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Explaining Corrugated Pottery in the American Southwest: An
Evolutionary Approach

by

Christopher Dion Pierce

A dissertation submitted in partial fulfillment of the
requirements for the degree of

Doctor of Philosophy

University of Washington

1999

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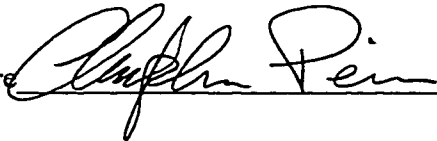
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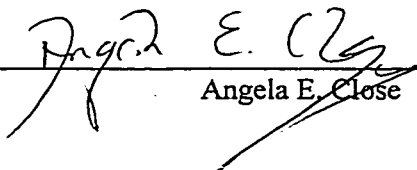
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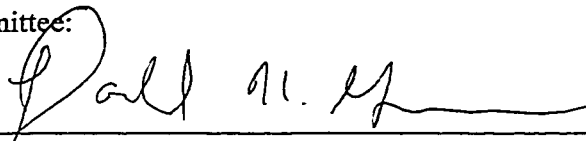
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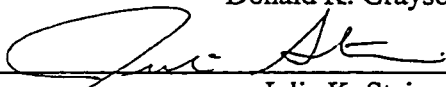


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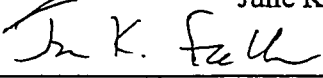
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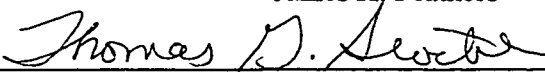
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Abstract

EXPLAINING CORRUGATED POTTERY IN THE AMERICAN
SOUTHWEST: AN EVOLUTIONARY APPROACH

by Christopher Pierce

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Corrugated pottery is a unique utility ware made by leaving construction coils unobliterated, and manipulating these exposed coils to produce a rough exterior surface. Ancestral Puebloan populations in the American Southwest made this pottery in various forms between AD 650 and 1450. Although archaeologists have tried to explain corrugation for over 100 years, none of these explanations has proven satisfactory. I employ an evolutionary approach in an attempt to explain the rise and fall of corrugated pottery.

Using analyses of ancient pottery, experiments with modern replicas, and syntheses of published data, I document that corrugation developed gradually from plain ware through a series of innovations in the size of coils and how they were applied and manipulated. Initially, corrugation appeared in the southern Mogollon region as wide, filleted, and unindented bands on jar necks, and spread north into the Anasazi areas of the Colorado Plateau. The development of overlapped and indented neck bands during the ninth and tenth centuries ultimately led to the use of these techniques over the entire exterior surface during the eleventh century producing full-body, indented corrugation. Full-body corrugation spread rapidly across a large area of the Colorado Plateau, and remained dominant until the fifteenth century when a return to plain pottery occurred. The development of corrugation coincided with an increase in the use of these vessels to cook food.

Although most of the innovations appeared first as decorative elaborations, some also affected the cost and performance of the vessels. The use of narrower and overlapped coils increased the time required to form a vessel over the earlier plain vessels. However, the extension

of the textured surface to the upper body and basal parts of vessels significantly improved control over cooking and the use-life of vessels respectively.

Explanations of corrugation emphasize how the environment with which corrugated pottery interacted changed through time, and how these changes affected innovation rates, and the selection or drift of particular corrugation variants. In formulating explanations, I address four problems: the advent of neck banding, experimentation with neck banding, the rapid adoption of full-body corrugation, and the return to plain-surfaced pottery.

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CHAPTER 1: INTRODUCTION

The goal of scientific explanation has proven to be a significant challenge in archaeology as well as other social sciences. During the rise of the “New Archaeology” in the 1960s, there was great optimism that archaeology could become a true science simply by adopting the methods of science, in particular the explicit formulation and testing of hypotheses (e.g., Watson et al. 1971). However, this optimism has waned considerably as archaeologists have come to recognize that scientific explanation requires far more than borrowing rituals and concepts from other well-established sciences. Currently, little agreement exists among archaeologists regarding the particular theories and methods that are most suitable for generating valid, accurate and useful scientific explanations, and numerous different approaches vie for acceptance (Cordell 1994; Trigger 1989).

One response to this state of affairs has been to reject science, particularly its reliance on causal explanation and empirical epistemological standards, as an appropriate or effective approach to understanding the human condition. Ever since the middle part of the twentieth century when Butterfield (1957), Hanson (1958), and Kuhn (1962) argued on philosophical and historical grounds for the theory-laden nature of all observation, a school of conceptual relativism has grown to challenge the hegemonic status of science in Western society (e.g., Barnes and Bloor 1982; Collins 1985; Feyerabend 1987; Nagel 1986). Although largely ignored by practitioners of the natural sciences, this relativist position has made greater inroads into the thinking and discourse of the social and cognitive sciences. Proponents of this approach argue that science’s claims for the progressive growth of more secure knowledge is merely a chimera, and that no true standards of reasoning exist allowing objective distinctions to be made between competing knowledge claims. Instead, relativists argue that change in science and other systems of knowledge occur through social and political processes, not objective evaluation. At the extreme, this form of relativism holds that anything goes, and all knowledge claims are equally valid from an evidential standpoint (Feyerabend 1975).

Among archaeologists, the conceptual relativist position has been promulgated under the rubrics of “post-processualism” and “post-modernism” (Hodder 1983, 1984; Shanks and Tilley 1987a, 1987b). As the name implies, this view developed in opposition to positivist and empiricist perspectives that served as major influences for the processual archaeology of the 1960s and 1970s (Binford 1968; Fritz and Plog 1970; Hill 1977; Watson et al. 1971). Proponents of the relativist position in archaeology argue that all facts are constructed, and consequently,

reflect more the beliefs, motivations, and cultural milieu of the constructor than an objectively true view of the past. Ardent defenders of the processual approach have criticized the relativism of post-processual archaeologists as conceptual posturing and promoting an unnecessary and undesired politicization of archaeology (Binford 1989; Watson 1990). Perhaps in response to these criticisms, but more likely as a self-initiated retreat from the edge of intellectual chaos, the hard line of conceptual relativism in archaeology has begun to soften (Hodder 1991; Wylie 1992). However, the critique of most archaeological practice as infused with implicit ontological biases and frequently lacking objective, empirical evaluation remains firm and generally accurate (Cordell et al. 1994).

If archaeologists, as well as other social scientists, are to continue pursuing the objective of scientific explanation, then we must confront the problems that prompted the valid aspects of the relativist, post-modern critique of current practice. A common theme in much of this critique is that science is not immune to the influence of the social and political climate of its practitioners as had been suggested by proponents of positivist and empiricist perspectives. Although it is true that the objective nature of science has been greatly mythologized (Bauer 1992), there has still been tremendous progress in our scientific understanding of the world around us despite social and political influences (Kitcher 1993). The fact that scientific practice involves a social and political component does not appear to disqualify the endeavor *a priori* from advancing secure and accurate knowledge. Rather, the significant differences between the natural and the social sciences lie in the conceptions of the roles and relationships between theory and measurement.

In the natural sciences, theory consists of a set of abstract concepts that specify the causal relationships and ontological status of classes of entities. Because these classes have empirical referents in the real world, both description (through measurement) and explanation (through the application of theoretical concepts) of particular cases occur within a logically coherent framework making empirical tests possible. In the social sciences, theory is frequently viewed as generalizing statements derived directly from observations (Dunnell 1982; Willer and Willer 1974). One examines specific cases and explains these cases by specifying the causal or structuring relationships thought to exist among the particular observations. Because theory tends not to play the logically structuring role that it does in the natural sciences, contradictory descriptive units and explanatory concepts abound in the social sciences, and empirical tests have little or no relevance beyond particular cases. However, the structuring role played by theory in the natural sciences is not absent in the social sciences. Instead, the concepts that fill this role tend

to be implicit and derived from common sense notions regarding the basic features of human nature (Dennett 1987, 1991; Dunnell 1982).

Several liabilities follow directly from the intrusion of common sense in the role of theory. Common sense lacks logical coherence by its very nature as a mostly intuitive hodge-podge of ways of making sense of the world around us. The various forces that have shaped our common sense notions did not require that these notions be coherent or even rational. Rather, they only needed to succeed more often than their competitors at generating effective, and usually rapid, predictions and solutions. In fact, detailed psychological studies have demonstrated that our common sense can easily produce illogical and irrational beliefs (Nisbett and Ross 1980; Vyse 1997).

These contingent and incoherent aspects of common sense also allow social and political influences to become seriously debilitating. The most common approach to explaining and predicting the actions of people around us relies on folk psychology, which invokes the intentions or agency of the actors involved (Dennett 1984, 1987). With this approach, particular explanations or predictions derive mainly from introspection regarding how we would feel, believe, act, or respond given the situation, and speculation about the thoughts of others based on various behavioral clues. In fact, this sense-making approach is so deeply ingrained that it is rarely explicit. Consequently, this notion of agency also underlies most of the theoretical positions within the social sciences, either implicitly or explicitly (Little 1991). When intentional explanations are derived from an implicit, common sense or folk view of agency, particular accounts tend to follow the concurrently fashionable or institutionally dominant trends in attitudes toward human motivation. Under these conditions, we learn nothing about human nature. Instead, we reify folk concepts that usually support the dominant social, political, and economic forces in society at the time, or the particular beliefs of the scholars involved.

As many of the post-processualist critics have argued (e.g., Leone et al. 1987; Shanks and Tilley 1987a), knowledge claims by archaeologists about the past can be particularly susceptible to the intrusion of this kind of common sense, intentional explanation. The artifacts from which we make our inferences rarely impinge on our tendencies to create the past in our own image. Consequently, it is not surprising that archaeologists have grown increasingly divided over possible explanations, and even our basic goals, as the discipline has become more pluralistic and less dominated by affluent white males.

Although folk-psychological accounts function reasonably well in our daily lives, this is no reason to believe that they can form the basis of scientific explanations. Just as we have common sense notions of ourselves, we also possess such notions regarding the physical world. Folk concepts such as temperature differences between wood and metal at the same temperature, and a world composed of four basic elements (earth, fire, water, and air), although based on common and compelling sensory experiences, have been replaced by more accurate scientific concepts. In fact, most major advances in scientific understanding of nature have come at the expense of common sense notions of the way the world works (Cromer 1993; Kitcher 1993; Wolpert 1994). This does not mean that common sense intentional explanations of human behavior are necessarily wrong. However, the history of science should make us suspicious of notions derived from folk psychology, and inspire us to evaluate these notions from both logical and empirical standpoints, as well as to make them consistent with other knowledge, particularly from the natural sciences.

The philosopher Wilfred Sellars (1962), in his now classic essay “Philosophy and the Scientific Image of Man,” describes what he sees as fundamental metaphysical differences between the manifest (folk) and scientific images of the world. In the manifest image, essential intentions and motivations underlie and cause human actions. Thus, explanation under the manifest image is teleological or goal directed, and it is the goals of the actors that are causal. In the scientific image, teleology and the language of intentions is abandoned in favor of a mechanistic view in which cause lies outside the phenomena under investigation. Although disciplines such as physics and chemistry adopted a scientific image long ago, the manifest image remains the dominant if not exclusive position in the social sciences. The persistence of the manifest image in the social sciences derives at least in part from constant exposure to our own and other people’s common sense reasoning and rationalizations, and resistance to objectifying or dehumanizing people by questioning the explanatory validity of the products of their common sense reasoning.

More recently, the philosopher Daniel Dennett (1987, 1995) has argued that the intentional stance of the manifest image also characterizes evolutionary explanations in biology although the intention is “free floating” rather than a quality of individual organisms. Thus, although Dennett, among others (Churchland 1981; Quine 1960; Stich 1983), has questioned the veracity and utility of folk-psychological concepts for explaining human thought and actions, he has defended intention as an important principle in scientific explanation. From this perspective,

the persistence of the manifest image among social scientists may also stem from the validity of some aspects of an intentional approach to explaining human behavior. However, even if parts of the manifest image have scientific validity, there is no guarantee that any specific common sense beliefs about the nature of human intentions are accurate or provide a useful basis for explanation.

Although it is not yet clear which concepts will prove most useful in explaining human behavior, it is abundantly evident that we must replace implicit, common sense notions with explicit theory if we are to move closer to the goal of scientific explanation in archaeology and other social sciences. By emphasizing the problems created by the intrusion of common sense into the role of theory, I do not mean to imply that there is no theory in the social sciences. A wide variety of theoretical and pseudo-theoretical positions exist within the social sciences (Little 1991; Trigger 1998), but, as yet, none has successfully escaped the influence of folk psychology, or ontological quandaries engendered by borrowing theory from other areas of science.

As the biologist Richard Lewontin (1974:8) points out for the case of population genetics, constructing viable scientific theory is no simple task. One must move back and forth between building conceptual and empirical units with the goal of improving the fit between them so that they form a logically coherent and empirically valid network of causation through explicit processes and mechanisms. This iterative process is difficult because constructing valid concepts often depends on having a set of valid empirical units, which, in turn, depend on concepts for determining their relevance. Such contradictions cannot be resolved easily in one short burst of theory and unit construction. Instead, we must be content to work through a process of trial, error, and synthesis to build a more scientific approach to explanation of sociocultural phenomena.

This dissertation presents an attempt to further the growth of scientific explanation in archaeology by building, applying, and beginning to test explanations derived from Darwinian evolutionary theory within the context of a specific empirical problem. The empirical problem I attempt to explain is the development of the roughly textured corrugated pottery from plain antecedents between the eighth and eleventh centuries AD in the Colorado Plateau region of the American Southwest. Because of the unusual and visually striking aspects of corrugated pottery, there have been numerous attempts, spread across more than 100 years of Southwestern archaeology, to describe and explain its adoption among the ancestors of the modern Pueblo Indians. In the next chapter, I expound upon this problem in more detail by presenting a brief description of the changes in pottery technology involved, and discussing the history of explanations for the development of corrugation. This history of explanatory attempts documents

how unevaluated, implicit notions regarding human nature have intruded into and compromised previous accounts of the change from plain to corrugated pottery.

In Chapter 3, I turn to the task of building the conceptual aspects of evolutionary theory so that this body of theory can be brought to bear on the corrugation problem. Although Darwinian evolutionary theory was developed in biology, it is no longer strictly a biological theory. Attempts to develop the notion of “universal Darwinism” and to apply evolutionary theory to problems outside of biology have demonstrated that evolution is an algorithmic process that occurs when ever the conditions of inheritance, variation, and competition are met (Brodie 1994; Calvin 1997; Czikó 1995; Dawkins 1978, 1982; Dennett 1995; Edelman 1987; Holland 1992; Hull 1988b; Koza 1992; Lewontin 1970; Smolin 1995). Despite the progress made in generalizing evolutionary theory beyond its biological roots, considerable disagreement exists among archaeologists and other social scientists regarding the most appropriate way to apply evolutionary theory to sociocultural phenomena. Consequently, I devote most of Chapter 3 to addressing these areas of discord, and developing concepts that I hope will lead to a more unified evolutionary approach.

However, formulating coherent concepts is just one side of the process of building sufficient scientific theory. The theory must also have some empirical referents among the phenomena under investigation, in this case, the archaeological record of artifacts and their spatial and temporal relationships. In Chapter 4, I present a research design for implementing an evolutionary approach to explaining the rise of corrugated pottery. Chapter 4 includes a discussion of the data requirements, the approach I take to formulating and testing specific hypotheses, and a description of the pottery collections analyzed for this study. In addition to describing the specific assemblages I chose to analyze, this latter section includes a discussion and justification of my selection criteria, and an evaluation of possible biases in the data generated from my analyses of these collections.

Chapters 5 through 7 present the methods and results of the various studies performed for this research. Chapter 5 focuses on the development and spread of corrugation in the American Southwest. Based on my analyses of utility ware collections, I detail the sequence of technological changes that occurred during the development of corrugation in the Mesa Verde region of southwestern Colorado. Then I draw on published data to reconstruct the spread of these innovations into different areas of the Southwest. In Chapter 6, I examine evidence for the production and use of Southwestern utility wares as potentially important aspects of the

environment in which corrugation developed. Again, the data for this chapter come from my analyses of pottery collections and published sources. Chapter 7 centers on determining whether any engineering (cost and performance) differences exist between plain and corrugated vessels. The data in this Chapter are based mainly on a series of experiments I performed with modern replicas of the different kinds of pottery.

With this theoretical and empirical groundwork, I turn to the task of explaining the rise and fall of corrugated pottery in Chapter 8. My goal in this chapter is to synthesize what we know about the history of corrugated pottery and the contexts in which the different kinds of corrugation developed, spread, and disappeared. In the context of this synthesis, I present a variety of possible explanations for different aspects of the corrugation problem that are compatible with the evolutionary approach adopted for this study. I intend these hypotheses to be an initial step toward explanation and not a final word. Although I attempt to evaluate the hypotheses when possible, thorough testing must wait until we have better data on several topics and more complete and formal development of the hypotheses. These additional data requirements and steps in hypothesis formulation specify clear directions for future research. I discuss several of these future research directions in Chapter 9 after considering some general insights derived from this study into the corrugation problem and the evolutionary explanation of technological change.

CHAPTER 2: THE PROBLEM: WHY CORRUGATED POTTERY?

Southwestern corrugated pottery consists mainly of utilitarian or culinary jars displaying distinctively textured exterior surfaces, but lacking slip and paint. The textured surface was produced by not obliterating or smoothing the thin coils or ropes of clay used to construct the vessels creating a horizontally ridged appearance, hence the name corrugated. From the late tenth through early thirteenth centuries AD, ancestors of the modern Pueblo people across most of the northern part of the American Southwest (Figure 1) adopted a variety of corrugated pottery referred to as all-over, or full-body indented corrugated. This form of corrugation has systematically pinched or indented coils left exposed over the entire exterior surface of the vessel. Precursors to full-body corrugation had unindented exposed coils restricted to the neck portions of the jars, and are referred to as neck-banded pottery. Earlier still, culinary vessels had entirely plain surfaces produced by scraping both interior and exterior surfaces until the coils or other construction elements were completely obliterated (Figure 2). The all-over indented corrugated technology continued until the fifteenth century when Pueblo potters returned to plain-surfaced cooking pots.

Although it took some time to work out this general sequence of technological change, speculation as to why Pueblo potters manufactured corrugated pottery began almost immediately after the existence of corrugation became known to Western scholars. As the rest of this chapter recounts in detail, the problem of corrugated pottery has been recognized and puzzled over by archaeologists off and on over the last century. During this time, a variety of different possible explanations have been advanced, but no convincing or lasting resolution to the problem exists. In fact, recent experimental research has cast doubt on some ideas regarding the advantages of corrugation that have been dogma among archaeologists for many years (Schiffer 1990; Young and Stone 1990). Consequently, the problem of explaining the development of corrugated pottery is ripe for a concerted research effort.

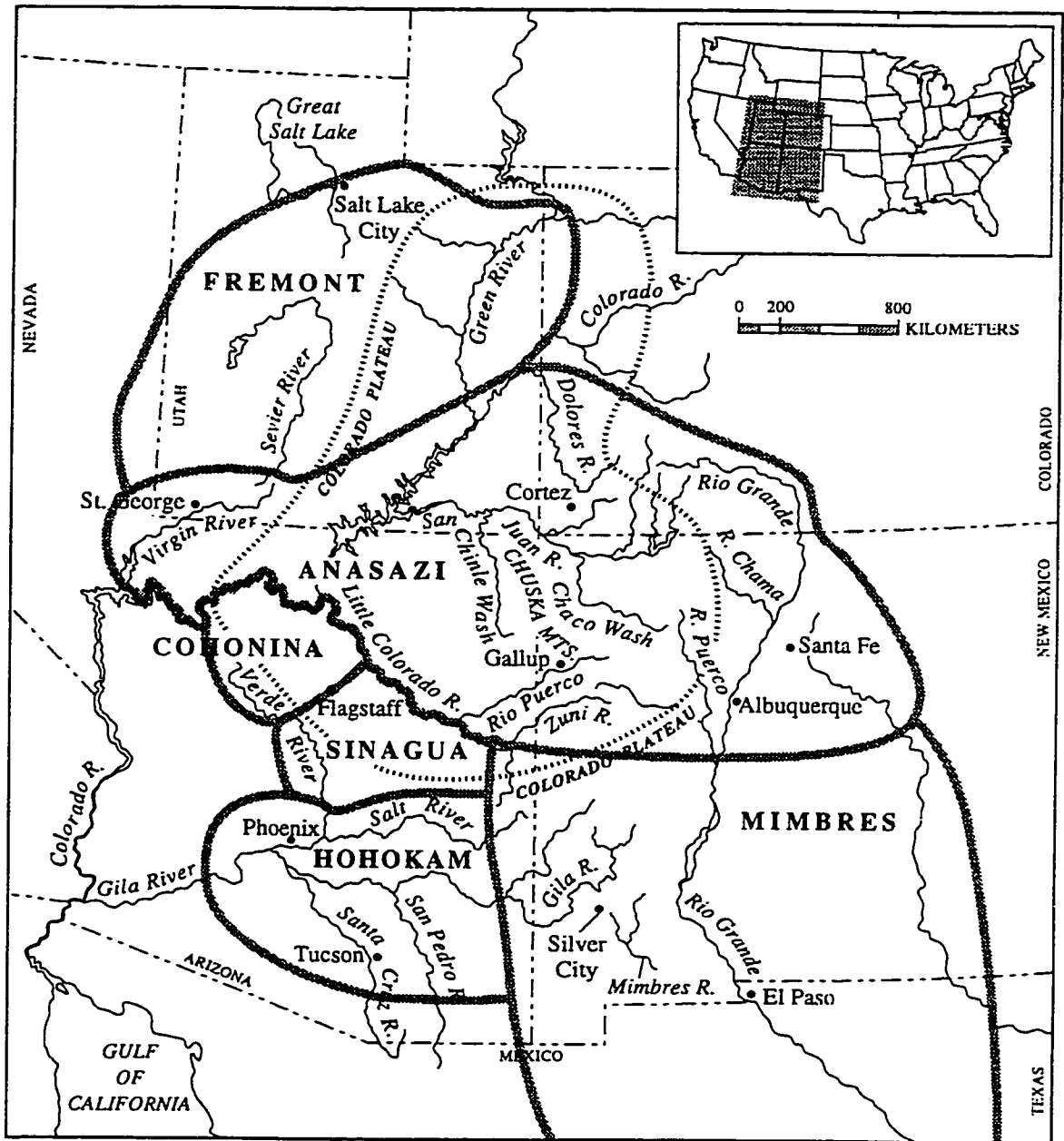


Figure 1. Map of the American Southwest

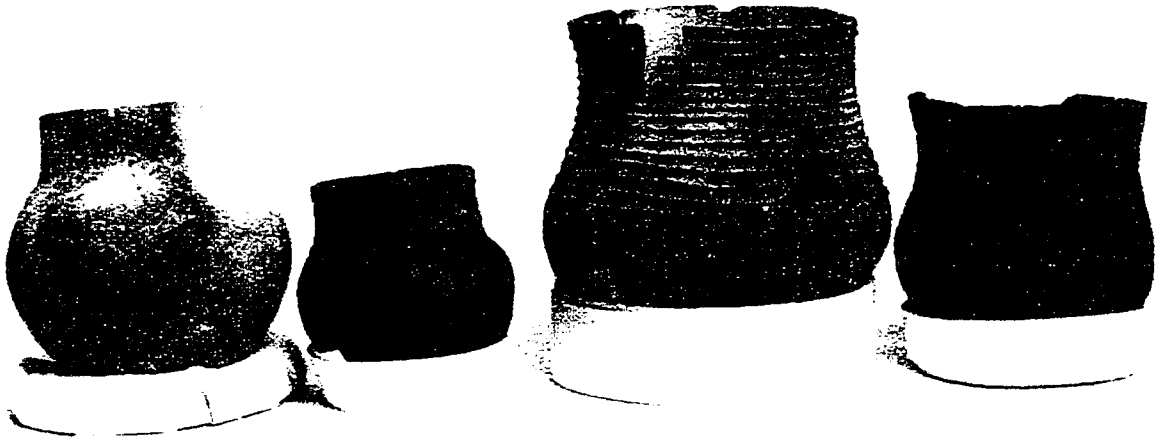


Figure 2. Examples of plain, neck-banded, and full-body corrugated vessels from the American Southwest. From left to right, the vessels are Chapin Gray (5MT2181, RC1) Moccasin Gray (5MT3868, Vessel # 26), Mancos Gray (5MT89, RC1), and Mancos Corrugated (vessel 2-975 from the Chappell collection). All vessels are curated at the Anasazi Heritage Center in Dolores, Colorado.

Previous Approaches to Explaining Corrugated Pottery

Shortly after the end of the Mexican War and the acquisition by the United States of what is now the American Southwest in 1848, U. S. military, survey, and exploring expeditions began to document this vast new territory. Reports produced by some of these expeditions contain the earliest published records of corrugated pottery. Simpson (1850) and Whipple et al. (1856) present illustrations of pottery encountered on ancient Pueblos including examples of corrugation. As part of their report on surveys west of the 100th meridian, Putnam and others (1879) noted the presence of coiled ware and indented pottery on sites in New Mexico and Arizona, but offered no further details. It was William Henry Holmes, as a member of the Hayden expedition to southwestern Colorado and southeastern Utah, who produced the first scholarly account of corrugated pottery. In his report, Holmes (1878) coins the term “corrugated” in reference to the pottery’s horizontally ridged appearance, and offers a simple reconstruction of how corrugated vessels were manufactured. In addition, he notes that modern Pueblos no longer produce this type of pottery, and observes that the forms of vessels produced by corrugation appear to be limited to jars and thus are considerably less varied than the forms of painted wares.

Eight years later, Holmes (1886) published a more thorough treatment of corrugated pottery, and, along with Frank Cushing (1886), proposed the first explanation for the development of corrugation. Holmes notes that while coils are frequently used in pottery construction, leaving these coils unobliterated is a unique and striking aspect of Pueblo pottery. He was impressed by the craftsmanship involved observing that: “So thoroughly were the fillets pressed down and welded together that the vessels seldom fracture more readily along the lines of junction than in other directions.” He also notes that examples exist in which corrugation occurs over limited parts of the vessel, particularly necks, the rest displaying a plain surface. Addressing the use of corrugated vessels, Holmes is the first to argue that they served mainly culinary uses because their exterior surface is commonly covered with soot, and modern Pueblo tribes cooked with vessels of similar form.

Holmes considered corrugation a kind of ornamentation, and made the following suggestions regarding the development of this technique (1886:279):

Ordinarily the coil has not been expected to contribute to the beauty of the vessel, but the Pueblo tribes made it a prominent feature in decoration. The primitive potter as he laid his rude coils noticed that the ridges thus produced served to enhance the appearance of the vessel. He also observed that the series of indentations left on the outer surface of the fillet in pressing it down gave a pleasing effect, and made use of the suggestion. Improving on the accidents of manufacture, he worked out a variety of decorative devices.

Based on corrugation’s visual resemblance to basketry, its absence from modern Pueblo pottery technology, and its association with earlier black-on-white painted pottery rather than the more recent polychrome wares, Holmes suggests that corrugation was the most archaic form of ancient Pueblo pottery. This erroneous reconstruction of the temporal placement of corrugated pottery also led him to believe that the idea for corrugation may have been inspired by basketry.

Cushing (1886) further elaborated on this latter notion. In an attempt to explain how corrugated pottery could have arisen from basket making, Cushing (p. 489–492) presents the following argument:

...she [the potter] pursued the process she was accustomed to in the manufacture of the basket bottle. That is, she formed a thin rope of soft clay, which, like the wisp of the basket, she coiled around and around a center to form the bottom, then spirally upon itself, now widening the diameter of each coil more and more, then contracting as she progressed upward until the desired height and form were attained. As the clay was adhesive, each coil was attached to the one already formed by pinching or pressing together the connecting edges at short intervals as the winding went on. This produced corrugations or indentations marvelously resembling the stitches of basket-work. Hence accidentally the vessel thus built

up appeared so similar to the basket which had served as its model that evidently it did not seem complete until this feature had been heightened by art. At any rate, the majority of specimens belonging to this type of pottery—especially those of the older periods during which it was predominant—are distinguished by an indented or incised decoration exactly reproducing the zigzags, serration, chevrons, terraces, and other characteristic devices of water-tight basketry. ...When, in the evolution of the pitcher, this type of basket was reproduced in clay, not only was the general form preserved, but also the details above described [strap handles]. that is, without reference to usefulness—in fact at no small expense of trouble—the handles were almost always made double; indeed often braided, although of clay. Frequently, especially as time went on, the bottoms were left plain, as if to simulate the smooth skin-bottoming of the basket-bottles.

Thus, with very little chronological information to go on, Cushing, Holmes and others working at that time (e.g., Nordenskiöld 1893:79-82) focused on similarities between corrugated pottery and basketry to construct their explanation of the development of corrugation. The intent of ancient potters to make vessels as visually similar to basketry as possible stood as a viable explanation for corrugation as long as the notion held that corrugation was the earliest pottery. However, this notion did not last long.

Archaeological investigations in the Southwest during the first two decades of the 20th century, employing the recent innovation of seriation and improved stratigraphic excavation (Lyman and O'Brien 1999), succeeded in documenting the temporal relationships between plain and corrugated pottery more accurately. Work by Earl Morris (1917, 1939) in the La Plata Valley of northwestern New Mexico and southwestern Colorado, J. O. Brew (1946) on Alkali Ridge in southeastern Utah, and Alfred Kidder and Samuel Guernsey (1919:141-143) in northeastern Arizona established that plain-surfaced pottery consistently occurred stratigraphically beneath pottery with corrugations. In addition, they noted that vessels with corrugations only on their necks appeared to occur stratigraphically between plain and fully corrugated pottery, and thus represent a developmental intermediate between plain wares and corrugated or coiled wares. Kidder and Guernsey also identified a decline in the quality of corrugation in the latest part of their Arizona sequence. Kidder's work at Pecos Pueblo (Kidder and Kidder 1917; Kidder and Shepard 1936), Nelson's (1916) work in the Galisteo Basin west of Pecos, and Spier's (1917) studies at Zuni further documented the decline of corrugation leading ultimately to its replacement by plain-surfaced vessels in the century before contact with Europeans. Based on this and other work, the general sequence of plain and coiled wares had been so well established that Kidder (1927:490), in summing up discussions at the first Pecos Conference in 1927, could make the following statement:

Pottery it was agreed, is at the present time the most abundant, convenient and reliable criterion, and the cooking wares the simplest type for preliminary chronological determinations. Discussion brought out the following outline of development in this class of ceramics: first, plain wares; later, neck corrugations produced by leaving unobliterated the upper structural rings; still later, spiral corrugations ornamented by indentations and covering the entire vessel; again later, a degeneration of the corrugation technique, and finally disappearance of corrugations and return to plain surface pots.

These changes in the utility wares also served as important criteria for distinguishing the different Basketmaker and Pueblo periods in the new classification scheme that emerged from the first Pecos Conference, and these criteria are still in use today.

Establishment of the proper chronological relationships between plain and corrugated pottery together with an increasing appreciation for the technical skill required to produce corrugated vessels led Morris (1917) and Kidder and Guernsey (1919) to reject the earlier, basketry inspired, explanation of corrugation presented by Cushing and Holmes. However, neither Morris nor Kidder and Guernsey offered an alternative explanation. This problem was not addressed until 1936 when Kidder (1936), in his superb treatise on the culinary wares from Pecos, presented a new explanation for the development and adoption of corrugated pottery. Kidder continued to view corrugation as a form of decoration, but rather than representing the initial attempts at pottery making, he saw corrugated pottery as the culmination, or apex of culinary ceramic art.

Indented corrugation, as practiced during the late Developmental and Great Pueblo periods constitutes one of the finest possible examples of that playing with technique, that virtuosity, that extraordinary devotion to pure craftsmanship, which develops from time to time among primitive peoples. For corrugation served, as far as one can see, no useful purpose whatever; no more than did, for example, the senselessly complex weaving of Basket Maker sandals. ... The mere pleasure of producing them, sheer satisfaction in perfectly accomplishing a supremely difficult task, must have actuated their makers. (Kidder 1936:300)

To Kidder, the changes in utility wares were a natural outgrowth of the development of Pueblo society. The development of corrugation came from a combination of increasing technical skill, play, and great cultural vitality. For example, he argues that the indented corrugated vessels of the Developmental Pueblo or Pueblo II period “are, indeed, exactly what one might expect from potters, who, during a period of vigorous cultural growth, and unhampered by convention, were experimenting with a new and fascinating method of handling a responsive and plastic medium” (Kidder 1936:301). In addition, he notes that the most elaborate and skillfully produced corrugated vessels were made during the Great Pueblo period, at a time of “more highly evolved

communities” and “the Pueblo Indian’s greatest cultural vigor” (Kidder 1936:301). Kidder also suggests that the decline in corrugation after the Great Pueblo period resulted from reaching the limits of possibilities for elaboration of the technique, and, thus thwarted, Pueblo potters turned their decorative attentions to the greater possibilities offered by new forms of painted pottery.

In essence, Kidder’s explanations for change in utility wares rest on the intuitive assumption that the potters are naturally or inherently motivated to decorate their pots. And, with sufficient technical expertise and freedom afforded by a prosperous culture, potters will pursue this inclination to a point of extreme elaboration. Thus, although Kidder’s explanations differed in detail from that of Cushing and Holmes because the understanding of what needed to be explained had changed, they stemmed from the same basic assumptions about human nature. Because these assumptions were taken to be obvious and self-evident, no consideration was given to the need to test either the particular explanations or their underlying assumptions.

Shortly after Kidder’s publication and despite his assertion that corrugation “served no useful purpose whatever,” possible functional explanations for corrugated pottery began to be articulated. Although Holmes (1886:275) and others (e.g., Morley 1908:609) had noted early on that indenting exposed coils probably strengthened the weld between coils, they still saw corrugations as primarily decorative. In the 1940s, other possible functions of corrugation began to be discussed on a more equal footing with decoration. For example, in his survey of Southwestern archaeology, McGregor (1941:255) states that: “Various writers have suggested that indented corrugations were made not only as a form of decoration but also to serve a definite utilitarian purpose by increasing the surface of the outside in relation to that of the inside of the vessel. This, it is felt, would gather heat over a large area and concentrate it in a much smaller area on the inside of the pot, thus making the contents cook more rapidly than in a vessel with a plain surface.” Linton (1944) also observed that the development of corrugation coincided with an increase in the size and relative abundance of these culinary vessels, features which he suggests indicate a greater reliance on boiling to cook food. Unfortunately, Linton provided no argument linking corrugation with the increased use of boiling.

Despite growing discussion of the possible functional aspects of corrugation, most archaeologists working in the Southwest at that time rejected functional arguments as viable explanations. McGregor’s comments on the matter likely typify the views of the time: “this [that corrugation could have been developed to promote heat transfer] credits the makers with more reasoning intelligence than they probably possessed in such a matter” (1941:255). Here, we see

the intrusion of common sense reasoning in the process of explanation. In the opinion of the archaeologists of the time, ancient Pueblo potters could not have understood the relationships between surface area and heat transfer, and thus could not have intended to produce pottery taking advantage of these properties. Consequently, this functional explanation could not accurately account for the development of corrugation. The notion that corrugation was developed as a decorative elaboration of otherwise mundane utility ware continued to be the principal, if not exclusive, view well into the 1960s (Gifford 1978). As a result, the little interest paid to utility wares after Kidder and Shepard's treatment in 1936 and before the 1980s consisted mainly of creating types which could be used as style markers for the temporal and spatial identification of traditions and cultures (e.g., Breternitz et al. 1974; Colton 1955, 1958; Colton and Hargrave 1937; Gifford and Smith 1978; Rinaldo and Bluhm 1956; Wendorf et al. 1956).

Opinions regarding corrugation began to shift to a greater emphasis on functional explanations during the 1960s (e.g., Linne 1965). This shift coincided with the growth in popularity of the more functionally oriented New Archaeology (see Dunnell 1986 for discussion of the rise of the New Archaeology). Because practitioners of the New Archaeology saw culture as a functionally integrated system, they had difficulty accepting the notion that ancient Pueblo potters would have chosen to invest additional energy in decorating their cooking pots without some benefit besides aesthetic appeal. Although decorative or stylistic treatments of corrugation continued (e.g., Pendleton and Washburn 1977; Popelish 1986a, 1986b; Stone 1986), by the 1980s and early 1990s most accounts of the adoption of corrugation cited some benefit it offered over plain pottery. Proposed benefits included more effective heat transfer (by far the most common suggestion), greater ease of handling, improved durability, or reduced production costs (e.g., Blinman 1993; Gumerman 1984:79-80; Rice 1987:232; Vivian 1990:146). Even studies that continued to conceive of corrugation as decoration began to cite functional benefits of decoration in the form of increased information transmission potential for marking social boundaries (e.g., Brunson 1985; Plog 1986).

Although consensus had shifted to functional accounts, the mechanisms of change continued to be conceived in common sense terms. Most of the functional accounts rely on a vague notion of improvement; ancient potters were constantly motivated to reduce the cost or improve performance of their craft. In some cases, corrugation is thought to have been consciously developed and adopted to cope with or adapt to some external condition. For example, Vivian (1990:146) argues that as fuel resources were depleted, potters were motivated

to develop corrugation to make cooking more efficient by improving heat transfer. However, if this was the case, it is unclear why corrugation was first employed on the necks of vessels rather than their bases. It is equally unclear why Pueblo people ultimately abandoned corrugation and returned to plain-surfaced vessels because it is unlikely that the abundance of fuel wood increased in the fifteenth century.

Recently, functional explanations of corrugation have fallen on hard times. This is due in part to a general shift away from simplistic functionalism among archaeologists because of revival of interest in historical processes and forms of explanation brought about by potent philosophical and theoretical attacks from advocates of post-processual and evolutionary approaches. However, there have also been some empirical stumbling blocks. Just as the advocates of decorative explanations had assumed the functional equivalence of plain, neck-banded, and corrugated vessels, the benefits of corrugation proffered in functional explanations were based mainly on assertions and speculation, not measurements. Confidence in these assertions began to erode when initial attempts to test experimentally the common claim that corrugation improves heating effectiveness failed to yield the expected results (Plog 1986; Schiffer 1990; Young and Stone 1990). Additional small scale experiments by Schiffer et al. (1994) and Blinman (1993) further underscore the recognition that the cost and performance consequences of corrugation are anything but clear-cut.

More than 100 years have passed since Holmes and Cushing presented the first attempt at explaining the development and wide-spread adoption of corrugated pottery in the American Southwest, and yet we have made very little progress toward reaching a viable and compelling explanation. Archaeological research has improved our understanding of certain aspects of the corrugation problem. We now know the general sequence of change from plain to full corrugation and back to plain vessels. We also have a better appreciation of the complexity of the cost and performance differences that are likely to exist between plain and corrugated vessels. However, theoretical and empirical problems continue to impede explanatory progress.

In this brief historical review, I have documented how implicit common sense notions have underlain each of the attempts to account for corrugation. Relying on common sense in the place of explicit theory has failed to yield robust, empirically justifiable explanations not because these notions are necessarily wrong or scientifically invalid, but because they are generally unevaluated, which results in short-cutting the research process. By generating explanations from implicit assumptions about human motivations, archaeologists have been able to offer

superficially plausible and satisfying accounts even without secure, detailed knowledge of the history and impacts of the technological changes involved. This has served to divert attention away from serious attempts to address the problem. In fact, some of the changes that have occurred in what is considered a reasonable or appropriate form of explanation of the rise and fall of corrugation have taken place in the absence of any change in our empirical knowledge. Rather, these shifts have followed larger social and political trends just as some critics have argued for the social sciences in general. To improve on these earlier efforts to answer the question “why corrugated pottery?” I will attempt to replace these unevaluated common sense notions with explicit theory and rigorous empirical investigation while building on previously generated data and insights.

CHAPTER 3: THEORY: TOWARD A UNIFIED EVOLUTIONARY APPROACH

One of the most significant challenges facing the application of evolutionary theory to the corrugation problem, or any other specific problem in the social sciences, comes from the wide range of opinion regarding the appropriate features of a viable evolutionary approach (e.g., Barton and Clark 1997; Boone and Smith 1998; Dunnell 1980, 1989; Durham 1991; Flinn 1997; Hallpike 1988; Lyman and O'Brien 1998; Maschner 1996a; Rindos 1985; Rosenberg 1994; Spencer 1997; Sperber 1996; Trigger 1998). Several schools of evolutionary thought have developed within the social sciences including sociocultural evolutionism, cultural selectionism, cultural transmissionism, coevolutionism, processualism, evolutionary archaeology, human evolutionary ecology, sociobiology, evolutionary psychology, cultural virus theory, and memetics. Although some of the differences among these evolutionary approaches are substantial, many points of disagreement are very subtle and difficult to follow.

Rather than try to characterize and sort out each of these approaches, I think much of the discord among evolutionists can be captured with a simpler classification based on the extent to which cultural change is seen to conform to the Darwinian processes. Three different idealized positions can be identified. On the pro-Darwinian side, cultural change is thought to have all of the features necessary (variation, replication, and sorting) to qualify as a fully Darwinian process. This position follows from the argument that human communication and social learning create a Darwinian process operating parallel to, and, to a variable extent, separate from biological evolution (Boyd and Richerson 1985; Brodie 1996; Campbell 1965, 1977, 1988; Cavalli-Sforza and Feldman 1981; Cloak 1975; Dawkins 1976, 1982; Dennett 1995; Dunnell 1978b; 1980; 1989; Durham 1991; Goodenough 1995; Hull 1982, 1988b; Leonard and Jones 1987; Lynch 1996, 1998; O'Brien 1996b; Rindos 1984, 1985, 1986, 1988; Teltser 1995). Another position takes the overall directionality and apparent progress of cultural change and unique aspects of human cognition and culture as evidence that Darwinism is a failed analogy for cultural evolution. Instead, proponents of the non-Darwinian evolutionary position argue that systemic relationships within societies and purposeful actions by individuals create unique mechanisms of cultural change that make it more analogous to the growth and development of organisms than to natural selection (Blanton et al. 1996; Brumfiel 1992; Carneiro 1972, 1992; Demarest 1989; Earl and Preucel 1987; Flannery 1972; Hallpike 1988; Harris 1977, 1979; Johnson and Earl 1987; Kosse 1994; Marcus and Flannery 1996; Rosenberg 1994; Spencer 1997; Trigger 1998; Wright 1984). Between these two positions lies the third view that rejects the notion that cultural change per se

is Darwinian because of a lack of viable cultural replicators. Proponents of this position argue that cultural change is made possible and directed by evolved constraints and plasticity in human decision making. From this perspective, cultural evolution is seen as the cumulative, and usually adaptive, effect of the human ability to flexibly apply evolved decision rules to cope with problems presented by changing social and ecological conditions (Barkow et al. 1992; Boone and Smith 1998; Flinn 1997; Hawkes and O'Connell 1992; Hawkes et al. 1997; Hill and Hurtado 1995; Mithen 1990; 1997; Pinker 1997; Smith 1991, 1992; Smith and Winterhalder 1992; Sperber 1996; Winterhalder and Goland 1993; Winterhalder and Smith 1981).

To evaluate these different positions adequately, it is important to be very clear and explicit about what we mean by the Darwinian process. Perhaps no single problem has resulted in greater confusion and conflict than subtle differences in meaning people bring to discussions of Darwinian evolution. Many of these differences in meaning can be traced back to how much and what aspects of the biological heritage of Darwinism have been retained in its application to cultural variation and change. However, the Darwinian process is not strictly biological, but is a general algorithmic process that can improve the fit between particular kinds of entities and their environment (Campbell 1974; Dennett 1995; Lewontin 1970). Consequently, the first section of this chapter is devoted to presenting an abstract, non-biological view of the essential features and units of the Darwinian process. In the process, I introduce a notion of frames of reference, which becomes a central theme in considering evolutionary explanations of cultural change.

Next, I address several objections raised against the broad applicability of the Darwinian process to cultural change. These objections include the reality of cultural replicators, the role of human behavioral plasticity, the importance of human intention and decision making, and the possibility of directed, orthogenic change in large-scale sociocultural systems. In each case, arguments have been made that features of human cognition, behavior, or social systems eliminate the Darwinian process as a viable model of cultural change. In evaluating these arguments, I find that some arise from the intrusion of common sense, while others stem from the adoption of one frame of reference to the exclusion of all others. However, none of these objections successfully undermines the applicability of the Darwinian process to cultural evolution. In fact, by recognizing the potential for multiple, causally relevant frames of reference, we see the importance of the Darwinian process to understanding cultural change.

The Darwinian Process

Recent interest in expanding the explanatory reach of evolutionary theory, together with a controversy over the units of selection in biology, have led to several attempts to identify the fundamental features of the Darwinian process, and generalize Darwinian ideas beyond those features relevant only to biological evolution (Brandon 1982, 1990; Brandon and Burian 1984; Calvin 1996a, 1996b, 1997; Campbell 1974; Dawkins 1976, 1978, 1982; Dennett 1995; Eldredge 1985; Ghiselin 1997; Gould 1982, 1989; Heyes and Plotkin 1989; Hull 1980, 1982, 1987, 1988a, 1988b; Lewontin 1970, 1982; Lloyd 1992; Lipo and Madsen 1998; Pocklington and Best 1997; Rose 1998; Salthe 1985; Sober 1984; Sober and Wilson 1994; Vrba and Eldredge 1984; Vrba and Gould 1986; Wilkins 1998; G. C. Williams 1966; M. B. Williams 1989). Many aspects of this literature have influenced my understanding of the conceptual structure of Darwinism, but my views conform most closely to those of David Hull, a philosopher of biology who has used Darwinian theory to explain variation and change in scientific concepts. I employ several of his terms and concepts in the following discussion. I should also point out that I use the term “Darwinian Process” in deference and recognition of Darwin’s brilliant, seminal insights, and not because the ideas I present are based strictly on his. We have learned a great deal in the 140 years since Darwin radically altered our view of life, and I try to take full advantage of that knowledge. I could adopt the term neo-Darwinian, but that has already been applied to a very narrow view of biological evolution, and one of my goals is to distance the theory from biology. Rather than invent another neologism, I have decided to stay with “Darwinian.”

Essential Features

In its most abstract form, the Darwinian process is the differential copying of heritable variation. This process has three essential features—replication, variation, and sorting. Replication requires a means for making copies of a given pattern or structure. The physical entities exemplifying a particular pattern are referred to as replicators. Variation consists of the creation or introduction of variant states, or traits in replicators. Sorting involves the filtering of the variant replicators resulting in biased or differential replication. Thus, each of these parts of the Darwinian process entails the operation of one or more mechanisms on classes of entities that are defined in terms of their role in the process itself. To make this clearer, let’s take a closer look at each of these features.

Genes are archetypal replicators. During meiosis and mitosis, DNA strands within cell nuclei unravel and the bonds between base pairs are broken yielding two halves, which form the

basis for reconstituting two separate DNA strands. These DNA replicas, together with certain enzymes and membrane tissues, split apart to form new cells. This specific and well-documented mechanism of replication has tended to bias our view of replication generally as being self-starting, particulate and involving the movement or transmission of a material pattern from parent(s) to offspring. However, nothing in the nature of the Darwinian process requires that all replication match that found in DNA. All that is required is the copying of some pattern such that offspring resemble their parent or parents more than they do non-parents (Calvin 1997; Hull 1980, 1988b). The particular material constituting the pattern need not be copied or transmitted. It is the replication of the pattern that is important because of the pattern's potential to contain, or code for information. This pattern copying definition of replication creates room for a wide variety of replicators (specific entities being copied) and mechanisms (particular copying procedures) of replication, of which self-replication is only one example (Ghiselin 1987, 1997; Vanechoutte 1998). Although theoretical and philosophical considerations of the nature and relative importance of different replicates are useful, ultimately, identifying and documenting the replicators and replication mechanisms involved in any particular case is an empirical problem (Pocklington and Best 1997).

If replication transpires with 100% fidelity, there can be no Darwinian evolution. The Darwinian process requires some variation through which various sorting mechanisms can work to produce differential replicative success. On the other hand, the replication process must occur with some degree of fidelity, or there is no inheritance. Without inheritance, change can still occur, but it would be completely random and chaotic with no potential for directionality or improvement. Although very high fidelity in replication is an important part of the operation of some sorting mechanisms, such as directional selection, it is not an essential feature of the general Darwinian process. The amount of variation between parent(s) and offspring must be low enough to avoid error catastrophe, the inability to maintain adaptive functional integration in the face of high mutation rates (Eigen and Schuster 1979; Kauffman 1993, 1995; Solé et al. 1999), and yet be less than 100% faithful.

In biology and elsewhere (e.g., Rindos 1989), it is also commonly argued that the generation of variation must be random with respect to fitness. In other words, the environment cannot instruct or determine the kind of new variation produced. This aspect of Lamarckism has been rejected by biologists because of the well-documented one way flow of information from the replicators in the germ line to those in the soma or body, known as the Weismannian barrier and

forming the central dogma of molecular biology (Dawkins 1986; Ridley 1985; Weisman 1893). However, this too is not an essential feature of variation in the Darwinian process. Directed variation does not preclude Darwinian evolution. In fact, recent advances in our understanding of self-organization indicate how the emergence of new variants can, even in biology, be ordered and directed in particular ways (Holland 1995, 1998; Kauffman 1993, 1995). As long as heritable variation exists among replicators, however that variation is produced, the full Darwinian process can occur. Issues involving both copying fidelity and directed variation have led some to reject cultural change as Darwinian. Consequently, I revisit to these topics in more detail later in this chapter.

The final part of the Darwinian process is sorting. As noted above, sorting involves the differential copying of variant replicators such that the frequencies of replicator traits change across replication events, or generations. Sorting takes place through two general mechanisms—selection and drift. Selection occurs when competition, created by environmental limits, exists among variable replicators, and the interaction of replicators with the environment, including each other, causes differential replicative success (Hull 1980, 1988b; Vrba 1984; Vrba and Gould 1986). Hence, there is a correlation between certain variants, or variant suites, and replication success that is determined, or caused by the nature of interaction. It is the relationship between interaction and replicative success that defines the fitness of variant traits. Over multiple generations (defined by replication events), selection tends to improve the fit, or adaptiveness of replicating and interacting entities to their environment by altering the frequency of replicator and interactor traits in larger scale aggregates, populations and lineages.

In contrast to the deterministic effects of selection, drift, the second general sorting mechanism, involves stochastic effects of random sampling errors that occur during replication (Beatty 1992; Wright 1931, 1932, 1949). Although drift works without regard to fitness differences, it is most prevalent as a sorting mechanism when alternative traits are selectively neutral. Selective neutrality can arise by either traits being equally fit or traits have very little or no impact on fitness because they are not involved in any interaction (Hull 1988b; Kimura 1983, 1992; King and Jukes 1969). The size of the replicator transmitting population also impacts the likelihood for drift to sort traits, even those with potentially adaptive consequences. In very large populations, the effects of drift tend to be negligible. That is, no significant change occurs in trait frequencies from one “generation” to the next (Boyd and Richerson 1985). However, in small populations, drift leads to the fixation of traits (one trait survives while others are lost) and the

homogenization of populations. The smaller the population, the more rapid the rate of fixation (Cavalli-Sforza and Feldman 1981; Neiman 1995). Mechanisms that introduce new variation, such as mutation, innovation and migration, counteract the tendency for drift to produce homogeneous populations (Neiman 1995). Thus, for selectively neutral or weakly selected (those having small fitness values) traits, drift can result in fixation with the rate dependent on the population size, mode of replication (mainly generation length), and the rate at which new traits are introduced.

The operation of all three features of the Darwinian process, replication, variation, and sorting, results in descent with modification, or Darwinian evolution. Loss of any one of these features renders the Darwinian process inoperative. For example, selective sorting of variant entities occurs frequently in nature, such as the separation of sediment by grain size during erosion or deposition. However, in the absence of viable replication, this sediment sorting process is non-Darwinian. An astute critic might argue that the break down of sediment into smaller particles is a form of replication, but, in this case, replication of the relevant pattern, namely grain-size, has not occurred.

It is also possible and, indeed, common to add features to the Darwinian process that can catalyze, constrain, or inhibit the process. This is usually done when considering specific problems, cases, or entities. Biologists have built a tremendous body of knowledge of particular mechanisms and conditions that play important roles in biological evolution. Although understanding these features is essential for generating explanations of specific cases of biological evolution, they do not necessarily constitute essential features of other forms of Darwinian evolution. Consequently, we must be very careful when using the literature on biological evolution to draw insights regarding the applicability of the Darwinian process to cultural change.

Units

Before turning to a consideration of whether cultural change is Darwinian, we need to focus more explicitly on units. Failure to adequately address and clarify unit issues has been a major source of confusion and friction in studies of cultural and biological evolution (Dunnell 1986b, 1995; Ghiselin 1989, 1997; Hull 1980, 1988a, 1988b; Lipo and Madsen 1998). Specifically, confusion concerning two unit issues has been especially damaging. These are the distinction between conceptual and empirical units, and relationships among units at different scales. Consequently, I will focus on these two more philosophical unit issues here, but

addressing other issues involving the validity and reliability of units will be a recurring theme throughout this dissertation.

As I discussed in Chapter 1, conceptual units (also termed theoretical units, classes, and universals) and empirical units (also termed individuals and particulars) occupy very different roles in scientific explanation. Conceptual units have the following characteristics: they are abstract, they have defining properties, they have instances, they are spatially and temporally unrestricted, and when organized hierarchically, they are related by inclusion. Empirical units, on the other hand, are concrete, have no defining properties or essences, have no instances, are spatially and temporally restricted, and when organized hierarchically, are related by part-whole incorporation rather than inclusion (see Ghiselin 1997 for an extended discussion of this distinction and its importance in biology). Because they are concrete, empirical units can also participate in processes whereas conceptual units cannot because they are abstract and unrestricted. However, conceptual units, when formulated properly by intentional definition, are the entities referred to by laws of nature, and thus, serve to define the processes in which empirical units can participate. In other words, universal laws must be generalizations about conceptual units, not empirical units that are spatially and temporally restricted. When these conceptual units are embodied by measurable empirical units, it becomes possible to explain the regularities, variation, and change of particular entities in terms of universal laws. Much of the controversy over the existence of laws of history stems from neglecting the distinction between conceptual and empirical units (Dunnell 1982; Ghiselin 1997; Mayr 1982; Popper 1964; Smart 1963).

In the previous discussion of the essential features of the Darwinian process, five different units, traits, replicators, interactors, environment, and evolvers (populations or lineages) were mentioned. All of these are conceptual units. They identify the kinds of entities required for and resulting from the operation of the Darwinian process, and each is defined in terms of the process itself. These five units can also be arranged hierarchically (Figure 3). Traits, which make up the lowest level of the hierarchy, are properties of replicators, interactors, and the environment that can vary, and thus have an impact on differential replicative success. Replicators, interactors and the environment occupy the middle level of the hierarchy. Replicators are patterned entities that are copied reliably over successive generations (Hull 1980, 1988b:408). Interactors are entities that interact with the environment as a cohesive whole in such a way as to bias replication (Hull 1980, 1988b:408). The environment consists of those external entities that interactors

interact with (Brandon 1990). Evolvers, the upper-most level of the hierarchy, are entities that are related by descent, and are cohesive with respect to particular sorting mechanisms or forces (Hull 1980, 1988b:409; M. B. Williams 1989). Evolvers, as the units of evolution, also provide the relevant counting frame from which to document changing frequencies of other units (Lipo and Madsen 1998).

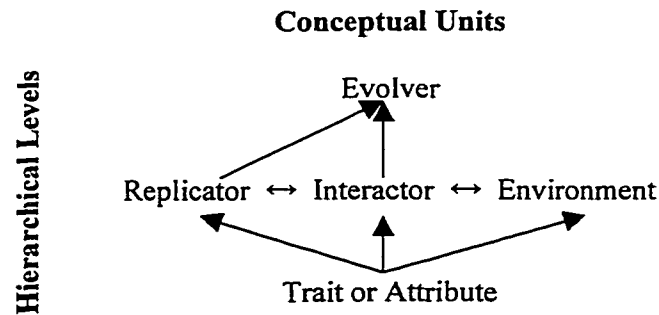


Figure 3. Hierarchical relationships among conceptual units in evolutionary theory.

All of these units are defined in terms of their relationships to one another in the Darwinian process. These dialectical relationships also make it difficult, and, in some cases, impossible to identify particular instances of one unit without reference to another (Levins and Lewontin 1985; Lewontin 1982). For example, interactor and environment are defined in relation to each other, and how that relationship affects replication success. Thus, there is no interactor independent of the environment, and no environment without an interactor, and the interactor-environment relationship specifies the domain of relevant replicators. The replicator-interactor-environment relationships also determine the kinds of information, defined as differences that make a difference (Bateson 1972, 1979), that are relevant to evolution. So, in addition to identifying material (matter and energy) relationships, these conceptual units also specify relationships of meaning, a kind of evolutionary semiotics (Emmeche and Hoffmeyer 1991; Hoffmeyer 1996, 1997; Hoffmeyer and Emmeche 1991).

Remaining cognizant of the distinction between conceptual and empirical units becomes critical when we shift focus from these conceptual units to the empirical entities that instantiate them. There is no necessary, fixed, or predetermined relationship between conceptual units and the particular empirical units to which conceptual units refer. Different conceptual units may

simultaneously refer to the same empirical entity, and multiple, different empirical units can be instances of the same conceptual unit. For example, although replicators and interactors define different roles in the Darwinian process, the same physical entity may function in both roles. In biology, individual organisms can be both replicators and interactors. In addition, empirical entities can also have different roles in the Darwinian process, exemplify different conceptual units, depending on the scale of the particular frame of reference. In other words, the inclusive hierarchy of conceptual units can slide up or down different scales of a part-whole hierarchy of empirical units. This flexible relationship between conceptual and empirical units means that the Darwinian process can be operating simultaneously across multiple empirical units and scales. Consequently, we must rely on the nature of the particular research problem to specify the relevant or appropriate reference scale(s) and unit identifications (Kawata 1987). This notion of the relativity of frames of reference, or the variable relationship between conceptual and empirical units, has major implications for how we conceive of cultural change in evolutionary terms.

