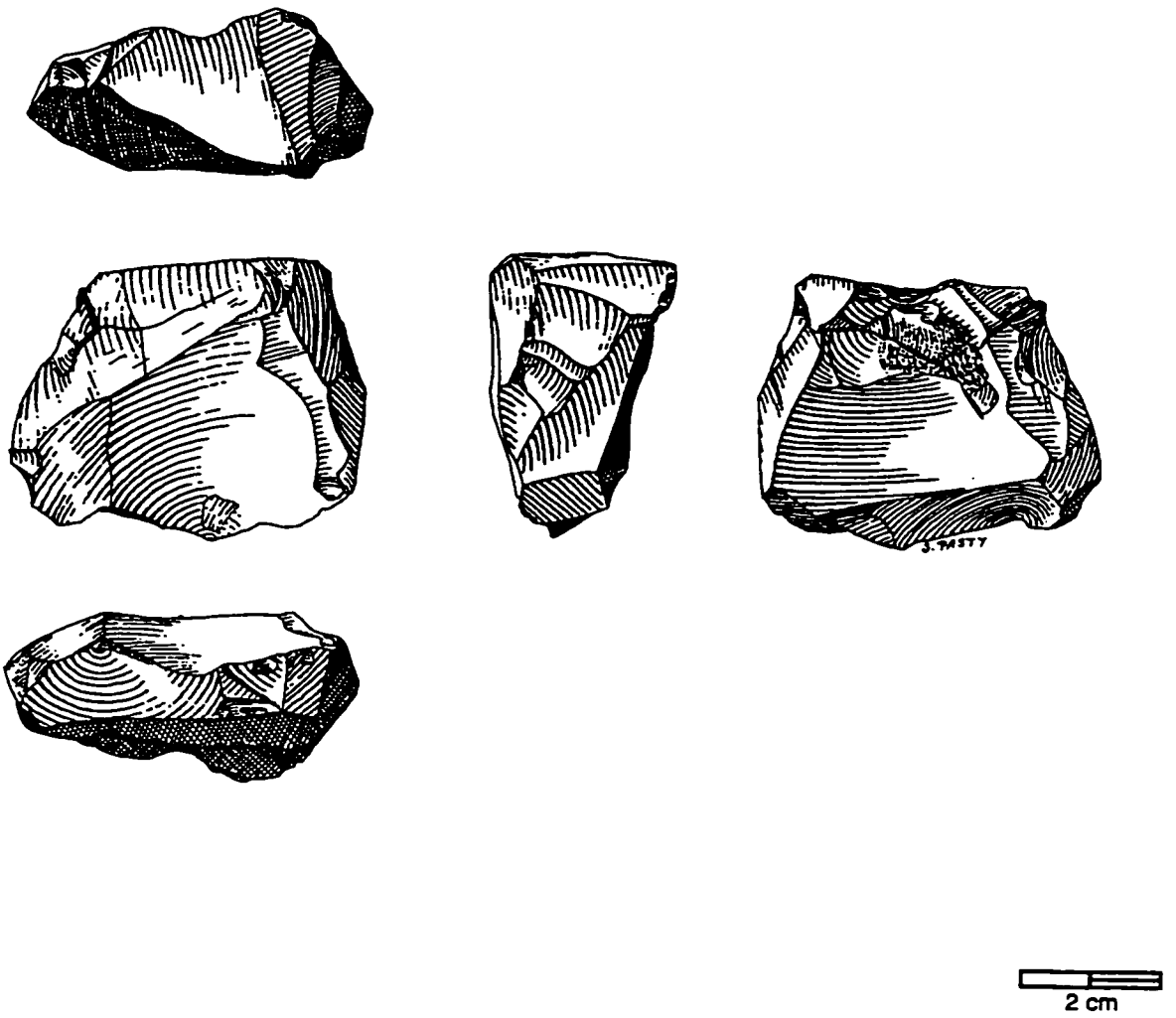



Figure A.2 Le Moustier, H8. 1069, Levallois core, in black Senonian silex.

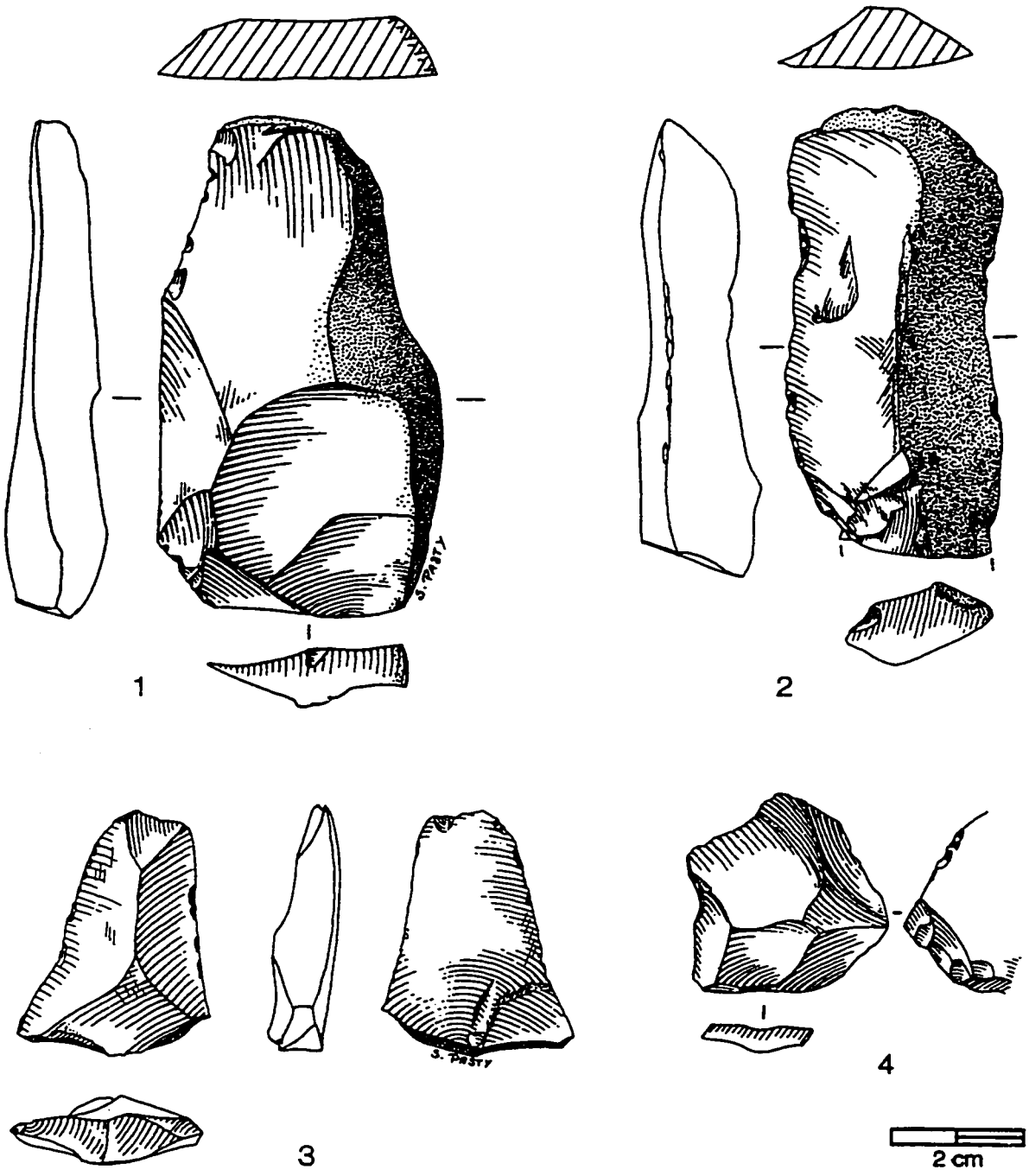



Figure A.3 Le Moustier, H8. 1: semi-cortical flake (naturally-backed knife); 2: cortical blade (naturally-backed knife); 3: non-cortical flake; 4: Levallois flake (non-cortical).

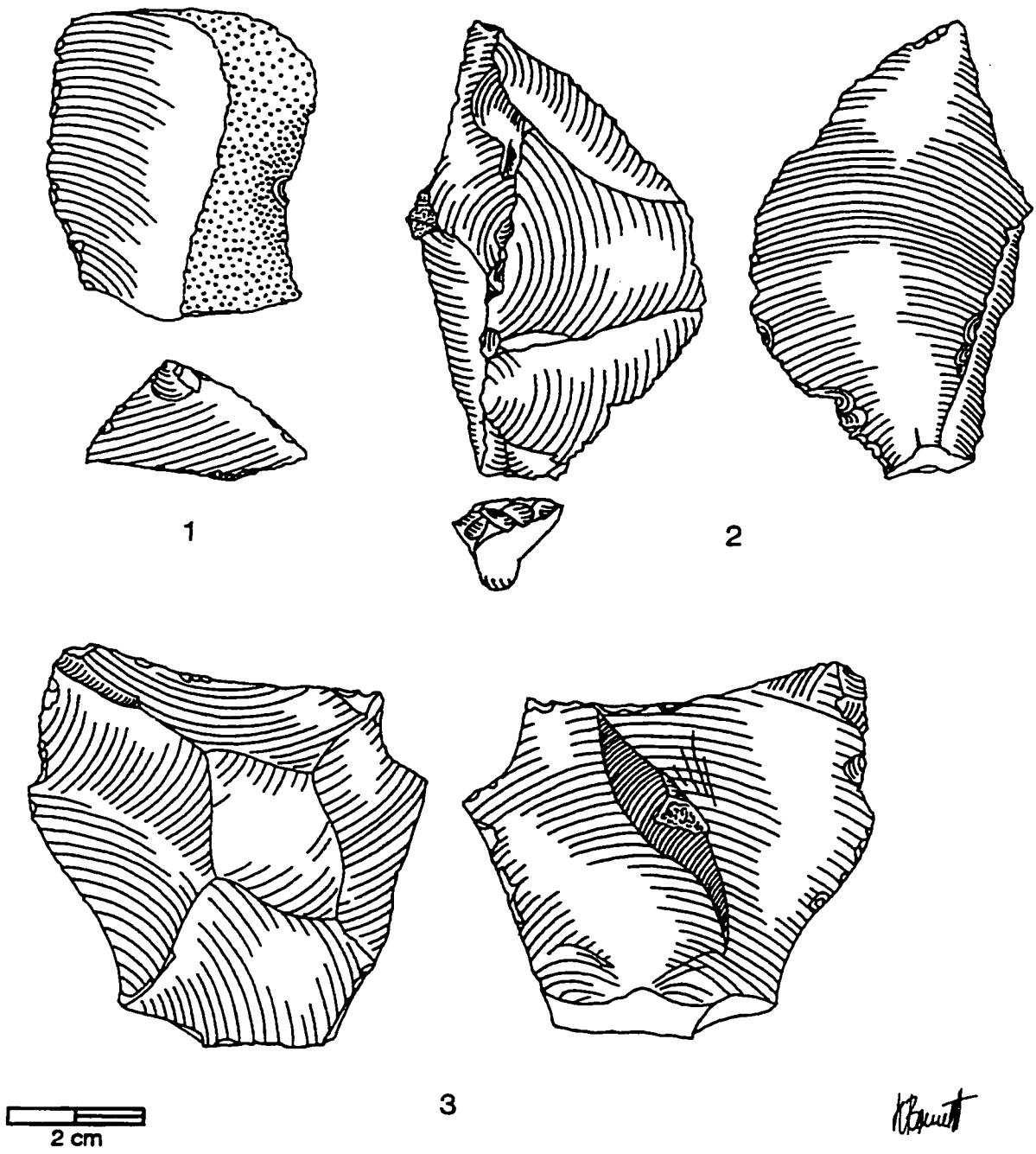



Figure A.4 Le Moustier, H8. 1: semi-cortical fragment (naturally-backed knife); 2: crested flake (non-cortical); 3: Levallois flake (non-cortical). All by K. Bennett.

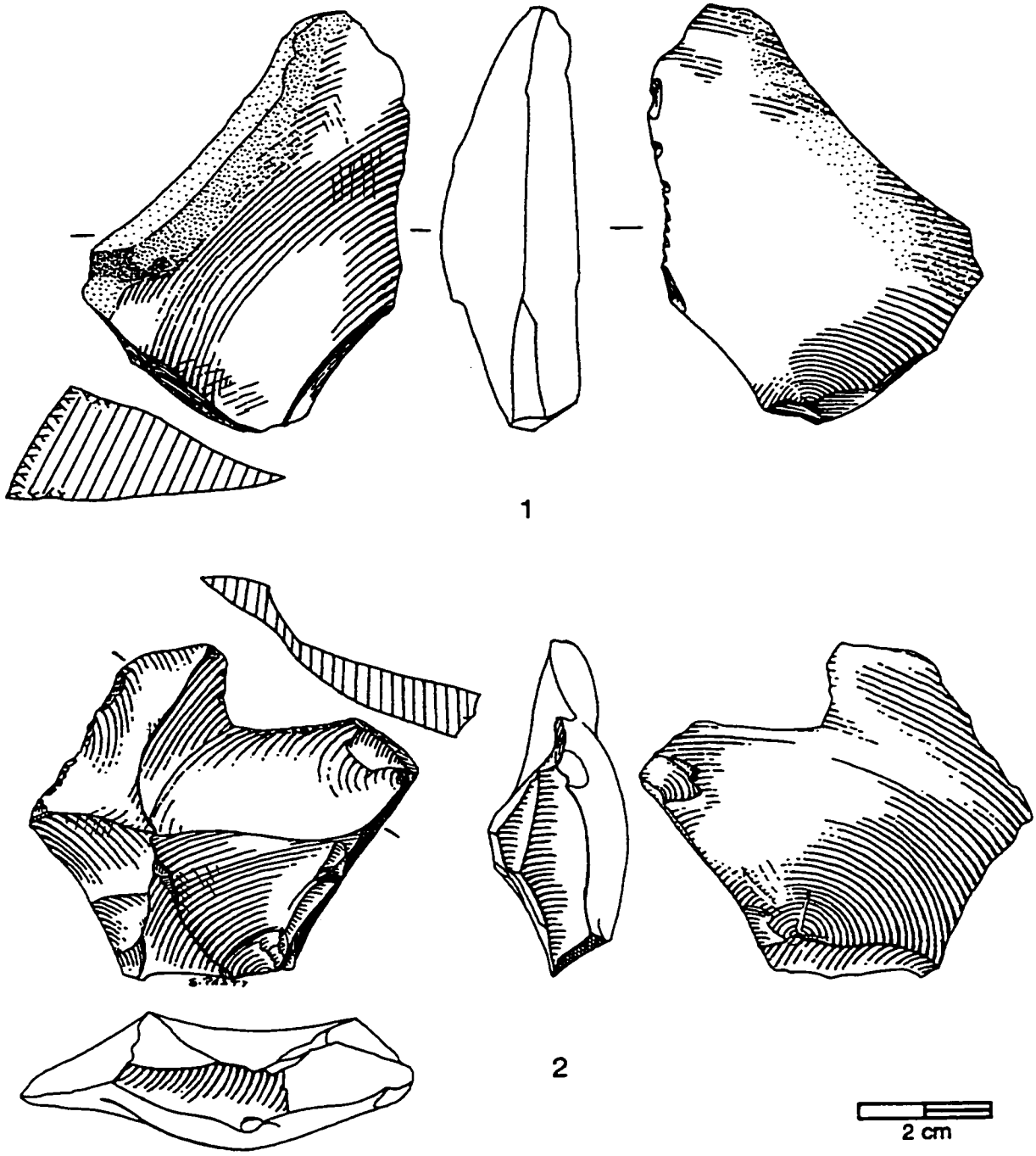



Figure A.5 Le Moustier, H8. 1: semi-cortical flake; 2: Levallois flake (non-cortical).

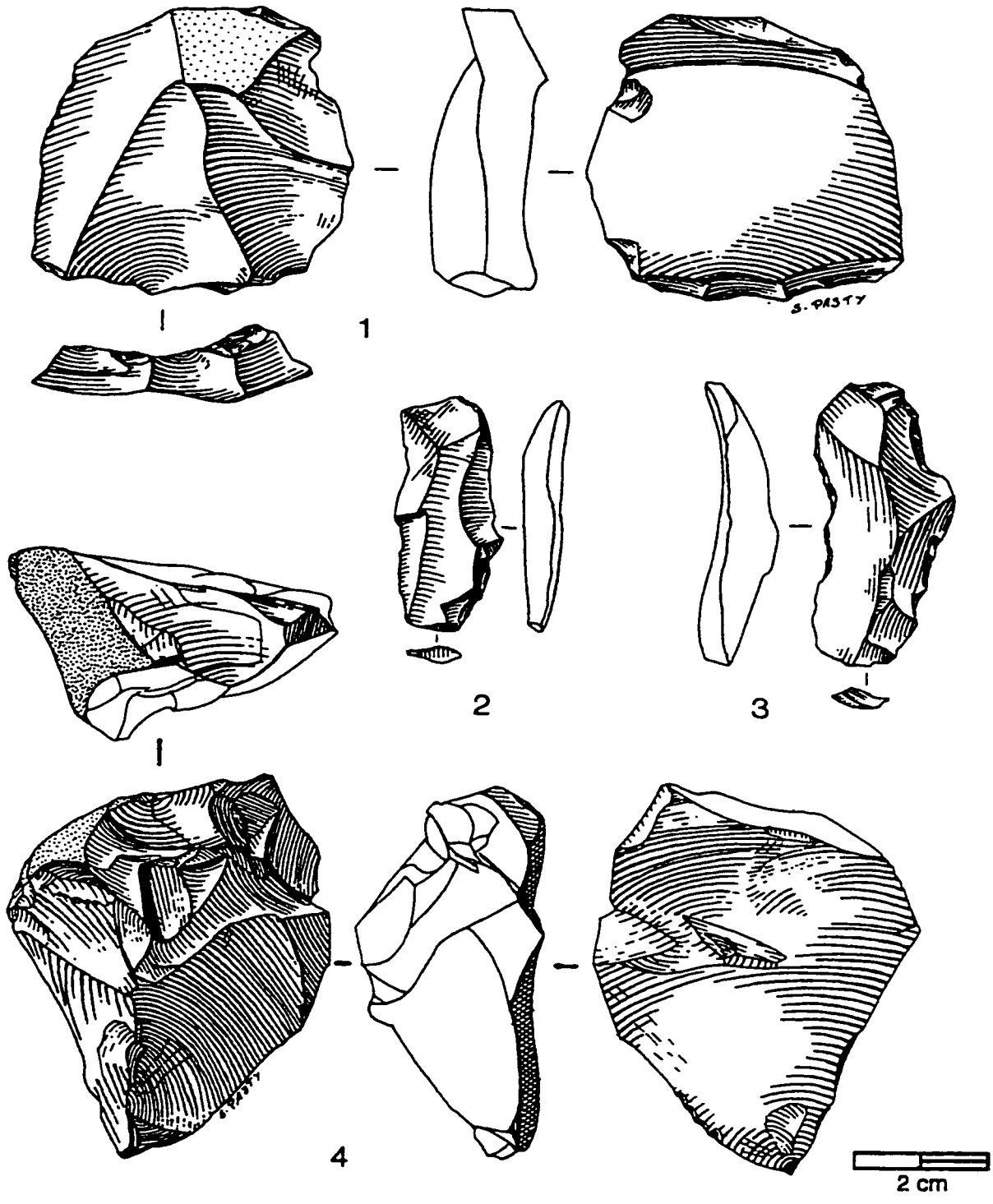



Figure A.6 Le Moustier, H8. 1: Levallois flake; 2 and 3: non-cortical blades; 4: semi-cortical flake, possibly produced as a crested flake.

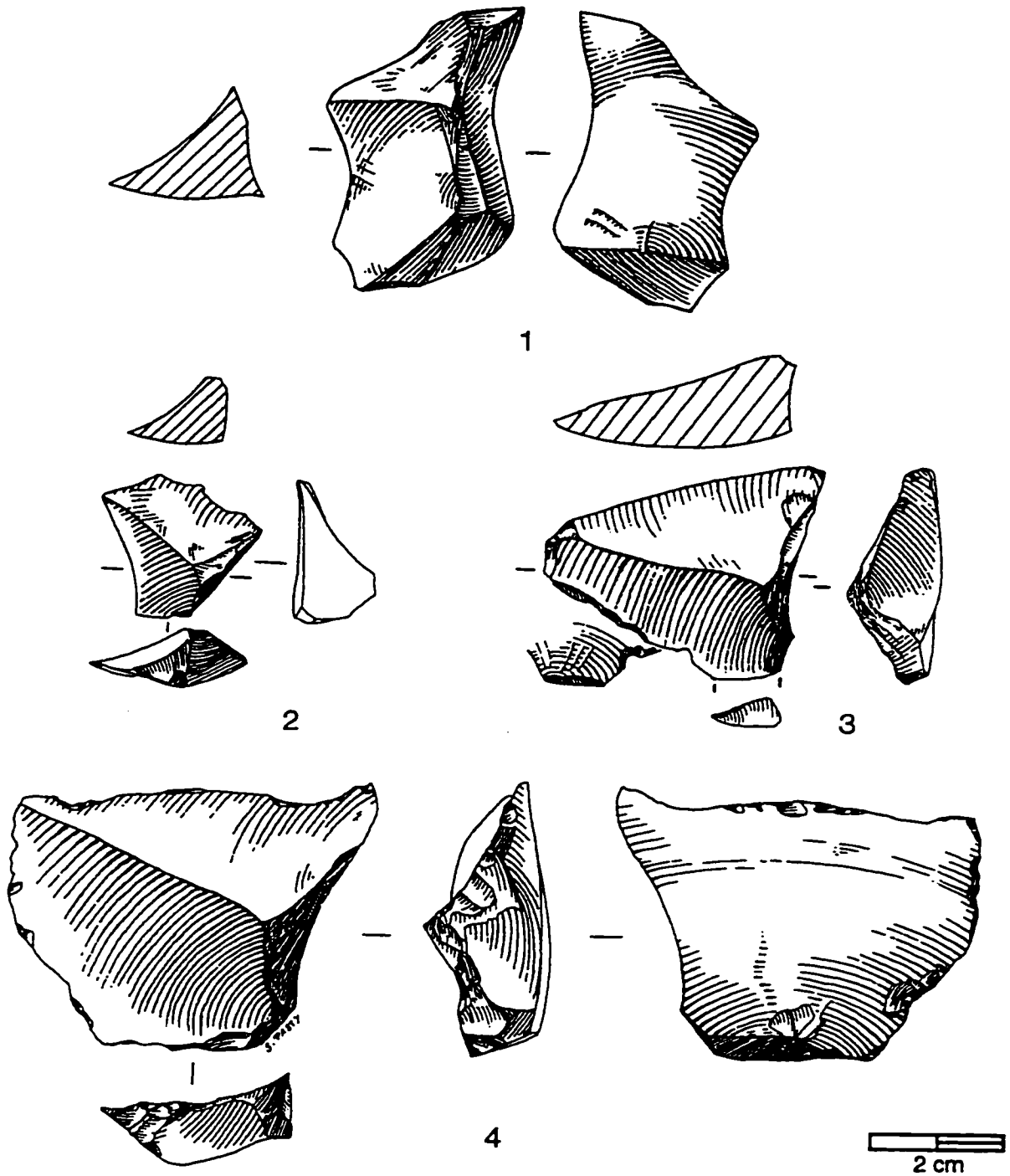



Figure A.7 Le Moustier, H8. 1: crested flake; 2-4: *éclats débordants*.

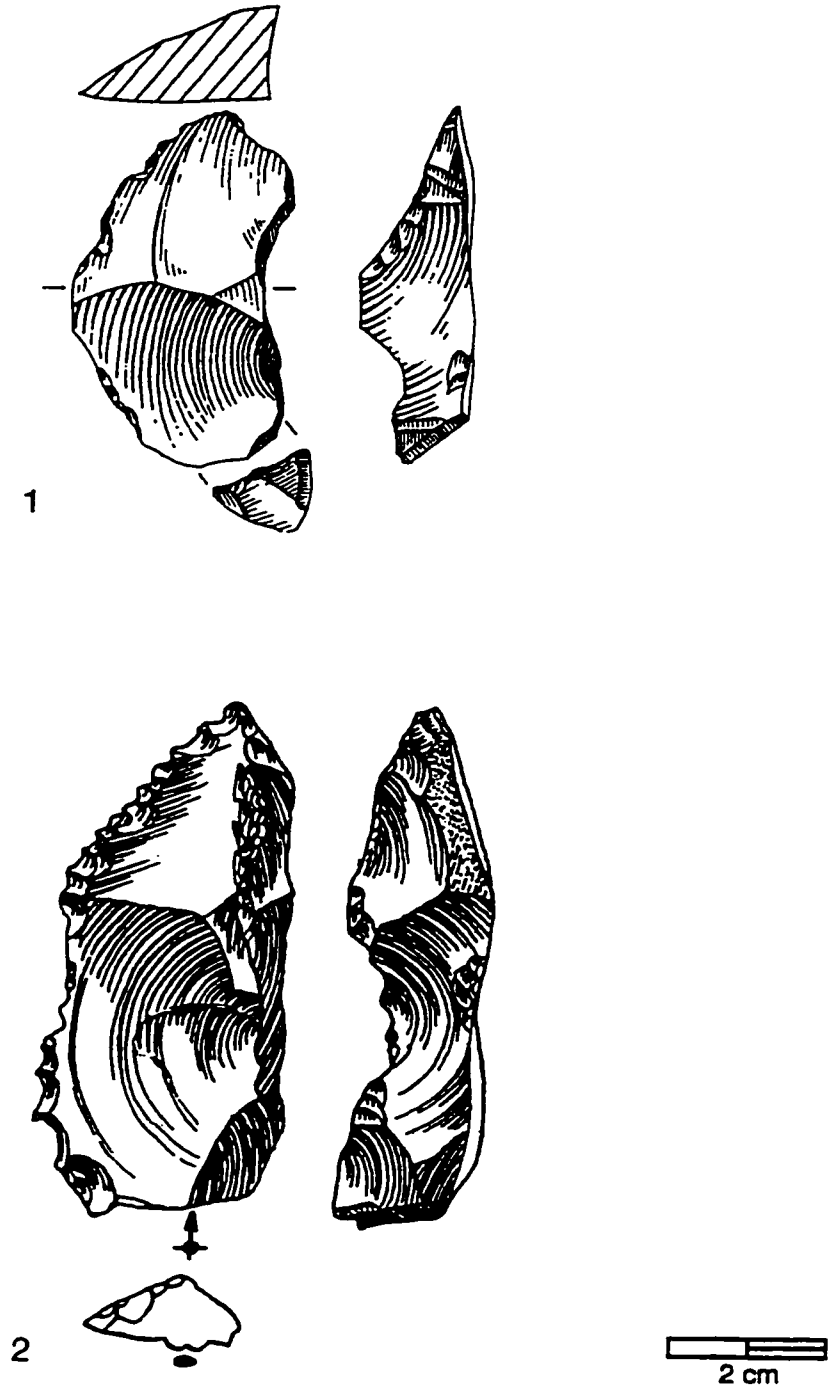



Figure A.8 1: Partial core rejuvenation tablet, from Le Moustier, H8. 2: "Lateral convergent denticulated piece made on an *éclat débordant*," from Fonseigner, F (Geneste 1985, plate 10). Both pieces could be considered either partial core reduction tablets (type 7b) or *éclats débordants* (type 5d).

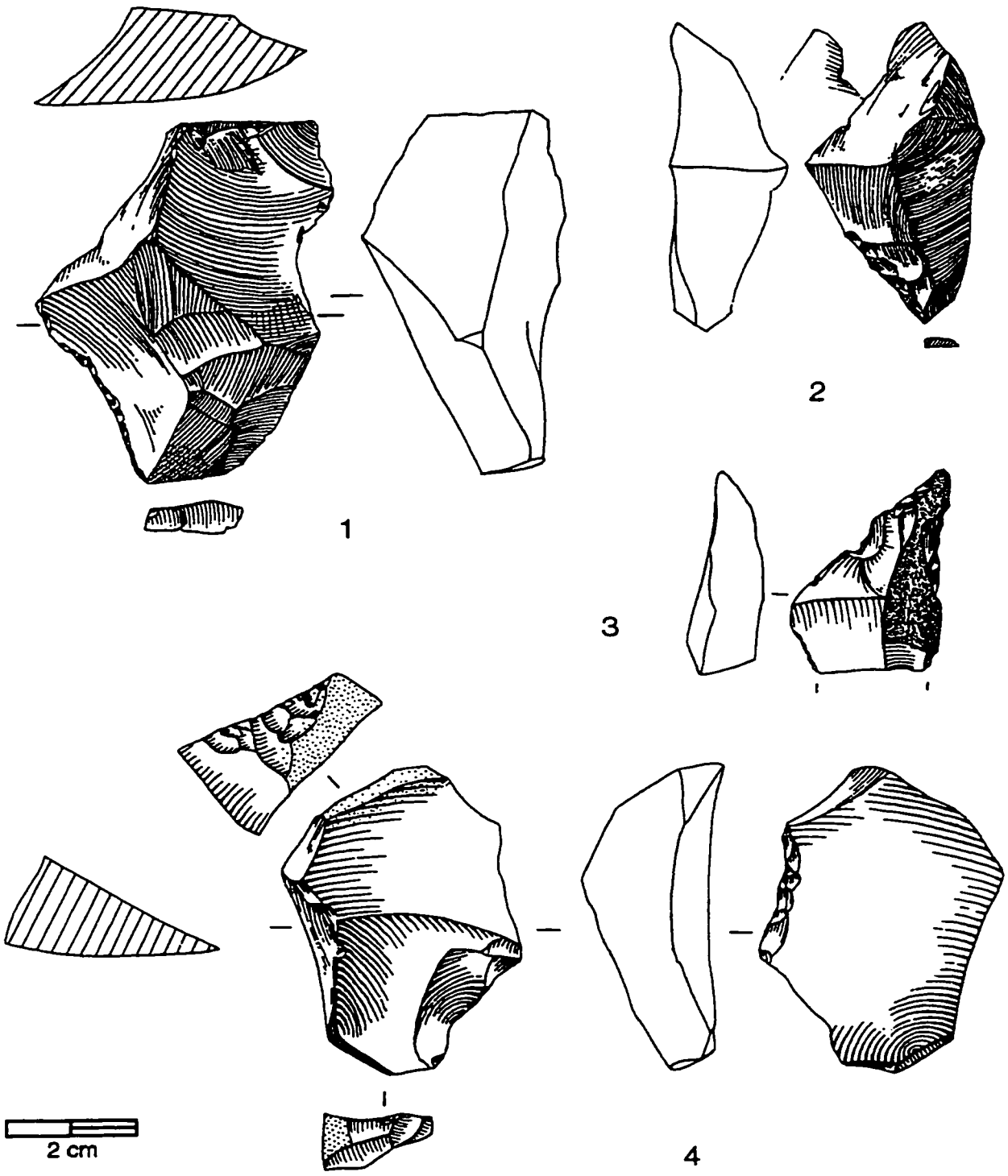



Figure A.9 Le Moustier, H8. 1: Crested flake, with sidescraper retouch (tool type 11); 2: crested flake with possible retouch; 3: semi-cortical fragment with sidescraper retouch (tool type 12); 4: partially cortical flake, with sidescraper retouch on ventral face (tool type 25).

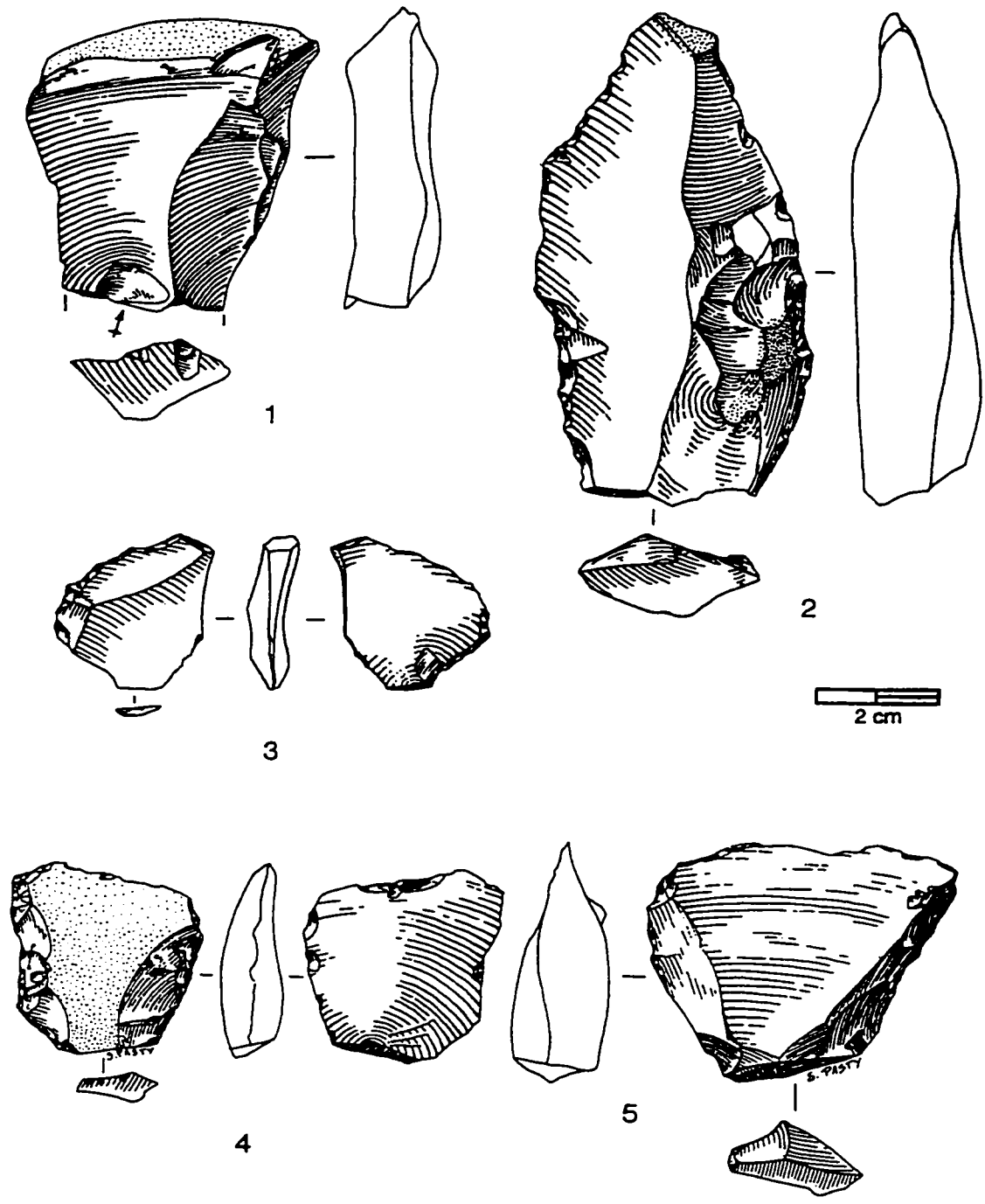



Figure A.10 Le Moustier, H8. 1: Semi-cortical flake; 2: semi-cortical blade, with sidescraper retouch (tool type 15); 3: non-cortical flake, with sidescraper retouch (tool type 10) and possible burin blow (obscured by distal snap fracture); 4: cortical flake, with sidescraper retouch (tool type 11); 5: non-cortical flake, with sidescraper retouch (tool type 9).

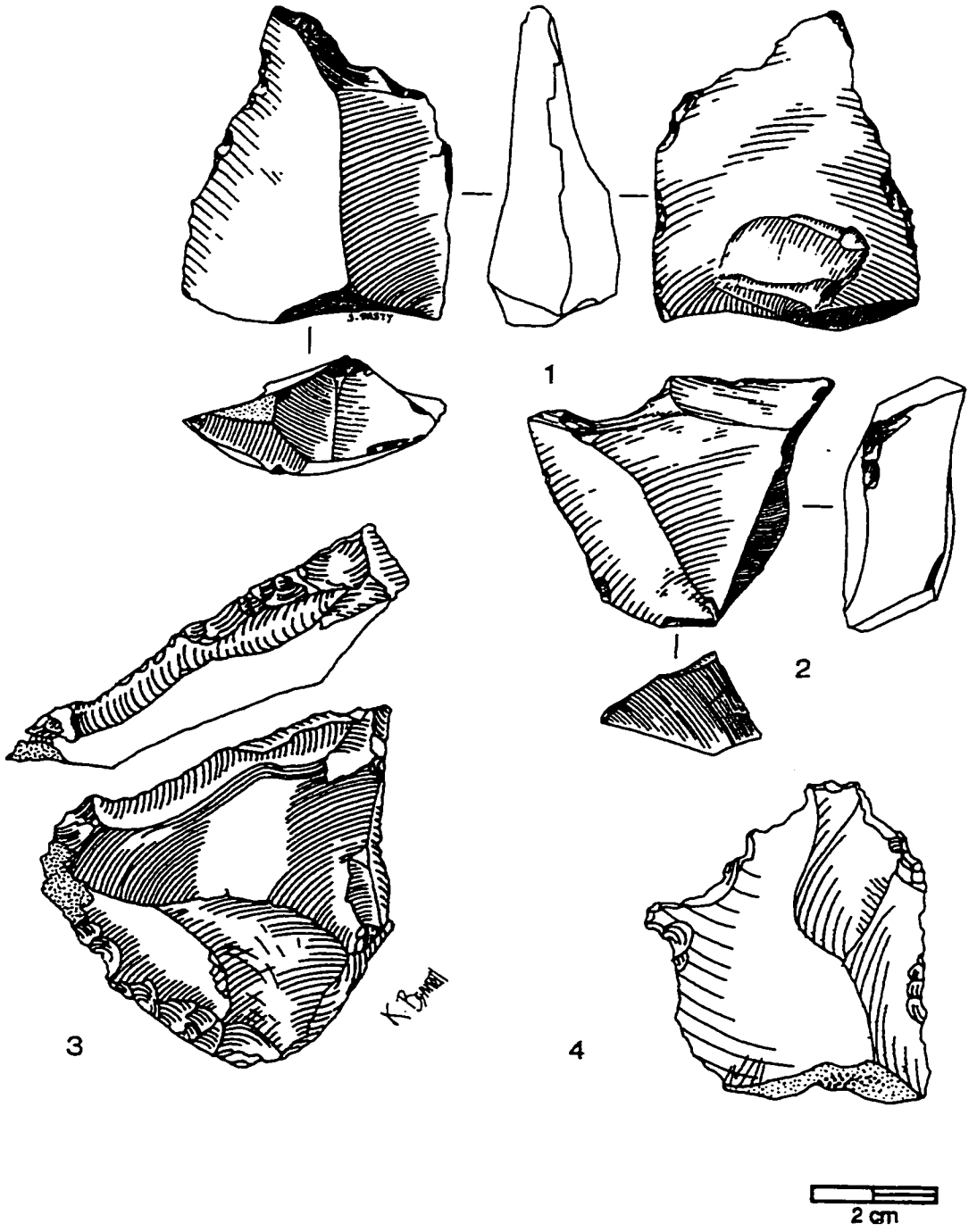



Figure A.11 Le Moustier, H8. 1: *éclat débordant*, with denticulated retouch (tool type 43); 2: non-cortical flake, with notch (tool type 42); 3: *éclat débordant*, with sidescraper retouch (tool type 9); 4: non-cortical flake with cortical butt, retouched as a perforator (tool type 34). 1, 2 by S. Pasty; 3, 4 by K. Bennett.

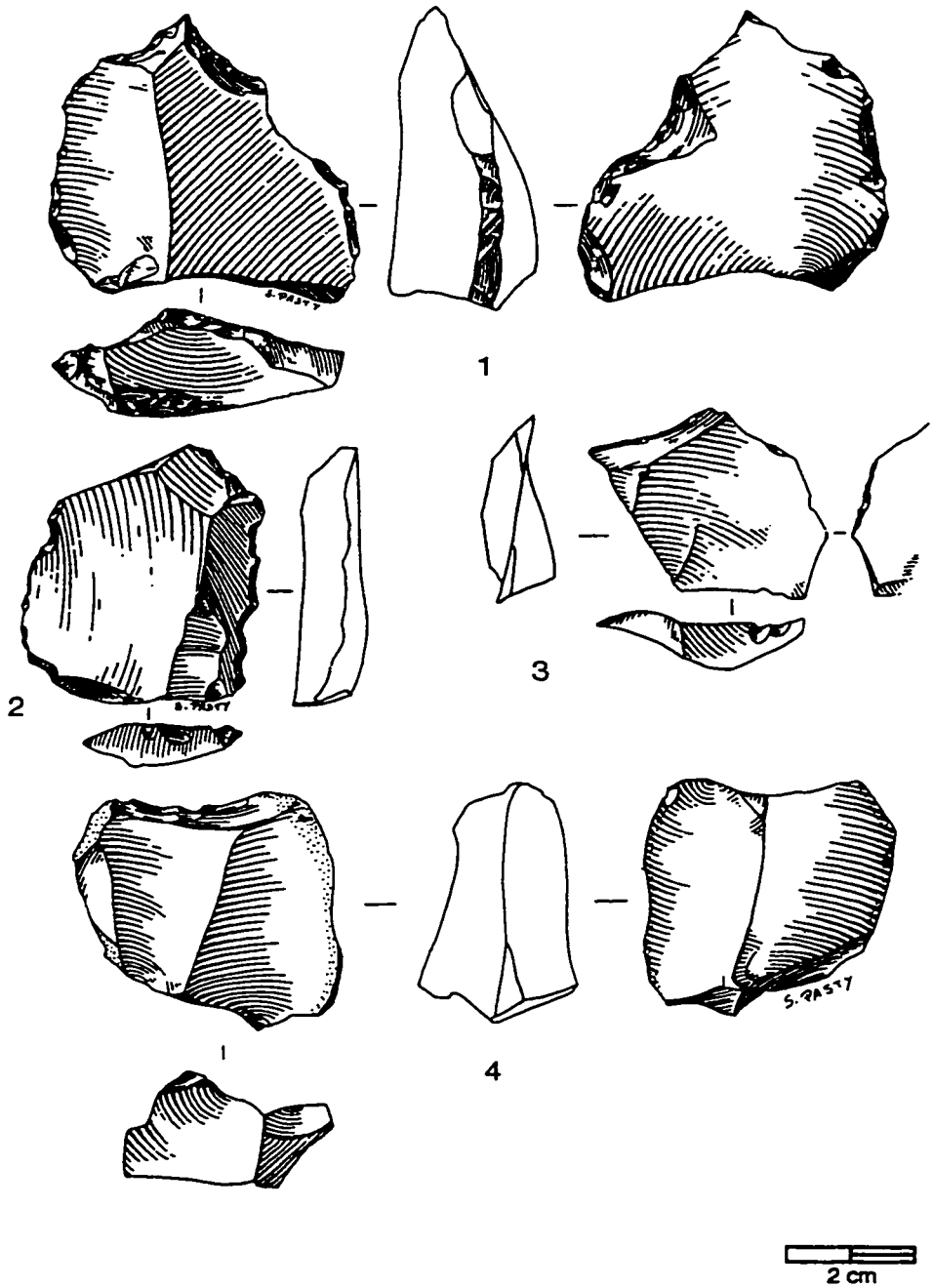



Figure A.12 Le Moustier, H8. 1: *Éclat débordant*, retouched as a perforator (tool type 34); 2: non-cortical flake, with abrupt alternate retouch (tool type 46); 3: *éclat débordant*, with raclette retouch (tool type 39); 4: semi-cortical flake, with retouched truncation (tool type 40); a blade was struck from the ventral face.

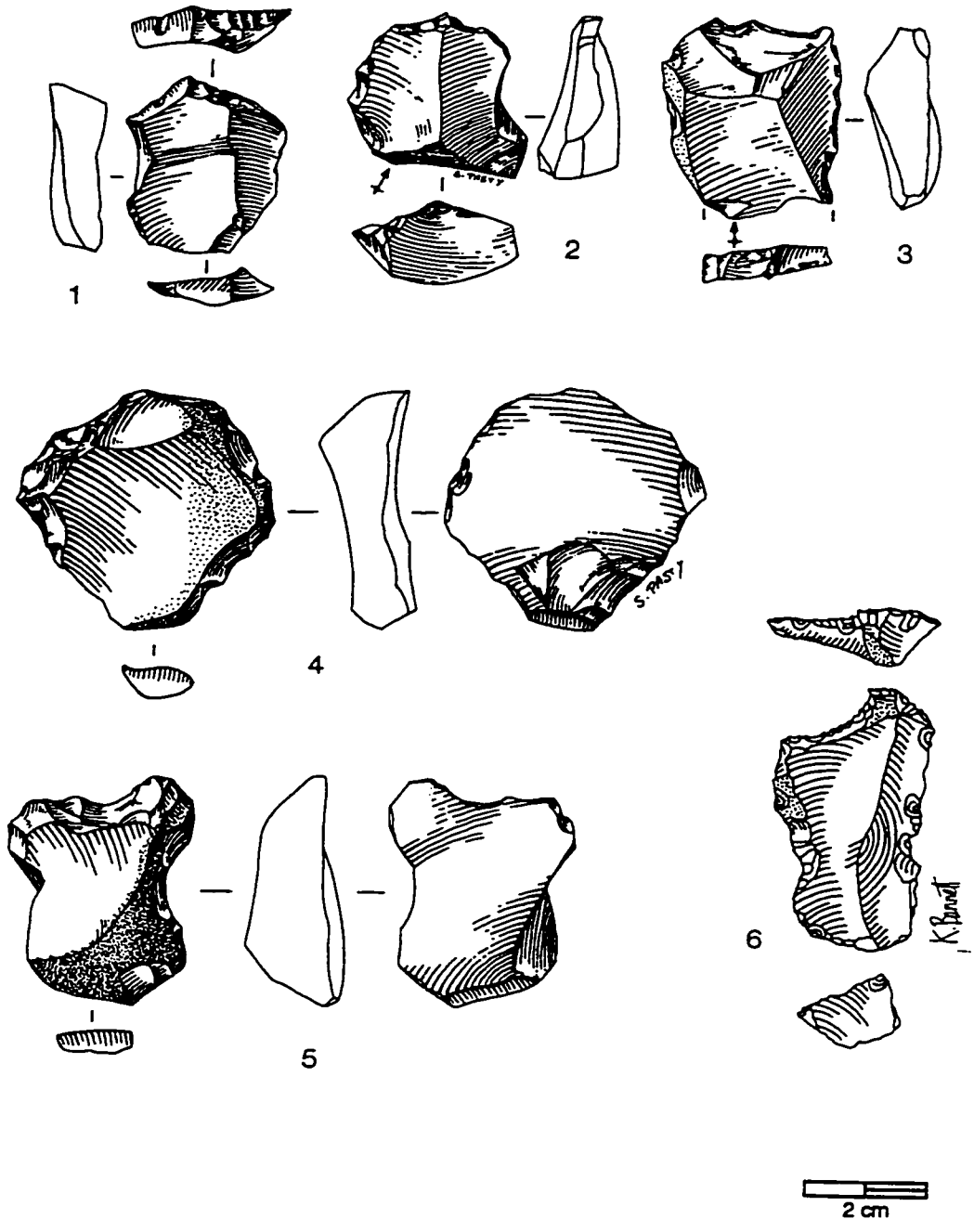



Figure A.13 Le Moustier, H8. 1: Non-cortical fragment, retouched as endscraper (tool type 30); 2: *éclat débordant*, retouched as atypical endscraper (tool type 31); 3: Levallois flake, retouched as perforator (tool type 34); semi-cortical flake, retouched as endscraper (tool type 30); 5: cortical flake, retouched as atypical endscraper (tool type 31); 6: semi-cortical flake, retouched as atypical endscraper (tool type 31). Number 6 by K. Bennett.

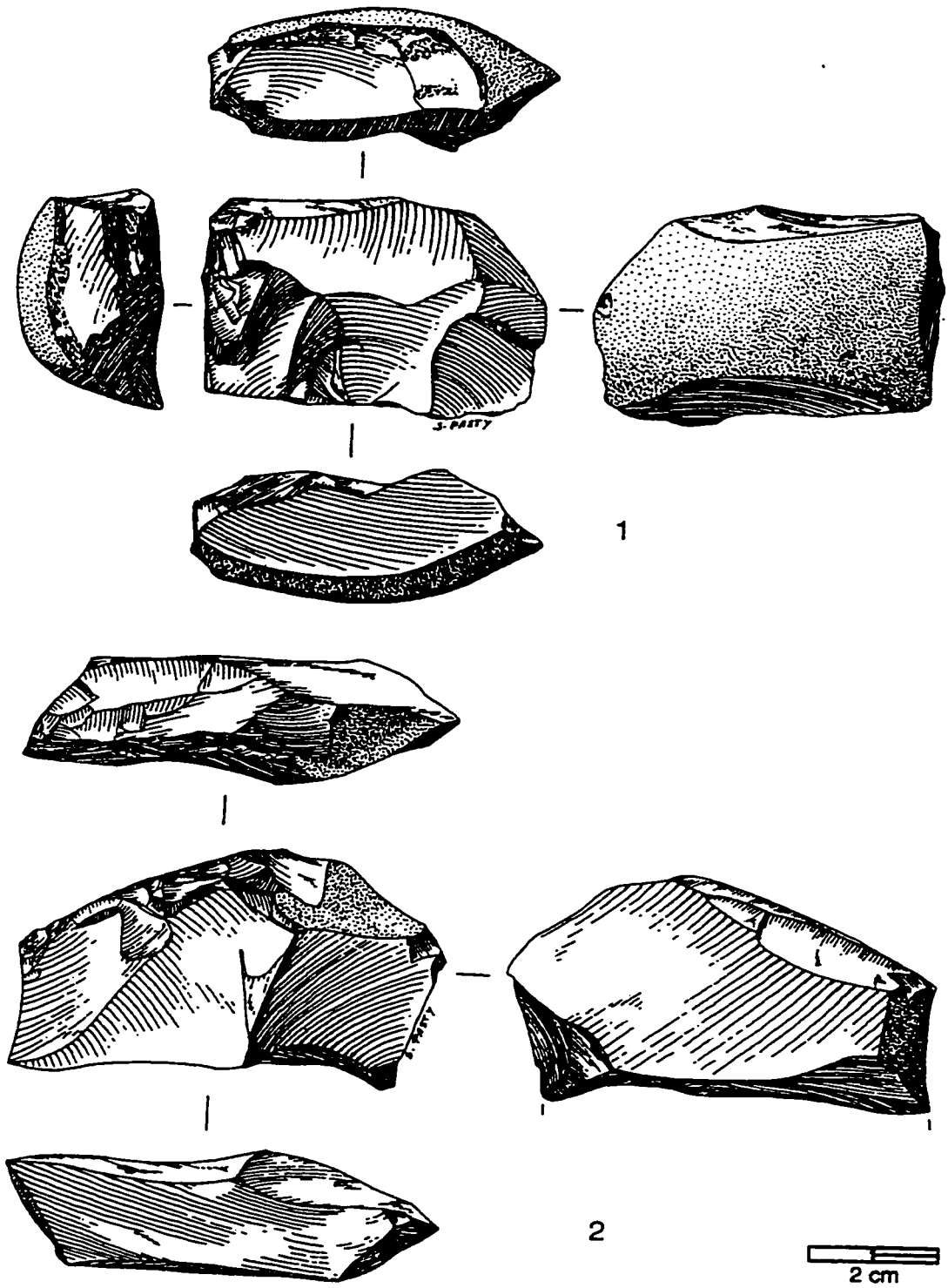



Figure A.14 Caminade Est, M3. 1: B9.523, core (category 2B), made in indeterminate Senonian chert; 2: Y10.27, proximal fragment, semi-cortical.