Is Cultural Change Darwinian?

Working from this understanding of the Darwinian process, we can now evaluate the different objections and reservations raised to applying Darwinian theory directly to cases of cultural change. Four issues occur again and again in discussions both critical and supportive of viewing cultural change as a Darwinian process. Three of these issues focus on different parts of the Darwinian process (replication, variation, and sorting), and question whether each is present in cultural change in a form sufficient for Darwinian evolution to occur. The fourth issue involves a question of the appropriate scale for explanation of cultural change, and whether the Darwinian process is the most important process of change at that scale. We can now examine each of these issues in light of the previous discussion of the Darwinian process.

Cultural Replication

As we have seen, replication, the copying of some pattern with a specifiable degree of fidelity, is an essential feature of the Darwinian process. Social learning among humans has long been thought to be analogous, in some ways, to the biological transmission of information through the replication of genetic material. Over the last 20 years, this notion has been developed into a full-fledged theory of cultural inheritance involving the transmission, or replication, of ideas, behaviors, and material traits by imitation and other forms of social learning (e.g., Alexander 1979; Ball 1984; Boyd and Richerson 1985; Cavalli-Sforza and Feldman 1981; Cloak

1975, 1986; Cullen 1996; Dawkins 1976, 1982; Dennett 1995; Durham 1991; Goodenough 1995; Hull 1982; Lumsden and Wilson 1981; Pulliam and Dunford 1980; Rindos 1985). From this perspective, human behavioral variation and change are, in part, a consequence of a dual inheritance, genetic and cultural, with varying opinions on the degree of autonomy between these different inheritance systems.

Recently, the term “meme” has been used to denote a unit of cultural replication. The biologist Richard Dawkins coined the term meme in his book *The Selfish Gene*, and defined a meme as “a unit of cultural transmission, or a unit of imitation” (1976:206). As examples of memes, he identified “tunes, ideas, catch-phrases, clothes fashions, ways of making pots or of building arches” (1976:206). Dawkins conceived of memes as analogous to genes, which he sees as the fundamental unit of biological replication. Subsequently, Dawkins restricted his notion of meme to “a unit of information residing in a brain” (1982:109) to distinguish between the meme as replicator and meme products, behaviors and artifacts, which he came to see as phenotypic effects and not replicators. This notion of cultural replicators as mentally stored information, in short, beliefs and ideas, has come to dominate most considerations of cultural replication (e.g., Boyd and Richerson 1985; Brodie 1996; Dennett 1995; Durham 1991; Laland 1992; Lynch 1996, 1998; Takahashi 1998). I think this is an unnecessarily restrictive view of cultural replication, just as Dawkins’s “selfish gene” view of biological replication is instructive yet overly restrictive. However, before presenting my views on the nature of cultural replication, we need to consider the possibility that the whole notion of cultural replication is misguided.

The idea that cultural replication plays a crucial role in cultural evolution has been strongly criticized, and, thus, should not be taken for granted. Two different kinds of critiques exist. One disputes the reality of cultural replication, while the other questions its fidelity, and thus its ability to function in a fully Darwinian process of cultural change (Cziko 1995:176-178; Flinn 1997; Flinn and Alexander 1982; Harms 1996; Mithen 1997; Pinker 1997:208-210; Sperber 1996:100-106). Both criticisms derive from problems engendered by the strictly ideational view of cultural replication as analogous to genetic replication. The basic problem is that, in the absence of telepathy, there is no mechanism for replicating the ideas and beliefs in one person’s mind to the mind of another. In addition, the brain does not store ideas and beliefs as discrete neurological entities that are the same in all individuals (Gazzaniga 1989, 1992). Consequently, neurological structures or patterns corresponding to specific ideas, beliefs, or behaviors cannot be

copied directly from one individual to another. Instead, ideas and beliefs must be translated into behaviors, or other phenotypic expressions for communication and transmission to occur.

If ideas and beliefs, the only cultural replicators in the ideational view, cannot be copied directly from one person to another, then these mental representations must be constructed anew by each individual through observation and contemplation of their environment, including the phenotypic expressions of other individuals. Not only does this undermine the simplistic ideational view of cultural replication, but it also forms the basis of the view that cultural transmission (communication and social learning) lacks sufficient fidelity to support a fully Darwinian process of cultural change. The notion here is that the individual construction of knowledge entailed in cultural transmission involves so many cognitive and physiological filters that it is more appropriately thought of as a process of transformation than replication (Sperber 1996). Specific details, the texts if you will, are often lost or garbled in this process whereas more general themes that resonate with particular filters are preserved (Heyes and Plotkin 1989). Thus, it is the nature of the filters involved in communication and the formation of mental representations that forms the causal basis of cultural change, leaving only a marginal role for the accurate replication of ideas.

Dennett (1995:352-360) has responded to these criticisms by arguing that memes are semantic, rather than syntactic, replicators. In other words, it is information, or meaning that is transmitted in cultural replication, not particular neurological or linguistic patterns. The tight correspondence between syntax and meaning present in genetic replication is just not a central feature of cultural replication. Instead, cultural replication is more analogous to transmission of radio or television signals where a pattern of information is maintained across multiple codes (digital and analog) and substrates (electromagnetic waves, conducted electrons, vibrating membranes, electro-chemical impulses, etc.). Dennett recognizes the importance of the filters involved in sorting among variant memes, but he also sees an understanding of the replication of particular kinds of cultural information as equally important for scientific explanation of cultural change. Although Dennett's approach may suggest a way to salvage the ideational view of cultural replication, it also carries with it some formidable epistemological challenges.

For the same reason that it is impossible for mental representations to be transmitted from mind to mind, it is impossible to know, through measurement, the contents of other people's minds (Gatherer 1998). As I discussed briefly in Chapter 1, we are particularly adept at making inferences about the contents of other people's minds based on observations of their behavior

(including linguistic communication), and introspection regarding our own thoughts. However, these inferences are notoriously unreliable. Although this is often seen as a methodological problem that may be overcome with advances in brain imaging technology, I suspect that there is a deeper problem here. It is likely that no simple one-to-one relationship exists between particular mental representations and consequent actions. Thus, using actions and artifacts to gauge accurately the content of hidden mental representations becomes a truly daunting task. The reverse is also true. Even if we were able to measure somehow the state of mental representations in someone's brain, this would not necessarily give us the power to predict accurately all actions. This is the situation found in biology where complex relationships among different parts of the genome, and between the genome and the environment result in a highly variable and often probabilistic relationship between genotypes and phenotypes.

Do these theoretical and methodological problems so undermine the notion of cultural replication that it negates the possibility that the Darwinian process is an accurate model of cultural change? Both sets of problems stem from relying exclusively on the ideational notion of cultural replicators. There is nothing in the Darwinian theory of replication that would limit cultural replicators to mental representations. The ideational replicator notion comes from an inappropriate borrowing of the genotype-phenotype distinction from biology. In the discussion of the Darwinian process, I did not include the genotype-phenotype distinction as an essential feature. Instead, I made a conceptual distinction between replication and interaction. The particular empirical entities that function in these necessary evolutionary roles can correspond to genes (genotype) and organisms (phenotype) as they often do in biology, but this is by no means a necessary condition. In fact, the same empirical entity can function in both roles, as was almost certainly the case in biology at the beginning of life (Kauffman 1993:329-333).

All that is needed for Darwinian replication is the copying of a pattern with sufficient, though not always perfect fidelity. In addition to possible semantic replicators, several cultural entities can meet this definition of replication including behaviors, artifacts, factions, institutions, and societies to name only a few. These additional cultural replicators have the added advantage of being eminently measurable, thus avoiding the epistemological problems posed by semantic replicators. However, critics of these kinds of non-genetic and non-ideational replicators emphasize their lack of ability to self-replicate (Leonard and Jones 1987; Lyman and O'Brien 1998). Behaviors, artifacts, and larger scale cultural entities ultimately require people for replication, and cannot make copies of themselves indefinitely as some biological replicators may

be able to do. However, self-replication is not a defining feature of a Darwinian replicator. Few, if any, would question the identification of DNA as a viable Darwinian replicator. Nonetheless, DNA replication requires the assistance of a suite of enzymes called DNA polymerases. DNA molecules are reproductively inert in the absence of these enzymes. Cells may be the only truly self-replicating entities, and even this is open to debate, as cells require food to maintain the machinery of replication. Thus, limiting replicators to those that can self-replicate is not only unnecessarily restrictive, but it would eliminate many entities that are currently considered viable Darwinian replicators.

The fact that behaviors, artifacts, and other non-ideational cultural entities can be interactors and even features of the environment should not be confused with their ability to function in replication as well. As discussed earlier, the evolutionary function of any given entity depends primarily on the particular frame of reference one adopts. From the perspective of people as biological organisms, behaviors and artifacts are indeed part of the phenotype of the organism (functioning as an interactor) when they are one's own, and part of the environment when they belong to others. Nevertheless, there is little, and possibly no valid *a priori* justification for privileging this or any other particular frame of reference over others, such as the perspectives of the behaviors and artifacts themselves. As we shift the frame of reference, the functions performed by various entities may also shift.

Given the current influence of the ideational notion of cultural replication, and the long tradition in archaeology of discounting artifacts and behaviors as viable Darwinian replicators (e.g., Brew 1946; Leonard and Jones 1987; Lyman and O'Brien 1998), I should elaborate more thoroughly on my rather unorthodox view on non-ideational replicators. Let us begin with behavior. One can question whether behavior is a true replicator by arguing that behaviors can not be copied independently of the ideas or mental representations that generate them. There is no doubt that all human behaviors involve some form of activity by the nervous system, and often considerable cognitive processing is required to match behaviors appropriately to different stimuli. In addition, the basic neurological configurations that process stimuli and produce behaviors are quite similar from one individual to another. Consequently, behaviors copied by one person from another involve activation of many of the same nervous system components. However, these neurological commonalities do not entail that the symbolic mental representations (beliefs, ideas, etc.) that might motivate the similar behaviors are also the same. In other words, behaviors can be imitated without any transmission or copying of the conscious or unconscious

mental states involved. For example, I can watch a person make a pot on a video with the volume turned all the way down, and copy that person's behavior without any knowledge of her motivations, beliefs, or ideas concerning why and how she is making the pot that way. Young children copy all manner of behaviors, for better or worse, well before they are linguistically, and likely, cognitively capable of understanding the motivations. It is even easier, quite often, to show adults how to do something than to describe it to them, although a combination of description and action probably results in the highest copying fidelity. Differences in copying fidelity notwithstanding, it should be clear the behaviors can be copied independently of ideas, and it is a matter for empirical research to determine if this kind of replication has occurred in a given situation.

A similar question of copying independence can be asked of artifacts. In this case, one wonders whether artifacts can be copied independently of the behaviors required in producing them. Certainly, the easiest way to learn how to make something is to watch and listen to someone while they are making it, and then try it yourself with their supervision. However, it is also possible to copy an artifact by only examining the artifact itself, and never actually seeing the behaviors or hearing the ideas of anyone else making the artifact. Given the limits on what is physically possible, particularly with things made by hand, it is likely that many behaviors will be employed in copying an artifact that are very similar, if not identical, to those unobserved behaviors used to make the original. However, these behavioral similarities can not be considered replicates because they arose through constraints rather than copying. Copying of artifacts and attributes of artifacts without observation of the behaviors involved in making them is a common practice among archaeologists. We frequently copy ancient artifacts that are no longer made today and thus, production behaviors cannot be observed. In addition, we often employ techniques and technologies that could not have been used by the ancient artisans. Despite limits to our knowledge of ancient behaviors, and known behavioral deviations, it can be extremely difficult to distinguish the copy of an artifact from the original. Indeed, as discussed in the next Chapter and in Chapter 7, I employed just such an artifact replication procedure as part of the experimental research conducted for this study.

That the replication of cultural entities, including ideas, behaviors, artifacts, and more, requires other entities, here biological organisms, capable of social learning and imitation should not discourage us from recognizing these entities as viable Darwinian replicators. Once we appreciate that self-replication is not essential to the definition of a Darwinian replicator, a world

of possibilities opens up. Although it may be possible to explain many aspects of cultural variation and change from the perspective of biological replicators, this is an empirical claim subject to evaluation, not a theoretical or philosophical principle. Other frames of reference may be equally, or perhaps more, valid for explaining particular aspects of cultural change than that derived exclusively from biology. This frame of reference problem is not restricted only to culture. The same issues occur in biology, and manifest themselves most explicitly in the context of the levels of selection controversy. Identifying the most appropriate frame or frames of reference for a given problem constitutes one of the principal challenges in constructing evolutionary explanations.

Behavioral Plasticity

Most organisms possess some ability to modify their behavior, physiology, or morphology in response to changing environmental conditions. Biologists call this ability phenotypic plasticity, and a large and complex literature exists on the topic (Gordon 1992). Many anthropologists, particularly those strongly influenced by ecology, maintain that most examples of cultural change entail behavioral plasticity rather than the direct working of the Darwinian process (e.g., Boone and Smith 1998; Flinn 1997). This argument involves several issues including the nature of replicators, addressed in the previous section and the roles of directed problem solving, decision making, and human intentions in cultural change.

The basic argument for plasticity rather than Darwinian evolution turns on two points. First, most cultural change occurs quite rapidly in comparison to biological evolution through changes in gene frequencies. Consequently, it seems very unlikely that the impact of cultural changes on biological reproductive success could be the direct cause of changes in the frequencies of behaviors through time. Second, cognitive abilities, which are a direct consequence of Darwinian evolution, allow humans to make strategic responses to a variety of situations in which they find themselves. These strategic responses can include innovation or invention of novel behaviors and technologies as well as rational calculation and other forms of decision making among existing alternatives. The ability to direct variation and make decisions gives tremendous flexibility to human behavior. The evolved nature of these cognitive abilities also results in novel behaviors and decisions being adaptive for the organism, or its genes, more often than not. Because behavioral plasticity yields adaptive responses, it produces similar outcomes to evolution, but over much shorter periods.

Because proponents of this position often do not accept behaviors, artifacts, and, in some cases, ideas as viable replicators, they adopt a strictly biological frame of reference. Biological entities, mainly genes, but occasionally organisms and groups (Sober and Wilson 1998; D. S. Wilson 1998; Wilson and Sober 1994), are the only true replicators. Consequently, behaviors and artifacts can only be part of the phenotype, that is, they can only function as interactors, not replicators. This conclusion is true only if we hold to a strict biological frame of reference. If we adopt a more flexible approach to frames of reference that allows cultural entities such as behaviors, artifacts, and ideas to function as replicators and other roles in the Darwinian process, the apparent distinction between behavioral plasticity and Darwinian evolution begins to break down.

Recognizing the existence of cultural replicators allows one to shift the frame of reference such that the decision rules and other cognitive, morphological, and physiological features of organisms, which facilitate their behavioral plasticity, now become features of the adaptive environment of these alternative replicators. This is a straight forward, logical deduction if one accepts the notion of cultural replication. It also forms the basis for a Darwinian concept of cultural selection in which cultural replicators compete in a complex environment composed of human cognition, social interaction, and physical possibilities (e.g., Braun 1995; Carneiro 1970; Campbell 1974; Cavalli-Sforza and Feldman 1981; Durham 1991; Fog 1999; Hill 1985; Pulliam and Dunford 1980; Rindos 1986).

Boone and Smith (1998:S168) have criticized this expanded view of Darwinian evolution calling it a semantic game that obscures important differences between biological and cultural change. Instead, they suggest that maintaining a biological frame of reference and seeing cultural change as involving unique mechanisms is preferable to adopting the perspective of the cultural replicators making a fully Darwinian account of cultural change possible. However, I can find no reason to be so restrictive, and see many potential benefits of embracing a more flexible perspective. For example, from a biological replicator frame of reference, cultural replication or transmission, as it is commonly referred to, looks extremely complex involving various unique biasing mechanisms (e.g., direct and indirect) and directions (vertical, oblique, and horizontal) with respect to biological generations (Boyd and Richerson 1985; Cavalli-Sforza and Feldman 1981). By shifting to the frame of reference of the cultural replicators, these unique complexities of cultural change vanish. The biases are no longer seen as unique parts of cultural replication, but instead make up only a few of the many potential biasing mechanisms involved in Darwinian

sorting. In addition, the complex relationship between cultural and biological transmission is simplified, as all cultural replication is vertical, one transmission event follows another, in the same way as biological replication. Rather than one perspective being right and another wrong, different kinds of insights can be realized by examining problems of cultural variation and change from multiple frames of reference.

From this approach, behavioral plasticity and Darwinian evolution provide alternative explanations for the same phenomena, but from different frames of reference. One does not necessarily preclude the other. In fact, the different perspectives can be quite complementary. Studies from the biological perspective of behavioral plasticity can serve to document aspects of the environment of cultural replication and interaction. On the other hand, studies of cultural replication and sorting from a Darwinian perspective can provide insight into how and why people can behave in ways that have no impact on or run counter to their own biological reproductive success, or that of their close kin. Unfortunately, this kind of cooperation has been inhibited by adherence to unnecessarily restrictive frames of reference, mainly that of the biology, and a controversy over the role of human intentionality in cultural change.

Intentionality

One of the most contentious issues in the debate over the applicability of the Darwinian process to explaining cultural change involves the role of human agency, or intentionality in determining the course of cultural change. People's abilities to manipulate symbols, pursue goals, possess agendas, subscribe to ethical and moral codes, rationally calculate options, and weave mental scenarios have made most social scientists extremely uncomfortable with the notion that the Darwinian process adequately models the causes of cultural change. The root of this uneasiness lies in a belief that people direct the course of most cultural change through their own agency, which usually involves purposeful innovation and decision-making. If people can respond appropriately to problems they face by creating new behaviors and technologies, or choosing among various known alternatives, then there is little or no causal role for selection and other sorting mechanisms in cultural change. Instead, human agency guides behavior in biologically adaptive (e.g., Boone and Smith 1998; Smith and Winterhalder 1992), cognitively determined (e.g., Barkow et al. 1992; Mithen 1997, Pinker 1997), or culturally meaningful (e.g., Geertz 1973; Hodder 1986; Sahlins 1976) directions prior to the action of any sorting mechanisms. Although many acknowledge that human intentionality arose through a Darwinian

process, once this unique cognitive ability was in place, Darwinian evolution was superseded by a variety of psychological, social, political, economic, ecological, and historical processes.

Despite the intuitive appeal and overwhelming belief in the significant role of human intention in cultural change, various philosophical, methodological, and empirical arguments have been made against a causal role for intention. Following Sellars's (1962) distinction between manifest (intentional) and scientific images of man discussed briefly in Chapter 1, Dunnell (1980, 1992) rejects intention, or reason-giving, as unscientific because the empirical entities under investigation are their own cause. Scientific causation, on the other hand, is mechanistic and supplied by theoretical concepts and units, which exist outside the phenomena to be explained. Dunnell further argues that this distinction is fundamentally philosophical, and not open to empirical evaluation. Consequently, one must choose between these different approaches to explanation. However, by choosing intentional over theoretical explanation of cultural phenomena, one is committed to an unscientific approach because it is extremely difficult, if not impossible, to observe intentions. Thus, the methodological requirement of science that knowledge claims be empirically testable cannot be met with intentional accounts. Marvin Harris (1979) also finds empirical support for the primacy of behaviors and their relationships and consequences over motivations or intentions as causes of cultural dynamics. Harris cites the high frequency of independent inventions and inventive insights not actualized until much later as evidence that it is the behavioral and material nexus in which one finds himself that determines his motivations and intentions rather than the other way around.

Dunnell offers an alternative to intentional explanation that emphasizes the consequences of behaviors rather than their motivations. Dunnell (1978a, 1978b, 1980, 1989, 1992) and others (e.g., Lyman and O'Brien 1998; O'Brien 1996; Rindos 1984, 1989; Teltser 1995) argue for a strictly Darwinian approach in which behaviors are seen as subject to selection by affecting the fitness (biological reproductive success) of the people involved, or selectively neutral and subject to stochastic mechanisms of drift. Although ambiguous and inconsistent statements exist (e.g., Lyman and O'Brien 1998:644), it appears that Dunnell's evolutionary approach restricts the role of human intention in the Darwinian process to that of generator of behavioral variation. The relative success of these behavioral variants is determined by the working of various sorting mechanisms, not by the intentions that generated them.

Clearly, compelling arguments exist on both sides of this debate over the causal significance of human agency, and there seems to be little or no basis for finding any common

ground. Resolution of this debate is further impeded by the fact that we still have a very limited understanding of the roots of human agency, such as how brains think and the nature of consciousness. However, recent studies in philosophy and the cognitive and neurological sciences indicate that our intuitive, common sense understanding of human agency is not particularly accurate (e.g., Calvin 1996a, 1996b; Dennett 1991, 1995; Gazzaniga 1998). To explore the implications of these findings for the issue at hand, let us look more closely at two problems, the creation of novel variants and decision-making, and their roles in directing the course of cultural change.

As an aid in considering these issues, think of all the possible solutions to any problem as a undulating landscape arrayed in order of similarity, and in which better solutions occupy higher positions and worse solutions occur in the valleys. This is a common metaphor in biology where species and other biological entities are arrayed on a landscape, with the height of different points determined by the fitness conferred by that particular configuration (Dawkins 1996; Dennett 1995; Eigen 1992; Kauffman 1993, 1995; Wright 1932). From this perspective, biological evolution is seen as a hill climbing process, in which blind mutations and genetic recombination explore the landscape and selection pushes populations to higher peaks. If the fitness consequences of different trait configurations are highly correlated because of functional, structural, and semiotic interrelationships, as is the case with biological entities, then the fitness landscapes can be quite rugged with many local peaks (Kauffman 1995). Under these conditions of blind, incremental variations and rugged fitness landscapes, Darwinian evolution tends to be only locally maximizing and progressive because populations become trapped on local peaks.

From this landscape perspective, the notion that human agency circumvents Darwinian evolution stems from the belief that intention results in cultural change being more globally maximizing than biological evolution. If, through intention, people can perceive the landscape from a global perspective, they can identify and choose the most advantageous options, even if this involves incurring short-term losses on the way to achieving higher long-term gains. Thus, intentionality, rational calculation, and other features of human cognition allow people to move off local peaks to scale higher peaks in the landscape of possibilities. Cultural change, in this view, involves directional shifts that are guided by our abilities to model fitness landscapes based on personal experiences, and the experiences of others (including ancestors and contemporaries), the latter of which are transmitted both culturally and genetically.

Now, we can evaluate this perspective in several ways. Let us look at the problem of creating novel variants first. In the landscape perspective, when people think or do something new, they are moving onto parts of the landscape that had previously only been possible, not actual. How do people know what lies beyond their accumulated experience, the actual? One might be able to use experience, knowledge of certain parts of a landscape, to project into the unknown space of possibilities. However, there are severe limits to this type of inductive reasoning which have been elucidated most profoundly by the eighteenth century Scottish philosopher David Hume. Hume recognized that our limited sensory experience of the external world could not induce general knowledge of that world. This insight shook the foundations of the empiricist, inductivist view of knowledge growth made popular a century earlier by the philosophical writing of Francis Bacon and Isaac Newton's advances in physics (Cziko 1995; Musgrave 1993). Deductive reasoning, on the other hand, can yield knowledge, predictions, of the form of landscapes beyond our experience. Hence, it is not surprising that modern philosophers and scientists rely very heavily on deductive logic as they explore the unknown. However, even in these highly intentional, goal directed, deductive enterprises, globally progressive, directional change has been extremely difficult to attain (Cziko 1995; Hull 1988b; Popper 1959).

A more realistic view of most innovation and invention is that it is blind (Campbell 1974; Cziko 1995; Dennett 1995; Popper 1979). This does not mean that new knowledge cannot arise from a search process, or that some search processes are not better than others. Striving to solve a problem, and using strategies such as deduction, correlation, metaphor, and analogy are all likely to speed up the process of creating novel, useful solutions. However, even when we take these approaches to problem solving, we are still faced with the dilemma that we cannot know what we do not already know. Consequently, even highly structured problem solving situations involve blind, random generation of possible solutions. For example, take a simple crossword problem. We know from the nature of the problem how many letters that are in the word we need to solve, and the rough meaning or context of the word. We may also know what some of the letters in the word are. To solve this problem, we guess at various possible words, and then test them against what we already know. If the correct word is part of our realm of experience, we can eventually solve the problem. However, if we do not know the word, say the puzzle is in a foreign language, the problem becomes much more difficult to solve.

Although humans are particularly adept at problem solving, and have developed many strategies for speeding up the innovation process, building new knowledge still presents us with significant challenges. Consequently, most novel cultural variations involve short, somewhat random explorations of unknown landscapes at the fringes of our experience, and large jumps are extremely rare (Basalla 1988; Burke 1978, 1995, 1997). Thus, the notion that, by thinking hard to generate novel, appropriate solutions to perceived problems, people have removed cultural change from the Darwinian process, does not appear to stand up to scrutiny.

However, what of our ability to decide among known, actual alternatives? Does this not short-circuit the Darwinian process of replication, variation, and sorting? Is this not the essence of free will, that we have the power to make decisions, wisely or foolishly, regarding a given course of action, and thus, determine the course of history? Here again, our intuitive common sense provides a very poor basis for understanding. Our ability to be consciously self-aware has engendered a dualistic mind-body, nature-culture view of human existence. Common sense leads us to believe that there is a “self”, someone inside us who is in control, making decisions, directing action. However, this dualistic, homuncular view of conscious decision-making is flawed both logically and empirically (Dennett 1991, 1995; Gazzaniga 1998; Hoffmeyer 1993).

Cognitive and neurological research have demonstrated that there is no single part of our brain responsible for processing all input and directing all output (Dennett 1991). Instead, our brains work through distributed, parallel processing, out of which consciousness appears to emerge (Minsky 1985). A large contributor to emergent consciousness is a functional part of the brain, located in the left hemisphere, that creates a post hoc, running narrative out of our behavior and cognition (Gazzaniga 1998). In other words, our brains process stimuli and make decisions before our conscious selves know about it, and our interpreter, as Gazzaniga calls it, makes sense out of the results by tying them together into a coherent narrative. Consequently, our conscious self-awareness has almost no access to how we actually make decisions, and constructs the sense of “self” to fill this void.

If you doubt that this is the case, consider the problem of speech, either speaking out loud or to yourself. Do you know what you are going to say or think before you say or think it? No. Yet, we have no difficulty speaking in complete, grammatically correct, understandable sentences. How does this happen? In fact, we do think about speech before speaking, but this mental processing is not part of our conscious self-awareness. We do not know about, or become aware of what we think until after the thinking has occurred. The vast majority of our mental

processing occurs “behind the scenes” of our consciousness, including most decision-making. If we are not aware of how we make our decisions, how can we, the conscious self, possibly be in control of them? In the absence of coherent theory and deductive reasoning, our interpreter constructs reasons for our decisions and actions that fit in with the running narrative. If we take these post hoc, accommodative reasons as viable scientific explanations, we are likely to be seriously misled.

On the other hand, denying mental processes a significant causal role in cultural change is also not the answer. Rejecting the importance of mental phenomena requires that we continue to see the world in dualistic terms, but favoring the body/nature side of the dichotomy in stead of the mind/culture side. Saying that our reasons are probably not good scientific explanations is not the same as saying our reasons are irrelevant. Although some have taken the extreme position that how and what people think is unimportant for explaining cultural change (e.g., Jones et al. 1995; Lyman and O’Brien 1998; O’Brien 1996a; O’Brien and Holland 1990), I do not.

Exactly how these aspects of human cognition are relevant can be clarified by considering decision-making in light of the Darwinian process rather than as an argument against a Darwinian model of cultural change. As I discussed earlier, decision-making can be seen as a Darwinian sorting mechanism if we shift the frame of reference to the concepts, behaviors, and artifacts being chosen, rather than the individual person involved in the choosing. From these alternate frames of reference, the cognitive processes involved in decision-making are part of the environment of the cultural replicators and interactors. Cultural replicators that are most fit in the human cognitive environment tend to out replicate those that are less fit resulting in what has been termed vicarious or cultural selection (Cziko 1995; Deacon 1997; Durham 1991; Rindos 1985). The interpreter part of our brain that generates narrative reasons for our past actions also aids vicarious selection by enabling the construction of scenarios for future action that can compete and die in our stead. In this way, decision-making can limit and provide direction for behavioral variation. As long as some behavioral variation continues to exist, the constraining effects of selection at other scales, or frames of reference does not preclude a Darwinian analysis of behavioral changes as well. Thus, rather than negating the importance of cognitive processes in cultural change, adopting a Darwinian perspective helps clarify the role of decision-making in cultural evolution.

However, if there is no “self” doing the selecting, how does cultural selection work? Unfortunately, cognitive research has not yet supplied any firm answers to this question, but three

different models exist. These models can be termed innatist, connectionist, and Darwinian. In the innatist model, our brains are thought to contain numerous domain or problem specific modules constructed of neural networks capable of symbolic processing, and designed by natural selection during the evolution of our species (Barkow et al. 1992; Brown 1991; Cosmides 1989; Lumsden and Wilson 1981; Pinker 1994, 1997). Particular stimuli cause specific cognitive modules or algorithms to be invoked resulting in certain behavioral and psychological outcomes or decisions. Because these cognitive modules are thought to have evolved during the early history of our genus and species, the decisions produced by these cognitive structures do not necessarily enhance biological reproductive success under the radically different conditions of modern and recent human existence (Maschner 1996b; Symons 1992; Tooby and Cosmides 1992). Although these cognitive modules have yet to be identified in concrete neurological terms, considerable behavioral and psychological evidence exists that strongly suggests some evolved, innate structuring of human decision-making (Pinker 1997).

The connectionist approach eschews innate cognitive modules in favor of learned decision rules accomplished by the conditioning of neural networks through the random addition and selective removal of neurons and the selective strengthening of neuronal connections (Edelman 1987; Elman et al. 1996; McClelland et al. 1986; Rumelhart et al. 1986; Seidenberg 1997). Experience with the world is the main force in conditioning our neural networks, and thus, we can learn how to do and think about things that involve recurrent aspects of our environment. Although neural networks that can learn complex patterns, including decision rules for grammars, have been developed in computers, it remains unclear whether the connectionist approach accurately models actual human cognitive processes, or can accomplish the full range of cognition displayed by people.

In the Darwinian model, well documented patterns of neuronal connections in the neocortex forms the basis for the differential replication of hexagonal arrays of synchronized neuron excitations that code for objects and ideas (Calvin 1994, 1996a, 1996b; 1998 Calvin and Ojemann 1994). Pyramidal neurons in the upper layer of the neocortex have axon connections to neighboring neurons at a patterned interval of about 0.5 mm, skipping neurons in between. It is this regular pattern of horizontal neuron connection that creates the possibility for synchronized arrays of excitation. These ephemeral, spatio-temporal patterns of neuron excitation expand across areas of the neocortex until the original stimulus disappears, or they encounter other arrays of synchronized excitation. When these encounters occur, the patterns may compete with one

another for territory, or spawn new patterns of excitation. Those patterns that are most successful in these copying competitions form the basis of decisions and provide raw material for our conscious experience.

Of course, each of these models is more intricate and subtle than I have been able to present in these thumbnail sketches. The important thing to recognize for our purposes is that these different models are not mutually exclusive, but can complement one another in significant ways. If each of these models accurately represents different aspects of cognition, the combined power for decision-making is quite remarkable. Innate cognitive modules may form the basis for many routine decisions, but the connectionist and Darwinian models enable our brains to create and learn novel decision rules that can greatly extend and alter our genetic dispositions. This multifaceted cognitive environment contains many niches and opportunities for exploitation by cultural replicators. These replicators might first evolve by resonating with innate rules (Ridley 1997), but, over time, can move well beyond what is good for the genes (Boyd and Richerson 1985, 1992; Dennett 1990, 1995, 1998).

Superorganic

Even if the unique aspects of human cognition do not exclude cultural change from the Darwinian process, what of the evolution of societies in general? It is generally, though not universally (e.g., Yoffee 1993, 1994), agreed that archaeological research has documented that the general course of cultural change has, for the most part, consisted of directional, developmental growth, with most human societies becoming progressively more complex over time (e.g., Blanton et al. 1993; Carneiro 1978; Flannery 1995; Harris 1979; Rosenberg 1994; Spencer 1997; Trigger 1998). In contrast, the common view of Darwinian evolution is that it is opportunistic, and lacking in overall direction, at least since the first development and diversification of multicelled organisms during the Cambrian (e.g., Gould 1989; Jacob 1982; Lewontin 1982:165). Does this distinction in the trajectories of cultural and biological evolution indicate that cultural change at the higher scales of institutions and societies involves a different process than Darwinian evolution?

From very early on, anthropology and sociology have included a concept of human societies as functionally integrated systems, the superorganic view, based on an analogy between societies and biological organisms (Garbarino 1977). Although this view has been expressed in a wide variety of ways (Spencer 1997; Trigger 1998; Wilson and Sober 1994), a common feature is the notion that institutions and societies are not simply the sum of the psychological and

behavioral characteristics of the people that participate in them. In other words, these larger scale sociocultural entities constitute emergent functional systems that are composed of the beliefs and actions of individual organisms. However, particular patterns of variation and trajectories of change of the systems cannot be explained solely in terms of the individual behaviors and beliefs.

For the purposes of this discussion, there are two important, interrelated points in the superorganic notion. If the behaviors and beliefs of individuals exist within a web of functional relationships, both metabolic and semiotic, at higher scales, then changes in individual traits are likely to be strongly influenced by the nature of those higher order relationships. Developments in social theory (Archer 1982; Bourdieu 1977; Brumfiel 1992; Giddens 1979, 1984; Hodder 1986) and complexity theory (Axelrod 1997; Kauffman 1995) have clarified the dialectic relationships that exist between individuals and society. The actions of individuals are both enabled and constrained by their position in relation to other actors with whom they interact. Higher scale structures—institutions, societies, etc.—emerge from and, in turn, structure these individual relationships. If these higher scale sociocultural entities change in ways other than through a Darwinian process, then their influence on smaller scale entities could severely limit the explanatory power of the Darwinian process with regard to cultural change generally.

The overall directionality of cultural change toward more complex, larger scale entities has led many scholars, beginning with August Comte and Herbert Spencer in the nineteenth century, to argue that cultures change by process of growth similar to that of biological organisms (Trigger 1998). Frequently, this notion has been expressed in the form of stages of cultural development, with a variety of different stages and developmental goals having been proposed. In addition, a variety of mechanisms have been suggested for the transformation from one stage to another, including various innate human drives, contradictions and conflicts within societies, and homeorhetic, deviation amplifying responses to external conditions.

Recently, these stage-based, developmental views of cultural change have been strongly criticized for a variety of reasons. These include the questionable empirical standing of the societal stages and types, the logically vacuous and ethnocentric nature of the notion of progress, and their failure to recognize the importance of chance and historical contingency in cultural change (e.g., Dunnell 1980; Hodder 1982, 1986; Leonard and Jones 1987; McGuire 1992, 1994; Spencer 1997; Yoffee 1979, 1993). From a Darwinian perspective, the mere presence of directionality of change does not preclude the applicability of the Darwinian process as I have

presented it here. Selection mechanisms, including decision-making by individuals and competition among social groups, can result in directional changes at various scales. By shifting our frame of reference and recognizing the potential for causal influences between different frames of reference, it may be possible to generate Darwinian accounts of cultural change at a variety of scales. However, the Darwinian process can also generate functional entities that change by means other than the Darwinian process. Biological organisms are just such entities. Consequently, the applicability of the Darwinian process to some aspects of cultural change does not preclude the operation of other process of change as well. Although this is an area in serious need of more theory building, ultimately, the explanatory relevance of different models of change must be determined by the formulation and testing of alternative hypotheses derived from different models. At this point, however, there does not appear to be any reason to eliminate the Darwinian process from consideration as a viable model of cultural change.

Multiple Frames of Reference and Evolutionary Explanation

Now that we have addressed the objections to a fully Darwinian view of cultural change and finding ample reason to proceed with a Darwinian approach to the problem of corrugated pottery, it is appropriate to turn to the question of how one should go about constructing Darwinian explanations. The most important insight to be gained from the discussion thus far is that what appears to be an example of non-Darwinian change from one frame of reference often becomes Darwinian when we shift the frame of reference. Alternative frames of reference can exist vertically within a hierarchy of replicators and interactors, or horizontally among different kinds of entities at the same hierarchical level. Rather than assuming that a single frame of reference is privileged, *a priori*, or that there is even only one relevant hierarchy, adopting a more flexible approach to frames of reference forces us to be more clear and precise about the causes of change.

If numerous, potentially valid frames of reference exist for any given problem, how does one determine which frame or frames of reference are causally relevant in a particular case? One way to do this is by answering the question “which entity or entities benefit?” Within a Darwinian context, the entity or entities identified as beneficiaries of some action must also fill the role of replicator. As Dennett (1998) points out “[a] benefit by itself is not explanatory; a benefit in a vacuum is indeed a sort of mystery; until it can be shown how the benefit actually rebounds to enhance the replicative power of a replicator, it just sits there, alluring, perhaps, but incapable of explaining anything.” By admitting the possible causal relevance of multiple frames of reference,

we recognize that there are many potential beneficiaries. Both biological and cultural replication can take place through a wide variety of replicator entities. In the context of cultural evolution, these range from genes and memes (including ideas, behaviors and artifacts) at the lowest hierarchical level, through organisms or persons (generated by a complex of genes and memes), to populations and larger-scale sociocultural systems (institutions, societies, etc.) at the highest hierarchical level.

When constructing explanations of particular phenomena, we must realize that there may be complex relationships among different replicators such that one benefits at the expense of others (parasitism), one benefits at no cost to another (commensalism), or there are multiple, simultaneous beneficiaries (mutualism). Hierarchical relationships can also come into play with the entities and processes at one level enabling, constraining, or entraining entities and processes at other levels. Commenting on the impact of considering multiple frames of reference in biological evolution, Vrba and Eldredge (1984:165) note that “[t]hinking hierarchically forces consideration of precisely at what level a causative process is lodged, precisely what its up- and downward causes may be to other levels, and precisely which individuals bear the characters that lead to differential sorting.”

Currently, most evolutionary approaches in the social sciences have focused on a single or very limited set of frames of reference. For example, sociobiology concentrates on genes and genetically determined behaviors, evolutionary psychology centers on innate cognitive architecture, behavioral ecology and cultural transmissionism focus on the innate and learned decision rules of organisms, evolutionary archaeology fixes on biological populations, memetics centers on socially learned ideas, behaviors, and artifacts, and processual approaches tend to concentrate on sociocultural systems. As I have tried to make clear, none of these approaches is necessarily wrong, but they are all incomplete. Incorporating multiple frames of reference into our theory of cultural evolution not only clarifies the importance of the Darwinian process in cultural change, but provides a basis for integrating, and potentially unifying the currently disparate bodies of theory in the social and natural sciences.

CHAPTER 4: RESEARCH DESIGN: IMPLEMENTING AN EVOLUTIONARY APPROACH TO THE CORRUGATION PROBLEM

Many different frames of reference may be causally relevant to the problem of the development and spread of corrugated pottery in the American Southwest. The pottery itself may be both replicator and interactor competing with other technological options known to the pottery makers and users for accomplishing some task. The behaviors and ideas required to make and use corrugated pottery may be the replicators while the pottery itself is the interactor in the particular human cognitive and behavioral environment present at the time. Plain and corrugated pottery may be traits of human organisms or populations, which affect their biological replicative success. The alternative pottery technologies may also be traits of larger social systems, potentially affecting the replicative success of these systems, or possibly just swept along as a consequence of differential replicative success at these larger scales.

Determining which of these frames of reference were causally involved in the rise of corrugated pottery requires that we know: (1) how corrugation developed out of plain pottery and then spread across the northern Southwest; (2) how the different plain and corrugated pottery vessels were made and used; (3) if there were any differences in the cost or performance of plain and corrugated vessels during manufacture and use; and (3) the relevant environmental contexts in which the various changes occurred. In the next section, I will discuss each of these data requirements in turn, and describe the analytical approaches I employ to generate the required data. These include analyses of selected pottery collections, and a series of experiments performed with replicas of plain and corrugated vessels. In the next section of this chapter, I discuss how I will use these data and the evolutionary approach developed in the previous chapter to formulate and begin testing hypotheses to account for corrugated pottery from different frames of reference. The final section presents information on the particular pottery assemblages analyzed for this study including their selection criteria, dating, sample selection, and potential biases.

Data Requirements

History of Corrugation

What was the sequence of technological changes that led from completely plain vessels to full-body corrugation? Where did these changes first take place, and how did they spread across the northern Southwest? We must answer these questions if we are to identify relevant frames of reference and construct testable hypotheses. Currently, most descriptions of pottery in

the American Southwest involve assigning individual pottery specimens to types. These types were created to distinguish the temporal order of assemblages, not to track technological changes. Consequently, the types tend to be defined by an uneven and, often, complex mixture of attributes that do not allow one to isolate particular technological features. This is especially true for utility wares, which are generally given short shrift because of their perceived lack of stylistic content needed to make the best temporal distinctions. Although the data on various utility ware types have allowed the reconstruction of the general outline of change discussed in Chapter 2, they do not allow one to construct the kind of detailed technological histories required for an evolutionary account.

To generate the needed technological descriptions, I must make new observations of samples of utility ware pottery that more fully document how the pottery was manufactured at different points in time, and both complement and enhance the existing published data. These new observations should be made on attributes of ancient utility ware pottery from selected assemblages that are dated accurately to different times during the shift from plain to corrugated vessels. Measuring attributes, rather than simply making typological distinctions, allows me to document the history of particular innovations as well as the association of technological features through the creation of classes by the paradigmatic or mutually exclusive formation of attribute combinations. Being able to distinguish individual features as well as combinations of features makes it possible to document the scale or scales at which replication may have taken place. Details on the pottery assemblages selected for these analyses, and the selection criteria employed are provided later in this chapter. The methods and techniques used in the specific analyses, and the technological history constructed from the various observations are presented in Chapter 5.

Once we have a better understanding of the technological changes involved in the development of corrugation, we can reexamine published data to construct a more complete picture of the spread of corrugation across the Southwest. This involves compiling information on the location and timing of the first appearance of particular corrugation traits, and tracking the spread of these traits to different areas of the Southwest. This is easier to do for some traits than for others because the pottery types often obscure particular traits by mixing them in unknown ways. Consequently, I focus on a few traits that can be reliably distinguished in the published data on utility ware types. This reconstruction of the spread of corrugation throughout the Southwest is presented in Chapter 5.

Pottery Production and Use

Documenting the production and use of utility pottery provides important information on the interaction dimension of the Darwinian process. Normally, when we think of how a pottery vessel may have interacted with its environment, we only consider how the pot was used. However, the process by which the pottery comes into being is just as important a part of a pot's environment as the conditions of use. Not only must a vessel survive the production process before it can be used, but pottery production can have very different functional and semiotic requirements than use. These differences between production and use can result in features of vessels that are puzzling when thought of from the use stand point alone. Did corrugation develop in a homogeneous or multifaceted production and use environments? What kinds of conditions were the utility vessels subjected to during production and use? Were there any changes in the production and use of utility wares during the transition from plain to fully corrugated vessels? These are the kinds of questions that must be answered for an understanding of Darwinian interaction that occurred during the development and spread of corrugation.

Archaeological analyses of the processes involved in pottery production come in many forms, and have been carried out with increasing sophistication during the last decade (Bey and Pool 1992; Costin 1991; Mills and Crown 1995a; Pierce et al. 1999). Although the production of utility ware pottery in the Southwest has been the focus of very few studies, some published information does exist. This information includes both direct and indirect evidence of pottery production. Relying heavily on these published sources and contributing original data, when available, from my analyses of pottery collections, I organize and synthesize our current knowledge of the production of Southwestern utility wares. The results of this synthesis are presented in Chapter 6.

Data on how plain and corrugated utility ware vessels were used will be derived from the morphology of the ancient vessels and patterns of use-related alterations they display. Again, existing typological data on Southwestern utility wares provide very little information on vessel use. Data on utility ware types do furnish some information on the shape and, occasionally, size of vessels, but data on possible use-related alterations, the most important source of information on use, are extremely rare and usually anecdotal at best. To generate more detailed information on the use of utility ware vessels during the development of corrugation, I record data on the shape and size of vessels, and possible use-related alterations from pottery sherds analyzed from the same assemblages selected for the technological analyses discussed above. I use these data in

combination with published information to develop as complete a picture as possible of vessel use during the transition from plain to corrugated utility ware pottery. The methods and results of these analyses are also presented in Chapter 6.

Engineering Properties

Evolutionary explanation involving selection as a mechanism necessitates that interaction with the environment differentially bias replication. Interactions that are more efficient or effective tend to result in greater replication. Consequently, being able to distinguish selection from other sorting mechanisms requires that we know something of the engineering properties of the interactors. Ever since Darwin, evolutionary explanations have involved a component of reverse engineering to document the efficiency and effectiveness of design features (Burian 1983; Dennett 1995). One of the significant challenges in conducting reverse engineering studies is determining what entity should be studied. Given our focus on changes in pottery technology, the engineering properties of plain and corrugated vessels are a logical place to begin. However, if multiple frames of reference were causally relevant to the development and spread of corrugation, we may also need to know the engineering properties of other entities such as the cognitive architecture of the people involved, or the larger-scale sociocultural systems in which the people were immersed.

To document the engineering properties of the pottery, I conducted a set of experiments designed to assess and document the relative cost and performance values of plain and corrugated vessels. I performed these experiments with replicas of ancient plain and full-body corrugated vessels. The design of these replicas is based on knowledge gained from analyses of ancient pottery fragments, with the goal of making the replicas resemble the ancient pottery as closely as possible. The procedures used to manufacture these replicas are described in Chapter 7. I designed the experiments to measure specific engineering properties that previous research and speculation have identified as potentially different between plain and corrugated. These include manufacture costs, heating effectiveness, ease of handling, and vessel use-life. In addition to these experiments, I draw on physical theory, the results of earlier experiments, and certain characteristics of ancient pottery assemblages when they are available and appropriate to the problem. Chapter 7 presents the methods and results of these various engineering studies. I address the properties of other entities that may be relevant to explaining corrugation in Chapter 8 in the context of formulating hypotheses regarding the development and spread of corrugated pottery.

Contexts of Change

As discussed in the previous chapter, the environment, or context of change, is the third part of a logical triad of conceptual units in Darwinian evolutionary theory. Defined as the entities interactors interact with, the environment is a critical factor in determining the kinds of sorting mechanisms that may be involved in any particular example of evolutionary change. Given the multiple frames of reference approach I have adopted in this study, there may be several different environments pertinent to the corrugation problem, one for each causally relevant frame of reference. In addition, the environment plays an important role in stimulating potential non-Darwinian processes of change including the behavioral plasticity of biological organisms, and, possibly, the orthogenetic growth of societies and institutions. Consequently, identifying and describing the relevant environments can only occur in the context of explanation. Hypotheses formulated to account for the rise of corrugation must specify the relevant environment(s) to be complete, and generic environmental descriptions are of little value. Therefore, I rely almost exclusively on data in the primary and secondary literature of the prehistoric Southwest and human cognition to characterize the environment in the various hypotheses for explaining corrugation presented in Chapter 8.

Formulating and Testing Hypotheses

In the normal notion of the scientific process, one begins a body of research with hypotheses, which clearly state the possible explanations for some phenomenon, and then proceeds to test these hypotheses with a battery of data. Although the true significance of this view of the scientific method is often over stated (Bauer 1992), it still represents an admirable goal. However, archaeologists rarely find themselves in a position where they can proceed in this manner. Usually, we lack sufficient understanding of the empirical problem we hope to explain to formulate detailed, testable hypotheses. This is compounded by the poor state of theory development in archaeology resulting in hypotheses that often take the form of intuitively appealing rationalizations for which empirical testing is nearly impossible.

Consequently, the goal of my research on the problem of corrugation is to present a set of useful hypotheses after we have a better understanding of the problem through generating the data described above. Attempting to formulate testable evolutionary hypotheses regarding the rise of corrugation would be foolish without first having a clear understanding of what it is we are trying to explain. Our understanding of the requirements for evolutionary explanation and our general knowledge of the corrugation problem are sufficient to specify the data needed to formulate, but

not necessarily test, viable evolutionary explanations. Once the necessary data on the history, environment and interaction of Southwestern utility wares are available, then we can turn to the problem of formulating and, possibly, testing hypotheses with a much greater likelihood of success.

Commonly, evolutionary accounts take the form of historical narratives that specify the nature and possible causal relationships of the various replicators, interactors, and environments relevant to a particular problem (Hull 1981; O'Hara 1992; Ruse 1971). I take this approach in presenting my explanations for corrugation in Chapter 8. In that chapter, I divide the corrugation problem into four parts corresponding to the initial adoption of neck banding, the introduction of variation in neck banding, the adoption of full-body corrugation, and the return to plain utility wares. For each part of the corrugation problem, I present a historical narrative that integrates the knowledge of different parts of the corrugation problem developed in Chapters 5 through 7, and presents possible explanations for changes seen in each period. To the extent possible with current evidence, I attempt to test the various alternative explanations formulated for each part.

The Pottery Collections: Selection, Sampling and Potential Biases

Ideally, to document the history of the development, spread and use of corrugated pottery, I should analyze samples of ancient pottery representative of the entire temporal and spatial range of the transition from entirely plain to fully corrugated vessels. Unfortunately, given the vast number of pottery collections involved, the ideal approach is not practical in this case. Consequently, I was forced to make several decisions to determine which pottery assemblages I would analyze for this study. Four levels of decisions needed to be made in designing the detailed analysis of utility ware pottery assemblages. First, I needed to select the region from which the assemblages would be drawn. Second, I had to frame the criteria I would use for selecting individual assemblages, and then make the selections based on data available for a larger number of sites. Third, I made sampling decisions regarding what pottery would be analyzed in each assemblage. Finally, I chose the observations I would make on pottery in these samples. Each of these decisions affects the kind and quality of the resulting data. Consequently, this section describes how and why I made these decisions, and assesses their impacts on data reliability and validity.

Selection of the Region

Corrugated pottery was used over a large area of the Southwestern U.S. and parts of northern Mexico. Rather than analyze pottery from widely separated areas, I chose to document

the development of corrugation in one region well, and rely on published data to extrapolate these findings to other areas. Few regions in the Southwest contain a sufficiently large number of well-dated pottery assemblages spanning the period of change from plain to corrugated pottery. Of those possessing a substantial number of dated assemblages, the Mesa Verde region of southwestern Colorado stands out for several reasons. The region has a long history of archaeological and paleoenvironmental research including some of the earliest studies to address the corrugation problem. Nearly 1/3 of all tree-ring-dated sites in the entire American Southwest are located in southwestern Colorado (Robinson and Cameron 1991). In addition, several of these sites date to the period of interest for this study, and have yielded substantial pottery assemblages from recent, well-controlled excavations. Finally, most of these pottery collections are available for study at easily accessible repositories located within the region. Given all of these qualities, the Mesa Verde or northern San Juan region seemed the most likely area to contain an adequate number of assemblages meeting the selection criteria described in the next section.

Selection of the Assemblages

Recent archaeological research in the Mesa Verde region, particularly the Dolores Archaeological Program and other work associated with the development of McPhee reservoir and related irrigation canals, has generated numerous collections dating to the period of change from completely plain to full-body corrugated vessels. In selecting among these collections for inclusion in this study, I strove for collections containing assemblages generated by well-dated, functionally equivalent, short duration occupations that provide even coverage of the period from AD 750 to 1050. Collections meeting the dating criterion include those with multiple absolute dates, either tree-ring dates, archaeomagnetic dates, or both (radiocarbon dates are rarely obtained in this area of the Southwest because of the dominance of tree-ring dating). In addition, these absolute dates must occur in an understandable and reliable association with the material to be analyzed, and the relative frequencies of painted pottery types in the selected assemblages must produce a properly ordered seriation. To control for functional variation in activities that might bias the formation and composition of the assemblages, I restricted consideration to collections from habitation sites with architectural features and recognizable trash or midden deposits. Finally, I distinguished relatively short duration occupations by a lack of substantial architectural remodeling, and a reasonable clustering of dating evidence. In addition, because assemblages form the unit of comparison for this study, selected collections must be relatively large, and collected in such a way that they are reasonably representative of the material deposited during

the occupation. I used an arbitrary assemblage size cut-off of at least 300 utility ware fragments. Although probably a higher cut-off than necessary, I wanted to avoid, as much as possible, the disruptive effects of small samples. This is one of the possible biases I examine at the end of this section and in Appendix A. Finally, to minimize biases introduced during the collection of the material in the field, selected collections must have been generated by systematic surface collection or screening of excavated deposits sampled in a representative manner.

Once I identified collections for inclusion in this study, I further sampled these collections for the actual specimens to be analyzed. To secure samples representative of the occupation as a whole, I selected only material from trash deposits. I focus on trash middens because the chance that individual sherds in the same collection unit derived from the same vessel is greatly reduced relative to assemblages collected from indoor and outdoor use or living surfaces. Thus, trash deposits have a better chance of yielding the maximum amount of data on variation for a given sample size. In addition, the composition of refuse assemblages is less susceptible to distortion by abandonment-related formation processes than exposed activity surfaces (Schiffer 1987). A comparison of variance in three collections under consideration for selection showed that trash deposits contain considerably less within sample variance in the abundance of pottery types than samples from activity surfaces. Finally, I chose to analyze only the utility ware pottery. In the American Southwest, pottery has been traditionally divided into groups based on the presence or absence of slip, polish, and paint. The utility wares consist of those vessels lacking these surface modifications. In the Mesa Verde region, these utility wares normally have a dull gray appearance produced by a neutral to reducing firing atmosphere, and are thus usually identified as gray wares. This gray, utility ware category includes the vast majority of pottery displaying corrugation in the northern Southwest.

Assemblage Descriptions

Application of these collection and assemblages selection criteria resulted in the inclusion of six assemblages from the Mesa Verde region in the current study. The following descriptions present very general information on the sites and the utility ware assemblages selected for analysis from these sites. More detailed information on each of these sites can be found the reports cited in each section.

Dos Casas Hamlet (5MT2193)

Dos Casas Hamlet is a residential site consisting of two, sequentially occupied pit structures with six associated post and adobe surface structures and several outdoor pit features,

and appears to have been occupied by a single household (Brisbin et al. 1986). The site is located in the Sagehen Flats area approximately 18 km north of Cortez, Colorado, and 2.5 km west of the old course of the Dolores River in the area now submerged by McPhee Reservoir (Figure 4). Members of the Dolores Archaeological Program carried out surface collections and excavations at the site prior to inundation by the reservoir, but after the site had been ploughed during a short period of cultivation. Artifacts over the entire surface of the site were collected in contiguous 4 by 4-meter squares while excavation focused on the areas with structural remains. All of the surface structures and the two pit structures were completely excavated either by hand or with heavy machinery. Material recovered from floor contexts and dense midden deposits was screened dry through ¼-inch mesh. These excavations revealed that pit structure 2 was built after and slightly superimposed over pit structure 1. Tree-ring dates on 23 charred roof beams recovered from pit structure 2 indicate that the structure was constructed between AD 769 and 771. Two dates on roof beams from pit structure 1 suggest that it was built around AD 760. Characteristics of the architecture, site layout, and painted pottery (Figure 5) match those found at other sites dated to the latter half of the 8th century in the Mesa Verde region.

A total of 315 gray ware sherds were selected for analysis from Dos Casas Hamlet. Almost half of these sherds (n=151) were recovered from trash used to fill pit structure 1 during and after the construction of pit structure 2. The remaining sherds were collected from the surface of the trash dump located in subarea 2 south of the pit structures. This trash dump appears to have accumulated throughout the use of both pit structures. Consequently, the sherds analyzed from Dos Casas Hamlet constitute a mixture of material deposited from the middle to late eighth century AD.

Periman Hamlet (SMT4671), Area 1

Area 1 of Periman Hamlet is a residential site consisting of one pit structure and 19 post and adobe surface rooms with associated outdoor features, and appears to have been occupied by three contemporary households (Wilshusen 1986). The site is located approximately 22 km north of Cortez, Colorado, on an alluvial fan immediately east of the Dolores River where the canyon narrows north of Sagehen Flats (Figure 4). The site was investigated by the Dolores Archaeological Program in advance of inundation by McPhee Reservoir. Investigations included surface collection of the entire site in contiguous 4 by 4-meter units, intensive excavation of the surface room block, plaza and pit structure, and test excavation of the trash dump located south of the pit structure. A combination of hand removal and the use of heavy machinery accomplished

these excavations. Material excavated from floor/use surface contexts and dense midden deposits were screened dry through ¼-inch mesh. A coherent site layout and lack of evidence of substantial renovation or abandonment of structures suggest that only one occupation occurred in Area 1 of Periman Hamlet. Seriation of painted pottery (Figure 5) and three archaeomagnetic dates indicate that the occupation dates to the first half of the 9th century AD.

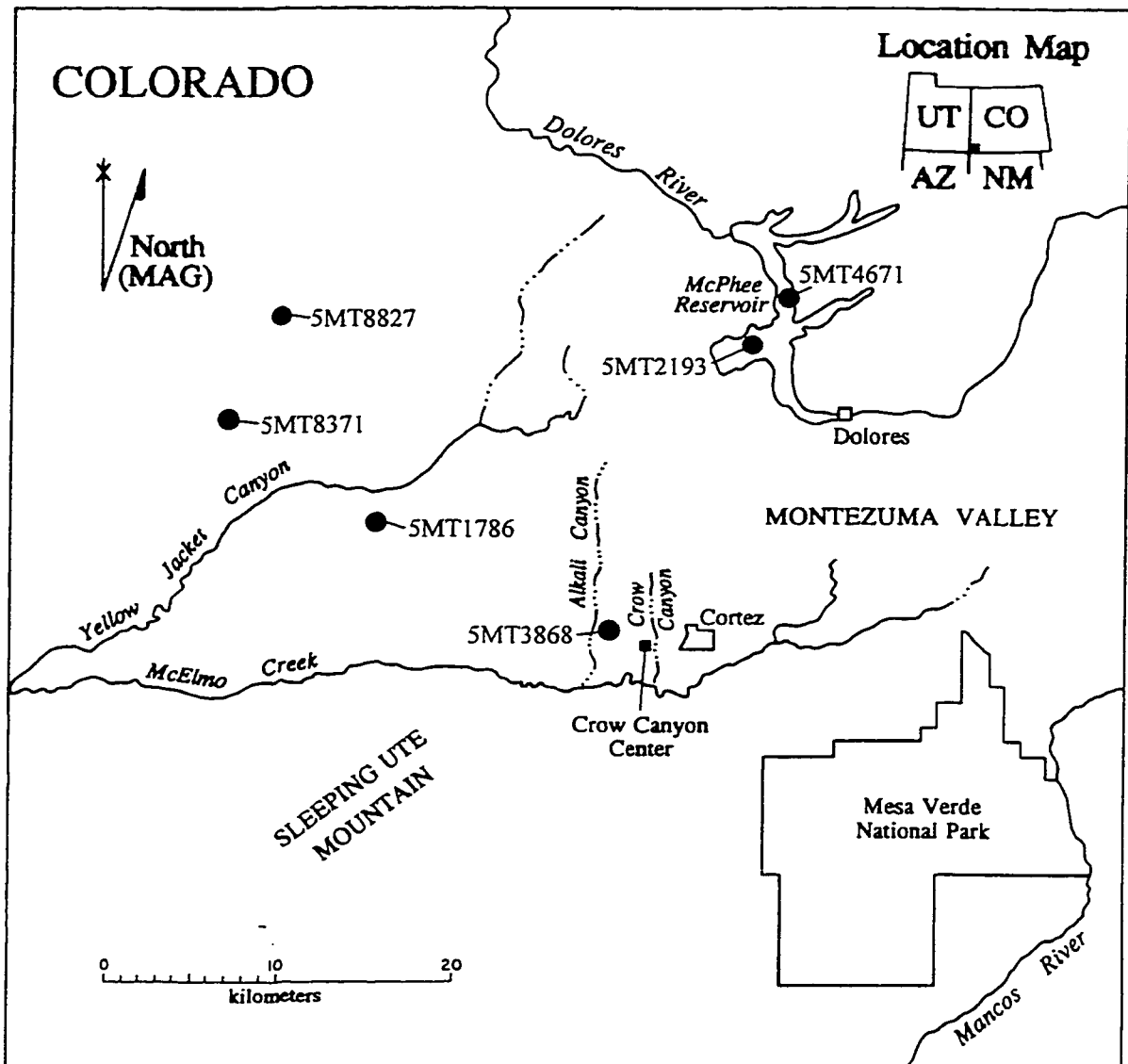


Figure 4. Map of the Mesa Verde region showing the location of the six sites from which utility ware sherds were analyzed for this study.

The sample of gray ware pottery selected for analysis from Periman Hamlet consists of 785 sherds recovered from two trash dumps at the site. Complete excavation of two trash filled

borrow pits located north (Feature 25) and east (Feature 144) of the surface room block yielded 323 sherds. Excavation of four systematically selected 2 by 2 meter test pits in the trash dump south of the pit structure produced the remaining 462 sherds included in the sample. The eastern borrow pit (Feature 144) was truncated by construction of a surface room suggesting that the trash deposited in this pit may date to the early part of the occupation at Periman Hamlet. However, most of the material analyzed accumulated during the entire occupation of the site, which likely lasted between 20 and 50 years.

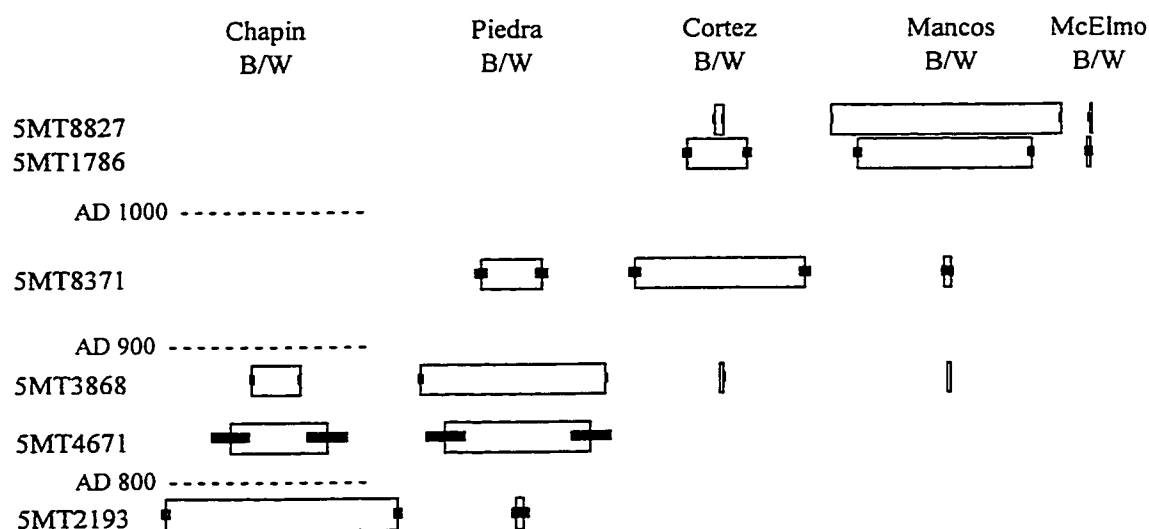


Figure 5. Seriation of painted pottery types recovered from the six sites from which utility ware sherds were analyzed for this study. Error bars = 90% confidence intervals.

Duckfoot Site (SMT3868)

This residential site consists of four pit structures, 20 post and adobe surface rooms north of the pit structures, and a trash dump located south of the pit structures, and appears to have been occupied by at least three contemporary households (Lightfoot 1994; Lightfoot and Etzkorn 1993). The site is located on the mesa top 5 km west of Cortez, Colorado (Figure 4), and was excavated from 1983 to 1987 by Crow Canyon Archaeological Center. The architectural, courtyard and midden areas of the site were completely excavated by hand and all excavated material was screened dry through ¼-inch mesh. A total of 375 tree-ring dates was obtained on construction beams recovered mainly from the pit structures with a few samples from other parts

of the site. Based on these tree-ring dates, seriation of painted pottery (Figure 5), and construction evidence, the site appears to have been continuously occupied from AD 855 to 880.

I selected a sample of 1504 gray ware sherds for analysis from the Duckfoot Site. All of these sherds were recovered from 2 by 2-meter pits excavated into the trash dump or midden south of the pit structures. Because the complete excavation of the trash dump produced almost 60,000 gray ware sherds, I used a probabilistic sampling approach to select the sherds included in the analysis. Unfortunately, existing information on the collection made it impossible to identify individual pottery sherds that would allow a simple random sample of gray ware sherds, which would produce the most representative sample from the midden. Consequently, I performed a cluster sampling based on provenience units similar to that prescribed by Cowgill (1964). Restricting the sampling to the trash dump should minimize the adverse impacts on sample variance commonly introduced by cluster sampling since sherds from the same vessel are less likely spatially associated than in other depositional contexts. I drew the analyzed sherd sample by randomly selecting three of the 100 pits excavated into the trash dump. The grid coordinates of the three 2 by 2-meter units selected are 66N/93E, 56N/111E, and 62N/101E. The relative frequencies of gray ware pottery types in the random cluster sample closely match those in the total midden collection indicating that the small sample analyzed for this study adequately represents the larger trash dump population.

5MT8371

Site 5MT8371 consists of a single, shallow pit structure, adjacent outdoor pit features and small trash dump, but apparently lacks any associated surface rooms (Dykman 1986). The presence of a pit structure with a rich assortment of floor features and a discrete trash dump indicate that this was a single household residential site. However, the lack of surface architecture suggests that the occupation was for a short duration (probably less than 20 years), or possibly on a seasonal basis. The site is located on the mesa top near the head of Negro Canyon approximately 30 km northwest of Cortez, Colorado (Figure 4). Complete hand excavation of the pit structure, adjacent outdoor use surface, and trash midden by a team from the Division of Conservation Archaeology, a private consulting firm, occurred in 1984 after the site was exposed in a pipeline trench. Dates on five different charred beams from the collapsed roof of the pit structure yielded two cutting dates of AD 935 and a noncutting date of AD 940. Four radiocarbon dates on small charred wood pieces from features at the sites and seriation of painted pottery types (Figure 5) add further support for a middle 10th century date for the occupation of this site.

All of the gray ware pottery recovered from the midden, consisting of 326 sherds, was included in the sample analyzed for this study. Ten square meters of the midden were excavated primarily in contiguous 2 by 2-meter pits, and all of the material removed from these units were screened dry through ¼-inch mesh to recover artifacts. The midden continued east of the excavated area for an unknown distance so it is impossible to determine the proportion the analyzed sample constitutes of the entire trash deposit. However, because the site appears to have been occupied only once for a relatively brief period, it is very likely that the analyzed sample adequately represents the pottery discarded during that occupation.

Gnatsville (5MT1786)

Gnatsville is a small residential site consisting of one pit structure, an unknown number of post and adobe surface rooms, various outdoor features, and two small trash dumps, and appears to have been occupied by a single household (Kent 1989, 1991). The site is located approximately 20 km northwest of Cortez, Colorado, on the broad upland between McElmo and Yellowjacket Canyons (Figure 4). Investigations at the site were conducted as part of a university field school, and involved systematic surface collections and excavations in the areas containing structural remains and the trash dumps. All excavations proceeded by hand and the excavated material was screened dry through ¼-inch mesh. Nine tree-ring dates (five from the burned and collapsed pit structure roof, two from the surface rooms, and two from midden 2) produced three cutting dates that indicate construction of the site in AD 1035. A single archaeomagnetic date from the surface room block and seriation of painted pottery (Figure 5) support this construction date estimate. Lack of architectural and feature remodeling and the shallow depth and small size of the trash dumps suggest a single, short duration occupation of the site probably lasting less than 20 years.

A sample of 918 gray ware sherds was selected for analysis from the Gnatsville site. All of the sherds were recovered through either surface collection or excavation in Midden 1, the largest and most dense trash dump at the site, located south of the pit structure and room block. Midden 2, a small, low density dump adjacent to the pit structure, appears to have been used for a very short time prior to the construction of the pit structure. I restricted my analyses to all of the sherds recovered from Midden 1 because it likely accumulated during the main occupation of the site.

Dobbins Stockade (5MT8827)

Dobbins Stockade is a residential site consisting of two sequentially occupied pit structures, four post and adobe surface rooms, numerous outdoor features, and a stockade that surrounded most of the structures and features (Kuckelman 1988a). The site is located in a modern farm field on the broad upland between the heads of Hovenweep and Ruin Canyons approximately 32 km northwest of Cortez, Colorado (Figure 4). Investigations at the site in 1986 by a team from Complete Archaeological Service Associates included intensive surface collection, blading with heavy equipment, and hand excavation of the central portion of the site containing architecture. All of the hand-excavated material was screened dry through ¼-inch mesh. Thirty-one tree-ring dates obtained on wood samples recovered from various structures and features at the site indicate that initial construction occurred around AD 1030 and the site was probably abandoned around AD 1060.

The only distinct trash dump documented at Dobbins Stockade was encountered during excavation of one of the pit structures (Pit Structure 2). Above a layer of roof fall and a thin deposit of wind and water transported sediment, a roughly 50 cm thick layer of trash filled almost half of the pit structure. After initially encountering the trash deposit in a backhoe trench, the layer was completely excavated by hand and screened dry through ¼-inch mesh producing the 326 gray ware sherds included in the analysis for this study. The roof fall deposit below the trash produced three tree-ring dates the latest of which is a noncutting date of AD 1034. It is likely that the initiation of trash dumping in the pit structure dates to sometime after AD 1040 because a 10 to 15 cm thick deposit of naturally transported sediment covered the roof fall layer before the deposition of trash began. The trash probably accumulated more or less constantly until the site was abandoned around AD 1060.

Potential Assemblage Biases

Although I have addressed the conceptual validity or purpose of the various descriptions I am trying to produce, it is also important to evaluate the reliability of the units and particular observations used to generate these descriptions (Ramenofsky and Steffen 1998). As I noted earlier, potentially disruptive biases can be introduced at several points in this analysis ranging from the choice of region to the size of the samples and the individual sherds analyzed. The actual impact of some of these potential biases on the accuracy and precision of the analyses performed for this study can only be speculated on at this point while others can be assessed quantitatively.

In this section, I evaluate what we can currently know about the biases that potentially affect the data derived from the collection analyses.

Restricting the analyzed collections to the Mesa Verde region has both positive and negative effects. On the positive side, it is unlikely that an adequate number of collections would have been available in most other regions of the northern Southwest given the selection criteria I employed. However, as one might expect, the Mesa Verde region is probably not representative of changes in pottery technology that occurred in other areas of the Southwest. Existing data indicate that at least the timing and rate of change differ among the various regions of the northern Southwest. These differences become a significant issue in Chapter 8 as I attempt to explain the change from plain to corrugated pottery, and the importance of processes working over very large spatial scales becomes clear. Carefully examining published data from other regions helps minimize the impacts of the Mesa Verde region bias, but ultimately, comparable analyses will be needed from other areas to obtain reliable descriptions at the appropriate scales.

The problem with the representativeness of the region also extends to the six assemblages within the Mesa Verde region selected for study. There are two issues here. How thoroughly do these assemblages document the period of change from plain to corrugated pottery, and how well do individual assemblages represent the particular span of time they cover? The late 8th, 9th and early 11th centuries are reasonably well covered by the selected assemblages, but the 10th century is represented by only one collection which accumulated during the early to middle part of that century. This paucity of 10th century assemblages is in large part a reflection of the decrease in population that occurred in the Mesa Verde region during that time. This resulted in few documented assemblages, and only one meeting the selection criteria. Assessing the representativeness of these six assemblages of the pottery made and used at a given time in the Mesa Verde region is a more difficult problem. Existing typological descriptions suggest that the pottery in the Mesa Verde region changed in similar ways at more or less the same time across the region. However, these typologies tend to obscure and suppress the kinds of technological details of interest for this study. Consequently, it remains an open question whether this typological uniformity can be reasonably extrapolated to the technological aspects of utility wares. In describing the history of corrugation in the next chapter, I attempt to assess the representativeness of various technological trends documented in the six assemblages by comparisons with other published information from the region. However, only comparable

analyses performed on multiple collections from the same period of time will produce a completely reliable answer to this question.

Deciding to focus my analyses on the gray, utility ware pottery in the selected assemblages also introduces some potential biases. As noted earlier, the gray ware category in the Mesa Verde region does include most of the pottery with corrugation, but not all. Some slipped and painted pottery is corrugated to a very limited extent. Although I am familiar with the occurrence of corrugation on non-gray ware vessels, the decision not to analyze white and red ware pottery means that I will have to present this information anecdotally rather than quantitatively. In addition, as discussed in Chapter 6, the gray ware category includes pottery used in a wide variety of ways. This is particularly true for the earliest assemblages when most of the pottery produced was unslipped and unpainted. Later, as more and more of the different vessel forms were manufactured as white or red wares, the gray ware category came to include cooking and possibly storage vessels almost exclusively. These changes in the range of vessel forms analyzed for this study could bias some aspects of our understanding of the manufacture and use of vessels during the transition to full-body corrugation. Consequently, I try to control for the potential biases where their effects might be most disruptive when I present and analyze the data in Chapters 5 and 6.

The particular assemblages of sherds selected for analysis in this study could also present a biased picture of utility ware technology for two reasons. If the samples drawn from each of the assemblages are not large enough, sampling error could affect the accuracy and reliability of the resulting descriptions. If significant differences exist among assemblages in the size of sherds, these differences could also affect the documentation of certain characteristics. Appendix A presents a detailed analysis of these potential sample and sherd size biases for the six assemblages. Although sample size varies considerably among assemblages, all of the samples appear to be large enough to avoid disruptive sample size effects on assemblage richness and the relative frequencies of most attributes. However, the assemblages differ, sometimes substantially, in terms of sherd size. Most of this sherd size variation derives from differences in the formation histories of the assemblages, particularly the context of deposition and resulting differences in post-depositional breakage. The effects of these differences in sherd size and occasional incidents of inadequate sample size will be considered in Chapters 5 and 6 as data potentially affected by these biases are presented.

CHAPTER 5: THE DEVELOPMENT AND SPREAD OF CORRUGATION

This chapter chronicles the development and spread of corrugation through analyses of attribute-level data on utility ware pottery from the Mesa Verde region and a synthesis of published and unpublished information on pottery from across the Southwest. This chronicle begins with a detailed presentation of data relating to the development of corrugation in the Mesa Verde region. In this section, I examine evidence for how the early plain utility ware vessels were manufactured, and the nature and timing of the various technological innovations that led to the development of full-body corrugated vessels. This evidence is drawn mainly from my analyses of gray ware pottery in the six assemblages selected from the Mesa Verde region described in the previous chapter, and supplemented with published data when available and appropriate. Following this detailed history, I compile published information on the spread of corrugation technologies across the northern Southwest. Given the general lack of attribute-level data on utility ware pottery in the published literature, I am forced to rely on type descriptions and frequencies to document the spread of corrugation. Consequently, I focus on major transitions, including the first appearance of exposed coils and the introduction of indented corrugation, that are reasonably well documented by typological distinctions and data available in published form.

The Development of Corrugation in the Mesa Verde Region

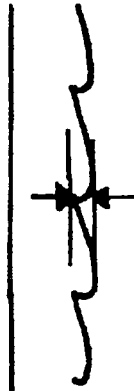
The transition from scraped plain to fully corrugated vessels involved several changes in how the pottery vessels were constructed prior to firing. Observations of ancient fragments from these different kinds of vessels can provide abundant evidence on the forming or construction techniques employed, and a wide range of techniques has been developed to extract this information (e.g., Carr 1990; Feathers 1990; Rice 1987; Rye 1981; Shepard 1976; Vandiver 1988). In the analyses I performed for this study, I relied on macroscopic and low power microscopic observations of surface features, core structure, and fracture patterns to document the techniques used to construct plain and corrugated gray ware vessels in the Mesa Verde region. Some of these attributes were measurable on all sherds, while others were applicable only to corrugated sherds with exposed coils.

For all sherds, I recorded five categorical attributes that provide data on the forming techniques employed: sherd fracture pattern, surface forming and finishing traces, surface applications, and core structure. The fracture morphology of sherds was recorded as random, cubic, stepped, or indeterminate. Cubic and stepped fractures display parallel fracture edges in the horizontal plane of the vessel resulting from the fractures occurring along the joins between coils

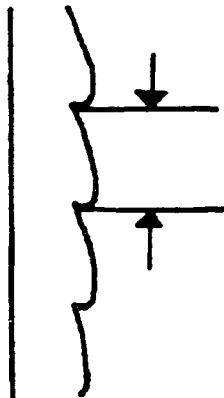
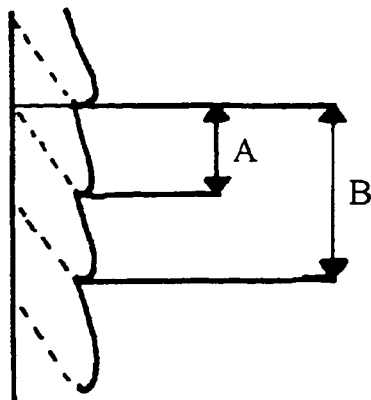
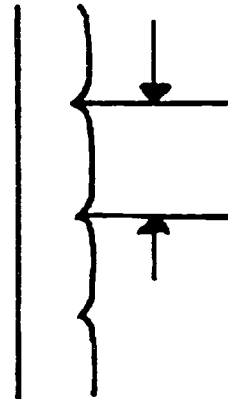
or other horizontally applied construction elements, and thus can be indicative of the use of coils in manufacture. Random fractures show no preferred edge orientation and result from either a lack of weaker coil junctions that produce preferred breakage planes, or the breakage of pots into pieces that are smaller than the coils used to construct the vessel. The states used to record surface forming and finishing traces include none, indented, incised, scraped, padded, pinched, wiped, polished, smeared, combination, other, and indeterminate. Surface application states include none, slipped, painted, slipped and painted, other, and indeterminate. Each of the surface attributes was recorded for both interior and exterior surfaces. Finally, the structure of the core exposed in a freshly broken edge of the sherd was recorded as homogeneous, blocky, laminar, irregular, or other. The quality and processing of the raw materials and the nature of pressures applied during manufacture contribute to the formation of different core structures. Finally, I also recorded the likely form, or shape of the vessel from which each sherd came. Vessel form categories include wide-mouth jar, narrow-mouth jar, seed jar, indeterminate jar, bowl, ladle, other, and indeterminate form. The definitions and identification criteria for each form category are discussed at length in Chapter 6.

For sherds with exposed or unobliterated coils on the exterior surface, I recorded five additional attributes indicative of the forming techniques employed. These attributes include coil application, coil junction depth, exposed coil height, coil surface indentation frequency, and the percent overlap between adjacent coils. Coil application technique was recorded as either filleted (non-overlapping), overlapping, or indeterminate. For overlapped coils, coil junction depth refers to the distance in millimeters between the crest of a coil and the point at which it joins the coil below (Figure 6). I measured this attribute by resting the base of the arm of a dial caliper against the crest of a coil and opening the caliper until the projecting rod came in contact with the surface of the coil below. For filleted coils, this measurement is the depth of the incision or crease between exposed coils. In both cases, an average of several measurements was recorded. Exposed coil height is the average distance in millimeters between the crests or junctions of adjacent coils, whichever is most convenient to measure on a given piece (Figure 6). To obtain an average, I measured the distance across as many coil crests as were present on a given sherd and divided this distance by the number of coils over which the measurement was taken. Coil surface indentation frequency refers to the average distance in millimeters between adjacent indentations visible on the surface of exposed coils (Figure 6). This was determined by measuring the distance between the same location on the indentations (crest of ridge, bottom of indent, etc.)

Overlapped Coils

Junction
Depth

Filletted Coils

Coil
Height

$$(A / B) * 100$$
 Percent Coil Overlap

Figure 6. Diagram of metric attributes recorded on exposed coils.

across as many indentations as possible and dividing this distance by the number of indentations across which the measurement was taken. Percent coil overlap is the percent of one coil that is overlapped or covered by the next coil applied above it (Figure 6). To measure this attribute, the boundaries between adjacent coils must be visible in an edge of the sherd. If coil boundaries were visible, I divided the distance from the coil junction at the inside surface of the vessel wall to the end of the overlapping coil by the distance from the same inside surface point to the end of the coil being overlapped. The percent overlap of filleted coils was recorded as 0 even though the base of filleted coils often drooped slightly over the top of the coil below.

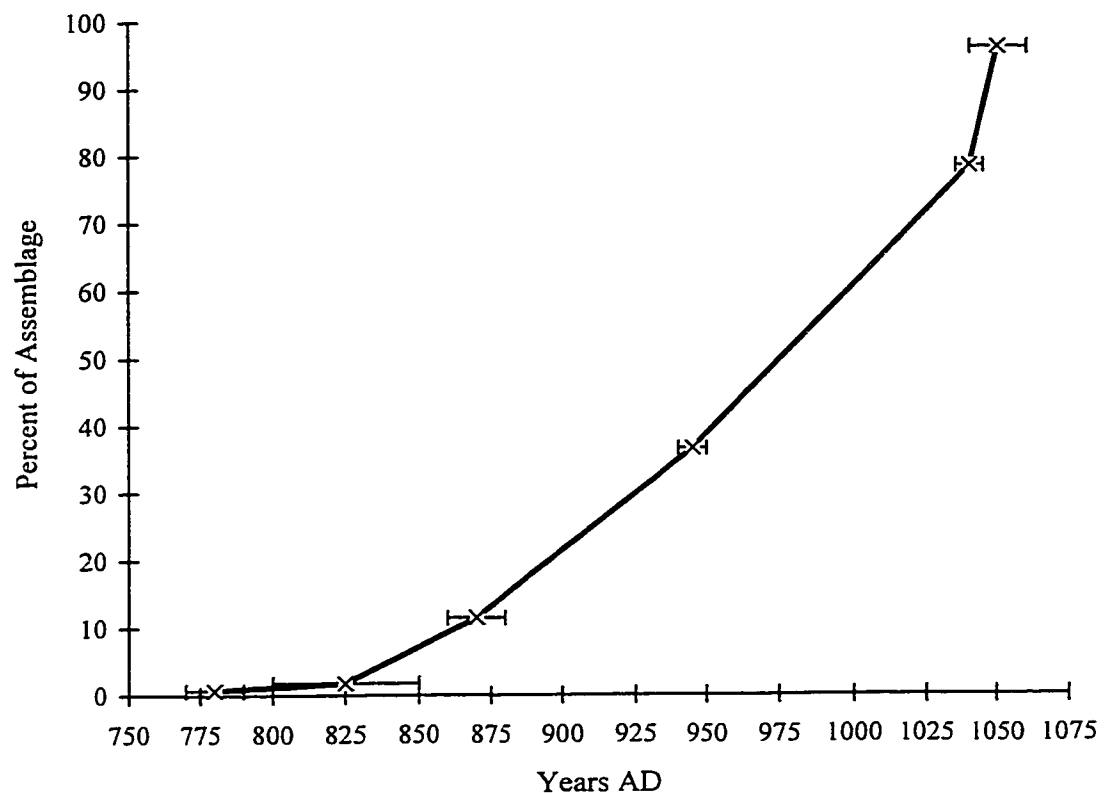


Figure 7. Relative abundance, by weight, of sherds with exposed coils in the six utility ware assemblages from the Mesa Verde region.

To obtain a general overview of the change from plain to corrugated vessels, we can track the occurrence of exposed coils in the six gray ware assemblages. Figure 7 shows the abundance, by weight, of sherds displaying exposed coils relative to the weight of plain sherds in each

assemblage. Initially, in the late eighth and early ninth centuries AD, plain pottery dominated utility ware assemblages. The relative abundance of pottery with exposed coils increased gradually, reaching just over 10 percent by the late ninth century, nearly 40 percent by the mid tenth century, and then accounting for almost all gray ware pottery by the early to mid eleventh century. This increase in the amount of pottery displaying exposed coils derives from both a change in the relative abundance of gray ware vessels with exposed coils and an increase in the amount of surface area per vessel covered with exposed coils. Table 1 indicates that exposed coils occur almost exclusively on wide-mouth jars, and the occurrence of exposed coils on wide-mouth jars increased rapidly during the ninth century. The proportion of wide-mouth jars in relation to other vessel forms in gray ware assemblages also increased during this time (see Chapter 6 for a discussion of changes in utility ware vessel forms through time). Table 2 presents the relative frequency of exposed coils on different vessel parts, and shows a gradual extension of exposed coils down the vessel body through time.

Table 1. Abundance, by weight, of pottery with exposed coils on different vessel forms in the six utility ware assemblages from the Mesa Verde region.

Assemblages	Vessel Form Classes										Totals	
	Wide-Mouth Jar		Indeterminate Jar		Olla		Seed Jar		Bowl			
	g ¹	% ²	g	%	g	%	g	%	g	%	g	%
5MT2193	173	9.1	1963	0	34	0	0	0	100	0	2269	0.7
5MT4671	486	21.0	5217	0.1	66	0	0	0	213	0	5981	1.8
5MT3868	804	93.5	6065	1.6	325	0.6	6	0	86	0	7286	11.7
5MT8371	475	93.4	1087	12.1	6	0	0	0	0	0	1568	36.7
5MT1786	320	98.6	3013	76.5	0	0	0	0	0	0	3333	78.6
5MT8827	754	100	2729	95.3	0	0	0	0	0	0	3483	96.3

¹Includes total grams of pottery identified to a particular vessel form in each assemblage.

²Percentage calculations for vessel form classes are based on the total amount of pottery identified to each form class in each assemblage.

Total percentages are based on the total amount of pottery assigned to any vessel form class.

Table 2. Abundance, by weight, of pottery with exposed coils on different vessel parts in the six utility ware assemblages from the Mesa Verde region.

Assemblages	Vessel Part													
	Rim		Neck		Shoulder		Upper Body		Lower Body		Base		Indet. Body	
	g ¹	% ²	g	%	g	%	g	%	g	%	g	%	g	%
5MT2193	264	0.0	95	16.6	5	0.0	86	0.0	17	0.0	24	0.0	1806	0.0
5MT4671	626	12.6	213	11.3	122	0.0	388	0.0	434	0.0	558	0.0	3697	0.1
5MT3868	698	46.0	629	66.8	274	29.5	281	10.0	293	0.0	282	0.0	4906	0.0
5MT8371	63	86.1	383	100	59	93.2	121	21.0	69	0.0	167	0.0	705	8.1
5MT1786	354	94.5	175	92.0	0	0	545	67.2	202	98.5	26	100	2015	75.3
5MT8827	280	100	273	100	151	100	542	100	527	100	264	88.3	1446	93.3

¹Includes total weight of pottery identified to this vessel part category in each assemblage

²Percentages based on weight of pottery with exposed coils calculated separately within each vessel part category for each assemblage.

Indet. = Indeterminate.

In presenting a more detailed account of the development of corrugation, I begin with a presentation of the evidence for how the early plain vessels and the plain portions of later vessels were formed. This is followed by a discussion of each of the innovations in forming techniques that led to corrugation. These innovations include changes in the techniques of coil application, and the manipulation of coils during and after their attachment to the vessel body.

Plain Surface Forming Techniques

Archaeologists commonly assume that plain-surfaced pottery in the Mesa Verde region was constructed from coils, which were then scraped to form the vessel (Blinman and Wilson 1988b; Breternitz *et al.* 1974). However, very little empirical evidence has been brought to bear on the issue. Examination of broken vertical edges of plain surface pottery in the six gray ware assemblages revealed several cases in which the join between adjacent construction elements (coils or slabs) was clearly visible from the orientation of large particles and pores. For the earlier assemblages, in which plain surface pottery is much more common, all observed joins or junctions were filleted or stacked rather than overlapping. However, in no cases were both lower and upper edges of a construction element visible in a single sherd. At least one sherd from 5MT4671 (Periman Hamlet) preserves slightly over 2 cm of vessel wall above a coil/slab junction. This suggests that, at least in the earlier pottery, construction elements were relatively large, and either pinched up or applied as broad, flattened segments.

Fracture pattern data also suggest that construction elements, whether considered slabs or coils, were relatively wide during the eighth and ninth centuries AD, and became smaller after that time. Table 3 shows the frequencies of random and non-random (cubic and stepped) fractures and the association between sherd size (as measured by maximum sherd length) and fracture pattern in the six gray ware assemblages. The high proportion of random fractures and significant association between fracture pattern and sherd size in the earliest three assemblages (5MT2193, 5MT4671, and 5MT8368) suggest that most of the sherds in these assemblages are smaller than the size of the coil or slab from which the vessel wall was constructed. The increase in non-random fractures and breakdown in the association between sherd size and fracture pattern in the tenth and eleventh centuries without a significant increase in sherd size indicates a smaller size of the coil from which the vessel was constructed.

Table 3. Association between fracture pattern and sherd size for plain-surfaced pottery in the six utility ware assemblages from the Mesa Verde region.

Assemblage	Fracture Pattern	Maximum Sherd Dimension			Total	Chi-Square	Sig. Level
		<20mm	>20mm & <40mm	>40mm			
5MT2193	Random	31	133	60	224	13.1	.001
	Nonrandom	4	31	34	69		
5MT4671	Random	38	324	196	558	11.0	.004
	Nonrandom	3	55	59	117		
5MT3868	Random	204	670	202	1076	17.2	<.001
	Nonrandom	18	132	57	207		
5MT8371	Random	7	86	19	112	0.1	.940
	Nonrandom	4	47	12	63		
5MT1786	Random	33	70	19	122	0.0	.999
	Nonrandom	14	30	8	52		
5MT8827	Random		7	6	13	0.2	.687
	Nonrandom		2	1	3		

Nonrandom fracture pattern includes cubic and stepped fractures. N equals count of sherds.

Table 4. Abundance of different surface forming marks on plain-surfaced utility ware pottery in the six utility ware assemblages from the Mesa Verde region.

Forming Marks	Surface	Assemblages											
		SMT2193		SMT4671		SMT3868		SMT8371		SMT1786		SMT8827	
		g	%	g	%	g	%	g	%	g	%	g	%
Scrape Marks	Interior	2148	99.2	5610	99.5	5723	98.4	951	99.8	706	99.8	128	93.4
	Exterior	2248	99.2	5774	98.8	6065	96.1	926	97.7	695	99.3	99	75.0
Wipe Marks	Interior	17	0.8	21	0.4	45	0.8	2	0.2				
	Exterior	17	0.8	44	0.7	86	1.4	11	1.1				
None	Interior			6	0.1	47	0.8			1	0.2		
	Exterior			15	0.3	135	2.1	6	0.6	5	0.7	22	16.3
Pinch Marks	Interior											9	6.6
	Exterior					15	0.2	2	0.2			12	8.7
Other	Interior												
	Exterior	2	0.1	11	0.2	13	0.2	3	0.3				

Percentages calculated separately for each surface.

Surface features and core structure can provide information on how the vessel wall was manipulated after primary construction elements were applied. Tables 4 and 5 show the frequencies of surface features and core structure respectively for the six gray ware assemblages. Sherds displaying scrape marks on both surfaces dominate plain-surfaced pottery in all assemblages. Irregular core structures dominate all assemblages except Gnatsville (SMT1786), while laminated structures, which might result from forming with a paddle, are rare in all assemblages. The variation that does exist in core structure among assemblages shows no clear temporal trend that might be related to the development of corrugation. My experience in pottery replication suggests that the greater occurrence of blocky and homogeneous core structures in the Gnatsville assemblage may be due to differences in composition or preparation of the clay. However, more focused and controlled experiments are necessary to further clarify the causes of these differences in core structure.

Table 5. Abundance of different core structures in plain-surfaced pottery in the six utility ware assemblages from the Mesa Verde region.

Assemblages	Core Structures								Totals g
	Irregular		Laminar		Blocky		Homogeneous		
	g	%	g	%	g	%	g	%	
5MT2193	2093	91.7	138	6.0	38	1.6	15	0.7	2289
5MT4671	4316	72.7	1030	17.3	513	8.6	81	1.4	5940
5MT3868	5919	90.6	324	5.0	169	2.6	120	1.8	6532
5MT8371	740	74.5	156	15.7	74	7.4	23	2.3	993
5MT1786	199	27.5	102	14.1	273	37.7	149	20.6	722
5MT8827	125	91.2	10	7.1			2	1.7	137
Totals	13397	80.6	1761	10.6	1066	6.4	390	2.3	16614

Techniques of Corrugation

The manufacture techniques used for vessels or portions of vessels with exposed coils vary in the way coils were applied, the height of the exposed coil, the depth of the exposed junction between coils, and the manipulation of the exposed coil surface during and after coil application. In the analysis of the six gray ware assemblages, I measured several attributes designed to document variation and change in these four aspects of exposed coils. In this presentation of the results of these analyses, I first discuss nature and temporal distribution of

each of the dimensions of variation separately, and then consider patterns in their covariation through time.

Exposed coils were applied by either filleting or overlapping. In filleting, coils are stacked on top of one-another with no significant overlap between adjacent coils. In overlapping, coils are applied at an angle so that the upper coil covers or overlaps some of the surface of the coil below. These coils, whether filleted or overlapped, can be applied either in concentric rings or in a spiral fashion simulating a single continuous coil to build up the vessel wall. Previous studies of complete vessels have shown that early exposed coils were applied using the concentric ring technique while later corrugated vessels were built with the spiral technique (Breternitz et al. 1974; Kidder and Shepard 1936; Morris 1939:186). The nature of the transition between these two techniques has never been adequately documented. However, because it is extremely difficult to discern concentric and spiral applications from vessel fragments, I was not able to document it in my analyses and will not discuss it further here.

Table 6. Abundance of filleted and overlapped exposed coils in the six utility ware assemblages from the Mesa Verde region.

Assemblage	Coil Application				Totals	
	Filleted		Overlapped		g	%
	g	%	g	%	g	%
5MT2193	16	100			16	100
5MT4671	77	71.2	31	28.8	108	100
5MT3868	607	74.4	208	25.6	815	100
5MT8371	138	26.0	393	74.0	531	100
5MT1786	3	0.1	2482	99.9	2485	100
5MT8827			3286	100	3286	100
Totals	840	11.6	6401	88.4	7241	100

Table 6 shows the abundance of filleted and overlapped coils in the six assemblages. The few fragments with exposed coils in the earliest assemblage are all filleted. Overlapped coils make up slightly less than 30 percent of assemblages dating to the ninth century. Overlapped exposed coils increased to almost 75 percent in the tenth century, and reached 100 percent in the eleventh century. Among overlapped coils, the amount of overlap between adjacent coils also increased through time. In the ninth century, most coils had less than 50 percent overlap while in the eleventh century, most coils overlapped more than 50 percent (Figure 8). Not only did

overlapping replace filleting as a coil application technique, but the degree of overlapping itself became more pronounced through time.

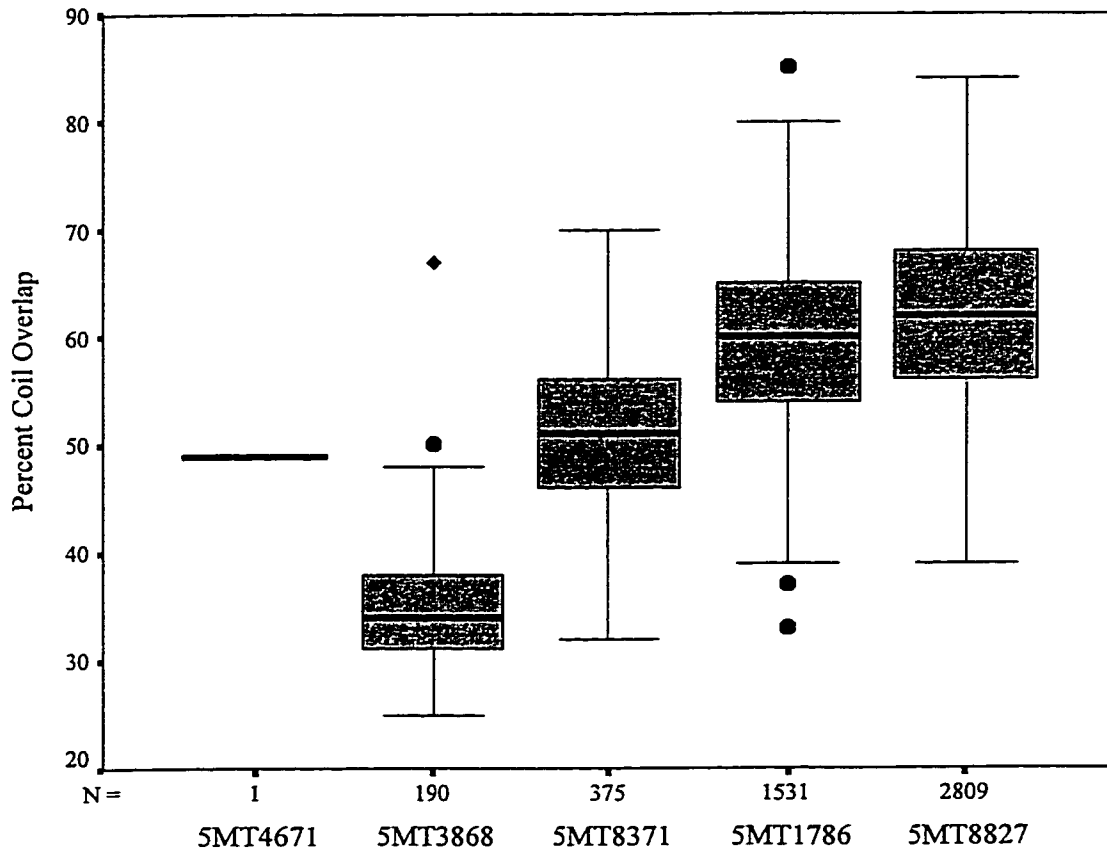


Figure 8. Box plot of the percentage of overlap between adjacent exposed coils in the six utility ware assemblages from the Mesa Verde region (N = grams of pottery).

Variation and change in the visible height of exposed coils follows a similar temporal pattern to coil application (Figure 9). During the eighth and ninth centuries, exposed coils were usually more than 10 mm high, although displaying considerable variation. In the tenth century, coil height decreased abruptly with most coils substantially less than 10 mm in height. This pattern of narrow exposed coils persisted into the eleventh century as the median and variation in coil height continued to decrease, although more gradually. A trend toward decreased exposed coil height has also been well documented for neck-banded pottery analyzed as part of the Dolores Archaeological Program (Blinman 1984). The decrease in coil height during the tenth century occurred in two ways. Increased use and degree of overlapped coil application resulted in

less of each coil remaining exposed on the surface, and some filleted pottery was made with smaller coils than were used earlier. These small filleted coils disappear in the eleventh century, and increased overlapping accounts for the continued decrease in coil height during that time.

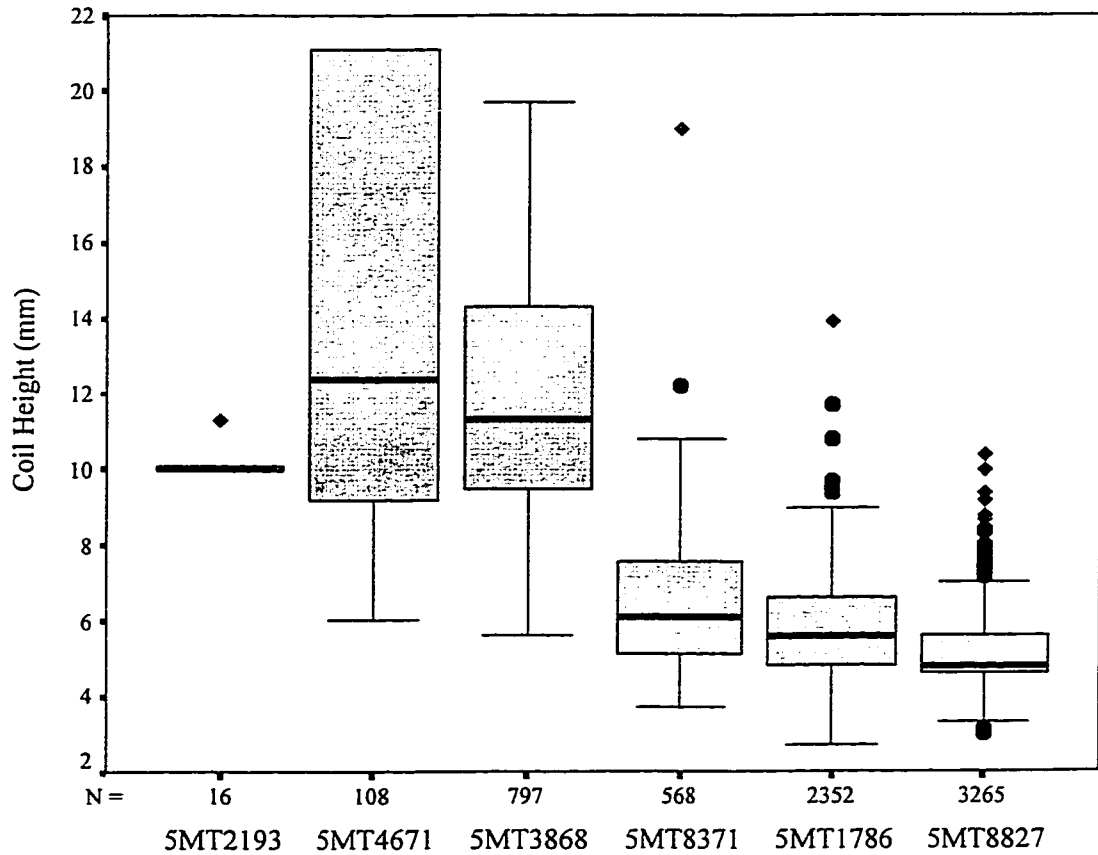


Figure 9. Box plot of the height of exposed coils in the six utility ware assemblages from the Mesa Verde region (N = grams of pottery).

The junction depth measurement was used to record two different attributes. For filleted coil pottery, junction depth refers to the depth of the depressed line or zone marking the join between two coils below the maximum height of the adjacent coils. For overlapped coil pottery, junction depth measures the degree of clapboarding, or the distance between the highest point on the ridge of a coil and the surface of the coil that it overlaps. Figure 10 shows the median and variation in junction depth for filleted and overlapped coils in the six assemblages. Both the filleted junction depth and degree of clapboarding increased through time. Although, the median degree of clapboarding in the Gnatsville (SMT1786) assemblage is less some earlier assemblages, it is difficult to determine if this is representative of a general trend in early eleventh century

pottery, or a consequence of sampling error. For filleted coils, the increase in junction depth probably came mainly from the greater use through time of narrow, rounded coils in place of broad, flattened coils, and thus, creating a deeper depression between adjacent coils. The more pronounced clapboarding through time, particularly in the latest assemblage, probably reflect the use of deeper indentations which would push up the surrounding clay and result in a greater distance between the ridge peak and the coil below.

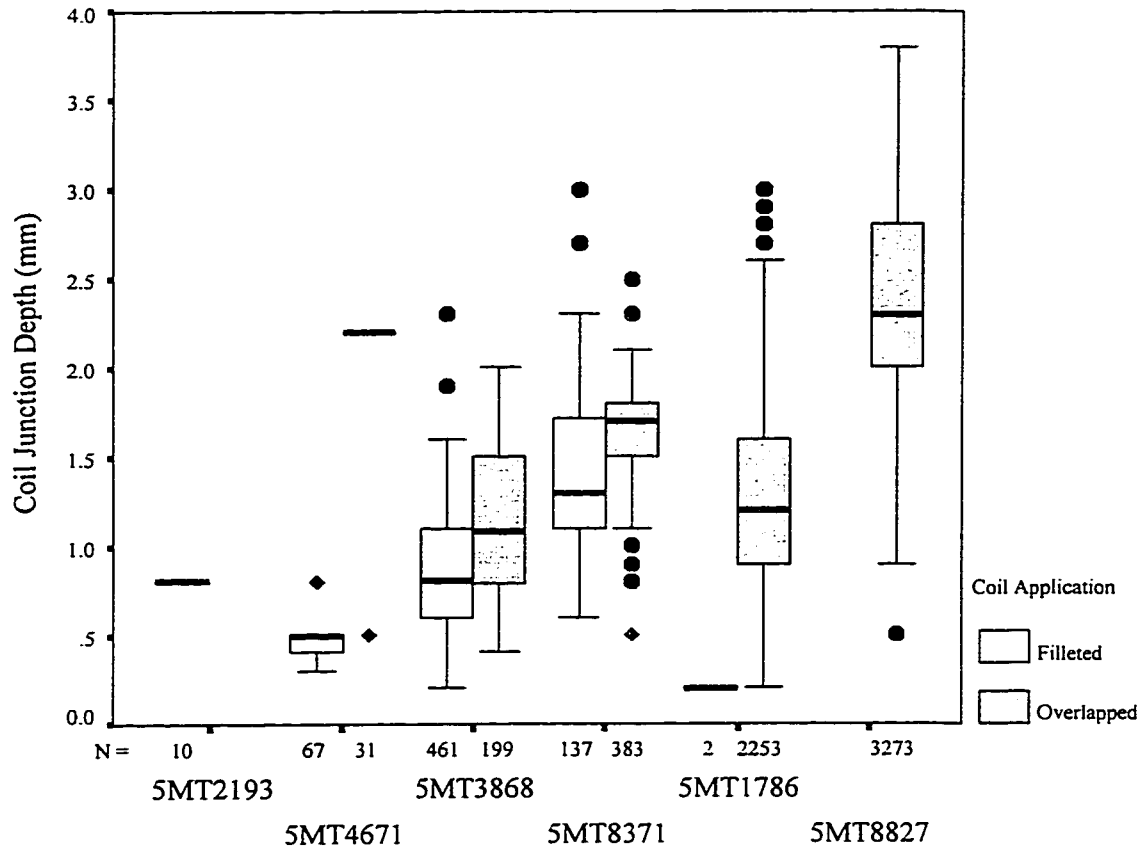


Figure 10. Box plot of coil junction depth for filleted and overlapped exposed coils in the six utility ware assemblages from the Mesa Verde region.

Table 7 presents the data on the different ways in which the surface of exposed coils were manipulated in the six assemblages. In the assemblages dating to the eighth and ninth centuries, most of the coil surfaces were pinched, scraped, or wiped probably during application. In the late ninth century, tool incising along coil joins appeared for the first time, and, in the tenth century, indenting of coil surfaces began. In both cases, these forms of coil manipulation occurred first on relatively few pieces. Most exposed coils were left unmanipulated through the middle of the tenth

century. By the early eleventh century, indentations occurred on almost 90 percent of exposed coils. Figure 11 shows that the spacing between indents was erratic and relatively wide during the tenth century, but became more closely and consistently spaced in the eleventh century. In addition, indentations occur mostly just below the rim on the last three or four coils applied to the vessel during the tenth century (Figure 12), and thus, probably began as a decorative elaboration.

Table 7. Abundance of different manipulations of exposed coil surfaces in the six utility ware assemblages from the Mesa Verde region.

Assemblages	Coil Manipulation												Totals g	
	Indented		Pinched		Scraped		Wiped		Incised		None			
	g	%	g	%	g	%	g	%	g	%	g	%		
SMT2193			10	65.8			5	34.2						16
SMT4671			62	57.7	30	27.5	7	6.2			9	8.6		108
SMT3868			34	4.0	204	24.2	311	36.9	49	5.9	244	29.0		843
SMT8371	66	11.4	19	3.3	14	2.4	2	0.3	135	23.5	340	59.1		575
SMT1786	2406	91.9	32	1.2	17	0.7	16	0.6	5	0.2	141	5.4		2617
SMT8827	2944	87.8	140	4.2	137	4.1	11	0.3			122	3.6		3354

Rounding error has produced small discrepancies in the totals.

To examine the relationships among the different exposed coil dimensions, I created a paradigmatic classification using selected attributes of three of the dimensions—coil application (filleted, overlapped <50 percent, or overlapped >50 percent), coil height (>10mm or <10mm), and indentation (present or absent). Of the 12 possible classes defined by this paradigm, only nine classes have members identified among the sherds in the six gray ware assemblages. Figure 13 shows the changes through time in the relative abundance (quantified by weight) of pottery in the nine different exposed coil classes. A majority of the exposed coils manufactured during the eighth and ninth centuries consisted of wide filleted coils without indentations. During the ninth century, however, narrower filleted coils and wide coils with slight overlap began to be manufactured in small to moderate amounts. In the tenth century, variation in the construction of exposed coils reached its zenith, and the most abundant class shifted to narrow, substantially overlapped coils without indentations. Although no single variant accounts for more than 40 percent of the assemblage from the tenth century, three different varieties of narrow, unindented coils make up more than 80 percent of exposed coils. By at least the early eleventh century, one of the variants, narrow, substantially overlapped, and indented coils, which appeared in low frequencies for the first time in the tenth century, almost completely replaced all others. The

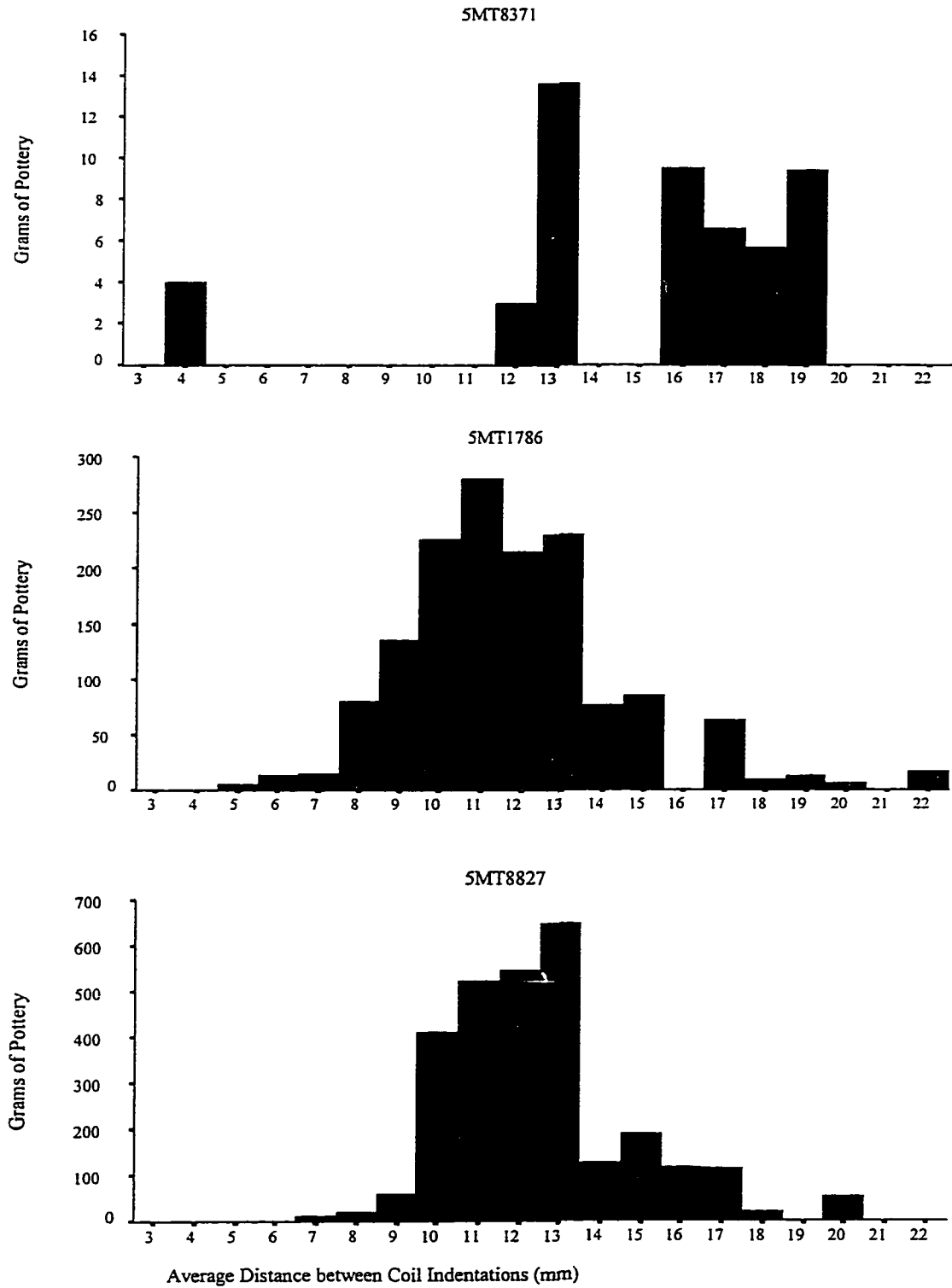


Figure 11. Histograms of the spacing of indentations on exposed coils in the latest three utility ware assemblages from the Mesa Verde region.



Figure 12. An example of early indenting on neck-banded pottery from the Mesa Verde region (Site 5MT4475, RC1, Anasazi Heritage Center).

abrupt increase in this class of exposed coils marks the adoption of indented corrugation. This also coincides with the spread of exposed coils over the entire exterior surface of most gray ware vessels. These data show conclusively that there was historical continuity in the development from vessels with entirely plain exterior surfaces, through various forms of neck banding, to full-body indented corrugation. In addition, the data document the gradual accumulation of innovations in the manufacture of exposed coils through the tenth century followed by the nearly complete fixation of one combination of these innovations, indented corrugation, by the early eleventh century in the Mesa Verde region.

The Spread of Corrugation in the American Southwest

Documenting the spread of corrugation technology on the basis of published information is a formidable undertaking. Given that one must rely, for the most part, on pottery type data from diverse regions of the Southwest, two hurdles present themselves. The first has to do with dating. Ideally, one reconstructs the spread of corrugation based on independent, absolute dates of the earliest appearance of a particular corrugation type, or technique, in different areas of the Southwest. However, many areas of the Southwest lack adequately dated pottery assemblages that span the entire sequence of changes. Consequently, the beginning and ending dates for many

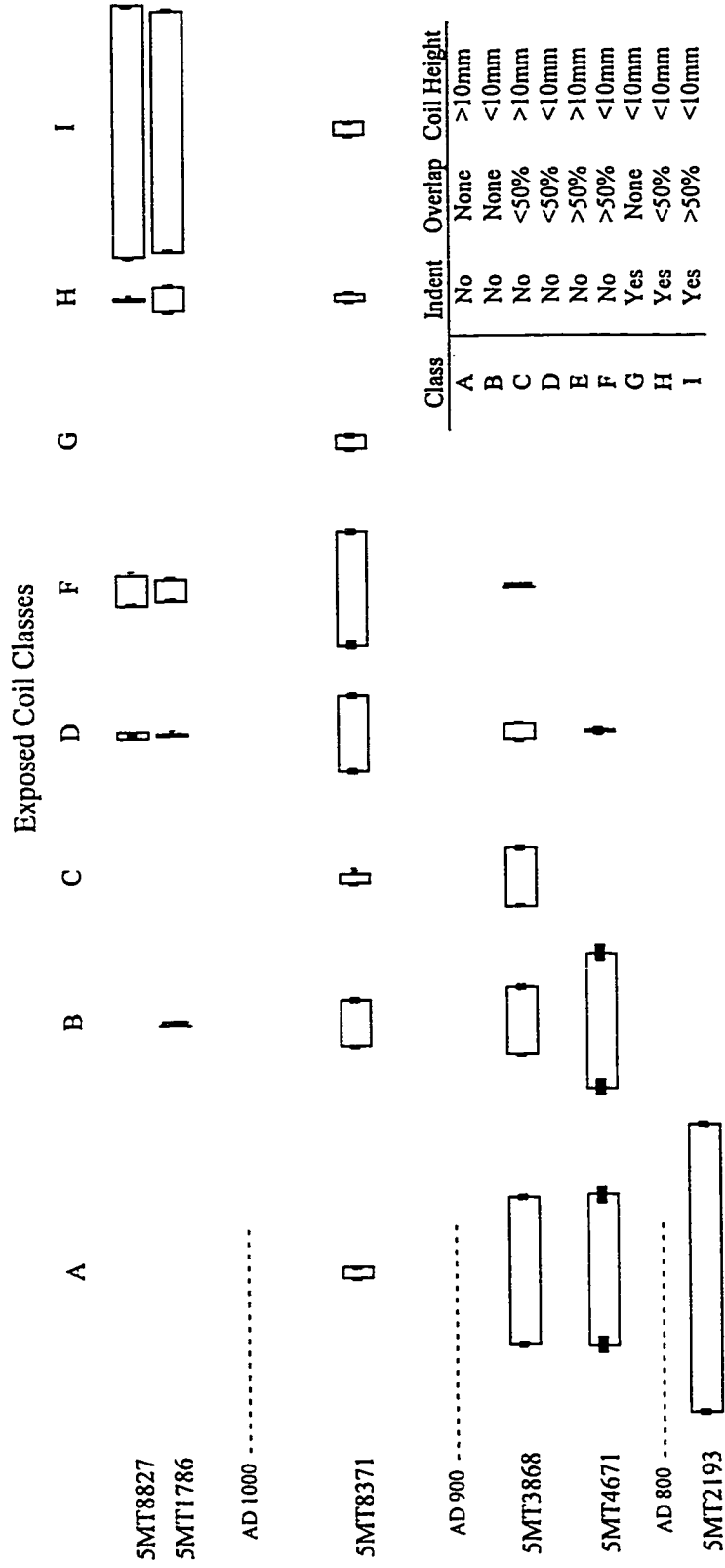


Figure 13. The relative abundance, by weight, of pottery assigned to different classes of exposed coils in the six utility ware assemblages from the Mesa Verde region. Class E is represented by only 6 grams of pottery from 5MT3868. Error bars = 90% confidence intervals. Class A in the assemblage from 5MT2193 is 100%.

pottery types are based on cross dating with other regions. While often useful for general chronological purposes, cross dating can introduce problems when one is trying to determine if a particular kind of pottery is slightly earlier or later in one region than another. The second hurdle involves the use of numerous different typological schemes across the Southwest. Pottery type names and descriptions can vary considerable from one region to another making it difficult, in some cases, to be sure that one is dealing with the same technology. Utility wares have not generally been accorded the kind of intense scrutiny often given to painted pottery in the Southwest. This lack of attention means that many dating and typological discrepancies and subtleties have gone unexamined or undocumented. As a result of these issues, the reconstruction of the spread of corrugation across the Southwest I present here should be considered tentative, and subject to alteration as new data come to light and more thorough evaluations of existing data are conducted.