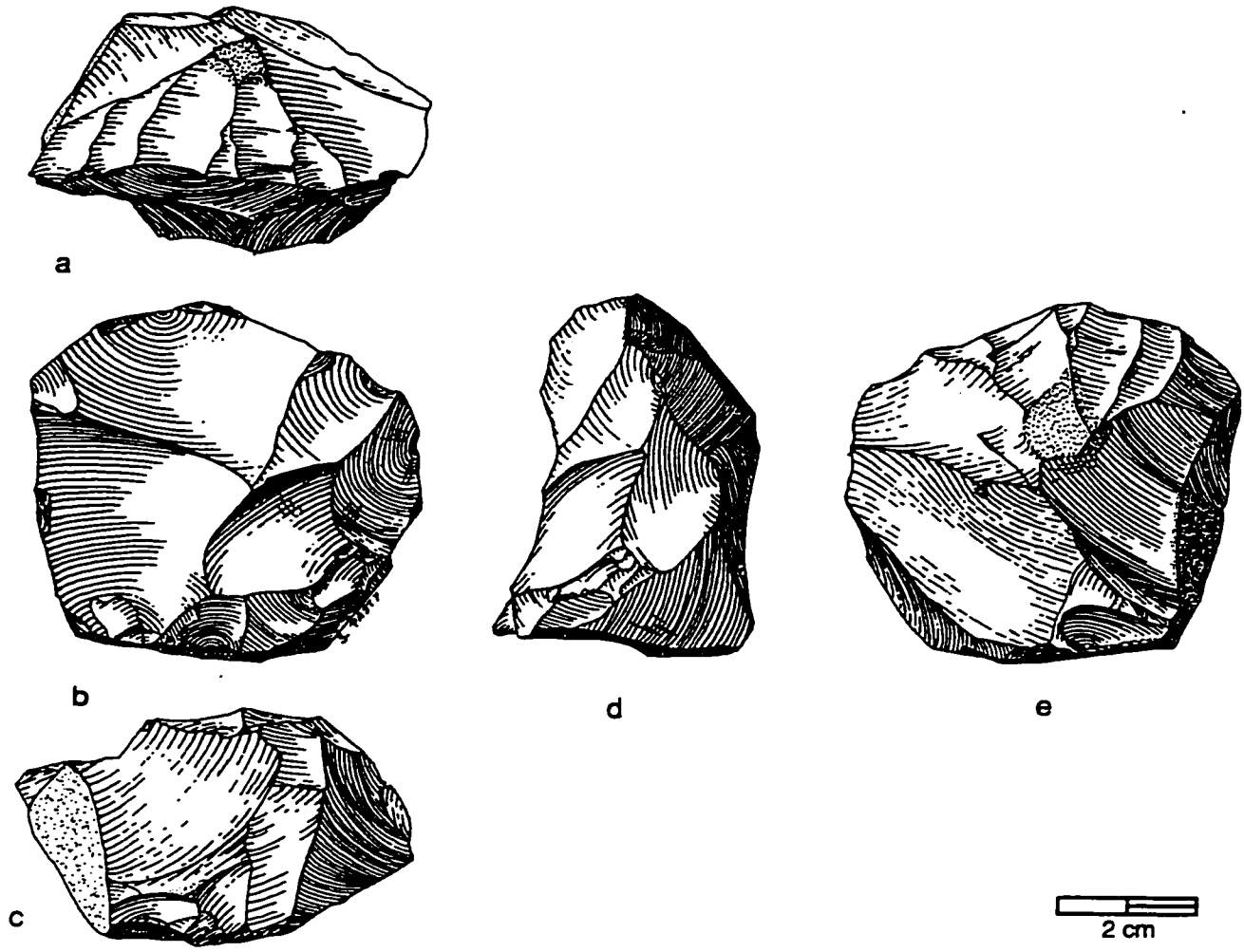



Figure A.15 Caminade Est, M3. B10.488, core (category 10A), made of black Senonian chert.

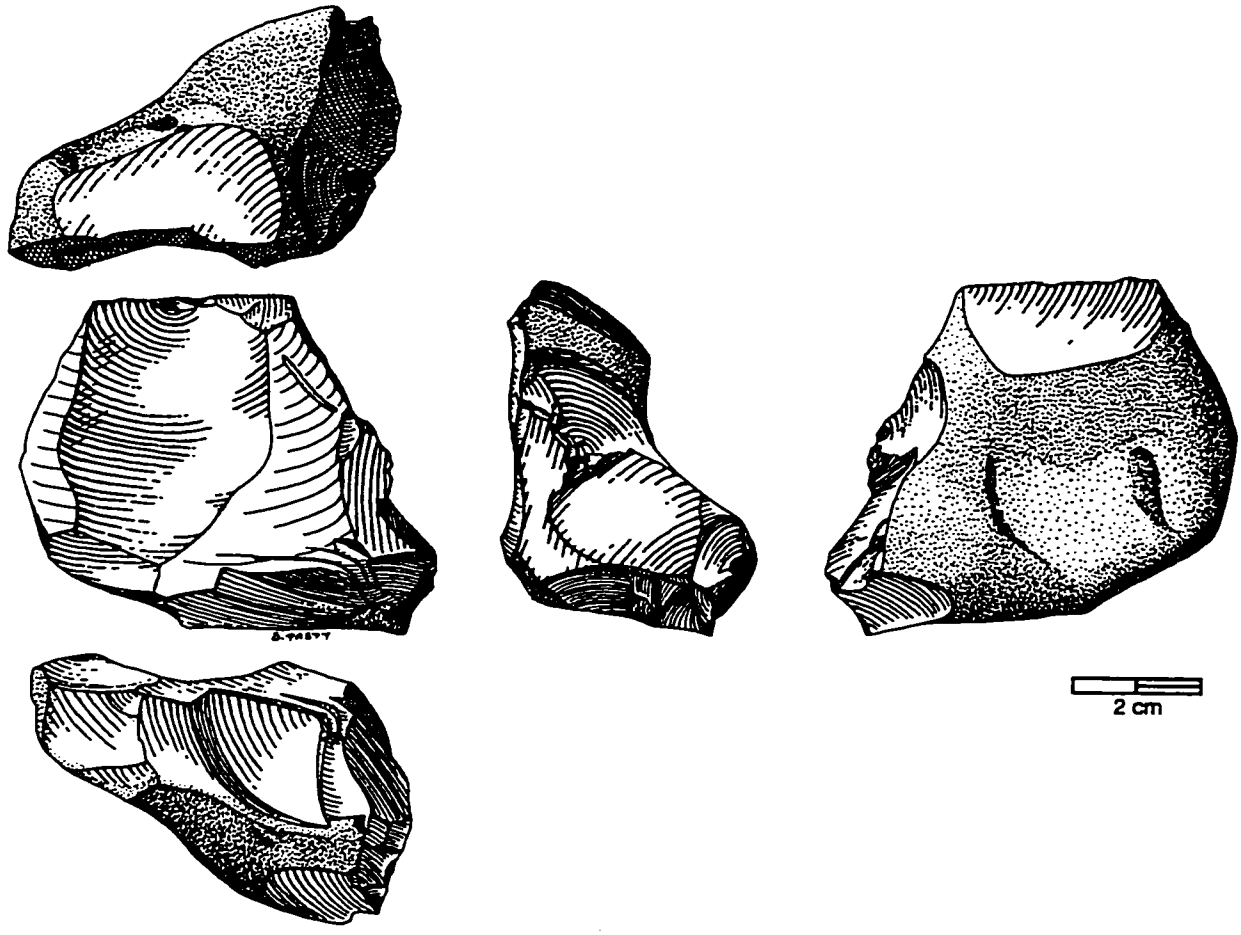



Figure A.16 Caminade Est, M3. Y10.3, Kombewa core (category 6), made of a flake of unidentified chert.

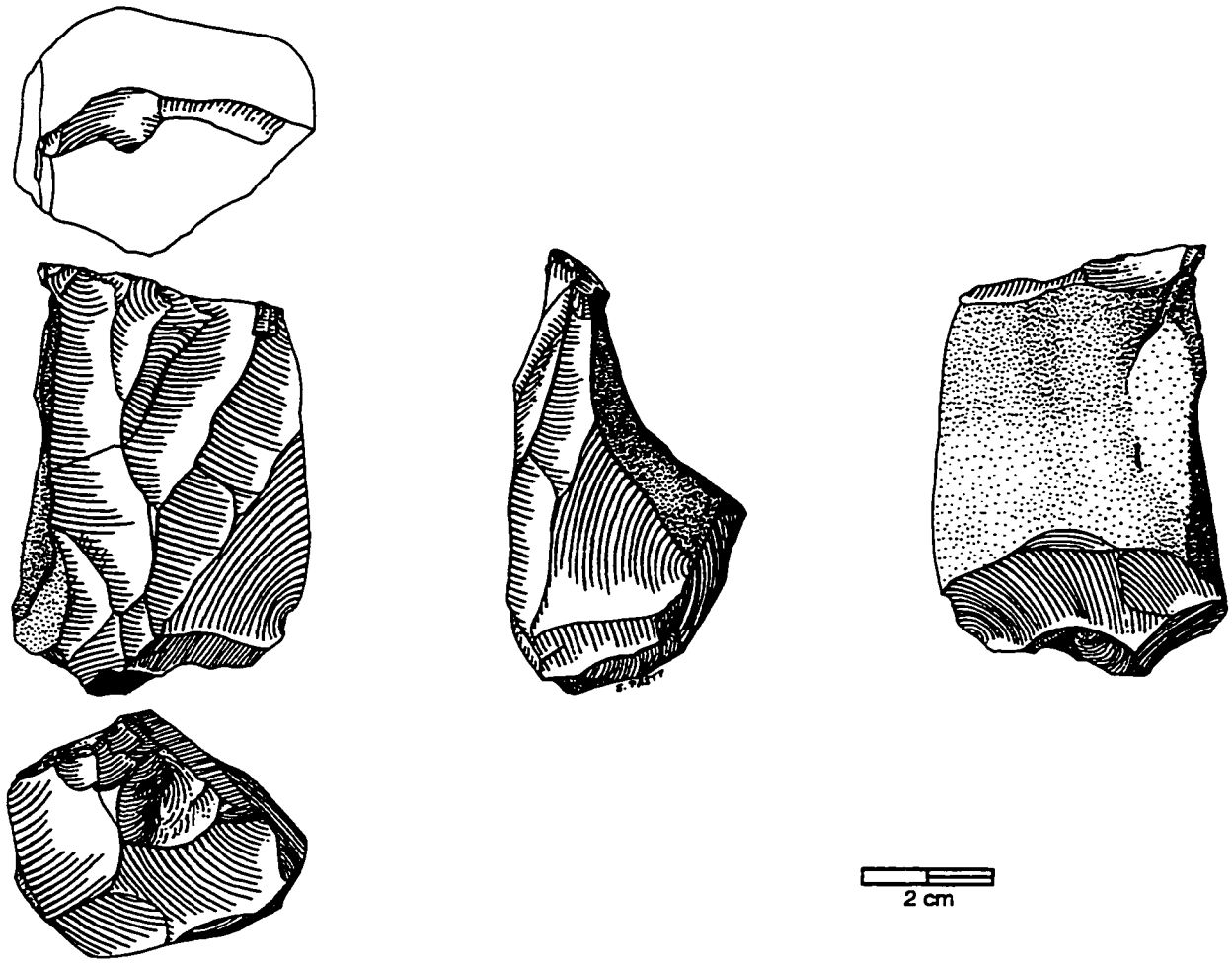



Figure A.17 Caminade Est, M3. A9.233, core (category 14A), made from a thick flake or nodule of black Senonian chert.

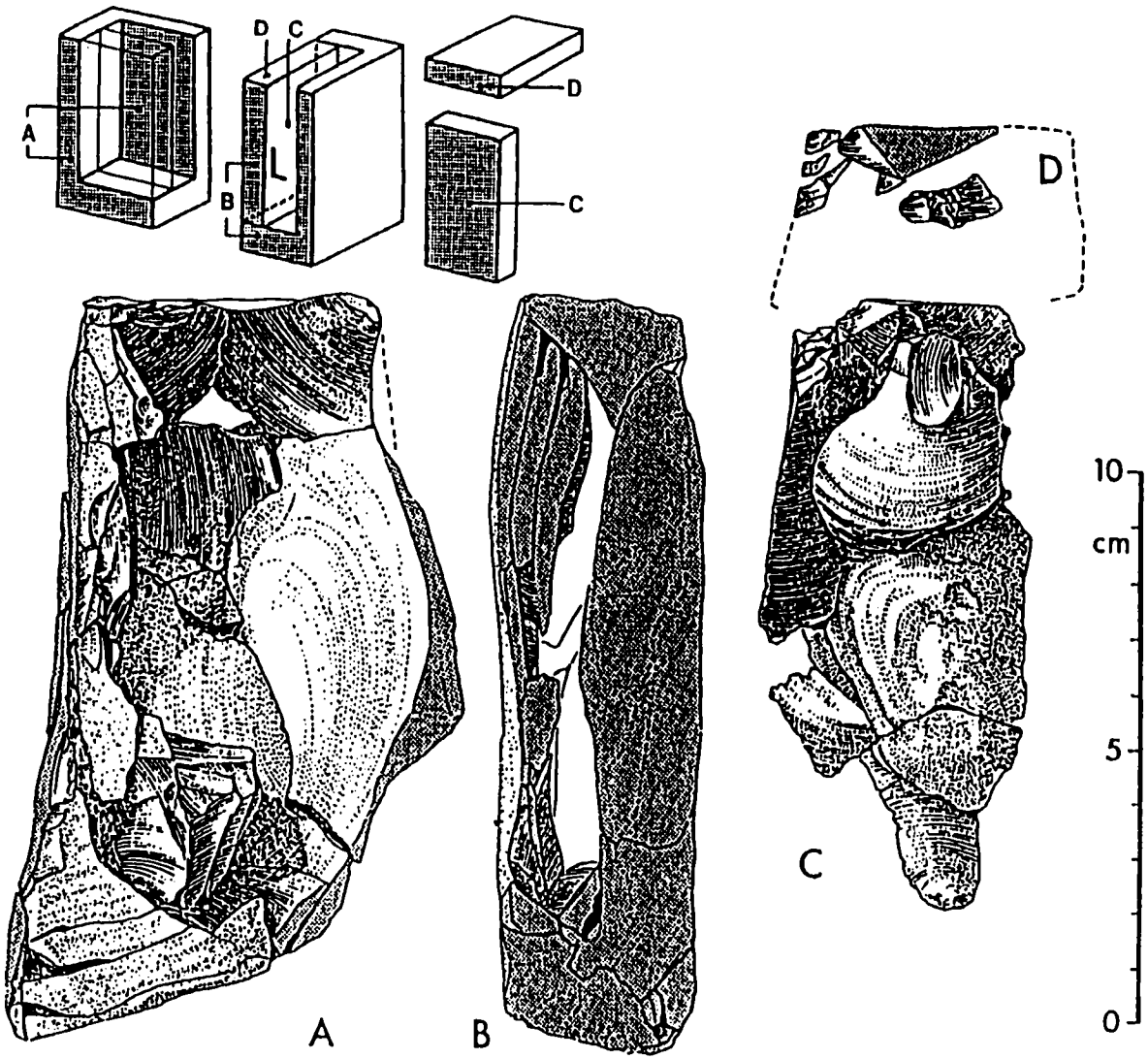



Figure A.18 Caminade Est, M3. Refit of "phantom core," made of Jurassic chert, from Sonneville-Bordes 1990. Diagram shows spatial arrangement of all parts of the refit when re-assembled.

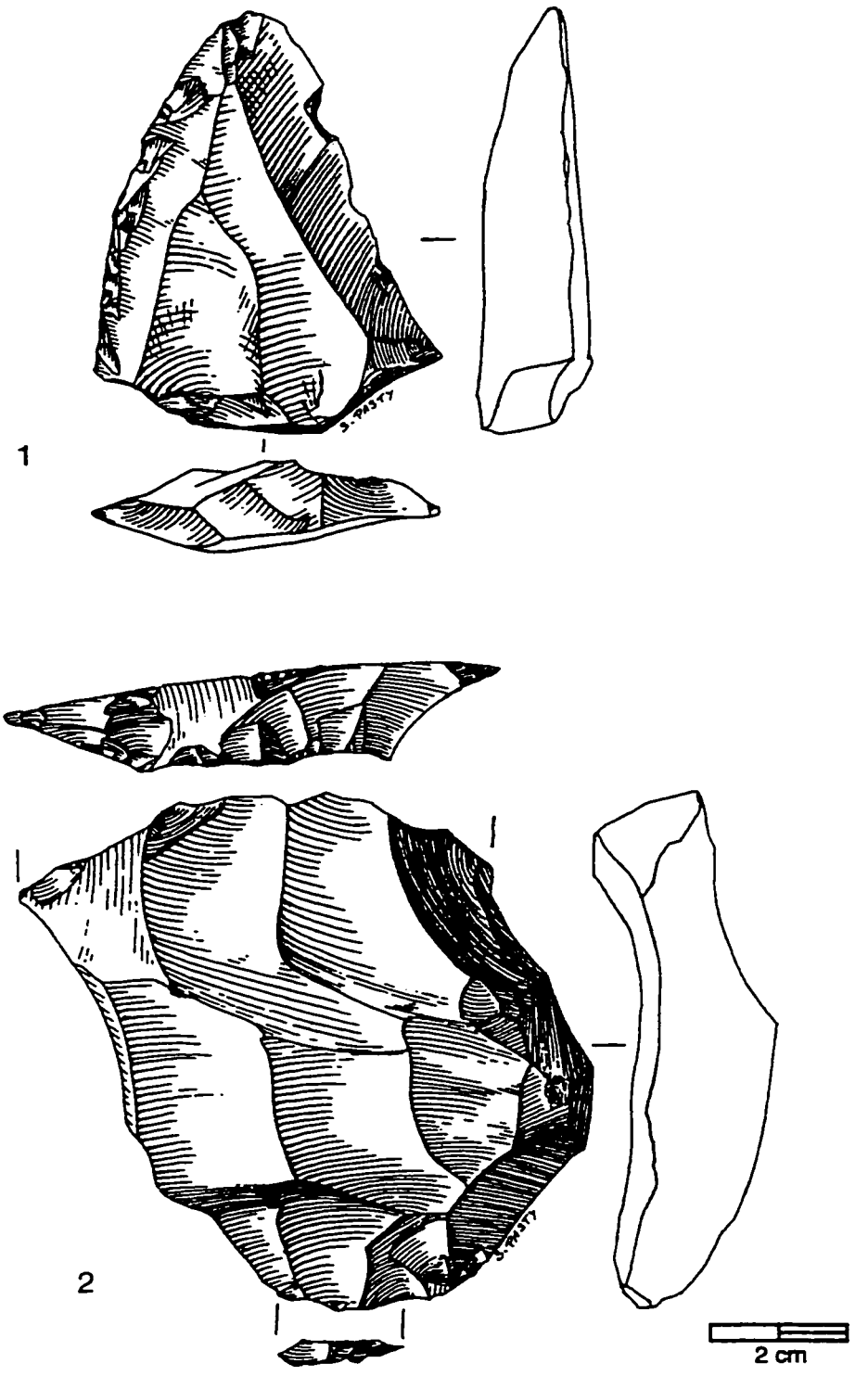



Figure A.19 Caminade Est, M3. 1: C9.730, retouched Levallois point; 2: B9.576, large flake showing bi-directional Levallois debitage.

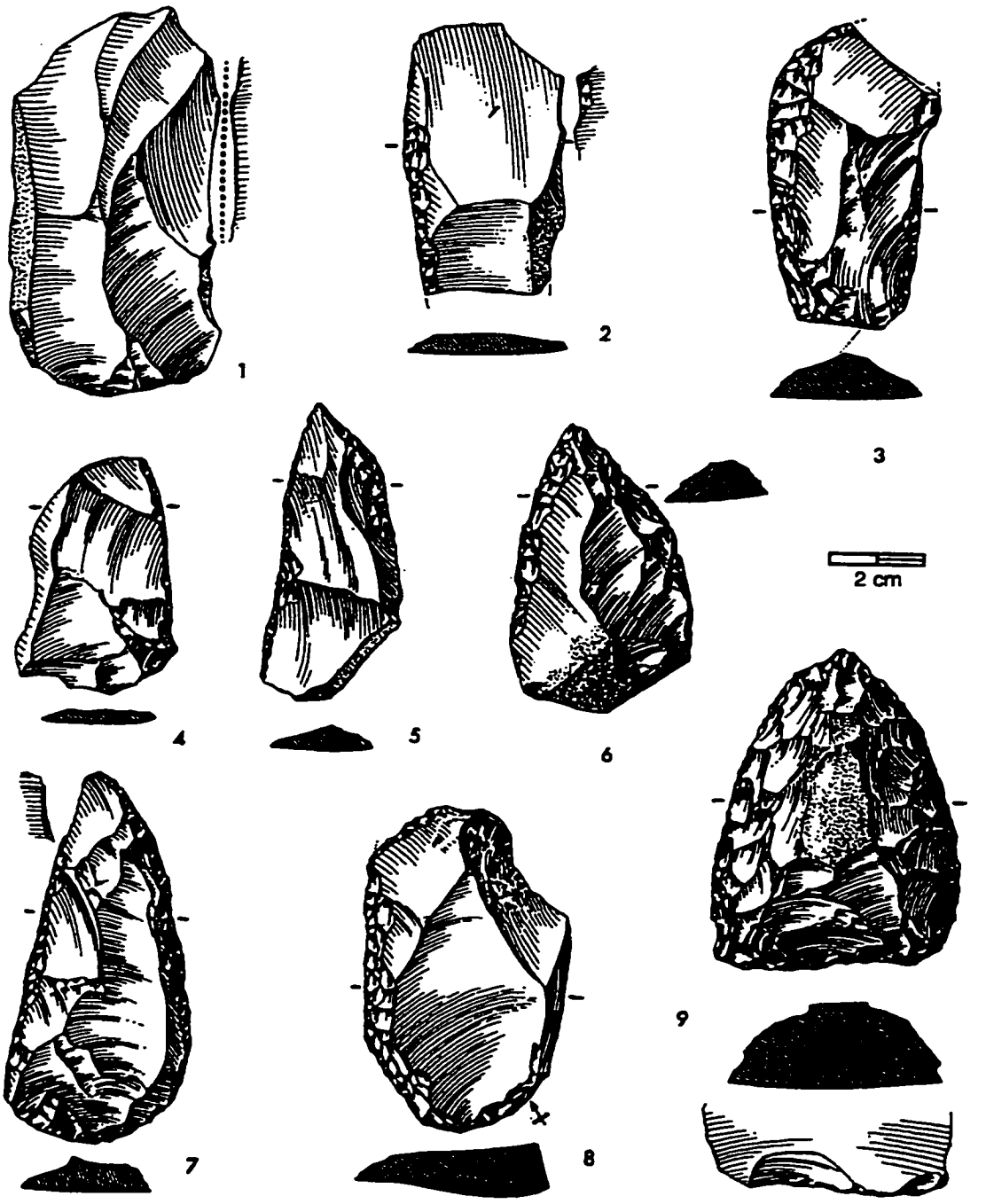



Figure A.20 Caminade Est, M3 (base). 1, Levallois flake; 2 and 4, simple straight sidescrapers; 3 and 7, double-edged straight sidescrapers; 5, elongated Mousterian point; 6, Mousterian point; 8, simple convex sidescraper; 9, convergent convex sidescraper. All by P. Laurent; from Sonneville-Bordes (1969: 306).

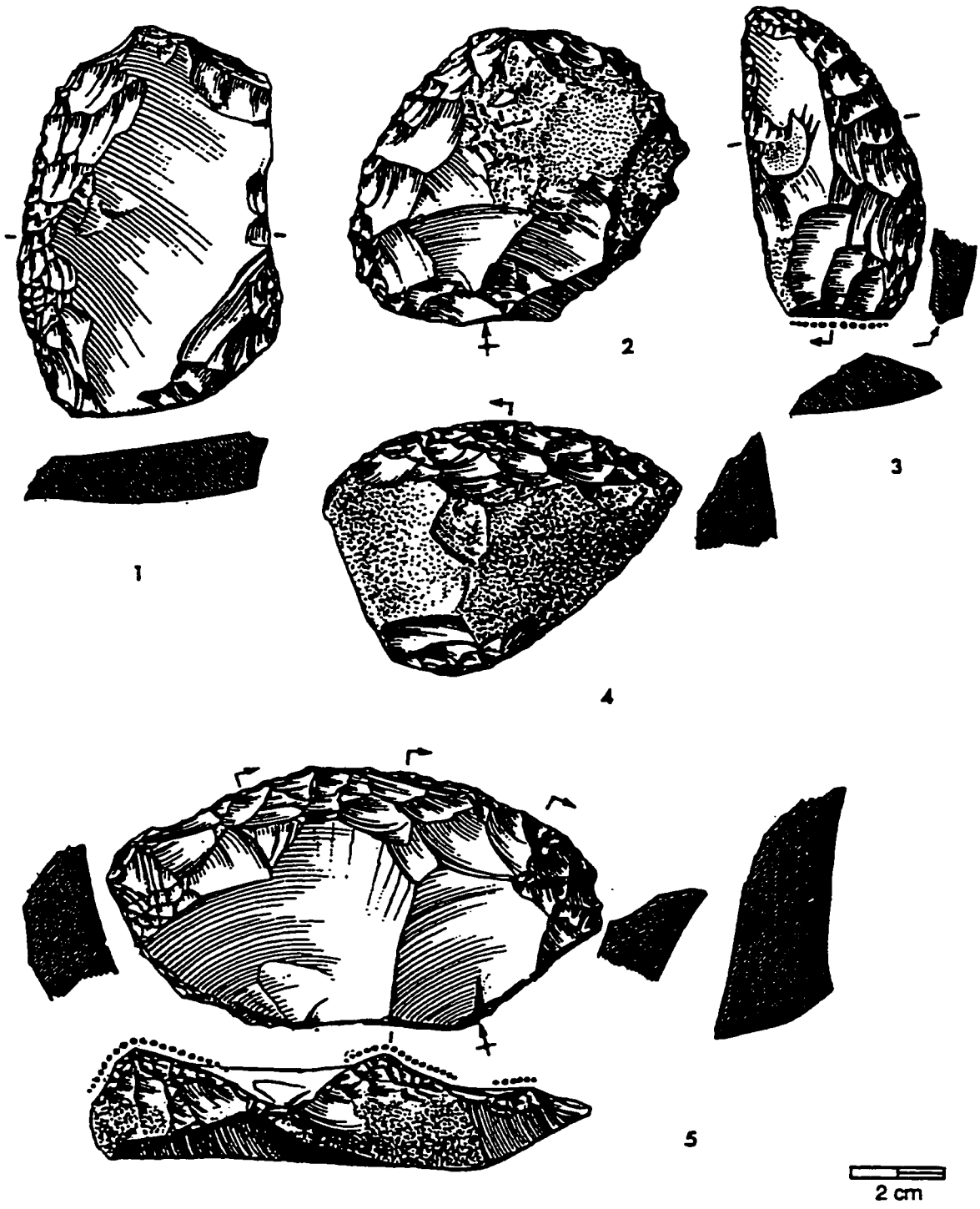



Figure A.21 Caminade Est, M3 (summit +). Retouched pieces, from Sonneville-Bordes (1969:307). 1, simple straight sidescraper; 2, denticulated endscraper; 3, convergent sidescraper; 4 and 5, transverse convex sidescrapers. All by P. Laurent.

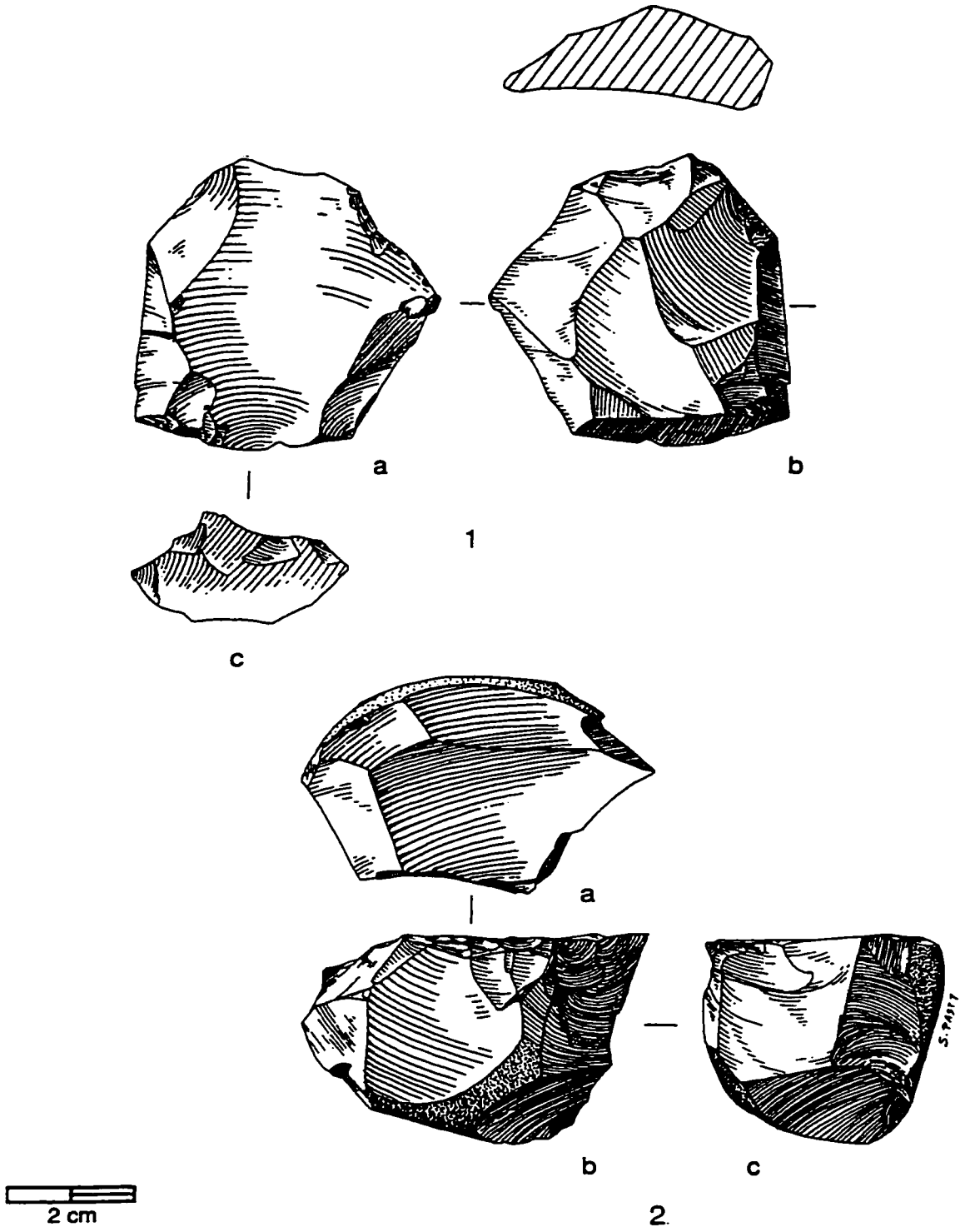



Figure A.22 Caminade Est, G. 1: B7.95, core (category 13A), made of unidentified chert. 2: C3.187, core (category 1B), made of unidentified chert.

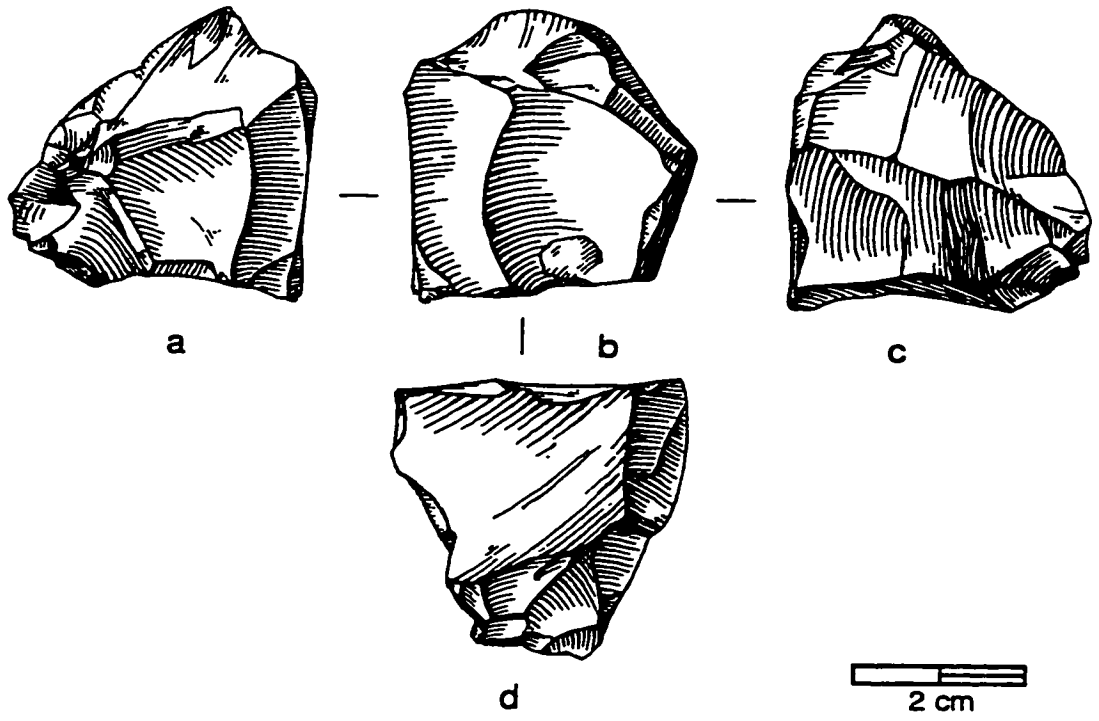



Figure A.23 Caminade Est, G. C8.843, core (category 2A), made on nodule of black Senonian chert.

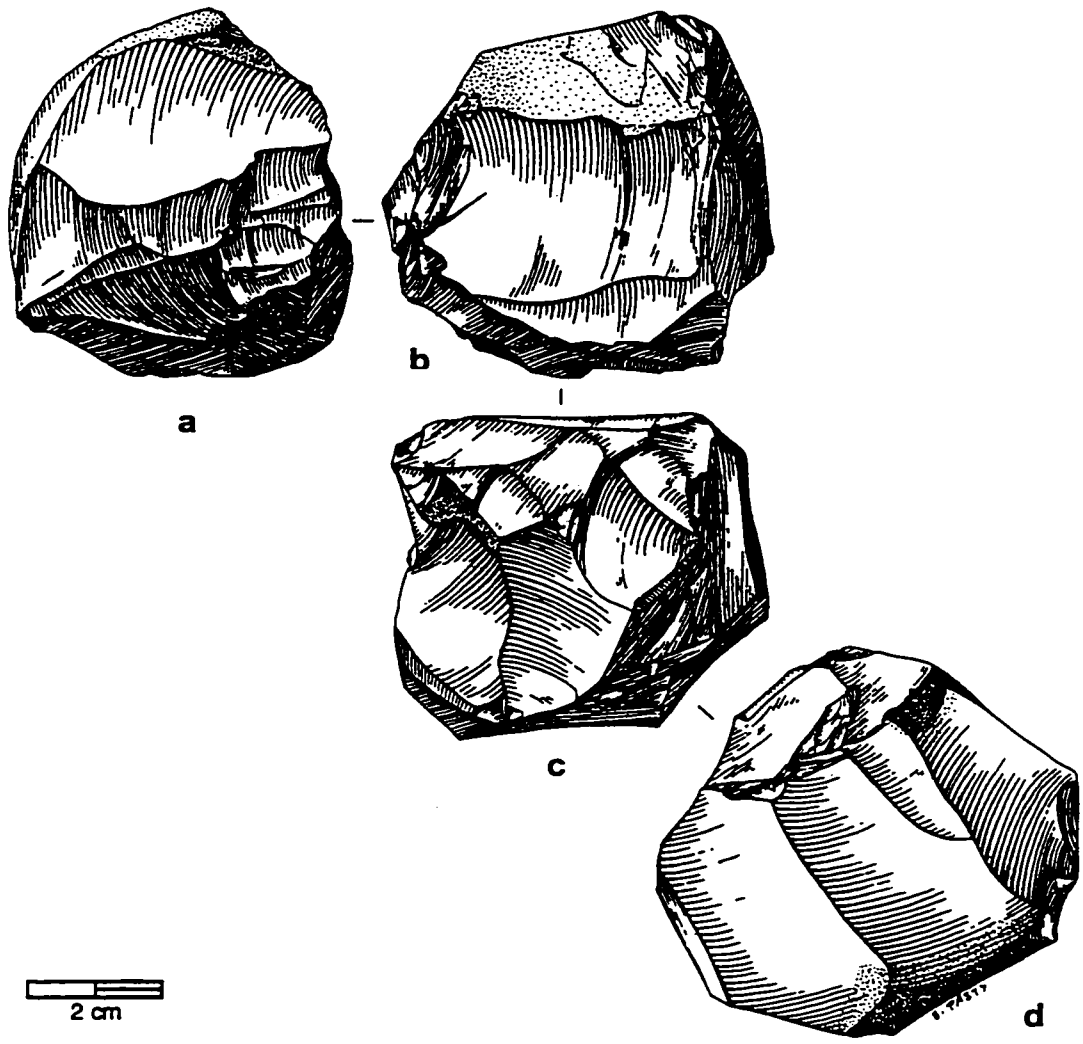



Figure A.24 Caminade Est, G. C10.88, core (category 4A), made from a nodule of indeterminate Senonian chert.

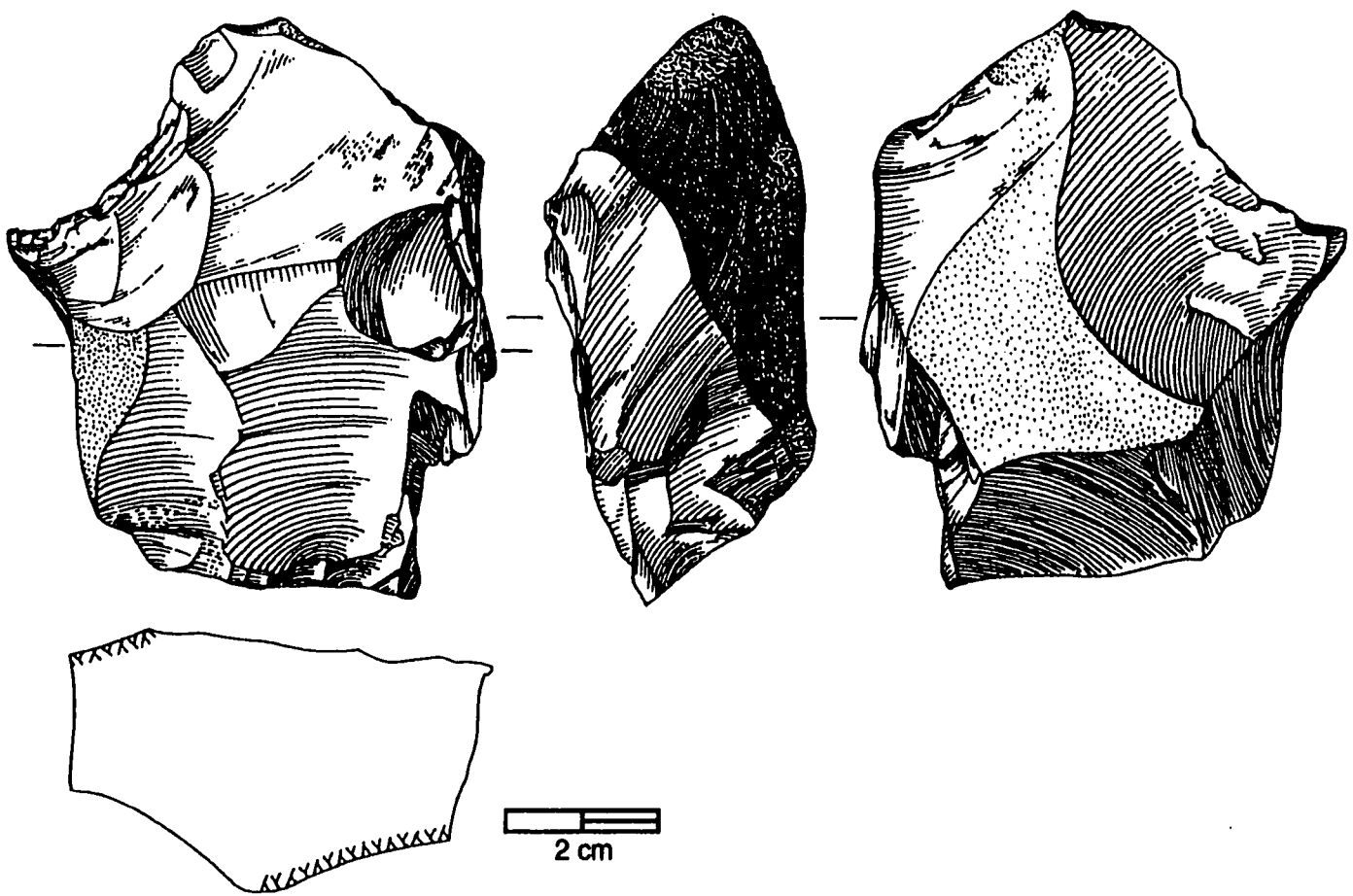



Figure A.25 Caminade Est, G. D7.116, core (category 13A), made from a nodule of black Senonian chert.

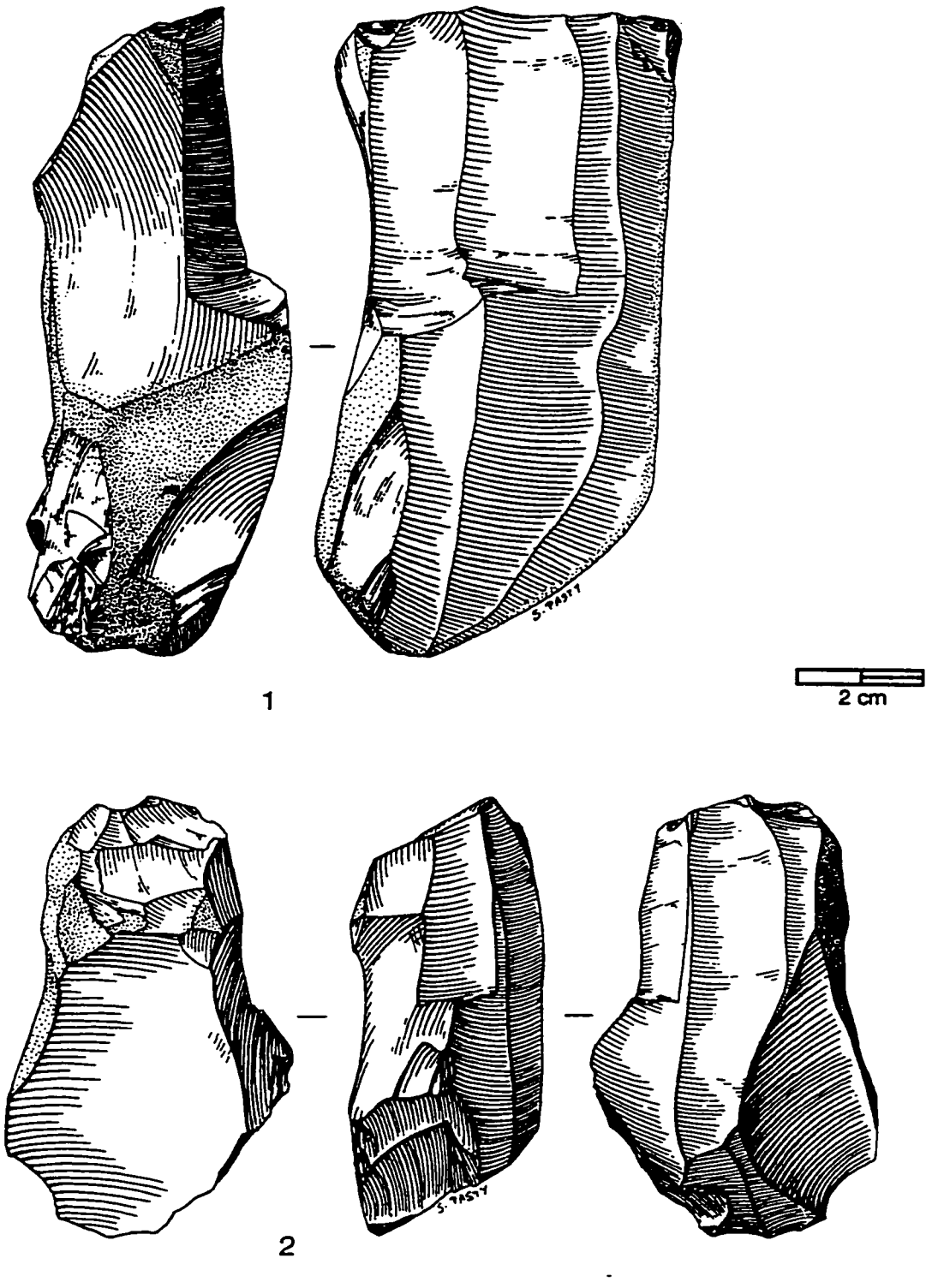



Figure A.26 Caminade Est, G. 1: C9.404, core (category 14A; 2: C6.116, core (category 14B). Both made from nodules of black Senonian chert.

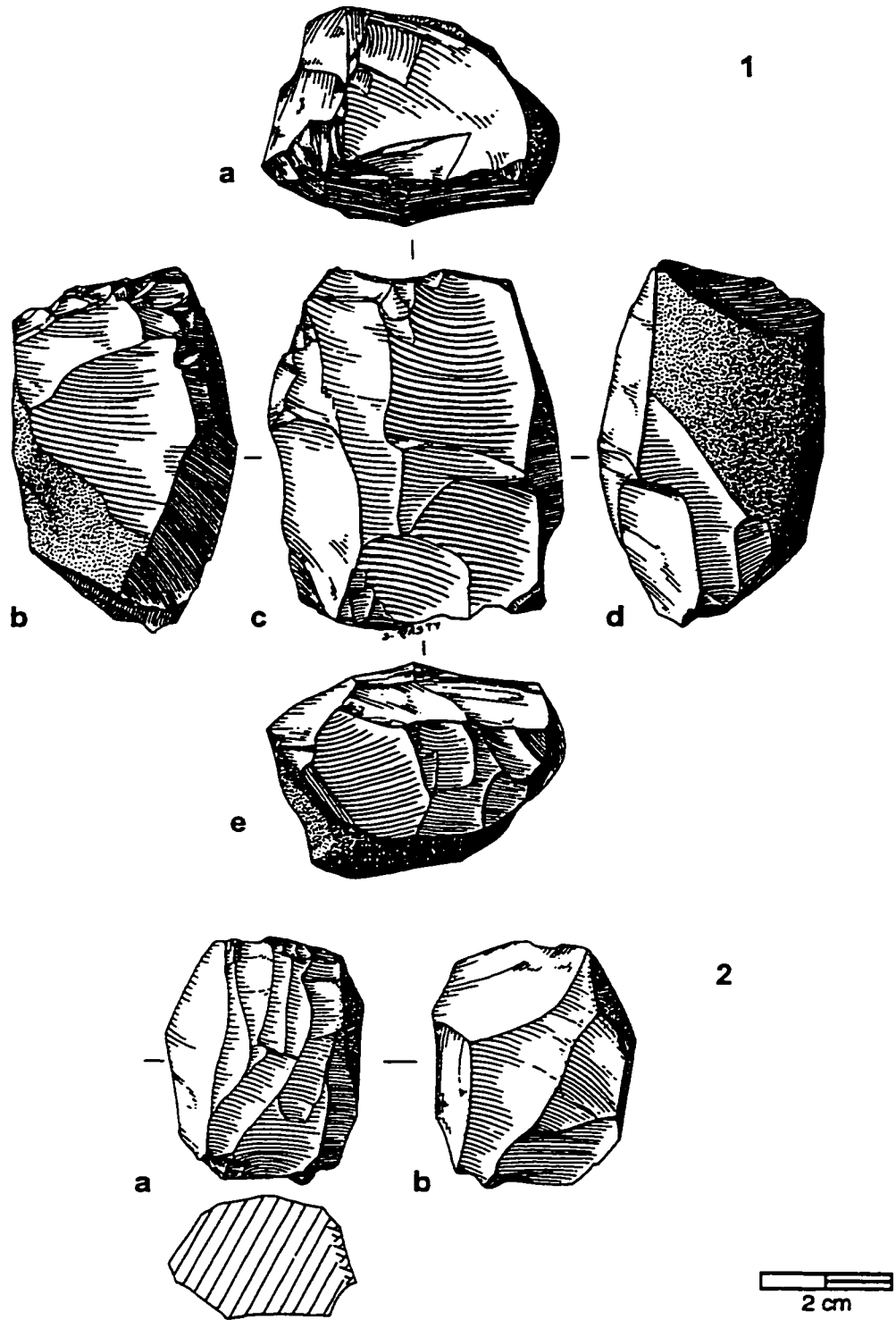



Figure A.27 Caminade Est, G. 1: A-10.181, core (category 14B); 2: D7.92, core (category 14B). Both made from nodules of black Senonian chert.

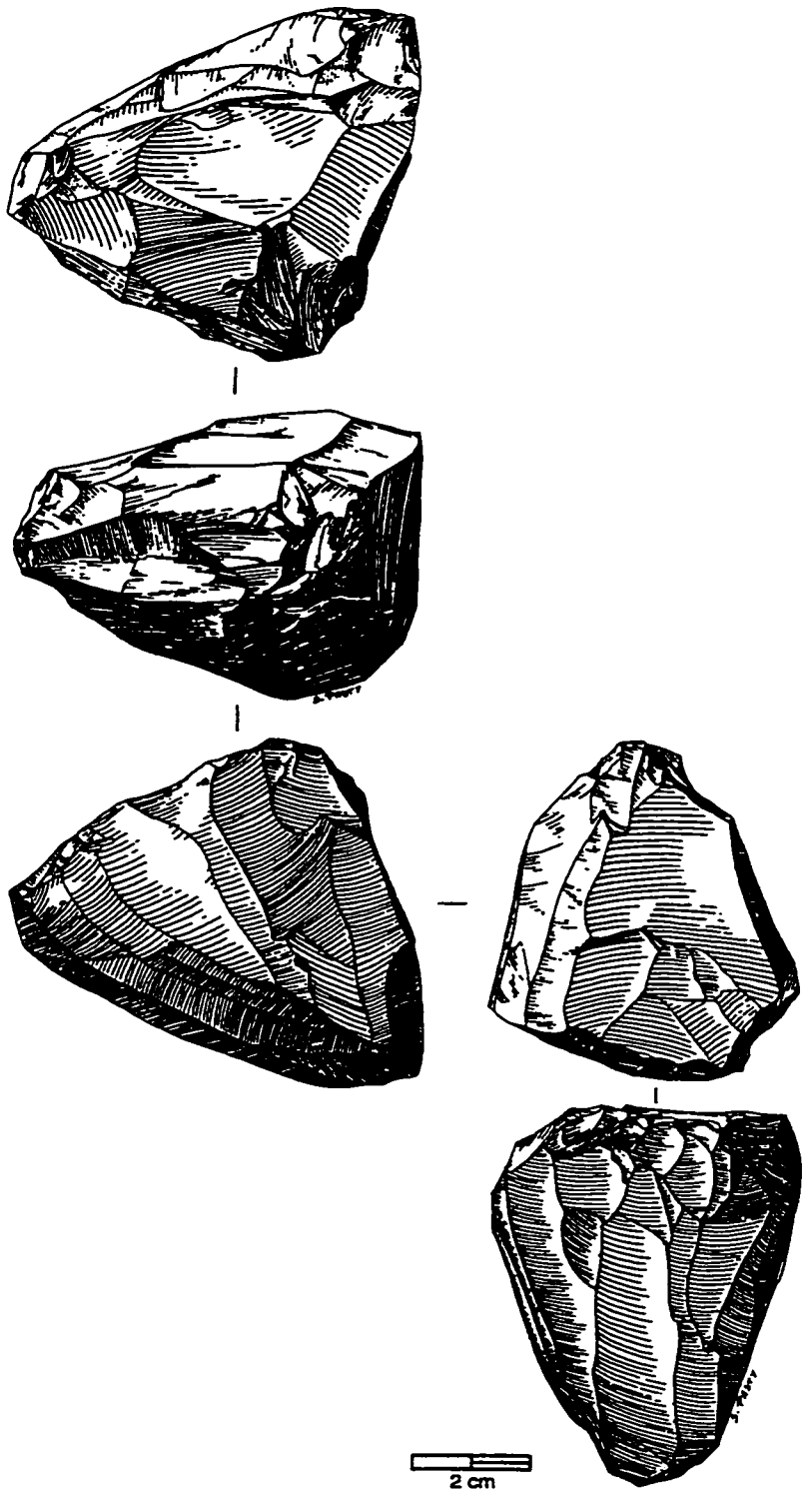



Figure A.28 Caminade Est, G. C6.164, core (category 14B), made from a nodule of unidentified chert.