The earliest evidence of any type of corrugation, or exposed coil technology in the American Southwest is during the middle to late seventh century AD in the southern Mogollon or Mimbres region of New Mexico (LeBlanc 1982; Wasley 1960). This pottery, referred to as Alma Neckbanded, is very similar to the earliest pottery with exposed coils in the Mesa Verde region and elsewhere in the northern Southwest. The unobliterated coils are relatively wide and non-overlapping, and they are restricted to the neck region of jars (Haury 1936; Hawley 1950). The main difference between Alma Neckbanded and the early neck banded pottery of the northern Southwest is that the Alma Neckbanded is a brown ware pottery made from iron-rich clay and fired in an oxidizing atmosphere. The northern neck-banded pottery, referred to as Kana'a or, in the Mesa Verde region, Moccasin Gray, is a gray ware fired in a reducing atmosphere.

The Alma Neckbanded technology, if not the pottery itself, spread north and west, appearing in the Quemado area of west-central New Mexico (Mills 1987; Wasley 1959) and the Forestdale Valley of east-central Arizona (Haury 1940a, 1940b) during the early part of the eighth century (Figure 14). In the Quemado area, both Alma brown neck banded and Kana'a gray neck banded pottery occur, but the Alma type appears earlier than the Kana'a type. The Kana'a style gray neck banding technology appears to have spread north across the Zuni and Puerco (of the west) Rivers, through the Hopi and Kayenta areas west of the Chuska Mountains, into the Mesa Verde and Gobernador regions to the north and east, and west into the Flagstaff, Grand Canyon and Virgin River areas (Figure 14). In each of these regions, with the possible exception of the Grand Canyon and Virgin River areas, this earliest form of corrugation appears to be

reasonably well dated to the late eighth or early ninth centuries (Breternitz 1966; Breternitz et al. 1974; Colton and Hargrave 1937; Dittert et al. 1961; Eddy 1966; Hall 1944; Harlan 1962; Hays-Gilpin and van Hartesveldt 1999; Layhe 1984; Plog 1984). The presence of Mogollon-like brown wares in early ceramic assemblages from the Colorado Plateau (Wilson and Blinman 1994), and greater than expected population growth in some parts of the Plateau during the eighth century (Schlanger 1986) suggest that migrations of people north out of the Mogollon region may have played an important role in the rapid spread of Kana'a style neck banding. However, the evidence for migration is not yet conclusive (Wilson 1988a).

After a delay of 50 to 100 years, Kana'a style neck banding spread into the southern San Juan Basin on the east side of the Chuska Mountains, and then into the Rio Puerco (of the east), Jemez and middle Rio Grande valleys (Figure 14). Recently reported evidence from the southern Chuska Valley (Freuden 1996; Loebig 1996; Reed et al. 1996; Stirniman and Yost 1996) and Chaco Canyon (Toll and McKenna 1997) date the earliest appearance of neck-banded pottery to the late ninth century. Although the first neck-banding is not as well dated in the Puerco/Rio Grande area, Kana'a style pottery does post date AD 800, and probably appeared closer to the turn of the tenth century (Durand and Hurst 1991; Hurst 1991; McNutt 1969; C. Dean Wilson, personal communication). It took even longer for neck banding to reach the Taos and Gallina areas of northern New Mexico where the technology appears to post date AD 1000, and never became a significant part of the utility ware tradition (Hibben 1949; Mera 1938; Wilson 1995; Wilson and Lakatos 1997).

The delayed appearance of neck-banding in the southern San Juan basin and Rio Grande areas suggests that these areas were isolated from the contacts, either migration or diffusion, that led to the initial spread of exposed coil technology into the northern Southwest. The delayed appearance of certain styles of painted pottery (e.g., Reed et al. 1996) supports the notion that these areas were isolated from interaction with other areas of the Southwest, rather than some other mechanism inhibiting the movement of utility ware technologies alone. This isolation broke down in the late ninth century when a drought and prolonged period of short growing seasons (Dean 1988; Peterson 1988) resulted in substantial population declines in the Mesa Verde region and elsewhere in the northern Southwest (Berry 1982; Nichols and Smiley 1984; Schlanger 1986; Wilshusen and Schlanger 1993; Wilshusen and Varien 1996). At the same time, population increased in the southern San Juan basin and Rio Grande areas, probably as a result of immigration from the areas to the north being partly or wholly abandoned (Baker and Durand

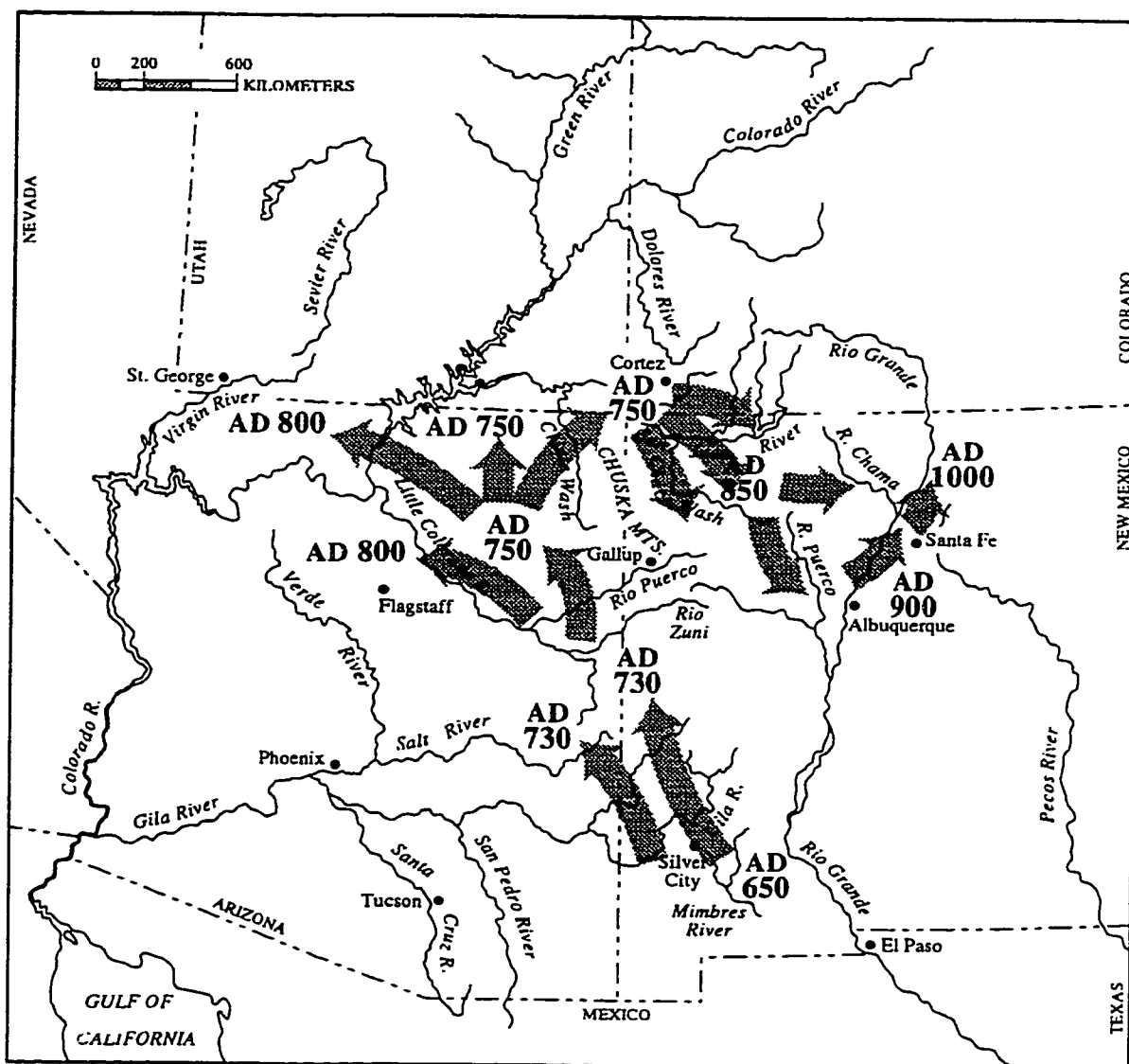


Figure 14. Map showing a reconstruction of the spread of early neck banding in the American Southwest.

1991; Hayes 1981; Kearns 1997; McNutt 1969; Wilshusen 1995; Windes 1987). Consequently, it appears that a substantial southward migration out of the upper San Juan basin during the late eighth and early ninth centuries may account for the introduction of neck banding into the southern San Juan and Rio Grande areas.

Despite the variable introduction of Kana'a style neck banding into different parts of the Southwest, the development of narrow filleted and overlapping coils and some form of indentation appears to have occurred in several places at more or less the same time during the

late ninth to mid tenth centuries. However, the dating of the individual innovations is extremely poor. One of the reasons for the poor dating is that the current typologies tend to lump all of these features into a single transitional utility ware type. By combining these features into single types with long temporal spans, it makes it extremely difficult to date the introduction of any one innovation as I did earlier in this chapter for the Mesa Verde region. The most common of these types include Medicine Gray west of the Chuska Mountains (Colton and Hargrave 1937; Colton 1955), Mancos Gray in the northern San Juan region (Breternitz et al. 1974), Tohatchi Banded in the southern San Juan basin area (Wendorf et al 1956; Windes 1977; Reed et al. 1996), and Three Circles Neck Corrugated in the eastern Mogollon region (Haury 1936; Hawley 1950). Based on current evidence, it appears that these innovations (narrow overlapped and filleted coils, and indenting) may have occurred first in the eastern Mogollon region, but this is by no means a secure conclusion.

The development of substantially overlapped and systematically indented pottery (indented corrugation), and the use of these techniques over the entire exterior vessel surface are more easily dated because this combination of attributes has tended to be distinguished by specific pottery types. The regular use of indented corrugation may have occurred first during the middle of the tenth century, in and around the Chaco Canyon and Chuska Valley areas of the southern San Juan basin. This dating is based on unusually high frequencies neck corrugation (overlapped and indented coils restricted to the neck portion of jars) in comparison to other areas of the northern Southwest, and a firm association of neck and full-body corrugation with Red Mesa Black-on-White, a painted pottery style manufactured during the tenth century at Chaco Canyon (McKenna and Toll 1984; Toll and McKenna 1997; Windes 1977).

The regular, and often exclusive, use of full-body indented corrugation on utility wares spread rapidly across most of the Colorado Plateau from the likely center of development in the southern San Juan basin (Figure 15). Full-body corrugation rapidly replaced neck banding between 1030 and 1060 AD from the Virgin River region on the west to the Rio Puerco (of the east) on the east, and from the Mesa Verde region in the north to the Rio Puerco (of the west) and San Jose River in the south (Breternitz 1966; Breternitz et al. 1974; Hays-Gilpin and van Hartesveldt 1995; Hurst 1991; Larson and Michaelson 1990; McKenna and Toll 1984; Plog and Hantman 1986; Reed et al. 1996; Toll and McKenna 1997). Indented corrugation on a variety of vessel forms also appears for the first time during the latter half of the eleventh century in the

Fremont area of southern and western Utah and eastern Nevada without any clear neck banded antecedent (Dodd 1982; James 1986; Lohse 1981; Madson 1970, 1979, 1986; Steward 1936).

Indented corrugation was adopted slightly later, during the middle of the twelfth century, in the far southern Colorado Plateau, the eastern and western Mogollon regions, the Sinagua region, and the middle Rio Grande Valley, and later still, during the early thirteenth century, in the Taos area indicating a slower south and eastward spread of the technology (Anyon and LeBlanc 1984; Barter 1957; Brunson 1985; Crown 1990; Doyel 1978; McGimsey 1980; McNutt 1969; Mills 1987; Rinaldo and Bluhm 1956; Stark 1995a; Tuggle 1982; Wetherington 1968; Wilson 1995; Wilson and Lakatos 1997). In the Rio Grande, Mogollon, and southern Sinagua areas, full-body corrugation existed side-by-side and in combination with a wide variety of other kinds of utility ware technologies including neck banded, incised, punched, plain, and smudged vessels. In the western Mogollon/Sinagua region, the appearance of indented corrugation during the eleventh century marks the first use of corrugation techniques in this area (Stark 1995a). Although some corrugation occurs in Classic Period (post AD 1150) Hohokam settlements in the Sonoran Desert of southern Arizona, the distributions are spotty, and frequencies tend to be quite low in comparison to other kinds of utility wares (e.g., Jewett 1986; Wood and McAllister 1982). Migration, trade, and large-scale socio-political integration or affiliation may have been involved in the rapid spread of full-body corrugation. Improved climatic conditions together with the adoption of new, intensified agricultural practices in the late tenth through the middle twelfth centuries, resulted in unprecedented population growth and territorial expansion by Puebloan agriculturalists in the American Southwest (Dean 1996; Dean et al. 1994; Dean et al. 1985; Gumerman and Gell-Mann 1994). This demographic surge is known as the Pueblo II expansion. The eleventh century demographic upturn also coincided with the possible development of the first large-scale economic, social, political and ideological integration in the Colorado Plateau area, commonly referred to as the "Chacoan regional system" (Crown and Judge 1991; LeBlanc 1989; Lekson et al. 1988). Although degree of integration in the Chacoan regional system may be overdrawn (Durand 1992), the generally accepted boundaries of this entity roughly correspond with the area of rapid spread of full-body corrugation with the exception of the far western and northern extensions. The eleventh century also provides the first secure evidence for specialized production and long-distance trade of utility ware pottery. In the early eleventh century, corrugated pots produced along the eastern flanks of the Chuska Mountains constitute half of all culinary pottery recovered from settlements in Chaco Canyon located over 90 km to the east (Toll

1991). This level of movement of culinary pottery into Chaco Canyon represents a dramatic increase over earlier periods.

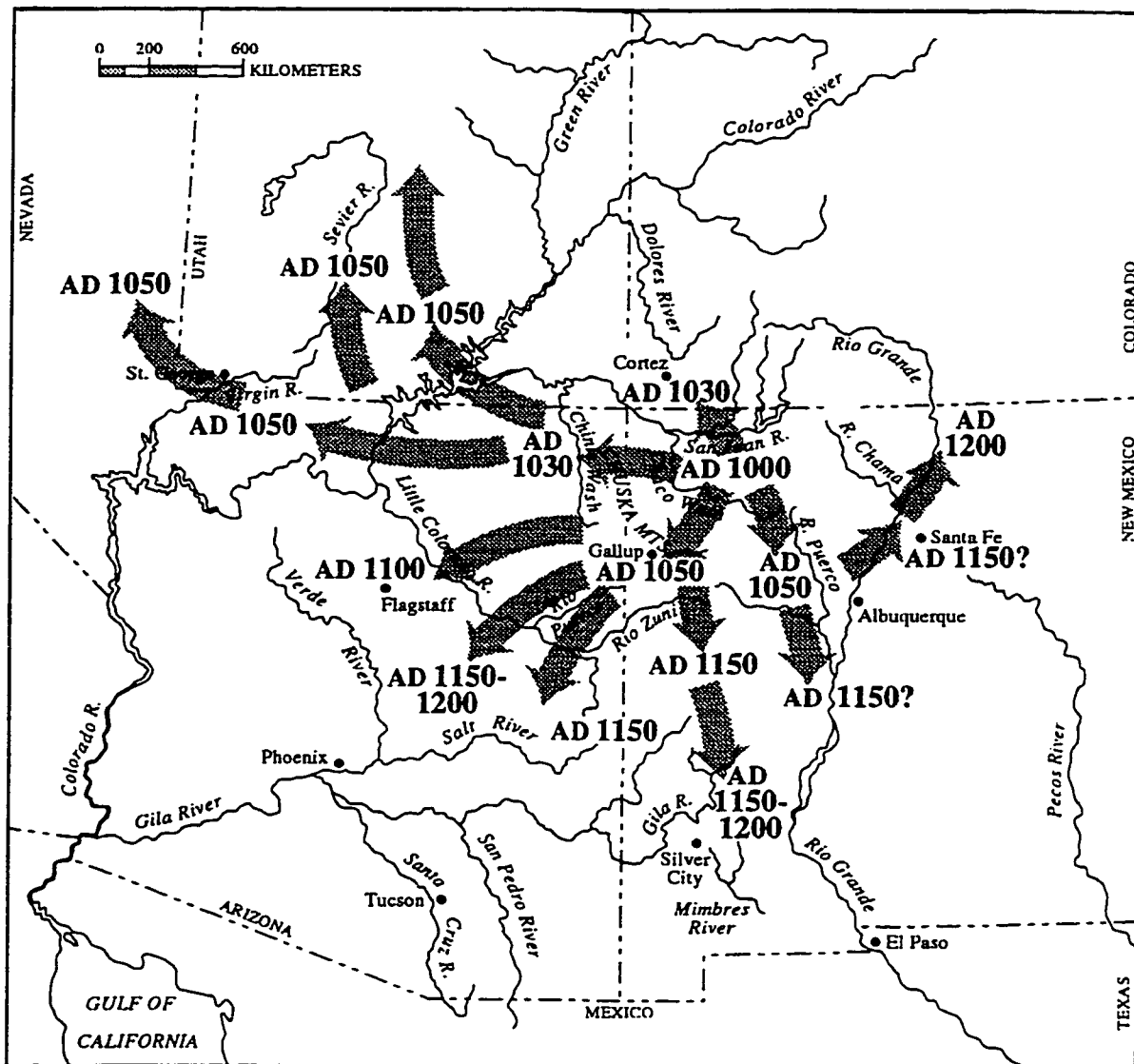


Figure 15. Map showing a reconstruction of the spread of full-body, indented corrugation in the American Southwest.

Evidence from the Mesa Verde region suggests that the population expansion and increased trade of culinary pottery during the late tenth and early eleventh centuries played a role in the relatively rapid spread and adoption of full-body corrugation in that area. Although the late ninth or very early tenth centuries saw the abandonment of most of the Dolores River valley (Blinman 1994; Kane 1986), some sites show signs of reoccupation by small groups in the late

tenth century. At McPhee Village, one of the large ninth century settlement clusters in the Dolores valley, two of the settlements (McPhee Pueblo and nearby Masa Negra Pueblo) were reoccupied in the middle to late tenth century by approximately 13 households (Brisbin et al. 1988; Kuckelman 1988b). Indented corrugated fragments from vessel bodies were recovered from these late occupations at both settlements. In addition, these late tenth century ceramic assemblages contain unusually high proportions of pottery manufactured in the Chuska and Cibola areas of the southern San Juan basin (Blinman and Wilson 1988a). Whether this increase in nonlocal pottery resulted from immigration of people from the southern San Juan, or increased trade between the two areas has not been determined. However, regardless of the mechanisms involved, these data indicate increased interaction of some sort with the potential of transmitting the new trait of full-body corrugation.

In the Rio Grande areas, however, evidence suggests a more complex set of mechanisms involved in the spread of corrugation. At least some of the corrugated pottery made in the Rio Grande valley was manufactured differently from corrugated pottery found elsewhere. Although the general appearance is similar, the forming techniques differed in an unusual way. Specifically, rather than applying and overlapping coils so that they slope down and away from the vessel as was done in the Mesa Verde region and elsewhere in the Southwest, some potters in the Rio Grande area applied their coils so that they overlap toward the inside of the vessel (Eric Blinman, personal communication). One possible reason for this difference is that the spread of corrugation into the Rio Grande involved the movement of pottery rather than the specific knowledge or instructions on how to make corrugated vessels. In evolutionary terms, it was the pottery that was the replicator in some cases, rather than particular behaviors or ideas.

In addition, recent research on eleventh and twelfth century Valdez Phase sites in the Taos area indicates that, although plain pottery dominates utility ware assemblages, a wide variety of corrugation techniques, including Kana'a style neck banding to indented corrugation, occur in very low frequencies (usually less than 1% of utility wares) at these sites (Wilson 1995). Some of this corrugated pottery appears to have been manufactured locally while others were imported. As noted above, indented corrugation was not a common feature of Taos area pottery until the thirteenth century. However, the designs on Valdez Phase painted pottery are very similar to those used at the same time farther south in the Rio Grande valley and on the Colorado Plateau to the west (Wilson 1995). These differences in the timing of the spread of painted designs and corrugation techniques indicate that simple migration or diffusion models cannot

account for their introduction. Instead, more complex political or social factors may have been involved in the spread of different pottery-making technologies to the Taos area.

In the Four Corners area, full-body indented corrugation continued to dominate utility ware assemblages until Pueblo people abandoned the region at the end of the thirteenth century. Indented corrugation also appeared on a small proportion of painted, white ware pottery; most commonly on the exterior of bowls during the eleventh century, and on the necks of narrow-mouth jars (ollas) during the thirteenth century. In the Mogollon areas and the Tonto Basin, corrugation of bowls was much more common than among Pueblo populations living on the Colorado Plateau. Full-body corrugation, in various forms, continued to be manufactured and, in most areas to dominate utility ware assemblages until, at least, the middle of the fifteenth century when Pueblo potters returned to making plain-surface utility vessels (Anyon and LeBlanc 1984; Gifford and Smith 1978:18; Hays 1991; Kidder and Shepard 1936; Lang 1982).

During the more than four hundred years that indented corrugation was used in the manufacture of utility wares, Pueblo society experienced a wide variety of changes including large-scale population movements, regional abandonments, and momentous changes in climate, social organization, and ideology (Adams 1991; Adler 1996; Dean 1996; Lipe 1989). After the large-scale adoption of full-body corrugation, the techniques used to produce corrugated vessels did not remain static, but continued to vary. Innovations came mainly in the areas of vessel morphology, and the elaboration of patterns created by the placement of indentations and appliques (Breternitz et al. 1974; Colton 1955; Gifford and Smith 1978). In addition, some plain utility vessels continued to be made throughout the period of dominance by corrugation, with some regions showing more variation than others. On the Colorado Plateau, most of these later plain types, such as Mummy Lake Gray in the Mesa Verde region and Kiet Siel Gray in the Kayenta region, were actually produced by smearing or obliterating corrugations (Breternitz et al. 1974; Colton 1955). In the late fourteenth and early fifteenth centuries, this long-standing, yet sporadically employed, technique of smearing corrugations became much more common and widespread. By the middle to late fifteenth century, pottery with smeared or blind corrugations was eventually replaced by entirely plain vessels (Kidder and Shepard 1936; Spier 1917). When the Spanish arrived in the Southwest during the sixteenth century, corrugation was not a part of the Pueblo pottery technology they observed.

CHAPTER 6: THE PRODUCTION AND USE OF PUEBLOAN UTILITY WARES

As discussed in Chapter 4, understanding the production and use of ancient plain and corrugated pottery provides crucial information on how the pottery interacted with different aspects of its environment during the development and spread of corrugation technology. By production, I refer to the conditions under which the manufacture of utility wares took place. These conditions include how potters learned their craft, technologies involved in the manufacture of utility wares, and aspects of the organization of utility ware production. In documenting the use of utility wares, I am concerned with the kinds and intensity of uses in which the manufactured vessels were employed.

Data on utility ware production and use come from two main sources: (1) analyses of the six assemblages from the Mesa Verde region, and (2) a review and synthesis of published information from the Mesa Verde region and elsewhere in the Puebloan Southwest. Consequently, this treatment focuses mainly on the Mesa Verde region. The extent to which the inferences regarding pottery production and use in the Mesa Verde region data are relevant to other areas of the American Southwest must be determined by future research.

Utility Ware Production

During the production process, utility ware vessels-in-the-making interact with a potentially complex environment including the learning and skill of the producers, other artifacts and technologies employed in utility ware production and competing for the same production resources, and the ways in which utility ware production was organized (Rogers 1995). How potters learned their craft and the skills needed to master a particular set of techniques can be important aspects of the environment in which utility ware technologies evolved. In the previous chapter, we saw that large-scale patterns of migration and other mechanisms of interaction affected the spread of various corrugation techniques. This is probably also true for patterns of interaction at much smaller spatial scales, such as within and between settlements (Zedeño 1995). The learning curves required by new pottery-making techniques and the ways in which they mesh with existing techniques and skills can also affect the development and adoption of new technologies. For example, corrugation techniques do not mesh well with production technologies in which vessels are formed with a paddle and anvil, a technique used in the Hohokam region, but not yet documented for the Anasazi. In addition, because pottery production involves time and energy costs, utility ware production must compete with other activities, particularly the production of other kinds of pottery, for potentially limited resources. Finally, the organization of

utility ware production, particularly the extent to which utility vessels were produced for exchange and the degree of production specialization by individuals or groups, can affect the development and spread of new technologies. If part or full time specialists produced utility ware for exchange rather than individual households producing these vessels for their own consumption, issues such as efficiency and economies of scale can come into play.

The Transmission of Pottery-Making Knowledge

Ethnographic observations of the transmission of knowledge of how to make pottery among historic and modern Pueblo potters indicates that most transmission occurred vertically from members of one biological generation to the next although not necessarily between biological parents and their offspring (Bunzel 1929; Guthe 1925; Stanislawski 1977, 1978). Bunzel and Stanislawski note that direct training in pottery making took place primarily within families and between biological generations (members of older generations teaching those of younger generations), and usually involved only the technological aspects of manufacture. Painted designs and other decorative treatments were learned through observation and imitation, which could involve a wide variety of models including whole or fragmentary pieces of the pottery itself. Where pottery was manufactured for exchange (in the historic and modern cases, for sale to non-Pueblo people), potters often copied the work of those who were the most successful. This kind of transmission played an important role in the rapid revitalization of white ware production at Hopi in the 20th century (Bunzel 1929; Danson 1965).

The archaeological record also provides some clues to the ways in which pottery-making knowledge may have been transmitted during the period of change from plain to corrugated pottery. Currently available evidence comes in two forms—settlement and community patterns, and the patterns of movement between areas with distinctive pottery-making traditions. Different ways of spatially organizing settlements and communities can affect the frequency of interactions among people involved in pottery manufacture, and thus the potential for inhibiting or promoting the transmission of pottery-making knowledge. For example, small, dispersed, more or less self-sufficient settlements that are only weakly associated with other settlements as parts of larger communities offer little opportunity for substantial transmission outside individual families. On the other hand, large settlements composed of many households and families, or tightly clustered smaller settlements participating heavily in a larger community offer many more opportunities for transmission among unrelated or distantly related individuals. In addition, if the rate of long distance movement of people involved in pottery production fluctuated, this could also affect the

ways pottery-making knowledge was transmitted. Periods of significantly increased short and long-distance mobility could increase the likelihood that new traits would be introduced into the populations or regions receiving these immigrants.

When neck-banding first appeared in the Mesa Verde region and elsewhere in the northern Southwest during the latter half of the eighth century AD, populations were relatively small and lived in dispersed, single household settlements (Kane 1986). Under these conditions, transmission of pottery-making knowledge was probably limited mainly to within families, and the spread of new traits occurring primarily through migration and exogamous marriage patterns. The potential for greater transmission increased as settlements grew to include multiple households in the ninth century and particularly when large villages (which may have included people who were not closely related) formed in the latter half of the ninth century in the Mesa Verde region (Kane 1986; Wilshusen 1991). With the apparent large-scale migrations and coalescence of populations in the southern San Juan basin during the late ninth and early tenth centuries, transmission among previously separate and isolated populations probably occurred. The possible formation of a large, integrated polity centered on Chaco Canyon, which apparently facilitated household mobility (Lekson 1996), during the tenth and eleventh centuries, probably also increased the potential for more, extra-familial transmission of pottery-making knowledge.

Pottery-Making Technologies

As discussed in Chapter 5, utility wares, in the Mesa Verde region at least, were all constructed by hand using coils or slabs. No pottery wheel technology existed in the Southwest prior to contact with Europeans (Peckham 1990). The use of a base mold or *puki* by Pueblo potters allowed vessels to be rotated during the application of coils, but with insufficient speed to produce thrown pottery. In addition, there is no clear or convincing evidence that a paddle and anvil technology was used to form the early plain utility wares. Simple rolling, pinching, and scraping appear to have been the core techniques used to form utility wares throughout the history of Pueblo pottery manufacture. These same methods were employed to form the painted pottery as well, with the addition of slipping, polishing, and painting techniques. No new or special technologies were required to manufacture corrugated pottery. However, full-body corrugated vessels may have required more skill on the part of the potters than plain or simple neck-banded pottery. This is because the corrugation technique allows less flexibility in the shaping the vessel than when making pottery that is scraped plain. When making a corrugated vessel, one must

shape the vessel at the same time the coils are applied. In contrast, plain vessels can be molded and shaped by pressure and scraping at any time before the clay hardens.

The production of utility wares differs from painted wares in terms of the selection and processing of raw materials. It is usually possible to distinguish utility wares from white, red, and polychrome wares on the basis of the texture of the paste alone. Most utility wares possess a very coarse-textured paste in comparison to the painted wares. The relatively coarse texture of utility wares is produced by using large, angular material for temper, and processing the paste in such a way that large pores are relatively common. Both coarse temper and abundant pores improve the ability of a pottery vessel to withstand thermal shock and other forms of catastrophic fracture (Bronitsky and Hamer 1986; Feathers 1989, 1990; West 1992). Although these textural differences appear very early in the Pueblo pottery-making tradition, in the Mesa Verde region the differences become more pronounced through time as the paste of painted wares becomes finer and the paste of utility wares becomes more consistently and completely coarse-textured (Breternitz et al. 1974).

Once the vessels were formed, they had to be fired to produce a useful ceramic. Very little published data exists on the firing of utility wares in the Mesa Verde region or elsewhere in the Southwest (e.g., Sullivan 1988). Although large, stone-lined kilns have been found in the Mesa Verde region, restorable utility ware vessels are conspicuously absent from most of these features (Joel Brisbin, personal communication; Fuller 1984; Helm 1973; Winter et al. 1977:14-15). Consequently, we still know very little about how utility ware vessels were fired, or if there were any changes in firing during the development of corrugation. By analyzing features of the pottery itself, we can gain some insight into this aspect of production.

Documenting the conditions under which ancient pottery was fired is fraught with difficulty because of the challenges involved in isolating and controlling the differential effects of temperature, atmosphere, and time on the physical responses of pottery (Feathers 1995). Rather than invest considerable resources in conducting complex and costly analyses that may not produce useful results, I decided to record two simple attributes on all sherds analyzed from the six Mesa Verde region collections that might indicate whether a change in firing regime occurred. If these studies indicate a change in firing took place, then the nature of this change can be more thoroughly investigated in the future. The attributes I recorded include the presence or absence of fire clouds on the interior and exterior surfaces of the vessel, and the patterns in the oxidation or reduction of the surface in relation to the core of the vessel wall.

The surface colors of the gray and white ware pottery produced in the American Southwest were obtained by firing in an atmosphere of limited oxidation. Because this atmosphere is difficult to control in primitive pit and surface firing, zones of over oxidation and over reduction frequently appear on the surfaces and in the cores of ancient pottery and in pottery replicated using similar firing technology. Dark, reduced cores can also occur if firing takes place very rapidly, even if the atmosphere of the kiln is oxidizing (Jim Feathers, personal communication). Thus, systematic changes in the occurrence of surface fire clouds and reduced or oxidized cores can indicate patterned alterations in the firing regimes employed. Although only the presence or absence of surface fire clouds was recorded, I recorded 14 different core color patterns, which are shown in Figure 16.

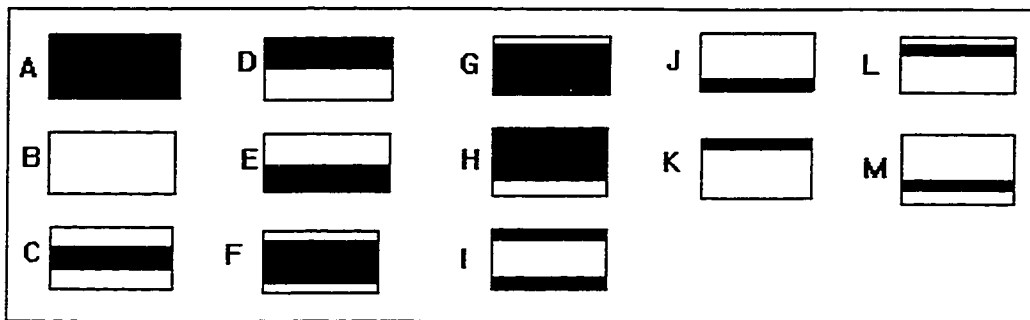


Figure 16. Diagrams of sherd core color pattern classification used in this study. Dark areas are reduced and light areas are oxidized portions of the sherd cross section. The upper side of each diagram refers to the exterior surface of the sherd, and the lower side is the interior surface.

Table 8 shows the data on the patterns of vessel core oxidation and reduction visible on a freshly broken edge. Table 9 shows the abundance of surface fire clouds in the six gray ware assemblages. Although presence of fire clouds remains fairly constant through time, variation in core reduction exists among the assemblages indicating a possible increase in the prominence or degree of reducing firing atmospheres through time. The abundance of reduced cores increased in the tenth and early eleventh centuries AD, but then appears to decrease again in the middle of the eleventh century. Unfortunately, this pattern is not consistent enough to rule out local variation rather than a clear temporal trend. The only comparable data come from the Dolores River Valley where gray ware jars show an almost ten fold increase in the amount of vitrification during the late ninth century AD (Blinman 1988b). However, we lack comparable data from the tenth and eleventh centuries.

Table 8. Abundance by weight of different core color patterns in the six utility ware assemblages from the Mesa Verde region.

Assemblage	Core Color Patterns												Totals
	No Reduced Core ¹		Central Core Reduced ²		Completely Reduced ³		Exterior Surface Reduced ⁴		Interior Surface Reduced ⁵		Both Surfaces Reduced ⁶		
	G	%	g	%	g	%	g	%	g	%	g	%	
5MT2193	1185	51.4	686	29.8	50	2.2	181	7.8	191	8.3	11	0.5	2305
5MT4671	3542	58.6	1339	22.2	224	3.7	604	10.0	253	4.2	81	1.3	6044
5MT3868	4302	58.5	1260	17.1	473	6.4	777	10.6	490	6.7	55	0.8	7358
5MT8371	569	36.4	273	17.5	137	8.8	365	23.4	169	10.8	49	3.2	1562
5MT1786	337	10.2	968	29.2	1115	33.7	385	11.6	499	15.1	8	0.2	3312
5MT8827	1632	46.7	1027	29.4	332	9.5	241	6.9	187	5.4	74	2.1	3493

Rounding error has produced small discrepancies in the totals.

¹Includes pattern B from Figure 16. ²Includes patterns C, F, L, and M from Figure 16. ³Includes pattern A from Figure 16. ⁴Includes patterns D, H, and K from Figure 16. ⁵Includes patterns E, G, and J from Figure 16. ⁶Includes pattern I from Figure 16.

Table 9. Abundance of fire clouds on interior and exterior surfaces of utility ware pottery in the six assemblages from the Mesa Verde region.

Assemblages	Presence of Fire Clouds			
	Interior Surface		Exterior Surface	
	g	%	g	%
5MT2193	275	11.9	248	10.8
5MT4671	538	9.0	860	14.2
5MT3868	998	13.7	1662	22.7
5MT8371	200	12.8	526	33.5
5MT1786	210	6.3	449	13.5
5MT8827	516	14.8	626	17.9
Totals	2738	11.4	4371	18.2

Percentages calculated separately for each surface.

Taken together, these data indicate a possible increase in control over firing regimes through time resulting in higher firing temperatures and more reducing atmospheres, both of which yield harder pottery. If this reconstruction is correct, the adoption of corrugation may have coincided with an increase in vessel hardness which may have made the vessels more brittle, and thus, susceptible to thermal shock and fatigue. However, the data are not conclusive and clearly more research on firing regimes is warranted.

Organization of Utility Ware Production

Although there are a variety of ways of analyzing the organization of pottery production (Costin 1991; Mills and Crown 1995b; Pool 1992), I am most interested in identifying any changes in the concentration and scale of utility ware production. Did each household produce its own utility vessels, or was there some degree of specialization in production for exchange? Differences in these modes of production organization have implications for how and why changes in gray ware manufacture occurred. Investigations of the organization of pottery production usually involve examination of both direct and indirect evidence. Direct evidence consists of the raw materials, tools, facilities, and by-products of manufacture while indirect evidence includes compositional and formal aspects of the pottery itself.

Differential distributions of direct evidence of utility ware manufacture prior to the ninth century AD in the Mesa Verde region indicates that there may have been some household level specialization in production (Blinman 1988b; Blinman and Wilson 1992). However, the size of the household sample is exceedingly small and thus potentially unreliable, but indirect evidence, in the form of amounts of nonlocal pottery in household assemblages, also indicates some production specialization (Blinman and Wilson 1992). After AD 800, direct evidence indicates that gray ware production occurred at most if not all households, and the movement of gray ware vessels within the region appears to have been minimal (Blinman and Wilson 1992; Glowacki 1995; Glowacki et al. 1995; Pierce et al. 1999; Wilson 1988b, 1991). Thus it appears that over the period of change from plain to corrugated vessels in the Mesa Verde region, utility ware production remained unspecialized and mainly, or entirely, occurred in individual households for their own consumption.

However, outside the Mesa Verde region, evidence suggests that other forms of production organization may have existed. Indirect evidence from Chaco Canyon indicates that import of corrugated vessels manufactured in the Chuska Valley to the west of Chaco increased through time. By the early eleventh century, Chuskan vessels constitute half of all utility ware pottery recovered in Chaco Canyon (Toll 1991). The substantial increase in the movement of utility ware pottery into Chaco Canyon suggests that certainly the scale and possibly the degree of specialization of gray ware production in the Chuska Valley also increased through time. Unfortunately, studies of direct evidence of pottery production in the Chuska region have not yet been conducted.

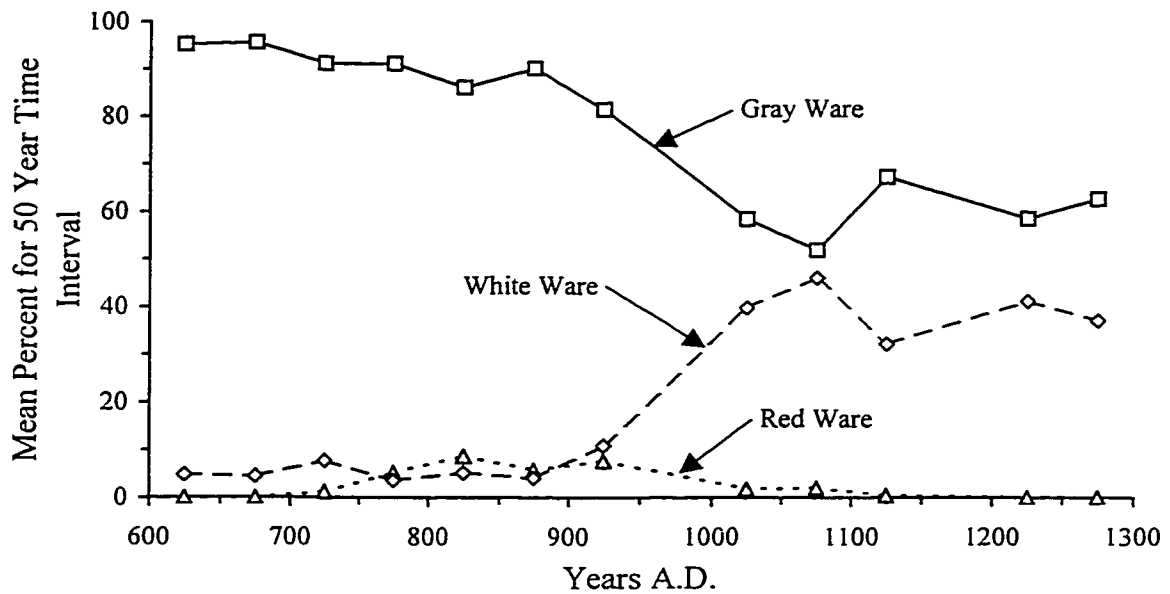


Figure 17. Change in the relative frequency of pottery wares through time in the Mesa Verde region compiled from published sources.

Another aspect of the organization of pottery production is the allocation of time and energy resources to the manufacture of different kinds of pottery. Figure 17 shows the average relative frequencies of different pottery wares recovered from sites in the Mesa Verde region by fifty-year intervals from the seventh to the thirteenth centuries. For about half of this time period, gray wares (pottery lacking slip, polish, or paint) account for over 80% of all pottery. From the seventh through the ninth centuries, slipped and painted pottery increased gradually relative to gray wares. Most of this increase resulted from a substantial rise in the abundance of red ware pottery imported from southwestern Utah (Blinman 1988b; Hegmon et al. 1995, 1997; Lucius and Breternitz 1981; Wilson and Blinman 1995). During the tenth century, the importing of red ware pottery from Utah declined while the relative frequency of locally produced white wares increased dramatically. This change in the relative frequencies of pottery wares also coincides with the adoption of full-body corrugation in the Mesa Verde region. From the eleventh century on, gray wares, the vast majority of which are from full-body corrugated vessels, and white wares account for roughly 60% and 40% of pottery, respectively, assemblages from the Mesa Verde region. A similar change in the relative abundance of utility and painted wares occurs in other areas of the Southwest, but this pattern is by no means universal. Although I have not systematically compiled data from other areas as I have for the Mesa Verde region, my

impression from reviewing the literature is that there is considerable variation in the relative frequencies of utility and painted wares at different times across the Southwest. However there may, in some areas, be a correlation between the adoption of full-body, indented corrugation and an increase in the relative abundance of painted pottery¹.

Because these values are relative frequencies, a change in the absolute frequency of one ware category necessitates a change in the other categories. Consequently, it is not clear from the ware data alone whether we are documenting an increase in white wares, a decrease in gray wares, or some combination of the two. In addition, these data record the amount of pottery that accumulated at sites through discard, which is not necessarily the same as the amount of pottery produced. Changes in the use-life and discard rate of pottery in one ware category would also affect the relative frequencies of wares recovered from archaeological deposits. Changes in the size of vessels in different ware categories can also affect the relative abundance of pottery wares in archaeological assemblages. However, larger vessels require more production investment per pot than smaller vessels, so the potential effects of changes in vessel size do not compromise our ability to track the allocation of production resources among different kinds of pottery.

Data on vessel forms and pottery accumulation rates indicate that, in the Mesa Verde region at least, the changes in the relative frequencies of pottery wares resulted from both increased white ware production and decreased gray ware accumulation. Vessel form data can further inform on production investments because certain forms were usually made in one ware category or another. Both the variety and relative abundance of different vessel forms change between the seventh and thirteenth centuries (Blinman 1988a, 1988b; Pierce and Varien 1999; Wilson 1988b, 1991). Most of the different vessel forms produced in the Mesa Verde region had been developed by the late ninth and early tenth centuries. After the tenth century, few new vessel forms were added, but the relative frequency of different forms continued to change. In addition, the ware category in which different vessel forms were made also changed through time. The most important change in the proportions of different vessel forms for this discussion is a gradual increase in the abundance of bowls (Figure 18). The vast majority of these bowls were slipped and painted. Consequently, an increase in bowl production involved an increase in white ware production as well. Other vessel forms, such as ollas and seed jars (see Figure 19 for diagrams of different vessel forms), which had been produced mainly as plain gray wares prior to eleventh

¹ My thanks to C. Dean Wilson for bring this possible relationship to my attention.

century, were mostly slipped and painted after than time. This shift further increased the investment in the production of white wares relative to gray utility wares.

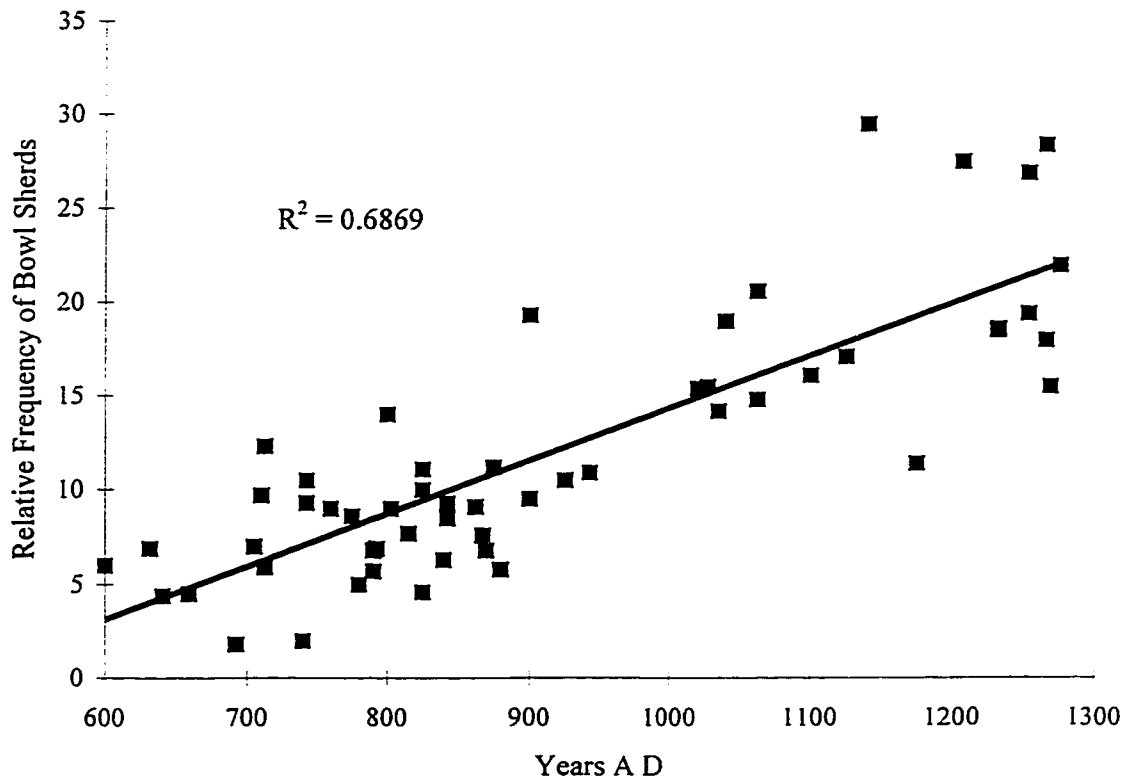


Figure 18. Plot of the relative frequency of bowl sherds against age for dated pottery assemblages from the Mesa Verde region.

A more direct way to circumvent the closed array problem in comparing the percentages of different pottery wares is to examine accumulation rates. Ideally, one calculates accumulation rates by dividing the amount of pottery in a particular deposit by the amount of time it took for that deposit to form. To do this with any reliability requires extremely well dated assemblages. Unfortunately, very few assemblages can be dated with the degree of accuracy and precision need to calculate reliable accumulation rates. Another way to track accumulation rates of pottery wares is to compare their abundance to the abundance of some other nonpottery artifact class using ratios. By calculating ratios of the abundance of gray and white wares to another artifact class, fluctuations in the abundance of the two pottery wares can be documented independently of one another. The artifact class used to calculate the ratios should be fairly abundant so that sample size effects do not cause wild fluctuations in the ratios from different assemblages. The only

artifact class besides in the Mesa Verde region that occurs in great abundance in most assemblages is stone chipping debris, or debitage. Although debitage abundance may vary through time and among contemporary assemblages, the amount of debitage serves as a fixed point of comparison for each assemblage (see page 159).

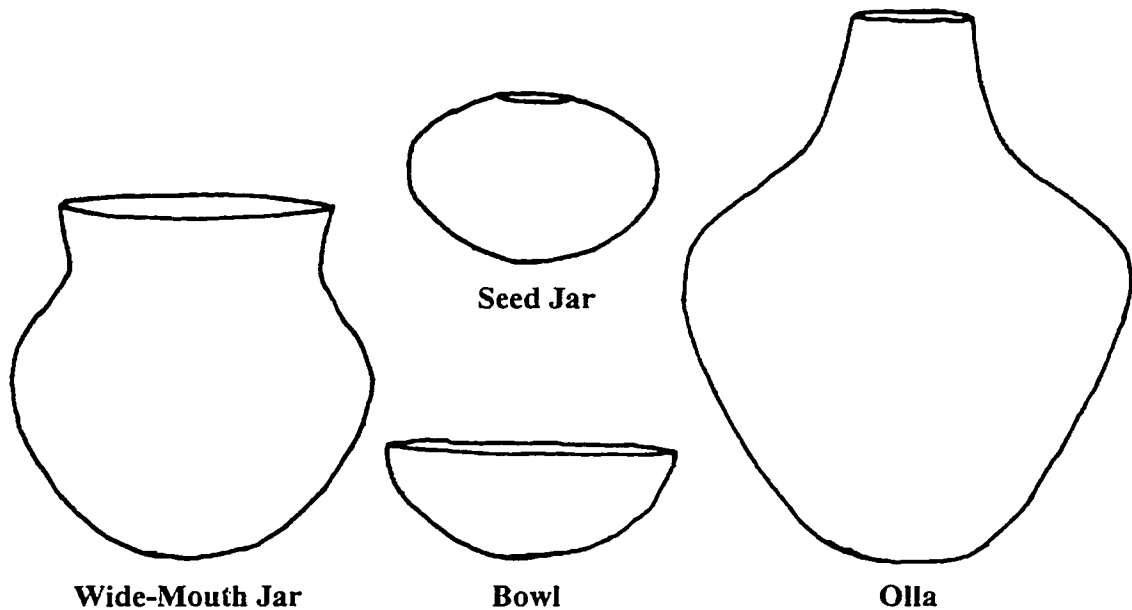


Figure 19. Diagram of common vessel forms in utility ware assemblages from the Mesa Verde region.

Figure 20 shows the ratios of white ware and gray utility ware pottery to debitage in assemblages from the Mesa Verde region, which have been grouped into 100 year time intervals. The measure of pottery abundance in these ratios is the weight of sherds in each ware category, while I use counts of flakes and angular debris to quantify the debitage. I used the weight of pottery rather than the count because many of the assemblages vary considerably, and, in some cases, systematically in the degree of fragmentation of the pottery. For example, sherds in plain and neck-banded gray ware assemblages are more than twice as large, on average, as sherds in assemblages dominated by indented corrugation (Figure 21). Such differences in sherd size introduce a systematic bias into the data when counts are used to quantify pottery abundance. The data used in these figures was drawn from reports on single component assemblages from which

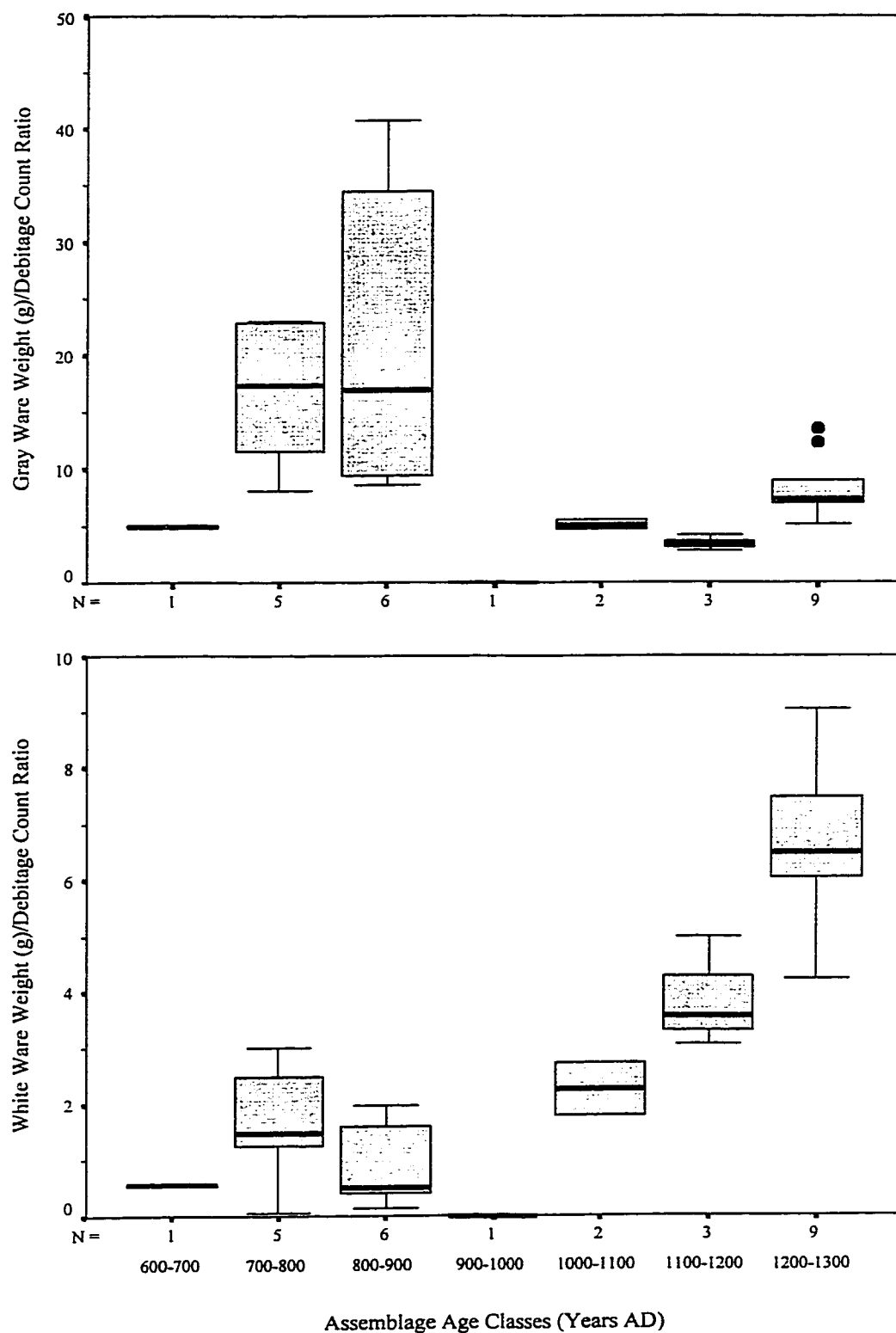


Figure 20. Box plots showing the change through time in estimates of the accumulation rates of utility ware (upper graph) and white ware (lower graph) pottery in assemblages from the Mesa Verde region.

large samples were recovered by excavation and surface collection using modern methods including probabilistic sampling and screening. Assemblages with large numbers of complete or restorable vessels were avoided. Unfortunately, few reports provide data on the weight of pottery than the count. Consequently, data from only a small fraction of the assemblages meeting these criteria could be used, and no data could be obtained for assemblages dating to the tenth century.

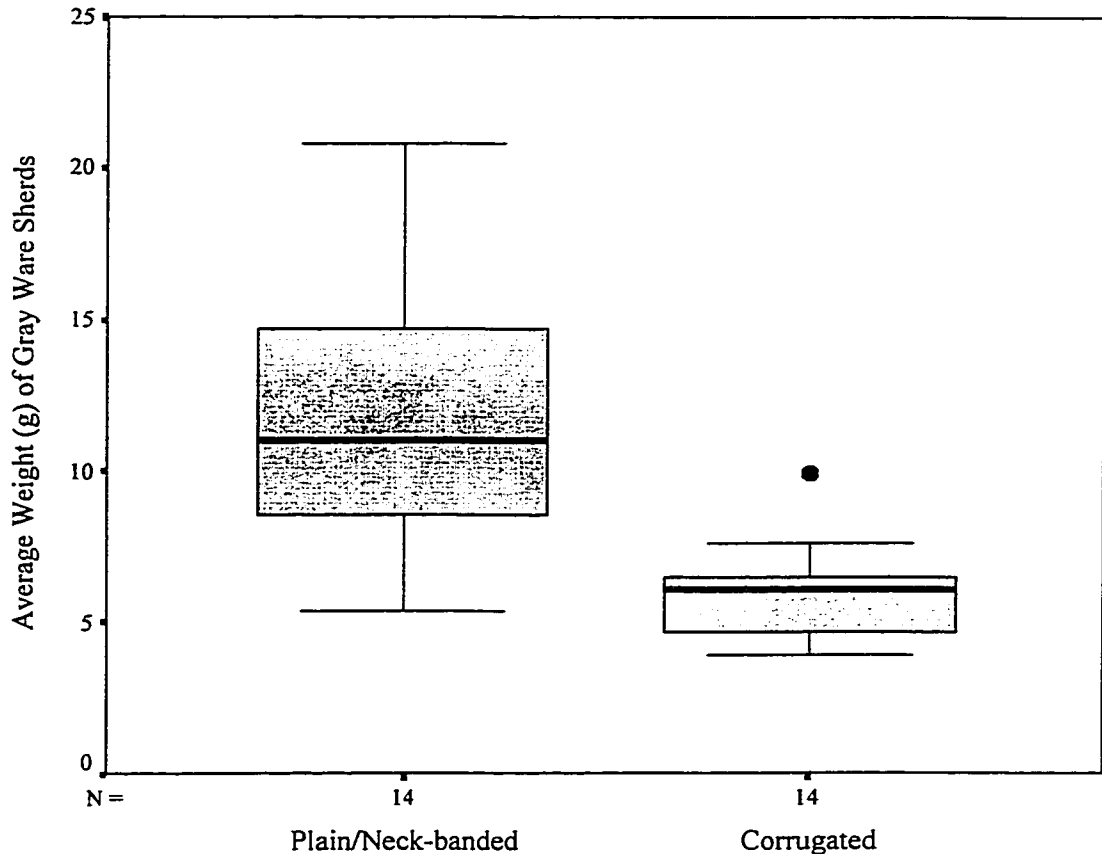


Figure 21. Box plots of the average weight of plain/neck-banded and corrugated utility wares compiled from published sources on pottery assemblages in the Mesa Verde region.

Despite the small number of assemblages, both graphs in Figure 20 show consistent results. The upper graph in Figure 20 demonstrates that the accumulation rates of gray utility pottery were relatively high during the eighth and ninth centuries, and then decreased dramatically after the adoption of full-body corrugation in the early eleventh century. This decrease in accumulation of utility wares may be due primarily to the increased durability of full-body corrugated vessels when used for cooking, an issue I address in more detail in Chapter 7. The lower graph in Figure 20 shows that white ware accumulation rates were very low until after

the adoption of full-body indented corrugation, when accumulation gradually increased. Taking these accumulation rate, vessel morphology and ware frequency data together, there is compelling evidence for a decreased investment in utility ware production and an increased investment in white ware production occurring roughly coincident with the adoption of full-body corrugation in the Mesa Verde region.

Utility Vessel Use

Utility ware ceramics in the Southwest are usually thought to have been used primarily for cooking and dry storage. However, none of the defining criteria for this class of pottery, lack of slip, polish, or paint, directly relates to vessel use. Consequently, one cannot assume that by focusing on utility wares, we have adequately identified, or significantly narrowed the range of uses of vessels in this class. Documenting the kinds and intensity of use of vessels in the utility ware class serves two important purposes for this study. First, the use environment is likely to be a significant context of interaction for plain, neck-banded, and full-body corrugated vessels. If the use of utility vessels changed through time, then the vessel-environment interactions also probably changed in ways that could have altered the fitness relationships among the traits of vessels, including various forms of corrugation. Second, designing the studies that document the engineering fitness (cost and performance) of pottery vessels with different combinations of traits, discussed in Chapter 8, requires some knowledge of the use environment in which the various kinds of vessels performed.

In this section, I present data and inferences regarding the kinds and intensity of use of gray utility wares in the Mesa Verde region during the period of change from plain to fully corrugated vessels. Both the morphology (shape and size) and use-related alterations (wear and accumulations) displayed by ancient utility wares provide clues to the use environment of the vessels (Skibo 1992; Smith 1985). To document variation and change in the use environment of Mesa Verde region utility wares, I recorded data on vessel morphology and use-related alterations in the six gray ware assemblages, and synthesize published information from a variety of sources. The data on vessel morphology and use alterations are presented in separate sections below. However, combined observations of use-related alterations and vessel form offer the strongest sources of data on vessel use. Unfortunately, use alterations are frequently restricted to the lower portions of vessels, and when sherds are examined, it is difficult to identify lower body fragments to a particular vessel form category. To examine form-alteration combinations, I rely on observations made by other investigators on whole or restored vessels, particularly those

recovered and analyzed during the Dolores Archaeological Program (Blinman 1986, 1988a, 1988b).

Vessel Morphology

Archaeologists, as well as producers and users of pottery, frequently equate particular vessel forms with specific uses or functions (e.g., Braun 1980; Henrickson and McDonald 1983; Rice 1987; Shapiro 1984; Smith 1985, 1988). Although the formal design of vessels can certainly affect performance during use (Braun 1980, 1983; Ericson et al. 1972), in most cases the relationship between form and use is not a necessary one creating the potential for variation and change in use within form categories (DeBoer and Lathrap 1979; Feathers 1990:62-66; Longacre 1985; Miller 1985; Nelson 1991; Stark 1995b). However, changes through time in the relative abundance of pottery in different form categories can reflect the intensity of use of those forms and possibly particular uses as well.

While analyzing the pottery sherds in the six gray ware assemblages from the Mesa Verde region, I recorded two sets of observations that provide information on vessel morphology. For every sherd, I tried to identify the form or shape class of the vessel from which the sherd derived. I also measured rim sherds to estimate the radius of vessel openings, which is correlated with the vessel size, and to quantify the abundance of different vessel shapes and sizes.

Gray ware pottery in the Mesa Verde region is known to encompass a wide range of vessel forms including a variety of jar forms, bowls, pitchers, dippers, and various effigy vessels (Blinman 1988a, 1988b). However, only five specific vessel forms were identified in the six assemblages I analyzed—wide-mouth jar, olla, seed jar, bowl, and a small cup form (see Figure 19 for illustrations). Wide-mouth jars include necked vessels in which the radius of the opening is at least half the maximum radius of the vessel. Ollas are necked vessels in which the radius of the opening is less than half the maximum radius of the vessel. Seed jars are a closed, jar form, but lacking shoulders and necks. Bowls are open forms in which the radius of the opening is roughly equal to the maximum radius of the vessel. The small cup form was represented by only one piece, and consisted of a crudely fashioned vessel with vertical wall and a flat base. Usually, neck and rim pieces were needed to assign a sherd to one of these specific form categories. Even with neck and rim pieces, distinguishing between wide-mouth jars and ollas could be challenging, particularly in pieces from smaller vessels. Consequently, I employed two more general form categories, indeterminate jar and indeterminate form, in my analysis of the six gray ware assemblages. Frequently, body sherds could be identified as coming from jars based on a

smoother exterior surface relative the interior surface, even though the specific jar form could not be identified. These pieces were placed into the indeterminate jar category. More ambiguous pieces were identified as indeterminate form. Most body sherds were assigned to one or the other of these two general form categories.

Estimating the radius of vessel rims in the six assemblages involved measuring the rim curvature and matching the curve to a template of circles with known radii. I measured the curvature by pressing a carpenter's gauge along the rim on the inside surface of the sherd to get an impression of the rim in the gauge. I then matched this impression to one of a set of concentric arcs marked off at one-centimeter radius intervals from one to 26 centimeters. Matching attempts began with small radius arcs and moved out to larger radii until a suitable match was found. If a suitable curve match could not be found, I did not record a radius estimate for that specimen. I also measured the degrees of arc covered by each rim for which a radius estimate was made, and the cord length of all rim sherd arcs to document the size of the rim segment.

Vessel Shape

Most vessel fragments provide very limited information on the shape of the complete vessel from which they are derived. This is certainly true for the collections analyzed in this study. Of the 4174 sherds analyzed, 88.4 percent were identified as indeterminate jar or indeterminate form. Of the sherds identified to one of the six specific form categories, 86.4 percent are rim (43.2 percent) or neck (43.2 percent) fragments where most of the features diagnostic of vessel form occur. Consequently, I compare the abundance of vessel forms in the six assemblages in two ways. First, I compare the weight of all sherds identified to a specific form category regardless of the part of the vessel represented by the sherd. Second, I compare vessel forms using rim sherds only and quantify the abundance based on the degrees of arc covered by the portion of rim present on each sherd. I use these two approaches to quantifying the abundance of different vessel forms because they are likely to introduce distinct biases that, taken together, may give us a clearer picture of vessel form changes (Pierce and Varien 1999).

Tables 10 and 11 show the abundance of the five different gray ware vessel forms in the six assemblages using sherd weight and degrees of arc, respectively, as the quantifier. Table 12 presents the residuals produced by subtracting the percentages in Table 10 from the percentages in Table 11. It is clear from Table 12 that the rim arc method documented fewer wide-mouth jars relative to other vessel forms than the sherd weight method. There are two likely causes of these differences. First, I was able to identify more non-rim pieces to the wide-mouth jar and olla

categories than the other forms resulting in greater weight of sherds than other vessel forms. Second, average olla rims tend to weigh less, but cover more degrees of arc than average wide-mouth jar rims because the olla rim openings are smaller. Given these causes, percentage values between those in Tables 10 and 11 are probably closer to the actual abundance of different vessel forms in these assemblages. However, small samples of sherds with features diagnostic of vessel form may reduce the accuracy and precision of these abundance data in the assemblages with multiple vessel forms represented (see Appendix A).

Table 10. Weight of pottery assigned to specific vessel form classes in the six utility ware assemblages from the Mesa Verde region.

Assemblages	Vessel Form Classes										Totals g	
	Wide-Mouth Jar		Olla		Bowl		Seed Jar		Small Cup			
	g	%	g	%	g	%	g	%	g	%		
5MT2193	173	56.3	34	11.0	100	32.7						307
5MT4671	497	63.0	66	8.4	213	27.0			14	1.7		789
5MT3868	804	65.9	325	26.6	86	7.1	6	0.5				1221
5MT8371	475	98.8	6	1.2								481
5MT1786	320	100										320
5MT8827	754	100										754
Totals	3023	78.1	460	11.1	399	10.3	6	0.1	14	0.3		3872

Despite the differences between quantification techniques and possible biases from small sample sizes, Tables 10 and 11 show very similar overall trends in the abundance of utility ware vessel forms. Although wide-mouth jars dominate all assemblages, the earliest three assemblages also contain notable amounts of bowls and ollas. Gray ware bowls are most abundant in the earliest assemblage and decrease dramatically, dropping out entirely by the late ninth century AD. Gray ware ollas are most abundant during the late ninth century, but continue to persist into the tenth century. By the tenth century, most bowls and ollas were made as white wares by adding slip and polish, and the gray utility ware pottery in the Mesa Verde region came to be focused almost exclusively on wide-mouth jars. Wide-mouth jars jump from being between one half and two thirds of gray ware vessels in earlier assemblages to around 90 percent gray ware vessels in the tenth century. Blinman (1988b:179) found a similar pattern of change in the relative

abundance of gray ware vessel forms in a much larger sample of sherds from trash deposits in the Dolores River area, which suggests that the data presented here are probably accurate.

Table 11. Degrees of arc encompassed by rim segments assigned to specific vessel form classes in the six utility ware assemblages from the Mesa Verde region.

Assemblages	Vessel Form Classes										Totals deg.	
	Wide-Mouth Jar		Olla		Bowl		Seed Jar		Small Cup			
	deg.	%	deg.	%	deg.	%	deg.	%	deg.	%		
5MT2193	179	54.1	17	5.1	135	40.8						331
5MT4671	555	49.7	177	15.8	347	31.1			38	3.4		1117
5MT3868	735	55.8	490	37.2	67	5.1	25	1.9				1317
5MT8371	182	87.9	25	12.1								207
5MT1786	552	100										552
5MT8827	378	100										378
Totals	2581	66.1	709	18.2	549	14.1	25	0.6	38	1.0		3902

Table 12. Differences in the relative abundance of vessels forms between the two quantification methods calculated by subtracting the percentage of weight (Table 10) from the percentage of degrees of arc (Table 11).

Assemblages	Vessel Form Classes				
	Wide-Mouth Jar	Olla	Bowl	Seed Jar	Small Cup
5MT2193	-2.2	-5.9	8.1		
5MT4671	-13.3	7.4	4.1		1.7
5MT3868	-10.1	10.6	-2.0	1.4	
5MT8371	-10.9	10.9			
5MT1786	0.0				
5MT8827	0.0				
Totals	-12.0	7.1	3.8	0.5	0.7

Archaeologists working in the American Southwest commonly refer to wide-mouth jars as cooking pots because of their suitable form and the frequent occurrence of soot on the exterior surface (Blinman 1988b; Mills 1989). Although some corrugated wide-mouth jars have been found in contexts that suggest use for storage (such as buried in the floors of structures), most of these vessels have sooted exteriors suggesting an earlier use in cooking (Mills 1989:154-155; Renken 1993; Rohn 1971). If the cooking use inference for wide-mouth jars is correct, it appears

that the primary use of gray ware vessels became more specialized through time, and, by the late ninth century, involved cooking almost exclusively.

Other studies of the relative abundance of all vessel forms in the Mesa Verde region, regardless of pottery ware category, have documented that wide-mouth jars were relatively rare in assemblages dating to the seventh century, but their abundance increased during the eighth, ninth, and early tenth centuries (Blinman 1988b). The occurrence of soot on vessel exteriors indicates that a wider variety of vessel forms, including mainly seed jars, were used for cooking during the seventh century whereas in later assemblages use-related soot appears on wide-mouth jars exclusively (Blinman 1988a, 1988b; Morris 1939:244-245). A slight decline in the relative abundance of wide-mouth jars during the tenth century coincides with a gradual increase in the abundance of bowls (Figure 18). Some of this change in the relative proportion of vessel forms may derive from a reduction in the accumulation rate of gray wares after the tenth century as discussed earlier in this Chapter. However, change in the bowl to gray ware jar ratio probably also resulted from an increase in the use and discard of bowls. Blinman (1986, 1988b:199) argues that the increase in wide-mouth jars during the eighth, ninth and tenth centuries, as well as other changes, resulted from intensified use of moist cooking or boiling as a part of food preparation. The expanded use of bowls in the tenth and eleventh centuries may also be related to the increased consumption of food prepared by moist cooking.

Vessel Size

For certain vessel forms, particularly wide-mouth jars and bowls, a strong linear correlation exists between the radius at the rim of the vessel and other attributes of vessel size such as volume, height, and weight (Blinman 1988b; Mills 1989). Given this correlation, it is possible to obtain a measure of vessel size from rim fragments by estimating the radius of the arc of the rim. Error in radius estimates can arise from rims that deviate from circular arcs and small rim segments that make curve matching difficult. In measuring the precision of the curve matching approach to rim radius estimation, Nicklaw (1995:52) found that variation among multiple, independent estimates of the same sherd by the same analyst increased precipitously for rim segments less than 40 mm in length and with an average estimated radius greater than 5 cm. By comparing estimates from rim segments to the true value of the complete or restored vessel, the accuracy of rim radius estimates can be assessed. Although this has not been done for the curve matching technique, Feathers (1990) assessed the accuracy of a different technique and

found that estimates decreased in accuracy for rims less than 40 mm long, but were quite accurate for larger rims segments.

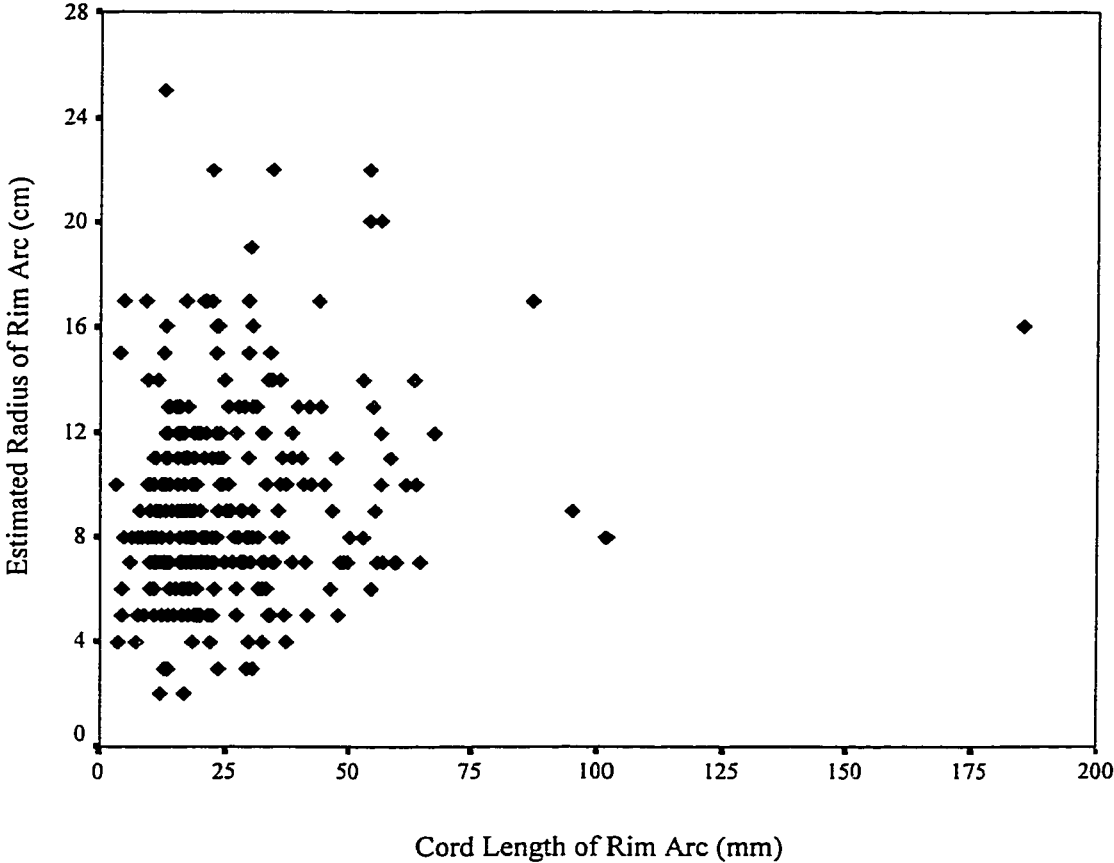


Figure 22. Scatter plot of rim radius estimates and rim cord length measurements for all rim sherds in the six utility ware assemblages from the Mesa Verde region.

Based on these results, Feathers (1990) suggests avoiding radius data from rims less than 40 mm long unless these data do not differ significantly from data derived from larger rims. Because most (86%) of the rim segments analyzed from the six gray ware assemblages are less than 40 mm in length, eliminating the smaller rims would have a devastating effect on sample size. Consequently, a thorough examination of radius results across different rim sizes is called for. Figure 22 shows the relationship between rim arc cord length and the estimated rim radius for all rim sherds in the six assemblages on which I was able to make these measurements. Although the points are quite scattered, a correlation analysis shows a very weak, yet significantly positive ($r_p=.180, p=.002, n=284$), relationship. This relationship can arise in two ways. First, smaller rims

could result in underestimates of the rim radius given the method of measurement. This is not the case for these data because the small rims account for many of the large radius estimates. Secondly, larger vessels have a tendency to produce larger fragments when they break, and thus, larger vessels will have a tendency to produce rim sherds with greater cord lengths. The increase in the minimum estimated radius with increased rim cord length visible in Figure 22 suggests that the latter cause is responsible for most of the weak correlation seen here. The large number of points and the presence of the single point at the far right side of the graph also contribute to the significant correlation. Fortunately, this relationship between sherd size and vessel size does not bias our estimates of vessel size even if assemblages differ significantly in rim cord length.

Given that corrugation was developed and most frequently employed on wide-mouth jars, my analysis of vessel size will focus on that form category. Figure 23 shows box and whiskers plots of rim radius weighted by degrees of arc and rim cord length for sherds identified as wide-mouth jars and indeterminate jars in the six gray ware assemblages. I include indeterminate jar rims in this analysis of vessel size to increase the sample size and because most of the rims identified to this form category are very likely to be from wide-mouth jars, especially in the later assemblages. The cord length plot shows that the earliest and latest assemblages have the longest rims while the assemblages in between are generally more fragmented. In contrast, the plot of rim radius shows a consistent trend toward larger jars through time. The differences in temporal trends between rim cord length and rim radius further indicate that variation in rim size among assemblages has not compromised the reliability of the rim radius data to document changes in vessel size. However, small sample size may reduce the accuracy and precision of these vessel size data (see Appendix A).

Cumulative percentage graphs of rim radii weighted by degrees of arc for the six assemblages (Figure 24) also show an increase in the abundance of larger wide-mouth jars through time while small jars also continued to be made. In addition, sharp inflections in the graph of the latest assemblage (SMT8827) show the differentiation of rim radii into three fairly discrete size modes. Both the general trend toward larger gray ware jars and the occurrence of size modes have been documented in a much larger sample of sherds and complete vessels from the Mesa Verde region (Blinman 1988b; Mills 1989) and elsewhere in the northern Southwest (Mills 1993:344). Thus, these patterns are probably robust and not a reflection of measurement error or sample size bias. What has not been noted previously is that multiple discrete size modes may have appeared for the first time in the eleventh century in the Mesa Verde region coincident

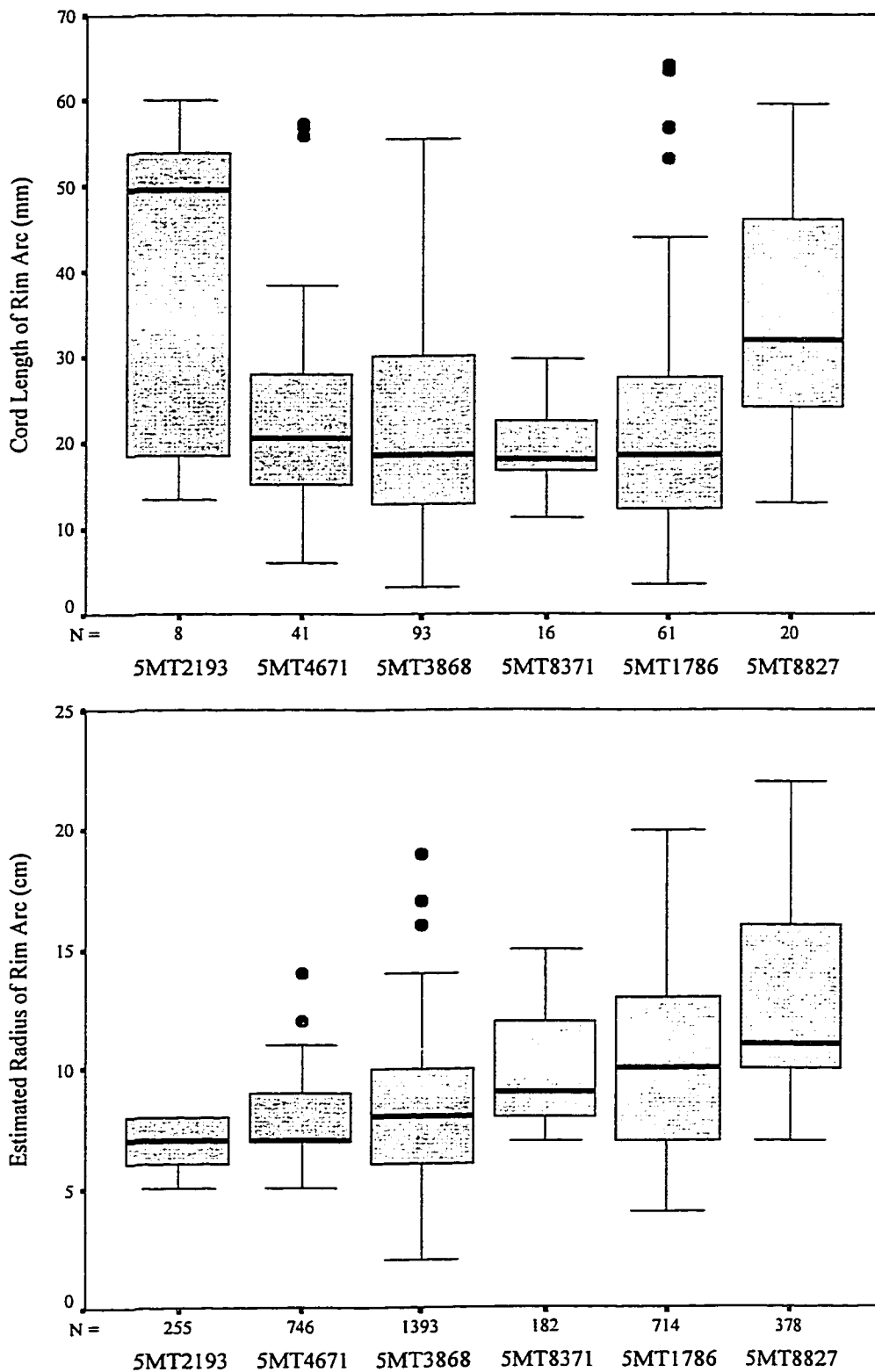


Figure 23. Box plots of rim cord length (N=count) and rim radius (N=degrees of arc) for wide-mouth and indeterminate jar forms in the six utility ware assemblages from the Mesa Verde region.

with the adoption of corrugation. A similar timing of the appearance of wide-mouth jar size modes occurs in data on radius estimates of rim sherds recovered from trash deposits excavated and analyzed by the Dolores Archaeological Program (Blinman 1988b: 184). However, data on the actual volume of a much smaller, though still substantial, sample of complete vessels recovered and restored during the same project conflict with the data from rim sherds and suggest that discrete wide-mouth jar size modes appeared earlier than the eleventh century (Blinman 1988b:128).

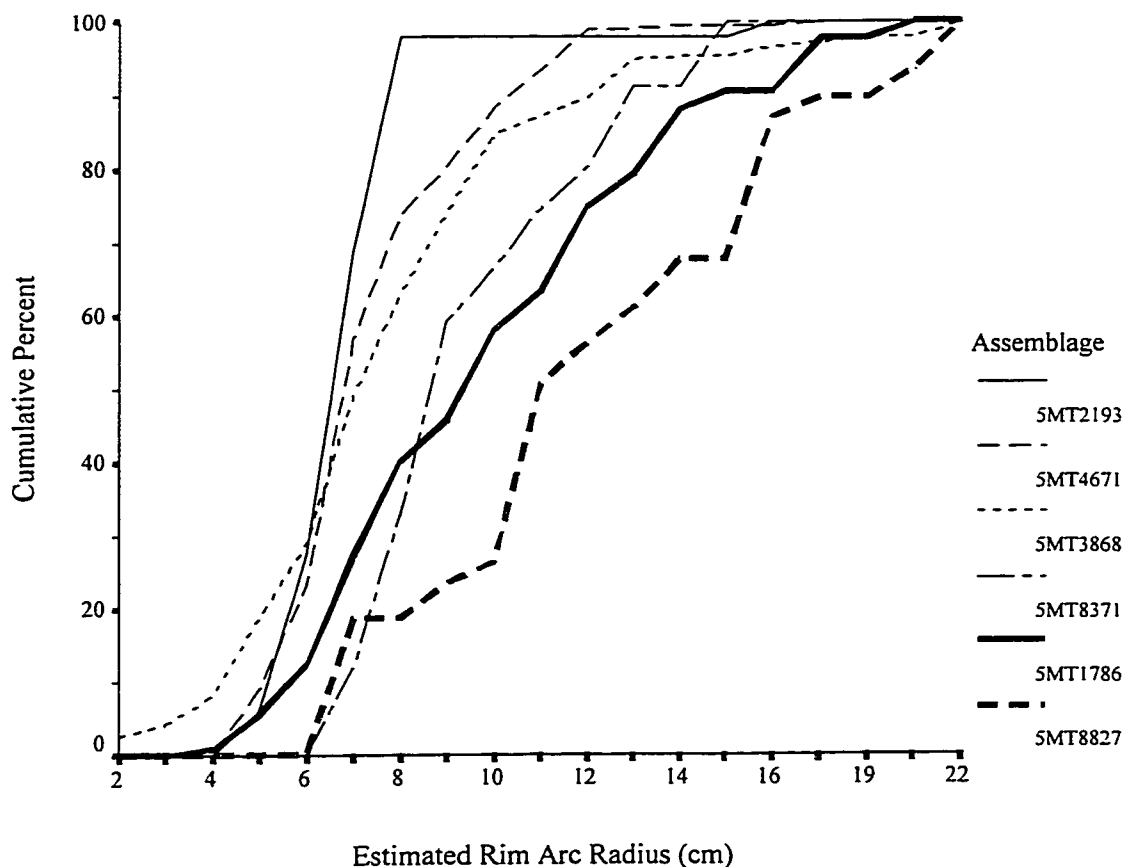


Figure 24. Cumulative percentage graphs of estimated rim radii weighted by degrees of arc for wide-mouth and indeterminate jars in the six utility ware assemblages from the Mesa Verde region.

Both the increase in the largest size of wide-mouth jars and the development of discrete size modes suggest that there may have been some changes through time in the way these vessels were used. If wide-mouth jars were used mainly as cooking pots, the addition of larger and larger vessels through may signal an increase in the size of groups involved in food preparation or

consumption. If wide-mouth jars were also used in the storing of dry goods, larger vessels may also indicate increased storage needs. The development of discrete size modes may be linked to more formalized production or use of wide-mouth jars. If size modes appeared for the first time in the eleventh century, the correlation between the adoption of full-body corrugation and the appearance of more formal production or use contexts may be significant.

Use Alterations

In the analysis of the six gray ware assemblages I examined for this study, I recorded data on two kinds of use-related alterations for each surface of all sherds—the type and degree of wear and the presence of accumulations. Wear types I monitored include abrasion, pitting, scratches, polish, flaking, and spalling, and the degree of wear was described as light, moderate, or heavy. The surface accumulations recorded include soot, charred material, uncharred material, and stains. These kinds of use alterations can be difficult to distinguish from traces left during the manufacture process and alterations produced after the sherds were discarded. Although I was extremely conservative in identifying traces as use-related alterations, it is important in analyzing these data to consider other possible sources for the ware and accumulations.

Table 13 shows the amount of pottery identified to different attritional wear classes. Most of the sherds show no clear signs of wear, which is common in pottery assemblages. However, small yet notable amounts of pottery are spalled and pitted. Pitting refers to clusters of small, shallow indentations or divots in the surface of the pottery, while spalled sherds include those with partially or completely missing surfaces that cannot be attributed to abrasion or pitting. Both of these wear classes could be produced through use or by post-depositional alteration. However, the tendency for spalling and pitting to occur preferentially on exterior and interior surfaces respectively, and for both types of wear to appear mainly on basal fragments (Figure 25) indicates that they were formed primarily through use. Use-life experiments presented in Chapter 7 also indicate that basal pitting and spalling are produced on some vessels as a consequence of their regular use in cooking. That many gray ware vessels were used for cooking is suggested by the fact that over 40 percent of all base fragments in the six assemblages show some pitting of the interior surface.

The incidences of spalling and interior surface pitting, as measured by the percentage of pottery with these alterations in each assemblage, show the same trajectory in time (Figure 26). Both of these forms of use-alteration increase from relatively low levels in the eighth century AD to a peak in the tenth century and fall off rapidly in the eleventh century. If the changes in the

Table 13. Abundance of different surface wear classes on utility ware pottery in the six assemblages from the Mesa Verde region.

Wear Class	Surface	Assemblages											
		5MT2193	5MT4671	5MT3868	5MT8371	5MT1786	5MT8827						
		g	%	g	%	g	%	g	%	g	%	g	%
No Wear	Interior	2067	89.7	5194	86.1	6099	84.0	1245	80.0	2770	83.3	3235	92.6
	Exterior	2230	96.7	5684	94.0	6781	93.1	1331	85.0	3247	97.5	3343	95.7
Spalling	Interior	16	0.7	114	1.9	144	1.9	57	3.7	65	2.0	1	0.0
	Exterior	31	1.3	202	3.3	223	3.1	212	13.6	42	1.3	0	0.0
Pitting	Interior	201	8.7	636	10.5	942	13.0	241	15.5	447	13.5	147	4.2
	Exterior	1	0.1	7	0.1	53	0.7	0	0.0	9	0.3	0	0.0
Abrasion	Interior	19	0.8	15	0.9	58	0.8	13	0.8	40	1.2	2	0.1
	Exterior	40	1.7	153	2.5	154	2.1	22	1.4	33	1.0	31	0.9
Other	Interior	3	0.1	35	0.6	15	0.2	0	0.0	3	0.1	108	3.1
	Exterior	3	0.1	0	0.0	74	1.0	0	0.0	0	0.0	118	3.4

Percentages calculated separately for each surface.

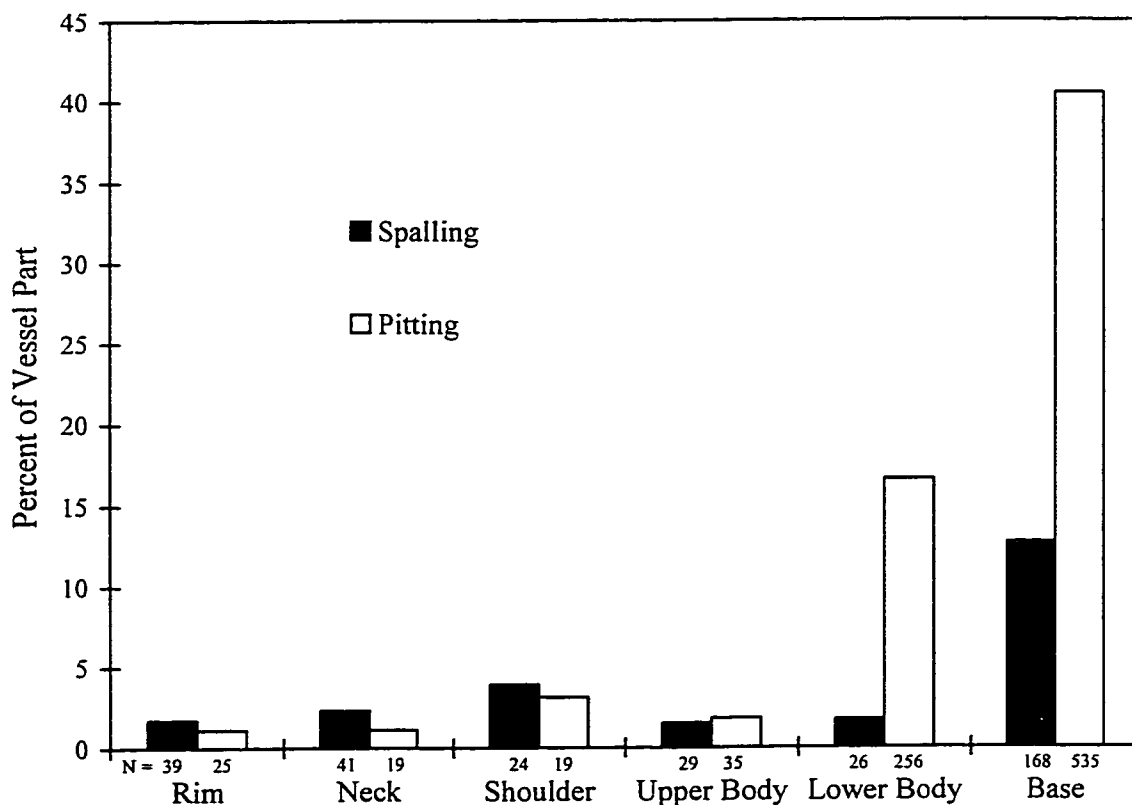


Figure 25. Relative abundance of spalling and interior surface pitting of different vessel parts in data combined from all six of the utility ware assemblages from the Mesa Verde region. N = grams of pottery.

incidence of spalling and pitting in plain surface pottery are related to the intensity of use in cooking, then the wear pattern data correspond with the vessel form data in indicating intensified use of gray wares in cooking through the ninth and tenth centuries. However, the reduction in the range of vessel forms, and presumably uses, among gray wares could also account for the increased incidence of pitting and spalling in the tenth century with a greater proportion of vessels being used in cooking rather a more intense use of individual vessels. Regardless of whether it was the intensity of use of individual vessels or the proportion of vessels used for cooking, the wear data indicate that use of gray wares for cooking increased from the eighth to the tenth centuries. The subsequent decrease in spalling and pitting after the adoption of full-body corrugation probably stems from the effects of corrugation on the nature of thermal stresses in the vessel wall (see the discussion in Chapter 7) rather than indicating a reduction in cooking intensity.

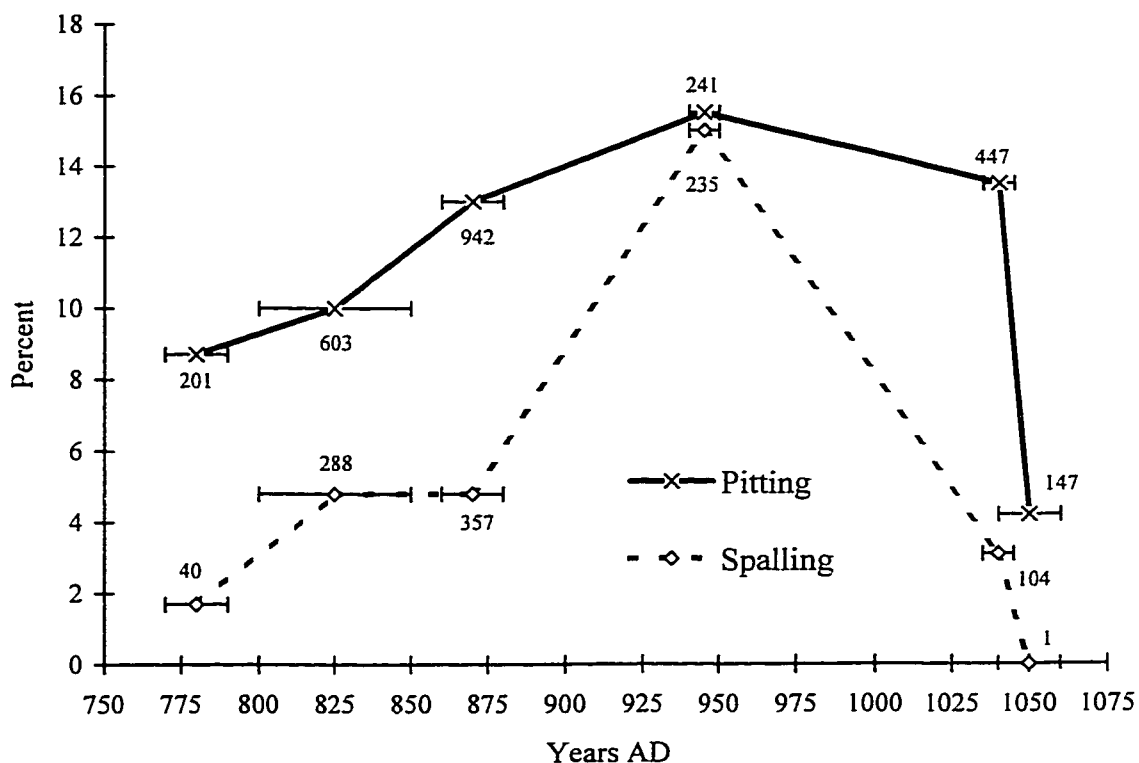


Figure 26. Relative abundance of spalling and interior surface pitting in the six utility ware assemblages from the Mesa Verde region. Data labels are grams of pottery and error bars represent the likely temporal span of each assemblage.

Use-related accumulations are fairly rare in the six assemblages except for soot adhering to the exterior surface of sherds, which occurs in all six assemblages to varying degrees (Table 14). Soot accumulations are quite abundant in some assemblages while almost entirely lacking in others. Soot adheres to vessel surfaces when the vessels rest for long periods over a source of smoke. Although pottery vessels can be exposed to smoke in various ways, the most common context in which this occurs is most likely through their use in cooking over an open fire. When vessels are used over an open fire, soot tends to accumulate in patterned ways. Experiments and ethnographic observations conducted by Jim Skibo (1992) indicate that soot accumulates most readily in the widest portions of the vessel, which have the greatest exposure to smoke rising from the fire. If the base of the vessel is suspended above the fire soot will also accumulate on the base. However, if the bottom of the vessel is left in the flames or resting on burning embers soot does not accumulate on the base. I have seen both patterns of soot accumulation in my experience

Table 14. Abundance of surface accumulations on utility ware pottery in the six assemblages from the Mesa Verde region.

Residue	Surface	Assemblages											
		5MT2193		5MT4671		5MT3868		5MT8371		5MT1786		5MT8827	
		g	%	g	%	g	%	g	%	g	%	g	%
None	Interior	1713	74.3	5525	91.8	6760	93.3	1483	95.1	3298	99.1	2907	83.2
	Exterior	1287	55.8	4293	71.1	5814	79.8	1170	74.8	3142	94.5	1873	53.6
Soot	Interior	319	13.8	149	2.5	24	0.3	0	0	2	0.1	89	2.6
	Exterior	918	39.8	1748	28.9	1418	19.5	395	25.2	183	5.5	1593	45.6
Stain	Interior	143	6.2	60	1.0	165	2.3	70	4.5	0	0	347	9.9
	Exterior	100	4.3	0	0	57	0.8	0	0	0	0	26	0.7
Charred	Interior	131	5.7	284	4.7	278	3.8	0	0	16	0.5	149	4.3
	Exterior	0	0	0	0	0	0	0	0	0	0	0	0
Other	Interior	0	0	0	0	16	0.2	7	0.4	13	0.4	0	0
	Exterior	0	0	0	0	0	0	0	0	0	0	0	0

Percentages calculated separately for each surface.

with whole and restored wide-mouth utility ware vessels from the Mesa Verde region. Almost all (99%) of the exterior sooting in the six utility ware assemblages occurs on wide-mouth and indeterminate jar fragments. The exceptions include a single olla sherd from Dos Casas Hamlet (5MT2193) and a single bowl sherd from Periman Hamlet (5MT4671), the two earliest assemblages. The distribution of soot across different vessel parts in all six of the utility ware assemblages (Figure 27) also suggests that both patterns of soot accumulation were present as well. The occurrence of these soot accumulation patterns on plain, neck-banded, and corrugated gray ware jars indicates that many of these vessels were used in cooking.

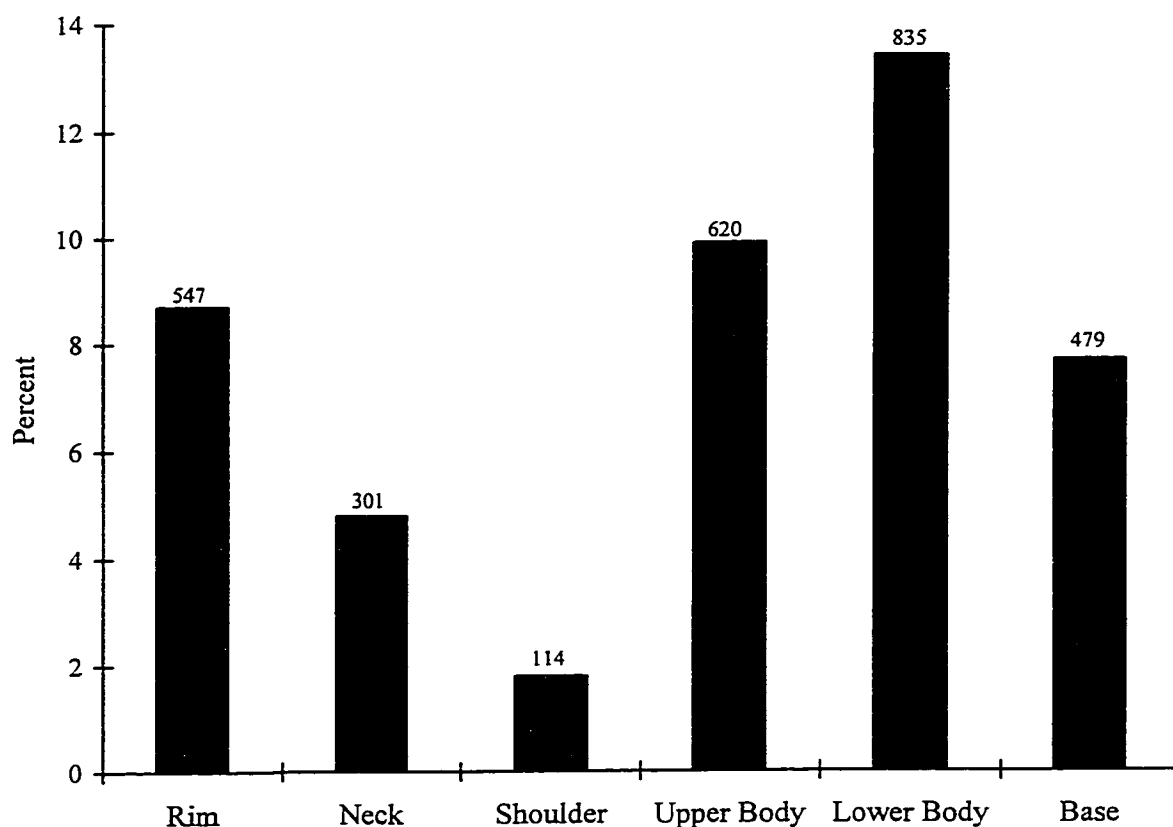


Figure 27. Relative abundance of sherds with surface soot accumulations for different vessel parts in combined data from all six of the utility ware assemblages from the Mesa Verde region. Data labels are grams of pottery.

The incidence of soot accumulations among the six assemblages shows a decline through time until the middle of the eleventh century AD when it appears to increase rapidly (Table 14). This is not what I would expect if the intensity of use in cooking was increasing through time. One possible explanation is that differences in sherd size among assemblages have biased the data

on soot accumulations because the variation in sooting is very similar to that in sherd size (see Appendix A). However there is strong evidence that this pattern is due mainly to post-depositional alteration rather than variation in use or sherd size. The three assemblages with the lowest amount of exterior sooting, Duckfoot (5MT3868), 5MT8371, and Gnatsville (5MT1786), are also the only assemblages for which the entire sample comes from the surface or from relatively shallow midden deposits. Comparison of the amount of sooting on sherds from shallow deposits to those from deeply buried deposits in pit features and structures shows considerable differences. At Dos Casas Hamlet (5MT2193), 2 percent of the sherds from the surface midden are sooted while 51 percent of the sherds from the trash fill of Pit Structure 1 show sooting. A similar pattern is found at Periman Hamlet (5MT4671) at which 14 percent of the surface midden sherds are sooted and 38 percent of the sherds from the fill of pit features show sooting. These results indicate that exposure to the intense weathering conditions at or near the surface results in the erosion of accumulated soot from the surface of pottery.

One possible way to control for this post-depositional bias is to only compare soot accumulations in assemblages from protected depositional contexts. Fortunately, the three protected contexts occur at opposite ends of the time range covered by the six assemblages. Fifty-one and 38 percent of the gray ware pottery from protected contexts at Dos Casas and Periman Hamlets have soot accumulations, while 46% of the pottery from Dobbins Stockade (5MT8827) have soot on their exterior surfaces. These data indicate that the degree of sooting was probably fairly consistent across the period covered by these assemblages, suggesting that cooking may have been a common use for gray ware jars throughout the period during which corrugation was developed.

Summary of Use Evidence

Both the vessel morphology and use alteration data indicate that the use of utility ware vessels became increasingly focused on cooking during the ninth and tenth centuries in the Mesa Verde region. In early assemblages, pottery in the gray utility ware category was made into a wide variety of vessel forms and shows little cooking-related ware. Through time, the variety of vessel forms decreased to a single form, wide-mouth jars, the size of these jars increased and became more formalized, and the relative abundance of cooking-related ware increased. Although soot accumulations are as common in earliest assemblages as they are in later assemblages, soot occurs on a wider variety of vessel forms in these earliest assemblages. These data indicate that cooking was always part of the use environment of utility wares, but utility vessels in the Mesa

Verde region became increasingly specialized in cooking through time. By the eleventh century when full-body corrugation was adopted, cooking appears to have been the primary use environment of utility wares.

Other data from the Mesa Verde region indicate that an increased production and use of agricultural products occurred simultaneously with the greater specialization of utility ware use during the ninth and tenth centuries. These data include greater investment in larger and more formalized storage facilities (Gross 1986), increased abundance of two-hand manos used for grinding grain on slab metates (Phagan 1986), and a reduction in the ratio of animal bones to cooking pot fragments in very large samples compiled from several sites suggesting that cooking became more focused on plant materials through time (Blinman 1986). These changes also coincide the introduction of a new corn variety, *Mais de Ocho*, which produces higher yields and has a softer endosperm more suitable for milling than the earlier flint corn varieties (Adams 1994; Cutler and Meyer 1965; Galinat 1985; Galinat and Gunnerson 1963; Galinat et al. 1970, Mathews 1986).

If corn grains were increasingly processed into meal, as the increase in two-hand manos and the use of *Mais de Ocho* suggest, then the cooking of corn products would also have shifted from roasting of whole ears to other cooking techniques more suitable for meal. Corn meal can be cooked in two ways: (1) boiling with water and, potentially, other food stuffs into a mush or stew, and (2) baking or grilling into bread or tortillas. The lack of griddle stones and other artifacts and features associated with baking and grilling until the fifteenth century in the northern Southwest suggests that corn meal was cooked primarily by moist cooking or boiling until very late in the prehistoric period (Snow 1990). Thus, cooking in pots increased in importance during the ninth and tenth centuries in the Mesa Verde region at the same time that there is increased evidence for the use of utility ware vessels in cooking.

Although detailed evidence is lacking, cooking appears to have been the primary use of Puebloan utility wares for the next 400 years. However, apparent changes in the processing of corn during the fifteenth century suggest that the importance of cooking corn meal in pots may have decreased at the same time as the shift back to manufacture of plain utility wares. During the fifteenth century in the Rio Grande region and possibly elsewhere, a suite of traits used in bread or tortilla making, including griddle stones or *comales*, rectangular hearths, and fire dogs (stones used to support the *comales* over the hearth), appeared for the first time (Snow 1990). Presumably introduced from Mexico where this technology has a much longer history, this bread or tortilla

making probably also involved soaking or mixing the corn with lime or alkali which significantly enhances its nutritional value (Katz et al. 1974). This adoption of a flat bread technology probably resulted in much less corn being cooked into mush and gruel. In fact, a general lack of information on porridge cooking in historical and ethnobotanical information on the Pueblos may indicate that this method of cooking corn was of little significance in historic times.

CHAPTER 7: ENGINEERING PROPERTIES OF PLAIN AND CORRUGATED VESSELS

Given this improved understanding of the history of corrugation and some aspects of the environment in which corrugation developed, we now need to determine whether plain and corrugated vessels would have interacted differently with that environment. Documenting the nature of these interactions involves a process of reverse engineering in which I use experiments and other pertinent data to measure relevant aspects of cost and performance of plain and corrugated vessels. Choosing the aspects of cost and performance to measure is based on knowledge of the environment with which the vessels interacted. Changes in the production and use environments documented in Chapter 6 indicate that differences between plain and corrugated vessels in manufacture costs, heating effectiveness, ease of handling, and use-life are likely to be relevant to explaining the development and spread of corrugation. In addition, other archaeologists have made claims about the relevance of these features based upon their own experiments and attempts to explain corrugation (e.g., Beals et al. 1945; Blinman 1993; Gumerman 1984; McGregor 1941; Schiffer *et al.* 1994). Certainly other cost and performance properties could be measured. However, practical limitations usually result in a trade-off between thorough measurement of a few properties and cursory measurement of many. In choosing a few properties to measure, I hope to generate enough well controlled experimental data to offer strongly warranted conclusions about the relative costs and benefits of plain and corrugated vessels at least in terms of these four variables.

This chapter is organized into five sections. In the first section, I describe the how the replica vessels were produced for use in the various experiments and provide information on the characteristics of each vessel. This is followed by sections covering the each of the four features under investigation: manufacture costs, heating effectiveness, ease of handling, and use-life. In each section, I present the procedures and results of my various experiments and discuss additional data relevant to the issue such as results of experiments performed by other investigators, knowledge drawn from engineering and material sciences, and data from ancient pottery assemblages.

Production of Replicas for Experiments

To perform these experiments, I needed to manufacture and use accurate replicas of the ancient cooking pots. These are not meant to be exact copies of particular ancient pots, but replicas that are accurate with regard to the particular features relevant to this study including

construction technique, raw material, and size. A total of 24 vessels, 12 plain and 12 corrugated, were made and individually numbered (1-24). In designing these replicas, I wanted to hold everything constant except those aspects of forming techniques that differentiate the ancient plain and corrugated pots. Thus, all pots were made from the same batch of raw materials, in the same size and shape (to the extent possible with hand-made items), formed by the same person, and fired together in the same kiln. The raw materials consist of clay from a Dakota Formation exposure along a road cut in the Cortez Industrial Park (designated as industrial park gray or IPG), which was mixed with 15 percent by volume of crushed igneous rock obtained from the back dirt of a rock crusher located in McElmo Canyon at the northern end of Ute Mountain. I processed the clay by grinding the raw chunks to a fine powder, and then mixing the clay powder with temper and water. The temper was cleaned and sorted by washing it through a set of nested sieves and consisted of equal amounts of material from two size classes, 1.4-.71 mm and .71-.25 mm. No other processing occurred with the temper before being mixed with the dry clay. The dry clay-temper mixture was then combined with normal Montezuma County tap water until saturated, and allowed to age for one week before the vessels were formed.

The moistened clay/temper mixture was divided into 800-g portions for making each vessel. When the vessel was complete, the remaining clay was weighed to determine the weight of moist clay used to construct each vessel. During forming of the replicas, their size and shape were controlled by constant matching with a template designed to yield a finished, fired vessel that is 15 cm high with a globular, wide-mouthed, slightly flaring jar form (Figures 28 and 29). I selected this form because it matches the shape of late neck-banded and early corrugated vessels from the Mesa Verde region. Although small by ancient gray ware standards, the size fits within the lower range of those actually used for cooking in the Mesa Verde region. The template is slightly larger than the finished product because approximately 8-10 percent shrinkage occurs during drying and firing. Clint Swink, an experienced replicator of ancient pueblo pottery, formed all of the vessels. Because the replicas were made by hand, they differ somewhat from the ideal template form. Table 15 presents measurements made on each vessel after firing and before use experiments began. Although most variation in the replicas is random, the corrugated vessels tend to weigh a little more than the plain vessels as a result of slightly greater wall thickness particularly at the base.

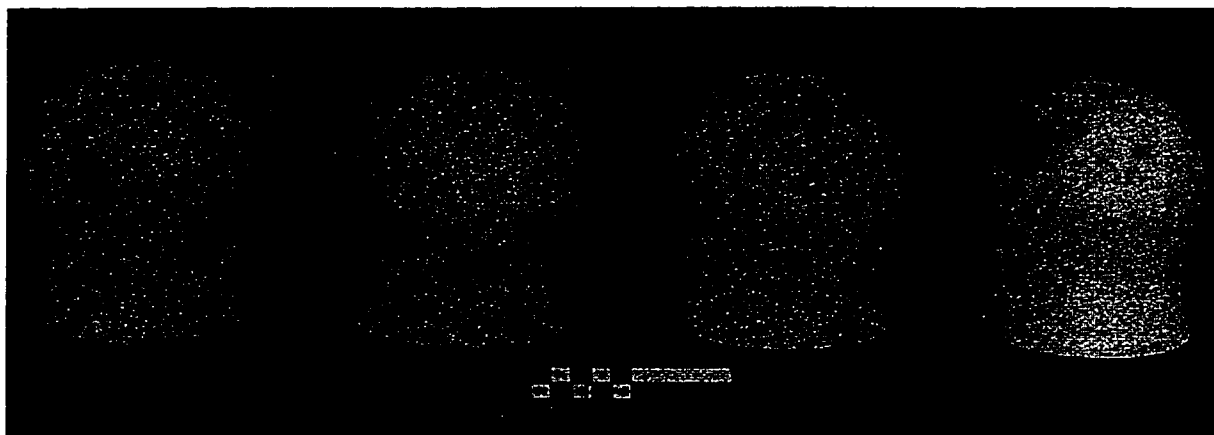


Figure 28. Examples of fired plain replica vessels used in experiments.



Figure 29. Examples of fired full-body corrugated replica vessels used in experiments.

Table 15. Measurements on replica utility ware vessels used in experiments.

Vessel ID	Vessel Type	Moist Clay Weight (g)	Fired Weight (g)	Vessel Height (mm)	Maximum Diameter (mm)	Total Volume (ml)	Upper Wall Thickness (mm)	Base Wall Thickness (mm)
2	Corrugate	939	670.1	155	141	1250	6.7	6.8
3	d	794	563.4	159	129	1215	5.3	6.3
4	"	798	563.8	154	131	1140	6.1	6.1
5	"	734	520.6	153	124	1115	NM	NM
6	"	766	553.8	153	129	1210	NM	NM
7	"	816	570.2	149	129	1170	NM	NM
8	"	804	590.4	154	131	1220	5.5	5.7
9	"	834	572.9	154	135	1310	5.4	6.4
10	"	781	562.9	155	131	1245	5.6	6.6
11	"	764	552.3	154	132	1240	NM	NM
12	"	787	536.3	155	132	1230	5.4	5
24	"	800	542.5	150	130	1150	5.6	5.7
1	Plain	764	536.9	158	128	1090	5.1	4.9
13	"	761	513.8	151	130	1280	5.1	5.8
14	"	778	529.3	153	131	1180	5	6
15	"	759	531.8	156	136	1285	NM	5.3
16	"	716	502.6	151	130	1150	NM	NM
17	"	759	517.2	151	128	1200	NM	NM
18	"	747	527.9	160	136	1290	NM	NM
19	"	662	453.5	152	125	1150	NM	4.7
20	"	741	506.3	151	128	1245	5.7	5.2
21	"	670	459.3	151	125	1090	6.1	4.7
22	"	741	510.7	149	134	1250	4.5	4.4
23	"	757	533.8	159	129	1280	NM	NM

NM = not measured.