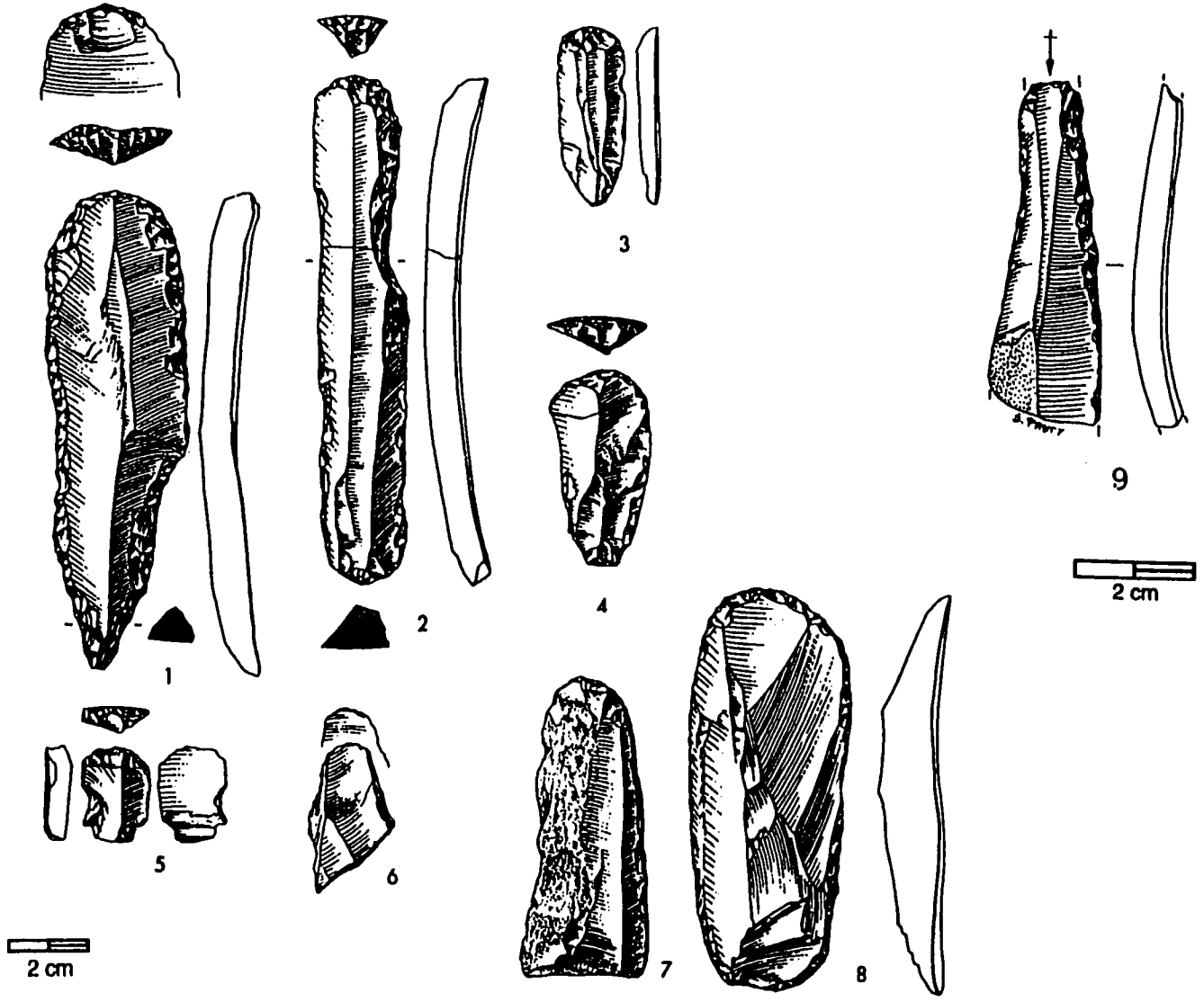



Figure A.29 Caminade Est, G, retouched pieces. 1, endscraper-perforator; 2 and 4, endscrapers on Aurignacian blades; 3, simple endscraper; 5, simple endscraper with notch; 6, "atypical endscraper, with an irregular front made with very small, partial retouch" (Sonneville-Bordes 1970:87); 7, endscraper made on retouched blade, with a bec (broken); 8, double endscraper "on wide and robust blade, with a raised front and small bilateral retouch," (Sonneville-Bordes 1970:89); 9, Aurignacian blade. 1-8, By P. Laurent, from Sonneville-Bordes (1970:88); 9, by S. Pasty

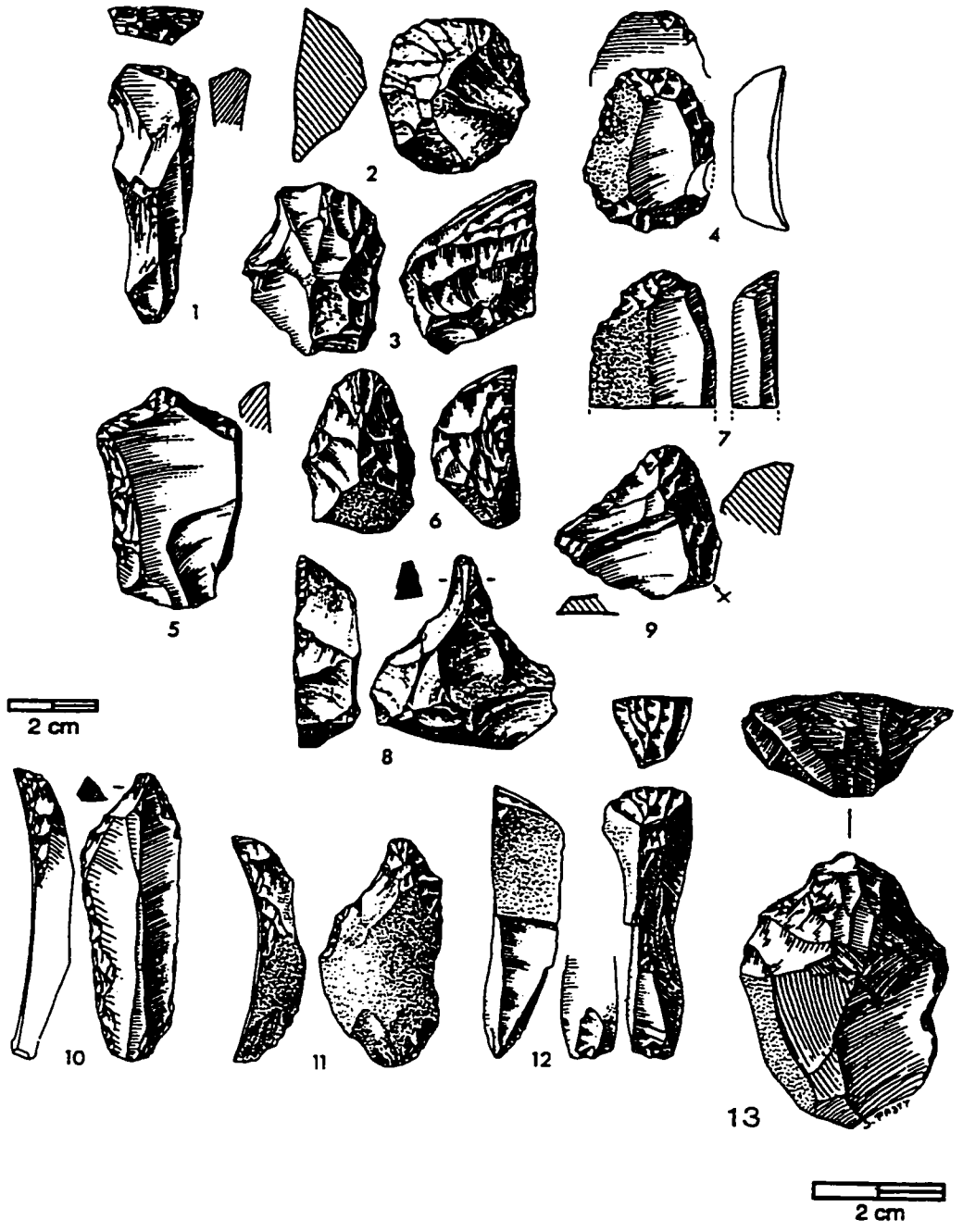



Figure A.30 Caminade Est, G, retouched pieces. 1, simple endscraper, asymmetrical, made on a blade from the edge of a core; 2, simple endscraper; 3, B7.158, listed by Sonneville-Bordes (1970) as "core-like endscraper," but recorded as a core (not analyzed in detail) with no retouch; 4, double endscraper; 5, thin muzzled endscraper; 6, carinated endscraper; 7-11 and 13, muzzled endscrapers; 12, carinated endscraper made on large burin spall. 1-12 By P. Laurent, from Sonneville-Bordes (1970:90), 13 by Sylvain Pasty.

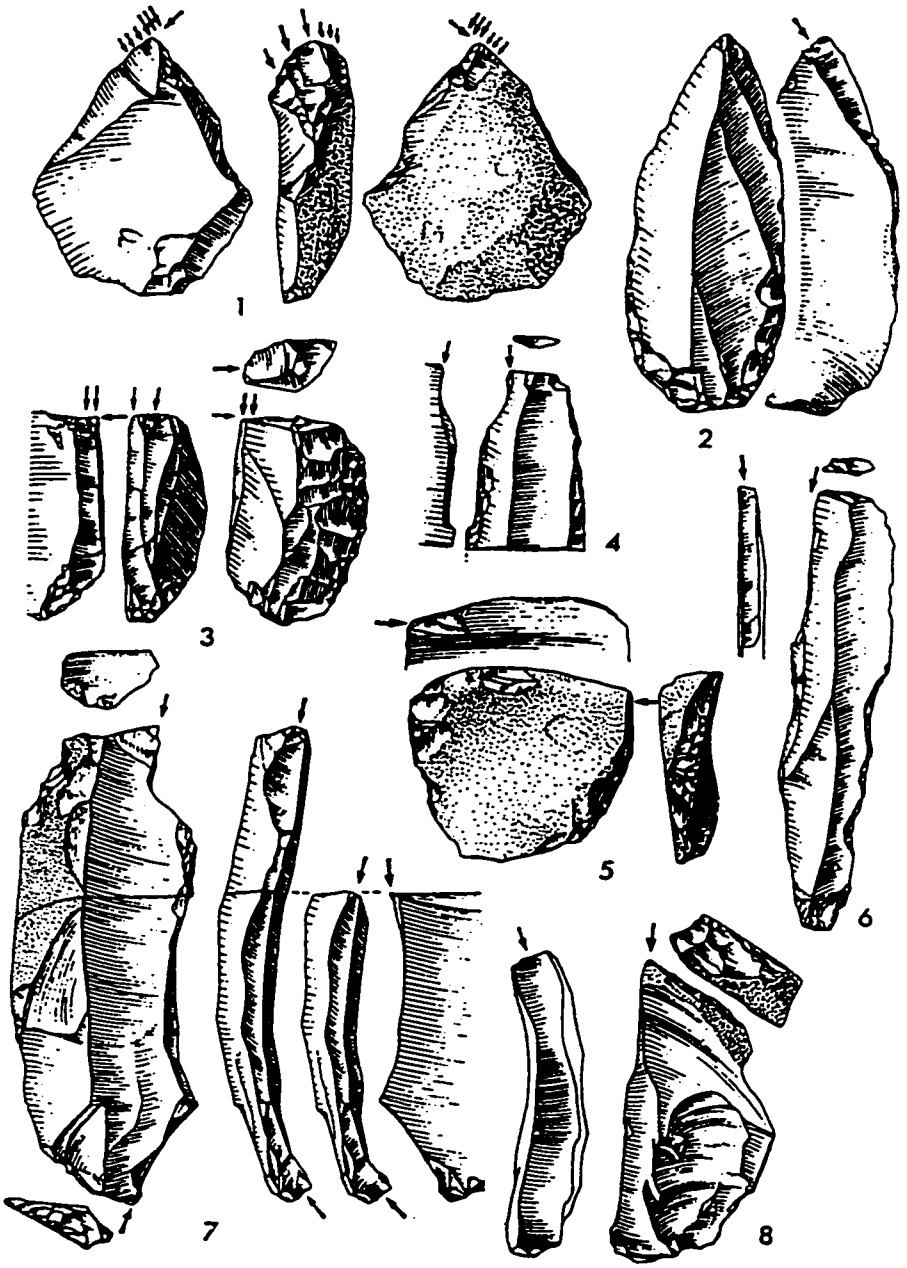


Figure A.31 Caminade Est, G, retouched pieces. 1, carinated burin made on a thick flake; 2, dihedral burin on ventral face, with bilateral Aurignacian retouch; 3, angle burin (type 29), with a convex sidescraper made by thick, bladelet-like, scalar retouch; 4, angle burin made on a break, with lateral retouch; 5, transverse burin with lateral truncation; 6, burin on straight truncation; 7, multiple mixed burin (two pieces, refit); 8, burin on convex truncation. By P. Laurent, from Sonneville-Bordes (1970:92).

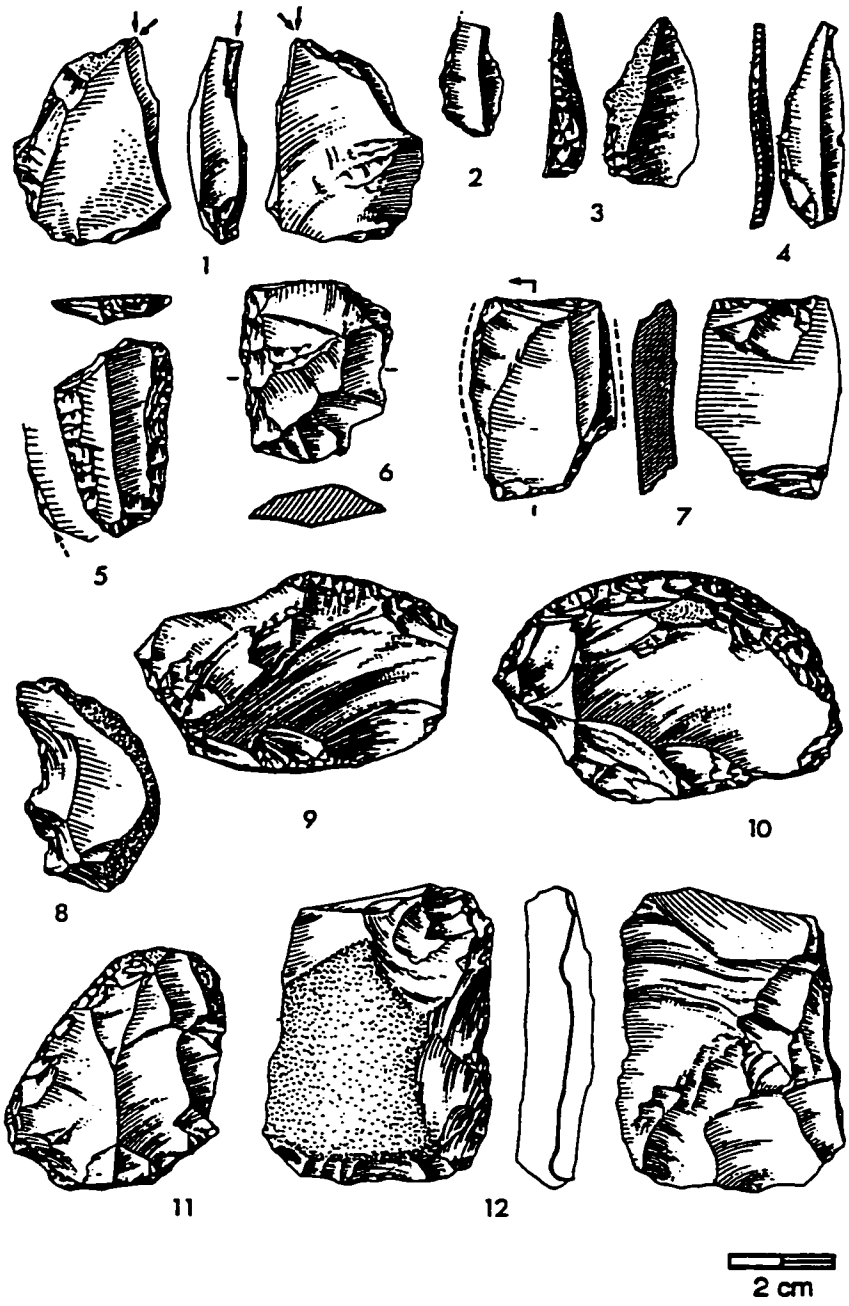



Figure A.32 Caminade Est, G. 1, angle burin with similarities to a very offset dihedral burin; 2-4, Châtelperronian points (#3 is from the base of level G in square C3); 5 "former double endscraper, made on an Aurignacian blade, reused as an endscraper-burin," (Sonneville-Bordes 1970:91); 6, 11, and 12, simple sidescrapers; 7, *pièce esquillé*; 8, notched piece; 9, transverse convex sidescraper; 10, transverse convex sidescraper with Quina retouch, By P. Laurent, from Sonneville-Bordes (1970:94).

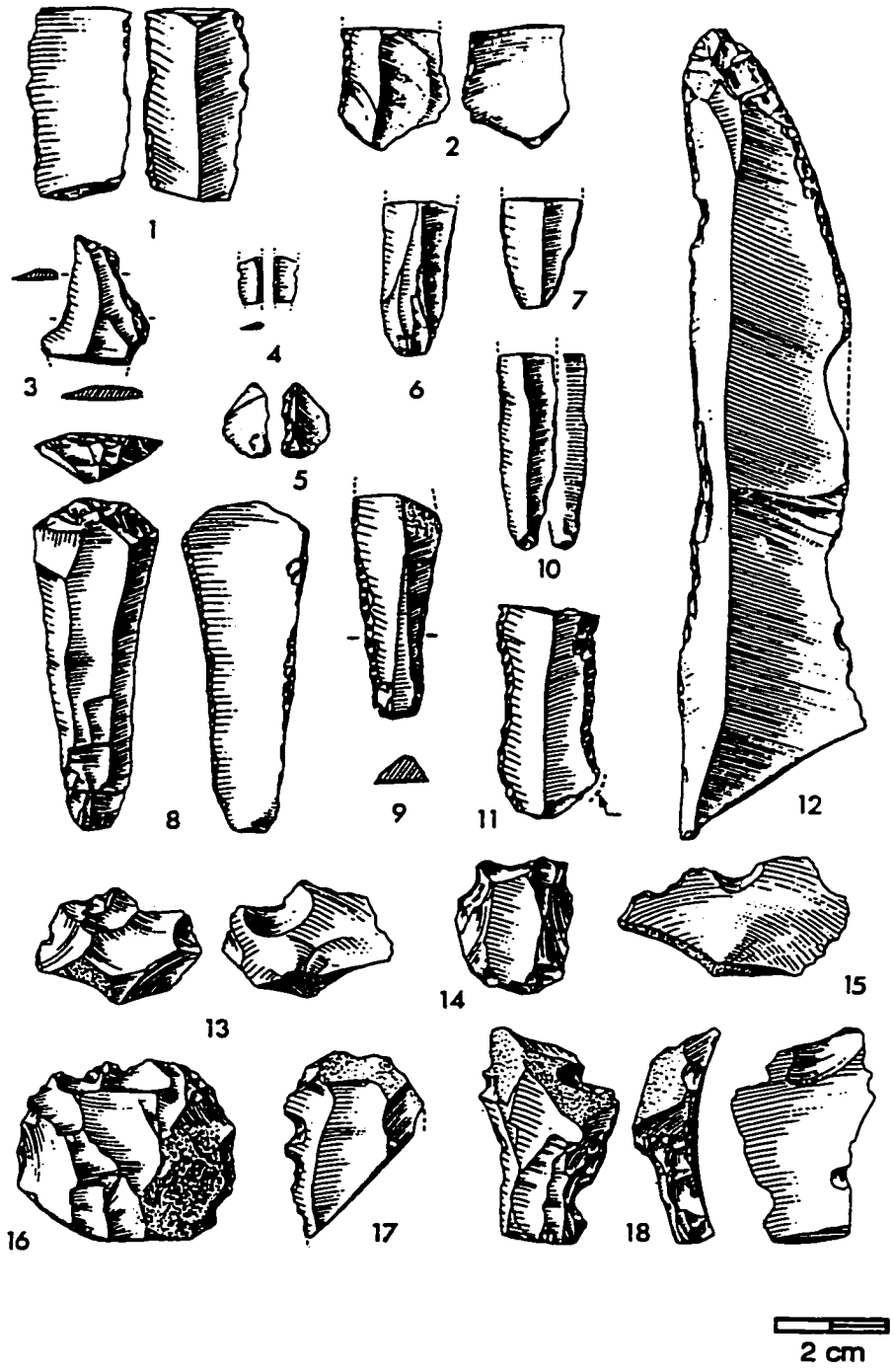



Figure A.33 Caminade Est, G. 1, 2, 6, 7, and 10: blades with continuous retouch (types 65 and 66); 3, truncated piece; 4, atypical Dufour bladelet; 5, "atypical microburin on fragment of a small blade," (Sonneville-Bordes 1970:97); 8, endscraper on retouched blade; 9 and 12, Aurignacian blades; 11, strangulated blade; 13,15, and 18: notched pieces; 14, perforator; 16 and 17, denticulated pieces. By P. Laurent, from Sonneville-Bordes (1970:96).

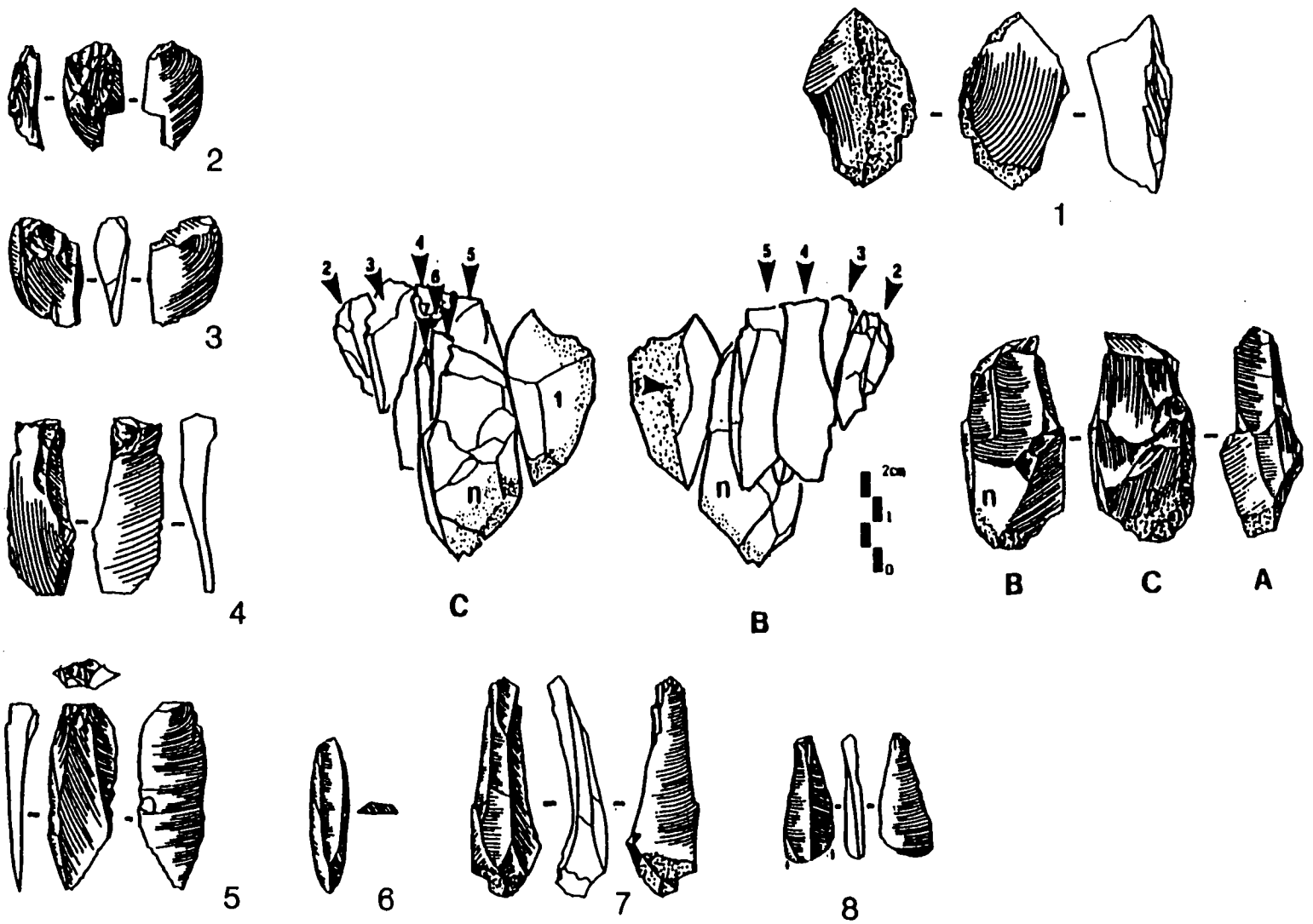



Figure A.34 La-Côte level III. A-1.16 (core, labeled "n") and pieces that refit to it. From Pelegrin 1986:484).

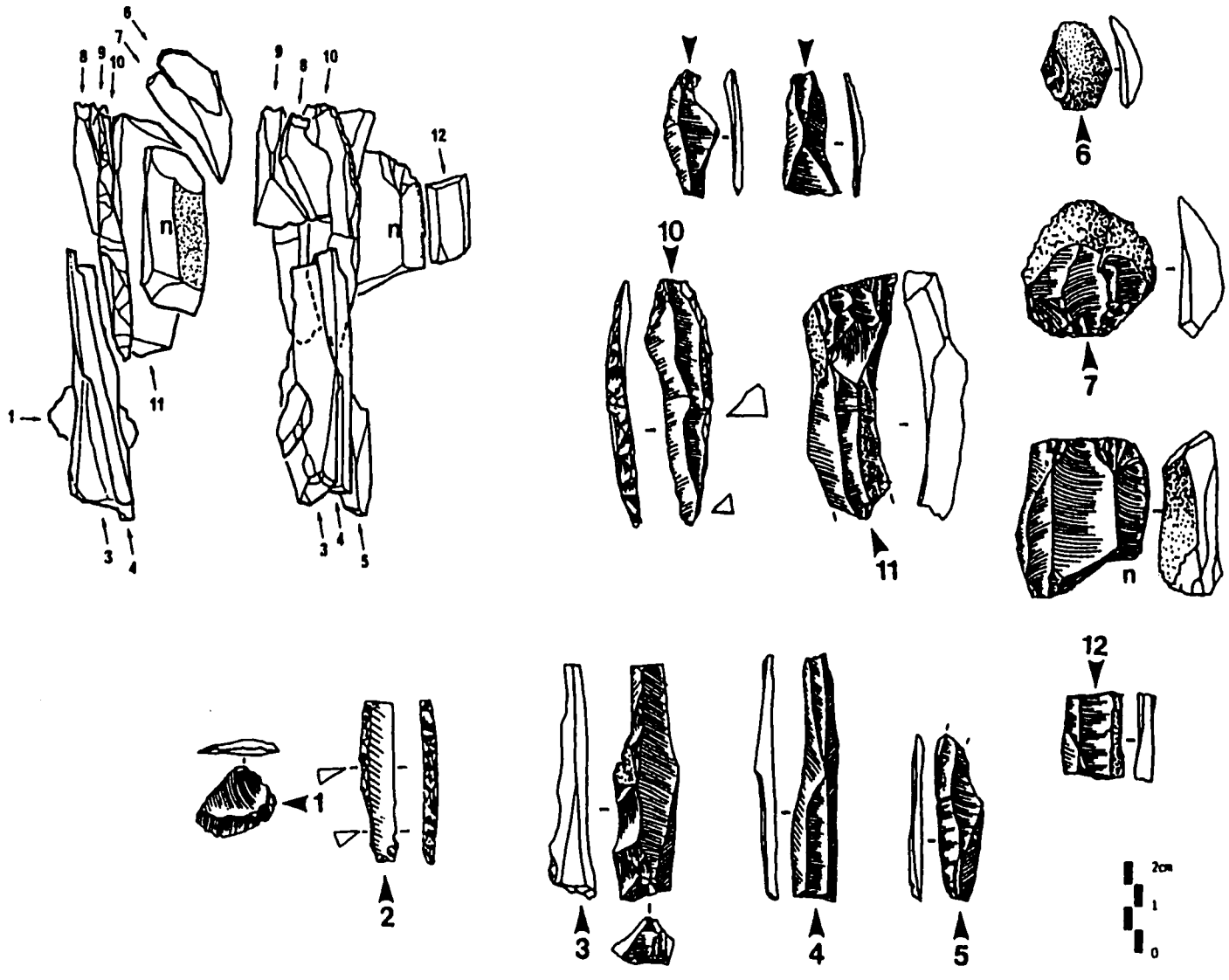



Figure A.35 La-Côte level III. C0.146 (core, labeled "n") and pieces that refit to it. From Pelegrin 1986:486).

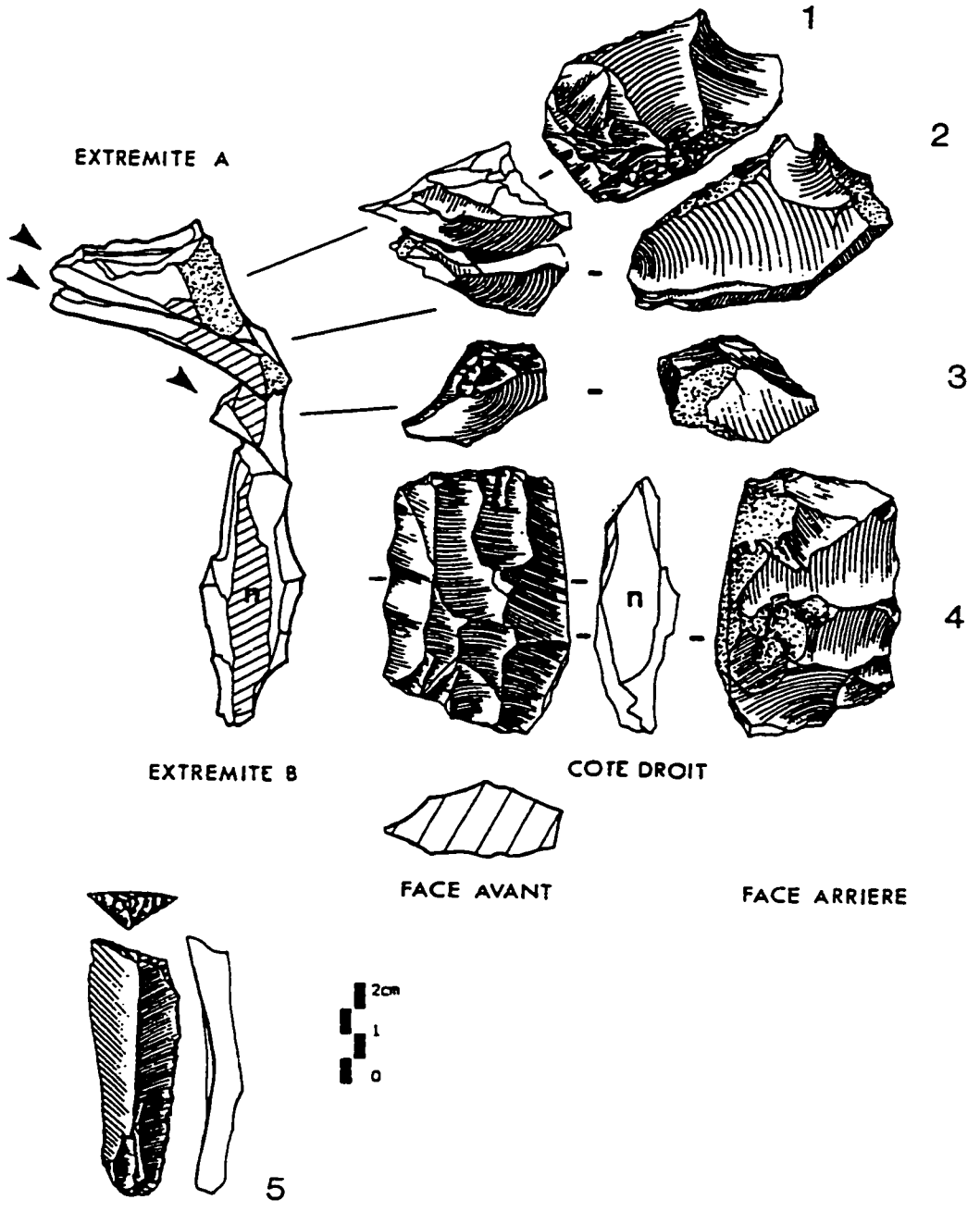



Figure A.36 La-Côte level III. B-1.24 (core, labeled "n") and blanks that refit to it. From Pelegrin 1986:490).

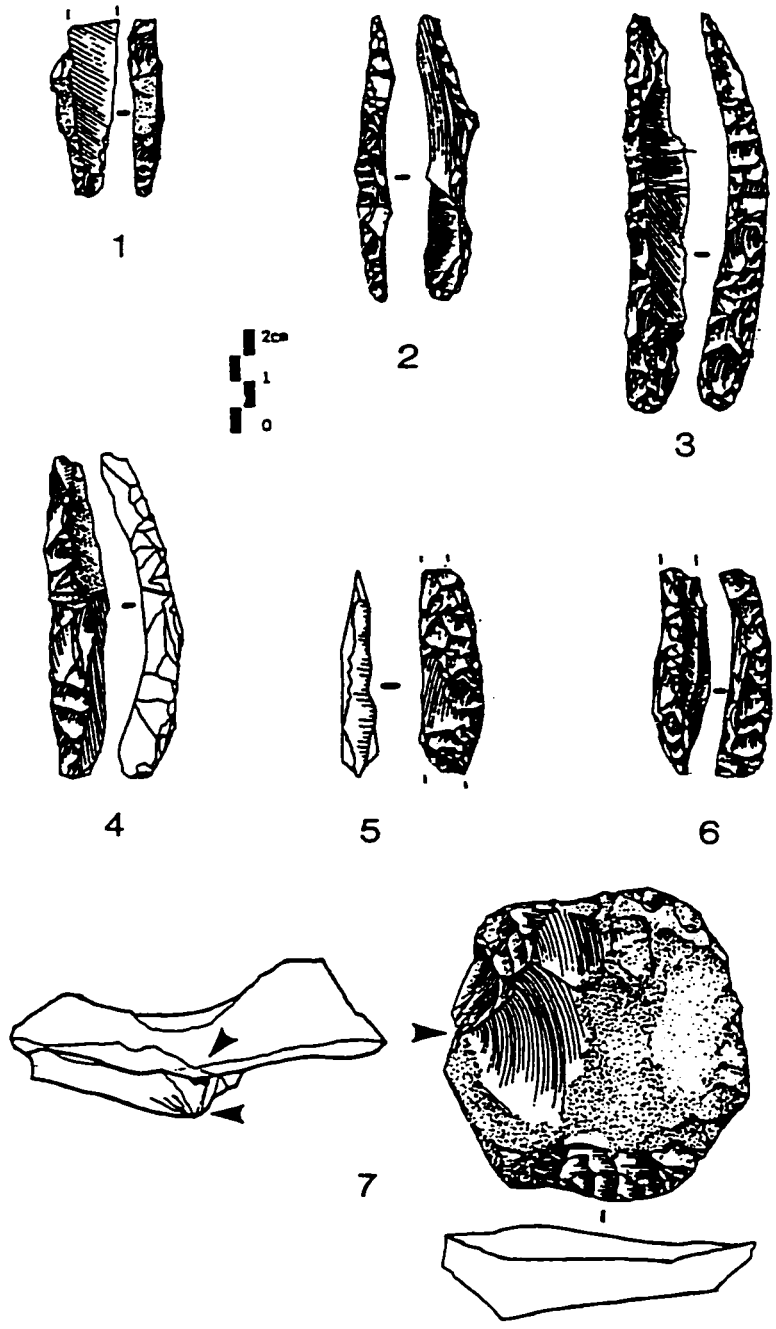



Figure A.37 La Côte, III. 1-6, crested blades; 7, two core rejuvenation tablets, refit. From Pelegrin (1986:494, 499).

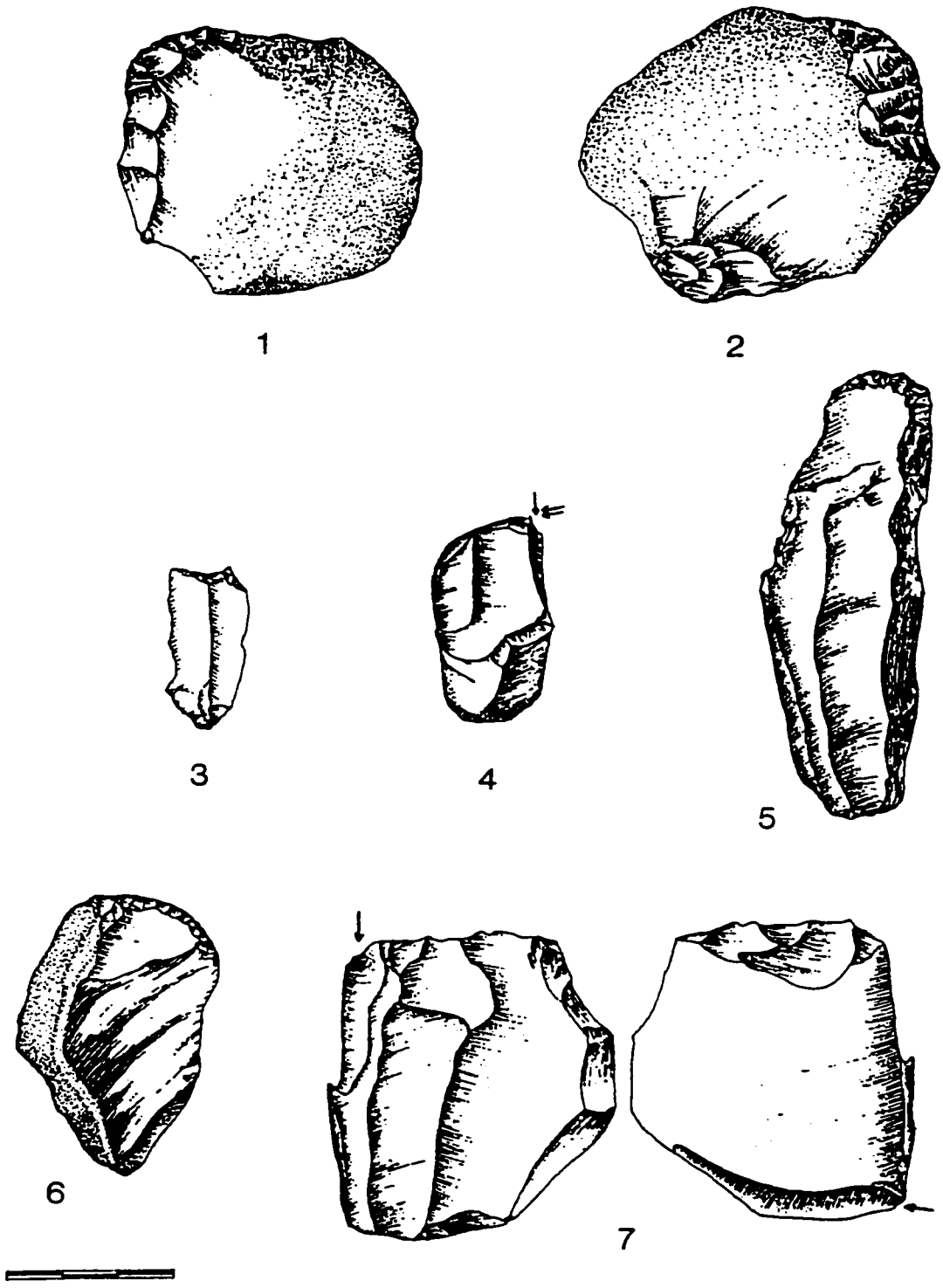



Figure A.38 La Côte, III. 1 and 2, endscrapers; 3, bec; 4, angle burin; 6 and 7, endscrapers; 8, multiple mixed burin. From Gaussen and Texier (1974:513).

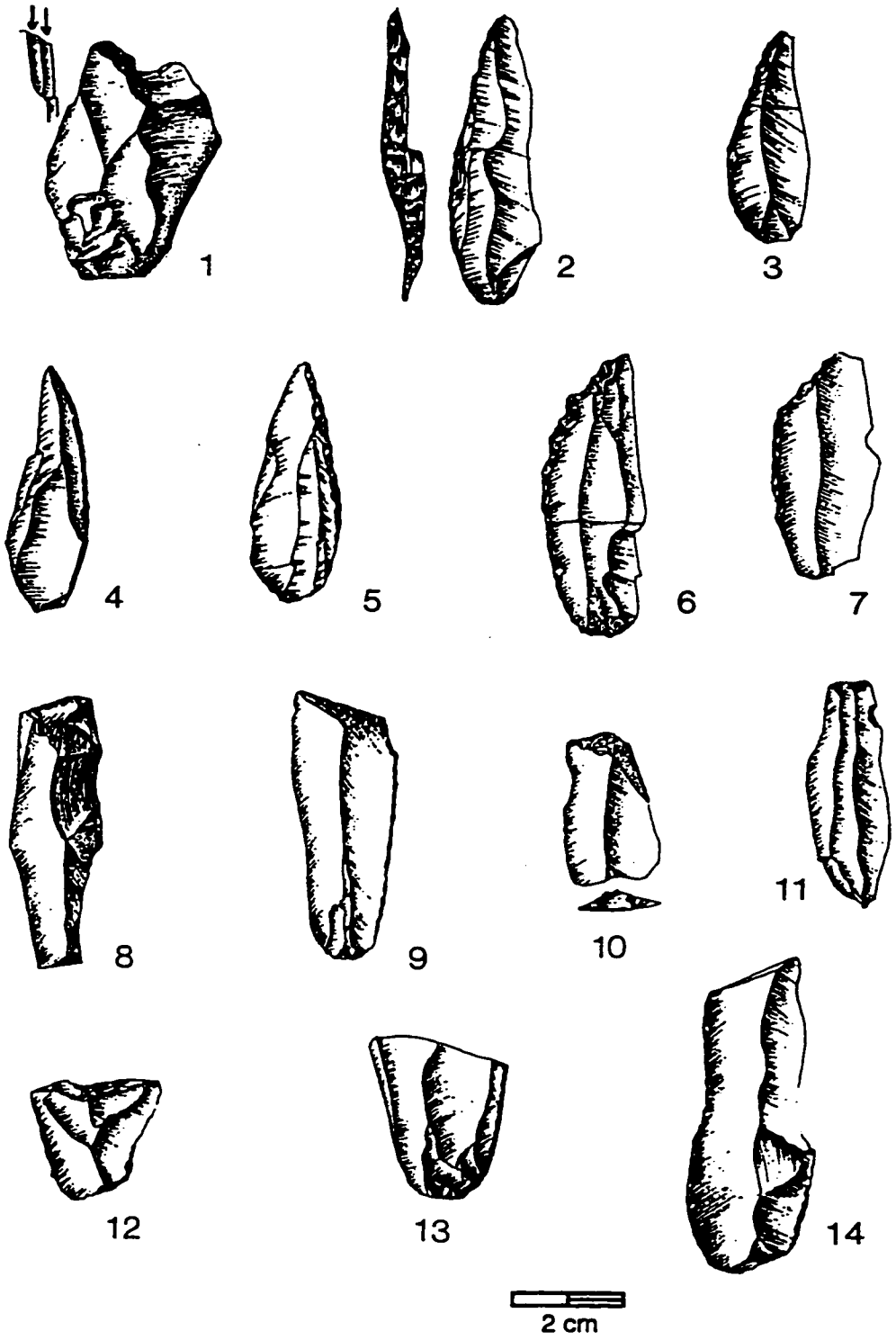



Figure A.39 La Côte, III. 1, burin with concave retouched truncation; 2 to 7, Châtelperronian points; 8 to 12, truncated pieces; 13 and 14, blades with continuous retouch. From Gaussen and Texier (1974:515).

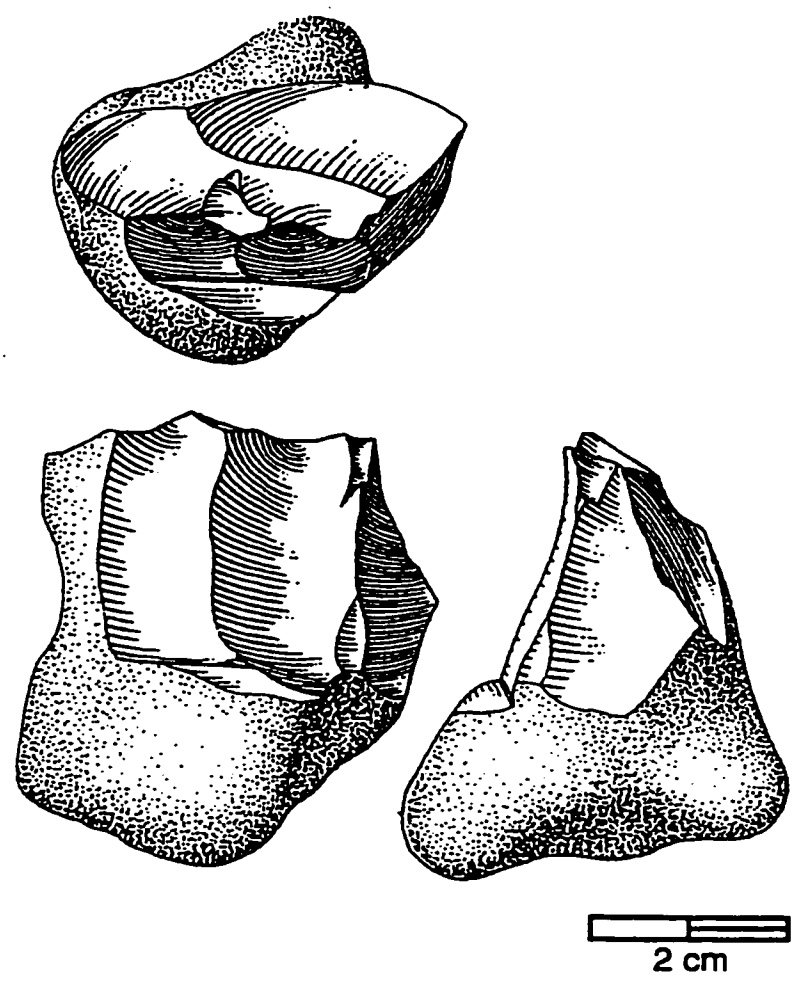



Figure A.40 Le Flageolet I, XI. C9.3352; category 1B, black Senonian chert, by J.-G. Marcillaud, from Lucas (2000:242).

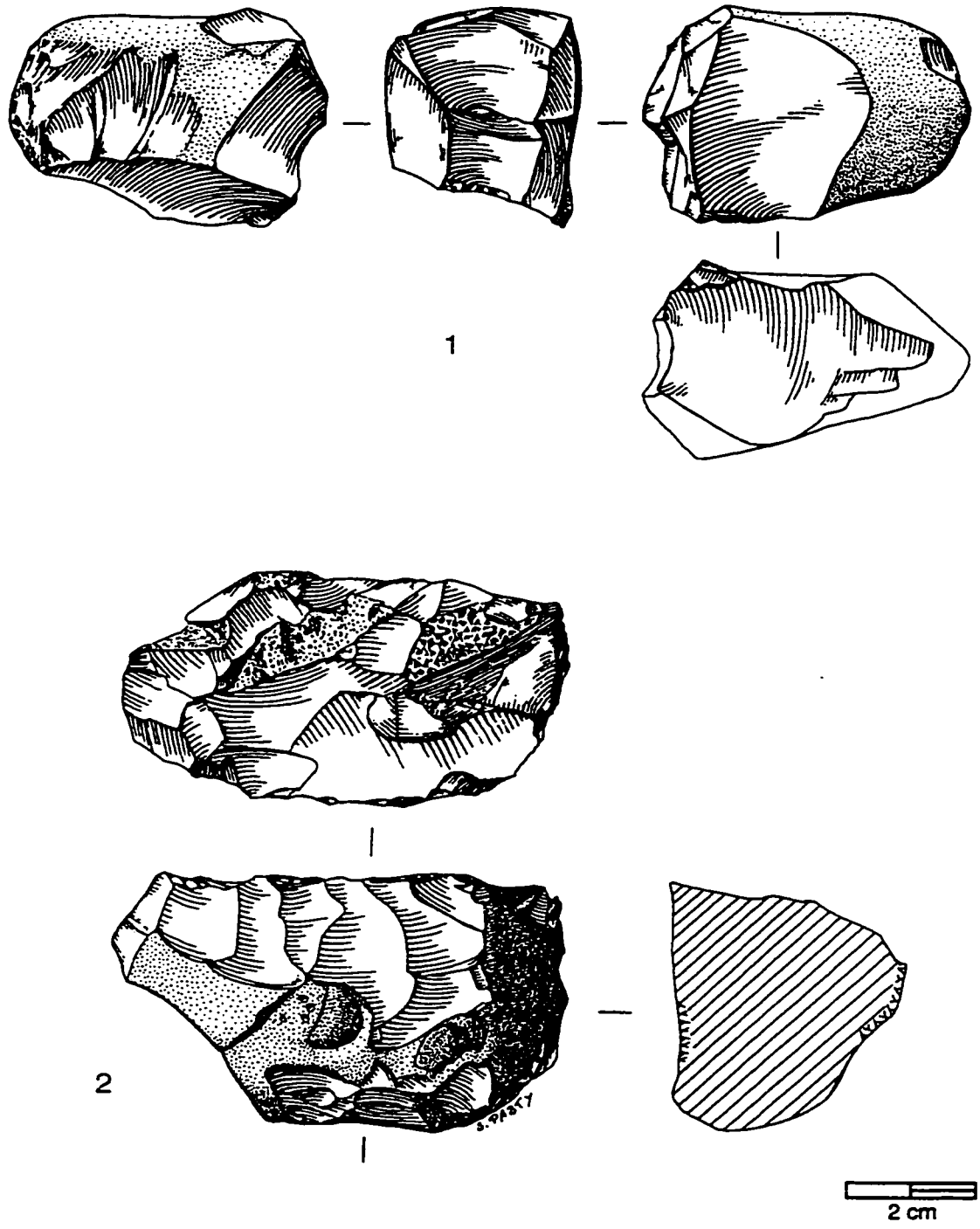



Figure A.41 Le Flageolet I, XI. Cores. 1, D10.2262, category 1B, beige Senonian chert; 2, D10.2639, category 1B, black Senonian chert.

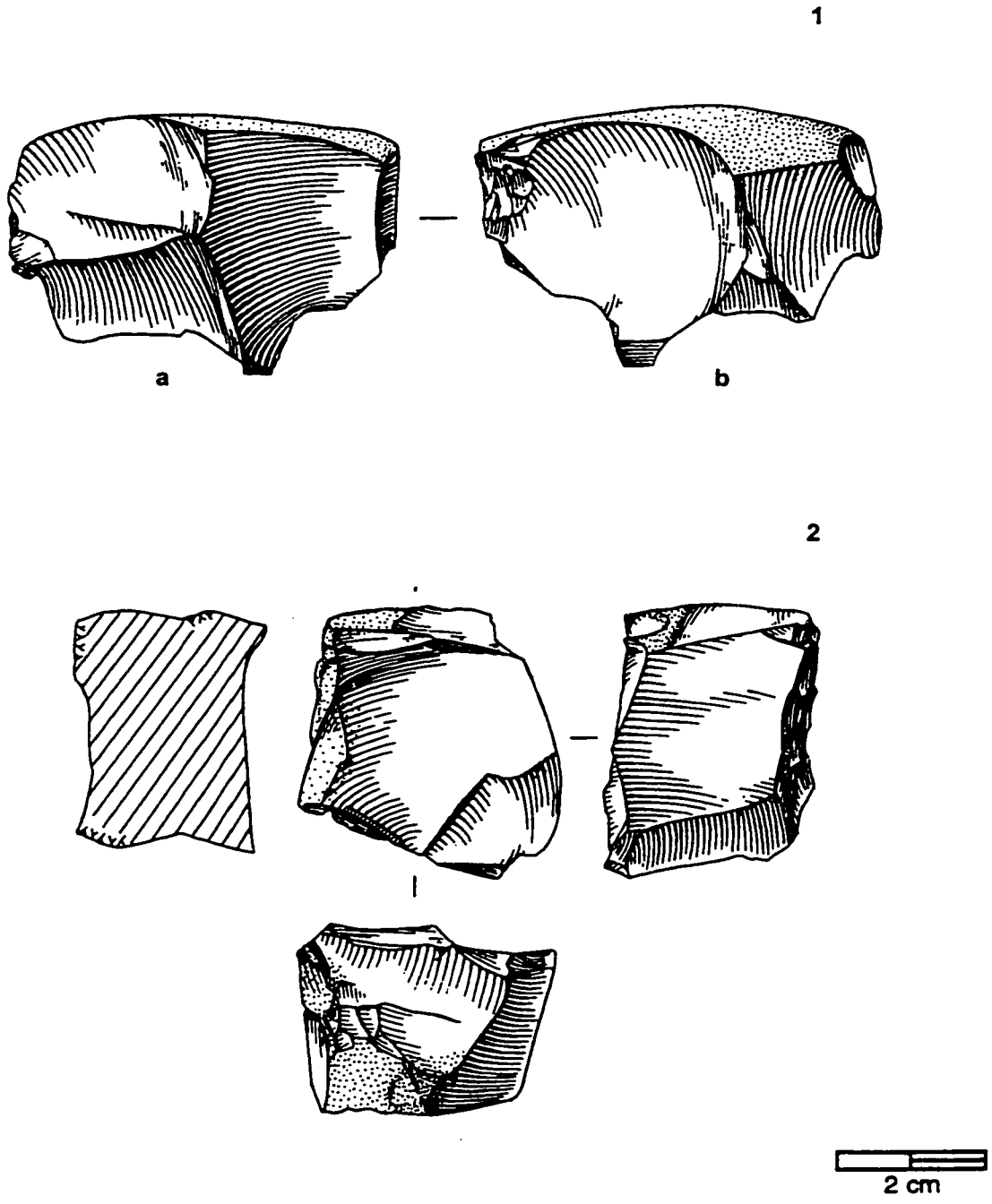



Figure A.42 Le Flageolet I, XI. Cores. 1, D10.2190, category 2C, black Senonian chert; 2, C9.3489, category 3, black Senonian chert.