The replicas were dried in a conventional oven overnight at 65 °C, and fired the next day in a replica of an ancient Mesa Verde region trench kiln using techniques developed to successfully fire organic painted black-on-white pottery (Swink 1993). After burning down pinyon and juniper wood to create a bed of coals in the bottom of the kiln, a layer of tabular sandstone rocks was added. We then arranged the 24 replicas systematically on top of these rocks so that plain and corrugated vessels were evenly distributed around the kiln. Next to each pot we placed a 6 by 10-cm tile made from the same raw material. Sixteen type k thermocouple probes were then placed around the vessels (Figures 30 and 31). The layer of vessels was covered with a second layer of pinyon and juniper fuel, which was then ignited from the top. Within 30 to 40 minutes after lighting of the secondary fuel layer, temperatures throughout the kiln had stabilized at about 800 °C (Figure 32). The pots were exposed to this peak temperature for another 40 minutes, and then the entire kiln was smothered with earth and allowed to cool over night. Although the temperatures within the kiln were fairly consistent during the firing, the atmosphere varied slightly with some vessels showing slightly more oxidation or reduction than others.

I designed the plain and corrugated replicas to differ in construction based on knowledge gained from the analysis of the gray ware assemblages discussed in Chapter 5. The plain vessels are replicas of the earliest cooking pots referred to as Chapin Gray (Figure 28). This variety of early gray ware vessel was made using relatively large coils or slabs which were filleted or stacked on top of one-another to build up the vessel wall and both surfaces were scraped smooth to weld coils together and form the finished shape. To mimic this, the plain surface replicas were made by first forming a small disk in a base mold or *puki* to serve as the base of the pot and then adding two or three large coils which were pinched up and scraped to form the 5 mm thick wall. The corrugated replicas were designed to match the early corrugated vessels produced in the 11th century AD (Figure 29). The average values for amount of coil overlap (60 percent), spacing of indentations (11 mm), and exposed coil height (6 mm), and wall thickness (5.5 mm) obtained from the two corrugated assemblages analyzed were used to guide forming of the corrugated pots. The application of coils involved placing the coil on the pot, indenting the coil between the index and middle fingers, and then creating a platform at the top of this coil for placing the next coil. This procedure was repeated until the desired height and form of the vessel was obtained.

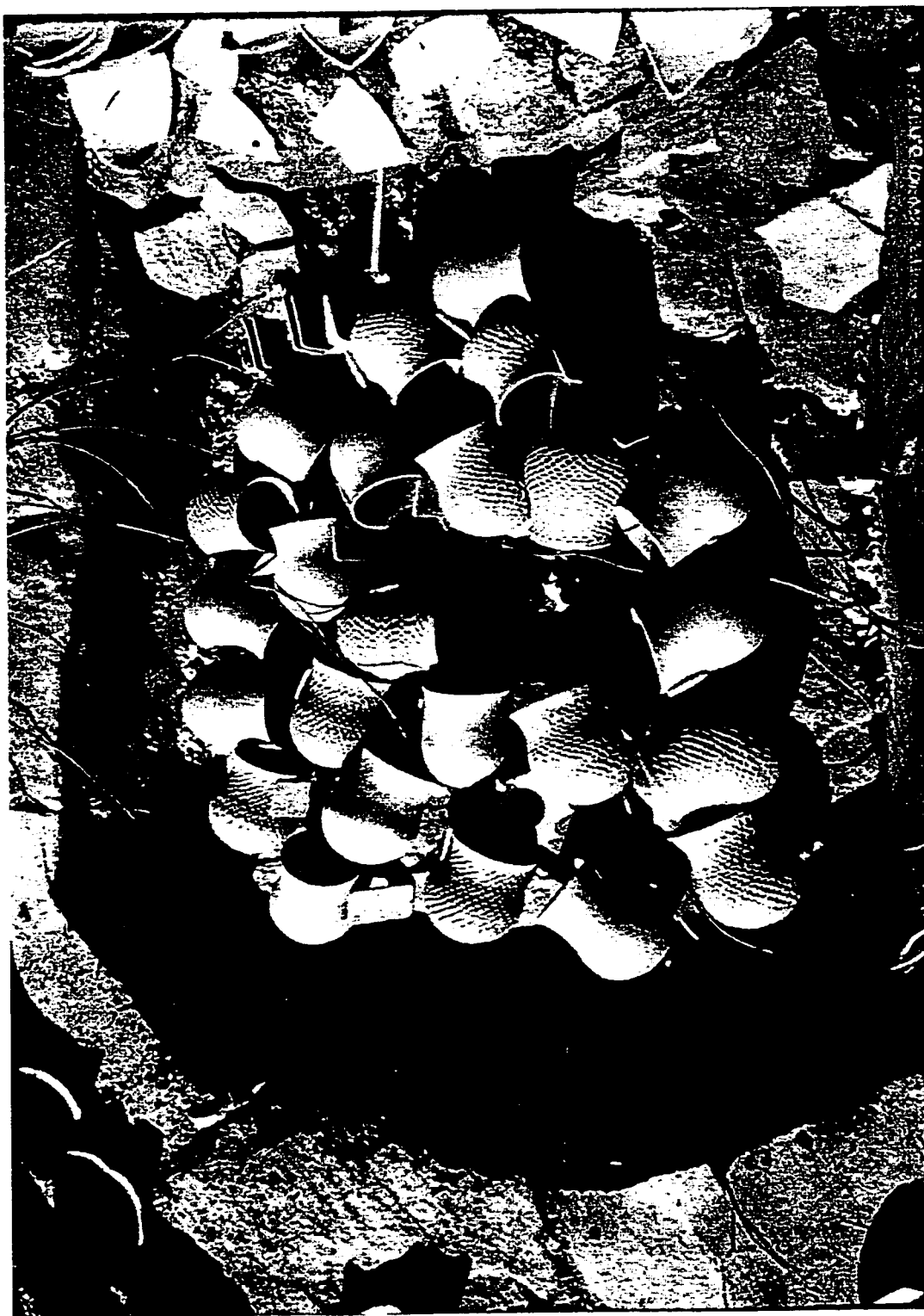


Figure 30. The placement of pots, tiles, and thermocouple probes in kiln before firing.

costs of plain and corrugated pottery has rarely been considered, some have argued that leaving coils exposed may affect the strength of the weld between coils and the frequency of structural failures during drying and firing (Blinman 1993; Schiffer et al. 1994). Still others have suggested that the use of overlapping and indenting of coils may have strengthened coil welds (Beals et al. 1945:140). These issues were either not addressed or left unresolved by earlier experiments.

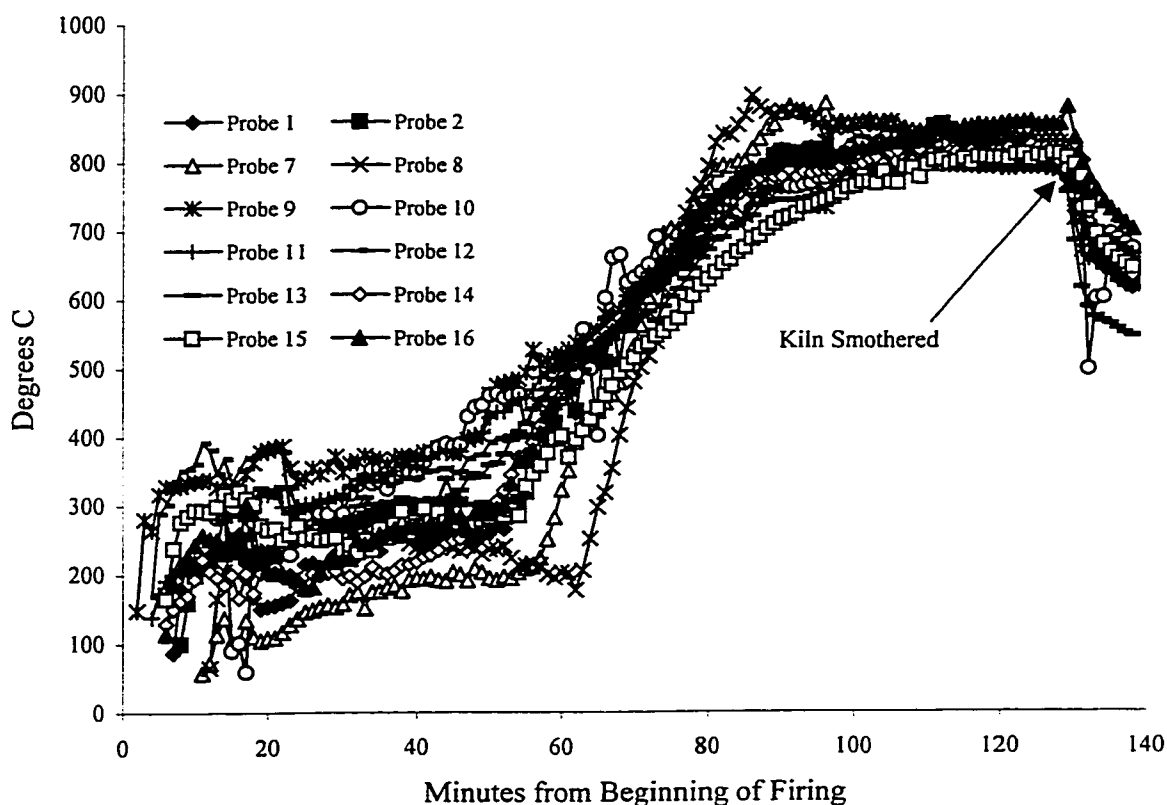


Figure 32. Temperature profiles for pit kiln firing of replica utility ware vessels used in experiments.

Forming Time

To measure differences in costs accrued during the forming stage of manufacture, the time required to form each of the 24 replica vessels prepared for this study was recorded. Only forming time was recorded because variation in clay preparation and drying times depend on several factors most of which are irrelevant to this study. As described in more detail above, the 12 plain vessels were formed using wide, filleted coils that were scraped on both surfaces to obtain a specified morphology and help weld the contacts between adjacent coils. The 12

corrugated jars were manufactured entirely of small, overlapping, and indented coils, which were scraped smooth on the inside surface. All vessels were made to the same size and shape specifications although some variation exists among individual vessels.

Two factors can significantly affect the validity and reliability of these forming time measurements. First, the values are useful only if the replicator is proficient in forming the vessels and enough vessels have been formed at a proficient level to yield an accurate estimate of forming time. Comparing vessel-forming times over the sequence of construction episodes from the first vessel to the last can be used to assess replicator proficiency. At the outset, forming times may be high, but as the potter's proficiency improves, forming times should decrease until maximum proficiency is attained and forming times stabilize with only small random fluctuations. It is only after the values have stabilized that forming time measurements are useful for estimating manufacture costs. Figure 33 shows the sequence of forming times for the plain and corrugated vessels manufactured for this study. Both sets show a slight trend toward decreased forming time through the entire sequence of 12 vessels, but values are more stable after 2 plain and 3 corrugated vessels were manufactured. In neither case is there a large decrease in forming times. This may result from the considerable experience Clint Swink, the potter, had with forming plain and corrugated vessels before the experiment began. In fact, it is possible that both sequences show mostly random fluctuations.

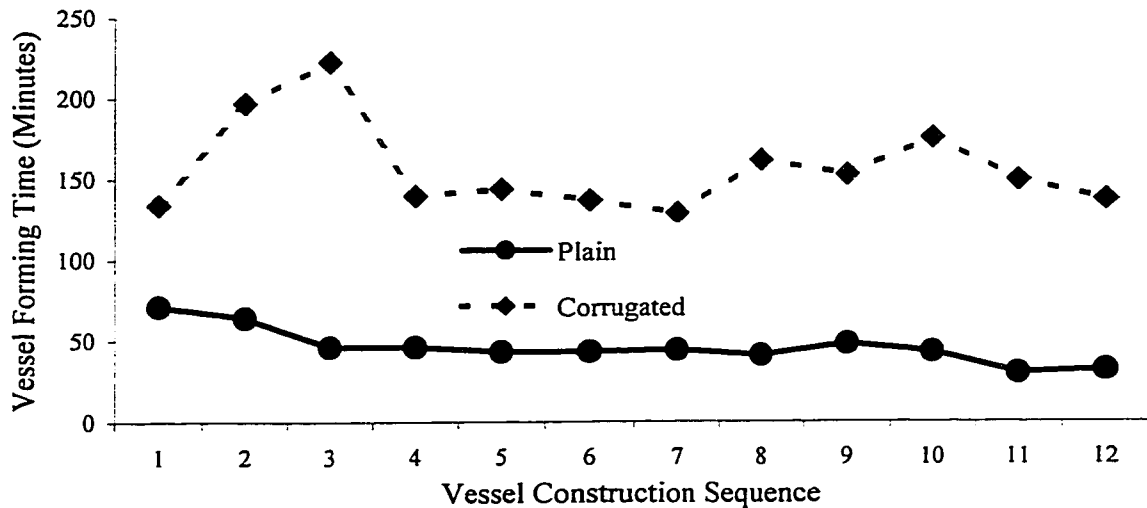


Figure 33. Vessel forming times by sequence of construction for the 12 plain and 12 corrugated replicas.

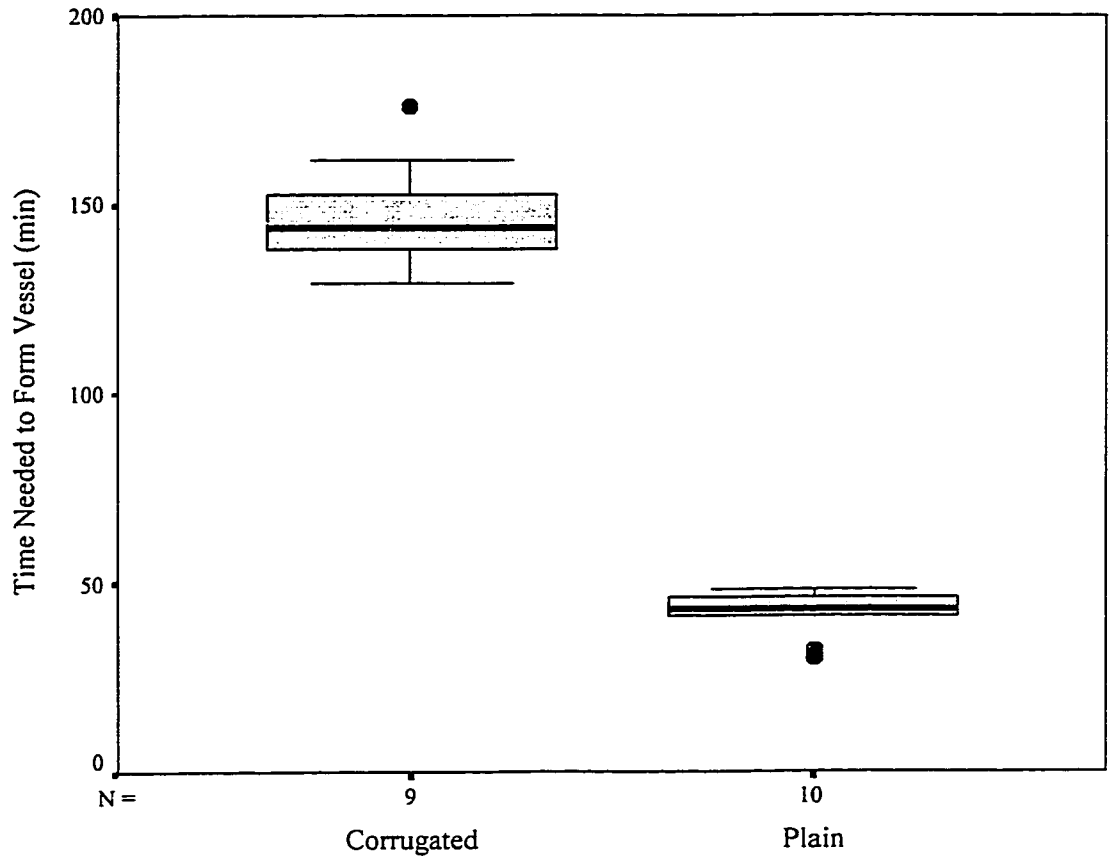


Figure 34. Box plot of time needed to form replicas of plain and corrugated vessels after forming times stabilized.

Second, the validity of forming time measurements requires that the techniques employed to form the vessels match as closely as possible those used by the ancient potters. The techniques used for forming the plain and corrugated replicas for this study were selected after examination of forming traces in the pottery analyzed from the six Mesa Verde region assemblages (see Chapter 5) and experimenting with techniques to produce pottery with the same characteristics. However, it is possible that multiple techniques can produce the same results, and that the techniques employed to make the replicas differ from those used by the ancient Pueblo potters. Although more detailed observations of the ancient pottery can improve our understanding of construction techniques, it is likely that we will never know with certainty what set of techniques were actually used in the past. Given that the best we can say about the forming techniques employed for this study is that they are reasonable approximations of those used in the past, we will need to be cautious in using the forming time results to measure manufacture costs.

These forming time experiments produced the opposite result of Blinman's (1993) replication experiments. In the experiments performed for this study, corrugated pots took an average of three times longer to form than the plain vessels (Figure 34) rather than one third less time suggested by Blinman. This fairly major difference probably results from the use of different forming techniques although it is difficult to say with certainty without knowing more details of Blinman's experiments. The large differences in forming times between the plain and corrugated vessels made for this study probably derive mainly from differences in coil size and application technique. If the same number of coils and degree of overlap were used to manufacture both plain and corrugated vessels, it is possible that forming times would be similar or that corrugated vessels could even take less time to form because the scraping step would be eliminated. However, the use of a small number of wide, filleted coils in the plain versus the numerous smaller, overlapping coils in the corrugated should, and experimentally did, result in less time to form the plain vessels. If coil size and application are the main determinants of forming time variation, then forming costs would have increased during the tenth and eleventh centuries as coil size decreased and overlapping applications increased.

Production Failure Rates

Failure of vessels during manufacture is most likely to occur during the drying and firing stages because of the shrinkage of the clay body that occurs during each of these steps. After both drying and firing the replicas, I visually examined each of the 24 vessels made for this study for the development of any flaws or failures. No flaws were detected after drying, but two vessels, both with plain surfaces, developed cracks during firing. One vessel (no. 21) sustained a rim crack that extended 2.7 cm down from the rim while the other vessel (no. 18) developed a 3.6-cm long crack parallel to the rim at the base of the neck. Although water leaked from both of these cracks, neither compromised the use of the vessel nor did the cracks expand during use. In various pottery replication and firing experiments performed over the past few years, some of us have also noted that in vessels with corrugated necks, cracks propagating down from the rim tend to stop at the first exposed coil junction below the rim. Based on these various anecdotal observations, it appears possible that corrugated vessels are slightly more resistant to the stresses generated during manufacture, and thus may fail less often. However, it is unclear whether the difference is sufficiently great to affect production costs.

Heating Effectiveness

Superior performance of corrugated pottery during use could offset its higher manufacture cost. Because the change to corrugation occurred when gray ware pottery was used mainly for cooking (see Chapter 6), differences between plain and corrugated vessels in the transfer of heat through the vessel wall and the effects of these differences on the contents being cooked constitute the relevant measures of performance. For many years, archaeologists have asserted that the greater exterior surface area of corrugated vessels would have resulted in more effective heat transfer between the heat source and the vessel contents, and that this difference may have played a significant role in the adoption of corrugation (Gumerman 1984:79-80; McGregor 1941; Rice 1987:232; Vivian 1990). However, recent experiments by Plog (1986), Schiffer (1990), and Young and Stone (1990) designed to measure the effects of various surface treatments, including exterior surface texturing, on heating effectiveness suggest that corrugation does not necessarily improve performance, and can even degrade it. Although intriguing, these experiments have not been convincing to all observers mainly because of problems seen with the design of the experiments. For example, the vessels used were not accurate replicas in terms of the raw materials, forming techniques, vessel morphology, or firing regimes employed, and the number of tests, or experimental runs, was extremely low.

To more thoroughly evaluate the heating effectiveness of plain and corrugated gray ware pottery, I used the 24 replicas described earlier in cooking experiments which were designed to assess the impacts of three factors—exterior surface treatment, interior surface lining, and cooking contents. Each factor consists of two states. Exterior surface treatment includes scraped plain and corrugated. Interior surfaces are either unlined or lined with pinyon pitch. I chose to study the effects of interior surface lining because previous experiments had shown that reducing vessel wall permeability through lining can affect heat transfer effectiveness (Schiffer 1990). Although there is no record of ancient Pueblo pottery being lined with pitch, this is a common practice with ceramic cooking pots in other parts of the world. In addition, I thought that pitch was probably one of the most effective lining materials available to ancient Pueblo potters, and I wanted to test the most extreme case. This assumption proved incorrect as I discuss in more detail below. The contents of vessels varied by filling some with 700 ml of plain tap water and others with 700 ml of corn mush created from 600 ml of tap water mixed with 100 ml of chicken stock and 15 ml of corn meal. I included chicken stock to add fat to the contents and to simulate the addition of turkey or other meat to corn-based recipes. The three factors with two states each

produce eight possible factor combinations (Table 16). With 24 vessels, three vessels can represent each factor combination. I randomly selected which vessels would be assigned to each factor combination.

Table 16. Vessel numbers assigned to different factor combinations for experiments.

Contents	Plain Surface		Corrugated Surface	
	Lined	Unlined	Lined	Unlined
Water	16, 17, & 20	14, 18, & 23	6, 7, & 12	3, 5, & 11
Corn Mush	1, 15, & 21	13, 19, & 22	4, 8, & 10	2, 9, & 24

The experiment involved heating each filled pot on a propane burner set at about 450 °C, and measuring the time elapsed before a peak temperature was reached, which was boiling (~95 °C because of high elevation) in most cases. Before filling the pots for each run of the experiment, they were weighed to the nearest 1/100th of a gram. After weighing, the pots were placed on the burners, and filled with the appropriate contents. Working rapidly, we then arranged all of the temperature probes and began logging temperature data. Temperatures were measured by placing the tips of stiff, submersible, type k thermocouples probes against the exterior surface of the vessel at three points (base, middle body, and neck) and one probe inserted into the contents of the vessel one cm above the base of the pot (Figure 35). After initiation of temperature recording, the burners were ignited and adjusted to the appropriate level. I selected 450 °C as the target flame temperature because open wood fires can easily reach that temperature. However, it was often difficult to set and hold the temperatures of the propane burners resulting in temperatures at the base of the pots fluctuating between 400 °C and 500 °C. This range is still well within that of open wood fires. The time elapsed between filling the pots and igniting the burners was usually less than 3 minutes.

The filled pots were heated for 40 minutes and then allowed to cool for 20 minutes, recording temperatures for the entire hour. After the cool down period, I emptied the vessel contents into a graduate beaker to measure remaining volume, the interior surface was rapidly wiped with paper towel, and the pot was weighed again to the nearest 1/100 of a gram. The temperature data for each vessel were logged every ten seconds by computer for each experimental run. In addition to the temperature data, we also recorded observations of vessel performance during heating and cooling, such as boilovers, leaks, etc., and noted any alterations to the vessel surfaces and vessel integrity after the experiment. We repeated this experiment 12

times for each vessel resulting in 36 measurements for each factor combination. Because four burners were used in each run of this experiment, the pots were rotated to a new burner for each run so that each pot was heated three times on each burner. In addition, four plain and four corrugated vessels containing corn mush were used in numerous additional cooking runs as part of the use-life experiments discussed below. Data on heating effectiveness generated during these use-life experiments are incorporated into this evaluation of heating effectiveness when appropriate.

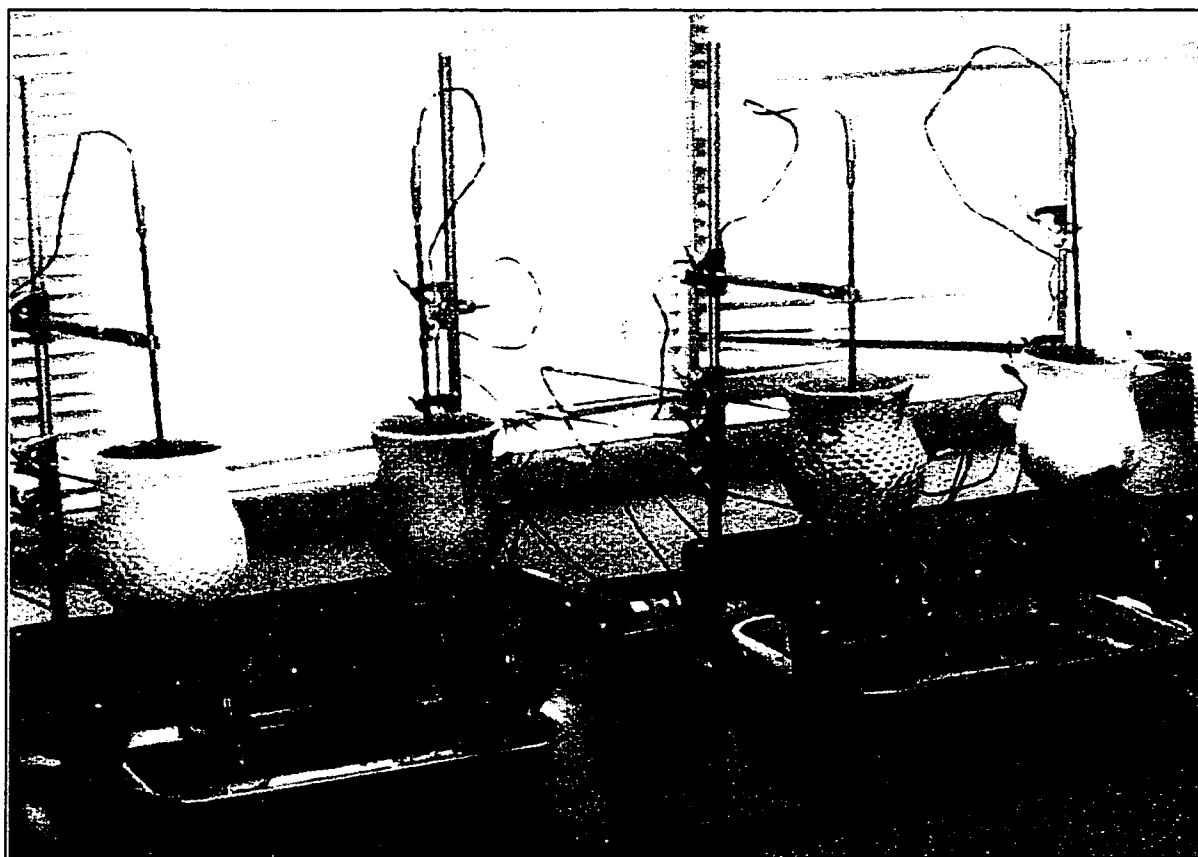


Figure 35. Arrangement of vessels and temperature probes used to perform heating effectiveness and use-life experiments.

In addition to performing the cooking experiments, I measured the permeability of the wall of each pot before the first experimental run and after run numbers 4, 8, and 12 for of each vessel. This was done by weighing the dry pot to the nearest 1/100 of a gram, and then filling the pot to the rim with tap water and letting the water soak into the vessel wall for 60 seconds. The water was then emptied and the inside surface wiped rapidly with a paper towel to remove any liquid remaining on the vessel surface. The empty pot was then weighed again to the nearest 1/100 of a gram. The difference between the two weights is a measure of the amount of water absorbed into the vessel wall during the soak period and thus reflects the permeability of the inside surface.

Heat Transfer

Box and whiskers plots of the time required for vessel contents to reach peak temperature for each of the eight factor combinations (Figure 36) show considerable variation among vessels containing only water, and remarkable similarity among vessels cooking corn mush. Among both the plain and corrugated vessels containing water, the unlined vessels took longer to reach peak temperature than the vessels lined with pitch, and the unlined corrugated vessels were by far the least effective at heating the water. In addition to taking longer to heat, water in unlined corrugated vessels frequently failed to boil in the 40 minutes of heating time during each experimental run (Figure 37). In contrast, no significant difference ($p < .001$) exists in the time required to reach peak temperature among the lined and unlined, plain and corrugated vessels in which we cooked corn mush, and the contents boiled vigorously in all cases.

These results support and extend those obtained by Young and Stone (1990) and Schiffer (1990). Reducing vessel wall permeability, either by applying a sealant before use or through cooking food, which is absorbed into and clogs pores in the vessel wall, greatly enhances heating effectiveness. Figure 38 shows the relationship between wall permeability (amount of absorbed water) and heating effectiveness (time to reach peak temperature) for plain and corrugated vessels. Each point in Figure 38 represents data for an individual vessel averaged from all measurements made after the first run. I excluded data from the first run because wall permeability frequently changed notably after that run, a phenomenon I address separately below. Figure 38 indicates that a strong, negative, relationship exists between heating effectiveness and wall permeability, and that the nature of this relationship differs between plain and corrugated vessels. For a given increase in vessel wall permeability, heating effectiveness degrades at a substantially greater rate for corrugated than for plain vessels. This difference is a function of the

greater exterior surface area of corrugated vessels. As liquid soaking through the vessel wall reaches the exterior surface, it evaporates. The heat energy used in this change from liquid to gas phase results in cooling of the vessel and its contents. The extended surface of corrugated vessels increases the rate of evaporative cooling producing a greater degradation of heating effectiveness than in plain surfaced vessels.

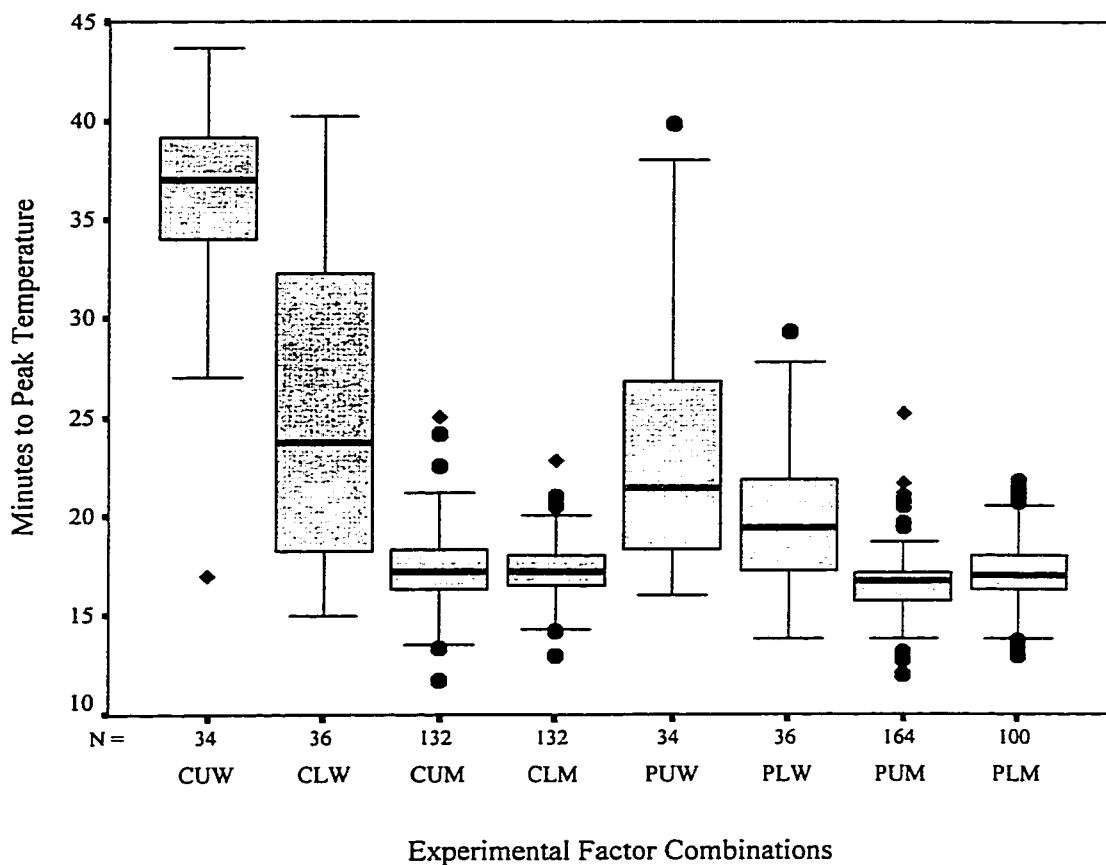


Figure 36. Box plots of time elapsed before reaching peak temperature for multiple runs with vessels in each of the eight experimental factor combinations (C=corrugated, P=plain, L=lined, U=unlined, W=water contents, M=mush contents). N = number of runs.

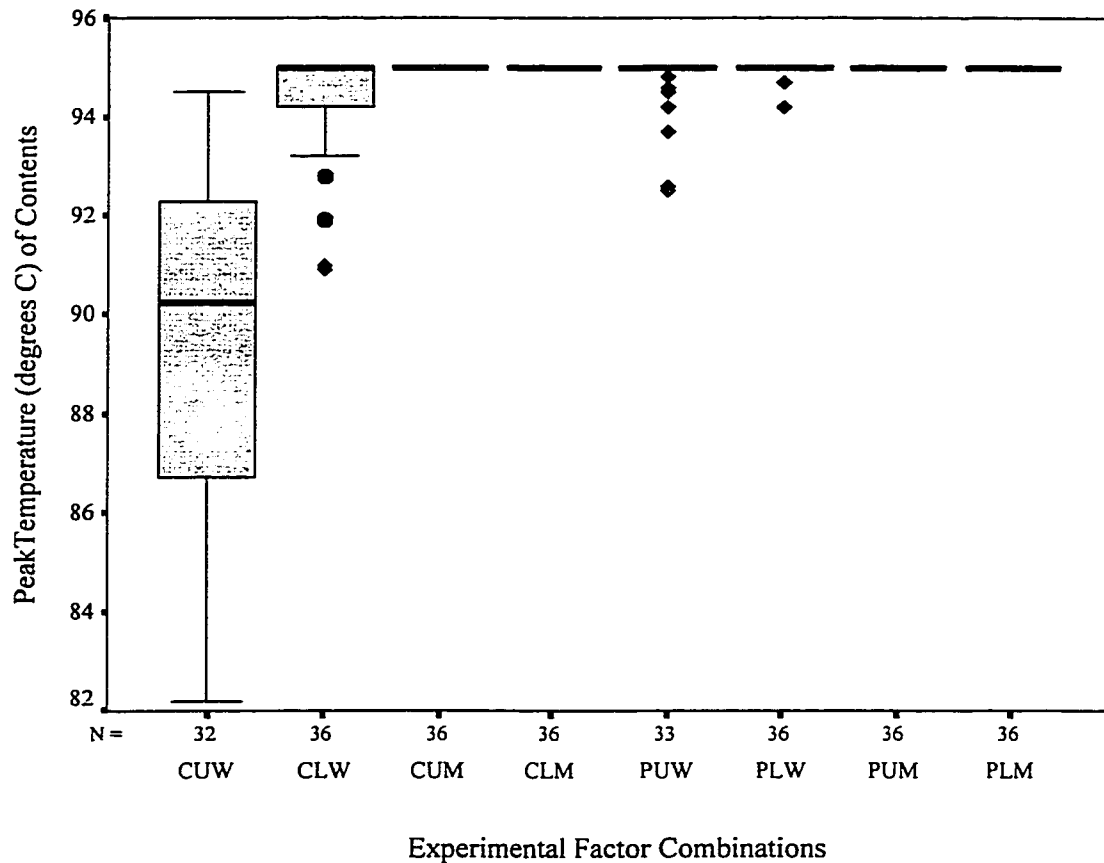


Figure 37. Box plots of peak temperature for multiple runs with vessels in each of the eight experimental factor combinations (see Figure 36 caption for factor combination definitions). N = number of runs.

Another difference in the permeability-heating effectiveness relationship between the two vessel forms is that the association is linear for plain vessels and slightly curvilinear for corrugated vessels. This difference derives from the degradation of the pitch lining over experimental runs (see Figure 39). The time needed to reach peak temperature in the lined vessels heat water increased gradually during the course of the experiment. This is due to the loss of some pitch during each run making the vessel walls more permeable. Given the different responses to wall permeability between plain and corrugated vessels, the lined corrugated vessels heating water lost heating effectiveness more rapidly than the comparable plain vessels. This produced the curvilinear relationship for corrugated vessels. I suspect that the relationship would be linear if another, more stable, method of controlling wall permeability was used.

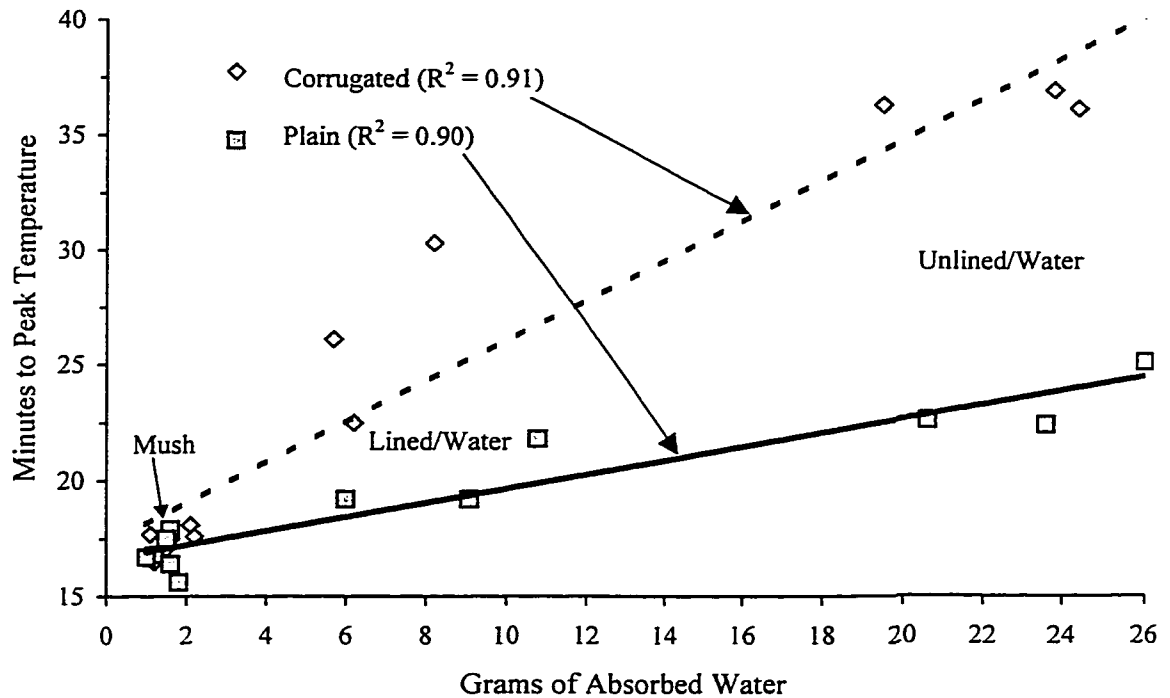


Figure 38. Scatter plot of heating effectiveness and vessel wall permeability. Points represent average values for individual vessels derived from multiple experimental runs.

Changes in the time required to reach peak temperature over the course of experimental runs, shown for different factor combinations in Figure 39, also expose important patterns in the relationship between wall permeability and heating effectiveness. In the first runs of each set, the contents (regardless of composition, water or mush) of corrugated vessels lined with pitch reached peak temperature more rapidly than in the pitch-lined plain vessels, while among unlined pots, the plain vessels heated their contents more rapidly. Degradation of the pitch lining through use resulted in a loss of heating effectiveness particularly for corrugated vessels heating water as discussed above. For the lined vessels cooking mush, heating effectiveness diminished after the first run, but then stabilized as the mush permeated and lined the vessel walls. Among the unlined vessels, the time to reach peak temperature in those heating water fluctuated randomly with the corrugated vessels consistently proving less effective than the plain vessels. For the unlined vessels cooking mush, the initial run required more time to reach peak temperature than subsequent runs. The heating effectiveness of these unlined vessels improved as the mush soaked into the vessel walls. Very small, yet consistent, differences in heating effectiveness between

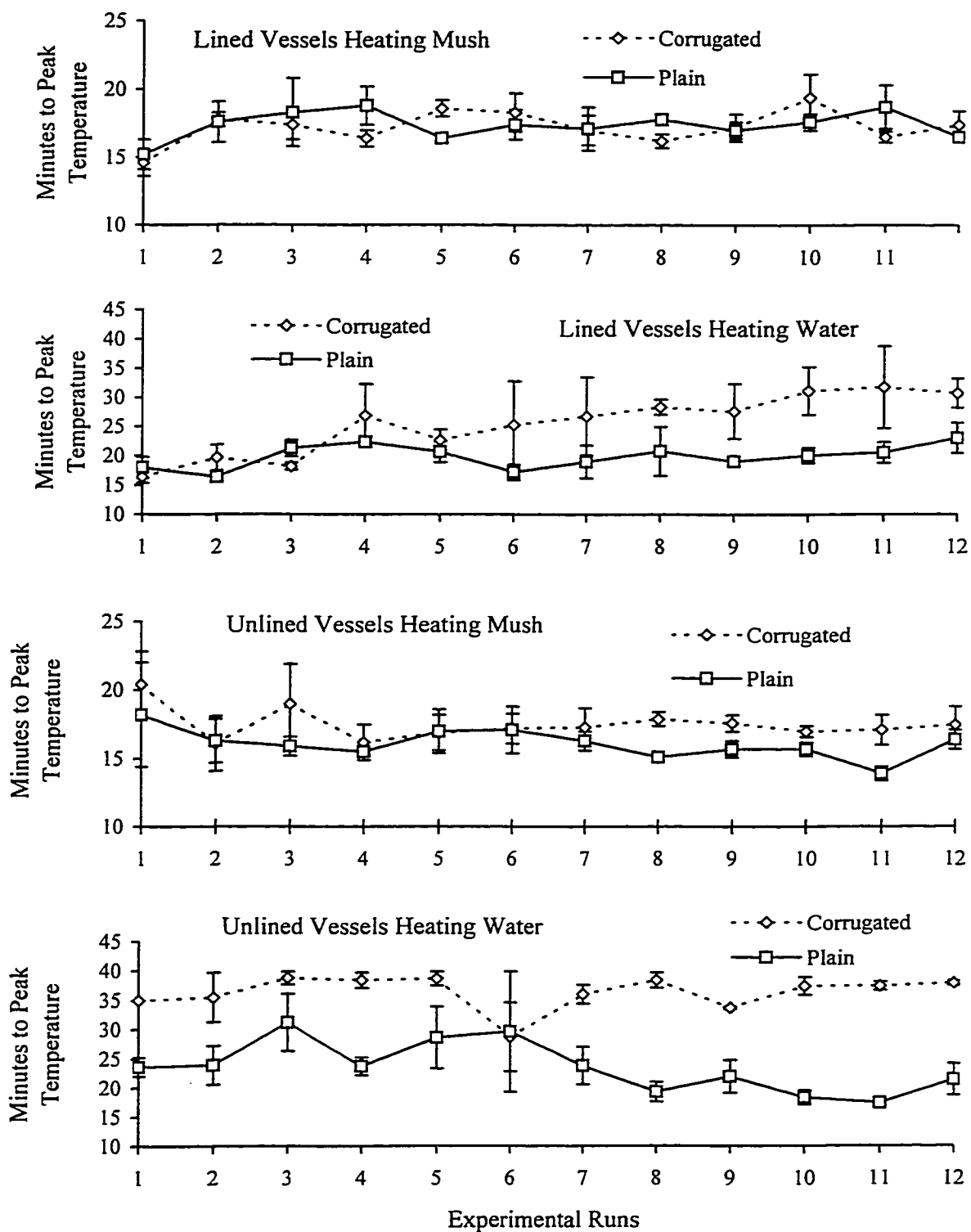


Figure 39. Changes in heating effectiveness over experimental runs for different factor combinations.

plain and corrugated vessels can be seen after the first run, with plain vessels remaining slightly more effective than corrugated vessels.

These results further reinforce the importance of vessel wall permeability to heating effectiveness. The slightly elevated effectiveness of pitch-lined corrugated vessels over pitch-lined plain vessels in the first run when wall permeability was extremely low indicates that the greater exterior surface area of corrugated vessels does improve the transfer heat to the vessel contents. However, even slight increases in wall permeability eliminate this advantage because the area of the surface losing heat through evaporative cooling is considerably greater than the small portion of the vessel, the base, actually being heated during use. The fact that a single episode of cooking food greatly reduces the permeability of an unlined vessel wall suggests that users of plain and corrugated pottery in the past would probably have been unaware of their significant differences in heating effectiveness when unlined.

Control over Cooking

In addition to heat transfer, the control of temperatures so that the contents cook but do not boil over has been shown ethnographically to be an important aspect of cooking pot performance, and can even supersede heat transfer effectiveness (Skibo 1994). During most of the heating effectiveness and use-life cooking experimental runs, we monitored the occurrence and intensity (heavy or slight) of boilover episodes. No boilovers occurred in the vessels containing only water, but boilovers were common in the vessels cooking corn mush because the starch in the corn meal tends to froth when it boils. For the cook, heavy boilovers present a problem because they can douse the cooking fire and waste food whereas slight boilovers waste little and usually evaporate before reaching the fire.

Out of the 140 experimental runs of plain and corrugated vessels cooking mush for which boilovers were recorded, heavy boilovers occurred in 48 percent of plain vessel runs and only 24 percent of corrugated vessel runs. I suspect that this pronounced difference in the rate of heavy boilovers probably results from the slightly lower heat transfer effectiveness of corrugated vessels cooking mush documented earlier. The greater evaporative cooling of corrugated vessels may have allowed improved control of cooking by slight reductions in the rate and intensity of boiling. If simmering or other more controlled forms of moist cooking were preferred to boiling, corrugated vessels would have offered an important benefit. Because the exposed coils on the upper portion of the vessel body produce this effect, later neck-banded and neck-corrugated vessels probably also offered an advantage over scraped plain vessels in cooking control.

Although boilovers can be avoided by other means such as using larger or more open vessels to cook the same amount of food, these adjustments introduce additional costs. Larger vessels involve greater manufacture costs whereas more open vessels lower heating effectiveness by allowing more heat loss from the opening of the vessel. How these costs compare to the higher cost of forming corrugated vessels has not been documented.

Ease of Handling

Ease of handling constitutes another frequently discussed area of possible performance differences between plain and corrugated vessels (Blinman 1993; Schiffer et al. 1994). Many argue that the corrugated surface is superior for handling because the rough surface provides more friction, which would reduce the number of accidental drops resulting in breakage of the vessel. Although I did not conduct any experiments designed explicitly to generate data on potential handling differences between plain and corrugated vessels, I did handle the vessels quite a lot during the cooking experiments and teaching which resulted in some anecdotal observations regarding ease of handling. Out of the nearly 2,000 times I transported the plain and corrugated replicas used in the heating effectiveness and use-life experiments, I dropped only one vessel. This was a plain-surfaced vessel that slipped out of my hand when I was setting it down while teaching a class after the experiments were completed. Both the relatively small sizes of the replica vessels and the extreme care I exercised when transporting the vessels probably contributed to the low droppage rate. Larger vessels (which are more common in actual gray ware assemblages) are heavier, and offer a broader surface for grasping which could have produced a higher droppage rate in the past. In addition, while handling the vessels after cooking, I frequently noted that the corrugated vessels were easier to handle hot than the plain vessels because less of the hot surface was in contact with my hands.

Based only on these anecdotal observations, it appears that a corrugated surface does offer some handling advantages, particularly when the vessels are hot, and probably the rougher the surface the better. Thus, the earliest forms of exposed coils, which were relatively wide and flat, would have offered little handling advantage over a plain surface. The introduction of overlapped coils resulting in a clapboard-like surface would have added considerably to surface roughness and perhaps improved handling. The later addition of indentations to the overlapped coils also increased surface roughness and greatly reduced the amount of vessel surface coming into contact with hands grasping the vessels.

Use-Life

The amount of use obtained from a pot before physical failure or degraded performance requires replacement affects the cost of vessel technologies. The longer a vessel lasts during use, the lower the production costs as fewer vessels need to be manufactured per unit of work performed. For many years, the prevailing view has been that plain surfaced pots are stronger than corrugated pots, and consequently may have had longer use-lives. This perspective derives from the reasoning of both potters and engineers. From the potter's perspective, experience has shown that the worst thing you can do when hand-building pottery from coils or slabs is to inadequately weld the junctions or joins between construction elements. Poorly joined coils constitute zones of weakness in the vessel wall that can crack more easily during drying, firing, and use. From the engineer's perspective, unevenness or discontinuities in the vessel wall produce areas of stress and strain concentration during mechanical or thermal stress loading (Manson 1966:250-253, 385-391; Smith and Smith 1960; Stokes 1968). Not only does stress tend to concentrate in the weakest area such as poorly joined coils, but the variation in thermal inertia created by adjacent zones of thin and thick wall can result in stress inducing temperature, and thus, thermal expansion differentials within the vessel wall.

However, recent experiments by Schiffer and others (1994) suggest that ceramic vessels with deeply textured exterior surfaces may be less susceptible to failure (cracking and surface spalling) due to thermal stress than vessels with plain exterior surfaces. In addition, Heidke and Elson (1988) and Weigand (1976) make a similar argument for the highly textured stucco-coated pottery found in Hohokam sites and produced historically by the Huichol Indians of northern Mexico. Although both experimental and ethnographic evidence suggests that exterior surface texturing may improve the use-life of cooking pots, no clear or convincing argument has been presented regarding the physical mechanisms involved. Consequently, it is appropriate to review current knowledge regarding the nature of potential stresses and strains generated in ceramic cooking pots during use.

Stress and Strain in Ceramic Cooking Pots

Two kinds of stress—mechanical and thermal—operate to produce strains within the wall of a ceramic cooking pot that can result in failure and significant performance degradation. Mechanical stress occurs when force is applied to the vessel through contact with another massive substance, usually a solid. The nature of the mechanical force(s) applied (whether static or dynamic, and their magnitude and direction) and the materials and forms involved determine, to a

great extent, the nature of the resulting stresses and strains. Thermal stresses arise from temperature effects. Temperature gradients and differential expansion of distinct materials exposed to the same heat within the vessel wall can produce stresses if some force constrains thermal expansion. This thermal stress can cause weakening and failure of the vessel wall through the initiation and propagation of cracks. As with mechanical stress, the nature of the temperature distributions in the vessel wall, and the composition and form of the vessel govern the thermal stresses and strains that develop.

Mechanical stresses normally generated during the use of ceramics pots for cooking include the more or less static forces exerted on the vessel wall by the contents of the vessel, and the dynamic forces of impact and abrasion. Thermal stresses arise from transient temperature changes experienced in the vessel wall during heating and cooling, from the temperature gradient that exists between different portions of the vessel (For example, the difference between the heated exterior surface and the interior surface which is cooled by contact with a liquid.), and from the differential thermal expansion of clay and temper constituents of the vessel. At a minimum, a useful ceramic vessel must be able to withstand the normal mechanical and thermal stresses of manufacture and use without catastrophic failure. Several studies have documented how a variety of compositional and formal design characteristics of traditional ceramic cooking pots improve resistance to stresses by raising the critical level of stress needed to induce catastrophic failure (Bronitsky and Hamer 1986; Feathers 1990; Feathers and Scott 1989; Rye 1976; Schiffer et al. 1994; Skibo et al. 1989; Steponaitis 1984; Wallace 1989; West 1992). However, repeated exposure to subcritical stresses causes fatigue which can eventually result in structural failure or significantly degraded performance of ceramic cooking pots. Thus, any aspects of vessel design that reduce stress or enhance stress resistance will increase the probability of longer use-life by raising the critical stress levels and reducing fatigue. On the other hand, aspects of design that produce local concentrations of stress and zones of weakness will probably decrease use-life.

Differential effects of given aspects of vessel design in the face of various kinds of stresses and strains create the possibility for design trade-offs. Consequently, we should consider the case of stresses generated during cooking in a little more detail. Cooking involves few and usually weak mechanical stresses such as those generated by the pressure of the contents, by impacts from stirring and serving utensils, by moving the vessel onto and off the fire, and perhaps by cleaning. Any vessel that survives forming and firing will probably be able to withstand these

stresses. Strong mechanical stresses such as those that occur during impact from dropping a vessel will frequently result in failure of the vessel because of the brittle nature of ceramics. However, vessels with thick walls will fail less frequently than vessels with thin or variable thickness walls. In addition to design adjustments, behavior can also be modified to reduce the frequency and force of mechanical stresses.

In contrast, ceramic cooking pots experience considerable, constant thermal stress during use. From the moment a pot is first placed on the fire until it has cooled after removal from the heat, a thermal gradient exists between the heated exterior surface and other cooler parts of the vessel. If the vessel is used to cook a liquid, the temperature of the interior surface will not exceed by much the boiling temperature of the liquid. The temperature of the heated portion of the exterior surface can be substantially higher depending on the temperature and configuration of the heat source. With a vessel sitting directly on a normal wood fire, the temperature difference between exterior and interior surfaces at the base of the pot can easily range between 300 and 600 °C. The thermal gradient produced by this temperature difference results in greater thermal expansion of the heated exterior surface than the cooler interior surface. In addition, the thermal gradient up the vessel wall from the heated base to the unheated upper body results in greater expansion of the lower part of the vessel relative to the upper part. Under these conditions, the cooler inside surface acts as a restraining force to the vertical and horizontal expansion of the exterior surface resulting in compressional stresses at the exterior surface of the vessel wall, tensional stresses at the interior surface, and shear stresses vertically within the wall (Kingery 1955). However, no radial stresses develop because no resistance exists to radial expansion.

A variety of compositional and formal design adjustments can improve resistance to thermal stress or reduce thermal stresses themselves in ceramic cooking pots (Crandall and Ging 1955; Hasselman 1970; Kingery 1955; Manson 1966; West 1992). Selection of raw materials with low thermal expansion coefficients reduces thermal stresses while using large, platy or fibrous temper improves thermal stress resistance by increasing the resistance to crack growth. Aspects of vessel form and construction techniques that reduce constraints on expansion (such as floating construction, contouring, and reducing thickness) and avoid stress concentrations (such as rounded shapes and homogeneous materials) also improve thermal stress resistance and potentially increase use-life.

The existence of conflicts among design choices indicates that no single design maximizes durability in the face of all potential stresses. To assess the impacts on vessel

durability and potential use-life of design choices actually made by ancient Pueblo potters, I conducted a set of strength and use-life experiments on a subset of the plain and corrugated vessels employed in the study of manufacture costs and heating effectiveness. I present and evaluate the results of these experiments in the next section. Following the discussion of the use-life experiments, I examine data on gray ware pottery fracture patterns, sherd accumulation rates, and vessel recycling to determine if changes in actual use-life can be detected in the archaeological record.

Use-Life Experiments

Use-life is a probabilistic concept. A well-designed vessel that is more resistant to the stresses experienced during use has, on average, a greater probability of lasting longer than a poorly designed vessel. However, pot drops and other accidental or chance events can cause a pot to fail well before it would have through normal use alone. In considering the results of the experiments I am about to discuss, I assume that the incidence of accidental failures remained fairly constant through time, and thus did not contribute to any differential use-life between plain and corrugated cooking vessels. My goal is to document and explain how plain and corrugated vessels respond to the mechanical and thermal stresses to which they would have been exposed during cooking, and to assess how any differences may have contributed to use-life probabilities for plain and corrugated vessels.

Response to Mechanical Stress

Cooking exposes ceramic pots to mechanical stresses although, as mentioned above, being careful during use and maintenance of the vessel can minimize these stresses. Pressure exerted by the contents of the vessel on the wall is the most constant mechanical stress and the most difficult to mitigate. Impacts can also occur routinely during use, but the frequency and force of these impacts can be reduced through behavioral adjustments. Accidental impacts, the force of which is difficult to control, constitute the most potentially damaging mechanical stress to which ceramic cooking pots, or any ceramic vessel, are subjected.

To document how plain and corrugated vessels respond to these kinds of mechanical stresses, I measured the strength of four of the plain (vessels 1, 14, 20, and 22) and four of the corrugated (vessels 3, 4, 9, and 12) replicas. Each of these vessels had been used for a total of eight hours during the heating effectiveness experiments. I employed three different strength measurement techniques, a falling-weight impact test (Mabry et al. 1988), a pendulum impact test, and a one-ball-on-three-ball biaxial flexure test (Neupert 1994). I performed these tests at the

Laboratory of Traditional Technology, University of Arizona with the able advice and occasional assistance of Mark Neupert and Michael Schiffer.

The results of the different strength tests are presented in Tables 17 and 18. In the falling-weight impact test, I set the rim of each vessel on a platform of wet clay arranged so that the falling weight, a 66.7 g steel ball bearing, would strike the center of the base. The first drop of the weight was from 40 cm above the base of the vessel, and the drop height was increased by one cm for each subsequent drop until the vessel failed. For seven of the eight vessels, the falling weight test resulted in a small hole being driven through the base of the pot. In one case (vessel no. 3), rather than producing a small hole, large cracks formed in the vessel wall. This latter failure required substantially more impacts to produce than the small holes. Using the results from the seven comparable tests, the four plain vessels required an average of 10.25 impacts to fail with a standard deviation of 4.72 while the three corrugated vessels required an average of 12.67 impacts with a standard deviation of 4.16. Although the corrugated vessels tend to be slightly more resistant to the stresses of focused impact on the base, the difference is not significant at the .05 level, and thus may result from sampling error particularly given the very small sample size. Another factor that may account for the small difference in strength is the slightly greater basal wall thickness of the corrugated vessels (see Table 15).

The pendulum impact test was performed on the vessels that were still intact after the falling-weight test except for a small hole in the base. To conduct this test, the vessels were suspended by a string tied around the vessel neck and fastened at the other end to an armature set far enough away from a concrete pillar so that the pot would just touch the pillar when suspended freely. The test involved pulling the vessels away from the pillar while maintaining tension on the string, and releasing the pots so that they would swing into the concrete pillar. This was done several times for each vessel from increasingly greater release angles until the pots failed completely. The first drop angle was 10 degrees and I increased the angle by 5 degree increments. During both the falling-weight and pendulum impact tests, I kept notes on the responses to impact displayed by each vessel. The four plain vessels failed at an average drop angle of 36.25 degrees with a standard deviation of 2.5 degrees while the three corrugated vessels failed at an average angle of 45.0 degrees with a standard deviation of 5.0 degrees. Although the sample size may be too small to document strength accurately, the differences are significant at the .05 level. Thus, the corrugated vessels again appear to be slightly stronger with respect to impact-induced stress. The slightly thicker walls of corrugated vessels may be contributing to this difference.

Table 17. Results of impact strength tests on plain and corrugated vessels used for different amounts of time.

Vessel No.	Vessel Type	Hours of Use	Falling-Weight Test			Pendulum Impact Test		
			No. of Impacts	Sum of Drop Heights (cm)	Result	No. of Impacts	Highest Angle	Result
2	Corrugated	608	18	873	Cracked			
8	Corrugated	608	3	123	Hole in base	7	40	Bottom cracked off
13	Plain	608	46	2875	Cracked			
24	Corrugated	301	64	4576	Cracked			
10	Corrugated	301	13	598	Hole in base	8	45	Bottom cracked off
21	Plain	301	16	760	Cracked			
3	Corrugated	8	55	3685	Cracked			
4	Corrugated	8	16	760	Hole in base	9	50	Cracked around vessel & to rim
9	Corrugated	8	8	348	Hole in base	7	40	Cracked around vessel & to rim
12	Corrugated	8	14	651	Hole in base	8	45	Bottom cracked off
1	Plain	8	7	301	Hole in base	6	35	Cracked from rim to rim
14	Plain	8	7	301	Hole in base	6	35	Cracked from rim to rim
20	Plain	8	17	816	Hole in base	7	40	Cracked from rim to rim
22	Plain	8	10	445	Hole in base	6	35	Cracked from rim to rim

Table 18. Results of biaxial flexure strength tests on fragments from plain and corrugated vessels used for different amounts of time.

Vessel No.	Vessel Type	Hours of Use	Upper Body Fragments				Base Fragments			
			Median Load (kg)	Mean MOR	Median MOR	N of Fragments	Median Load (kg)	Mean MOR	Median MOR	N of Fragments
2	Corrugated	608	39.0	3.1	3.1	6	47.4	3.5	4.1	6
8	Corrugated	608	36.7	4.1	3.6	7	33.6	4.0	3.3	5
13	Plain	608	64.9	8.3	8.4	8	76.7	9.0	8.9	5
24	Corrugated	301	37.6	4.4	4.6	9	39.2	4.2	4.1	6
10	Corrugated	301	30.2	3.4	3.5	6	48.3	3.8	4.0	6
21	Plain	301	44.0	4.9	4.5	7	49.0	5.2	5.2	6
3	Corrugated	8	25.4	3.5	3.5	8	35.8	3.8	3.3	5
4	Corrugated	8	40.8	4.2	4.2	8	40.1	3.7	3.5	6
9	Corrugated	8	23.1	2.9	2.9	7	24.7	2.1	2.0	6
12	Corrugated	8	30.8	4.1	3.8	7	25.2	3.9	3.2	6
1	Plain	8	34.5	5.0	4.9	7	29.9	4.5	4.5	6
14	Plain	8	36.7	5.5	5.1	9	77.1	7.5	6.9	6
20	Plain	8	35.8	3.7	3.9	9	38.8	5.2	5.2	6
22	Plain	8	34.5	6.3	6.3	8	31.3	7.0	5.9	6

MOR = Modulus of Rupture.

In addition to subtle differences in strength, I also observed a striking difference in how plain and corrugated vessels broke during the pendulum impact tests. The plain pots all failed from cracks that extended from one side of the rim to the other through the base of the pot creating two, fairly symmetrical vessel halves. The corrugated vessels failed in more complex ways, but usually the cracks extended around the circumference of the vessel following coil joins and resulting in a fairly intact base and upper body/neck segments. I have seen both of these characteristic fracture patterns duplicated in ancient plain and corrugated gray ware pottery.

The biaxial flexure test was performed on fragments cut with a rock saw from the upper body and base of each of the plain and corrugated vessels included in the use-life experiments. The strength of these pieces, cut to roughly 2 by 2 cm, was measured by breaking them in a compression cage using the ball-on-three-ball biaxial flexure test described by Neupert (1994). In this test, the sherd is placed horizontally, concave surface down, over three balls equally spaced around a 1.27 cm radius circle and a third ball applies a load at .25 mm/sec onto the upper surface of the sherd at the center of the circle. When the sherd breaks, a peak load indicator shows the maximum load applied at failure. I then converted the peak load values to a modulus of rupture (MOR) using the formula presented by Neupert (1994) which standardizes the load data for differences in wall thickness. Figure 40 shows box plots of the MOR data for all measured fragments from vessels with 8 hours of cooking time. The data are grouped by vessel type (plain and corrugated) and vessel part (upper body and base). The corrugated sherds consistently failed at lower MOR values, and a Mann-Whitney U test confirms the statistical significance ($p < .001$) of the lower strength of corrugated vessel fragments indicating that differences are greater than expected from sampling error alone. Comparing average median MOR values for individual vessels also indicates that the corrugated vessels are slightly, yet significantly ($p < .001$), weaker than the plain vessels regardless of vessel part.

Discrepancies in results between the biaxial flexure tests and the impact tests probably derive from the former controlling for differences in wall thickness, and thus, eliminating it as a factor in strength comparisons. The greater similarity among corrugated and plain vessels in the median values of peak load at failure (Table 18), which does not control for wall thickness, supports this interpretation. If corrugated vessels are mechanically weaker than plain vessels given the same wall thickness as these results suggest, then it is probably the relatively poorer weld between coils and the uneven surface, both of which can concentrate stress, which accounts for the lower resistance of corrugated vessels to mechanical stress. However, because the two sets

of tests also measure different aspects of strength (Neupert 1994), it is also possible that corrugated vessels are more resistant to the stresses created by repeated impacts while plain vessels have greater resistance to the tensile stresses generated during bending. The small sample size and lack of control for wall thickness in the impact tests curtail our ability to explore this possibility further with existing experimental data.

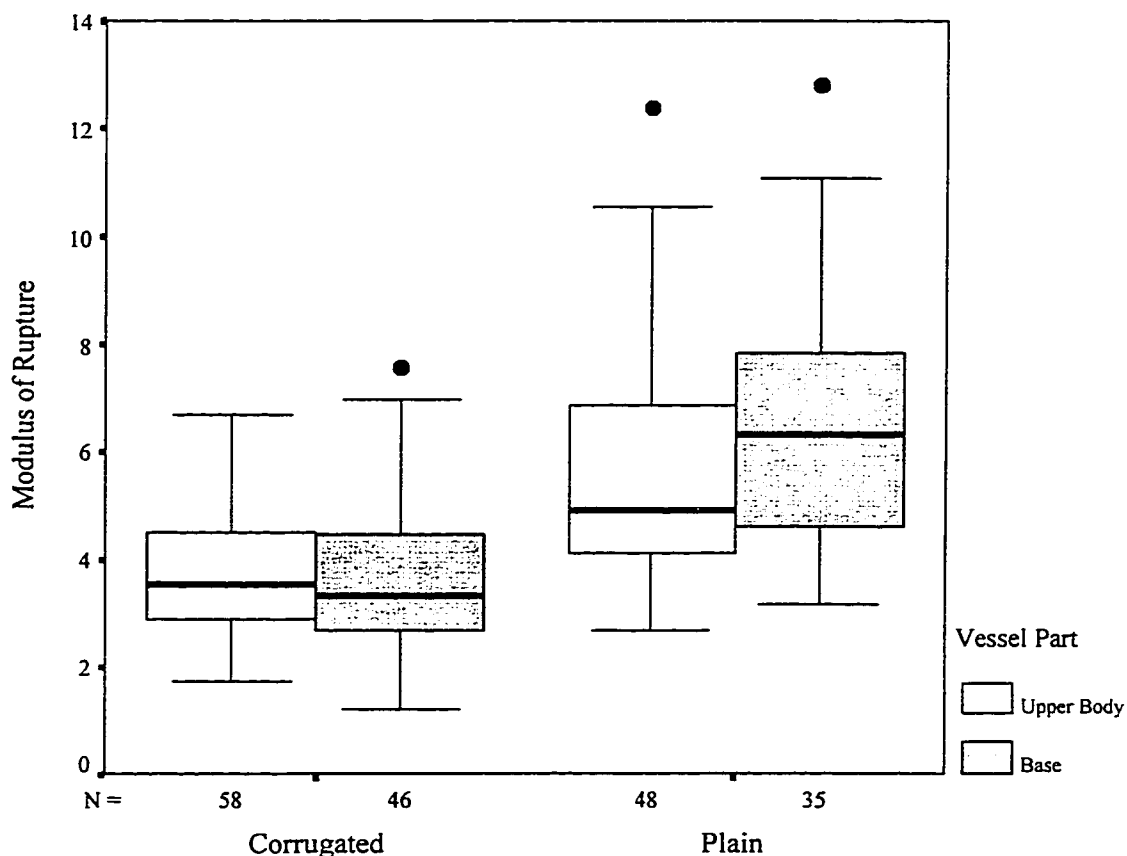


Figure 40. Box plots of the strength (MOR) of upper body and base fragments cut from replica plain and corrugated vessels used for eight hours in cooking experiments.

Response to Thermal Stress

As mentioned earlier, cooking produces three principal kinds of thermal stresses within the wall of a vessel: compressional stress at the exterior surface; tensional stress at the interior surface; and shear stress within the vessel wall. The tensional and shear stresses are the most potentially damaging because ceramic materials are relatively weak in the face of these stresses while relatively strong with regard to compressional stress (Grimshaw 1971). These stresses arise

from the differential expansion of the hotter, lower, exterior portion of the vessel relative to the cooler, interior and upper body portions. The period of peak stress in a vessel used for cooking occurs during initial exposure to heat when thermal gradients are most extreme. Heating of the contents reduces the thermal gradient through the wall somewhat, but because the peak temperature of food mixed with water is relatively low (~100 °C), fairly intense thermal gradients, and thus thermal stresses, continue throughout the duration of the cooking episode.

Strain, which in brittle ceramics is frequently permanent in the form of cracks, is one undesirable way of alleviating thermal stress in the vessel wall. Cracking that does not lead to the catastrophic failure of the vessel can still reduce use-life through weakening of the vessel wall thereby increasing its susceptibility to mechanical stresses, and by degrading heating effectiveness through increasing the amount of irregularities in the vessel wall which can inhibit heat transfer. However, corrugated pottery, as well as other pottery with a textured exterior surface, may extend vessel use-life by altering the nature of stresses and strains within the vessel wall as some have argued (Heidke and Elson 1988; Schiffer et al. 1994). If true, the most likely mechanism is the reduction of stress rather than increased stress resistance. An uneven, undulating exterior surface such as produced with corrugation, although possibly acting to concentrate stress, also allows expansion to occur in the exterior portion of the wall, and thus, potentially generates considerably less stress than a plain surface. This phenomenon is analogous to grooves placed in the upper surface of concrete slabs exposed to the sun. These grooves allow expansion to occur in the surface heated by the sun without producing as much compressional stress that might cause buckling of the slab. In the case of corrugated pottery, the relatively poor weld between adjacent overlapping coils, which appears to reduce mechanical strength, may also alleviate thermal stress by allowing expansion to occur along these planes analogous to the floating construction used in many bridges today. Both of these mechanisms potentially serve to reduce the constraint on lateral (vertical and horizontal) expansion that results in the buildup of thermal stress in a cooking pot. In addition, the undulating surface of corrugated vessels may alter the distribution of stresses at the surface where compressive stresses are at their maximum (Singh et al. 1996).

To measure the responses of plain and corrugated pottery to prolonged exposure to thermal stress, I selected eight vessels (four plain and four corrugated) from among the replicas used to cook mush in the heating effectiveness experiments, and used these vessels for extended periods. The experimental protocol was the same as the heating effectiveness experiments except

cooking continued for several hours at a time and thus more water had to be added periodically so they did not cook dry. Temperature data were only recorded until the contents of each pot had boiled. After each day of cooking, I examined the pots visually, and carefully squeezed, poked, and tapped them to expose any degradation such as cracks, spalls, pits. Periodically during the use-life experimental runs, I performed the same vessel wall permeability measurements as I had during the heating effectiveness experiments. The goal of the experiment was to cook in all eight pots until they failed resulting in an average use-life estimate for each vessel type. However, after a little more than 600 hours of cooking in one set of four pots (vessel nos. 2, 8, 13, and 19) and 300 hours of cooking in the other set (vessel nos. 10, 15, 21, and 24), only two vessels had failed. Consequently, I decided to forgo using each vessel until it failed. Instead, I attempted to gauge potential use-life differences by observing the development of flaws and failures during use, measuring the residual strength of the intact vessels with impact and biaxial flexure tests, and tracking changes in heating effectiveness over the course of the experiments.

Flaws and Failures from Use. I observed two kinds of physical alterations that occurred in the vessels as a consequence of use—pitting and cracking. No spalling such as that described by Schiffer et al. (1994) occurred during the cooking experiments. Pitting consists of the loss of small amounts of pottery from the interior surface of the base of a pot, and closely resembles pitting observed on the interior surface of ancient gray ware pottery from the Mesa Verde region (see discussion of use-alterations in Chapter 6). The pieces removed are not really spalls, but rather are flakes or slivers of the interior vessel surface. Using observations from the heating effectiveness and use-life runs, only seven of the 24 replica vessels developed interior basal pitting. For all but one of the pitted vessels, pitting occurred and reached its maximum extent within the first few hours of use. Of the seven vessels with pitting, all were used to cook mush, two were lined with pinyon pitch, and five have plain exteriors (Table 19). It seems likely that pitting results from tensional stresses on the interior surface that cause a network of short, very shallow cracks to develop which creates enough surface weakness to allow attrition of the surface to occur. The restriction of pitting to the lower portions of the vessel where tensional stresses would be greatest lends support to this interpretation. The correlation between cooking mush and pitting also suggests that there may also be a chemical component to pitting, or that reduced vessel wall permeability encourages pitting. Finally, although the sample size is extremely small, the preponderance of pitted vessels with plain exteriors (71 percent) suggests

that plain vessels are more susceptible to pitting. If interior tensional stresses are the main cause of basal pitting and more stress develops within the wall of plain vessels than corrugated, this would explain why more pitting occurred on the plain cooking pots.

Table 19. Frequency of replica vessels with pitted interior basal surface after use in experiments by factor combination.

Contents	Plain Surface		Corrugated Surface	
	Lined	Unlined	Lined	Unlined
Water	0	0	0	0
Corn Mush	2	3	0	2

None of the 24 vessels used in the heating effectiveness experiment developed cracks during the combined eight hours of use in those experimental runs. However, the extended exposure to thermal stress during the use-life experiment produced cracking in five of the eight vessels. These included all four plain vessels (vessel nos. 13, 15, 19, and 21) and one corrugated vessel (vessel no. 2), and resulted in the complete failure of two of the plain vessels (vessel nos. 15 and 19). No corrugated vessels failed during the use-life experiment. In both cases of complete failure, light pressure on the inside surface produced a pie wedge-shaped hole in the base after cracks had caused significant weakening of the vessel wall (Figure 41). Vessel number 15 failed after 287 hours of use while vessel number 19 failed at the end of the last run of the experiment after 620 hours of use. The first cracks appeared on Vessel 15 after 47 hours of use and on Vessel 19 after 100 hours of use. Among the three other vessels that developed visible cracks but did not fail completely, the first cracks appeared in vessel numbers 2 and 13 after almost 80 hours of use while it took almost 215 hours for cracks to first appear in vessel number 21. The remaining three vessels included in the use-life runs, all corrugated, remained visually intact throughout the experiment.

In the four plain vessels, cracks appeared first on the exterior surface about 2.5 to 3 cm up from the very base of the vessel. These cracks initially spread in a narrow band horizontally around the circumference of the vessel as a network or web of short, interconnected, hairline fractures. Radial separation along some of the cracks in this horizontal band indicated clearly that the cracks extended into the vessel wall at a very shallow angle. In the two vessels that failed, cracks also extended down from this band of fractures toward the base. Eventually, these vertical cracks extended perpendicularly all the way through the wall. It was along these vertical cracks

that failure ultimately occurred producing the pie wedge-shaped holes shown in Figure 41. When the pots did fail, the network of shallow angle fractures resulted in numerous pieces missing some or all of one or both surfaces (Figure 42). These fragments closely resemble the alteration identified as spalling in the six gray ware collections discussed in Chapter 6. Cracks did eventually appear on the interior surface of some, but not all, of the plain vessels. These interior cracks always developed in the very base of the vessel, both as linear cracks across the base and circular cracks around the base, located well below the level of the band of horizontal cracks on the exterior surface. In the single corrugated vessel to develop cracks, interior surface cracks appeared first followed almost 50 use-hours later by the appearance of horizontal cracks on the exterior surface at the same height above the base as occurred with the plain vessels.

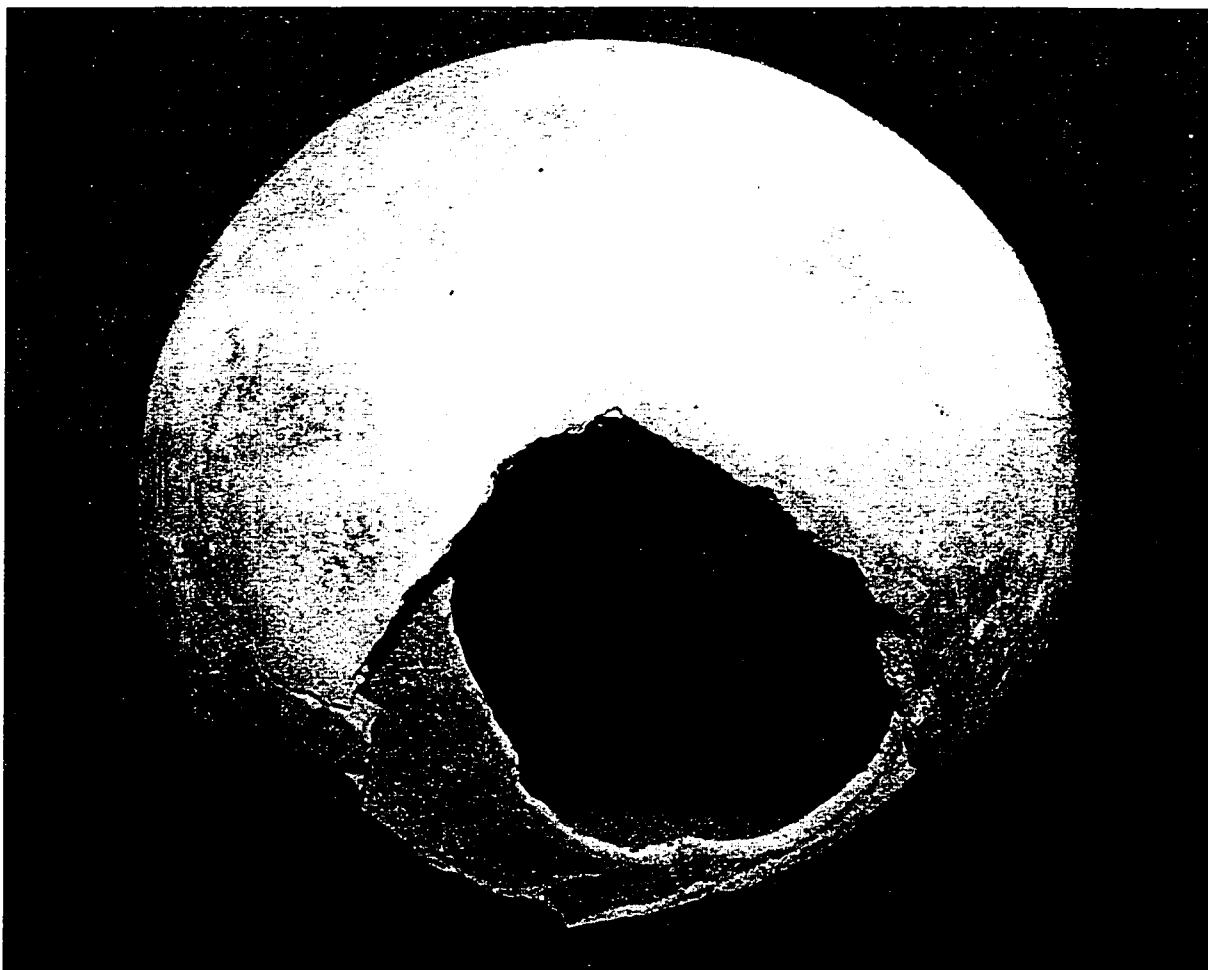


Figure 41. Photograph of vessel 15 failure.



Figure 42. Photograph of fragments produced when vessel 15 failed.

The rate and extent of visible crack propagation varied considerably among vessels, and given the extremely small sample size, it would be imprudent to generalize about these particular aspects of cracking at this time. However, an explanation of the consistent pattern of crack development does seem warranted. Two thermal gradients exist within the vessel wall during use, and these gradients generate most of the thermal stress. One gradient extends through the wall between the heated exterior and the cooler interior, and the other extends up the vessel wall from the heated base to the cooler upper body. Figure 43 shows the average temperatures of the exterior and interior² surfaces along a vertical profile of a replica vessel during use. The difference between the interior and exterior surface temperatures at a given position on the vessel wall indicates the intensity of the thermal gradient through the wall, while exterior temperature

²Interior surface temperatures were not measured directly. Instead, I used the temperature of the liquid contents as a measure of inside surface temperature. For the lower portion of the vessel that was always in contact with liquid, this provides an reasonably accurate estimate of interior surface temperature, although the actual temperature would be slightly higher. For the upper portion of the vessel, interior surface temperature would have fluctuated as the level of the contents fluctuated resulting in periods of exposure to the air.

differences vertically show the gradient up the wall. Compressive exterior and tensile interior stresses would be greatest at the bottom of the pot where the thermal gradient through the vessel wall is the most extreme. Shear stress within the vessel wall would be most intense in the area of greatest change in exterior surface temperature. This is because the cooler interior surface acts as a constant constraining force on the vertical and horizontal expansion of the entire exterior of the vessel wall while, at the same time, the hotter basal portions of the exterior need to expand more than the cooler upper portions. Consequently, rapid change in exterior surface temperature creates a situation in which the hotter portions of the wall are being thrust into the cooler portions because of the differential expansion. The low angle fractures produced by shear stress within the vessel wall appear on the exterior surface as a horizontal band of cracks at the upper edge of the zone of greatest vertical temperature change, and extend down through this zone of intense shear stress (Figure 43). It is not surprising that these cracks would be the first to appear given the relative weakness of ceramics in the face of shear stress. Ultimately, combined shear and tensile stresses cause cracks to extend through the vessel wall leading the failure of the vessel. The lower incidence and slightly different pattern of development of flaws and failures in corrugated vessels support the notion discussed above that the corrugated surface reduces thermal stress by relaxing constraint on the expansion of the exterior surface. However, this advantage would only accrue to vessels for which the base and lower body are corrugated. Neck-banding would not improve the use-life of ceramic cooking pots.

Residual Strength. For the vessels that did not fail during the extended use-life experiments, I performed falling-weight, pendulum, and biaxial flexure strength tests to determine if any differences exist between plain and corrugated vessels in the amount of strength lost over different use intervals. The vessel sample for these strength tests includes two corrugated and one plain used for 600 hours (vessel nos. 2, 8, and 13 respectively), and two corrugated and one plain used for 300 hours (vessel nos. 10, 24, and 21 respectively). This extremely small sample produced ambiguous results (Tables 17 and 18). In the falling-weight impact test, two of the corrugated (vessel nos. 2 and 24) and both of the plain vessels cracked while the other two corrugated vessels developed small holes. Of the two corrugated vessels that cracked, the vessel used for 300 hours required 63 drops of the ball bearing to fail while the vessel used for 600 failed after only 18 drops. The single corrugated vessel used for 8 hours, which cracked during the falling-weight test of mechanical stress resistance, required 55 drops to fail. Of the two corrugated vessels that developed holes, the vessel used for 300 hours failed after

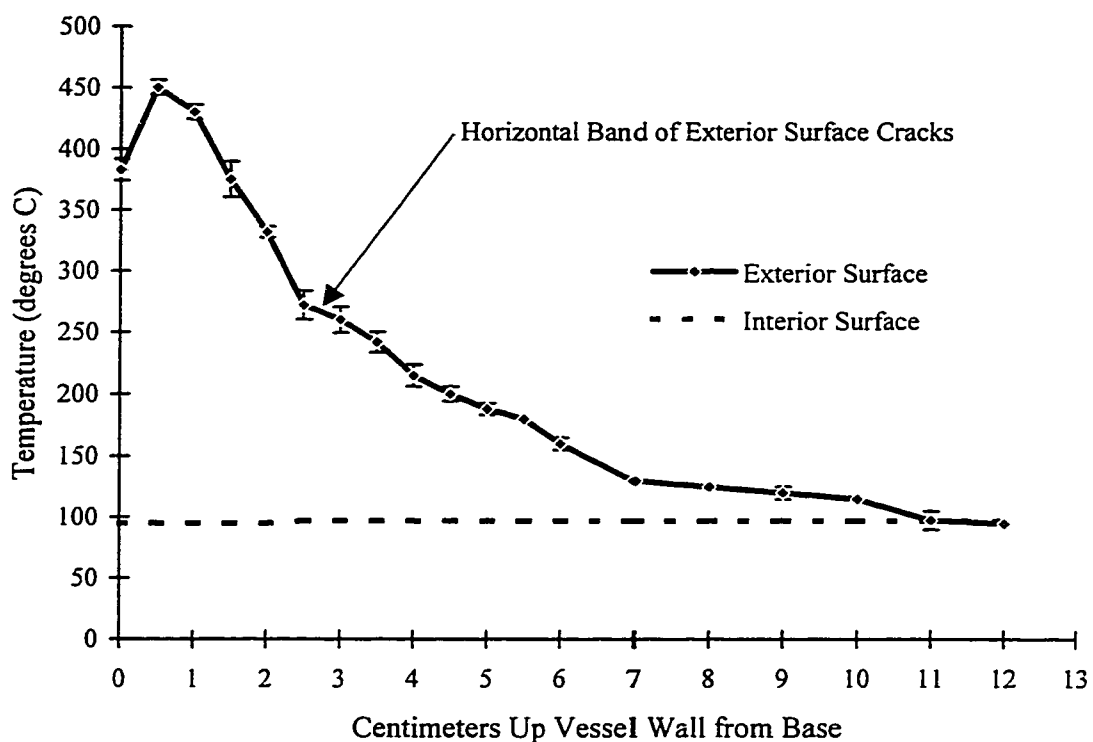


Figure 43. Vertical profiles of exterior and interior vessel wall temperatures on replica vessels during cooking experiments. Error bars show the standard error of the mean temperature obtained from multiple measurements.

13 drops and the vessel used for 600 hours failed after 3 drops. The three corrugated vessels used for eight hours discussed earlier which also developed holes failed after an average of 13 drops. Thus, it appears that for corrugated vessels there is little or no strength reduction between eight and 300 hours of use, but 70 percent to 75 percent of strength is lost between 300 and 600 hours of use. For the two plain vessels, the vessel used for 300 hours required 16 drops to fail while the vessel used for 600 hours failed after 46 drops. This unexpected result may derive from the differences in basal wall thickness between the two vessels (vessel no. 21 = 4.7 mm; vessel no. 13 = 5.8 mm), or possible slight differences in manufacture or firing. Unfortunately, no comparable data exist from plain vessels used for eight hours because all developed holes rather than cracking during the falling-weight test. The only data available from the pendulum impact test is for the corrugated vessels that did not crack during the falling-weight test. The vessel used for 300 hours failed when dropped from an angle of 45 degrees and the vessel used for 600 hours failed when dropped from 40 degrees. The average drop angle for the vessels used for eight hours was 45 degrees.

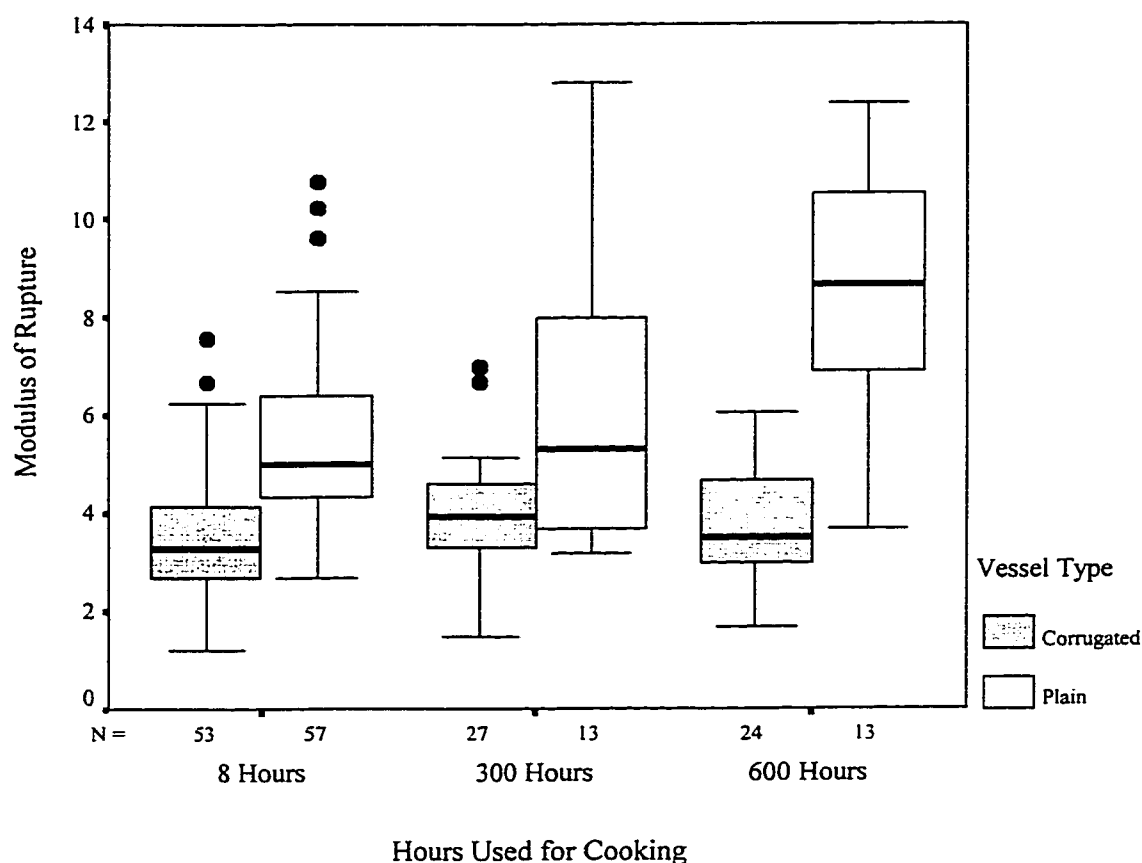


Figure 44. Box plot of strength (MOR) of base fragments cut from replica plain and corrugated vessels used for different amounts of time in cooking experiments.

Biaxial flexure tests on pieces cut from the six vessels that survived the cooking phase of the use-life experiment are equally ambiguous (Table 18). A box plot of MOR values for sherds cut from the base of the plain and corrugated vessels used for different lengths of time shows that the strength of corrugated vessels remained fairly constant while the strength of plain pottery appears to increase across the three use-life intervals (Figure 44). To control for differences in original strength of the vessels, I computed a ratio of median MOR of the base sherds to the median MOR of the upper body sherds for each vessel. Figure 45 shows that these ratios generally vary little across different use intervals and most of the values are not significantly different from 1.0. This indicates that the strength of base pieces did not degrade significantly over use-life relative to upper body pieces. This result is difficult to explain and probably results from trying to use an extremely small sample to measure a complex phenomenon. However, it is

possible that the development of cracks reduces stress and strain locally so that areas in between cracks retain their original strength while the overall strength of the vessel degrades.

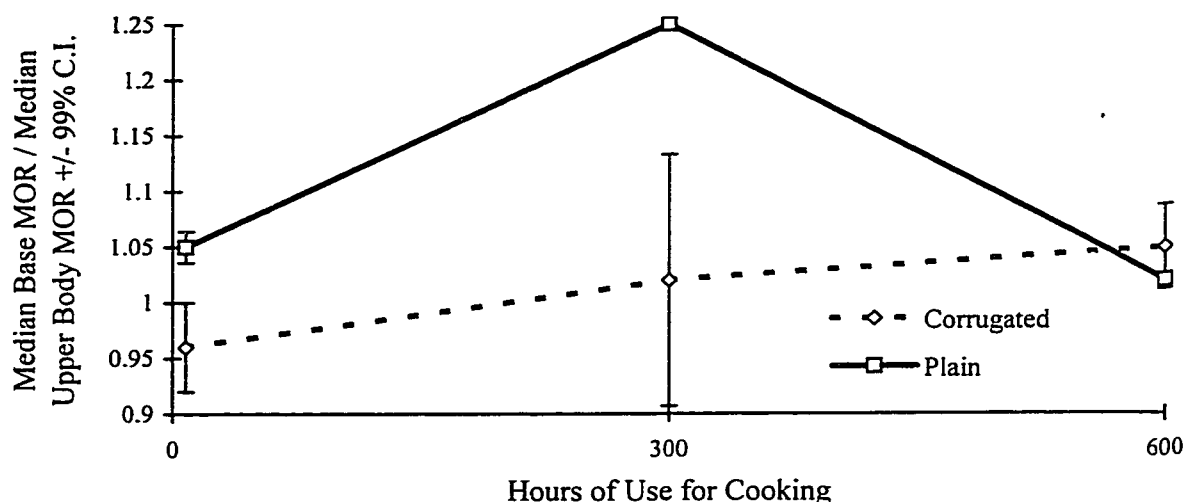


Figure 45. Ratios of median base to median upper body strength (MOR) values for plain and corrugated replicas used for different amounts of time in cooking experiments.

Effective Use-Life. The development of subcritical fractures in the vessel wall of a cooking pot can degrade its heat transfer effectiveness by introducing voids that impede heat flow. It is possible then, that through use, a vessel could become so ineffective that it is no longer practical for it to continue serving as a cooking pot although the vessel remains physically intact. Thus, the effective use-life of a cooking pot might be shorter than its use-life as determined by structural integrity. Figure 46 shows the heating effectiveness (time to reach peak temperature) over the cumulative hours of cooking use to which the vessels were exposed. Although some variation exists among vessels and between runs of the same vessel, Lowess trend lines for both plain and corrugated vessels show that heating effectiveness remained fairly constant over the period for which these vessel were used. Because two of the plain pots failed during this experiment, it appears that the structural use-life of plain vessels is shorter than the effective use-life. Because none of the corrugated vessels failed, it is still possible that corrugated vessels could remain structurally intact beyond the point at which they are no longer effective cooking pots. An experiment involving many more hours of use would have to be conducted to determine if this is the case.

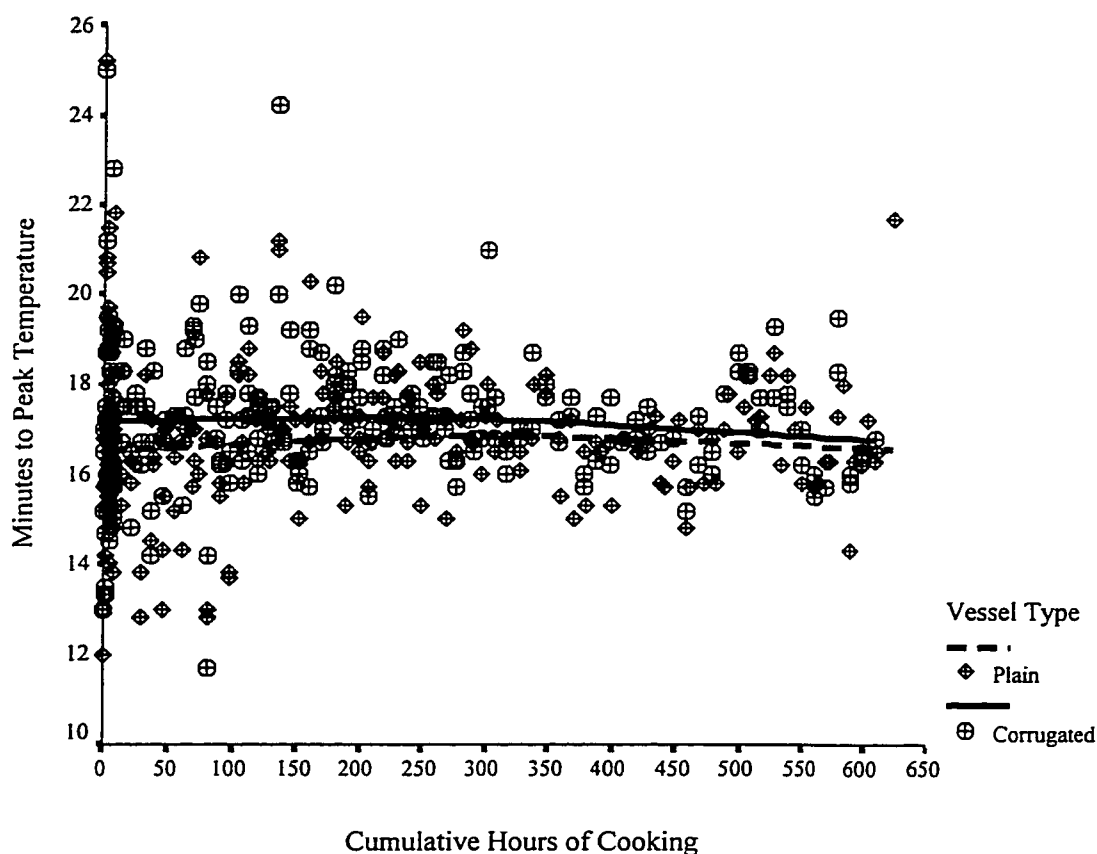


Figure 46. Scatter plot of the heating effectiveness of plain and corrugated vessels over experimental use-life with Lowess best-fit lines for each vessel type.

Use-Life Evidence from Utility Ware Assemblages

If the different responses of plain and corrugated vessels to mechanical and thermal stresses had an effect on vessel use-life, these differences should have left traces in the archaeological record. In this section, I examine evidence from the Mesa Verde region on fracture patterns, accumulation rates, and vessel recycling in plain and corrugated gray ware pottery. Patterns in these data appear to reflect, at least in part, differences in actual vessel durability and use-life.

Fracture Patterns

In analyzing the six gray ware assemblages from the Mesa Verde region, I recorded the fracture pattern (random, cubic, or stepped) for each sherd. Nonrandom fractures frequently result from cracks following the joins between coils particularly in pottery with exposed coils. The mechanical stress experiments discussed earlier in this chapter indicate that corrugated pottery produced with overlapped and indented coils is slightly weaker than pottery in which the coils are

scraped smooth. If this is true, then corrugated pottery should produce more nonrandom fractures than plain pottery. In addition, ancient Pueblo potters employed a wide variety of techniques to produce pottery with exposed coils and the relative frequency of these techniques changed through time (see Chapter 5). To the extent that the degree for overlapping of adjacent coils and use of indenting affects strength, pottery that vary in these qualities should display different amounts of nonrandom fractures.

Table 20 shows the abundance of sherds with random and nonrandom fractures in three categories of pottery with exposed coils and scraped plain pottery. The greatest relative frequency of nonrandom fractures, 84 percent, occurs in the earliest form of exposed coils, those lacking overlapping and indentations. The use of overlapping without indentations decreases the amount of nonrandom fractures to 75 percent, and the addition of indentations to overlapped coils to produce corrugated pottery results in a further decline in the relative abundance of nonrandom fracture to only 60 percent. Scraped plain pottery produced only 20 percent nonrandom fractures. Thus, it appear that the mechanical strength of exposed coil pottery increased through time with the additions of overlapping and indenting of coils, and none of the exposed coil forms appears to be as strong as scraped plain pottery. However, the difference between corrugated and plain pottery is probably exaggerated in the fracture pattern data because of the use of large coils or slabs to construct early plain pottery and the existence of few sherds large enough to break nonrandomly along the widely-spaced coil joins (see Chapter 5). Not only do these results support the conclusions reached in the mechanical stress experiments, but also they have implications for the importance of strength as a factor in the development of full-body corrugation. The extension of exposed coils to cover the entire exterior surface of vessels only after the adoption of overlapping and indenting probably relates to the improvements in strength provided by these innovations.

Table 20. Fracture pattern data for different classes of exposed coils and scraped plain pottery in the six utility ware assemblages from the Mesa Verde region.

Forming Technique	Sherd Fracture Patterns				Totals N
	Random		Nonrandom ¹		
	N	%	N	%	
Filletted, Exposed Coils	28	16.1	146	83.9	174
Overlapped, Unindented, Exposed Coils	51	24.9	154	75.1	205
Overlapped, Indented, Exposed Coils	373	40.4	550	59.6	923
Scraped Plain	2105	80.5	511	19.5	2616

¹The nonrandom category includes both cubic and stepped fractures.

Accumulation Rates

A variety of factors determine how much of a given artifact class accumulates in a particular archaeological deposit including duration of the accumulation episode, the number of people involved, and the rate of artifact discard (Schiffer 1987:47-58). For cooking pots, the discard rate depends primarily on the kind and intensity of use, and vessel durability or use-life (Varien and Mills 1997). Consequently, it may be possible to detect changes in cooking pot use-life if the other factors affecting accumulation rates can be controlled. Using simulation to assess the affects of various factors on discard rates, Varien and Potter (1997) found that the longer the occupation and the larger the population, the more stable and predictable discard rates become. Nelson, Kohler, and Kintigh (1994) also document that in probabilistically recovered samples from habitation sites in the Dolores River valley, a strong linear relationship exists between the quantities of various artifact classes suggesting that absolute accumulation rates were determined primarily by the occupation length and population size. Thus, comparing assemblages using a ratio of gray ware pottery to another common artifact class, as I did in Chapter 6 with as stone chipping debris (debitage), should control for length of occupation and population size as long as the occupations were long enough and similar activities were performed. The upper graph in Figure 20 (in Chapter 6) shows that the accumulation rate of gray utility wares decreased dramatically in the Mesa Verde region after the adoption of full-body corrugation. Although the number of assemblages for which the ratio could be calculated is small because few reports provide data on the weight of pottery, the pattern fits that expected if corrugated vessels were more durable.

Vessel Recycling

If gray ware cooking pots remained more or less structurally intact after their performance in cooking had deteriorated to point of being no longer effective, these vessels could have been recycled into other uses that would not involve too much mechanical stress. The recovery contexts of gray ware vessels provide some evidence for vessel recycling and possible differences in use-life between plain to fully corrugated vessels. In structures dating to after AD 1000 across much of the northern Southwest, corrugated vessels were buried in the floor up to their neck or rim and covered with a stone or pottery lid. Although these vessel presumably served as domestic, indoor storage space, they usually have soot accumulations and other evidence of having been used in cooking as well (Mills 1989:154-155; Renken 1993; Rohn 1971). Because they could not have been used to cook while buried in a floor, they must have

been used in cooking earlier and were then recycled for use in storage. Although this is a common recovery context for corrugated vessels, I know of no examples of similar treatment of plain or neck-banded gray wares. This may indicate that not only were corrugated vessels more durable than plain vessels as cooking pots, but that the structural use-life of corrugated vessels was often longer than their effective use-life. It is also possible that the use of vessels to line subfloor storage pits was an innovation that just happened to coincide with the adoption of full-body corrugation and no causal relationship involving vessel use-life exists between the two. More extended use-life experiments are required to address this issue.

Summary of Engineering Properties

I investigated four engineering properties of plain and corrugated vessels—manufacture costs, heating effectiveness, ease of handling, and use-life—mostly through controlled experiments, but also drawing on physical theory, data from ancient pottery collections, and anecdotal experiences when appropriate. In some cases, these investigations have yielded new insights into the functional aspects of the corrugation problem, while in others, they have supported earlier views and reinforced their theoretical and empirical justifications. However, in all cases, I found cost or performance differences to exist between plain and corrugated vessels.

For manufacturing costs, I found that the full-body corrugated vessels were considerably more time consuming, and thus more costly, to form than the early plain vessels. The principal determinant of this cost difference is the size and application technique of the coils. Vessels constructed with narrow, substantially overlapped coils are more costly to form than vessels made with large filleted, or nonoverlapped, coils. Consequently, I infer from this that as the size of coils decreased and the amount of overlapping application increased through time, the manufacture cost of Puebloan cooking pots increased as well.

I examined two aspects of heating effectiveness: heat transfer and cooking control. Regarding the heat transfer properties of plain and corrugated vessels, my experiments demonstrate beyond any doubt that corrugation substantially degrades net heat transfer effectiveness unless vessel walls are made impermeable. Although the corrugated exterior surface does improve heat transfer rates, this is true for heat entering and leaving the vessel. Because the heated portion of the vessel is usually smaller than the unheated portion, substantial heat loss can occur from the unheated surface. This upper body heat loss significantly degrades performance as liquid soaks through the vessel wall resulting in evaporative cooling, and there is a greater surface area from which heat loss can occur. When the permeability of the vessel wall is minimal, which

fortunately occurs as a consequence of cooking food, this limits evaporative cooling and greatly reduces upper body heat loss. Under these conditions of normal use, the heating performance of corrugated vessels is only slightly less than that of plain vessels. This supports and extends earlier studies that had undermined the dogma of improved heat transfer effectiveness of corrugated vessels because of the extended exterior surface. However, it also appears that the slightly degraded heat transfer performance of corrugated vessels has an additional benefit of improving cooking control through a considerable reduction in boilovers. This improved cooking control would have appeared as exposed coils began to be used below the neck of vessels, and would have increased as more and more of the upper body surface was covered with corrugation.

Although most of my data on ease of handling are anecdotal, it does appear that a corrugated surface improves handling particularly when the vessels are hot. This improvement comes mainly from the increased surface roughness of corrugation which both increases friction and reduces amount of hot vessel wall coming in direct contact with hands. Consequently, innovations that increased surface roughness, such as overlapping and indenting coils, would have improved the graspability of cooking pots particularly when these techniques were employed on the necks of vessels.

Finally, corrugation does improve the probable use-life of cooking pots, but only if the corrugations occur on the base of the vessel. This improvement comes mainly from a reduction in the amount of thermal stress generated in the vessel wall during use. Thermal gradients produced both through and up the vessel wall during use in cooking result in a greater expansion of the exterior base in relation to other parts of the vessel. Although the use of corrugation reduces the mechanical strength of the wall, the uneven surface also creates room for the differential expansion of the base to occur without producing as much stress as in a plain, or smooth-surfaced vessel. Unfortunately, I could not quantify the difference in probable use-life with my experiments, but data on the accumulation rates of gray ware pottery in the Mesa Verde region indicate that the introduction of full-body corrugation may have substantially improved the use-life of these cooking pots.

CHAPTER 8: EXPLAINING CORRUGATION

Now that we have laid the theoretical and empirical groundwork for an evolutionary approach to the corrugation problem, we can turn to the goal of explanation. The logical structure of evolutionary theory and explanations derived from that theory, discussed in Chapter 3, requires that both replication and variation exist in the empirical entities under investigation. The presence of replication and variation establishes the necessary and sufficient conditions for descent with modification. Once these conditions exist, differential replication of variation can occur through a variety of stochastic and deterministic sorting mechanisms. The nature of the interaction of different variants with their environment determines which sorting mechanisms are causally relevant to explanations of any particular empirical case.

Evidence regarding the development and spread of corrugation in the American Southwest, presented in Chapter 5, indicates that corrugation developed through a sequence of innovations that introduced new variation into the repertoire of techniques used to make utility ware vessels. The evidence also documents that these innovations were copied with sufficient fidelity to produce clear lineages of descent or replication of corrugation techniques. Our current knowledge suggests that a variety of replicators may have been involved in the spread of corrugation. These possible replicators include the pottery itself, the knowledge of how to make different forms of corrugation, the meaning attached to corrugation, the biological reproduction of the people possessing different utility ware technologies, and larger scale sociocultural systems. This diversity of potentially relevant replicators suggests that adopting multiple frames of reference may be necessary for formulating a complete account of changes in corrugated pottery in the Southwest.

Evidence presented in Chapters 6 and 7 indicates that characteristics of the utility ware environment and the ways different plain and corrugated utility wares interacted with their environments changed during the development and spread of corrugation. This, together with the rapid adoption of neck banding and full-body corrugation, suggests that deterministic sorting mechanisms were probably involved in at least some aspects of the shift from plain to corrugated utility wares. However, these observations do not rule out the possibility of a significant role for stochastic sorting mechanisms as well.

The evidence presented in the previous three chapters also shows that the question “why corrugation?” with which I began this research is too simplistic to serve as a basis for developing explanations of the complex history of corrugation in the American Southwest. We can not

understand why ancestral Puebloan populations used full-body, indented corrugation on their utility wares without understanding how and why this technique of corrugation developed in the first place. In addition, it is quite possible that explaining different aspects of the corrugation problem will require shifting our frame of reference and employing alternative sorting mechanisms. To more adequately approach the explanation of corrugation, I have divided the problem into four parts based on our current understanding of the rise and fall of corrugation and the context in which these changes took place. These four parts are the initial adoption of neck banding, the experimentation and elaboration of neck banding, the adoption of full-body corrugation, and the eventual return to plain-surfaced utility wares among Pueblo populations. In addressing each of these components of the corrugation problem, I begin by summarizing the evidence from Chapters 5 through 7. I then attempt to identify potentially causal relationships from different frames of references that may account for the patterns of differential persistence and spread of particular corrugation techniques.

Advent of Neck Banding

The technique of leaving structural coils unobliterated first appeared on jar necks in the American Southwest during the seventh century AD. Before this, all utility wares were scraped plain. This earliest neck banding occurred in brown ware pottery from the southern Mogollon region of New Mexico. At the same time, utility pottery produced in the Puebloan areas to the north consisted of scraped plain gray wares made primarily in the forms of bowls and narrow-mouth jars or ollas. Formal cooking jars, identified by the co-occurrence of a wide-mouth jar form with substantial soot accumulations, were relatively rare in these early Basketmaker assemblages. In addition, cooking with pottery involved a wider variety of vessel forms than in later times. Both these lines of evidence suggest that cooking in pottery jars was neither as common nor as formal as it would become later.

The earliest appearance of neck banding in the northern Southwest occurred in the early to middle part of the eighth century, 50 to 100 years after its emergence in the southern Mogollon region. This early date for neck-banded pottery applies to the southern edge of the Colorado Plateau, areas west of the Chuska Mountains, and the northern San Juan basin, including the Mesa Verde region. However, east of the Chuska Mountains in the southern San Juan basin and the Rio Grande valley, neck banding did not appear until the latter half of the ninth century. Deteriorating climatic conditions during the late ninth and early tenth centuries brought about a substantial southward movement of people out of the Mesa Verde region and other parts of the

northern southwest. Contemporary population increases in the south including the southern San Juan basin, the southern Chuska Valley, and parts of the Rio Grande region, all east of the Chuska Mountains, are almost certainly a result of immigration from the areas being partially or wholly abandoned. This migration coincides with the first appearance of neck banding in the areas east of the Chuska Mountains.

Regardless of the region or the age of first appearance, the earliest neck banding consists of relatively wide, flattened coils applied without overlap (i.e., filleted). Rather than being an example of independent invention or convergent evolution, the strong similarities in all of these early neck-banded forms suggest that the innovation of leaving coils unobliterated probably spread north from the Mogollon region through migration, diffusion or a combination of the two. Regardless of how the trait spread, its delayed appearance in the southern San Juan basin and Rio Grande valley indicates that these regions may have been isolated from the contacts necessary for transmission until the middle of the ninth century.

At the time neck banding was introduced into the manufacturing repertoire of ancestral Puebloan peoples of the Colorado Plateau, these potters were forming their vessels by stacking up relatively wide coils or slabs. Leaving some of these construction elements unobliterated on the necks of jars added little or nothing to the cost or performance of the vessels. Because the exposed coils were wide and not overlapped, very little additional roughness was created on the exterior surface that could have improved handling. Although the weld between exposed, filleted coils is weaker than between coils that have been scraped together, the necks of vessels are not exposed to intense stress during most uses. Thus, the reduced strength of neck-banding probably did not present a significant problem. Consequently, the initial adoption of neck banding may have been as a decorative elaboration involving little or no change in labor investment.

The preceding paragraphs conform well to a traditional approach to explaining the rise of neck banding that combines culture historical and processual notions. A style of decoration, neck banding, appeared, perhaps by chance, and spread over a vast area through the migration of people and the transmission of the trait through various forms of interaction and communication. Although this may be a satisfactory account in some ways, important questions remain unanswered. For example, why neck banding and not some other decorative techniques such as incisions, impressions and appliqués? Further, why did neck banding spread when it offered no apparent advantage to the makers and users of the pottery? Kidder (1936) tried to answer such questions by stating that people are simply compelled to decorate. However, this assertion does

not advance our understanding of the situation. Does an evolutionary approach offer any further insight into these questions?

Let us look first at the question of why neck banding and not other decorative techniques. At the time neck banding first arose in the southern Mogollon region and spread to the western Anasazi areas, other techniques for creating decorative elaborations do not appear to have been part of the repertoire of these potters. Incising did appear later in these areas, but only after neck banding was well established. In the Rio Grande and Gallina areas to the east, incising and neck banding appeared at about the same time, and, in these areas, incised and punched decorations competed well with neck banding for many years. This suggests that the dominance of neck banding was simply a historical accident. However, incising also arose in the Mogollon area and competed with neck banding quite well even after neck banding had already become established.

Perhaps subtle distinctions in the cost of the various techniques for decorating utility wares played a role in their differential success in particular areas. Neck banding requires no additional cost. In fact, neck banding may actually save a very small amount of time during the forming of the vessel in comparison to entirely plain vessels by eliminating the need for obliterating the coils in the neck of jars. In contrast, the other possible decorative techniques all require some additional effort after the entire vessel has been scraped plain, and added technology in the form of tools, materials and techniques used to create the decorations. Although these cost differences were probably quite small, they may have been sufficient to inhibit, but not completely exclude, the encroachment of the other decorative techniques after neck banding was already well established.

Although a combination of history, or chance, and subtle cost differences may account for the dominance of neck banding in the northern Southwest, we still must answer the question of why neck banding or any other decorative technique was adopted at all. The temporal and spatial patterns of appearance of neck banding in the northern Southwest and other evidence presented in Chapter 5 indicate that migration played a prominent role in the spread of the technique. As people moved to new areas, they brought with them the techniques they learned in other areas. However, unless the immigrants completely replaced the indigenous populations, which seems unlikely given the continuities in other local material culture, neck banding must have also spread by diffusion from the immigrants to the indigenous people. In evolutionary terms, neck banding apparently replicated independently of, or in addition to, the replication of biological organisms and ethnic groups.

It is difficult to identify anything inherent in neck banding itself that would promote its replication over entirely plain-surfaced utility wares. Neck-banded vessels were not superior to plain vessels in some way that would have triggered people's cognitive algorithms for evaluating and rationally selecting innovations on the basis of performance benefits or cost reductions. However, I can imagine three other possible explanations that I present briefly here. Unfortunately, thoroughly testing these hypotheses will have to wait until we know more about the migrations that took place during the eighth and ninth centuries, and the nature of any adaptive differences and patterns of interaction that may have existed between migrant and indigenous populations.

Perhaps there was something in the social context in which neck banding spread, or in the meaning ascribed to neck banding that contributed to its adoption. At the time neck banding spread into the northern Southwest, most people lived in small, dispersed settlements, which probably consisted mainly of close kin. Under these conditions, exogamous marriages are essential for the long-term viability of populations. Arranging such marriages requires the establishment and maintenance of relationships with people in other settlements. As migrant populations moved into new areas, perhaps the back and forth transfer of innocuous, decorative traits signaled a willingness to engage in cooperative interactions including intermarriage. If the migrant and indigenous populations were small, establishing such cooperative relationships may have been essential for biological survival. Consequently, the spread of neck banding and possibly other decorative traits may have indirectly enhanced the biological reproductive success of both migrant and indigenous populations. However, the spread of neck banding occurred too fast for these possible impacts on biological reproductive success to account for the adoption of neck banding directly. Instead, the environment with which utility wares interacted changed in a way that promoted the replication of neck banding because it facilitated potentially difficult, yet essential, social interactions.

Another possibility is that, for one reason or another, the migrant populations were seen as especially good models by the indigenous populations. Perhaps the migrant populations were particularly successful relative to the indigenous people because of some adaptive advantage. If so, this may have resulted in an indirect bias (*sensu* Boyd and Richerson 1985:241-279) toward the adoption of traits possessed by the migrant population irrespective of their adaptive value. This could have created a strong selection for neck banding as a cultural replicator despite its lack of direct impact on biological fitness.

It is also possible that the spread of neck banding was a consequence of drift rather than selective sorting. In other words, stochastic processes acting in small populations led to the fixation of neck banding even though it was selectively neutral. In this case, patterns of interaction and the chance adoption of traits because of these interactions led to the spread of neck banding. In encounters between people possessing neck-banded and scraped plain technologies, the simplest model of transmission indicates that each individual or group would have a 50% chance of adopting the technology used by the other. Under these conditions, a purely random increase in the abundance of neck banding could have led to its complete adoption in small populations as an increasing proportion of interactions resulted in the transmission or replication of neck banding. In addition, if the migrating populations entering the northern Southwest were large relative to the indigenous population, then neck banding could have spread relatively rapidly as most encounters would have involved exposure to neck banding.

Experimentation with Neck Banding

During the ninth and tenth centuries in the Mesa Verde region and other areas of the Southwest, neck banding increased in frequency and diversity. The use of neck banding increased both in terms of the relative frequency of wide-mouth jars possessing the trait and the extent of vessel surface with exposed coils. By the late ninth century, most wide-mouth jars displayed exposed coils, and on some, these coils extended down past the neck and onto the upper body of the vessel. We also see at this time the beginnings of variation in the techniques of neck banding with the appearance of narrower filleted coils in the early ninth century and slight to moderate overlapping of adjacent coils in the late ninth century.

Among the small population remaining in the Mesa Verde region in the middle tenth century, variation in the techniques of neck-banding continued to increase with the addition of rippling and sporadic indenting of exposed coils. This elaboration usually occurred as a narrow decorative band just below the rim. The relative frequency of narrow and substantially overlapped coils also increased, becoming the most abundant form, and the use of exposed coils on the upper body of vessels below the neck continued to expand. Incising of coil junctures, primarily on narrow filleted coils, also increased during this time, resulting in greater surface roughness.