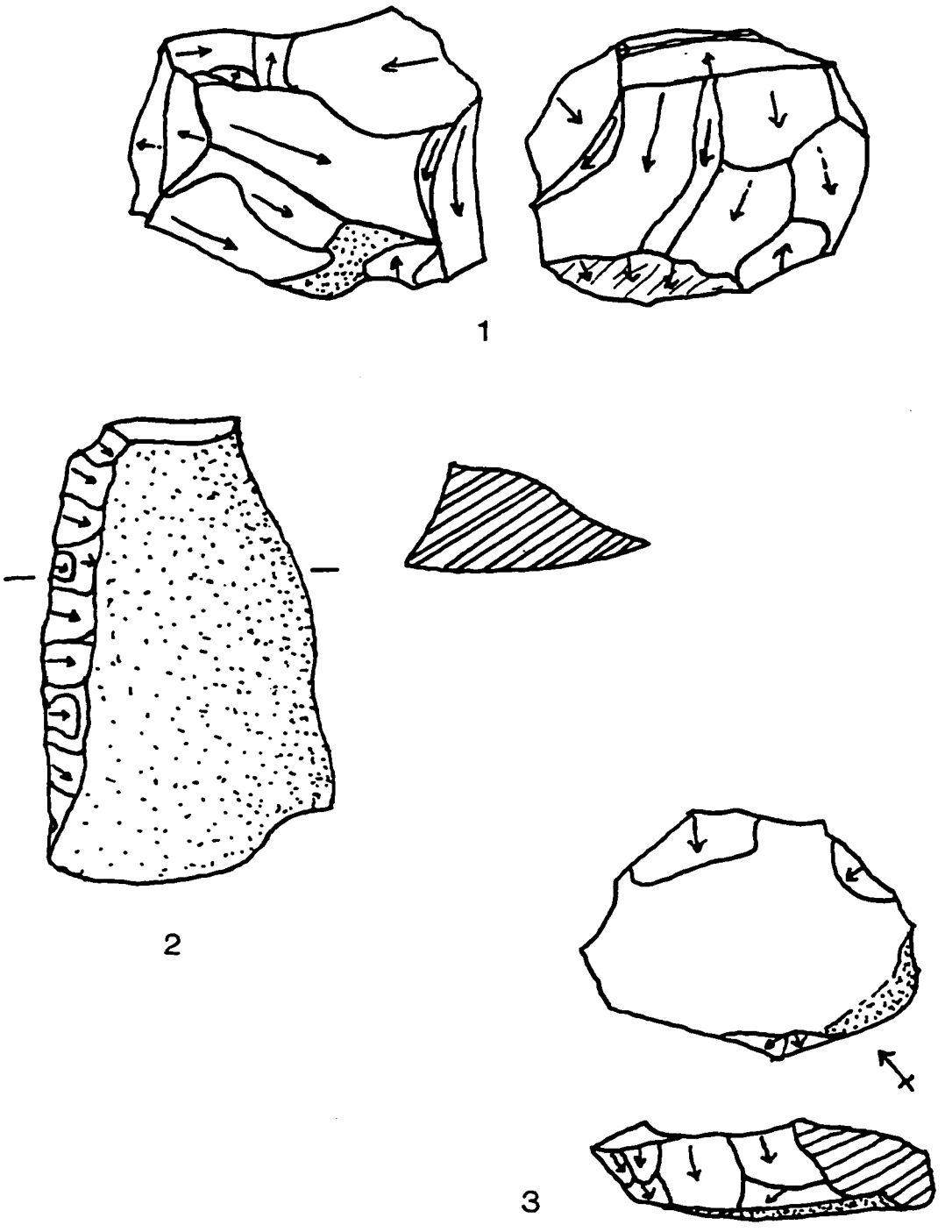



Figure A.43 Le Flageolet I, XI. Cores. 1, D11.10001, category 4B, black Senonian chert; 2, B-1.500, and 3, D11.2661: category 7, black Senonian chert. Sketched by this author.

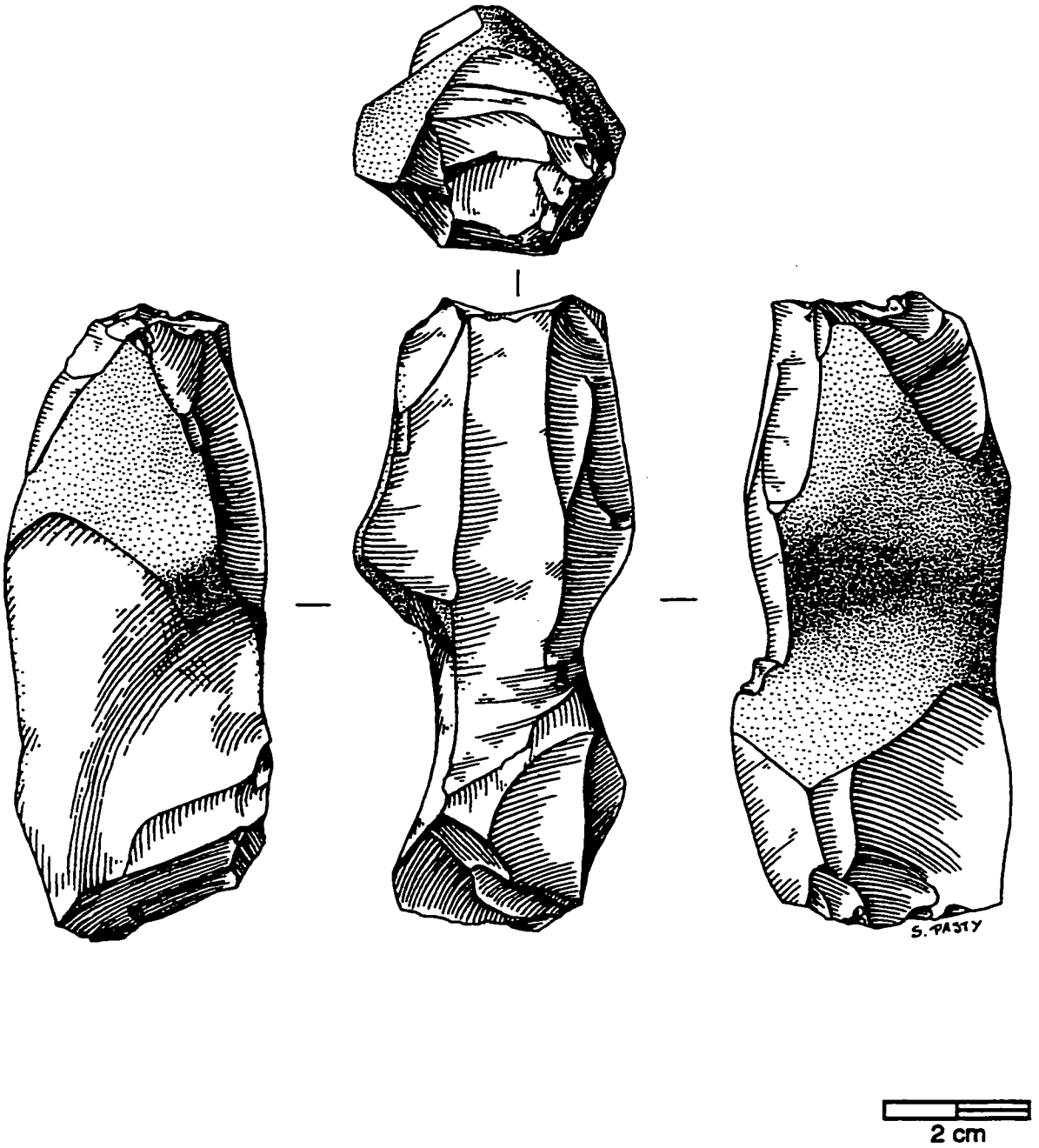



Figure A.44 Le Flageolet I, XI. C7.1774, core category 12B, black Senonian chert.

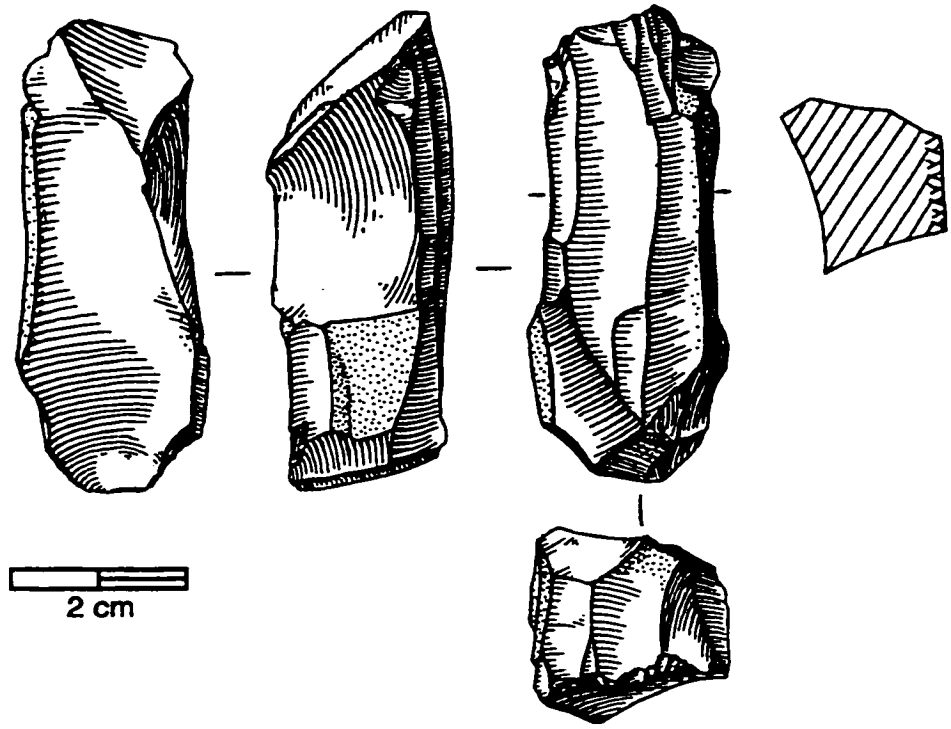



Figure A.45 Le Flageolet I, XI. D11.2382, core category 13A, black Senonian chert.

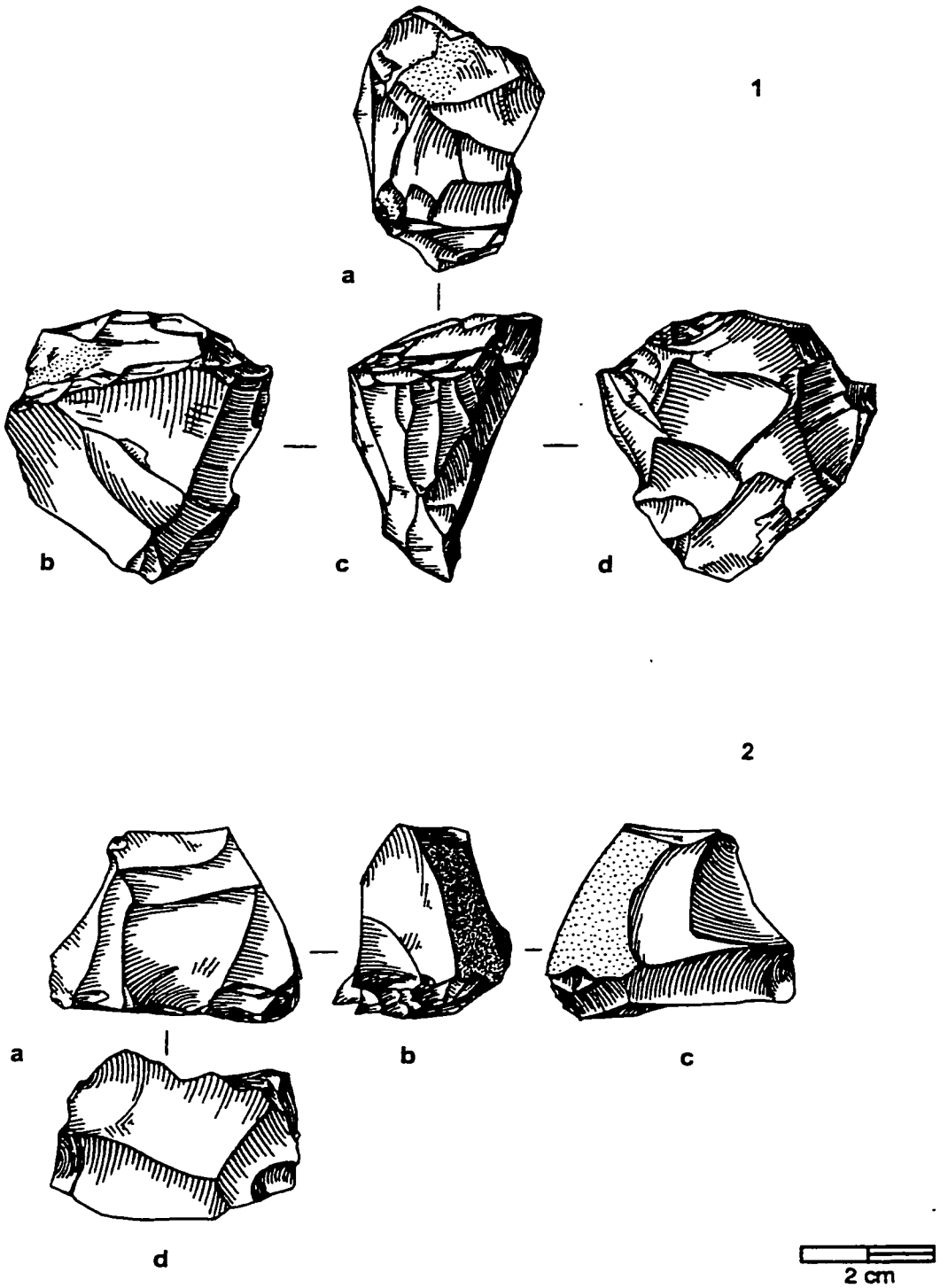



Figure A.46 Le Flageolet I, XI. Cores. 1, D11.2166, category 13A, black Senonian chert; 2, D10.2348, category 13B, black Senonian chert.

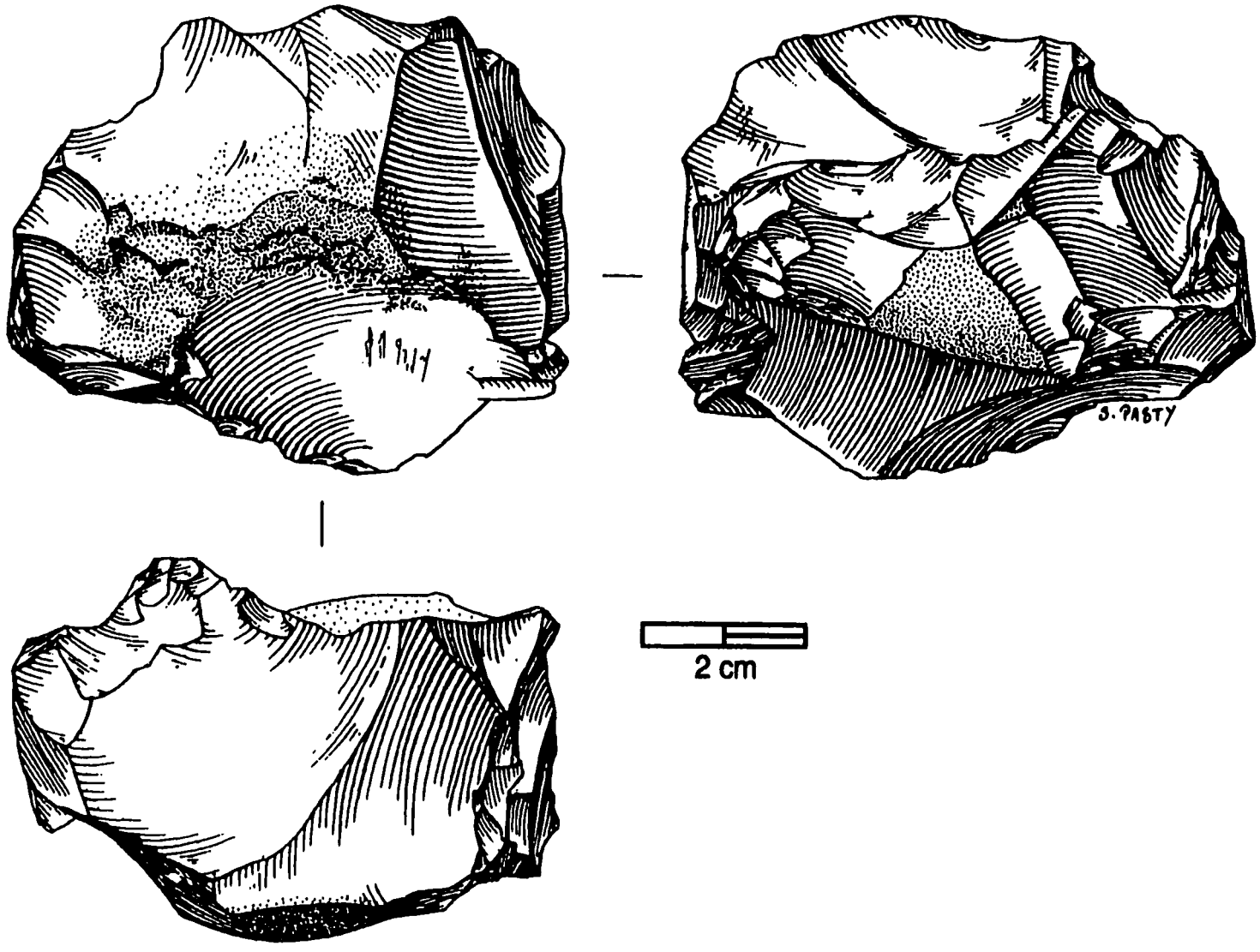



Figure A.47 Le Flageolet I, XI. C9.3368, core (category 99A), black Senonian chert.

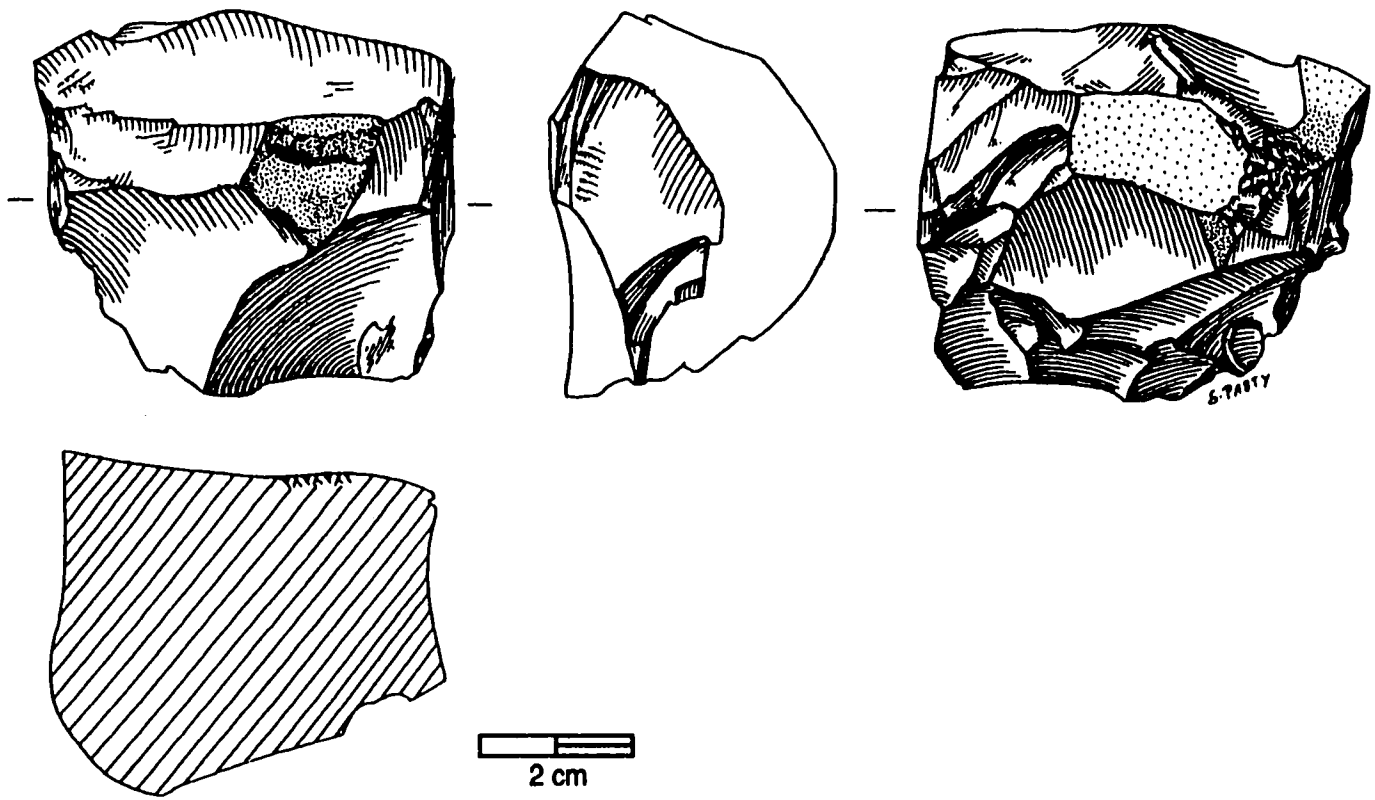



Figure A.48 Le Flageolet I, XI. C9.3680, core (category 99A), black Senonian chert

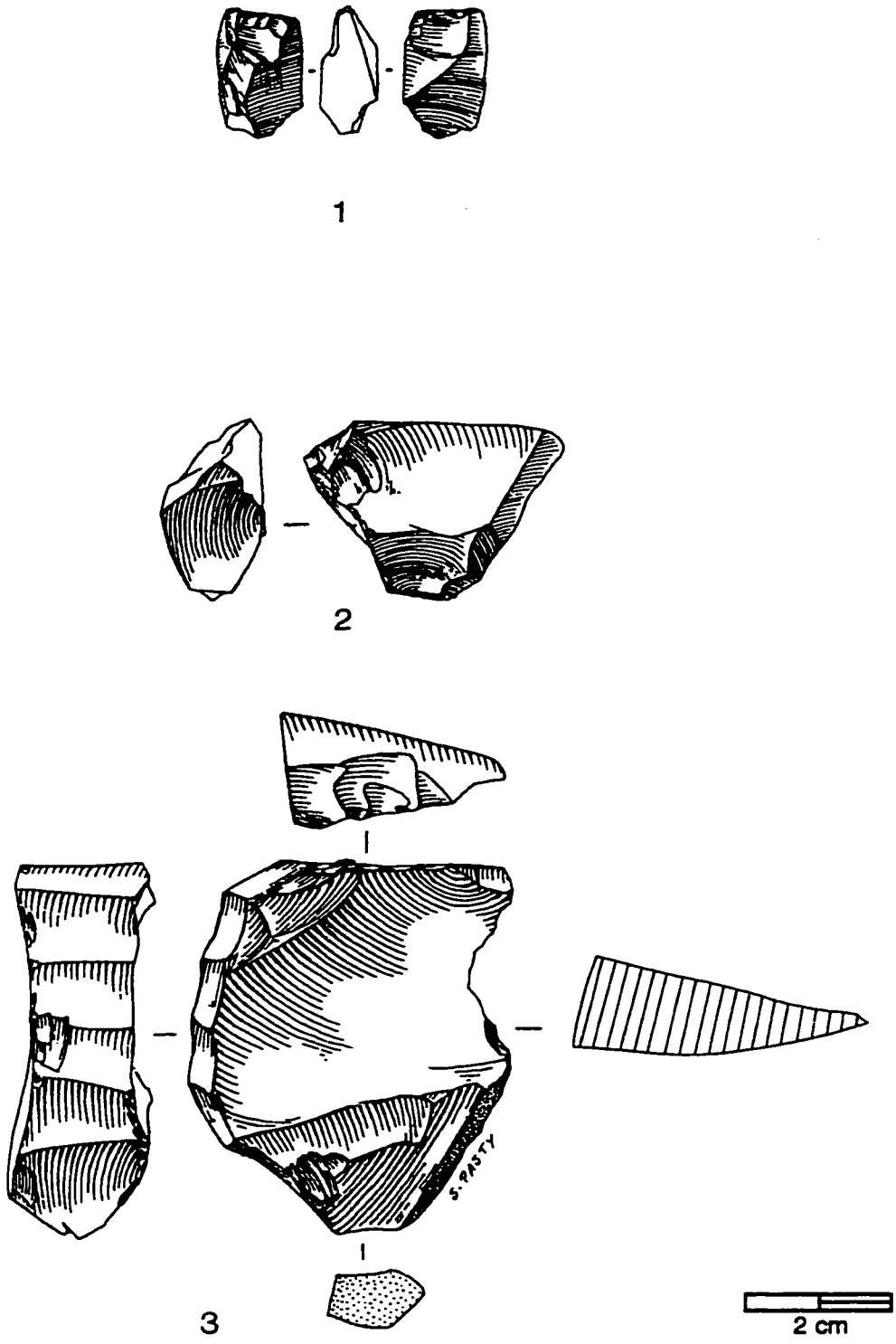



Figure A.49 Le Flageolet I, XI. 1, *pièce esquillé* from square C7, screening; 2, B10.3407, rejuvenation flake (technological type 7c) resembling an *éclat débordant*; 3, C7.1834, core rejuvenation tablet (technological type 7b).

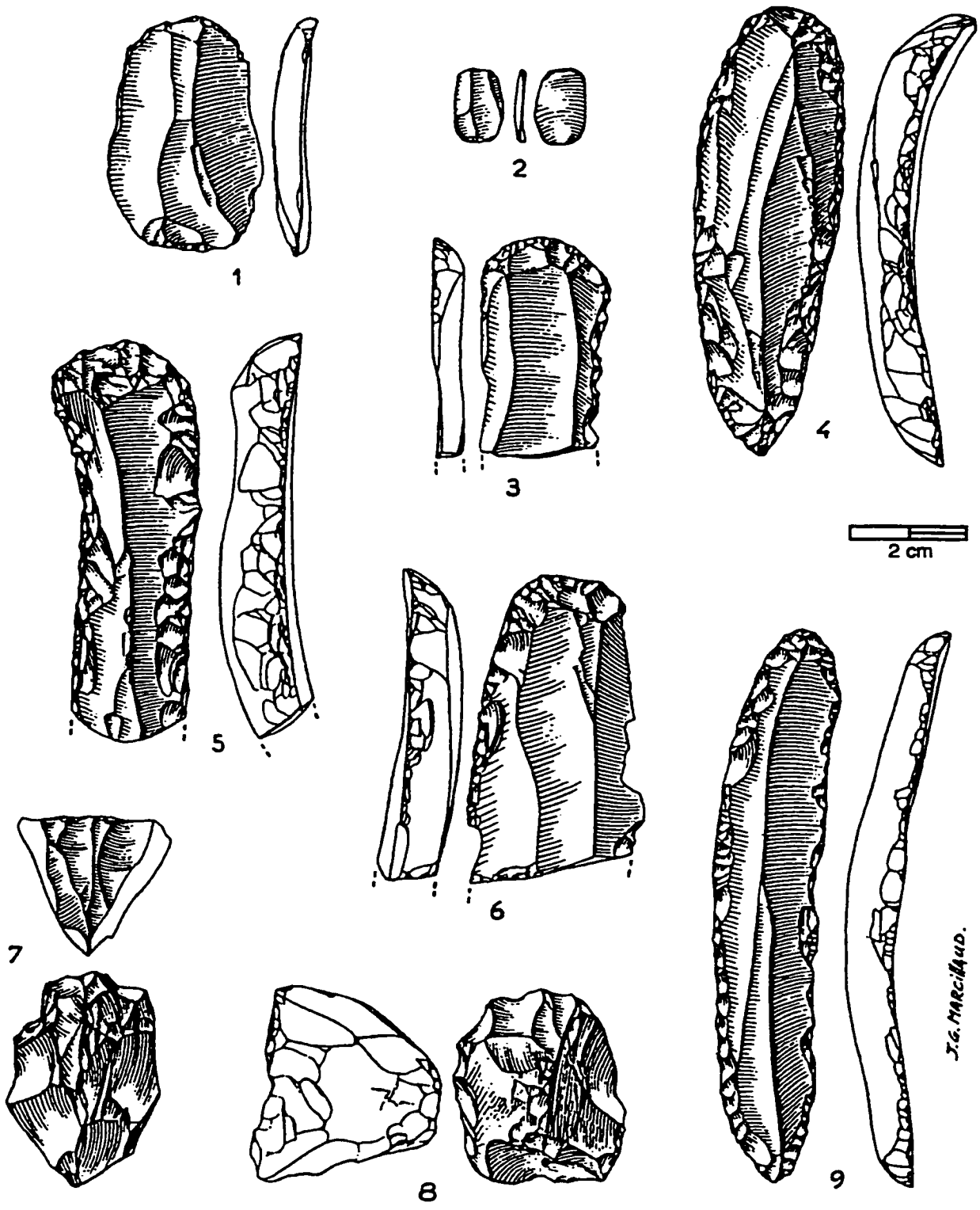



Figure A.50 Le Flageolet I, XI. Retouched pieces, from Rigaud 1982.

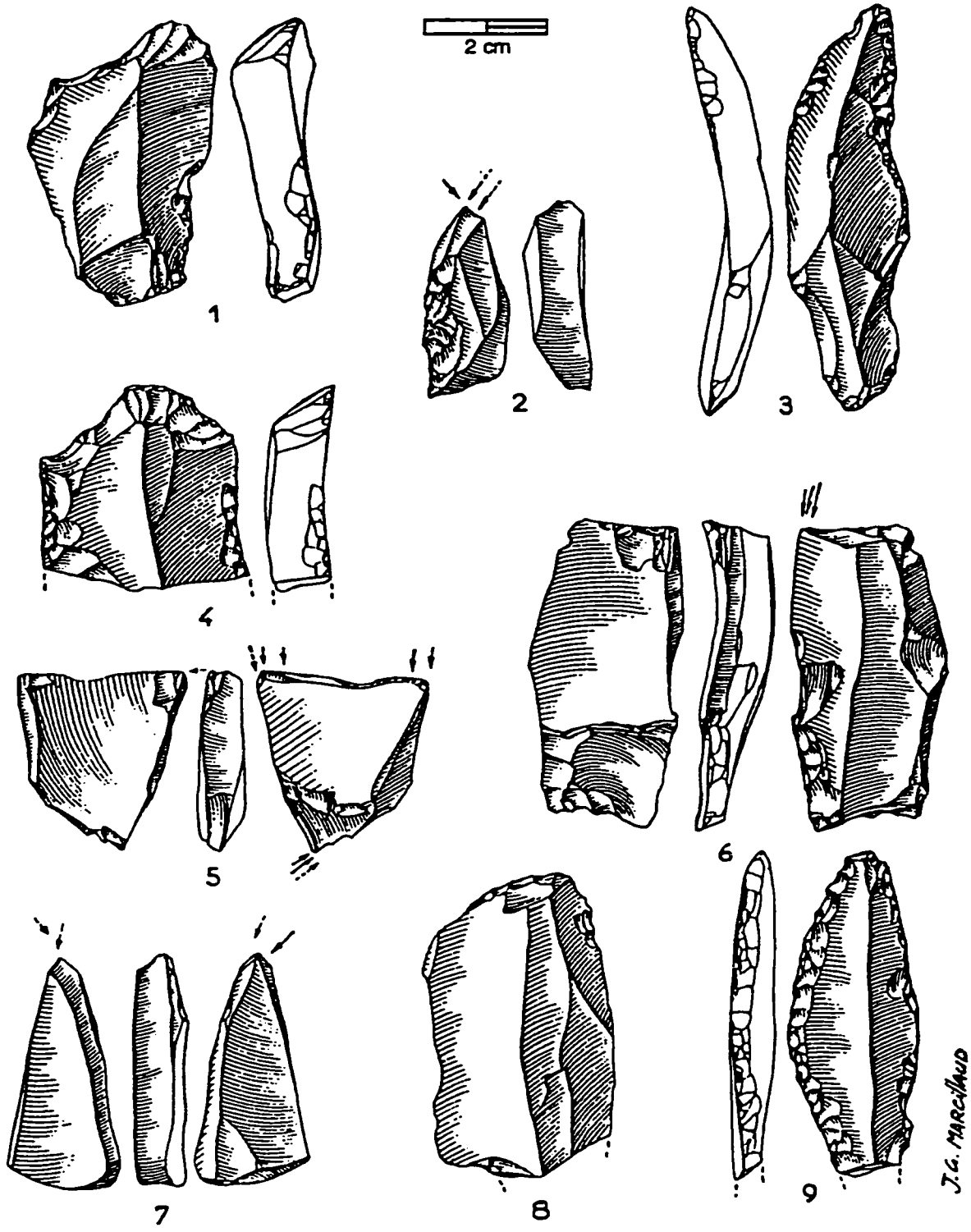



Figure A.51 Le Flageolet I, XI. Retouched pieces, from Rigaud 1982.

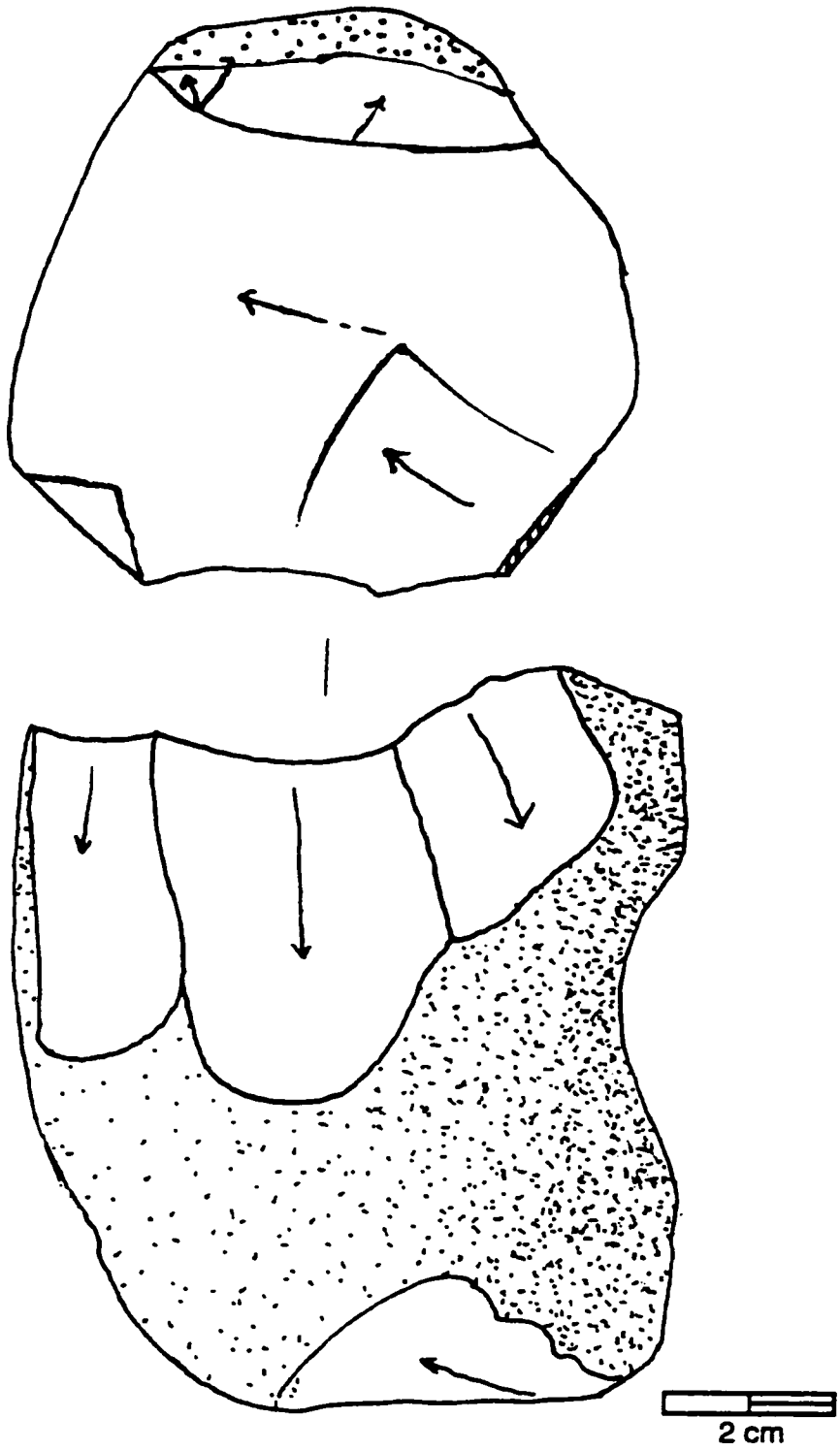



Figure A.52 Le Flageolet I, IX. B-1.290, core (category 1B), indeterminate Senonian chert; Sketched by this author.

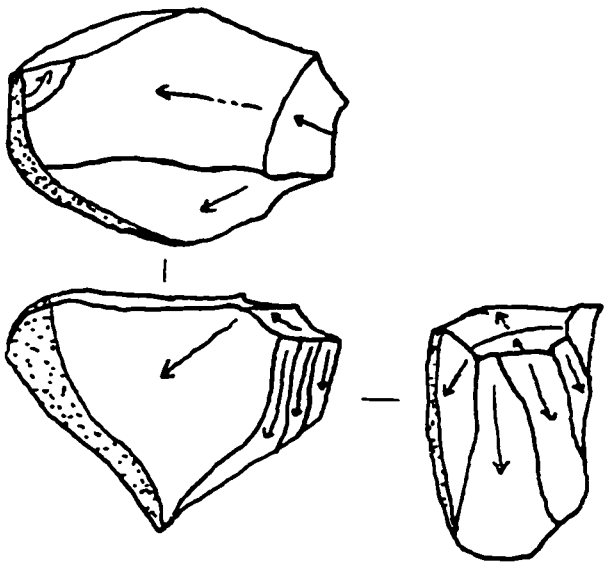


Figure A.53 Le Flageolet I, level IX. B11.1776, core category 13A, black Senonian chert. Sketched by this author. Actual size.

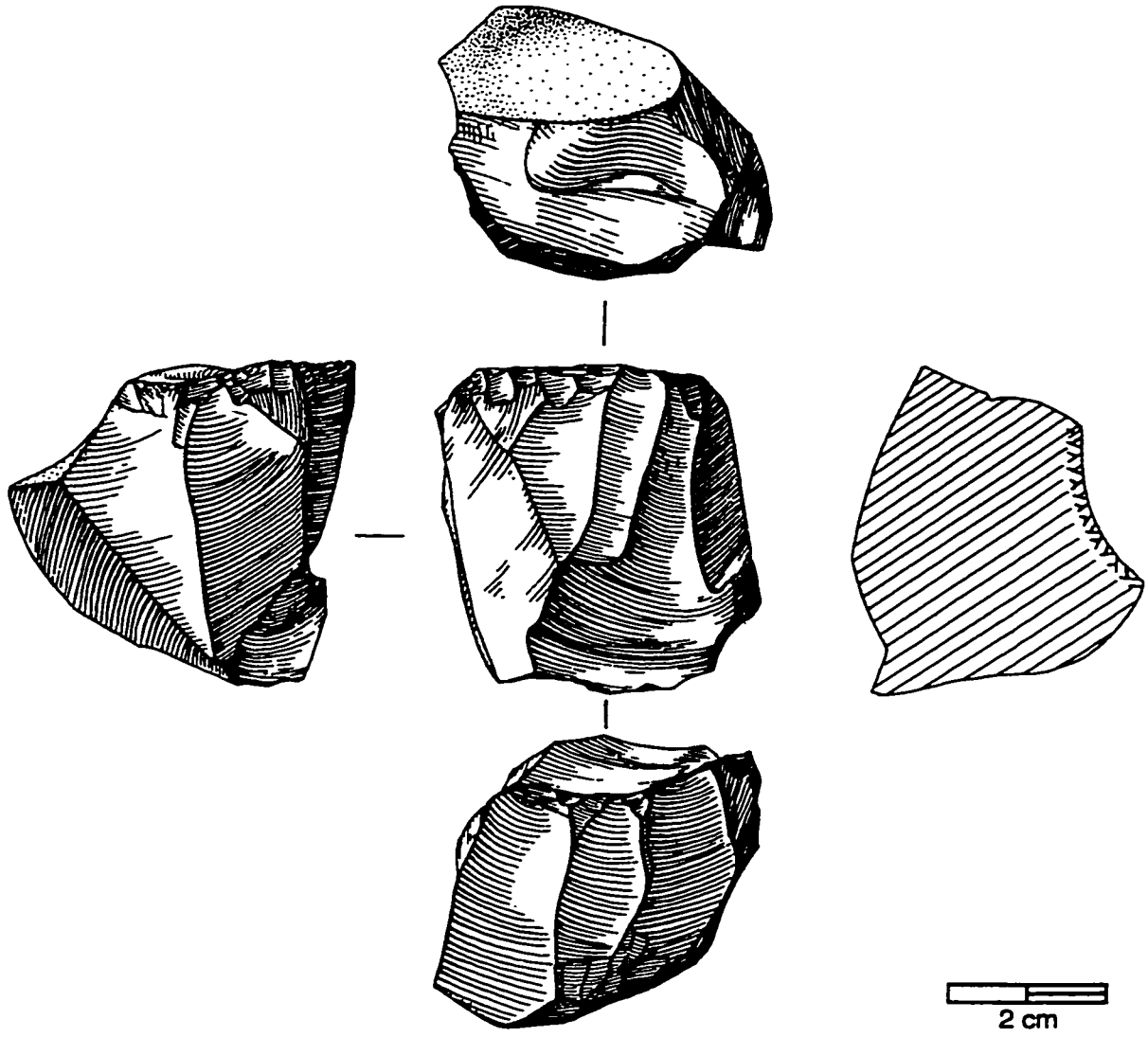



Figure A.54 Le Flageolet I, level IX. D6.2004, core category 13A, black Senonian chert.

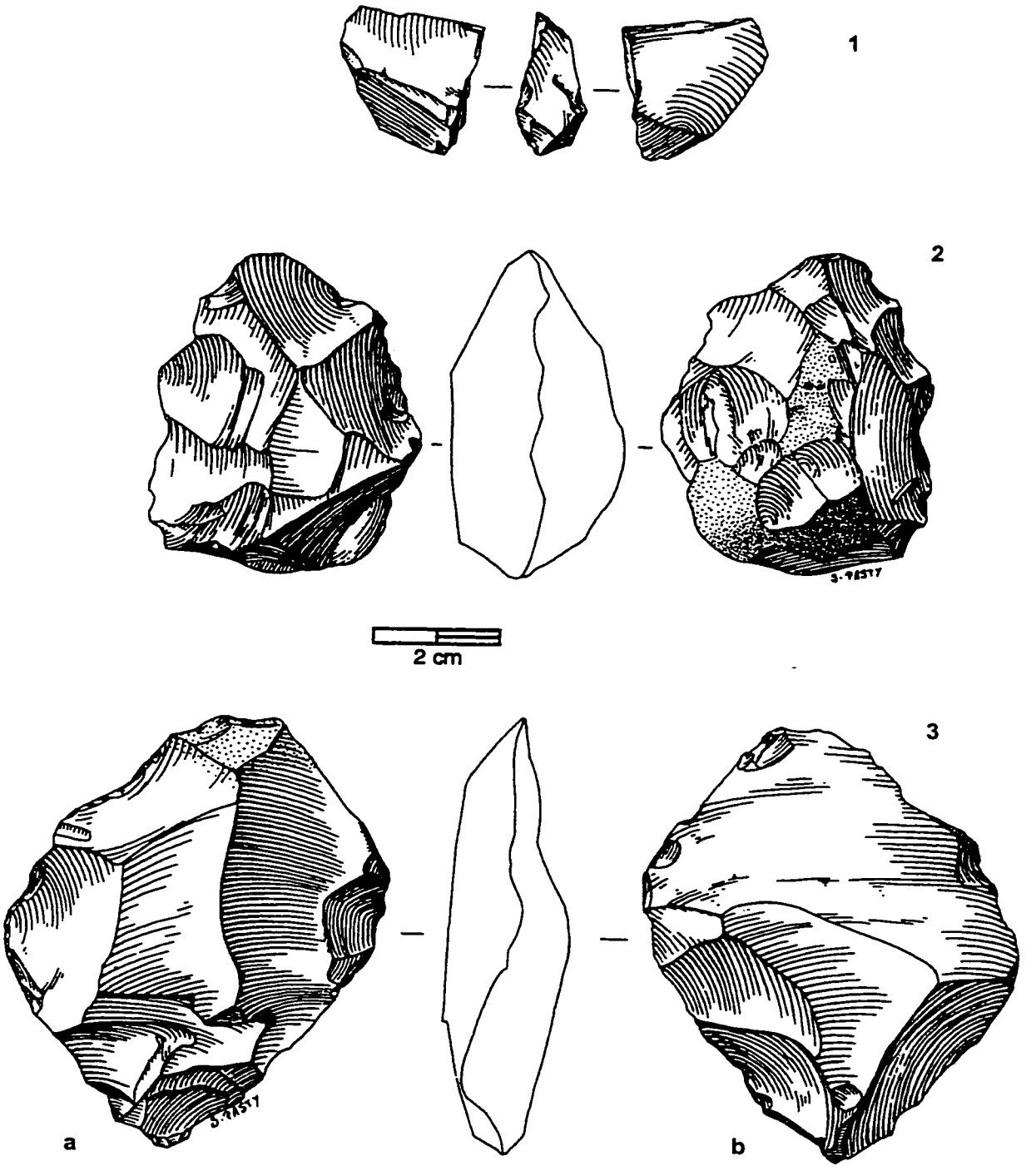



Figure A.55 Le Flageolet I, level IX. 1, C-1.493, rejuvenation flake (technological type 7c); 2, D6.2084, core category 10A, black Senonian chert; 3, C2.160, core category 10A, black Senonian chert.

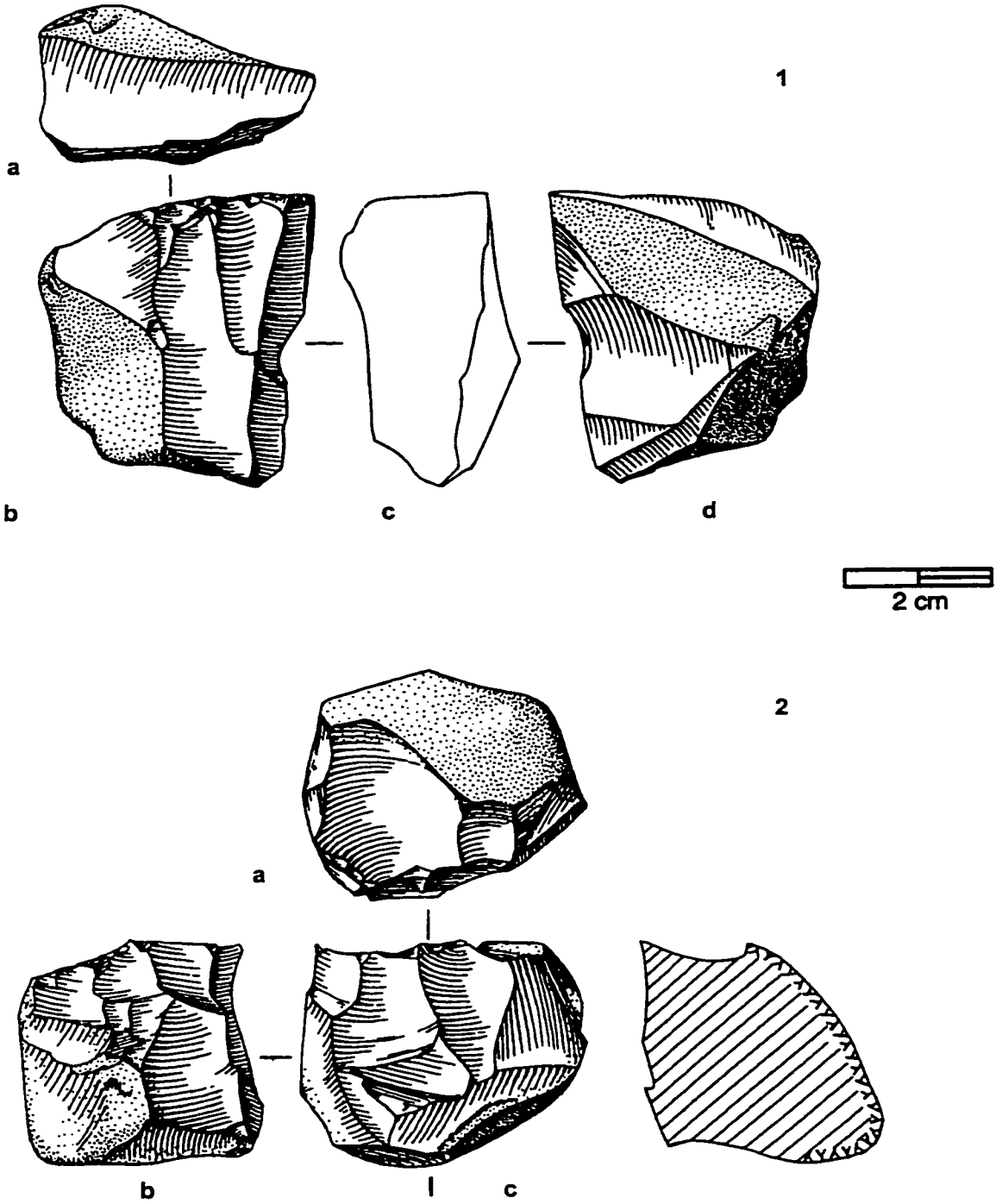



Figure A.56 Le Flageolet I, level IX. Cores. 1, B10.2773, core category 13A, beige Senonian chert; 2, C2.178, core category 1B, beige Senonian chert.

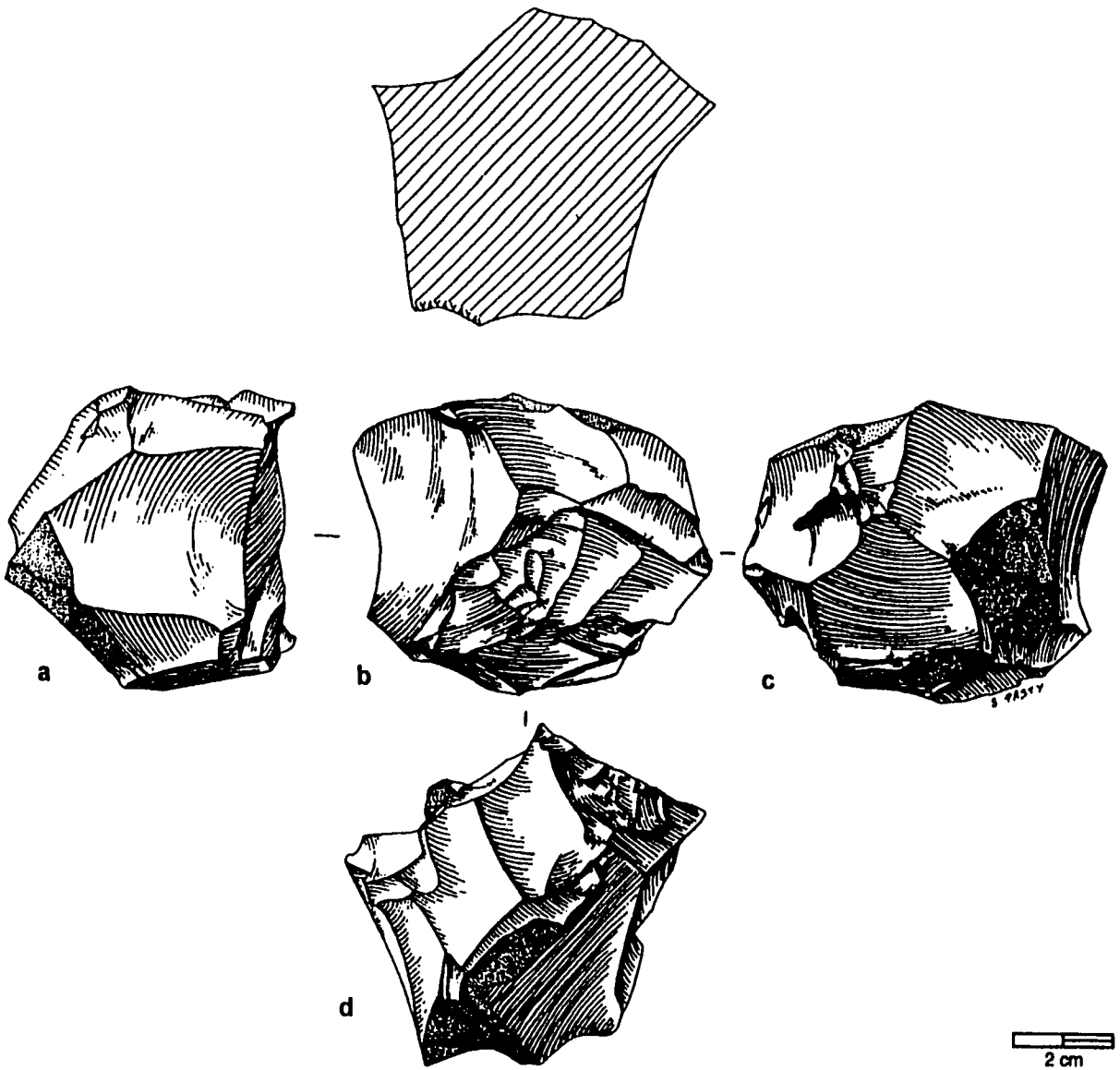



Figure A.57 Le Flageolet I, level IX. C-1.679, core category 7, indeterminate

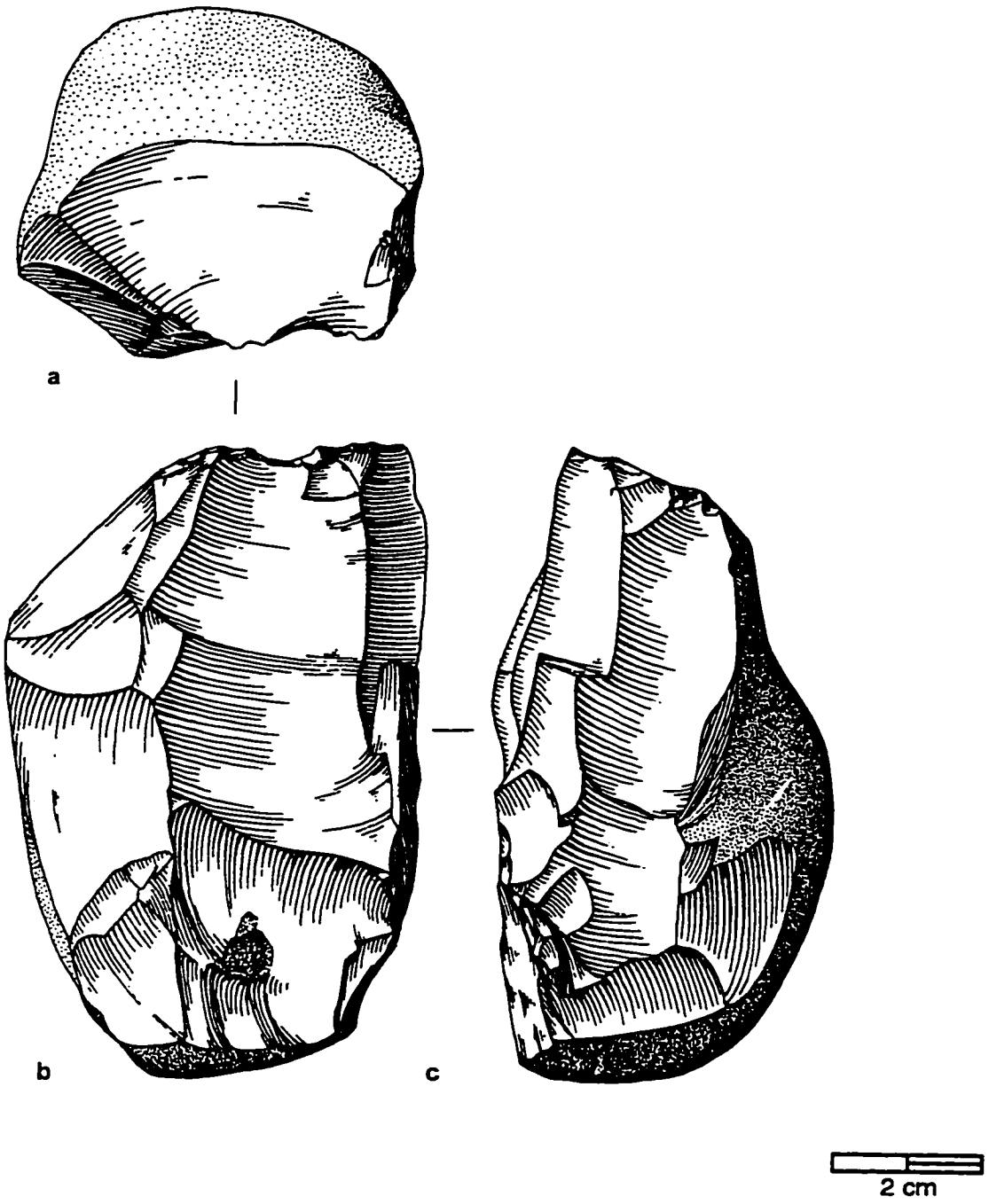



Figure A.58 Le Flageolet I, level IX. D9.2351, core (category 12B), black Senonian chert.

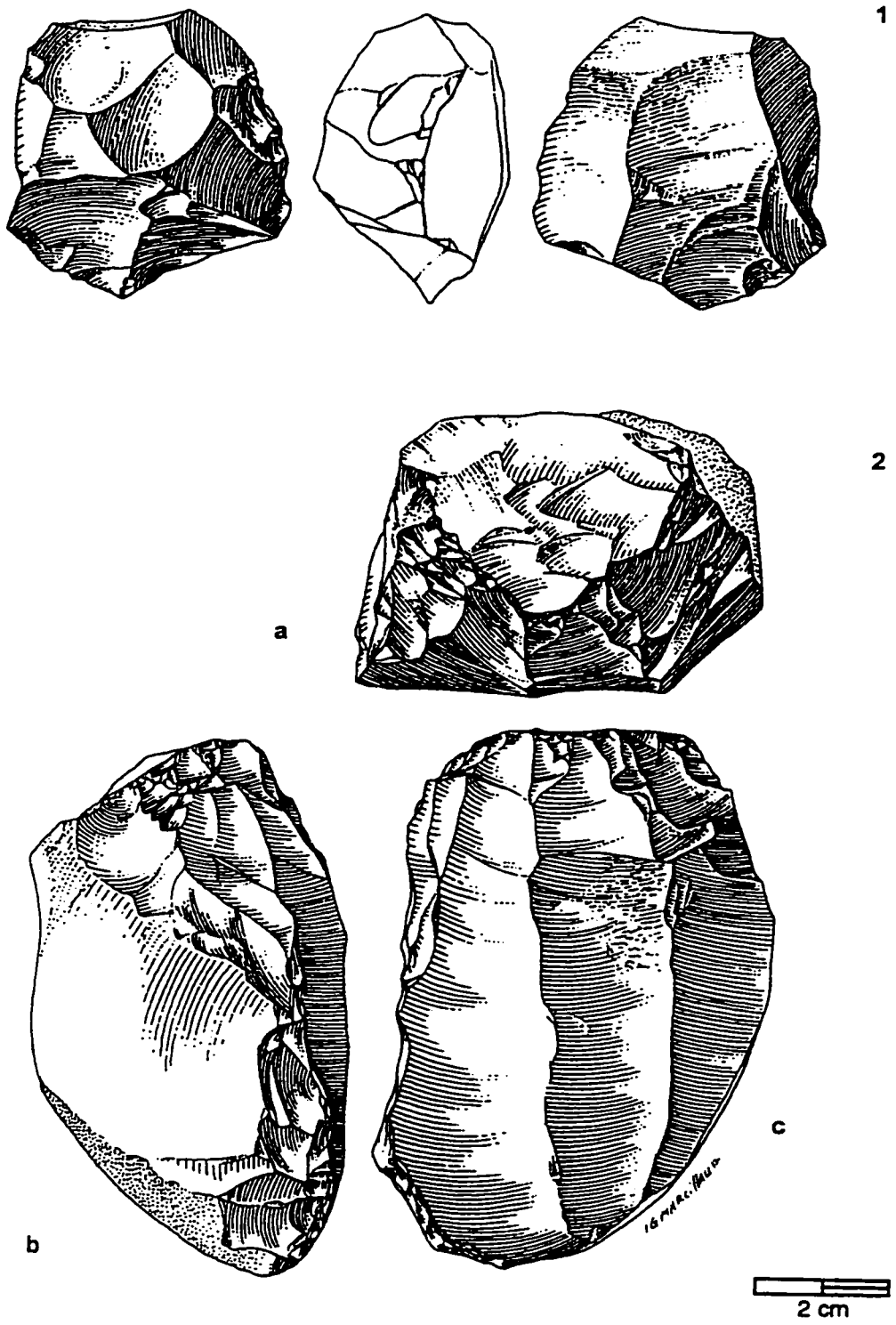



Figure A.59 Le Flageolet I, level IX. Cores. 1, not analyzed in detail; 2, A5.497, category 14A, black Senonian chert. Both by J.-G. Marcillaud, from Lucas (2000, plates 4 and 5).

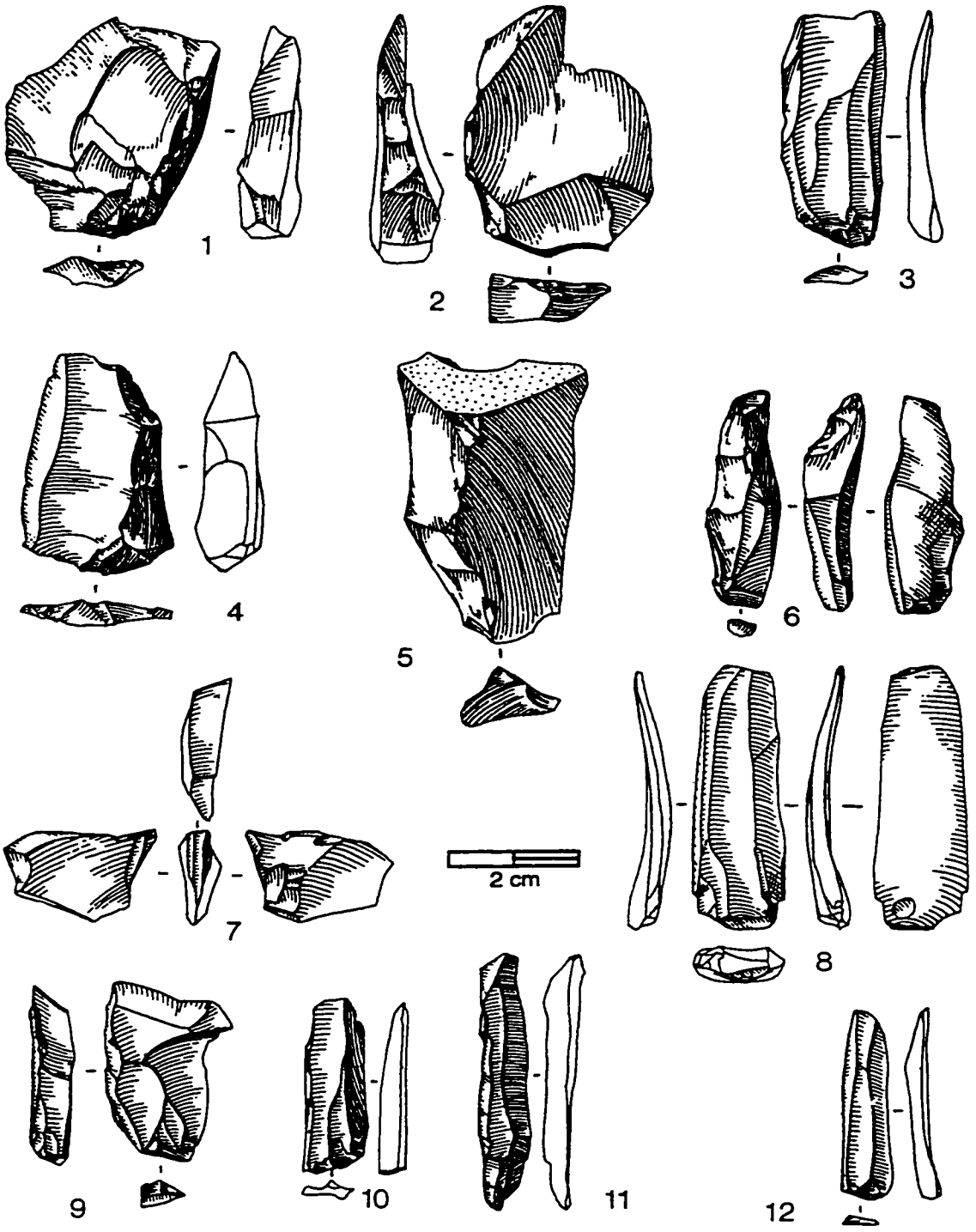



Figure A.60 Le Flageolet I, level IX. 1, 2: core rejuvenation tablets with remnant of debitage surface along one edge only; 3: blade with traces of lateral maintenance from an adjacent surface of the core; 4: blade with traces of preparation from a previously removed crested blade; 5,10: "other" rejuvenations; 6: crested blade; 7: core (category 13A); 8, 11, 12: ordinary blades; 9: ordinary flake.

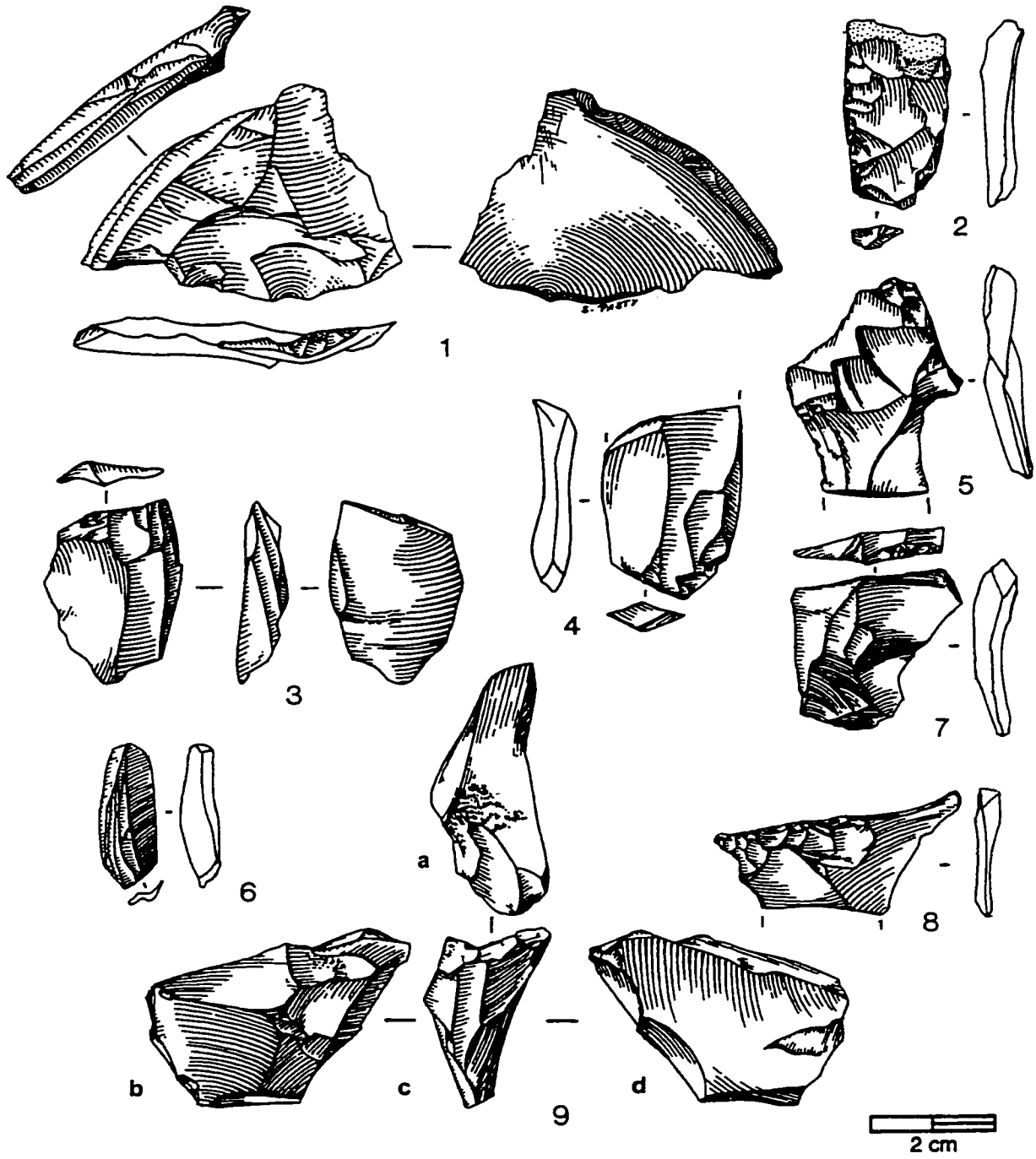



Figure A.61 Le Flageolet I, level IX. 1, 2, 5, 8, rejuvenation flakes; 3, 4, non-cortical flakes; 7, core rejuvenation tablet; 9, core (category 13A). 1, 3, and 6 are rejuvenations of the bits of carinated endscrapers.

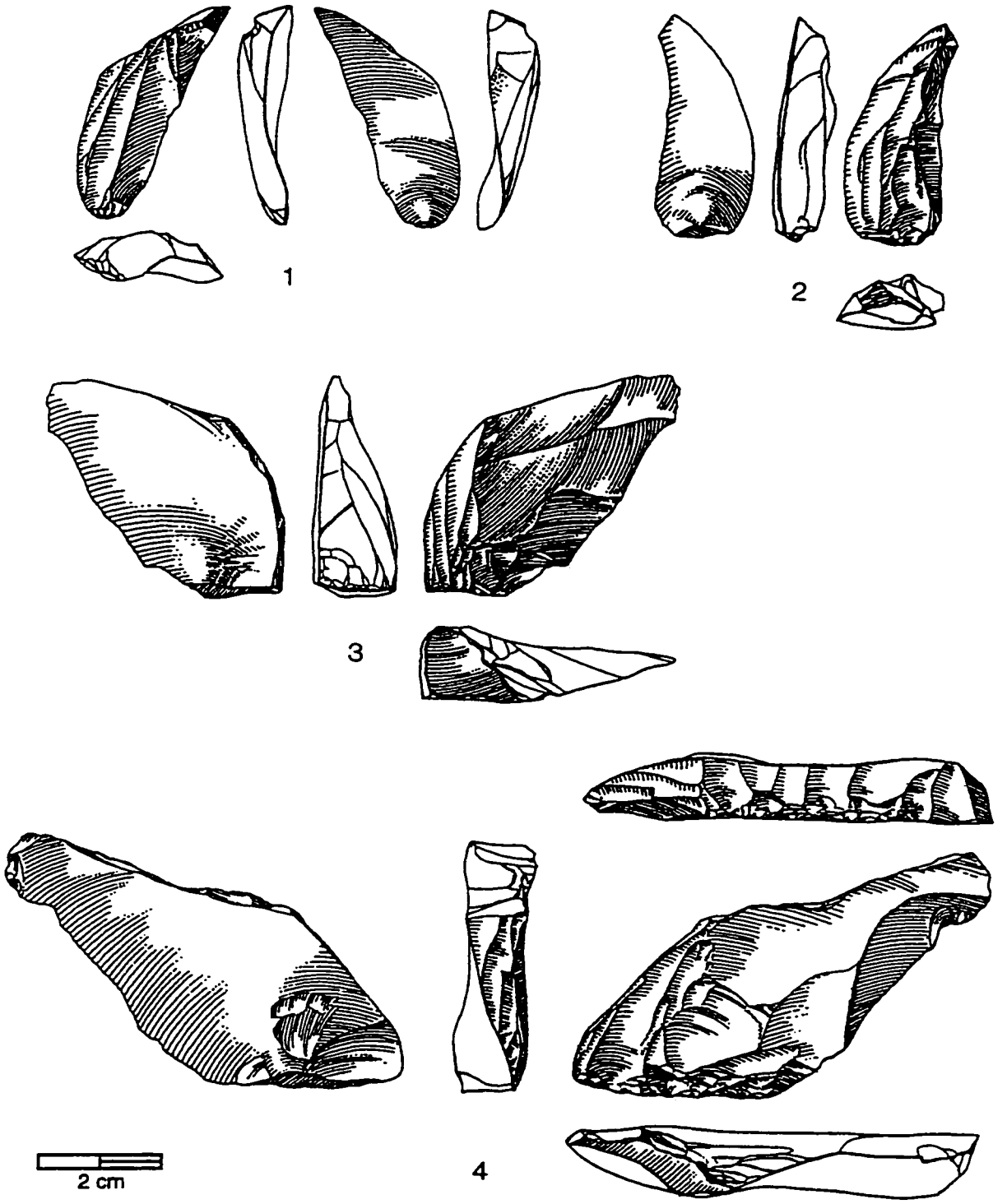



Figure A.62 Le Flageolet I, level IX. 1, 2, 4: rejuvenations of the bits of carinated endscrapers; 3: rejuvenation that accidentally removed the bit of a carinated endscraper. By J.-G. Marcillaud, from Lucas (2000:257).

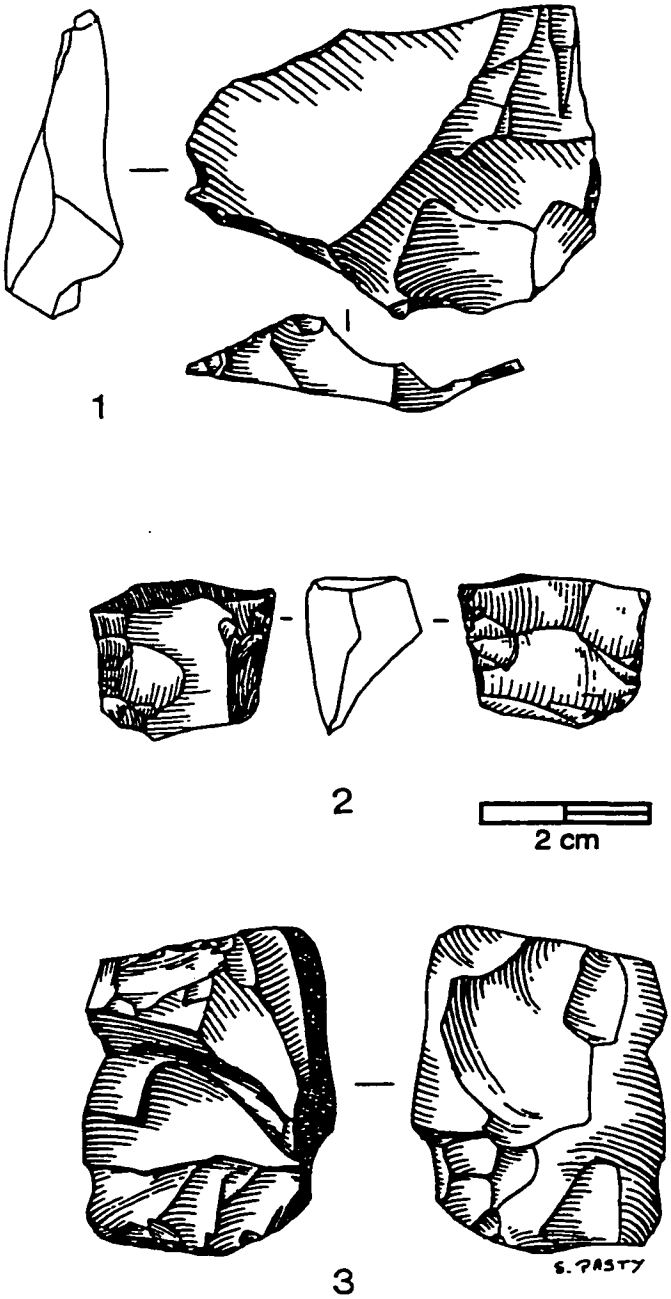



Figure A.63 Le Flageolet I, level IX. 1, *éclat débordant*; 2 and 3, *pièces esquillés*.

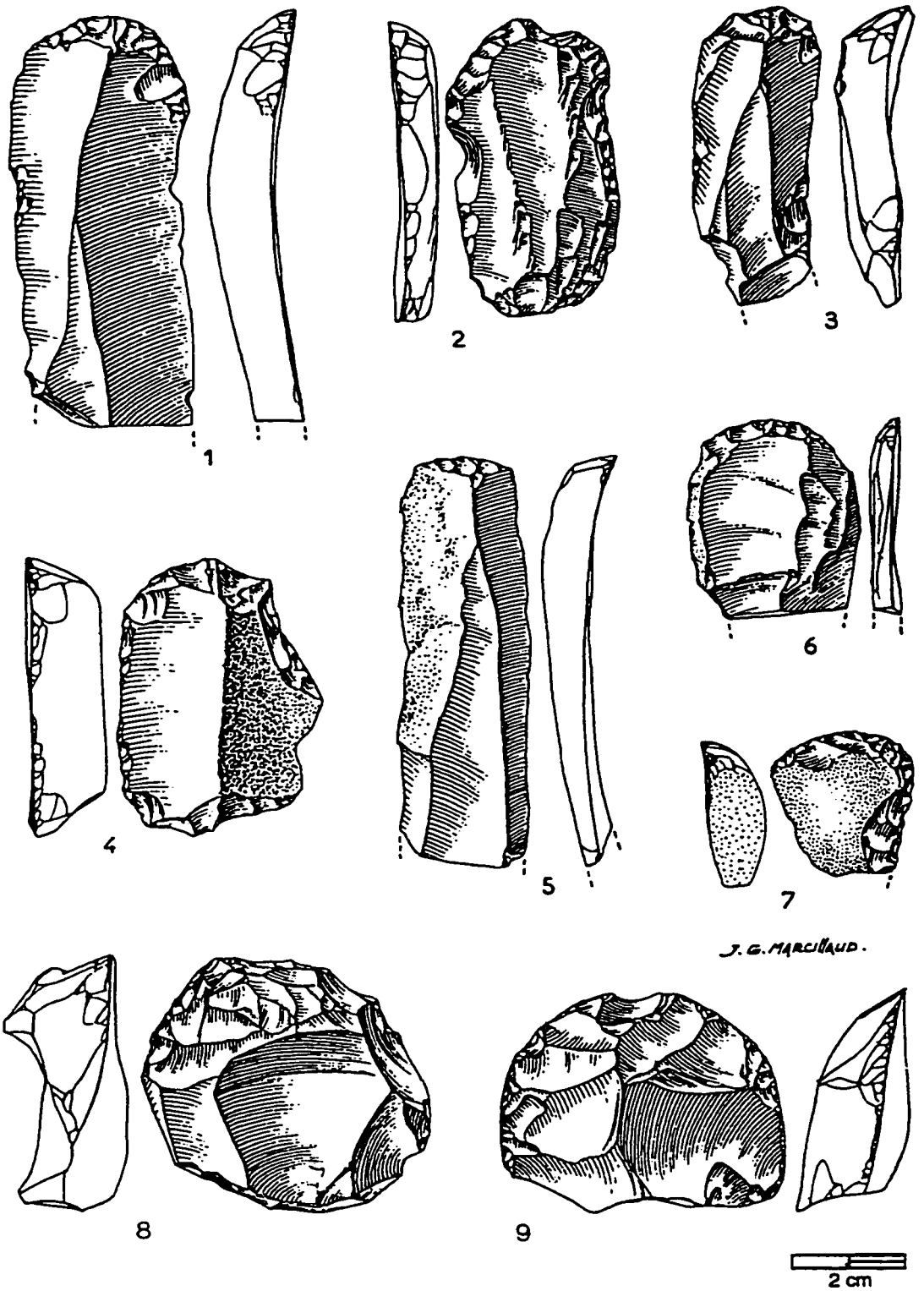



Figure A.64 Le Flageolet I, level IX. Endscrapers. By J.-G. Marcillaud, from Rigaud 1982.

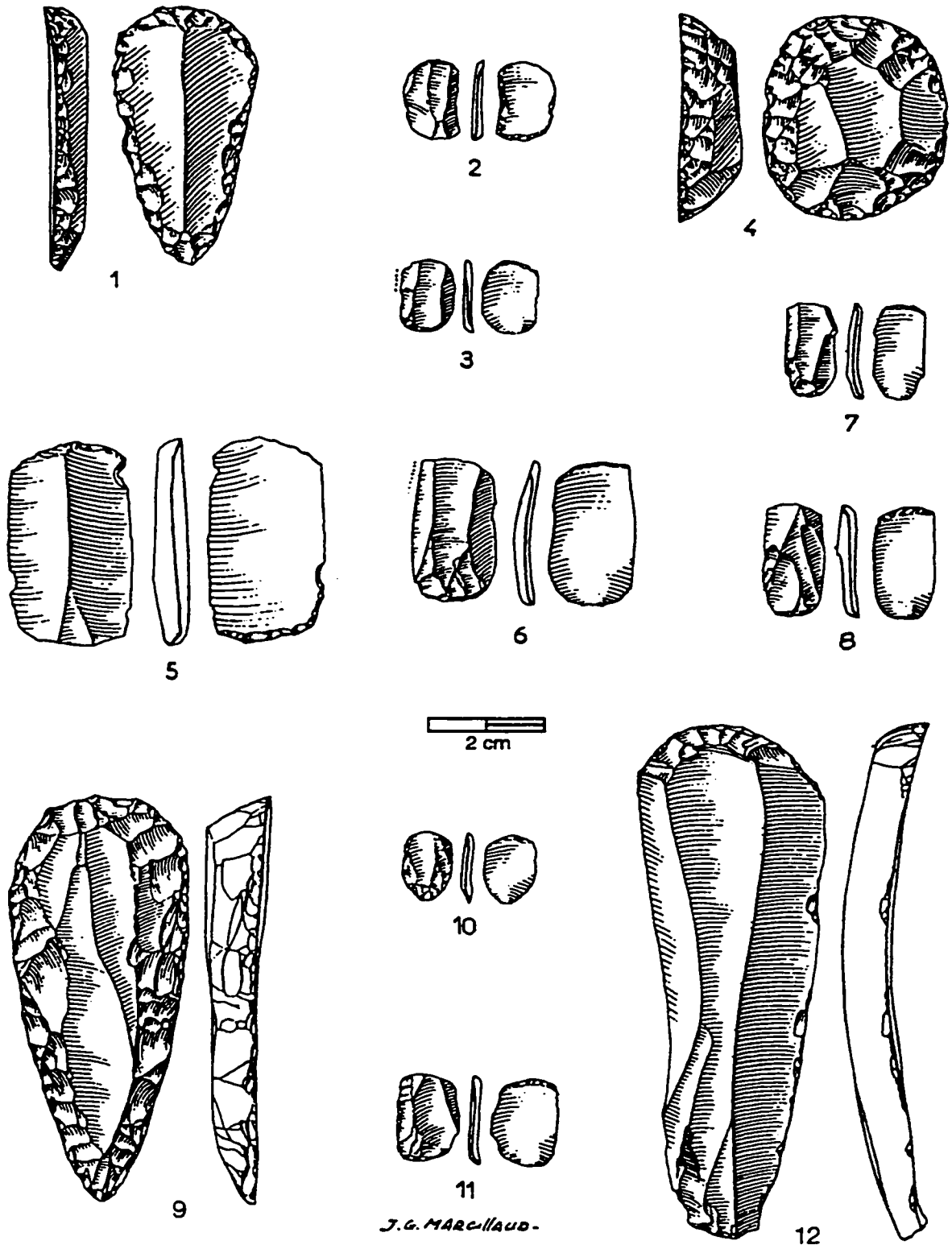



Figure A.65 Le Flageolet I, level IX. Endscrapers. 1, endscraper on retouched blade; 2, 3, 5-8, 10, 11: caminade endscrapers; 4, circular endscraper; 9, endscraper on Aurignacian blade; 12: simple endscraper on a blade. By J.-G. Marcillaud, from Rigaud 1982.

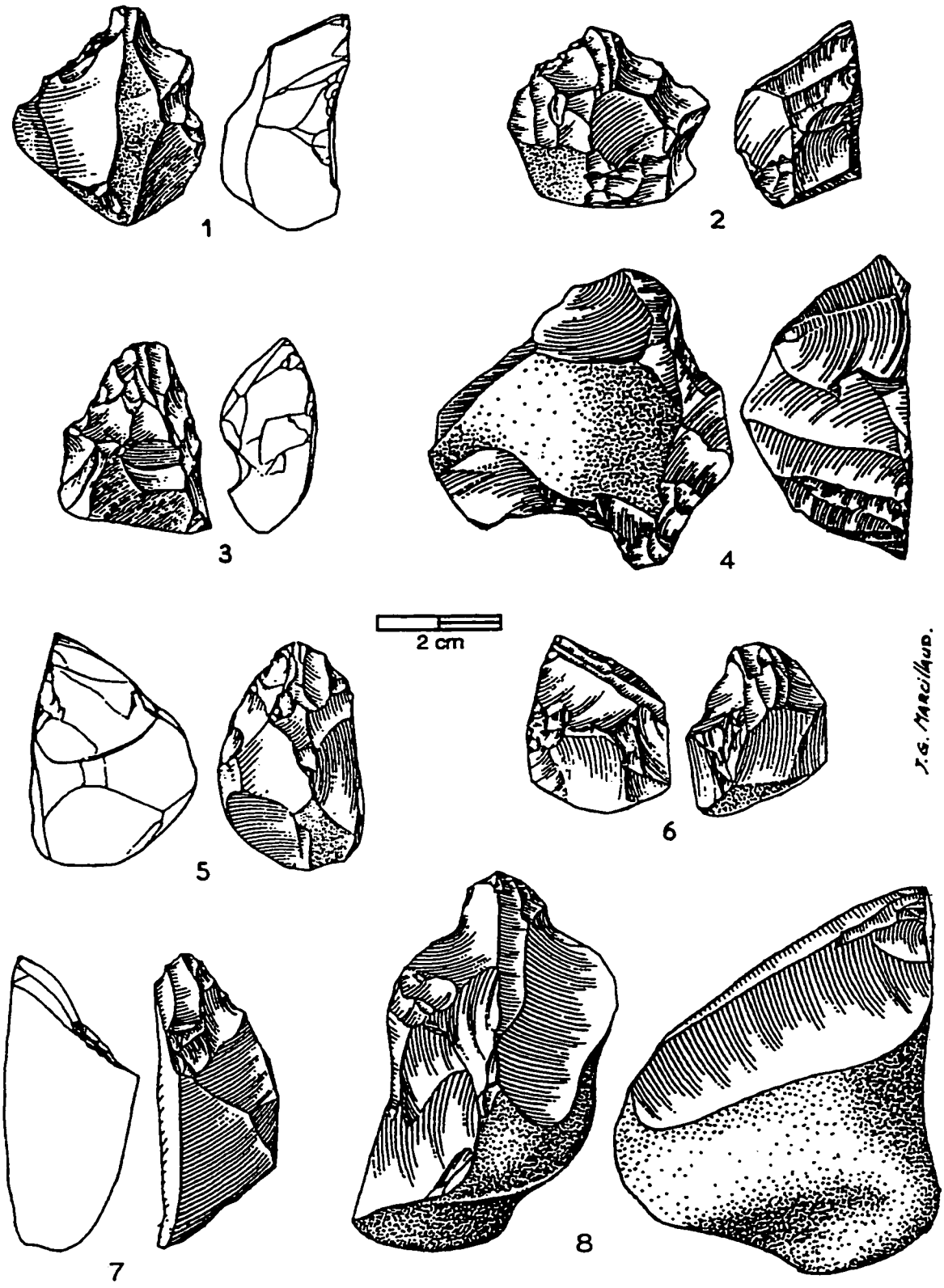



Figure A.66 Le Flageolet I, level IX. Carinated and muzzled endscrapers. By J.-G. Marcillaud from Rigaud 1982

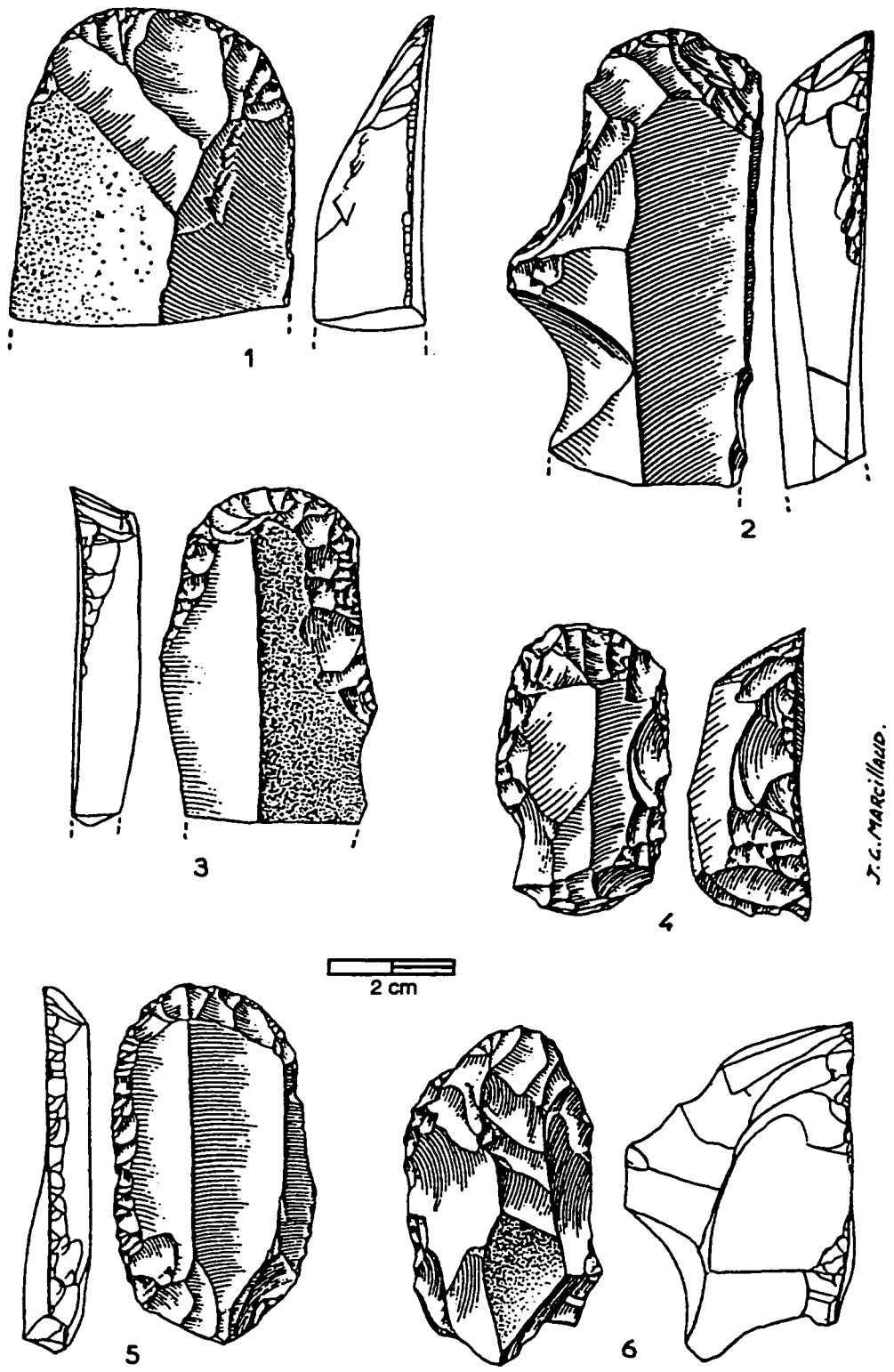



Figure A.67 Le Flageolet I, level IX. Endscrapers. By J.-G. Marcillaud, from Rigaud 1982.

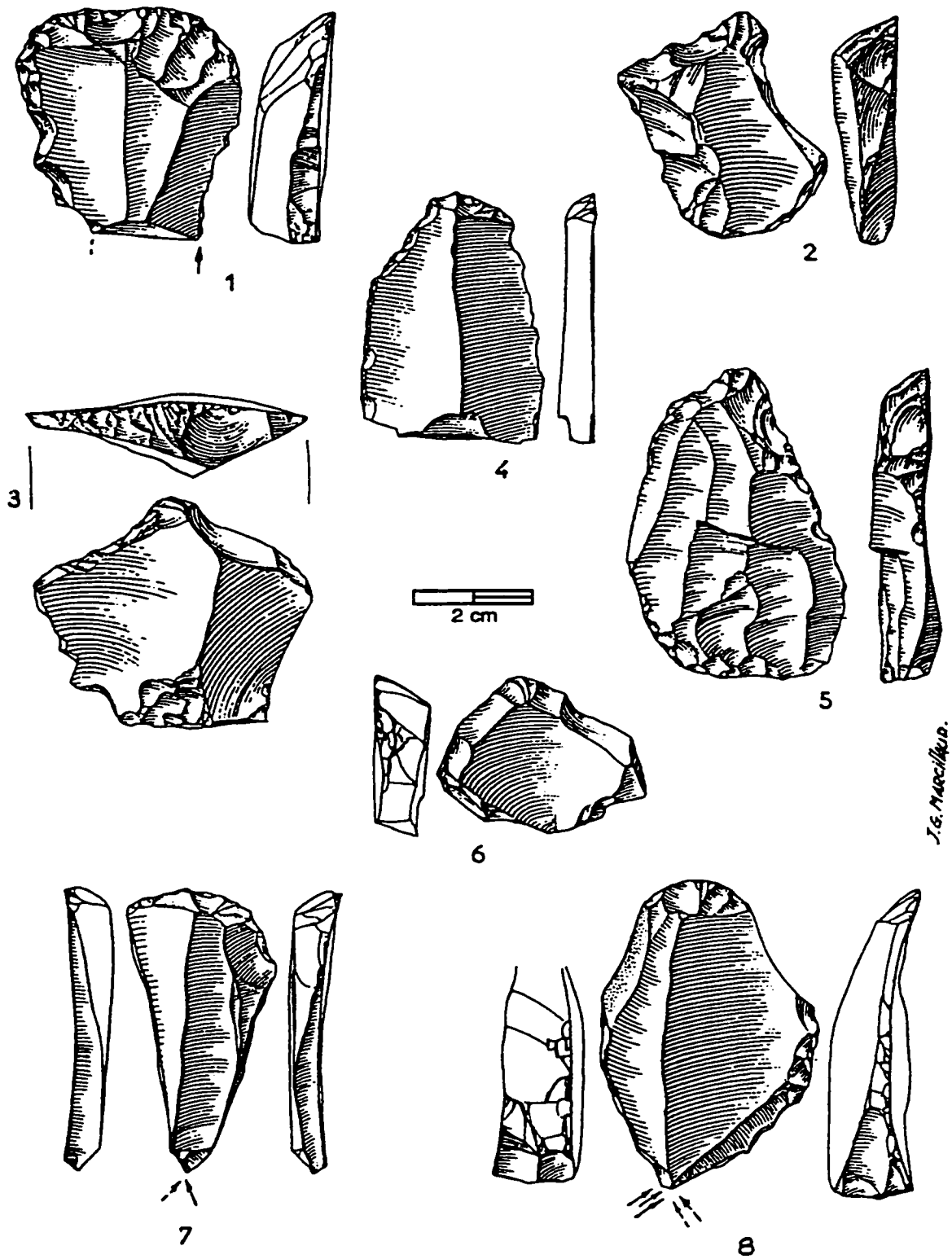



Figure A.68 Le Flageolet I, level IX. Endscrapers. By J.-G. Marcillaud, from Rigaud 1982.

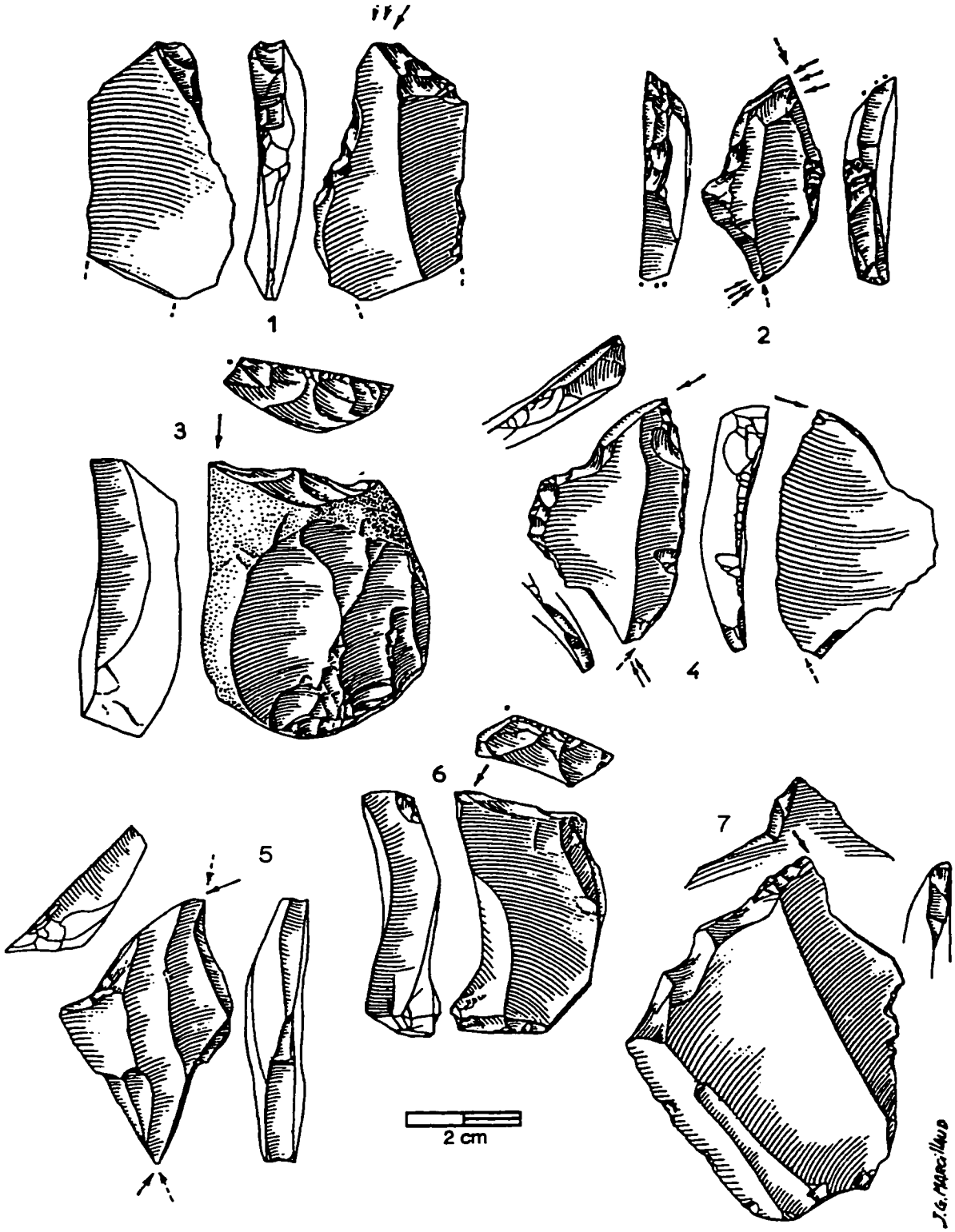



Figure A.69 Le Flageolet I, level IX. Burins. By J.-G. Marcillaud, from Rigaud 1982.

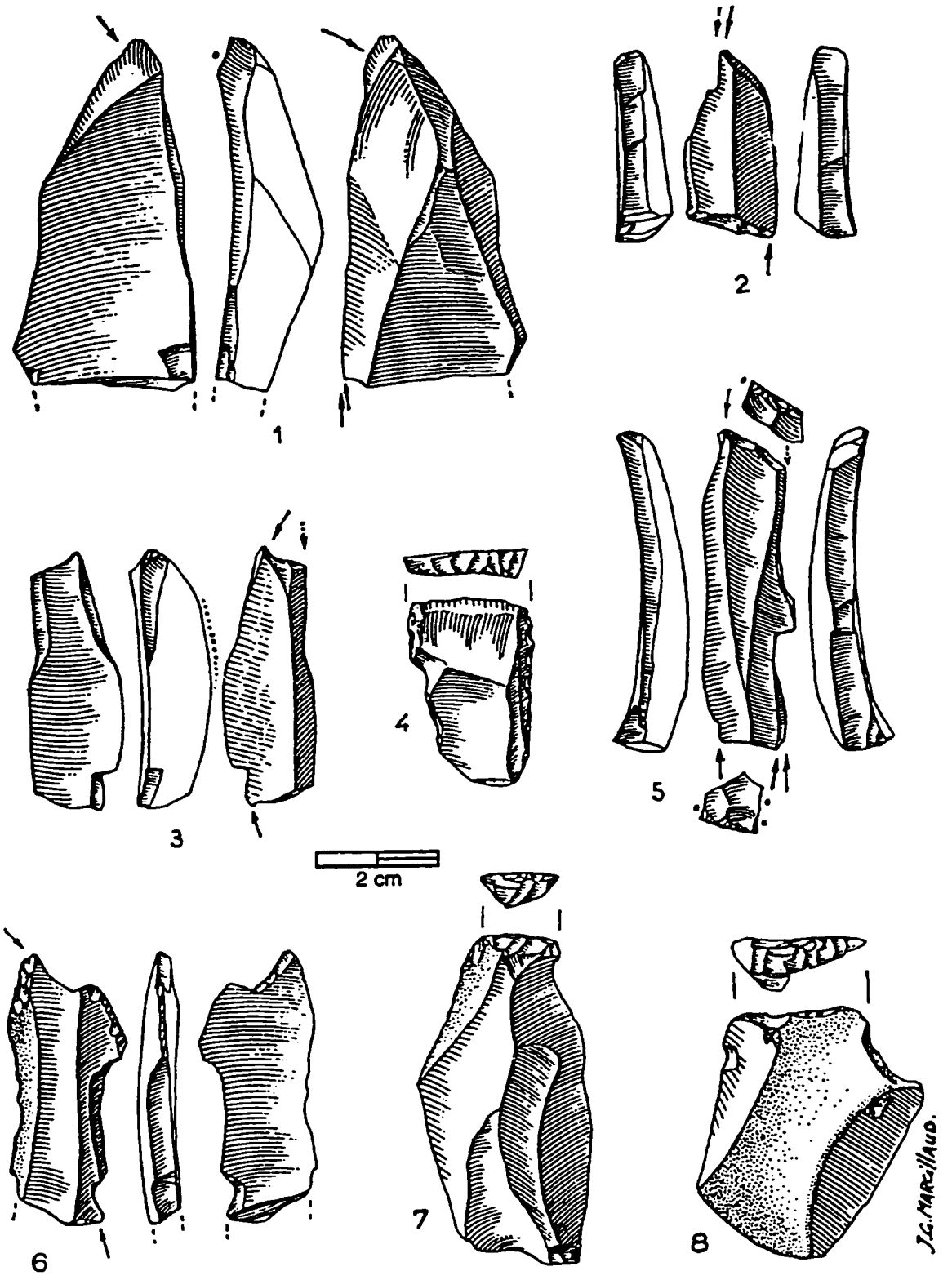



Figure A.70 Le Flageolet I, level IX. 1-3, 5, 6: burins; 4, 7, 8: truncated pieces. By J.-G. Marcillaud, from Rigaud 1982

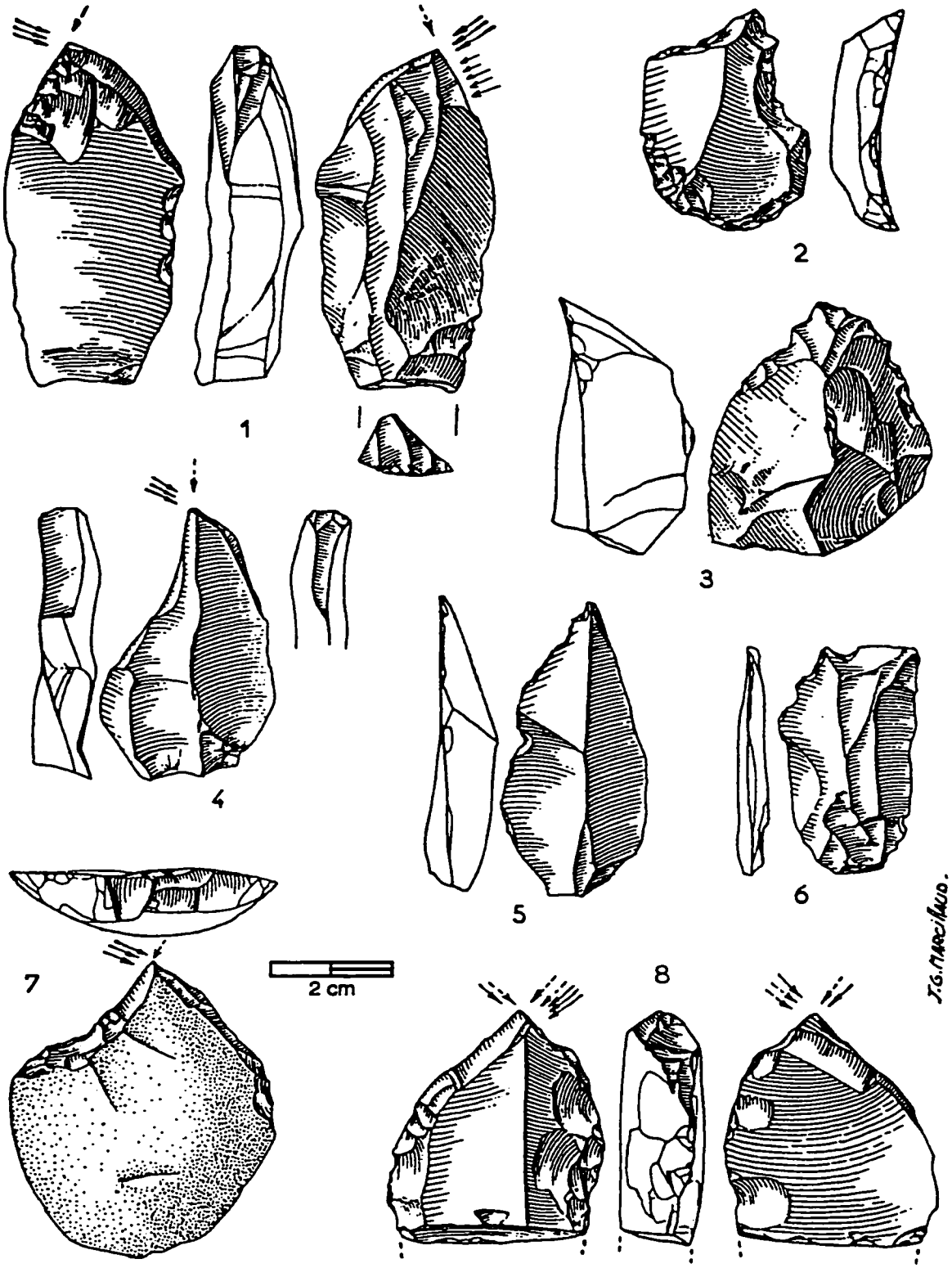



Figure A.71 Le Flageolet I, level IX. 1, busked burin; 2, 3: muzzled endscrapers; 4, angle burin; 5,6: perforators; 7, dihedral burin; 8, straight dihedral burins. By J.-G. Marcillaud, from Rigaud 1982.

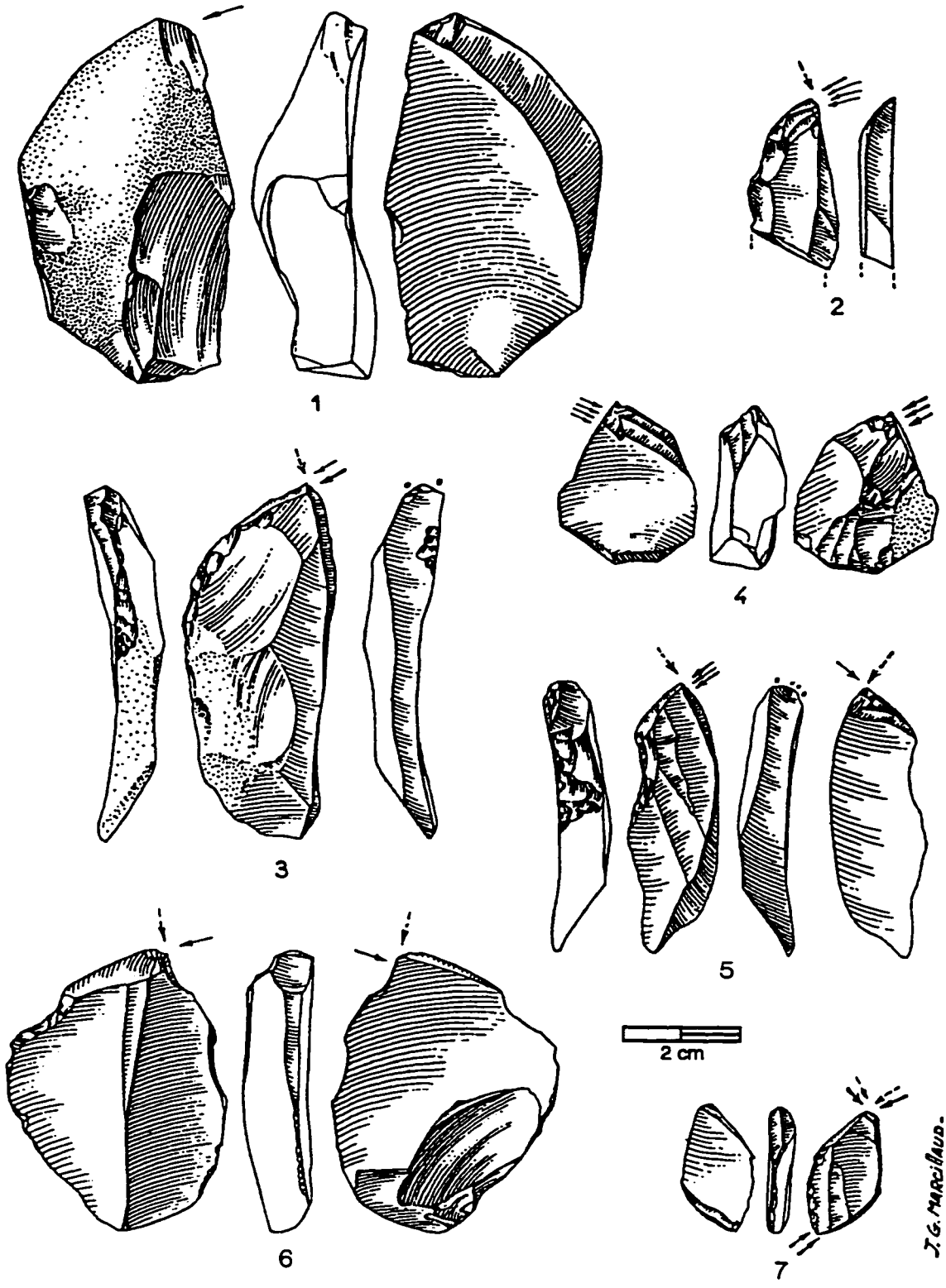



Figure A.72 Le Flageolet I, level IX. Burins. By J.-G. Marcillaud, from Rigaud 1982

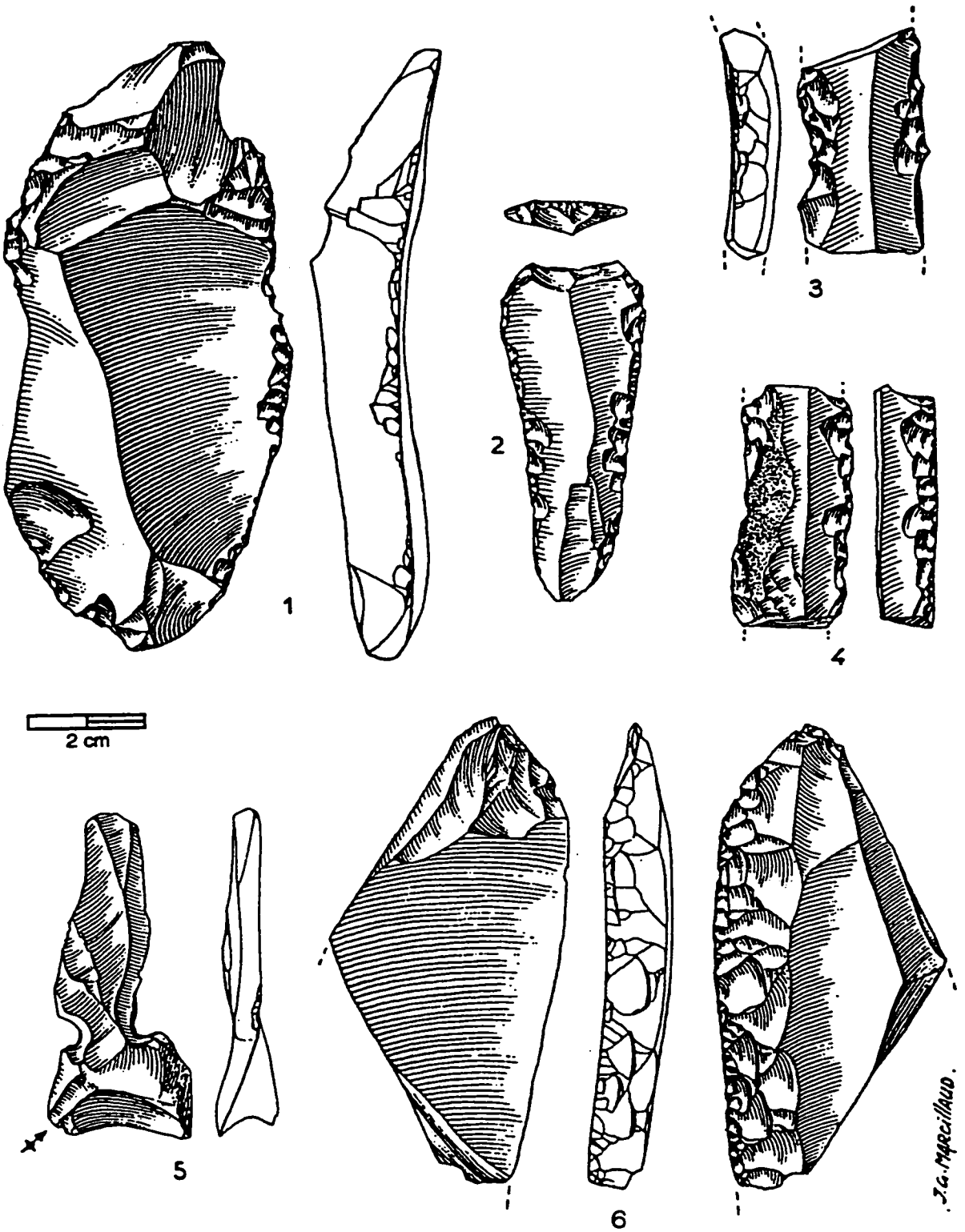



Figure A.73 Le Flageolet I, level IX. Various tools. By J.-G. Marcillaud, from Rigaud 1982.

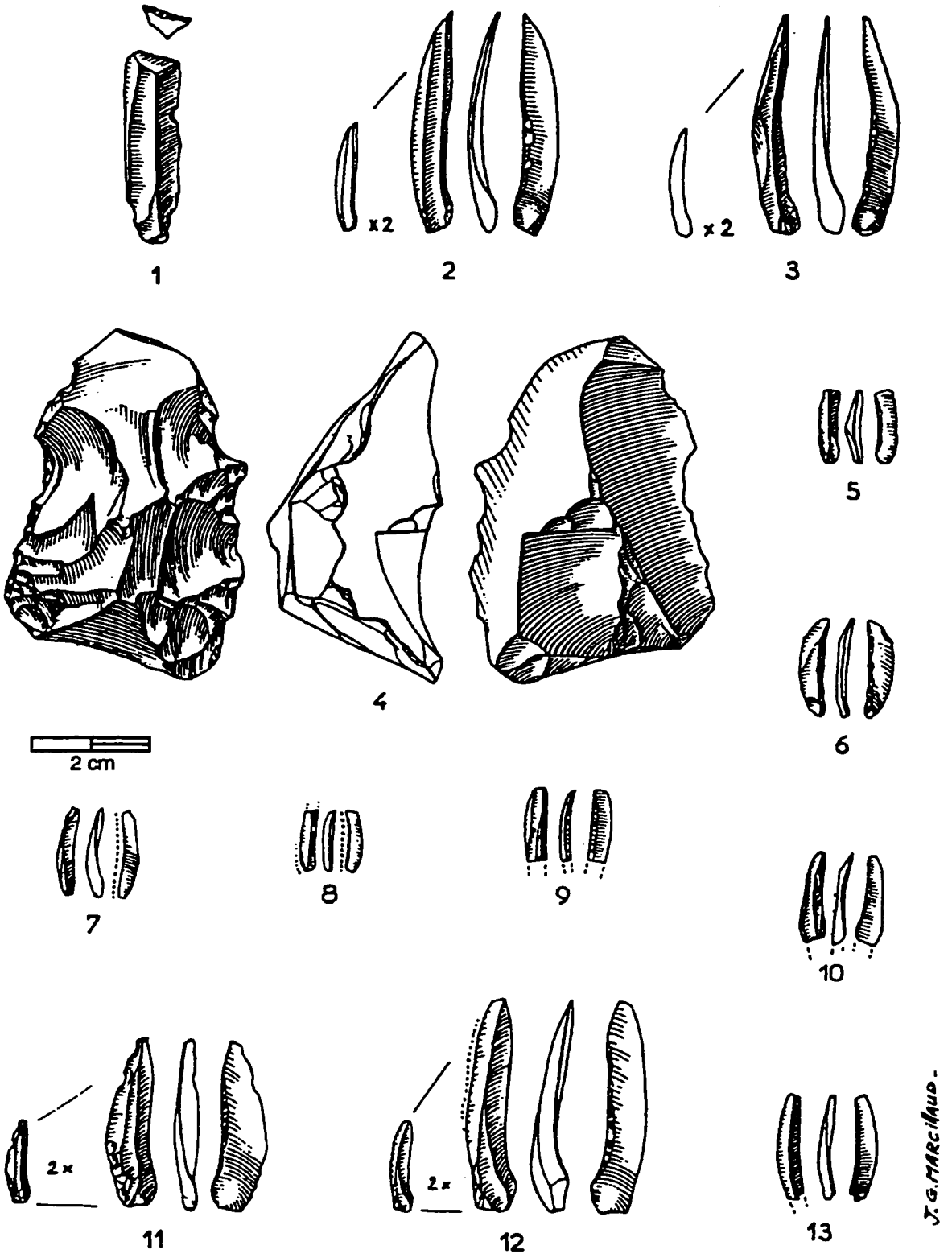



Figure A.74 Le Flageolet I, level IX. 1, bladelet with direct, marginal retouch on distal end; 2, 3, 5-13, Dufour bladelets; 4, thick flake with invasive inverse retouch. By J.-G. Marcillaud, from Rigaud 1982.

# Appendix B

## Display of Results from Pendulum Indenter Tests

For each rock, this appendix displays the PIT results with a series of three charts. The first chart is a scatterplot in which the mean weight loss value from each trial is represented by a single point. There is significant overlap of points in the charts, especially for the non-failures (i.e., where mean weight loss < 1.50 mg, and is therefore set at 0.00 mg; see Chapter 6 for explanation). The vertical scale of each scatterplot is determined by the magnitude of the largest weight loss value, and so it changes from chart to chart. The horizontal scale, which represents load (in Joules) normally ranges from 0.00-0.80 J, because the maximum load tested for most rocks is 0.72 J. However, I tested some rocks at a load of 1.05 J, and in those cases the horizontal scale is adjusted accordingly.

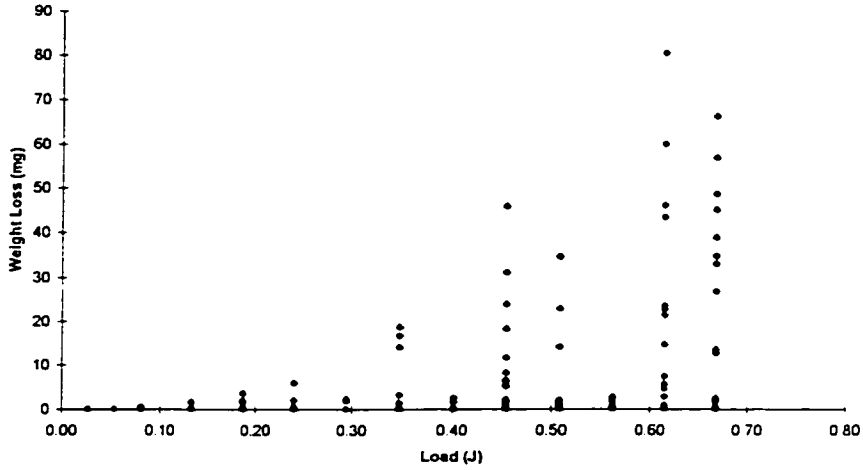
The middle chart in each series shows the median weight loss per load tested, for all valid failures. A valid failure is a trial that resulted in a conchoidal chip and a weight loss of ≥ 1.50 mg. Invalid failures (those trials resulting in a snap fracture or crumbly fracture) and non-failures (those trials resulting in weight loss of less than 1.50 mg) are excluded from the data used to calculate the median. The error bars represent 95% confidence intervals around the median, based on the sample sizes (from the column labeled "No. failures" in Appendix D) and $S_{med}$ values from Appendix D. The vertical scale of most of these charts ranges from 0 - 80 mg, although the maximum value is higher in a few cases that had very large median weight loss values. The horizontal scale is set to match that in the scatterplot. Loads for which no valid failure resulted (that is, where $S_{med} = 0.00$) are not shown.

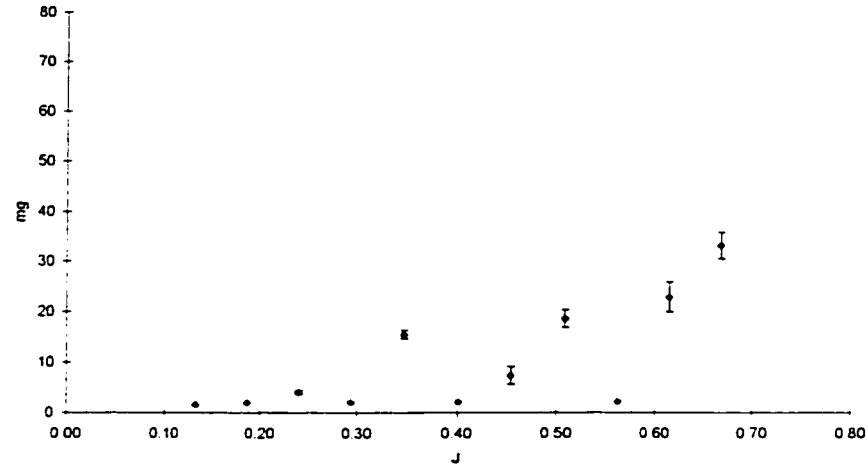
The bottom chart in each series shows the fail rate per load. Fail rate is calculated as the number of valid failures divided by the number of valid trials. The data are listed in Appendix C. The horizontal axis shows a bar for each load tested.

**Figure B.1** Raw data from PIT analysis, 1B (black Senonian).

**Figure B.2** Median weight loss per load tested, 1B (black Senonian).

**Figure B.3** Fail rate per load tested, 1B (black Senonian).


Weight Loss (mg)
90
80
70
60
50
40
30
20
10
0
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
0.80
Load (J)


mg
80
70
60
50
40
30
20
10
0
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
0.80
J

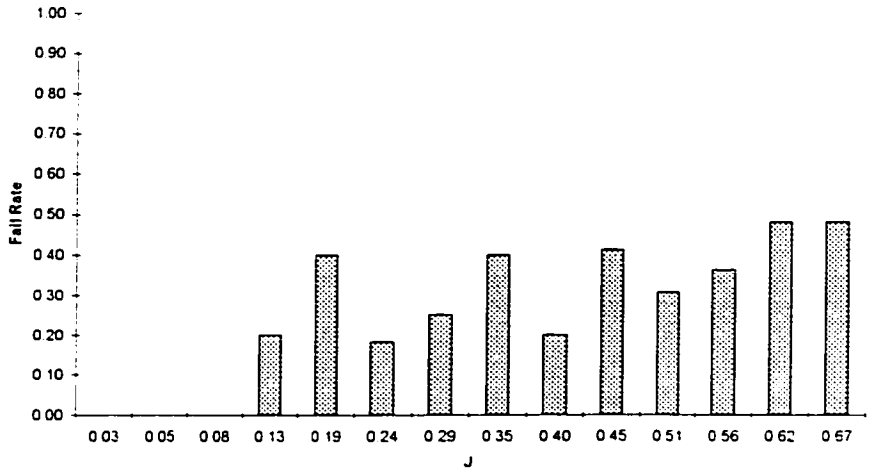
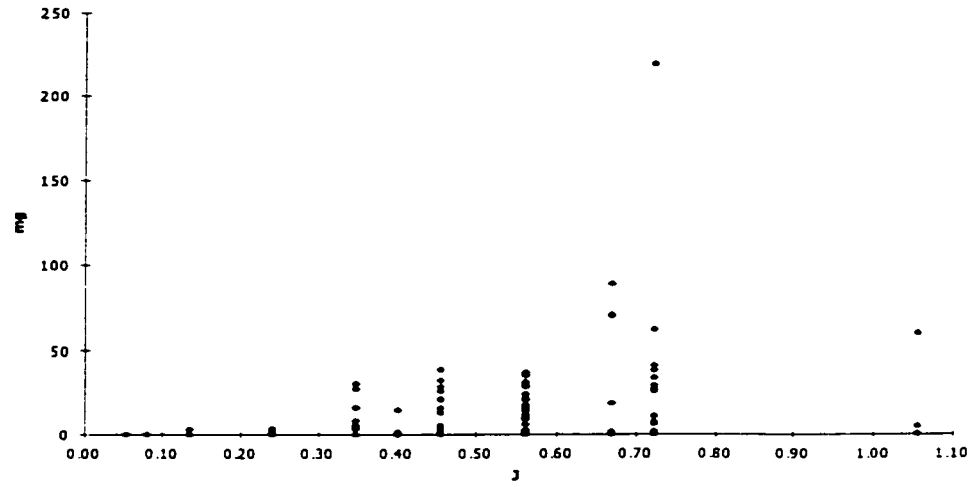
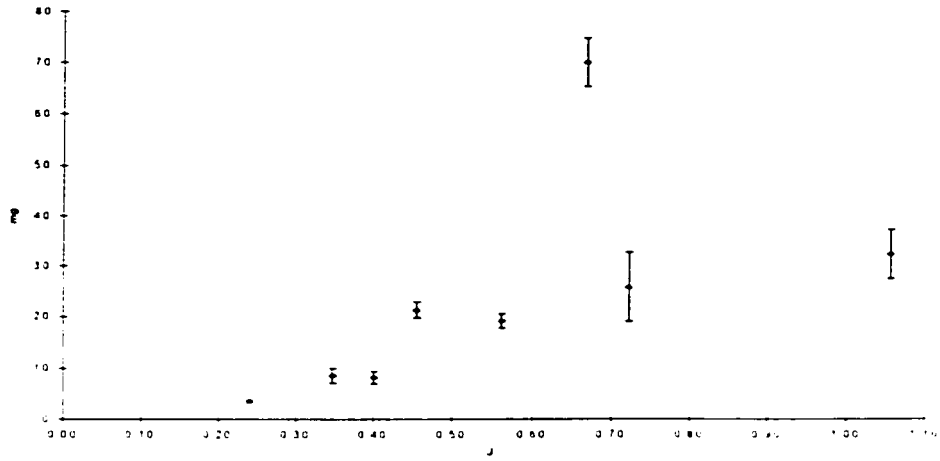

Fail Rate
1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
0.03
0.05
0.08
0.13
0.19
0.24
0.29
0.35
0.40
0.45
0.51
0.56
0.62
0.67
J

**Figure B.4** Raw data from PIT analysis, 1C (black Senonian).

**Figure B.5** Median weight loss per load tested, 1C (black Senonian).

**Figure B.6** Fail rate per load tested, 1C (black Senonian).


250
200
150
100
50
0
mg
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
0.80
0.90
1.00
1.10
J


mg
J

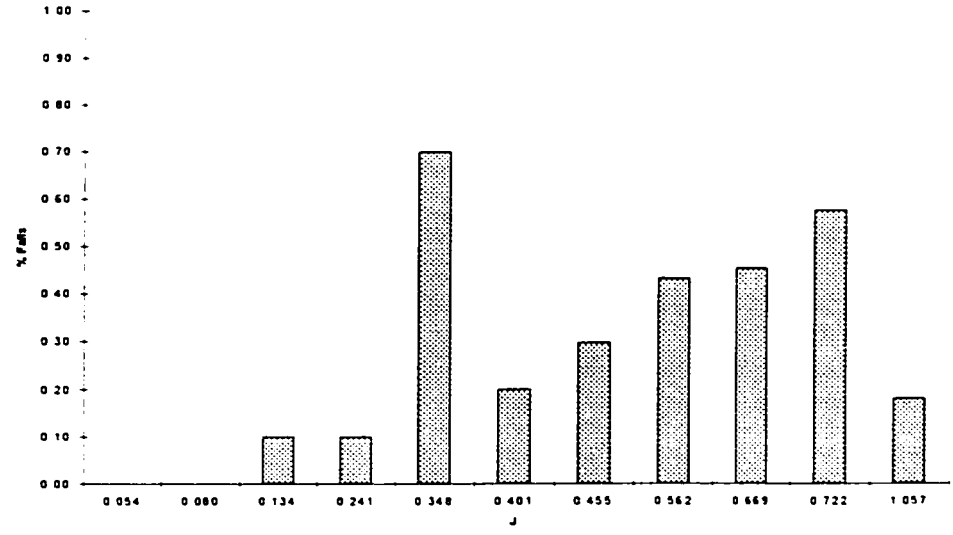
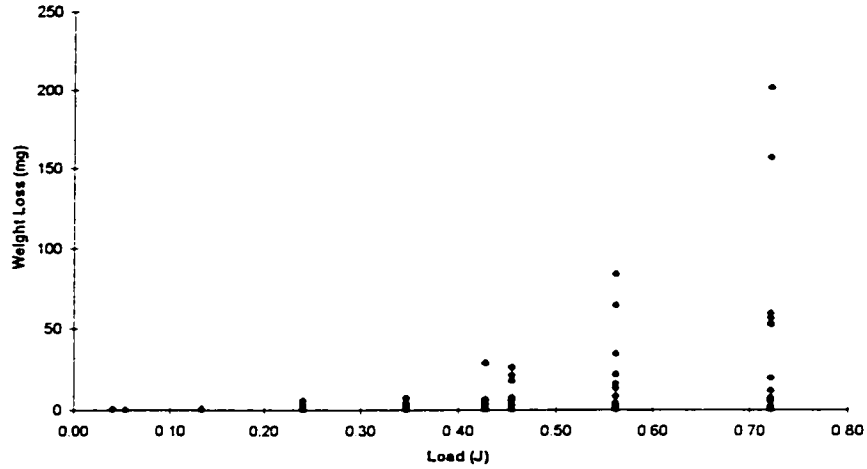
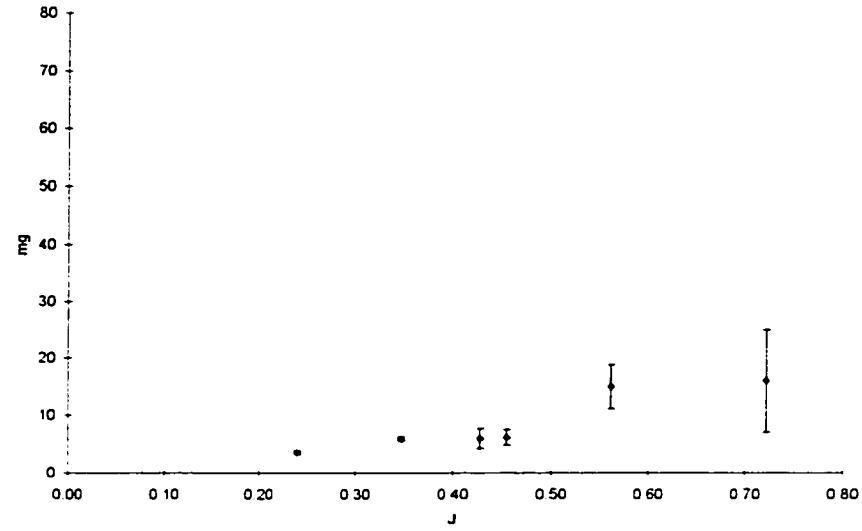

1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
0.054
0.080
0.134
0.241
0.348
0.401
0.455
0.562
0.669
0.722
1.057
J

**Figure B.7** Raw data from PIT analysis, 2A (beige Senonian).

**Figure B.8** Median weight loss per load tested, 2A (beige Senonian).

**Figure B.9** Fail rate per load tested, 2A (beige Senonian).


Weight Loss (mg)
250
200
150
100
50
0
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
0.80
Load (J)


mg
80
70
60
50
40
30
20
10
0
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
0.80
J

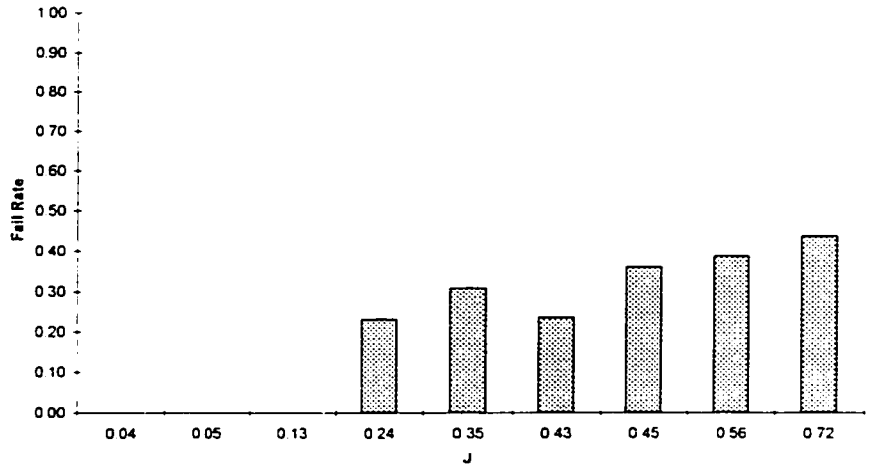
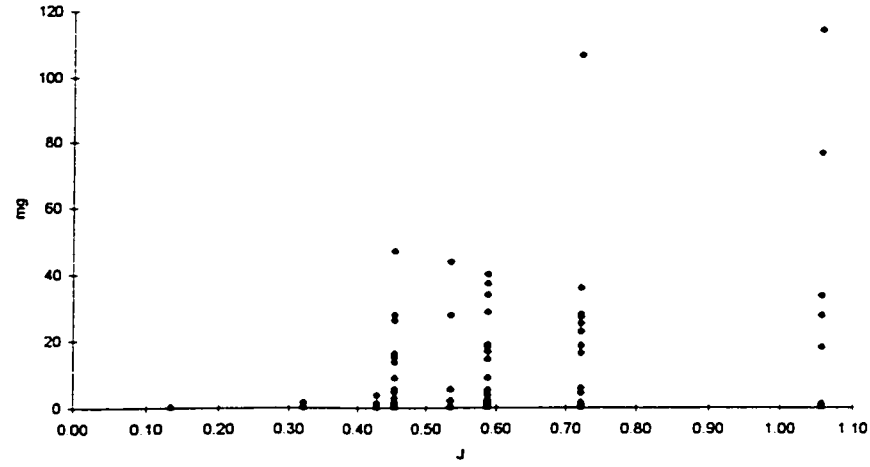
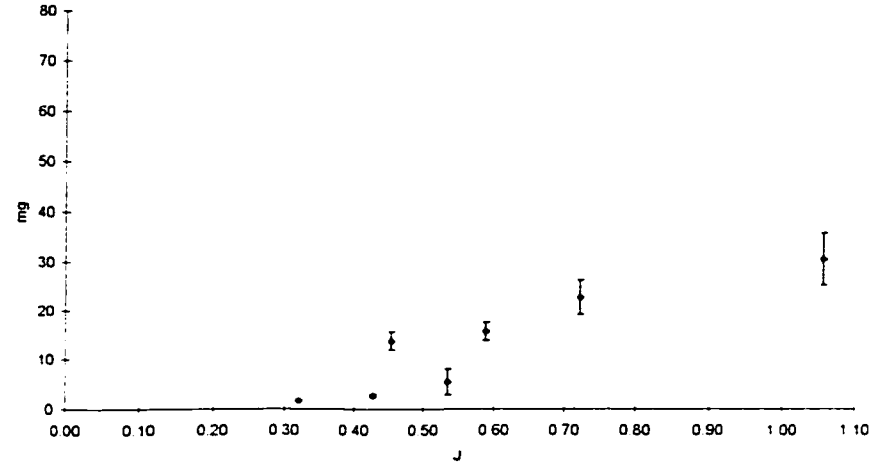

Fail Rate
1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
0.04
0.05
0.13
0.24
0.35
0.43
0.45
0.56
0.72
J

**Figure B.10** Raw data from PIT analysis, 2C (beige Senonian).

**Figure B.11** Median weight loss per load tested, 2C (beige Senonian).

**Figure B.12** Fail rate per load tested, 2C (beige Senonian).


120
100
80
60
40
20
0
mg
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
0.80
0.90
1.00
1.10
J


80
70
60
50
40
30
20
10
0
mg
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
0.80
0.90
1.00
1.10
J

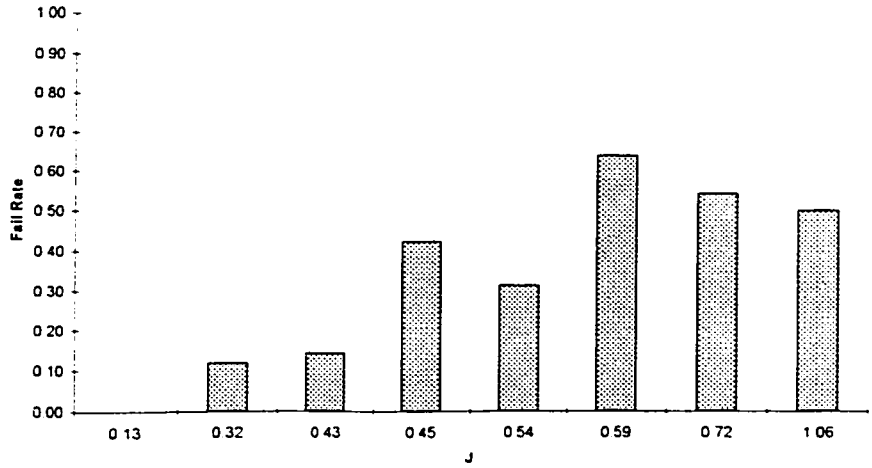
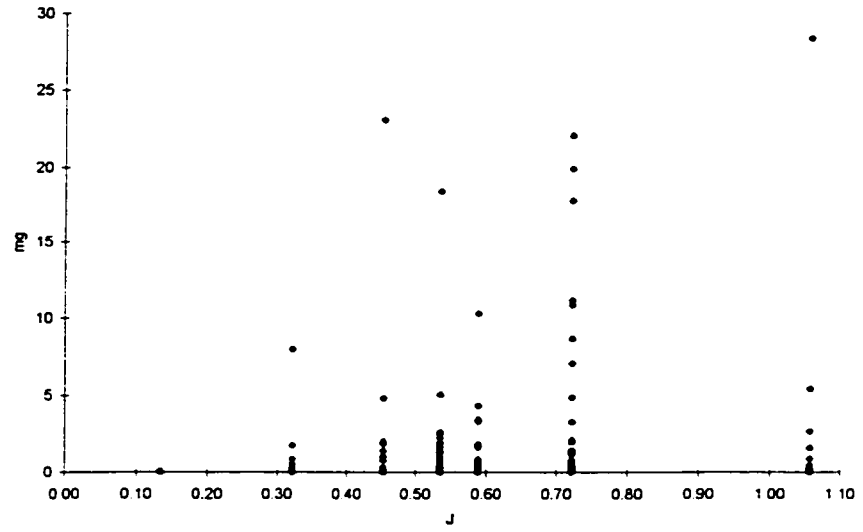
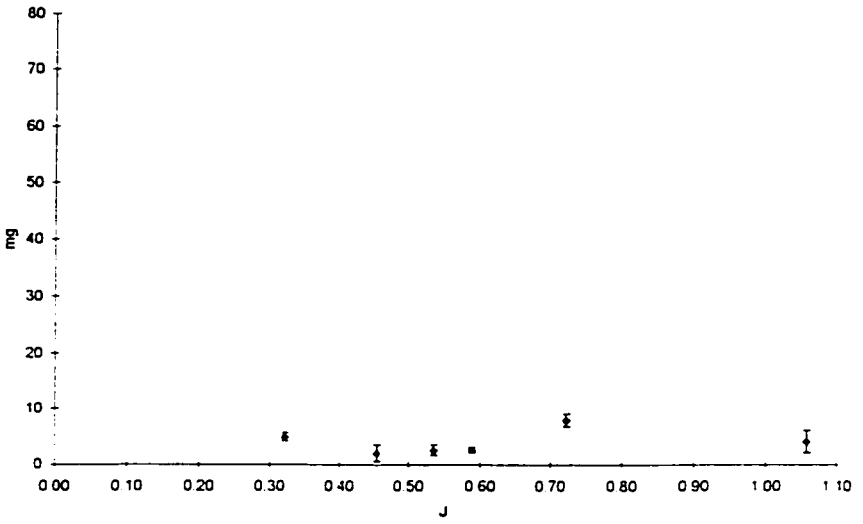

1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
Fail Rate
0.13
0.32
0.43
0.45
0.54
0.59
0.72
1.06
J

**Figure B.13** Raw data from PIT analysis, 6B (black Senonian).

**Figure B.14** Median weight loss per load tested, 6B (black Senonian).

**Figure B.15** Fail rate per load tested, 6B (black Senonian).


30
25
20
15
10
5
0
mg
0 00
0 10
0.20
0.30
0 40
0.50
0.60
0.70
0.80
0.90
1 00
1 10
J


80
70
60
50
40
30
20
10
0
mg
0 00
0 10
0.20
0.30
0 40
0.50
0 60
0.70
0.80
0 90
1 00
1 10
J

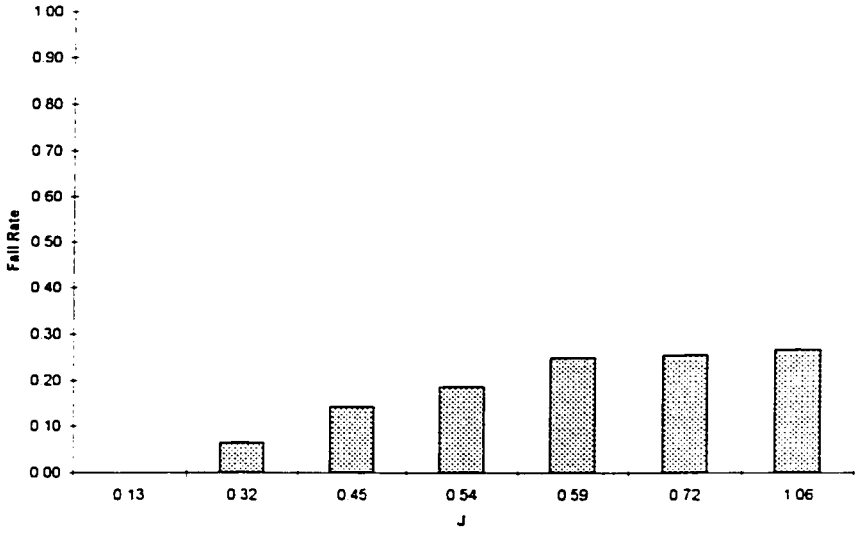
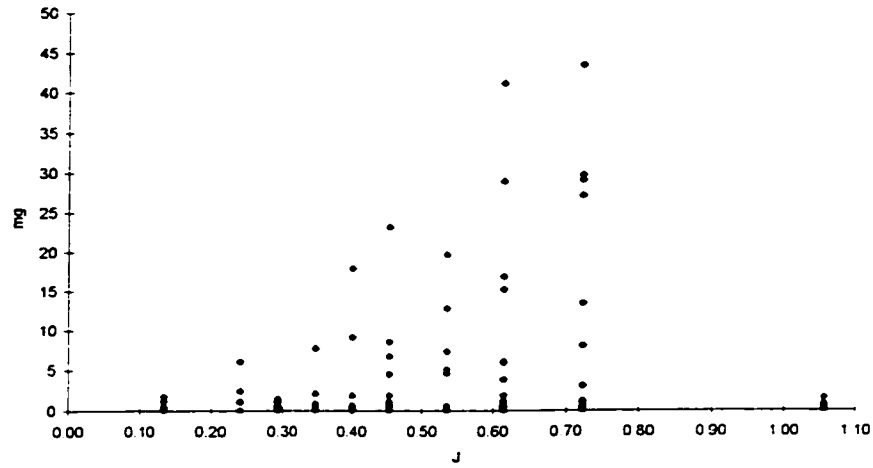
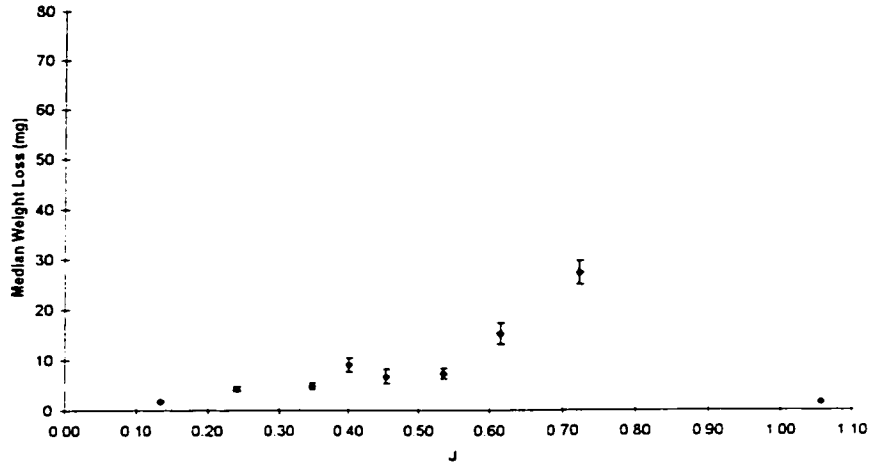

1 00
0.90
0.80
0.70
0 60
0 50
0 40
0.30
0.20
0 10
0 00
Fail Rate
0 13
0 32
0 45
0 54
0 59
0 72
1 06
J

**Figure B.16** Raw data from PIT analysis, 9A (chalcedony).

**Figure B.17** Median weight loss per load tested, 9A (chalcedony).

**Figure B.18** Fail rate per load tested, 9A (chalcedony).


mg
J
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
0.80
0.90
1.00
1.10


Median Weight Loss (mg)
J
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
0.80
0.90
1.00
1.10

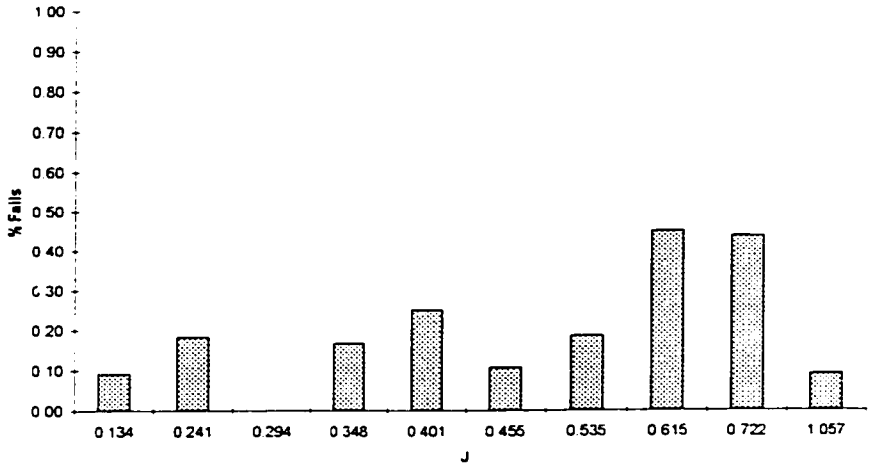
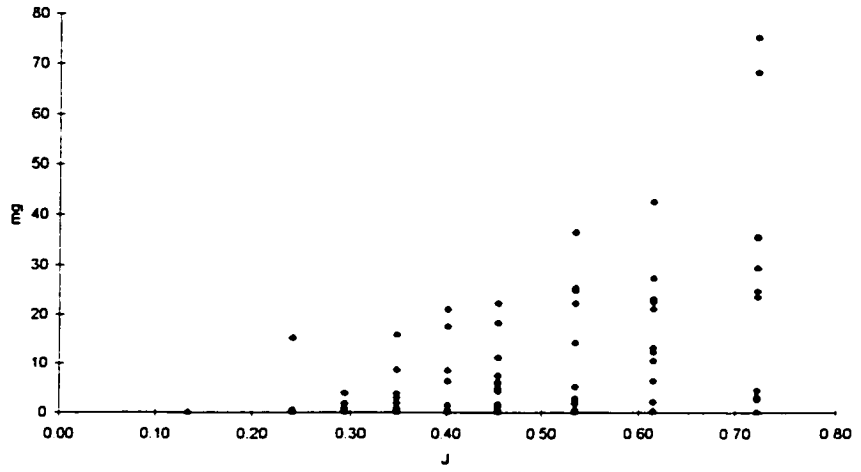
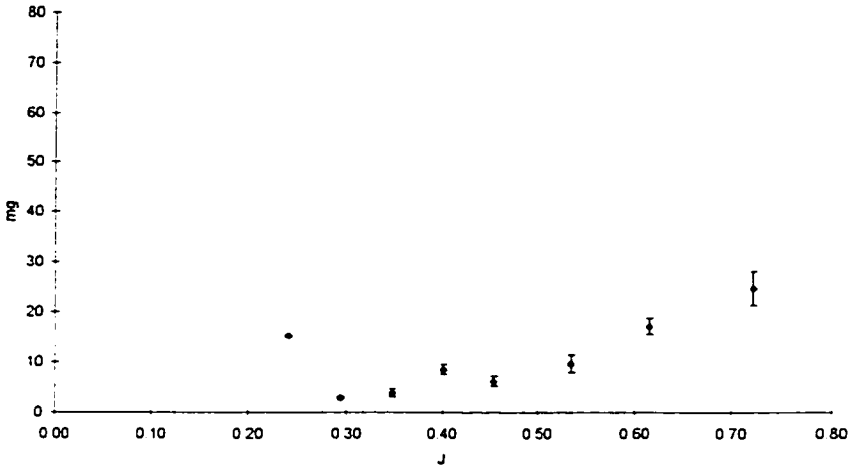

% Falls
J
0.134
0.241
0.294
0.348
0.401
0.455
0.535
0.615
0.722
1.057

**Figure B.19** Raw data from PIT analysis, 9D (chalcedony).

**Figure B.20** Median weight loss per load tested, 9D (chalcedony).

**Figure B.21** Fail rate per load tested, 9D (chalcedony).


mg
J
0 00
0 10
0 20
0 30
0 40
0 50
0 60
0 70
0 80


mg
J
0 00
0 10
0 20
0 30
0 40
0 50
0 60
0 70
0 80

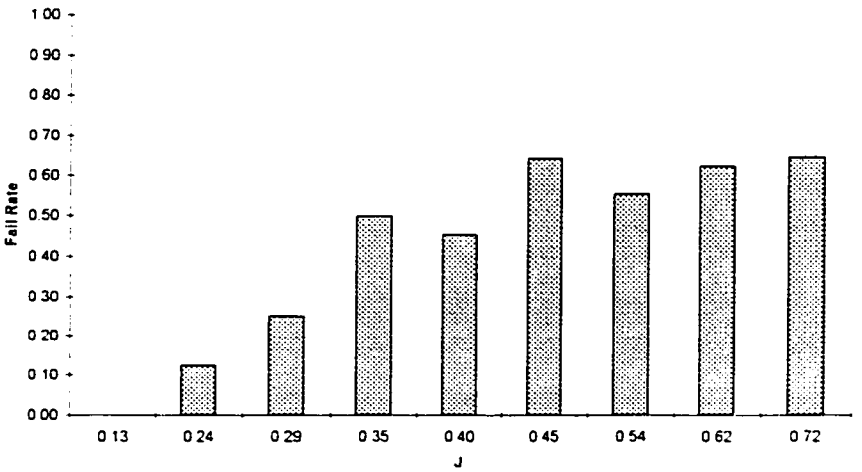
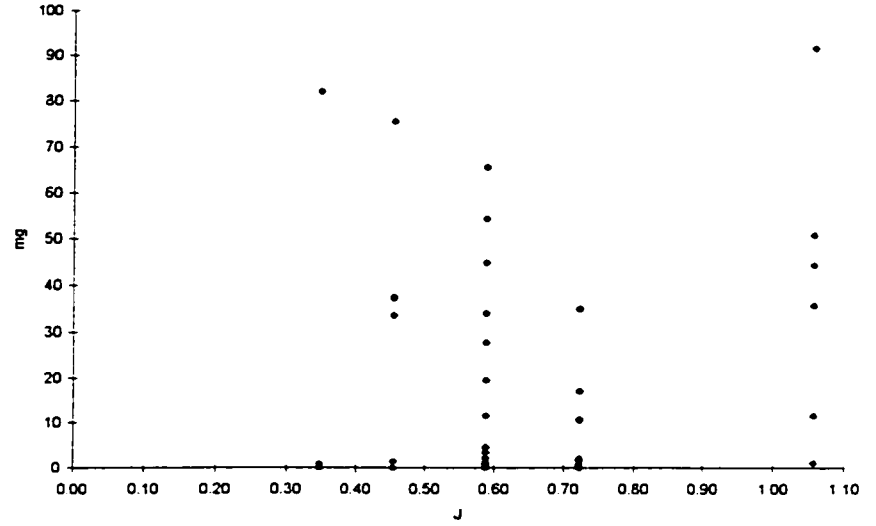
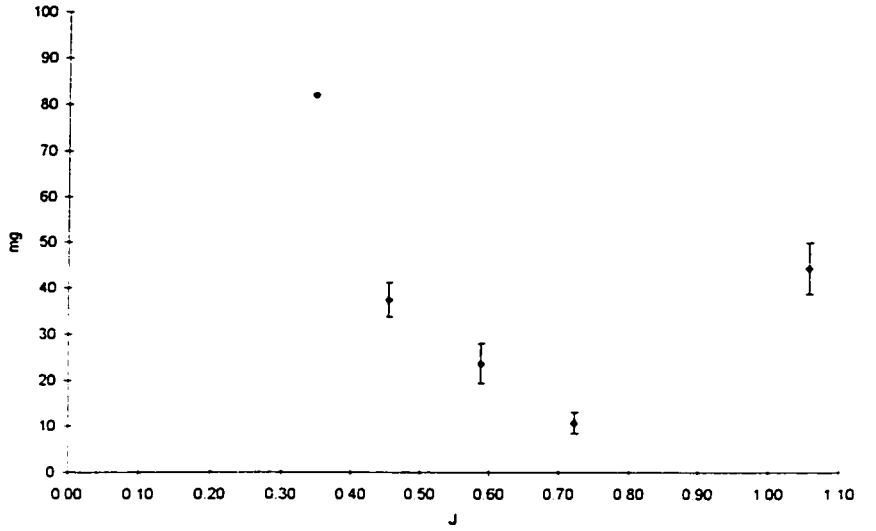

Fail Rate
J
0 13
0 24
0 29
0 35
0 40
0 45
0 54
0 62
0 72

**Figure B.22** Raw data from PIT analysis, 9E (jasper).

**Figure B.23** Median weight loss per load tested, 9E (jasper).

**Figure B.24** Fail rate per load tested, 9E (jasper).


mg
J
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
0.80
0.90
1.00
1.10


mg
J
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
0.80
0.90
1.00
1.10

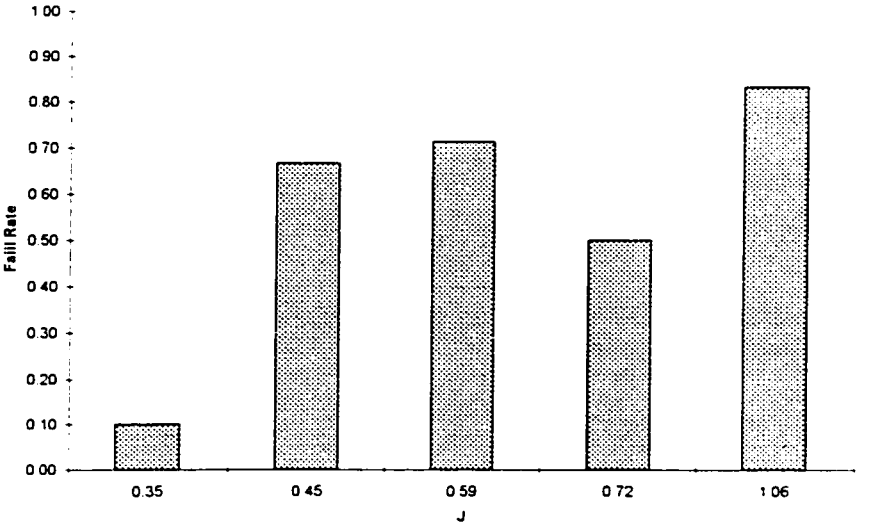
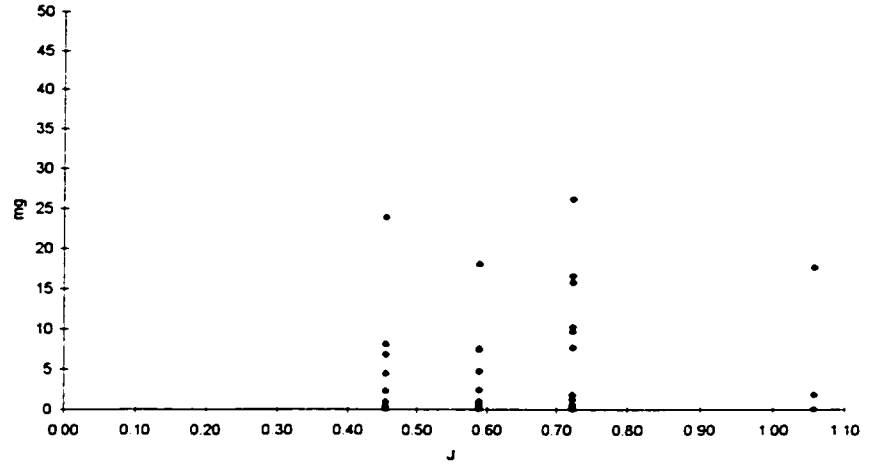
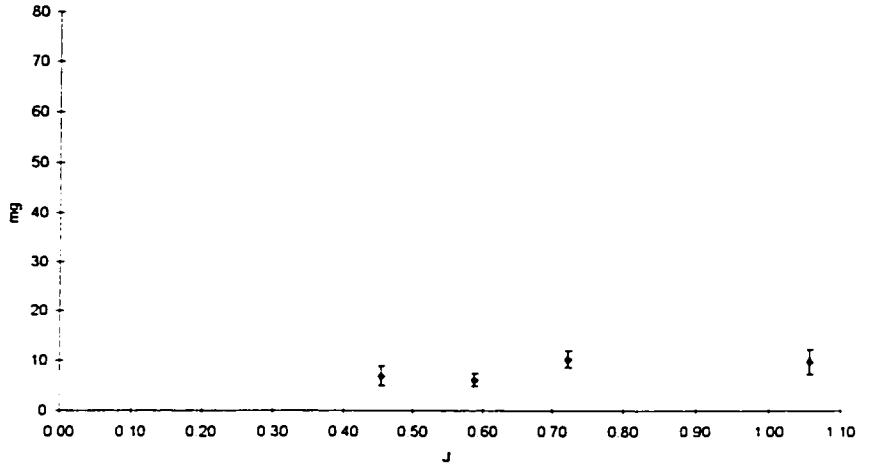

Failll Rate
J
0.35
0.45
0.59
0.72
1.06

**Figure B.25** Raw data from PIT analysis, 9G (jasper).

**Figure B.26** Median weight loss per load tested, 9G (jasper).

**Figure B.27** Fail rate per load tested, 9G (jasper).


mg
50
45
40
35
30
25
20
15
10
5
0
0 00
0 10
0 20
0 30
0 40
0 50
0 60
0 70
0 80
0 90
1 00
1 10
J


mg
80
70
60
50
40
30
20
10
0
0 00
0 10
0 20
0 30
0 40
0 50
0 60
0 70
0 80
0 90
1 00
1 10
J

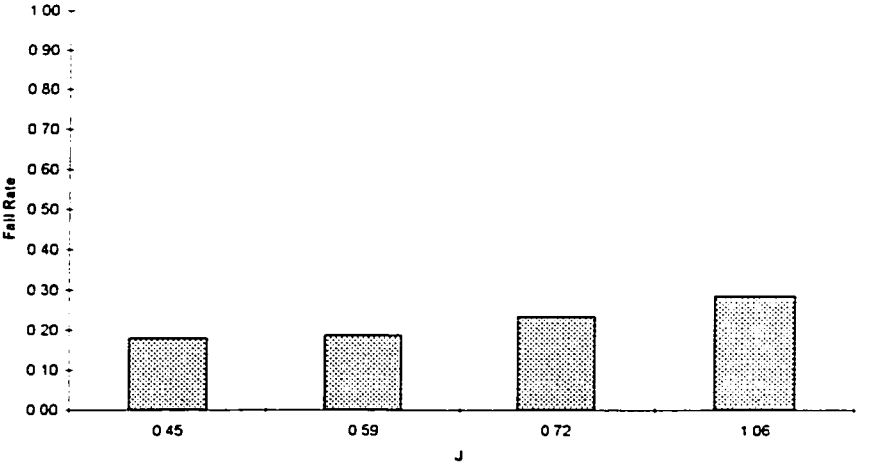
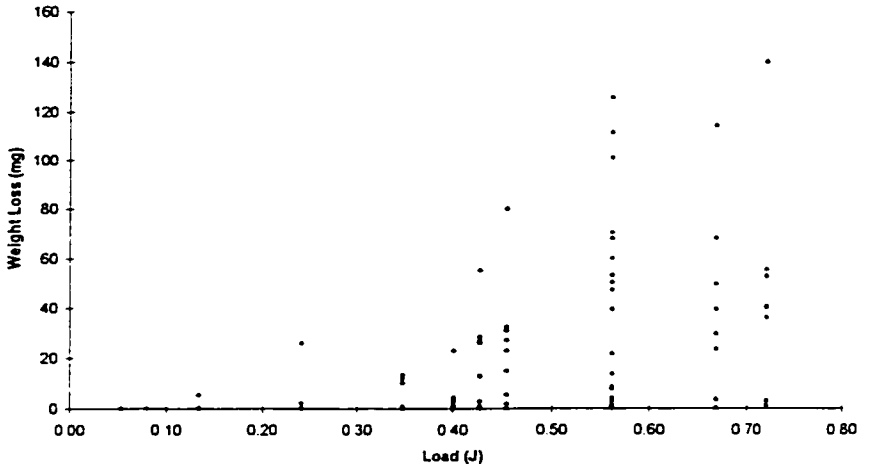
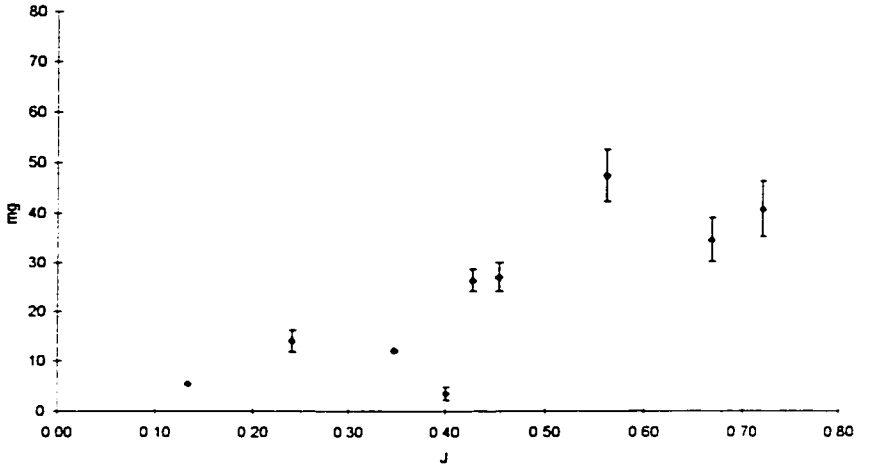

Fail Rate
1 00
0 90
0 80
0 70
0 60
0 50
0 40
0 30
0 20
0 10
0 00
0 45
0 59
0 72
1 06
J

**Figure B.28** Raw data from PIT analysis, 10A (jasper).

**Figure B.29** Median weight loss per load tested, 10A (jasper).

**Figure B.30** Fail rate per load tested, 10A (jasper).


Weight Loss (mg)
160
140
120
100
80
60
40
20
0
0 00
0 10
0.20
0 30
0 40
0.50
0.60
0 70
0 80
Load (J)


mg
80
70
60
50
40
30
20
10
0
0 00
0 10
0 20
0 30
0 40
0 50
0 60
0 70
0 80
J

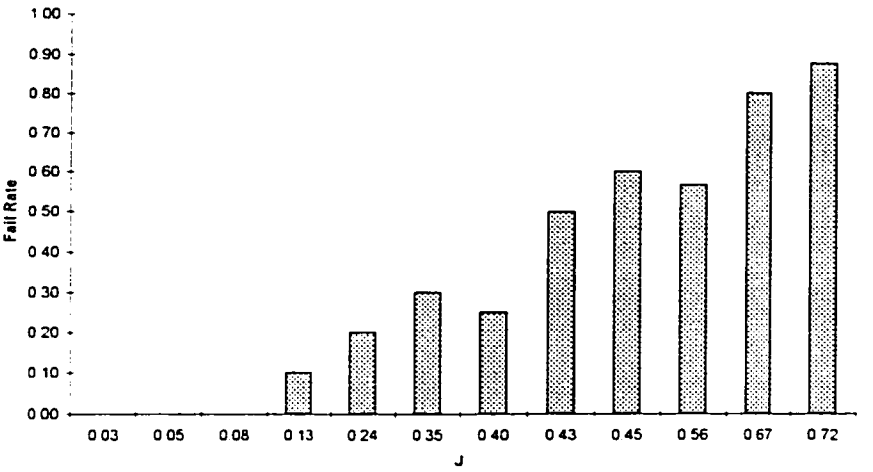
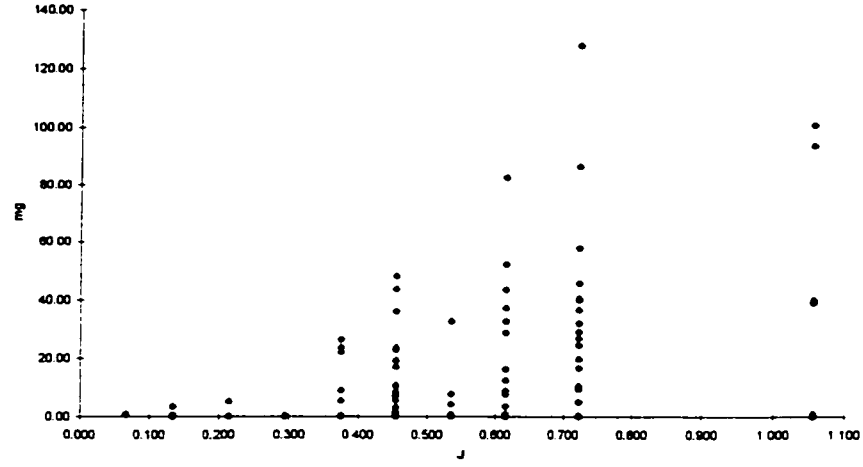
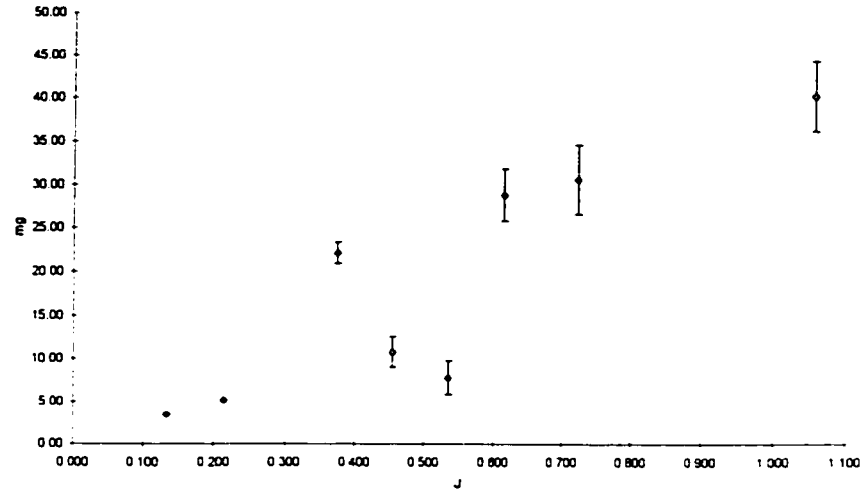

Fail Rate
1 00
0 90
0 80
0 70
0 60
0 50
0 40
0 30
0 20
0 10
0 00
0 03
0 05
0 08
0 13
0 24
0 35
0 40
0 43
0 45
0 56
0 67
0 72
J

**Figure B.31** Raw data from PIT analysis, 10C (jasper).

**Figure B.32** Median weight loss per load tested, 10C (jasper).

**Figure B.33** Fail rate per load tested, 10C (jasper).


140.00
120.00
100.00
80.00
60.00
40.00
20.00
0.00
mg
0.000
0.100
0.200
0.300
0.400
0.500
0.600
0.700
0.800
0.900
1.000
1.100
J


50.00
45.00
40.00
35.00
30.00
25.00
20.00
15.00
10.00
5.00
0.00
mg
0.000
0.100
0.200
0.300
0.400
0.500
0.600
0.700
0.800
0.900
1.000
1.100
J

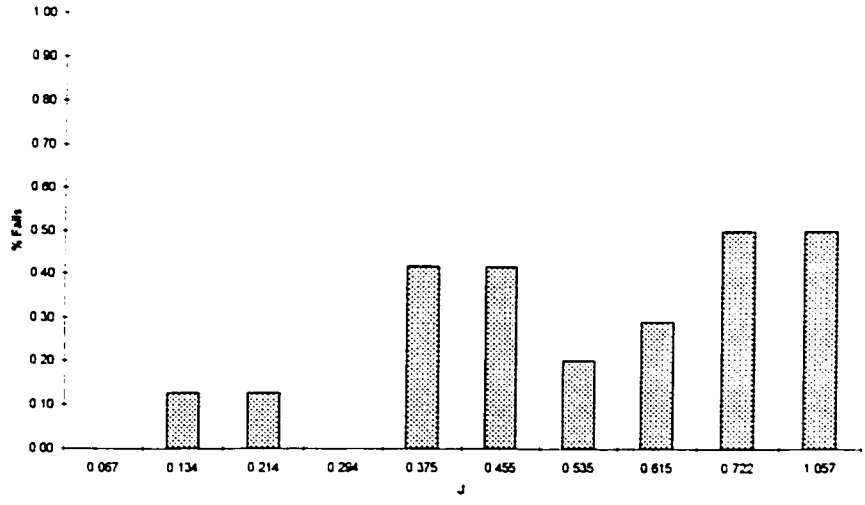
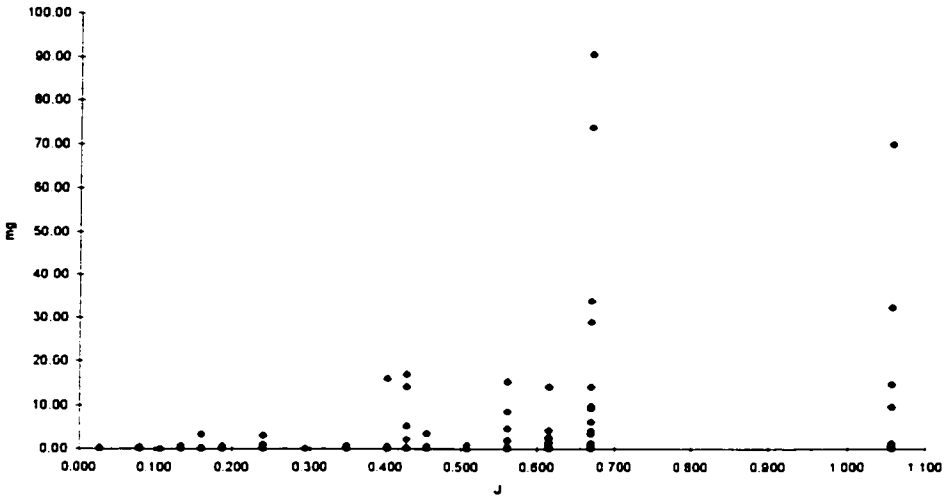
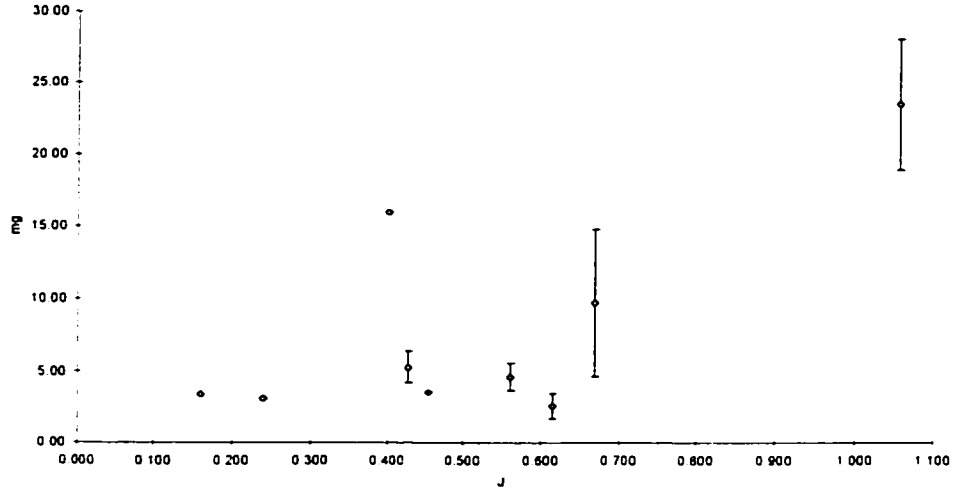

1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
% Falls
0.057
0.134
0.214
0.294
0.375
0.455
0.535
0.615
0.722
1.057
J

**Figure B.34** Raw data from PIT analysis, 11A (beige Senonian).

**Figure B.35** Median weight loss per load tested, 11A (beige Senonian).

**Figure B.36** Fail rate per load tested, 11A (beige Senonian).


100.00
90.00
80.00
70.00
60.00
50.00
40.00
30.00
20.00
10.00
0.00
mg
0.000
0.100
0.200
0.300
0.400
0.500
0.600
0.700
0.800
0.900
1.000
1.100
J


30.00
25.00
20.00
15.00
10.00
5.00
0.00
mg
0.000
0.100
0.200
0.300
0.400
0.500
0.600
0.700
0.800
0.900
1.000
1.100
J

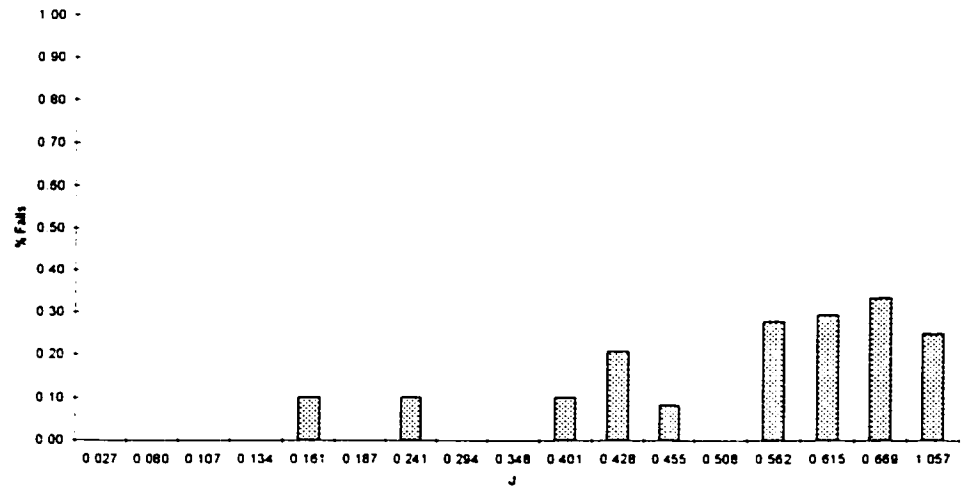
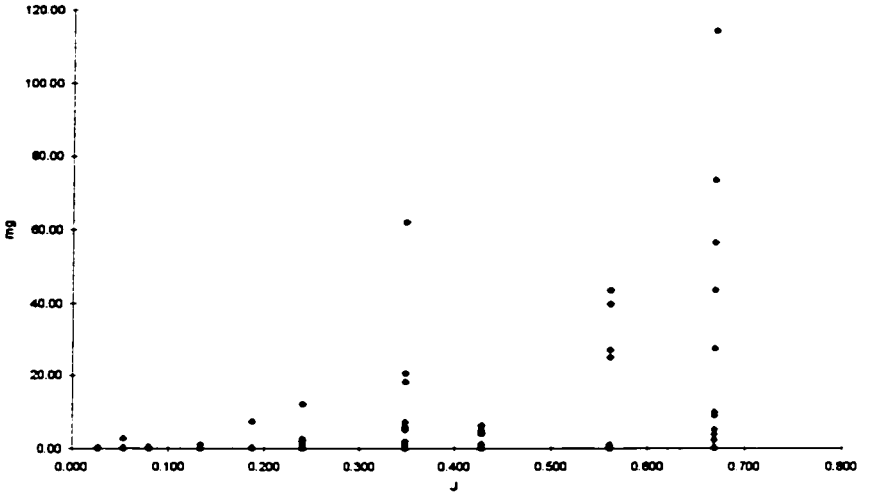
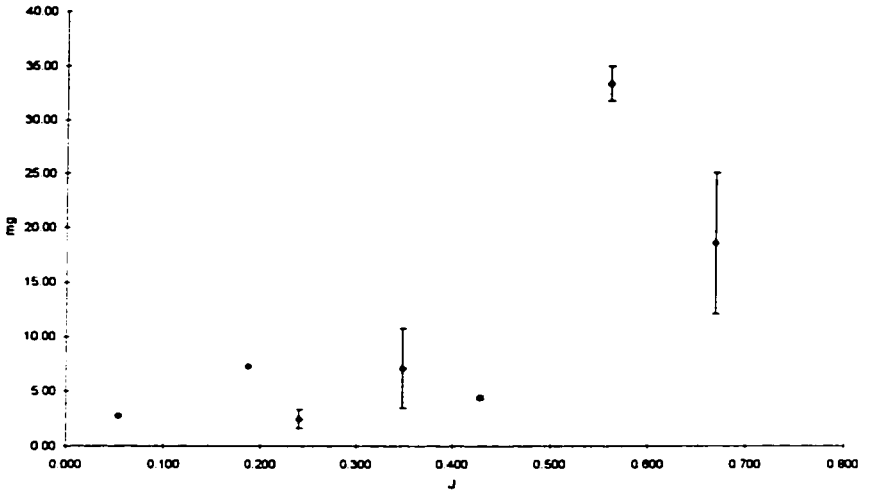

1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
% Fails
0.027
0.080
0.107
0.134
0.161
0.187
0.241
0.294
0.348
0.401
0.428
0.455
0.508
0.562
0.615
0.669
1.057
J

**Figure B.37** Raw data from PIT analysis, 11A' (beige Senonian).

**Figure B.38** Median weight loss per load tested, 11A' (beige Senonian).

**Figure B.39** Fail rate per load tested, 11A' (beige Senonian).


120.00
100.00
80.00
60.00
40.00
20.00
0.00
mg
0.000
0.100
0.200
0.300
0.400
0.500
0.600
0.700
0.800
J


40.00
35.00
30.00
25.00
20.00
15.00
10.00
5.00
0.00
mg
0.000
0.100
0.200
0.300
0.400
0.500
0.600
0.700
0.800
J

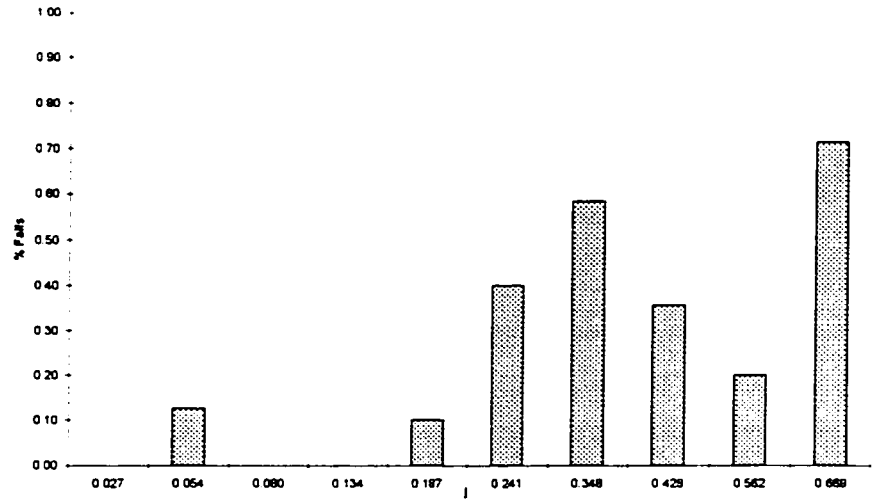
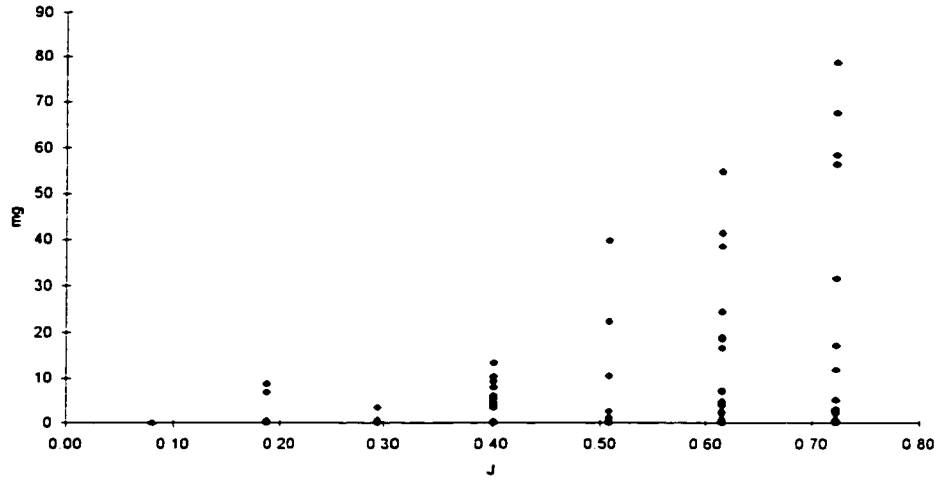
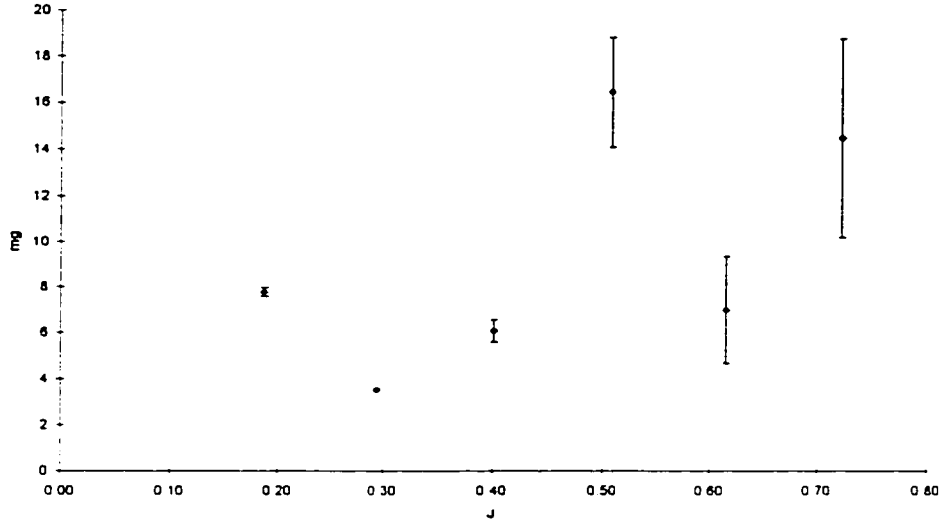

1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
% Fats
0.027
0.054
0.080
0.134
0.187
0.241
0.348
0.429
0.562
0.668
J

**Figure B.40** Raw data from PIT analysis, 12A (black Senonian).

**Figure B.41** Median weight loss per load tested, 12A (black Senonian).

**Figure B.42** Fail rate per load tested, 12A (black Senonian).


mg
90
80
70
60
50
40
30
20
10
0
0 00
0 10
0 20
0 30
0 40
0 50
0 60
0 70
0 80
J


mg
20
18
16
14
12
10
8
6
4
2
0
0 00
0 10
0 20
0 30
0 40
0 50
0 60
0 70
0 80
J

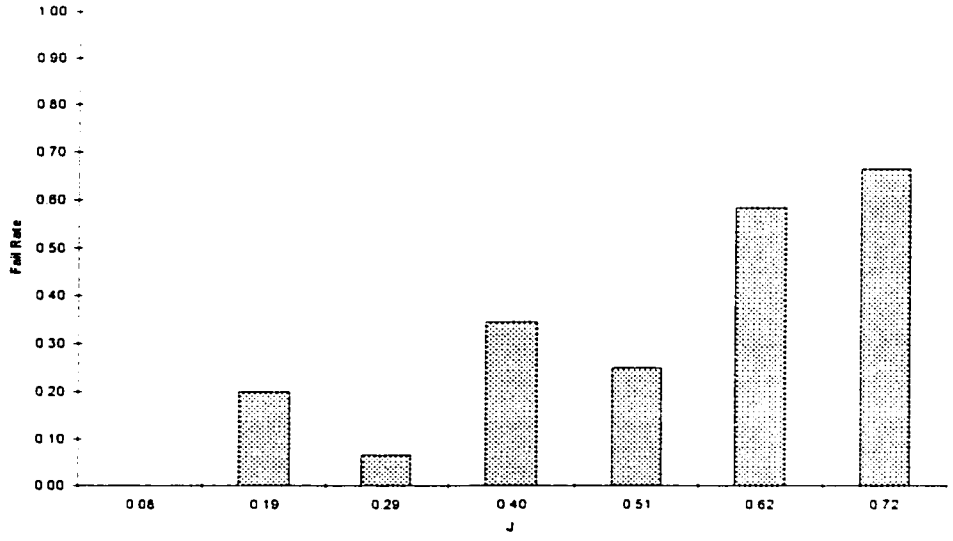
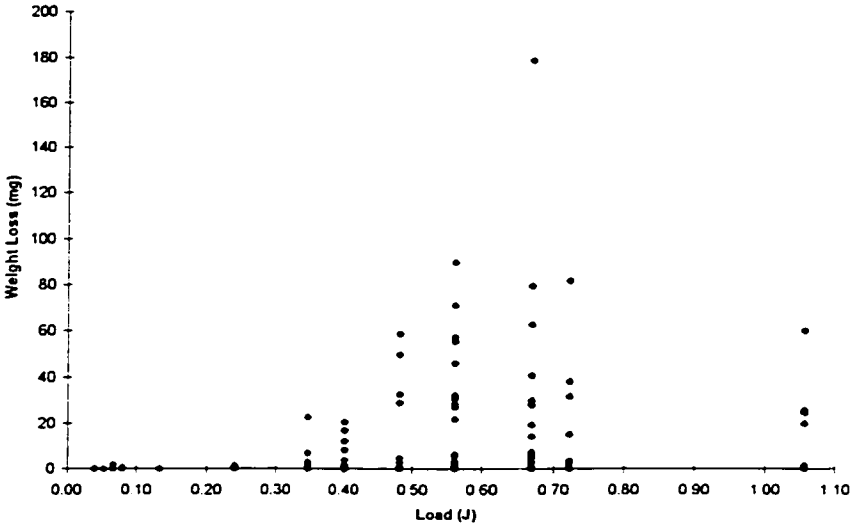
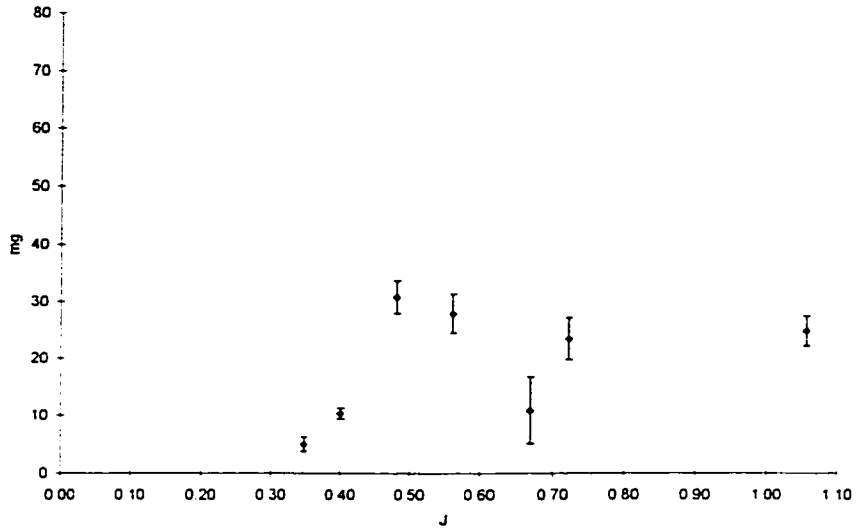

Fail Rate
1 00
0 90
0 80
0 70
0 60
0 50
0 40
0 30
0 20
0 10
0 00
0 08
0 19
0 29
0 40
0 51
0 62
0 72
J

**Figure B.43** Raw data from PIT analysis, 12A' (black Senonian).

**Figure B.44** Median weight loss per load tested, 12A' (black Senonian).

**Figure B.45** Fail rate per load tested, 12A' (black Senonian).


Weight Loss (mg)
200
180
160
140
120
100
80
60
40
20
0
0.00 0.10 0.20 0.30 0.40 0.50 0.60 0.70 0.80 0.90 1.00 1.10
Load (J)


mg
80
70
60
50
40
30
20
10
0
0.00 0.10 0.20 0.30 0.40 0.50 0.60 0.70 0.80 0.90 1.00 1.10
J

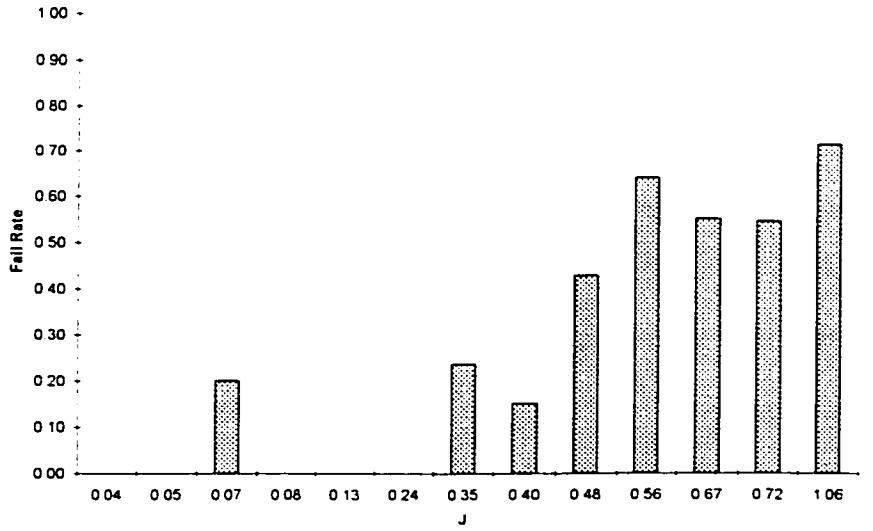
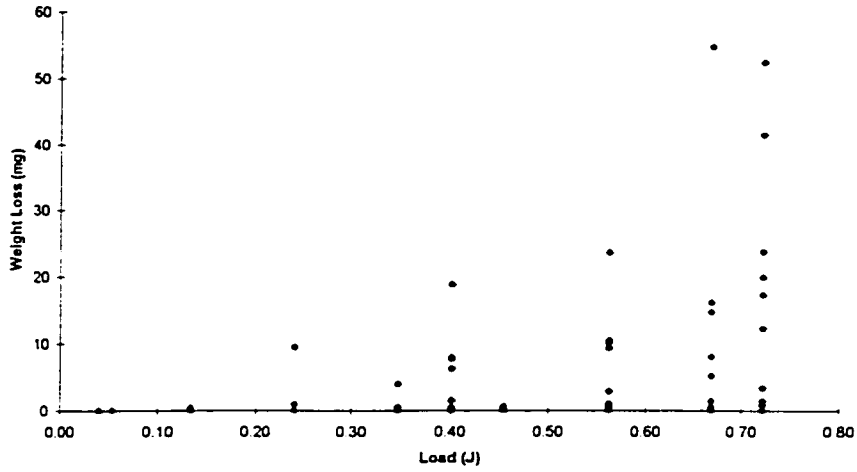
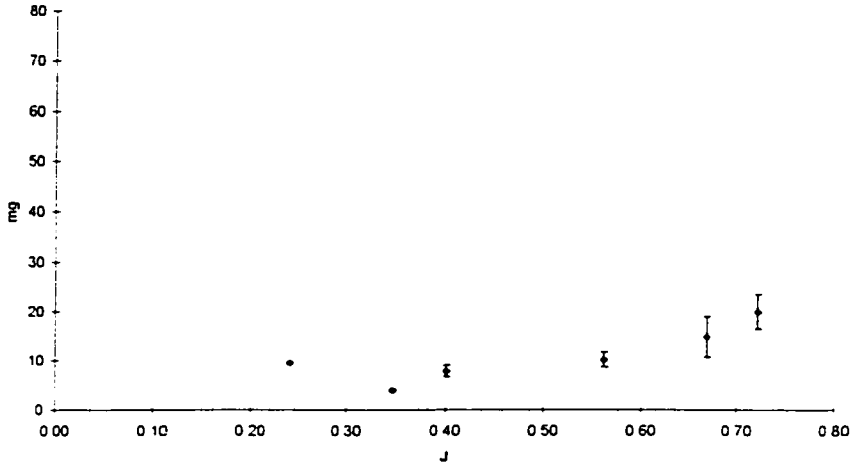

Fail Rate
1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
0.04 0.05 0.07 0.08 0.13 0.24 0.35 0.40 0.48 0.56 0.67 0.72 1.06
J

**Figure B.46** Raw data from PIT analysis, 13A (Bergeracois).

**Figure B.47** Median weight loss per load tested, 13A (Bergeracois).

**Figure B.48** Fail rate per load tested, 13A (Bergeracois).


Weight Loss (mg)
60
50
40
30
20
10
0
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
0.80
Load (J)


mg
80
70
60
50
40
30
20
10
0
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
0.80
J

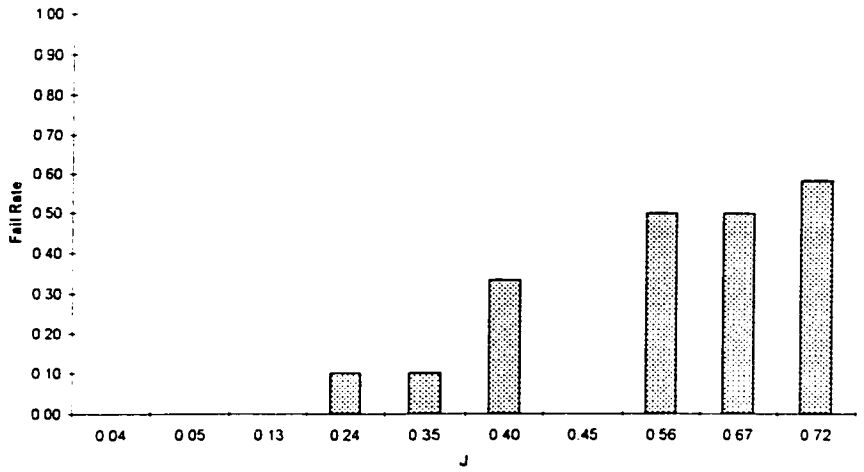
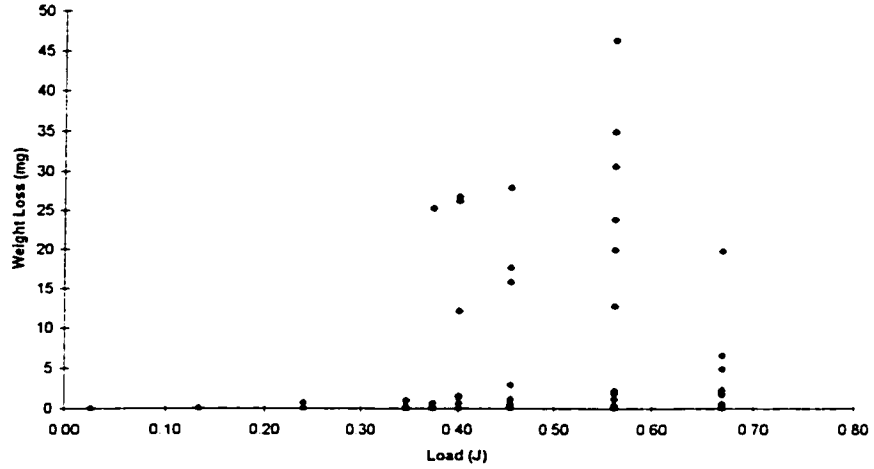
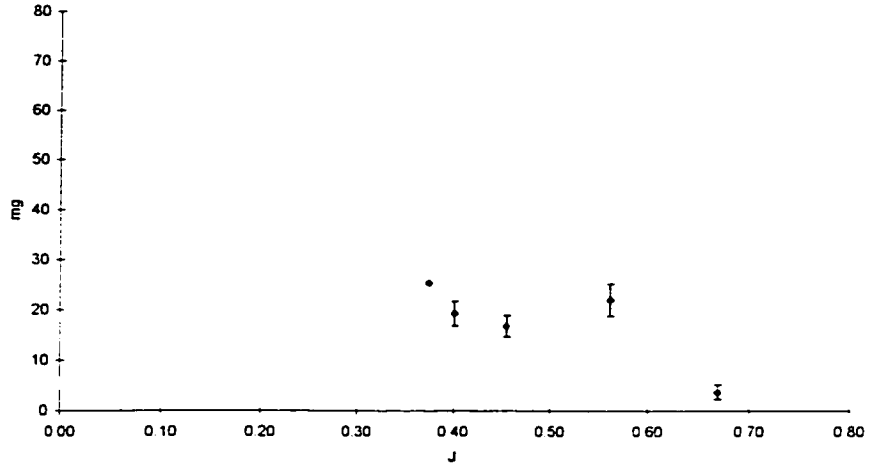

Fail Rate
1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
0.04
0.05
0.13
0.24
0.35
0.40
0.45
0.56
0.67
0.72
J

**Figure B.49** Raw data from PIT analysis, 13B (Bergeracois).

**Figure B.50** Median weight loss per load tested, 13B (Bergeracois).

**Figure B.51** Fail rate per load tested, 13B (Bergeracois).


Weight Loss (mg)
50
45
40
35
30
25
20
15
10
5
0
0 00
0 10
0 20
0 30
0 40
0 50
0 60
0 70
0 80
Load (J)


mg
80
70
60
50
40
30
20
10
0
0 00
0 10
0 20
0 30
0 40
0 50
0 60
0 70
0 80
J

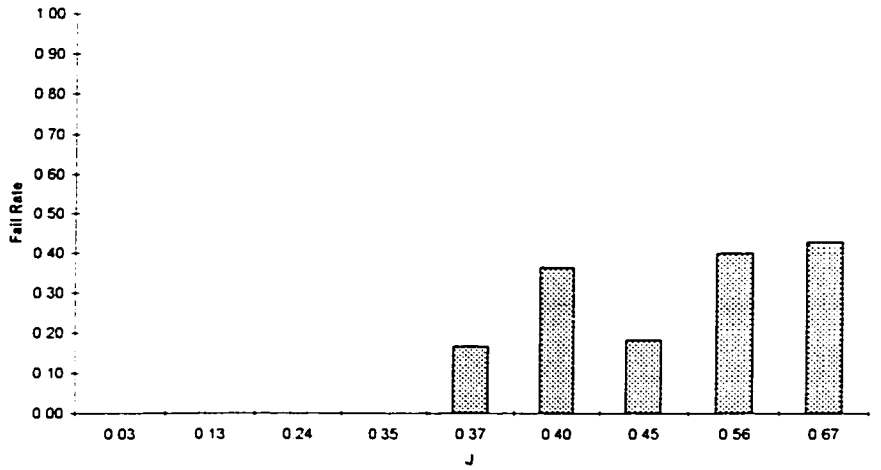
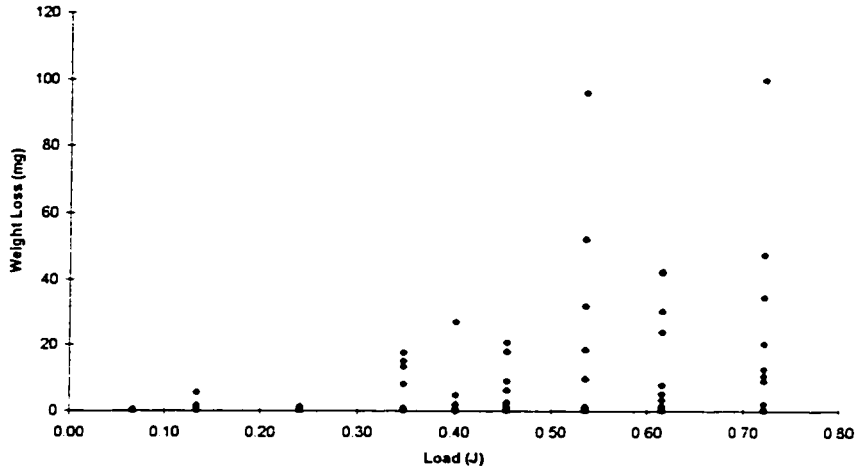
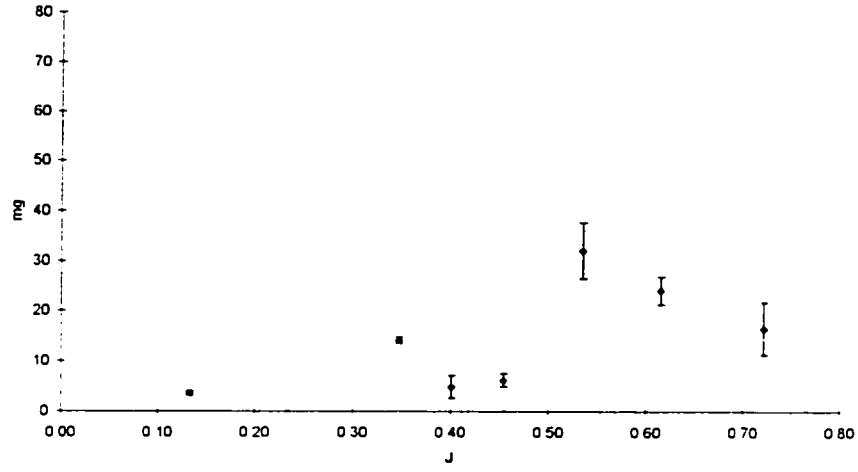

Fail Rate
1 00
0 90
0 80
0 70
0 60
0 50
0 40
0 30
0 20
0 10
0 00
0 03
0 13
0 24
0 35
0 37
0 40
0 45
0 56
0 67
J

**Figure B.52** Raw data from PIT analysis, 14B (beige Senonian).

**Figure B.53** Median weight loss per load tested, 14B (beige Senonian).

**Figure B.54** Fail rate per load tested, 14B (beige Senonian).


Weight Loss (mg)
120
100
80
60
40
20
0
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
0.80
Load (J)


mg
80
70
60
50
40
30
20
10
0
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
0.80
J

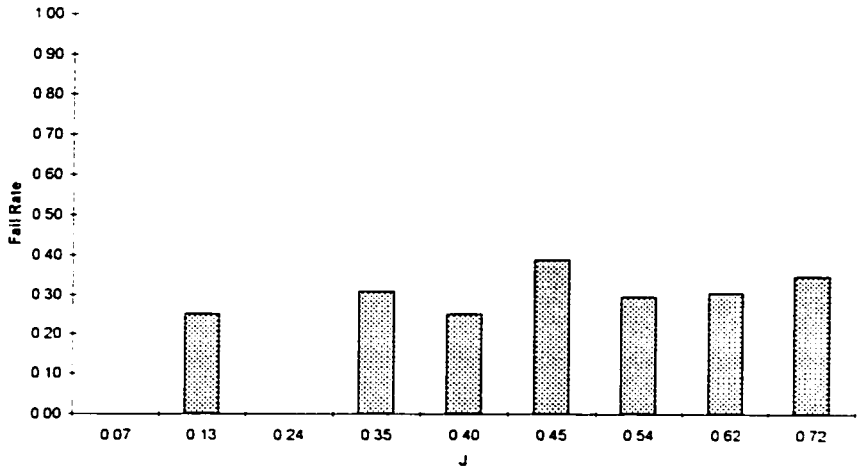
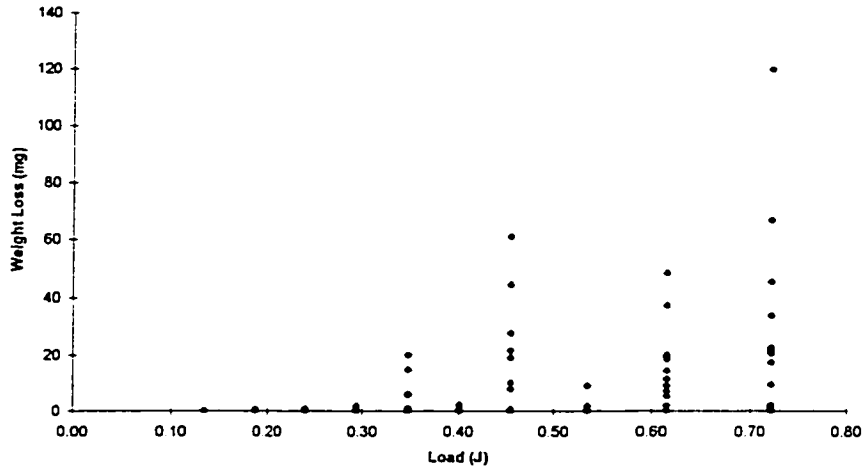
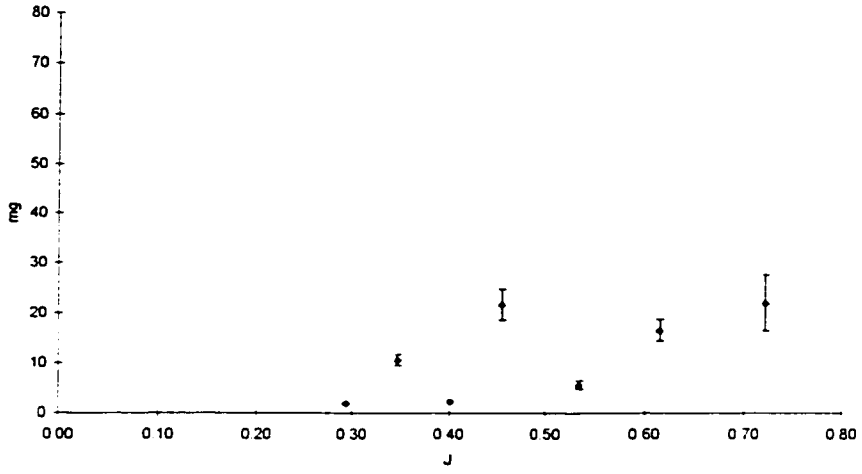

Fail Rate
1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
0.07
0.13
0.24
0.35
0.40
0.45
0.54
0.62
0.72
J

**Figure B.55** Raw data from PIT analysis, 18B (*meulière*).

**Figure B.56** Median weight loss per load tested, 18B (*meulière*).

**Figure B.57** Fail rate per load tested, 18B (*meulière*).


Weight Loss (mg)
140
120
100
80
60
40
20
0
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
0.80
Load (J)


mg
80
70
60
50
40
30
20
10
0
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
0.80
J

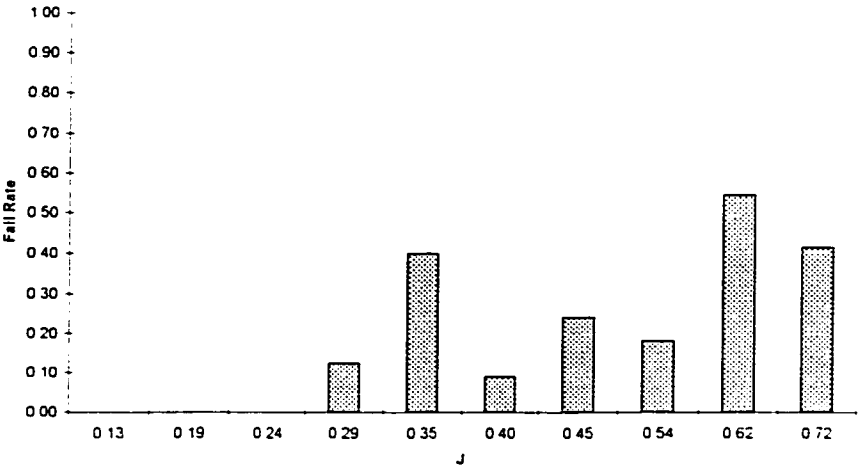
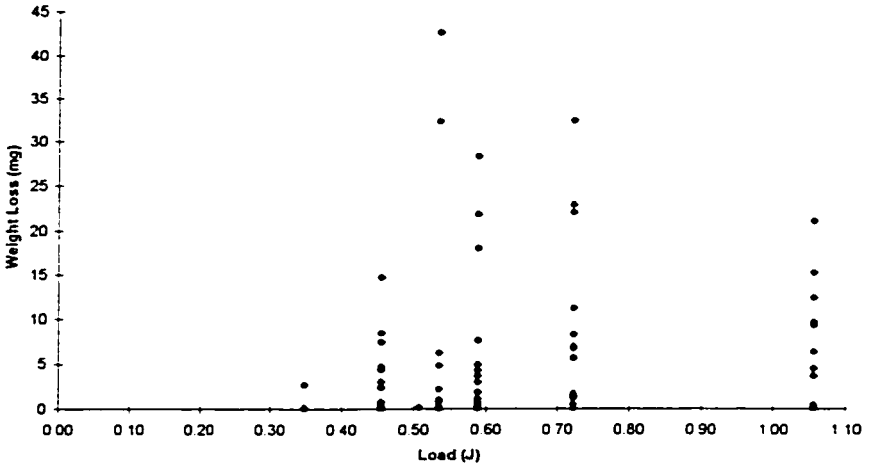
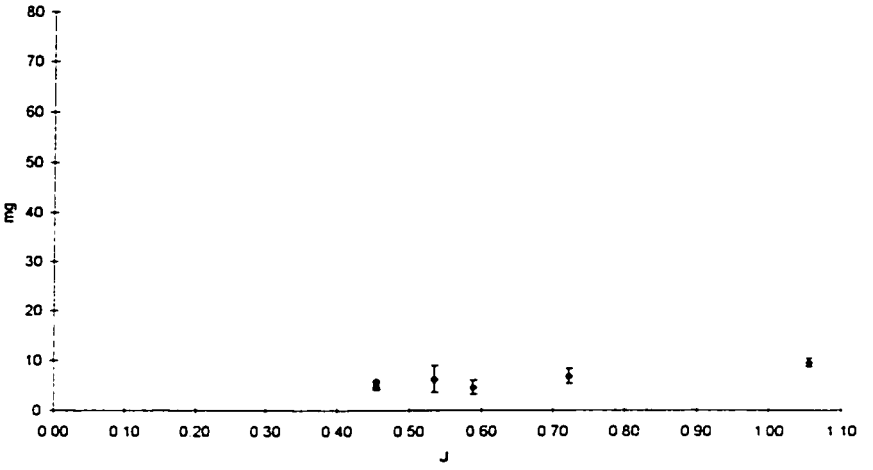

Fail Rate
1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
0.13
0.19
0.24
0.29
0.35
0.40
0.45
0.54
0.62
0.72
J

**Figure B.58** Raw data from PIT analysis, 21D (*meulière*).

**Figure B.59** Median weight loss per load tested, 21D (*meulière*).

**Figure B.60** Fail rate per load tested, 21D (*meulière*).


Weight Loss (mg)
45
40
35
30
25
20
15
10
5
0
0 00
0 10
0 20
0 30
0 40
0 50
0 60
0 70
0 80
0 90
1 00
1 10
Load (J)


mg
80
70
60
50
40
30
20
10
0
0 00
0 10
0 20
0 30
0 40
0 50
0 60
0 70
0 80
0 90
1 00
1 10
J

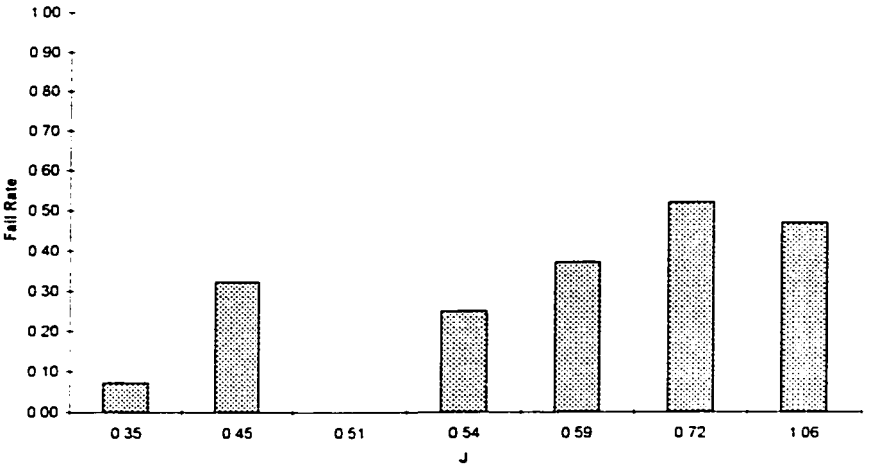
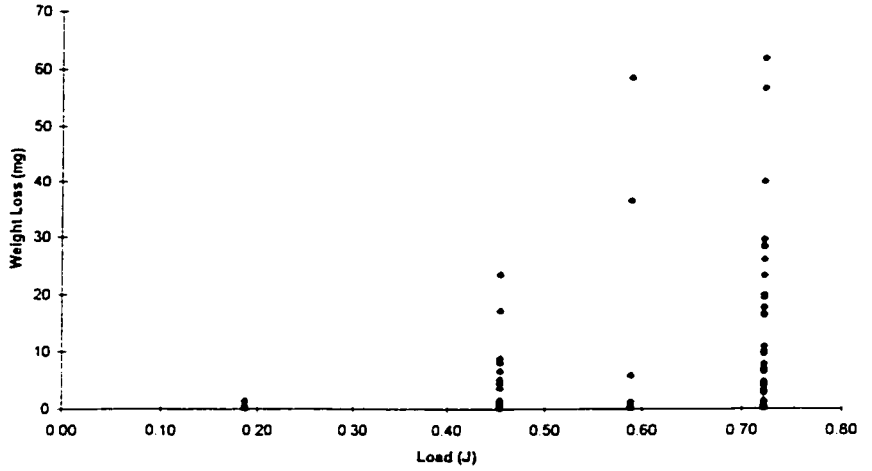
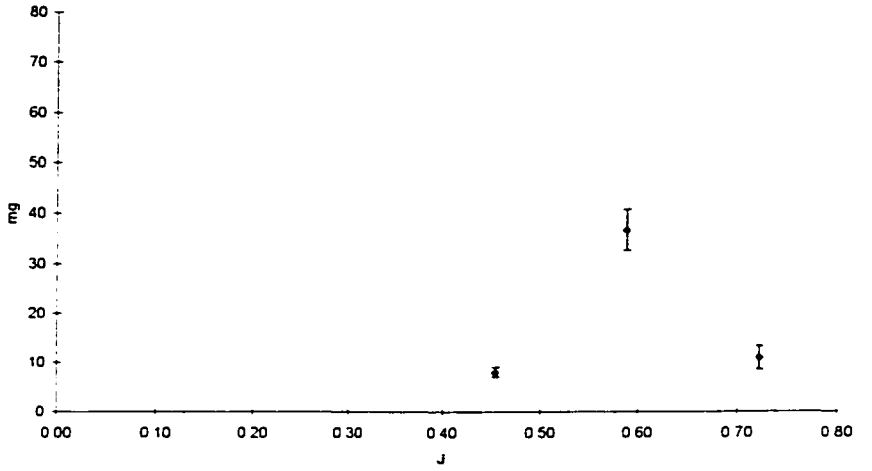

Fail Rate
1 00
0 90
0 80
0 70
0 60
0 50
0 40
0 30
0 20
0 10
0 00
0 35
0 45
0 51
0 54
0 59
0 72
1 06
J

**Figure B.61** Raw data from PIT analysis, 26 (Bergeracois).

**Figure B.62** Median weight loss per load tested, 26 (Bergeracois).

**Figure B.63** Fail rate per load tested, 26 (Bergeracois).


Weight Loss (mg)
70
60
50
40
30
20
10
0
0 00
0 10
0 20
0 30
0 40
0 50
0 60
0 70
0 80
Load (J)


mg
80
70
60
50
40
30
20
10
0
0 00
0 10
0 20
0 30
0 40
0 50
0 60
0 70
0 80
J

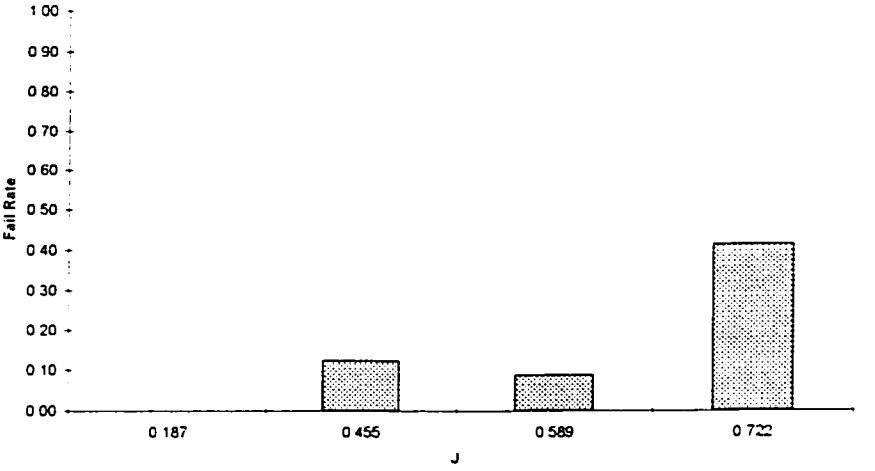
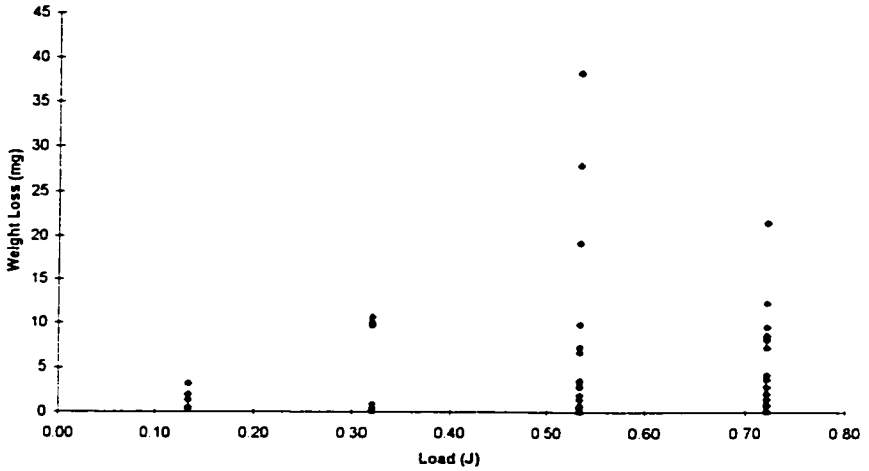
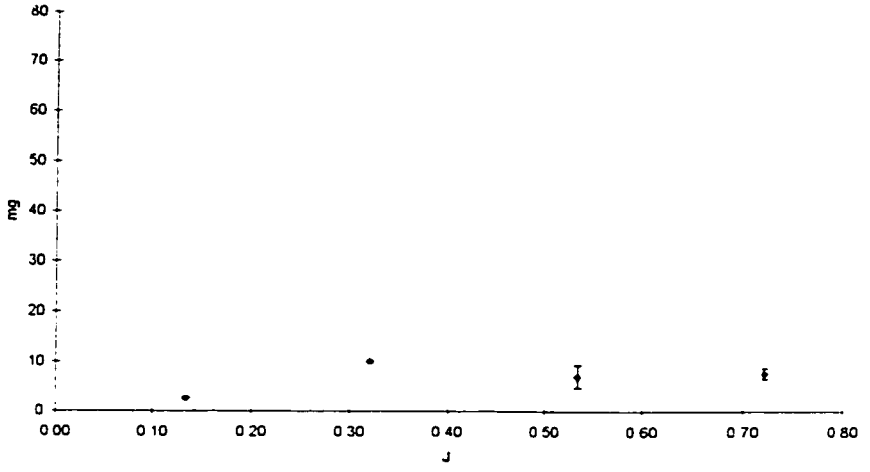

Fail Rate
1 00
0 90
0 80
0 70
0 60
0 50
0 40
0 30
0 20
0 10
0 00
0 187
0 455
0 589
0 722
J

**Figure B.64** Raw data from PIT analysis, 28 (quartzite).

**Figure B.65** Median weight loss per load tested, 28 (quartzite).

**Figure B.66** Fail rate per load tested, 28 (quartzite).


Weight Loss (mg)
45
40
35
30
25
20
15
10
5
0
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
0.80
Load (J)


mg
80
70
60
50
40
30
20
10
0
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
0.80
J

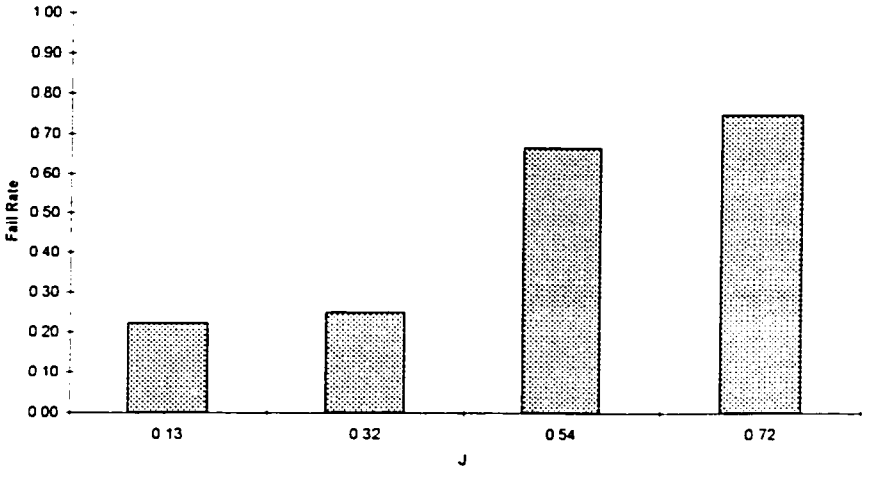
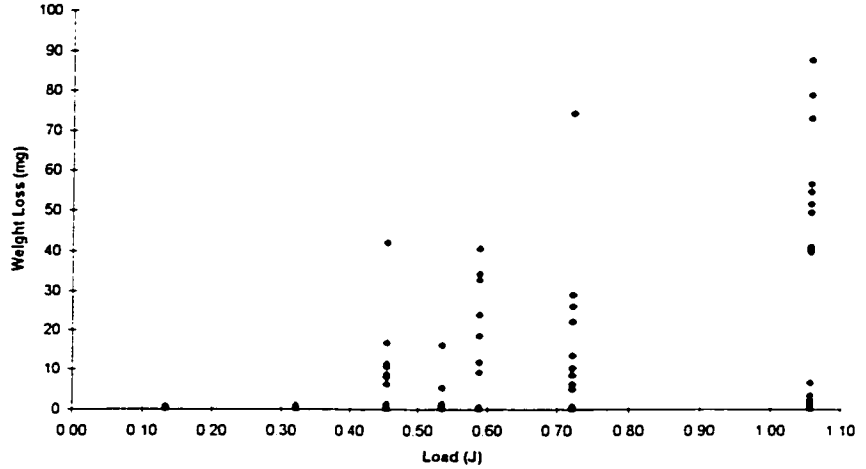
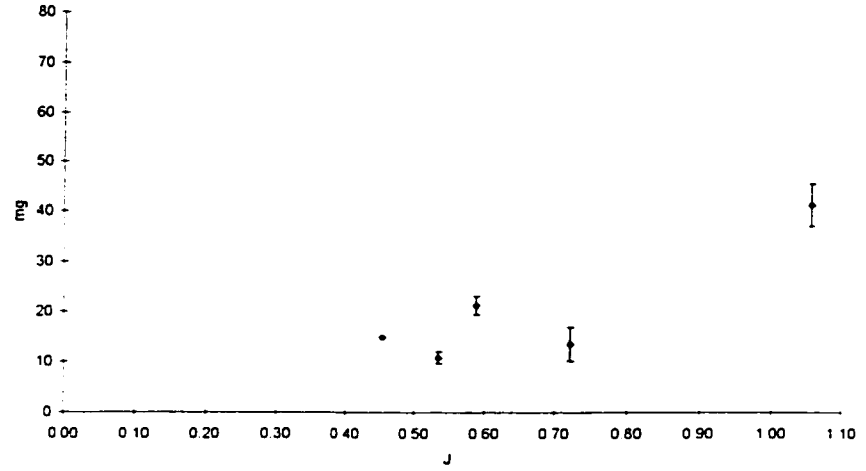

Fail Rate
1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
0.13
0.32
0.54
0.72
J

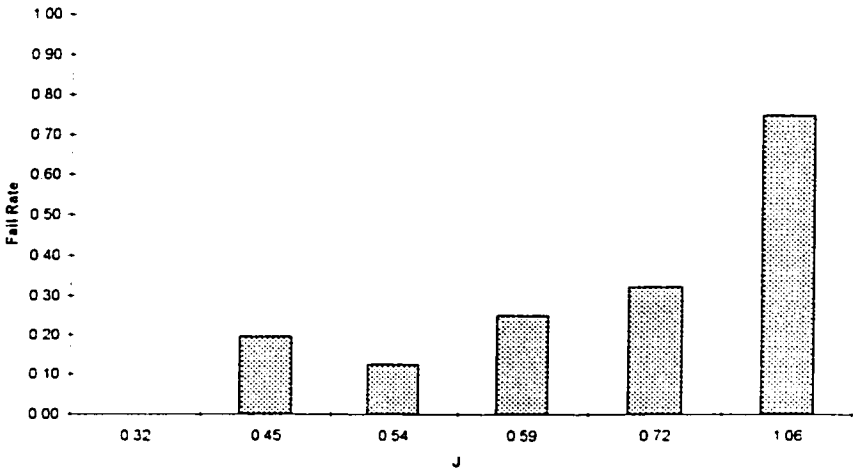
**Figure B.67** Raw data from PIT analysis, 29 (Mussidan).

**Figure B.68** Median weight loss per load tested, 29 (Mussidan).

**Figure B.69** Fail rate per load tested, 29 (Mussidan).


Weight Loss (mg)
100
90
80
70
60
50
40
30
20
10
0
0 00
0 10
0 20
0 30
0 40
0 50
0 60
0 70
0 80
0 90
1 00
1 10
Load (J)


mg
80
70
60
50
40
30
20
10
0
0 00
0 10
0.20
0.30
0 40
0 50
0 60
0 70
0 80
0 90
1 00
1 10
J


Fail Rate
1 00
0 90
0 80
0 70
0 60
0 50
0 40
0 30
0 20
0 10
0 00
0 32
0 45
0 54
0 59
0 72
1 06
J

# Appendix C

## Fail rate data from Pendulum Impact Tests

This table contains the data used to draw the Fail Rate/Load charts in Appendix B (e.g., Figure B.3, B.6, etc.). The first three column headings are self-explanatory. The fourth, fifth, and sixth columns contain the following data: "No. Trials" is the number of trials at the given load that resulted in either a failure or a non-failure. Trials that resulted in crumbly fracture or snap fracture are not counted here. "No. Fails" is the number of failures, or conchoidal fractures produced at the given load. A failure is a trial in which the mean weight loss value (for all weight measurements for that trial) is $\geq$ 1.50 mg. ($D_{test} - D_{control} \geq 1.50$ mg), as explained in Chapter 6. "Fail Rate" is the number of failures divided by the number of trials at that load.

| Rock | RM Type | Load (J) | No. Trials | No. Fails | Fail Rate |
|---|---|---|---|---|---|
| 1B | black Senon. | 0.027 | 8 | 0 | 0.00 |
| 1B | black Senon. | 0.054 | 8 | 0 | 0.00 |
| 1B | black Senon. | 0.080 | 8 | 0 | 0.00 |
| 1B | black Senon. | 0.134 | 5 | 1 | 0.20 |
| 1B | black Senon. | 0.187 | 10 | 4 | 0.40 |
| 1B | black Senon. | 0.241 | 11 | 2 | 0.18 |
| 1B | black Senon. | 0.294 | 8 | 2 | 0.25 |
| 1B | black Senon. | 0.348 | 10 | 4 | 0.40 |
| 1B | black Senon. | 0.401 | 10 | 2 | 0.20 |
| 1B | black Senon. | 0.455 | 29 | 12 | 0.41 |
| 1B | black Senon. | 0.508 | 13 | 4 | 0.31 |
| 1B | black Senon. | 0.562 | 11 | 4 | 0.36 |
| 1B | black Senon. | 0.615 | 27 | 13 | 0.48 |
| 1B | black Senon. | 0.669 | 27 | 13 | 0.48 |
| 1C | black Senon. | 0.054 | 10 | 0 | 0.00 |
| 1C | black Senon. | 0.080 | 10 | 0 | 0.00 |
| 1C | black Senon. | 0.134 | 10 | 1 | 0.10 |
| 1C | black Senon. | 0.241 | 10 | 1 | 0.10 |
| 1C | black Senon. | 0.348 | 10 | 7 | 0.70 |
| 1C | black Senon. | 0.401 | 10 | 2 | 0.20 |
| 1C | black Senon. | 0.455 | 37 | 11 | 0.30 |
| 1C | black Senon. | 0.562 | 37 | 16 | 0.43 |
| 1C | black Senon. | 0.669 | 11 | 5 | 0.45 |
| 1C | black Senon. | 0.722 | 26 | 15 | 0.58 |
| 1C | black Senon. | 1.057 | 11 | 2 | 0.18 |
| 2A | beige Senon. | 0.040 | 5 | 0 | 0.00 |
| 2A | beige Senon. | 0.054 | 7 | 0 | 0.00 |
| 2A | beige Senon. | 0.134 | 10 | 0 | 0.00 |
| 2A | beige Senon. | 0.241 | 13 | 3 | 0.23 |
| 2A | beige Senon. | 0.348 | 13 | 4 | 0.31 |
| 2A | beige Senon. | 0.428 | 17 | 4 | 0.24 |
| 2A | beige Senon. | 0.455 | 25 | 9 | 0.36 |
| 2A | beige Senon. | 0.562 | 31 | 12 | 0.39 |
| 2A | beige Senon. | 0.722 | 32 | 14 | 0.44 |
| 2C | beige Senon. | 0.134 | 9 | 0 | 0.00 |
| 2C | beige Senon. | 0.321 | 17 | 2 | 0.12 |
| 2C | beige Senon. | 0.428 | 14 | 2 | 0.14 |
| 2C | beige Senon. | 0.455 | 26 | 11 | 0.42 |
| 2C | beige Senon. | 0.535 | 16 | 5 | 0.31 |
| 2C | beige Senon. | 0.589 | 22 | 14 | 0.64 |
| 2C | beige Senon. | 0.722 | 24 | 13 | 0.54 |
| 2C | beige Senon. | 1.057 | 12 | 6 | 0.50 |

| Rock | RM Type | Load (J) | No. Trials | No. Fails | Fail Rate |
|---|---|---|---|---|---|
| 6B | black Senon. | 0.134 | 19 | 0 | 0.00 |
| 6B | black Senon. | 0.321 | 31 | 2 | 0.06 |
| 6B | black Senon. | 0.455 | 35 | 5 | 0.14 |
| 6B | black Senon. | 0.535 | 43 | 8 | 0.19 |
| 6B | black Senon. | 0.589 | 32 | 8 | 0.25 |
| 6B | black Senon. | 0.722 | 47 | 12 | 0.26 |
| 6B | black Senon. | 1.057 | 15 | 4 | 0.27 |
| 9A | chalcedony | 0.134 | 11 | 1 | 0.09 |
| 9A | chalcedony | 0.241 | 11 | 2 | 0.18 |
| 9A | chalcedony | 0.294 | 10 | 0 | 0.00 |
| 9A | chalcedony | 0.348 | 12 | 2 | 0.17 |
| 9A | chalcedony | 0.401 | 12 | 3 | 0.25 |
| 9A | chalcedony | 0.455 | 47 | 5 | 0.11 |
| 9A | chalcedony | 0.535 | 27 | 5 | 0.19 |
| 9A | chalcedony | 0.615 | 20 | 9 | 0.45 |
| 9A | chalcedony | 0.722 | 16 | 7 | 0.44 |
| 9A | chalcedony | 1.057 | 11 | 1 | 0.09 |
| 9D | chalcedony | 0.134 | 5 | 0 | 0.00 |
| 9D | chalcedony | 0.241 | 8 | 1 | 0.13 |
| 9D | chalcedony | 0.294 | 8 | 2 | 0.25 |
| 9D | chalcedony | 0.348 | 10 | 5 | 0.50 |
| 9D | chalcedony | 0.401 | 11 | 5 | 0.45 |
| 9D | chalcedony | 0.455 | 14 | 9 | 0.64 |
| 9D | chalcedony | 0.535 | 18 | 10 | 0.56 |
| 9D | chalcedony | 0.615 | 16 | 10 | 0.63 |
| 9D | chalcedony | 0.722 | 17 | 11 | 0.65 |
| 9E | jasper | 0.348 | 10 | 1 | 0.10 |
| 9E | jasper | 0.455 | 6 | 4 | 0.67 |
| 9E | jasper | 0.589 | 14 | 10 | 0.71 |
| 9E | jasper | 0.722 | 12 | 6 | 0.50 |
| 9E | jasper | 1.057 | 6 | 5 | 0.83 |
| 9G | jasper | 0.455 | 28 | 5 | 0.18 |
| 9G | jasper | 0.589 | 32 | 6 | 0.19 |
| 9G | jasper | 0.722 | 30 | 7 | 0.23 |
| 9G | jasper | 1.057 | 7 | 2 | 0.29 |
| 10A | jasper | 0.027 | 1 | 0 | 0.00 |
| 10A | jasper | 0.054 | 10 | 0 | 0.00 |
| 10A | jasper | 0.080 | 10 | 0 | 0.00 |
| 10A | jasper | 0.134 | 10 | 1 | 0.10 |
| 10A | jasper | 0.241 | 10 | 2 | 0.20 |
| 10A | jasper | 0.348 | 10 | 3 | 0.30 |
| 10A | jasper | 0.401 | 16 | 4 | 0.25 |

| Rock | RM Type | Load (J) | No. Trials | No. Fails | Fail Rate |
|---|---|---|---|---|---|
| 10A | jasper | 0.428 | 12 | 6 | 0.50 |
| 10A | jasper | 0.455 | 15 | 9 | 0.60 |
| 10A | jasper | 0.562 | 30 | 17 | 0.57 |
| 10A | jasper | 0.669 | 10 | 8 | 0.80 |
| 10A | jasper | 0.722 | 8 | 7 | 0.88 |
| | | | | | |
| 10C | jasper | 0.067 | 3 | 0 | 0.00 |
| 10C | jasper | 0.134 | 8 | 1 | 0.13 |
| 10C | jasper | 0.214 | 8 | 1 | 0.13 |
| 10C | jasper | 0.294 | 8 | 0 | 0.00 |
| 10C | jasper | 0.375 | 12 | 5 | 0.42 |
| 10C | jasper | 0.455 | 41 | 17 | 0.41 |
| 10C | jasper | 0.535 | 15 | 3 | 0.20 |
| 10C | jasper | 0.615 | 38 | 11 | 0.29 |
| 10C | jasper | 0.722 | 32 | 16 | 0.50 |
| 10C | jasper | 1.057 | 10 | 5 | 0.50 |
| | | | | | |
| 11A | beige Senon. | 0.027 | 10 | 0 | 0.00 |
| 11A | beige Senon. | 0.080 | 10 | 0 | 0.00 |
| 11A | beige Senon. | 0.107 | 3 | 0 | 0.00 |
| 11A | beige Senon. | 0.134 | 10 | 0 | 0.00 |
| 11A | beige Senon. | 0.161 | 10 | 1 | 0.10 |
| 11A | beige Senon. | 0.187 | 10 | 0 | 0.00 |
| 11A | beige Senon. | 0.241 | 10 | 1 | 0.10 |
| 11A | beige Senon. | 0.294 | 10 | 0 | 0.00 |
| 11A | beige Senon. | 0.348 | 10 | 0 | 0.00 |
| 11A | beige Senon. | 0.401 | 10 | 1 | 0.10 |
| 11A | beige Senon. | 0.428 | 24 | 5 | 0.21 |
| 11A | beige Senon. | 0.455 | 12 | 1 | 0.08 |
| 11A | beige Senon. | 0.508 | 16 | 0 | 0.00 |
| 11A | beige Senon. | 0.562 | 18 | 5 | 0.28 |
| 11A | beige Senon. | 0.615 | 17 | 5 | 0.29 |
| 11A | beige Senon. | 0.669 | 33 | 11 | 0.33 |
| 11A | beige Senon. | 1.057 | 16 | 4 | 0.25 |
| | | | | | |
| 11A' | beige Senon. | 0.027 | 10 | 0 | 0.00 |
| 11A' | beige Senon. | 0.054 | 8 | 1 | 0.13 |
| 11A' | beige Senon. | 0.080 | 7 | 0 | 0.00 |
| 11A' | beige Senon. | 0.134 | 6 | 0 | 0.00 |
| 11A' | beige Senon. | 0.187 | 10 | 1 | 0.10 |
| 11A' | beige Senon. | 0.241 | 10 | 4 | 0.40 |
| 11A' | beige Senon. | 0.348 | 12 | 7 | 0.58 |
| 11A' | beige Senon. | 0.428 | 14 | 5 | 0.36 |
| 11A' | beige Senon. | 0.562 | 20 | 4 | 0.20 |
| 11A' | beige Senon. | 0.669 | 14 | 10 | 0.71 |

| Rock | RM Type | Load (J) | No. Trials | No. Fails | Fail Rate |
|---|---|---|---|---|---|
| 12A | black Senon. | 0.080 | 8 | 0 | 0.00 |
| 12A | black Senon. | 0.187 | 10 | 2 | 0.20 |
| 12A | black Senon. | 0.294 | 15 | 1 | 0.07 |
| 12A | black Senon. | 0.401 | 26 | 9 | 0.35 |
| 12A | black Senon. | 0.508 | 16 | 4 | 0.25 |
| 12A | black Senon. | 0.615 | 29 | 17 | 0.59 |
| 12A | black Senon. | 0.722 | 18 | 12 | 0.67 |
| | | | | | |
| 12A' | black Senon. | 0.040 | 10 | 0 | 0.00 |
| 12A' | black Senon. | 0.054 | 10 | 0 | 0.00 |
| 12A' | black Senon. | 0.067 | 10 | 2 | 0.20 |
| 12A' | black Senon. | 0.080 | 10 | 0 | 0.00 |
| 12A' | black Senon. | 0.134 | 10 | 0 | 0.00 |
| 12A' | black Senon. | 0.241 | 10 | 0 | 0.00 |
| 12A' | black Senon. | 0.348 | 17 | 4 | 0.24 |
| 12A' | black Senon. | 0.401 | 40 | 6 | 0.15 |
| 12A' | black Senon. | 0.482 | 14 | 6 | 0.43 |
| 12A' | black Senon. | 0.562 | 25 | 16 | 0.64 |
| 12A' | black Senon. | 0.669 | 29 | 16 | 0.55 |
| 12A' | black Senon. | 0.722 | 11 | 6 | 0.55 |
| 12A' | black Senon. | 1.057 | 7 | 5 | 0.71 |
| | | | | | |
| 13A | Bergeracois | 0.040 | 10 | 0 | 0.00 |
| 13A | Bergeracois | 0.054 | 10 | 0 | 0.00 |
| 13A | Bergeracois | 0.134 | 10 | 0 | 0.00 |
| 13A | Bergeracois | 0.241 | 10 | 1 | 0.10 |
| 13A | Bergeracois | 0.348 | 10 | 1 | 0.10 |
| 13A | Bergeracois | 0.401 | 12 | 4 | 0.33 |
| 13A | Bergeracois | 0.455 | 10 | 0 | 0.00 |
| 13A | Bergeracois | 0.562 | 10 | 5 | 0.50 |
| 13A | Bergeracois | 0.669 | 10 | 5 | 0.50 |
| 13A | Bergeracois | 0.722 | 12 | 7 | 0.58 |
| | | | | | |
| 13B | Bergeracois | 0.027 | 5 | 0 | 0.00 |
| 13B | Bergeracois | 0.134 | 6 | 0 | 0.00 |
| 13B | Bergeracois | 0.241 | 7 | 0 | 0.00 |
| 13B | Bergeracois | 0.348 | 8 | 0 | 0.00 |
| 13B | Bergeracois | 0.375 | 6 | 1 | 0.17 |
| 13B | Bergeracois | 0.401 | 11 | 4 | 0.36 |
| 13B | Bergeracois | 0.455 | 22 | 4 | 0.18 |
| 13B | Bergeracois | 0.562 | 20 | 8 | 0.40 |
| 13B | Bergeracois | 0.669 | 14 | 6 | 0.43 |

| Rock | RM Type | Load (J) | No. Trials | No. Fails | Fail Rate |
|---|---|---|---|---|---|
| 14B | beige Senon. | 0.067 | 6 | 0 | 0.00 |
| 14B | beige Senon. | 0.134 | 8 | 2 | 0.25 |
| 14B | beige Senon. | 0.241 | 8 | 0 | 0.00 |
| 14B | beige Senon. | 0.348 | 13 | 4 | 0.31 |
| 14B | beige Senon. | 0.401 | 12 | 3 | 0.25 |
| 14B | beige Senon. | 0.455 | 18 | 7 | 0.39 |
| 14B | beige Senon. | 0.535 | 17 | 5 | 0.29 |
| 14B | beige Senon. | 0.615 | 23 | 7 | 0.30 |
| 14B | beige Senon. | 0.722 | 23 | 8 | 0.35 |
| 18B | millstone | 0.134 | 5 | 0 | 0.00 |
| 18B | millstone | 0.187 | 4 | 0 | 0.00 |
| 18B | millstone | 0.241 | 7 | 0 | 0.00 |
| 18B | millstone | 0.294 | 8 | 1 | 0.13 |
| 18B | millstone | 0.348 | 10 | 4 | 0.40 |
| 18B | millstone | 0.401 | 11 | 1 | 0.09 |
| 18B | millstone | 0.455 | 29 | 7 | 0.24 |
| 18B | millstone | 0.535 | 11 | 2 | 0.18 |
| 18B | millstone | 0.615 | 22 | 12 | 0.55 |
| 18B | millstone | 0.722 | 24 | 10 | 0.42 |
| 21D | millstone | 0.348 | 14 | 1 | 0.07 |
| 21D | millstone | 0.455 | 28 | 9 | 0.32 |
| 21D | millstone | 0.508 | 1 | 0 | 0.00 |
| 21D | millstone | 0.535 | 20 | 5 | 0.25 |
| 21D | millstone | 0.589 | 27 | 10 | 0.37 |
| 21D | millstone | 0.722 | 23 | 12 | 0.52 |
| 21D | millstone | 1.057 | 17 | 8 | 0.47 |
| 26 | Bergeracois | 0.187 | 43 | 0 | 0.00 |
| 26 | Bergeracois | 0.455 | 73 | 9 | 0.12 |
| 26 | Bergeracois | 0.589 | 34 | 3 | 0.09 |
| 26 | Bergeracois | 0.722 | 70 | 29 | 0.41 |
| 28 | quartzite | 0.134 | 9 | 2 | 0.22 |
| 28 | quartzite | 0.321 | 12 | 3 | 0.25 |
| 28 | quartzite | 0.535 | 15 | 10 | 0.67 |
| 28 | quartzite | 0.722 | 16 | 12 | 0.75 |
| 29 | Mussidan | 0.134 | 10 | 0 | 0.00 |
| 29 | Mussidan | 0.321 | 14 | 0 | 0.00 |
| 29 | Mussidan | 0.455 | 36 | 7 | 0.19 |
| 29 | Mussidan | 0.535 | 16 | 2 | 0.13 |
| 29 | Mussidan | 0.589 | 32 | 8 | 0.25 |
| 29 | Mussidan | 0.722 | 28 | 9 | 0.32 |
| 29 | Mussidan | 1.057 | 20 | 15 | 0.75 |
| Total | | | 3313 | 954 | |

# Appendix D

## Weight loss data from Pendulum Indenter Tests

This table contains the data pertaining to weight loss for each trial on each rock. "Rock" is the ID number of the rock tested, and RM is the raw material type to which that rock is assigned (see Table 4.1 for a list of RM types). "N" is the number of failures, which is defined the same way as in Appendix C and as explained in Chapter 6. "Median WL" is the median weight loss value for all failures at the given load, and "$S_{med}$" is the standard deviation of median weight loss. $S_{med}$ was calculated with the following formula (Sokal and Rohlf 1994:138):

$$S_{med} = (1.2533)S_x$$

where $S_x$ is the standard deviation of the mean. The Median Weight Loss/Load charts in Appendix B (such as Figure B.2, B.5, B.8, etc.) are based on the medians in this table. The confidence intervals in those charts were calculated with the sample sizes, medians, and standard deviations reported in this table. "Mean WL" is the mean weight loss value for all failures at the given load, and $V_{wt}$ is coefficient of variation of weight loss.

| Load (J)<br>*Rock (RM)* | N | Median WL | $S_{med}$ | Mean WL | $S_{mean}$ | $V_{wt}$ |
|---|---|---|---|---|---|---|
| *26 (Bergeracois)* | | | | | | |
| 0.455 | 9 | 7.97 | 6.59 | 9.44 | 5.262 | 55.712 |
| 0.589 | 3 | 36.53 | 26.52 | 33.60 | 21.162 | 62.981 |
| 0.722 | 29 | 10.83 | 15.39 | 16.90 | 12.276 | 72.643 |
| *28 (quartzite)* | | | | | | |
| 0.134 | 2 | 2.55 | 0.87 | 2.55 | 0.696 | 27.290 |
| 0.321 | 3 | 10.03 | 0.47 | 10.10 | 0.375 | 3.715 |
| 0.535 | 10 | 6.98 | 12.40 | 12.10 | 9.894 | 81.747 |
| 0.722 | 12 | 7.63 | 5.54 | 7.47 | 4.417 | 59.116 |
| *29 (Mussidan)* | | | | | | |
| 0.455 | 7 | 10.60 | 12.52 | 14.83 | 9.993 | 67.366 |
| 0.535 | 2 | 10.77 | 7.59 | 10.77 | 6.055 | 56.241 |
| 0.589 | 8 | 21.22 | 11.99 | 22.89 | 9.566 | 41.790 |
| 0.722 | 9 | 13.47 | 21.61 | 21.70 | 17.244 | 79.479 |
| 1.057 | 15 | 41.10 | 27.88 | 41.90 | 22.245 | 53.093 |
| *10A (jasper)* | | | | | | |
| 0.134 | 1 | 5.45 | 0.00 | 5.45 | 0.000 | 0.000 |
| 0.241 | 2 | 13.97 | 16.65 | 13.97 | 13.287 | 95.076 |
| 0.348 | 3 | 12.03 | 1.52 | 11.82 | 1.213 | 10.263 |
| 0.401 | 4 | 3.45 | 10.07 | 7.80 | 8.038 | 102.999 |
| 0.428 | 6 | 26.32 | 17.71 | 25.29 | 14.133 | 55.880 |
| 0.455 | 9 | 26.98 | 22.71 | 27.33 | 18.120 | 66.292 |
| 0.562 | 17 | 47.23 | 39.56 | 46.25 | 31.582 | 68.286 |
| 0.669 | 8 | 34.52 | 33.82 | 44.65 | 26.986 | 60.442 |
| 0.722 | 7 | 40.63 | 42.19 | 52.52 | 33.662 | 64.089 |
| *10C (jasper)* | | | | | | |
| 0.134 | 1 | 3.47 | 0.00 | 3.47 | 0.000 | 0.000 |
| 0.214 | 1 | 5.13 | 0.00 | 5.13 | 0.000 | 0.000 |
| 0.375 | 5 | 22.10 | 9.45 | 17.31 | 7.540 | 43.564 |
| 0.455 | 17 | 10.73 | 13.94 | 17.17 | 11.126 | 64.792 |
| 0.535 | 3 | 7.73 | 15.52 | 14.83 | 12.383 | 83.483 |
| 0.615 | 11 | 28.80 | 23.75 | 29.64 | 18.949 | 63.932 |
| 0.722 | 16 | 30.55 | 31.36 | 38.05 | 25.020 | 65.751 |
| 1.057 | 5 | 40.17 | 31.82 | 62.59 | 25.391 | 40.569 |
| *11A (beige Senonian)* | | | | | | |
| 0.161 | 1 | 3.43 | 0.00 | 3.43 | 0.000 | 0.000 |
| 0.241 | 1 | 3.13 | 0.00 | 3.13 | 0.000 | 0.000 |
| 0.401 | 1 | 15.97 | 0.00 | 15.97 | 0.000 | 0.000 |
| 0.428 | 5 | 5.30 | 6.44 | 8.74 | 5.134 | 58.746 |
| 0.455 | 1 | 3.55 | 0.00 | 3.55 | 0.000 | 0.000 |
| 0.562 | 5 | 4.65 | 5.63 | 6.48 | 4.496 | 69.357 |
| 0.615 | 5 | 2.60 | 5.20 | 4.97 | 4.151 | 83.553 |
| 0.669 | 11 | 9.72 | 30.10 | 25.26 | 24.015 | 95.060 |
| 1.057 | 4 | 23.48 | 27.31 | 31.67 | 21.792 | 68.818 |

| Load (J) / Rock (RM) | N | Median WL | $S_{med}$ | Mean WL | $S_{mean}$ | $V_{wt}$ |
|---|---|---|---|---|---|---|
| *11A' (beige Senonian)* | | | | | | |
| 0.054 | 1 | 2.77 | 0.00 | 2.77 | 0.000 | 0.000 |
| 0.187 | 1 | 7.25 | 0.00 | 7.25 | 0.000 | 0.000 |
| 0.241 | 4 | 2.45 | 4.94 | 4.64 | 3.944 | 84.929 |
| 0.348 | 7 | 7.07 | 20.96 | 17.23 | 16.722 | 97.066 |
| 0.428 | 5 | 4.40 | 0.89 | 4.75 | 0.711 | 14.960 |
| 0.562 | 4 | 33.36 | 9.30 | 33.85 | 7.418 | 21.916 |
| 0.669 | 10 | 18.52 | 37.41 | 34.46 | 29.848 | 86.612 |
| *12A (black Senonian)* | | | | | | |
| 0.187 | 2 | 7.77 | 1.32 | 7.77 | 1.053 | 13.560 |
| 0.294 | 1 | 3.53 | 0.00 | 3.53 | 0.000 | 0.000 |
| 0.401 | 9 | 6.07 | 3.27 | 7.23 | 2.606 | 36.069 |
| 0.508 | 4 | 16.42 | 16.18 | 18.81 | 12.912 | 68.649 |
| 0.615 | 17 | 7.00 | 15.96 | 15.21 | 12.736 | 83.713 |
| 0.722 | 12 | 14.45 | 29.19 | 28.08 | 23.287 | 82.936 |
| *12A' (black Senonian)* | | | | | | |
| 0.067 | 2 | 1.83 | 0.21 | 1.83 | 0.169 | 9.268 |
| 0.348 | 4 | 4.99 | 9.59 | 8.65 | 7.654 | 88.511 |
| 0.401 | 6 | 10.36 | 7.45 | 10.65 | 5.947 | 55.825 |
| 0.482 | 6 | 30.77 | 22.68 | 29.51 | 18.100 | 61.342 |
| 0.562 | 16 | 27.84 | 27.19 | 30.06 | 21.696 | 72.176 |
| 0.669 | 16 | 10.87 | 45.64 | 30.64 | 36.417 | 118.862 |
| 0.722 | 6 | 23.35 | 29.57 | 28.73 | 23.595 | 82.125 |
| 1.057 | 5 | 24.73 | 21.10 | 26.35 | 16.838 | 63.909 |
| *13A (Bergeracois)* | | | | | | |
| 0.241 | 1 | 9.46 | 0.00 | 9.46 | 0.000 | 0.000 |
| 0.348 | 1 | 3.92 | 0.00 | 3.92 | 0.000 | 0.000 |
| 0.401 | 4 | 7.81 | 5.84 | 10.19 | 4.658 | 45.728 |
| 0.562 | 5 | 10.10 | 7.55 | 11.26 | 6.023 | 53.505 |
| 0.669 | 5 | 14.74 | 20.13 | 19.78 | 16.062 | 81.187 |
| 0.722 | 7 | 19.92 | 17.06 | 24.37 | 13.611 | 55.861 |
| *13B (Bergeracois)* | | | | | | |
| 0.375 | 1 | 25.33 | 0.00 | 25.33 | 0.000 | 0.000 |
| 0.401 | 4 | 19.19 | 12.18 | 16.69 | 9.717 | 58.227 |
| 0.455 | 4 | 16.72 | 10.28 | 16.09 | 8.201 | 50.978 |
| 0.562 | 8 | 21.92 | 15.69 | 21.58 | 12.518 | 58.011 |
| 0.669 | 6 | 3.64 | 6.91 | 6.23 | 5.516 | 88.524 |
| *14B (beige Senonian)* | | | | | | |
| 0.134 | 2 | 3.53 | 2.73 | 3.53 | 2.182 | 61.740 |
| 0.348 | 4 | 14.12 | 3.95 | 13.48 | 3.152 | 23.374 |
| 0.401 | 3 | 4.77 | 13.77 | 11.22 | 10.987 | 97.900 |
| 0.455 | 7 | 6.13 | 7.78 | 8.58 | 6.211 | 72.383 |
| 0.535 | 5 | 32.00 | 34.38 | 41.69 | 27.434 | 65.811 |
| 0.615 | 7 | 23.97 | 17.04 | 22.18 | 13.599 | 61.324 |
| 0.722 | 8 | 16.47 | 32.08 | 29.60 | 25.599 | 86.483 |

| Load (J) / Rock (RM) | N | Median WL | $S_{med}$ | Mean WL | $S_{mean}$ | $V_{wt}$ |
|---|---|---|---|---|---|---|
| *18B (millstone)* | | | | | | |
| 0.294 | 1 | 1.85 | 0.00 | 1.85 | 0.000 | 0.000 |
| 0.348 | 4 | 10.50 | 6.96 | 11.75 | 5.555 | 47.278 |
| 0.401 | 1 | 2.25 | 0.00 | 2.25 | 0.000 | 0.000 |
| 0.455 | 7 | 21.67 | 19.20 | 27.45 | 15.322 | 55.813 |
| 0.535 | 2 | 5.50 | 5.14 | 5.50 | 4.100 | 74.543 |
| 0.615 | 12 | 16.45 | 13.40 | 17.73 | 10.695 | 60.313 |
| 0.722 | 10 | 21.92 | 34.75 | 35.86 | 27.724 | 77.304 |
| *1B (black Senonian)* | | | | | | |
| 0.134 | 1 | 1.57 | 0.00 | 1.57 | 0.000 | 0.000 |
| 0.187 | 4 | 1.96 | 0.90 | 2.24 | 0.718 | 31.980 |
| 0.241 | 2 | 3.97 | 2.79 | 3.97 | 2.228 | 56.063 |
| 0.294 | 2 | 2.05 | 0.32 | 2.05 | 0.254 | 12.392 |
| 0.348 | 4 | 15.42 | 6.90 | 13.22 | 5.506 | 41.663 |
| 0.401 | 2 | 2.05 | 0.60 | 2.05 | 0.480 | 23.397 |
| 0.455 | 12 | 7.35 | 13.80 | 13.55 | 11.008 | 81.228 |
| 0.508 | 4 | 18.54 | 13.80 | 18.43 | 11.013 | 59.753 |
| 0.562 | 4 | 2.14 | 0.55 | 2.18 | 0.437 | 20.025 |
| 0.615 | 13 | 22.73 | 23.67 | 27.35 | 18.888 | 69.067 |
| 0.669 | 13 | 33.07 | 21.67 | 29.45 | 17.294 | 58.729 |
| *1C (black Senonian)* | | | | | | |
| 0.134 | 1 | 2.70 | 0.00 | 2.70 | 0.000 | 0.000 |
| 0.241 | 1 | 3.50 | 0.00 | 3.50 | 0.000 | 0.000 |
| 0.348 | 7 | 8.52 | 11.31 | 13.56 | 9.028 | 66.565 |
| 0.401 | 2 | 8.17 | 9.26 | 8.17 | 7.391 | 90.501 |
| 0.455 | 11 | 21.30 | 12.23 | 18.85 | 9.760 | 51 778 |
| 0.562 | 16 | 19.13 | 10.61 | 19.68 | 8.468 | 43.022 |
| 0.669 | 5 | 69.88 | 37.65 | 49.84 | 30.043 | 60.276 |
| 0.722 | 15 | 25.77 | 54.13 | 34.24 | 43.190 | 126.144 |
| 1.057 | 2 | 32.27 | 38.94 | 32.27 | 31.068 | 96.287 |
| *21D (millstone)* | | | | | | |
| 0.348 | 1 | 2.70 | 0.00 | 2.70 | 0.000 | 0.000 |
| 0.455 | 9 | 4.60 | 3.95 | 5.81 | 3.151 | 54.261 |
| 0.535 | 5 | 6.23 | 18.56 | 17.67 | 14.812 | 83.808 |
| 0.589 | 10 | 4.58 | 9.39 | 9.77 | 7.492 | 76.657 |
| 0.722 | 12 | 6.83 | 9.94 | 10.56 | 7.934 | 75.127 |
| 1.057 | 8 | 9.50 | 5.85 | 10.29 | 4.666 | 45.356 |
| *2A (beige Senonian)* | | | | | | |
| 0.241 | 3 | 3.55 | 1.64 | 3.91 | 1.310 | 33.524 |
| 0.348 | 4 | 5.89 | 2.44 | 5.42 | 1.945 | 35.888 |
| 0.428 | 4 | 5.99 | 11.89 | 11.04 | 9.490 | 85.981 |
| 0.455 | 9 | 6.17 | 9.33 | 10.08 | 7.442 | 73.849 |
| 0.562 | 12 | 14.87 | 26.14 | 23.19 | 20.858 | 89.934 |
| 0.722 | 14 | 15.97 | 61.62 | 45.60 | 49.163 | 107.813 |

| Load (J) | N | Median WL | $S_{med}$ | Mean WL | $S_{mean}$ | $V_{wt}$ |
|---|---|---|---|---|---|---|
| *Rock (RM)* | | | | | | |
| *2C (beige Senonian)* | | | | | | |
| 0.321 | 2 | 1.60 | 0.05 | 1.60 | 0.038 | 2.354 |
| 0.428 | 2 | 2.67 | 1.65 | 2.67 | 1.316 | 49.356 |
| 0.455 | 11 | 13.60 | 13.62 | 15.37 | 10.870 | 70.711 |
| 0.535 | 5 | 5.37 | 18.75 | 16.18 | 14.964 | 92.483 |
| 0.589 | 14 | 15.55 | 13.58 | 16.51 | 10.835 | 65.630 |
| 0.722 | 13 | 22.60 | 26.29 | 25.55 | 20.978 | 82.119 |
| 1.057 | 6 | 30.42 | 39.03 | 47.85 | 31.139 | 65.077 |
| *6B (black Senonian)* | | | | | | |
| 0.321 | 2 | 4.85 | 4.41 | 4.85 | 3.517 | 72.509 |
| 0.455 | 5 | 2.00 | 9.25 | 6.74 | 7.379 | 109.487 |
| 0.535 | 8 | 2.52 | 5.68 | 4.61 | 4.533 | 98.394 |
| 0.589 | 8 | 2.55 | 2.92 | 3.52 | 2.332 | 66.305 |
| 0.722 | 12 | 7.87 | 7.24 | 9.30 | 5.780 | 62.146 |
| 1.057 | 4 | 4.02 | 12.67 | 9.48 | 10.109 | 106.600 |
| *9A (chalcedony)* | | | | | | |
| 0.134 | 1 | 1.73 | 0.00 | 1.73 | 0.000 | 0.000 |
| 0.241 | 2 | 4.23 | 2.59 | 4.23 | 2.069 | 48.873 |
| 0.348 | 2 | 4.90 | 3.96 | 4.90 | 3.160 | 64.480 |
| 0.401 | 3 | 9.07 | 8.06 | 9.61 | 6.434 | 66.944 |
| 0.455 | 5 | 6.73 | 8.36 | 8.99 | 6.672 | 74.248 |
| 0.535 | 5 | 7.30 | 6.38 | 9.91 | 5.093 | 51.408 |
| 0.615 | 9 | 15.17 | 12.94 | 15.03 | 10.327 | 68.711 |
| 0.722 | 7 | 27.23 | 14.29 | 22.02 | 11.402 | 51.770 |
| 1.057 | 1 | 1.53 | 0.00 | 1.53 | 0.000 | 0.000 |
| *9D (chalcedony)* | | | | | | |
| 0.241 | 1 | 15.12 | 0.00 | 15.12 | 0.000 | 0.000 |
| 0.294 | 2 | 2.85 | 1.53 | 2.85 | 1.222 | 42.894 |
| 0.348 | 5 | 3.83 | 5.72 | 6.63 | 4.562 | 68.825 |
| 0.401 | 5 | 8.50 | 6.86 | 11.89 | 5.473 | 46.019 |
| 0.455 | 9 | 6.17 | 6.88 | 9.10 | 5.492 | 60.380 |
| 0.535 | 10 | 9.65 | 12.77 | 13.66 | 10.189 | 74.571 |
| 0.615 | 10 | 17.08 | 11.74 | 18.06 | 9.368 | 51.863 |
| 0.722 | 11 | 24.70 | 25.39 | 27.75 | 20.258 | 73.007 |
| *9E (jasper)* | | | | | | |
| 0.348 | 1 | 81.97 | 0.00 | 81.97 | 0.000 | 0.000 |
| 0.455 | 4 | 37.30 | 19.80 | 45.89 | 15.797 | 34.422 |
| 0.589 | 10 | 23.53 | 22.57 | 26.75 | 18.009 | 67.322 |
| 0.722 | 6 | 10.67 | 12.32 | 12.82 | 9.832 | 76.710 |
| 1.057 | 5 | 44.27 | 29.14 | 46.71 | 23.253 | 49.785 |
| *9G (jasper)* | | | | | | |
| 0.455 | 5 | 6.87 | 8.57 | 9.15 | 6.840 | 74.726 |
| 0.589 | 6 | 6.12 | 5.81 | 7.11 | 4.637 | 65.205 |
| 0.722 | 7 | 10.23 | 7.80 | 12.57 | 6.226 | 49.524 |
| 1.057 | 2 | 9.73 | 11.17 | 9.73 | 8.914 | 91.587 |

# Vita

Stephen C. Cole was born in Nashville Tennessee on October 5, 1966, during a record heat wave. He lived there in a house on Draughon Avenue with his parents and two brothers until he graduated from John Overton High School in 1984. He has made many trips to France since 1982, including several seasons of excavation in Dordogne and a year analyzing collections in Bordeaux. He has also done archaeological fieldwork in the Southeast and the Pacific Northwest. In 1988, he graduated from the University of Tennessee, Knoxville with a B.A. in Anthropology. He immediately moved to Seattle and enrolled in the Archaeology Program in the Department of Anthropology at the University of Washington, where he earned an M.A. in Anthropology (1993) and a Ph.D. in Anthropology (2002). He currently lives in south Seattle with his wife and two young daughters. In addition to a score of technical reports written for projects in cultural resources management, he has authored or co-authored four articles:

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