In the southern San Juan basin area, the middle to late tenth century also exhibits a zenith in variation of neck-banding and corrugation techniques. Although the first use of wide, filleted neckbands occurred much later in the southern San Juan basin, utility ware type descriptions for the area indicate a similar pattern of development to that seen in the Mesa Verde region. In fact,

the routine use of systematic indenting may be earlier in the southern San Juan basin than other areas of the northern Southwest.

Although the goal of these innovations appears to have been decorative embellishment, producing narrower, more elaborate neckbands rather than improved performance, it was with these innovations that neck-banding began to affect the cost and performance of vessels. One means of producing narrow bands, the overlapping of adjacent coils, created a rougher surface and increased the strength of coil welds in comparison to the various forms of filleted neckbands. The rougher surface would have made handling the vessels easier particularly when they were hot. The increased weld strength of overlapped coils probably also facilitated the extension of exposed coils farther down the vessel body. The application of exposed coils below the vessel neck and, more importantly, below the upper level of the heated liquid contents of the vessel would have resulted in a slight loss in heating efficiency, but also significantly improved cooking control through reduced boilovers. The addition of systematic indenting or pinching of substantially overlapped coils further improved the strength of welds between adjacent coils, and increased the external surface area of the vessel, which may have resulted in even greater control over cooking. However, the use of more, narrow or substantially overlapped coils over a greater portion of the surface would have also increased the cost of vessels by requiring more time in the forming stage of manufacture.

The use of utility wares also appears to have changed during the latter half of the ninth century and the tenth century, at least in the Mesa Verde region. The increasing focus of utility ware production on a single vessel form, wide-mouth jars, and the growing relative abundance of cooking-related use alterations attest to the expanded importance of cooking in the use of utility wares. Not only does cooking appear to have become the primary use of utility wares in the Mesa Verde region by the tenth century, but the intensity and formality of use in cooking may have also increased. This increased focus on cooking in jars may have resulted from the introduction into the Southwest of *Mais de Ocho*, a variety of corn that is more suitable for milling than were earlier flint varieties. If more corn was being milled, as an increase in the relative abundance of milling stones suggests, rather than roasted on the cob, then the cooking of corn meal into mush or stew was a natural consequence in the absence of technology for bread making.

Increased moist cooking of agricultural products high in starch such as corn and beans would have had important consequences for populations employing this food processing strategy. Nutritional studies of the effects of cooking on starch digestibility demonstrate that cooking

significantly increases the digestibility of starches (Bishnoi and Khetarpaul 1993; Collings et al. 1981; Jenkins et al. 1982; Stahl 1989; Wandsnider 1997). In an unprocessed form, starch occurs as more or less complex glucose-based polymers. These complex molecules resist hydrolysis by our digestive enzymes, and, consequently, can pass through our intestinal tract relatively undigested. Cooking, particularly moist cooking, aids digestion by breaking down the complex starch molecules, through gelatinization and pasting, into their simpler and more readily hydrolyzed constituents. In addition, moist cooking removes or neutralizes antinutrients, such as phytic acid, polyphenols, and saponins, which inhibit absorption. Consequently, boiling or simmering of food, particularly for long periods, would have increased the nutritional yield of a given quantity of food. Studies show a 50 to 100 percent increase in *in vitro* starch digestibility for intensely cooked grains over uncooked starches with the amount of increase depending on the kinds of precooking processing, such as soaking (Bishnoi and Khetarpaul 1993; Hellendoorn et al. 1970). In addition, porridge produced by this cooking method could have been used to wean infants at a younger age which may have resulted in shorter birth spacing, or increased workload for women in activities other than child rearing (Buikstra et al. 1987; Nerlove 1974).

Skeletal evidence indicates that Pueblo populations in the northern Southwest during the ninth century may have experienced both better nutrition and early weaning. Ninth and early tenth century populations in the Mesa Verde and Black Mesa (northeastern Arizona) areas had slightly greater life expectancy (higher mean age at death) than later populations in the same areas suggesting better nutrition (Martin 1994; Martin et al. 1991; Nelson, Martin, Swedlund, Fish, and Armelagos 1994; Stodder 1987). Younger ages for the formation of tooth enamel defects or hypoplasias, which are frequently associated with weaning stress in young children, during the ninth century in comparison to the twelfth and thirteenth centuries in the Mesa Verde region indicate that early weaning may well have been a common practice during the earlier period (Stodder 1987). A similar pattern in hypoplasias among early and late populations on Black Mesa in northeastern Arizona (Martin et al. 1991) suggests that early weaning may have been common during the ninth and possibly tenth centuries in the northern Southwest. Both better nutrition and shorter birth spacing would have contributed to the tremendous population growth that occurred in the Mesa Verde region during the ninth century (Schlanger 1986, 1988; Wilshusen and Varien 1996). Unfortunately, a very sparse skeletal record from the preceding Basketmaker periods precludes comparing the data from the ninth and tenth centuries to earlier populations.

In addition to affecting the reproductive success of the biological populations, the increased importance of moist cooking in the ninth and tenth centuries changed the environment with which the utility ware vessels interacted. Greater use in cooking meant that thermal stresses became a more significant factor in determining the use-life, and performance during cooking may have begun to outweigh other performance characteristics. Because of their impacts on cooking control and ease of handling, increasing the surface area of exposed coils and extending the use of exposed coils farther down the vessel body may have come under heightened positive selection during this time.

Although some of the innovations in neck banding introduced during the ninth and tenth centuries could have enhanced the reproductive success of the people that used them, these changes are difficult to explain in terms of these biological impacts alone. Actual increases in fecundity cannot explain the changes in neck banding because there was not sufficient time for significant population growth to occur. Too few biological generations could have occurred during the later half of the ninth century and the tenth century for the effects of moist cooking and improved cooking control to be felt unless these activities improved reproductive success by a factor of 4 or more. Although settlement data indicate that populations did grow in some areas during this time (e.g., Schlanger 1986), we lack estimates of actual changes in fecundity. However, in a study of skeletal populations from the Midwest that date to before, during, and after an increase in the consumption of boiled starchy seeds, Buikstra and others (Buikstra and Konigsberg 1985; Buikstra et al 1986, 1987) estimate a fertility increase of approximately 1.5 associated with this change in diet. It is very unlikely that a similar change in diet together with the beneficial innovations in neck banding could have resulted in substantially greater fertility in the Southwest.

By shifting the frame of reference to the cognitive and behavioral aspects of the organisms rather than their actual reproductive success, we gain more insight into this period of increased innovation in neck banding. One might begin with the common assumption that necessity is the mother of technological innovation, and try to explain the experimentation with neck banding as a response to the altered use environment. As moist cooking with ceramic vessels became more important, the potters tinkered with how they made their pots in an attempt to improve their performance. However, both overlapping of adjacent coils and indenting first appear as decorative elaborations. Overlapping coils was just one way potters used to produce narrower neckbands, and indenting was initially sporadic and limited to only a few of the exposed

coils. Although some of the innovations in neck banding did have consequences for how the vessels performed during use, these consequences were likely unintended. In addition, these innovations in neck banding techniques also increased the cost of producing the vessels without any offsetting improvements in durability. Thus, it appears that the changes in neck banding techniques that occurred during the ninth and tenth centuries were not conscious design adjustments motivated by utilitarian or economic concerns. Perhaps only the extension of exposed coils below the neck of vessels can be accounted for in these cost-benefit terms.

However, strict cost-benefit assessments of individual neck banding variants is not the only calculus that may have been involved in bringing about this period of heightened experimentation. In the remainder of this section, I discuss four models that specify different conditions under which the rate of innovation can increase without regard to the specific utilitarian benefits accrued by individual innovations themselves. In the first model, population size is the sole determinant of innovation rate. The second model examines the relationships between risk sensitivity, innovation rates, and productivity. The third model focuses on the meaning of innovation in a social context and the conditions that can produce fluctuations in the cost of innovations both within and between social groups. Finally, the fourth model considers the role of learning curves in determining innovation rates.

Both logic and data indicate that a relationship exists between population size and innovation rate. If innovations occur randomly and at some more or less constant per capita rate, then the more people there are the more innovations there are likely to be. A similar exponential curve for global population increases and increases in the number of innovations suggests that this logical relationship may have been an important cause of gross changes in frequency of innovations over the course of human history. However, I am doubtful, based on current evidence, that this relationship held for the period of increased innovation in neck banding techniques during the ninth and tenth centuries. Demographic reconstructions indicate that the period between AD 880 and, at least, 940 saw substantial population decline in the Mesa Verde region and rapid population growth in the southern San Juan basin (Dean et al. 1994; Wilshusen and Varien 1996). The Mesa Verde region assemblage analyzed for this study from the middle of the tenth century (5MT8371) shows the greatest variety of neck banding techniques. Published data suggest that similar increases in the variety of neck banding occurred in the southern San Juan basin at the same time. Given that migrations account for at least some of the regional differences in population trajectories, it is difficult to obtain a clear picture of overall population

size for this period. However, I find no clear evidence to suggest that the late ninth and early tenth centuries was a period of sizable population growth for the northern Southwest as a whole. Consequently, it does not appear at this time that the increase in neck banding innovations during this time could have been caused directly by population growth in the absence of an increase in the per capita innovation rate.

The second model suggests that the per capita innovation rate may have increased during the late ninth and early tenth century as a result of changes in the sensitivity to risk on the part of populations in the northern Southwest during that time. Recently, Fitzhugh (1999) has attempted to model innovation rate as dependent not on population size, but on the productivity and/or consumption of resources. Based on microeconomic and ecological theory, this approach models marginal utilities, the relationship between a unit of production and the utility or value derived from it, as a sigmoid or logistic function shown in Figure 47 (see also Blurton Jones 1987; Boone 1992; Kohler and Van West 1996; Smith 1988; Smith and Boyd 1990; Winterhalder 1986, 1990). In the lower portion of the curve, marginal utility increases as productivity increases until the inflection point after which marginal utility decreases as productivity increases. The risk sensitivity of individuals, defined as susceptibility to variance in outcomes, is determined by their position on the marginal utility curve (Figure 47). An individual with productivity in the area of increasing returns will be more risk-prone while an individual in the area of diminishing returns will be more risk-averse. This is because a greater variance under conditions of increasing returns is more likely to yield beneficial outcomes than a higher variance in the region of diminishing returns.

In Fitzhugh's (1999) formulation, people experiencing low productivity, and thus in the increasing returns portion of the marginal utility function, are more likely to increase variance through innovation than people with higher productivity and diminishing returns. Consequently, innovation rates should be relatively high during periods of resource stress, as long as sufficient energy and time are available for investment in innovations, and relatively low during periods of high productivity. This prediction matches the temporal pattern of innovation in neck banding. During the late ninth and early tenth centuries, environmental degradation reduced agricultural productivity across the northern Southwest resulting in southward migrations and the abandonment of some areas. This is also the period of greatest innovation in neck banding techniques. The stress on pottery producers and consumers may have also been high during this period. Increased reliance on moist cooking during the ninth and tenth centuries probably reduced

the use-life of cooking pots, as evidenced by a possible increase in accumulation rate (see Figure 20). This would have required a greater investment in pottery production to maintain household inventories at a suitable level. This heightened demand for pottery production at a time of decline in agricultural productivity may have focused at least some of the increased innovation on the pottery itself. However, it is unclear how the apparent decorative nature of most of the neck banding innovations fits with this model.

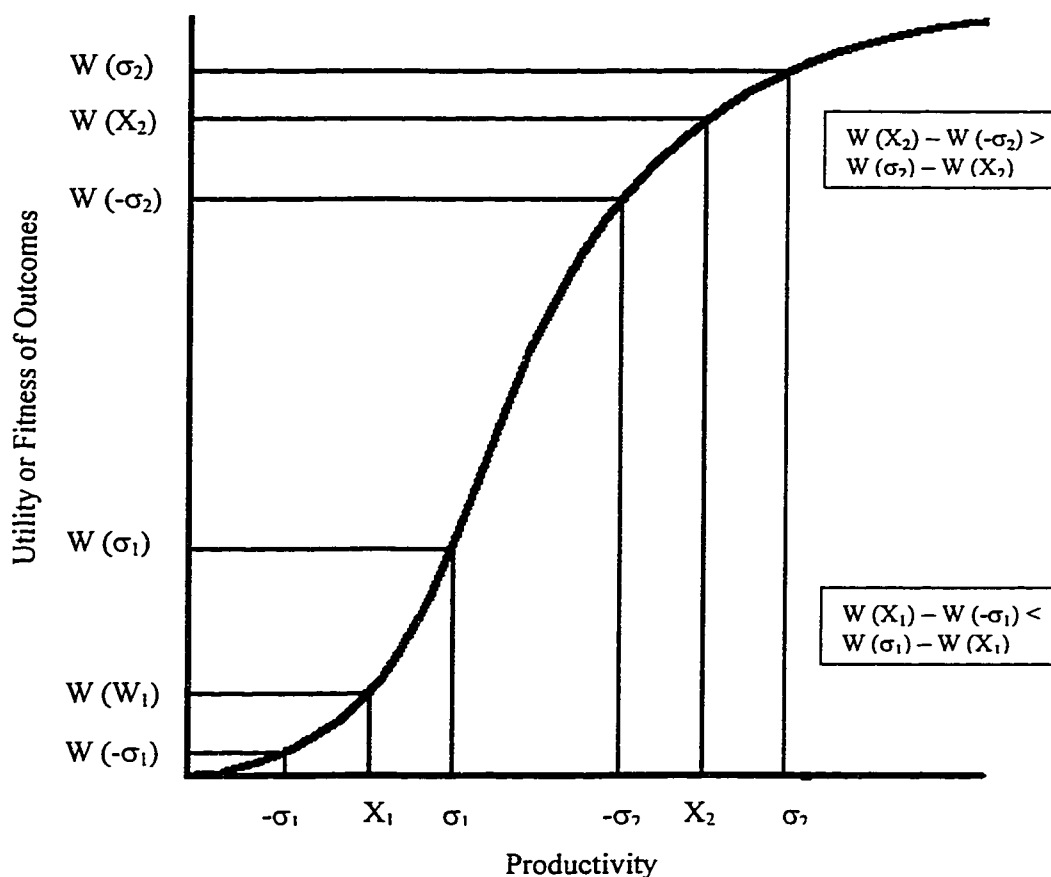


Figure 47. A model that shows the relationship between sensitivity to the risks of innovation and productivity under conditions of increasing and diminishing returns.

The third model is based on the handicap, or costly signaling theory developed by the biologist Amotz Zahavi (1987, 1991; Zahavi and Zahavi 1997) and formalized by Grafen (1990a, 1990b). This theory attempts to explain elaborate displays or decorations in the biological and cultural worlds as signals of competitive ability or some other hidden feature of the signaler. The amount of investment made in signaling varies in proportion to the ability of other potential competitors, the composition of the audience, and the likely payoff from signaling. The advantage of costly signals is in the response that they engender in the receivers, which depends on their

ability to interpret the signals accurately. If costly signals result in avoidance of unnecessary conflict or promote beneficial cooperation, then there can be an advantage for both the senders and the receivers of the signals.

Recently, some anthropologists have begun to use this theory to explain variation in elaboration or waste exhibited by human behavior (e.g., Bird and Smith 1999; Boone 1997, 1999; Neiman 1997, 1999). Although most of these applications have focused on monuments and other massively elaborate constructions, there is no reason for the theory of costly signaling to be limited to such cases. Even small differences in cost can produce the same effects under the right conditions. The increased investment in neck banding innovations, particularly during the tenth century, may represent just such a case.

Using narrower coils, overlapping adjacent coils and applying indents and incisions all add to the cost of manufacturing neck-banded pottery, and thus could provide a basis for costly signaling. Although we lack data on spatial variation in the use of these different techniques that would allow us to assess the applicability of costly signaling, temporal trends in the investment in these techniques do appear to match the costly signaling model. In the Mesa Verde region, investment in neck banding elaboration increased gradually during the ninth century and then rose dramatically during the tenth century. During the late ninth century, the first large villages formed which probably included unrelated or distantly related households. This period of village formation could have elevated the potential for competition because the likelihood of competition among individuals and groups increases with the decreased degree of biological relationship. Under these conditions, we would expect an increase in costly signaling, perhaps with the senders being the potters and the receivers being potential mates.

The significant increase in the variety of neck banding during the tenth century, including substantial decrease in exposed coil height and the first use of indenting, also occurred during a period when the importance of costly signaling was probably on the rise. The large-scale migrations at the end of the ninth century and the apparent coalescence of populations in the southern San Juan basin brought many people together who had previously been isolated from one another. Again, the association of unrelated individuals with no historical knowledge of one another could have prompted an increased investment in costly elaborations to signal competitive advantage and skill. Comparisons of the energy investments in pottery and possibly other material culture from different households and settlements occupied at the same time could be used to test this hypothesis more fully.

The final model of change in innovation rate draws on the metaphor of an adaptive landscape or design space to explain technology trajectories or learning curves. Economists have noted for some time that technological innovations follow a consistent trajectory with a rapid innovation rate occurring early in the history of a new technology followed by a diminished rate of innovation despite continued investment. Recently, Stuart Kauffman and his colleagues at the Santa Fe Institute have attempted to explain this pattern of innovation as a consequence of adaptive search on a rugged but correlated landscape formed by the space of possible designs (Kauffman 1995:201-206; Kauffman and MacReady 1995; Kauffman et al. 1998). The basic idea is that after an innovation opens a new area of design space, the innovation rate rises as people explore that new space in a more or less random fashion. These innovations during this initial period of exploration tend to come from the top down, finding major variations on the theme that involve changes in several attributes at once. These innovations represent relatively long jumps across the space of possible designs. However, as people discover these new design themes, it becomes progressively harder to make further innovations. Consequently, innovation becomes increasingly difficult and more focused on small changes that involve very short moves in design space. This pattern in the introduction of variation is seen in both technological and biological change and probably results from more general constraints on the adaptive exploration of rugged yet correlated landscapes.

It is possible that the initial development of neck banding opened up a new area of design space in the construction of ceramic vessels among early Puebloan populations. Leaving coils unobliterated moved from being in the domain of the possible to that of the actual. It did not take long after the initial innovation for further innovations on the neck-banding theme to follow. Making narrower coils, overlapping coils, applying indents, and various combinations thereof represent major variations on the theme that occurred during the ninth and tenth centuries. Once these major innovations had occurred, a series of small, incremental changes, such as degree of overlap and spacing of indentations, could result in further, short distance exploration of this new area of design space. Thus, the florescence of innovation in neck banding during the ninth and tenth centuries may represent a simple combinatorial expansion of actual design space, which was unrelated to any external conditions. These new variants on the neck banding theme could have arisen through a blind innovation process requiring no prior knowledge of the consequences of the innovations. In situations with conflicting design constraints, as is the case with ceramic cooking pots (see Chapter 7), and limited engineering knowledge, almost certainly the case for

Pueblo potters circa AD 900, blind variation can be equally or perhaps more effective than rational calculation at finding solutions to design problems

I doubt that any one of these possible explanations can account fully for the increased variation in neck banding during the ninth and tenth centuries. Instead, I suspect that we can explain different aspects of this variation in distinct ways. For example, we may be able to explain the application of corrugations over a greater amount of the vessel surface by their performance benefits when used on cooking pots. Innovations that increased the cost of making utility wares without providing some performance benefit may have been selected because conditions arose that favored costly signals. Other innovations may have been selectively neutral. These may have arisen because of an increase in blind innovations caused by environmental stress or exploration of new areas of design space. These neutral variants would have been sorted by drift. The apparently stochastic fluctuations in the relative frequencies of different kinds of neck banding shown in Figure 13 suggest that most of these trait combinations were selectively neutral. However, certain attributes that make up these trait combinations do show directional change indicative of selection. These attributes include the frequency and degree of coil overlapping and the extent of the vessels covered with exposed coils. However, selection appears to have become much more important at the scale of attribute combinations after the tenth century with the development and spread of full-body corrugation.

Adoption of Full-Body Indented Corrugation

Within a very brief period, the tremendous variation that had characterized neck-banded assemblages during the tenth century was reduced to the almost exclusive use of a single corrugation technique by the early eleventh century. This technique involved the substantial overlapping and systematic indentation of exposed coils. Using this technique increased the strength of the joins between adjacent coils and, consequently, made more feasible the use of corrugation over more of the vessel surface. Shortly after the adoption of these techniques during the late tenth century, the first full-body corrugated vessels appear in the record.

Full-body corrugation spread extremely rapidly over a large area of the Colorado Plateau. Full-body corrugated vessels appear to replace neck-banded utility wares in the southern San Juan basin, Mesa Verde, Kayenta, Sinagua, and Virgin Branch regions nearly synchronously during the early to middle eleventh century. Some of this spread of corrugation coincides with the reoccupation of areas that were abandoned during the tenth century. The spread of full-body corrugation beyond these areas took longer, and its replacement of earlier technologies was

apparently less abrupt and complete in some areas such as the Rio Grande region to the east and the Mogollon and Sinagua regions to the south. In some areas, such as the Gallina region of north-central New Mexico, it appears that corrugation was never adopted to any significant degree. These differences in the spread of full-body corrugation may indicate variation among areas of the Southwest in patterns of population expansion, interaction, and, possibly, economic pursuits during the eleventh century

Extending the use of exposed coils to the lower body and basal portions of cooking jars results in a more durable vessel by reducing the amount of thermal stress generated during use. In the Mesa Verde region, this improved durability of cooking pots appears to be reflected in a reduced accumulation rate of utility wares. This may signal a decrease in the labor investment required for utility ware production, but the increased cost of fully corrugated vessels may have offset the savings engendered by improved durability. The adoption of full-body corrugation also marks the first time for which we have secure evidence of large scale, probably economic, production and distribution of utility wares in the northern Southwest. This appears in the massive import of corrugated vessels into Chaco Canyon from the Chuska Valley. In some areas, increased investment in production of white ware vessels, which were used for storage and serving, accompanies the adoption of full-body corrugation.

These changes in the environment in which utility ware vessels were manufactured and used would have made full-body corrugation a benefit to the people possessing the technology. The improved durability of full-body corrugated vessels when used for cooking may have made moist cooking of food more efficient than it had been previously, further boosting the caloric return of this method of food processing. Substantial growth of Puebloan populations during the eleventh century may have been supported, in part, by this improved efficiency of food processing and shorter birth spacing made possible by the early weaning of infants. Improvements in climate and intensified agricultural practices also contributed to the population growth seen during this period of Pueblo expansion. However, the rapid adoption of full-body, indented corrugation to the almost complete exclusion of earlier neck-banded varieties over a large area of the northern Southwest cannot be explained by increased fecundity alone. As with some of the changes in neck banding, there were too few biological generations during the period of adoption for the impacts on fertility to account for the widespread use of full-body corrugation.

The greater efficiency of full-body corrugation may have been one factor that led people to choose this technique over the less efficient neck banding. In addition to this greater efficiency,

the longer use-life of full-body corrugated vessels may have compensated for, or perhaps enabled the increased investment in white ware production that took place in some areas. Thus, with the trade of pottery on the rise, as it was in at least some areas, individual potters and pottery making groups may have benefited from the adoption of full-body corrugation of their utility wares. By concentrating utility ware production on a technology that extended the use-life of vessels, fewer vessels would have needed to be produced. This would have allowed them to shift more of their production time to other kinds of pottery. Modern psychological studies indicate that people do have the cognitive abilities necessary for making these kinds of cost-benefit calculations (Cosmides 1989; Cosmides and Tooby 1992). Consequently, this kind of decision-making algorithm may have been responsible for the rapid selection for full-body corrugation.

However, discontinuities in the spread of full-body corrugation suggest that this explanation may not yield a complete understanding of the adoption problem. Although the adoption of full-body corrugation was extremely rapid over a large area, it occurred later and was apparently less abrupt in other areas such as the Rio Grande valley, the southern edge of the Colorado Plateau, and farther south in the Mogollon region. If full-body corrugation was so clearly beneficial, why was the technology not adopted more rapidly in these other areas as well? One possibility is that the conditions that made full-body corrugation beneficial—routine use of moist cooking and, possibly, extensive trade in pottery or investment in producing painted pottery—were not present in these other areas. Further research on the use of utility wares and pottery exchange in these peripheral areas is needed to evaluate this possible explanation for the delayed adoption of full-body corrugation in some areas.

Another possible explanation is that patterns of interaction among different regions of the Southwest structured the spread or replication of knowledge regarding the manufacture and benefits of full-body corrugation. The area of rapid and complete adoption of full-body corrugation may have been involved in frequent interactions, which facilitated the replication of this variety of corrugation. If interaction between this core area for corrugation and adjacent areas was not as frequent or was constrained in some way, this could have inhibited the replication of full-body corrugation beyond the core area.

The apparent development of full-body corrugation in the southern San Juan basin during the late tenth and early eleventh centuries coincided with two events that may have affected the patterns of large-scale interaction in the American Southwest. First, the substantial growth of Pueblo population during the eleventh century discussed above also involved migrations of

people into new areas and areas that had been abandoned during the during the late ninth and early tenth centuries. These migrations may have been sufficient to encourage the replication of full-body corrugation in the areas receiving the migrant populations, and inhibit the spread of corrugation beyond the area of the migrations if migration was the primary mechanisms of dispersal.

The second event involved the emergence of the Chaco regional system. Although the exact nature of this system remains obscure, a variety of evidence suggests that Chaco Canyon may have been the center of the first truly large-scale, integrated sociopolitical system in Pueblo prehistory (Lekson 1996, 1999; Lekson et al. 1988). If the establishment of the Chaco regional system took place through the replication of a suite or system of political, religious, economic, and technological traits, as some have argued, full-body corrugation may have been just one part of this larger replicating entity. Perhaps the simultaneous development of full-body corrugation and the Chaco regional system, likely a historical accident, led people to ascribe some meaning to corrugation in relation to the Chaco system that went beyond its utilitarian benefits. In evolutionary terms, full-body corrugation may have benefited from the successful replication of the larger scale Chaco system. Beyond the area covered by this regional system, full-body corrugation spread more slowly because it lacked the additional semantic replicator that it had within the Chaco system. The use of indented corrugation on some bowl exteriors among the Anasazi during the Chacoan period, but not in the later Pueblo III period, may have occurred because of this added semantic component to replication.

Current evidence suggests that both migrations and the development of a large-scale sociocultural system affected the spread of full-body corrugation. To the east and south, the area of rapid adoption of full-body corrugation corresponds with the apparent edge of the Chaco system. An abrupt boundary to the spread of corrugation exists to the east, which roughly corresponds with the edge of the San Juan basin. Although innovations in painted designs appear to have moved easily across this boundary (Wilson 1995), full-body corrugation did not. This suggests that the spread of corrugation farther to the east may have been limited by something other than simple interaction frequency. One possibility is that the meaning of corrugated wares differed from the painted pottery and this distinction obstructed the spread of corrugation. Another possibility is that the populations living in the Rio Grande valley and other areas east of the San Juan basin had not yet adopted moist cooking as their primary means of food preparation. If true, full-body corrugation may not have offered the benefits that it did in areas where moist

cooking was common. Full-body corrugation was eventually adopted in the Rio Grande area during the twelfth or early thirteenth century. This adoption, however, was not as complete as in other areas to the west, and earlier plain, incised, and neck-banded styles continued to be used in the Rio Grande area after the appearance of full-body corrugation.

To the south, full-body, indented corrugation spread rapidly to the boundary between the Anasazi and Mogollon culture areas where the spread slowed abruptly. It was not until after the collapse of the Chaco system in the twelfth century that full-body corrugation continued to spread south into the Mogollon region. Corrugation appears to have spread rapidly after about AD 1150 along with masonry pueblo-style architecture and black-on-white painted pottery. Southward migration during the twelfth and thirteenth centuries may have again played an important role in the further spread of corrugation, but this has not yet been demonstrated (Lekson 1993, 1996b; Reid 1989; Reid et al. 1996). In the Mogollon region, plain, neck-banded and incised utility wares continued to be used after the introduction of full-body corrugation, and indented corrugation occurs frequently on bowls and jars. If corrugated vessels were commonly used for tasks other than cooking in the Mogollon region, as appears to have been the case, then corrugation may have spread to this area for reasons other than its benefits as a cooking pot. Perhaps some meaning attributed to corrugation played a role in its replication through the Mogollon area. The nature of this meaning and its relationship to the collapse of Chaco are intriguing subjects for speculation.

To the west and north of the San Juan basin, full-body corrugation appears to have spread rapidly during the eleventh century well beyond the area commonly recognized as participating in the Chaco system. Perhaps migrations associated with the Pueblo II expansion of agricultural populations in the northern Southwest accounts for some of this rapid spread of corrugation. However, migration does not appear to explain the spread of corrugation into the Fremont areas of Utah and Nevada. Among the Fremont, other utility ware styles continued to be used along with corrugation and indented corrugation appears on a wider variety of vessel forms than on the Colorado Plateau. We still know so little about the production and use contexts of corrugation in these areas that formulating adequate explanations poses a formidable challenge.

Return to Plain Utility Wares

After its adoption, full-body corrugation remained the dominant Puebloan utility ware for another 400 years. During this time, corrugation persisted through several dramatic changes in Pueblo society including large-scale population movements, some involving the abandonment of entire regions, and momentous changes in climate, social organization, and ideology. Although

not explicitly a focus of my empirical research, we do know that the techniques used to manufacture full-body corrugated vessels did not stagnate during this period of dominance. Innovations came mainly in the areas of vessel morphology and the elaboration of patterns created by the placement of indentations and appliques. In addition, small amounts of plain gray vessels continued to be made throughout the period of dominance by corrugation. However, many of these plain vessels were actually produced by smearing or obliterating corrugations.

In the late fourteenth or early fifteenth centuries, the long-standing yet sporadically employed technique of smearing corrugations became much more common and widespread; eventually replacing indented corrugation. By the middle to late fifteenth century, the smeared or blind corrugation was itself replaced by entirely plain vessels. Unfortunately, we still know very little about this change back to plain-surfaced utility wares. However, existing evidence does indicate that changes in the processing of corn occurred at about the same time as the shift back to plain cooking pots. The adoption of flat bread making in the fifteenth century may have significantly reduced the amount of corn processed by moist cooking in pots. If so, then the additional costs of producing corrugated cooking pots may not have been adequately returned through the benefits of control over boiling and improved vessel durability.

Because we still know so little about the return to plain utility wares, I will not try to explain this change as fully as I have attempted to do with the other three aspects of the corrugation problem. Instead, I want to address an aspect of the shift back to plain vessels that has perplexed me and other pottery specialists working in the Southwest. This is the question of why Pueblo potters went to the trouble of making corrugated pottery only to smear and obliterate the coils after they had applied them. From a purely economic standpoint, this extra step is difficult to explain. If one is going to make plain-surfaced pottery, it would be less costly to use large coils or slabs as they had done before the advent of corrugation.

However, smearing corrugated coils as a part of a transition back to plain pottery may be understandable from an evolutionary perspective in which the different ways to make utility ware vessels are the replicators. During the period of experimenting with neck banding techniques, each different technique was a viable replicator. Hence, coil size, amount of overlapping (if any), indentation, incising, etc. all varied more or less independently of one another resulting in a wide variety of combinations. After the adoption of full-body indented corrugation, only a single replicator remained from among the diverse array present in earlier assemblages. Not only did the diversity of techniques decline precipitously, but the scale of the replicator may also have

changed. Instead of each different technique replicating independently, a suite of techniques, including substantial overlapping and systematic indenting over the entire exterior surface, replicated as a single unit. Consequently, when the environment of utility wares changed during the fourteenth and fifteenth centuries, which may have eliminated the benefits of full-body corrugation, potters could not draw on earlier techniques because they were no longer viable replicators. To get back to a plain-surfaced utility ware, the potters had to start from a corrugated vessel first. By the time the Spanish arrived in the Southwest during the sixteenth and seventeenth centuries, smearing corrugations to make a plain utility ware pot was no longer practiced. Sometime during the fifteenth or early sixteenth centuries, innovations must have occurred that replaced corrugation resulting in a less costly utility ware technology.

CHAPTER 9: CONCLUSIONS

The goals of this research have been threefold. First, I wanted to explain the development and adoption of corrugated pottery in the American Southwest. Second, I aspired to move beyond the intuitive, often simplistic historical and functional explanations for corrugation proffered in the past. Finally, I hoped to contribute to the development of scientific explanation in archaeology and the social sciences generally, by using theory in its proper role as a set of concepts that supply the logical structure for both explanation and description. The theory, evidence and hypotheses presented in this dissertation indicate that I have had some success in each of these goals.

At the outset, I argued that explanations in social sciences, and archaeology in particular, have lacked the impact they have had in the natural sciences because intuitive, common sense notions have generally taken the place of theory in the social sciences. This has allowed various ideological biases and agenda to play a much larger and more detrimental role in the social sciences than in the natural sciences. To avoid this deficiency in my research on corrugated pottery, I have made explicit use of evolutionary theory to design my observations and formulate my explanations.

However, theory too is not immune to the intrusion of common sense. Consequently, I went to great lengths to try to expose and eliminate inconsistencies and intuitive biases from the evolutionary approach that I adopted for this research. This led me to develop the notion of frames of reference in which the conceptual units of evolutionary theory can have many different logically coherent and causally relevant relationships with the empirical entities under investigation. In this view, there can be many different replicators, interactors, environments, and lineages that are relevant to any given problem. The goal in formulating evolutionary explanations, then, is to identify those frames of reference that yield the most explanatory insight into the problem at hand. This was the approach I took in formulating the possible explanations for different aspects of the corrugation problem. Although the approach has been fruitful in terms of formulating hypotheses, it has been difficult to thoroughly test the various alternative explanations I have presented mainly because testing most of them required data not yet available. Consequently, the final step in determining the scientific validity of this approach and the specific explanations it spawned must await further research. In the remainder of this concluding chapter, I explore some general insights gleaned from my attempts to explain the

evolution of corrugated pottery in the American Southwest, and discuss directions for future research.

Evolutionary Explanation of Corrugation: Some General Insights

Even without being able to test fully my various alternative explanations for the rise and fall of corrugated pottery, I have demonstrated clearly that the different varieties of corrugation form a lineage of common descent in the Southwest. But, common descent of what? In my hypotheses, I identify several replicators that appear to be relevant to the corrugation problem. These replicators include biological individuals and groups, the knowledge of how to make and use corrugated pottery, the meaning ascribed to corrugation, sociocultural institutions, and, to a limited extent, the corrugated pottery itself. As corrugation developed and spread, the significance or causal relevance of some of these replicators also fluctuated. However, it also appears likely that many of these replicators were active simultaneously. Each of these replicators also interacted with unique environments. The pottery interacted with production and use environments. Biological individuals and social groups interacted with one another and the physical and technological environment. The beliefs and knowledge people held about corrugated pottery interacted within a cognitive environment. Each of these replicator-interactor-environment combinations represents a different frame of reference from which to examine the corrugation problem. Although I attempted to probe the corrugation problem from several frames of reference in explanations presented in the previous chapter, I suspect that more frames of reference remain to be explored.

The various hypotheses I have formulated thus far also suggest that the rise and fall of corrugated pottery involved a mixture of drift and selection working through a variety of scales and units. This combination of multiple mechanisms and units produced a complex history that cannot be adequately captured with simple functional or historical accounts. The concepts of style and function that are frequently used by archaeologists to distinguish different kinds of variation do not appear to do justice to the actual workings of cultural change. This is because they tend to gloss important details of real evolutionary histories.

History and function are difficult to distinguish because of path dependence of particular technological forms. For example, I have demonstrated that corrugated cooking pots developed through a series of innovations and intermediate steps rather than being designed as a complete package. In addition, the innovations that ultimately led to the performance enhancements in corrugation appear to have been introduced originally for other reasons. That is, the benefits of

corrugations were unintended consequences. Looking at the product of this process, such as full-body corrugated pots, and understanding the costs and benefits conferred by this technology in the context of intense use of moist cooking, we can begin to imagine other possible technologies that may have offered better solutions. For example, rather than leaving coils exposed, one could scrape smooth the interior and exterior surfaces to produce stronger coil welds, and then score the exterior surface to attain similar cooking control and durability enhancements offered by corrugation. This approach would allow the use of larger construction elements, thereby reducing the per unit production costs in comparison to a corrugated vessel. This scoring approach to producing a textured exterior surface did develop in other parts of the world, but was used only sparingly by ancestral Pueblo potters, and then never on the base of their vessels. This is primarily because exterior surface texturing began as a decorative use of exposed coils on vessel necks. Once they started down this path of leaving coils exposed, the use of substantial scoring became less and less likely or compatible.

This notion of path dependence is certainly not new (e.g., Adams 1996; Arthur 1989, 1994; Basalla 1988; Burke 1978) nor is it unique to technology, but is a feature common to all evolutionary trajectories. However, it is often ignored by purely functional accounts that frequently rely on the assumption that adaptation and decision making produce optimal solutions. This recognition of path dependence does not constitute a rejection of the explanatory significance of functional issues. An evolutionary approach accommodates and integrates both history and function in its explanatory structure. We also tend to think of path dependence as arising from a lack of theoretical and empirical knowledge. If only the ancient Pueblo potters and cooks had known what we know about physics and engineering, they would have arrived at a more efficient, perhaps even optimal, solution to the problems posed by intense boiling in ceramic vessels. However, path dependence is certainly not a feature only of primitive technologies. The logically constrained nature of innovation and the historically constrained features of selection result in historical accidents that can have significant impacts on the course of technological change. This is true regardless of our understanding of the physical or engineering principles involved. The combination of deterministic and contingent processes produce unique histories that are probably often neither optimal nor completely free of the constraints of energetic efficiency.

Directions for Future Research

Although this study has enhanced our understanding of corrugated pottery in the American Southwest, several issues require further research before we can be confident that this understanding is complete and accurate. We need to improve our knowledge of the history of corrugation both within and outside the Mesa Verde region. We need additional studies focused on documenting the production and use of utility wares in different areas of the Southwest. Additional studies are needed to document more thoroughly the engineering properties of plain and corrugated vessels. Finally, the hypotheses presented in the previous chapter need to be further developed and evaluated.

History of Corrugation

Through my analyses of utility ware collections from the Mesa Verde region and examination of published data from other areas, I have presented a sketch of the development and spread of corrugated pottery in the Southwest. I call it a sketch because we lack secure data on the timing and source of variation in corrugation techniques in many areas. The broad outline of what I have presented is probably correct, but formulating testable evolutionary hypotheses for the rise and fall of corrugation requires more than a broad outline of the changes we are trying to explain. Detailed analyses such as I performed in the Mesa Verde region should be carried out in other areas. This would allow us to date the appearance of particular variants in different areas and track their spread across the Southwest. The lack of well-dated assemblages for certain times in some areas may require the use of other dating techniques, such as thermoluminescence dating of the pottery itself, to resolve questions of chronological priority.

We may also need a more detailed understanding of variation in corrugation techniques within regions. My analyses in the Mesa Verde region produced a good temporal record of change in utility wares, but we still know very little about variation within and among settlements within the region. This kind of knowledge could help us distinguish different mechanisms, such as migration, diffusion and innovation, responsible for the introduction of new corrugation techniques.

Utility Ware Production and Use

We still have very limited secure knowledge regarding the production and use of utility wares in the Southwest. Two issues, in particular, need more thorough attention. Current evidence suggests that the organization of production and distribution of utility and painted pottery may have changed dramatically at about the same time that full-body corrugated pottery was adopted.

However, this evidence is spotty and, in some cases, circumstantial. We need to expand our knowledge of utility ware production through more sourcing studies aimed at utility wares, and a greater attention to documenting direct evidence of utility ware production during new excavations. In addition, we need to document more thoroughly the relationship between the production of utility wares and painted pottery outside the Mesa Verde region. I was able to generate some intriguing evidence related to this issue in the Mesa Verde region based on published information alone. I suspect this will be true for other parts of the Southwest as well making the huge primary literature, consisting mainly site reports, a potential gold mine of information on this topic.

Regarding the use of utility wares, the evidence I generated on the intensification of use in moist cooking needs to be expanded by conducting the same analyses for additional assemblages from the Mesa Verde region and on assemblages from other areas. Studies of large samples of whole and restored utility ware vessels from well-dated and documented contexts could significantly augment analyses of sherd assemblages. It may also be useful to bring new analytical approaches, such as residue analyses, to bear on the problem. We need to know if the same pattern of change in the type and intensity of use documented for the Mesa Verde region occurred in other areas of the Southwest. I am especially curious as to whether these changes in use accompany the development and adoption of corrugation in other areas, particularly those areas in which corrugation was adopted more slowly.

Engineering Properties

The engineering analyses conducted for this study succeeded in documenting several differences and similarities in the cost and performance of Southwestern plain and corrugated utility wares. Nonetheless, I was not able to address some areas as well as I would have liked. These issues include vessel use-life, the effects of vessel size on cost and performance, and ease of handling. Both the use-life experiments and estimates of actual accumulation rates suggest that full-body corrugated pots are more durable than plain pots when used for cooking. However, the small sample of vessels included in the use-life study resulted in ambiguous and conflicting results from the strength testing. To improve our documentation of differences in vessel use-life, the number of vessels subjected to use-life experiments and the duration of use must be increased substantially. Estimating accumulation rates for utility wares for other assemblages in the Mesa Verde region and elsewhere in the Southwest can also contribute to a clearer understanding of the impacts of full-body corrugation on vessel use-life.

In my cost and performance experiments, I held vessel size constant, and used relatively small vessels to minimize the cost of experiments, which were already extremely labor and time intensive. This means that I do not have data to address how changes in vessel size may have affected the cost or performance of plain and corrugated vessels. It is possible, though I think unlikely, that differences in vessel size could affect performance and use-life due to the allometric increase in volume relative to surface area. To assess this possibility, experiments similar to the one I performed should be conducted using larger vessels more in keeping with the average size of actual Puebloan utility wares.

My studies of ease of handling were purely anecdotal, and thus the observations I made lack any real quantitative dimension. To further document potential differences in ease of handling between plain and corrugated vessels, controlled observations and experiments should be designed and carried out. These studies should measure the actual surface roughness of different kinds of corrugation, and the effects of this roughness on friction and slippage under static load. For example, a clamp could be set up to squeeze vessels around the neck at a constant pressure. Pots with different kinds of corrugation on their necks but the same in other respects could then be placed into this device, and a substance could then be added gradually to the pot to increase its weight at a constant rate. The weight of added contents at the time of first slippage in the clap would be a measure of one aspect of ease of handling.

Further Development and Testing of Hypotheses

In presenting the hypotheses regarding various aspects of the corrugation problem in the previous chapter, I chose to employ a narrative format that emphasized the possible causal relationships of different historical contexts. In the interests of creating a readable narrative of reasonable length, I did not take the time to present the hypotheses in a more formal way. A formal treatment would involve explicitly specifying the evolutionary function (i.e., replicator, interactor, environment, population, etc.) of each of the units under discussion, and possibly expressing the proposed causal relationships in a more quantitative manner. Given the preliminary nature of much of the evidence on which the hypotheses are based, I also thought it would be premature to present formal hypotheses at this time. However, as our knowledge of the history, production and use contexts, and engineering properties of Southwestern utility ware improves, it will be important to formalize these hypotheses so that they can be evaluated with explicit empirical tests.

Further testing of the hypotheses will also require better data on several topics that are well beyond the realm of pottery. These include issues such as the extent and direction of migrations, the constitution of migrant and indigenous populations, and the existence and character of large-scale sociocultural entities. Obtaining accurate knowledge of these issues will require archaeologists to generate and synthesize data on scales much larger than we normally work. We may also need new ways to think about and document these kinds of problems. Consequently, I expect it will be a long time before we have any secure scientific explanations of the rise and fall of corrugated pottery. However, I hope that the research presented here has set us moving in the right direction.

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APPENDIX A: ANALYSIS OF POTENTIAL ASSEMBLAGE AND SHERD SIZE BIASES

In addition to the issues discussed in Chapter 4, the assemblages selected for analysis in this study could present a biased picture of utility ware pottery technology and use due to the effects of sample size and the size of the sherds themselves. If the samples are not large enough to represent adequately the true range of variation present at the time the assemblages were formed, then both the richness and the relative abundance of different attributes could be distorted. If significant differences exist among assemblages in the size of sherds and the measurement of certain attributes is affected by sherd size, then variation among assemblages could result from differences in sherd size rather than accurate descriptions of technological variation. In this appendix, I evaluate these potential sources of bias, beginning with sherd size and followed by sample size.

Sherd Size

I measured two attributes that provide data on the size of each sherd, maximum length and sherd weight. The distributions of values for both attributes show considerable right skew in all six assemblages. Most of the weight and length values are low, but a few sherds in each assemblage are unusually heavy and long. However, these data can be made to conform more closely to a normal distribution by transforming the data using a Log10 transform. The transformed data from all of the assemblages combined display a significant linear correlation ($r_p = .948$, $p < .000$) between sherd weight and maximum length. This correlation means that we can rely on only one of the attributes to track variation in sherd size among the six assemblages.

Figure 48 gives the averaged sherd weight in each assemblage with error bars showing the 95% confidence interval around each mean. Assemblages whose error bars do not overlap have significantly different average sherd size at the .05 level. This figure indicates that significant differences exist among the assemblages in the size of sherds. The three assemblages with artifacts recovered from deeply buried contexts (5MT2193, 5MT4671, and 5MT8827) have significantly larger sherds on average than the three assemblages with artifacts from surface or shallow midden deposits. The correlation between recovery context and sherd size indicates that post depositional breakage is the primary cause of variation in sherd size among the assemblages. In addition to introducing possible biases into the data from the six assemblages, these differences in the degree of fragmentation of the pottery reinforce the decision to use the weight rather than the count of pottery to quantify abundance.

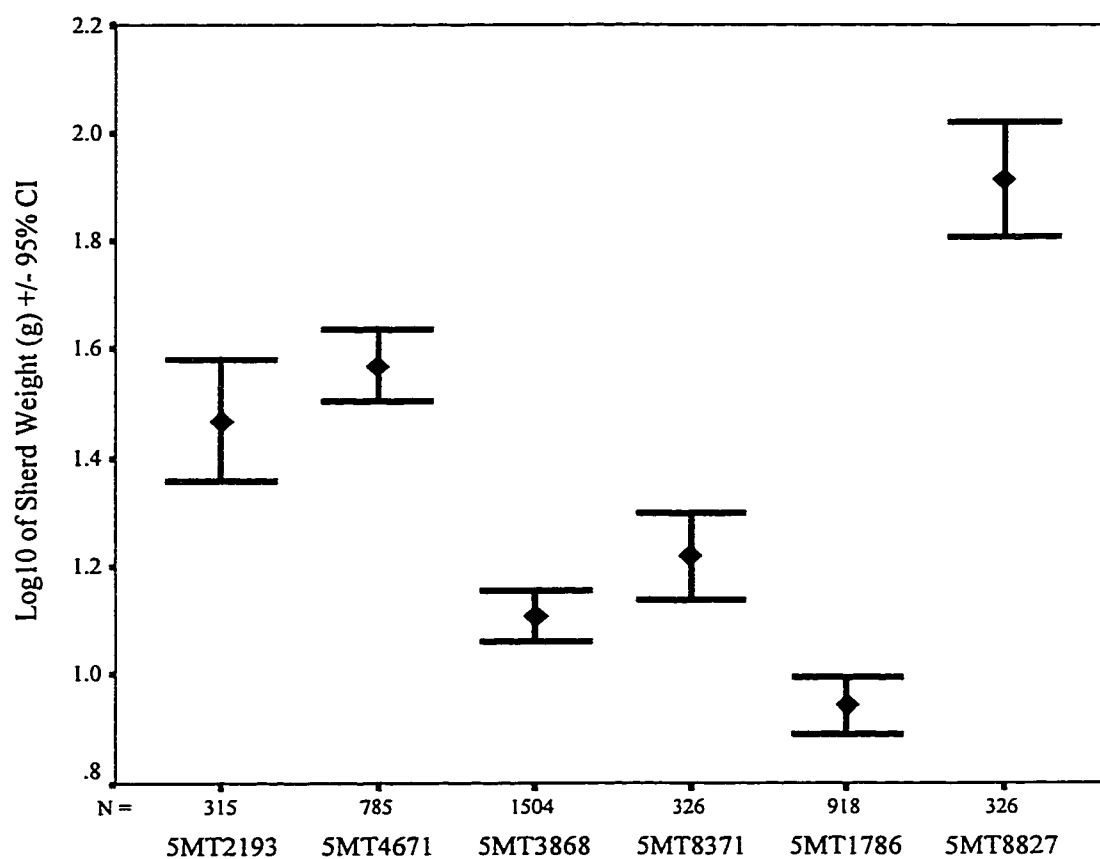


Figure 48. Variation in sherd size among the six utility ware assemblages.

With the exception of measurements of the arc and radius of vessel rims, it is difficult to anticipate exactly which attributes will be adversely affected by variation in sherd size. Attributes that monitor features of the interior and exterior surface of the pottery are the most likely to be affected because, as the sherd size increases, the area of the surfaces increases more rapidly than the area of the edge. Consequently, attributes such as forming marks, firing clouds, and use-related alterations could differ among sherds due to differences in sherd size. However, if the sample size from each assemblage is large enough—the subject of the next section—the data from each assemblage as a whole should not be affected. Thus, assemblage-based comparisons should limit, but not necessarily eliminate, the detrimental effects of variation in sherd size. Another way to identify the impact of sherd size is to compare the pattern of variation among assemblages in a given attribute to the pattern of variation in sherd size. Those attributes that match the sherd size pattern should be considered suspect in terms of reflecting biases created by

sherd size differences. However, given the correlation between sherd size and depositional context, one must also assess the possibility that the depositional context, rather than sherd size, is responsible for the similar patterns. As I present and discuss the results of my analyses of the six pottery collections in Chapters 5 and 6, I use this approach to identify and evaluate possible sherd size biases.

Sample Size

For some time, archaeologists have recognized that the size of their samples can affect the accuracy and precision of their descriptions in terms of the range (richness) and relative abundance (evenness) of objects and attributes represented (e.g., Beals et al. 1945; Leonard and Jones 1989). A positive correlation between the richness and sample size of assemblages has been used to identify possible sample size biases in a group of assemblages. Among the six utility ware assemblages, there is no consistent correlation between sample size and assemblage richness (Table 21). Assemblages with the lowest number and weight of sherds possess the greatest richness of surface forming marks, exposed coil manipulations, and exposed coil classes. Although the vessel form data may show a minor sample size effect, it is not the primary cause of variation in the richness of vessel forms among the assemblages as discussed in Chapter 6.

Table 21. The richness of utility ware features in relation to sample size in the six assemblages.

Assemblage	N	Grams	Forming Marks	Exposed Coil Manipulation	Exposed Coil Classes	Vessel Forms
5MT2193	315	2306	5	2	1	3
5MT4671	785	6049	5	4	3	4
5MT3868	1504	7383	6	5	5	4
5MT8371	326	1568	8	6	8	2
5MT1786	918	3344	7	6	3	1
5MT8827	326	3493	7	5	3	1

The presence or absence of a particular feature is less susceptible to sample size biases than the relative abundance of pottery assigned to a category or a specific ratio or interval scale measurement. To assess whether sample size effects appear in the quantitative data, I performed an iterated resampling of each assemblage by randomly selecting sherds at increasing sample sizes. I began with a sample size of 10 randomly selected sherds and increased each subsequent sample by 10 sherds until reaching a sample size of 100, then incremented by 25 sherds until reaching a sample size of 300 and then incremented by 50 sherds until I reached the total sample size of the assemblage. This produced numerous subsamples of each assemblage for which I

calculated relative frequencies of categorical data and the mean values of measurements. With these resample data, I can examine how relative frequencies and mean values change with increasing sample size by graphing the values by sample size. Large fluctuations in values between different samples indicates the presence of sample size effects, while stable values indicate measurement redundancy and adequate sample size. As the size of the subsamples come close to the total sample size, the resampled values inevitably begin to converge on the values found in the total sample. This is not necessarily an indication of adequate sample size. Consequently, values must stabilize well before the total sample size to indicate convincingly that the size of a sample is sufficient to avoid the biasing effects of small samples.

To evaluate these sample size effects, I focus on the attributes that play an important role in this study and the three assemblages (5MT2193, 5MT8371, and 5MT8827) with the smallest number of sherds in the total sample. If these three smaller assemblages do not show sample size effects, then it is extremely unlikely that the data from the three larger assemblages are adversely affected by sample size. Fortunately, the three smaller samples also span the temporal range of the assemblages, so the full range of features is represented. If these smaller assemblages do show sample size effects, I then examine the larger assemblages as well.

I begin this assessment with data that have a direct bearing on my reconstructions of how the plain and corrugated vessels were formed. These data include coil application technique, fracture pattern of plain-surfaced pottery, percent coil overlap, exposed coil height, coil junction depth, spacing of coil indentations, and exposed coil classes. I then turn to data on the firing of the pottery including core color patterns and the presence of fire clouds. Finally, I evaluate sample size effects in data related to the use of the pottery including vessel forms, vessel size, and use-related alterations. In each case, I present the resample data in a series of graphs that show the relationship between relative frequencies (percentages) or mean values and sample size.

Pottery Forming Data

Figure 49 shows the resample data on the frequency of pottery with exposed coils relative to plain pottery, and the abundance of filleted and overlapped exposed coils relative to one another in the three smaller assemblages. Although sample sizes below about 100 sherds produce variable quantities, values are sufficiently consistent above 100 sherds to indicate no sample size effects for these attributes. The frequency of nonrandom fracture patterns relative to random fractures of plain pottery required larger sample sizes (~200 sherds) to reach redundancy, but the total sample sizes appear to be adequate in each of the smaller assemblages (Figure 50).

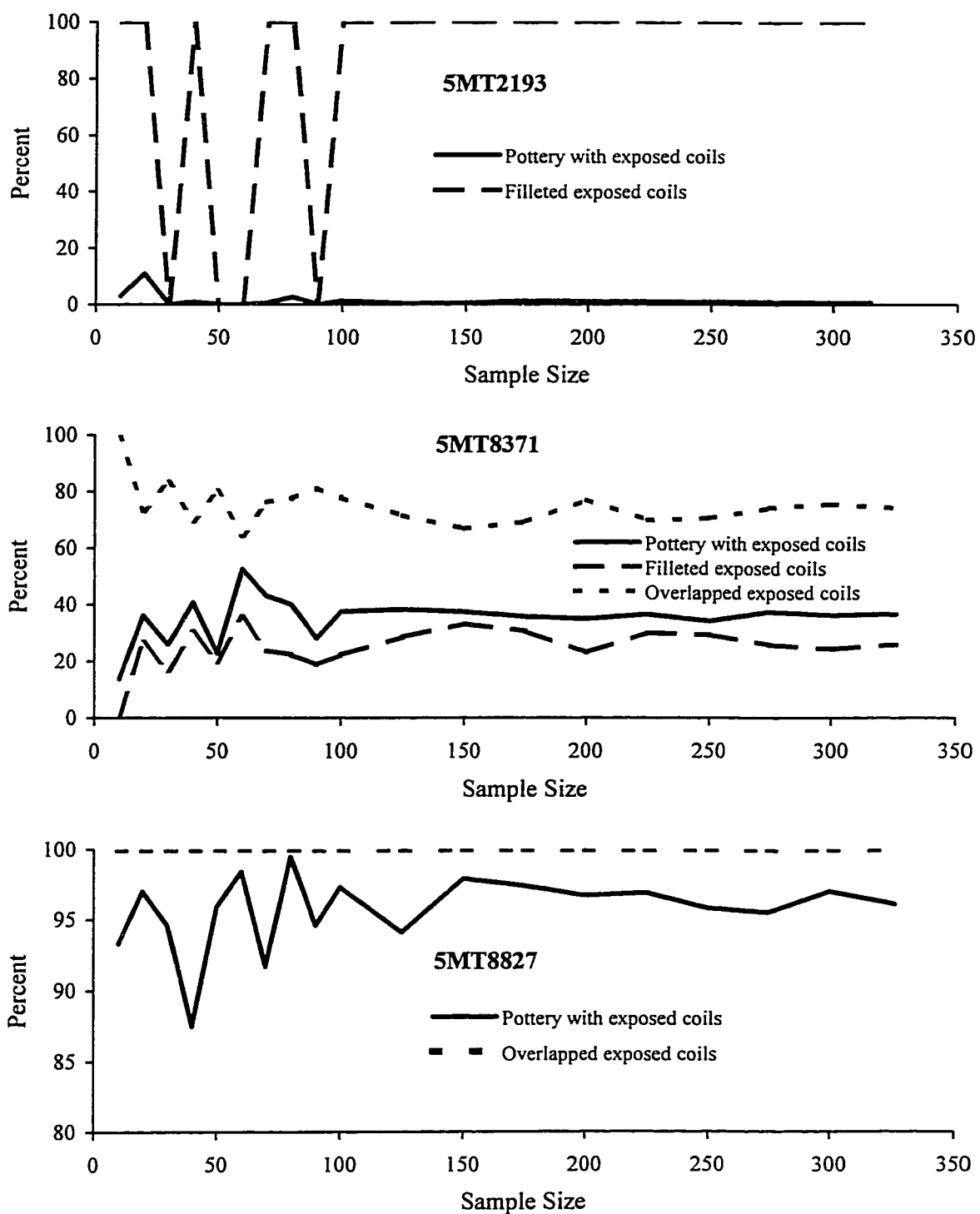


Figure 49. Change in the percentage of pottery with exposed coils, filleted exposed coils, and overlapped exposed coils with increasing sample size in the assemblages from 5MT2193, 5MT8371, and 5MT8827.

The mean values of quantitative measurements on exposed coils shown in Figure 51 also indicate no sample size effects for these data, and sample sizes of 150 sherds were sufficient for their precise documentation. Finally, the resample data on the relative frequencies of different exposed coil classes defined in Chapter 5 also show adequate sample sizes in the three smaller assemblages (Figure 52). Samples of 100 to 150 sherds were sufficient to document the two assemblages very few classes represented. However, the assemblage from 5MT8371, which has the greatest variety of classes, required over 250 sherds to reach redundancy. Even then, a few of the very infrequent classes show some fluctuations in relative abundance indicating possible sample size effects on the quantitative data for these rare classes.

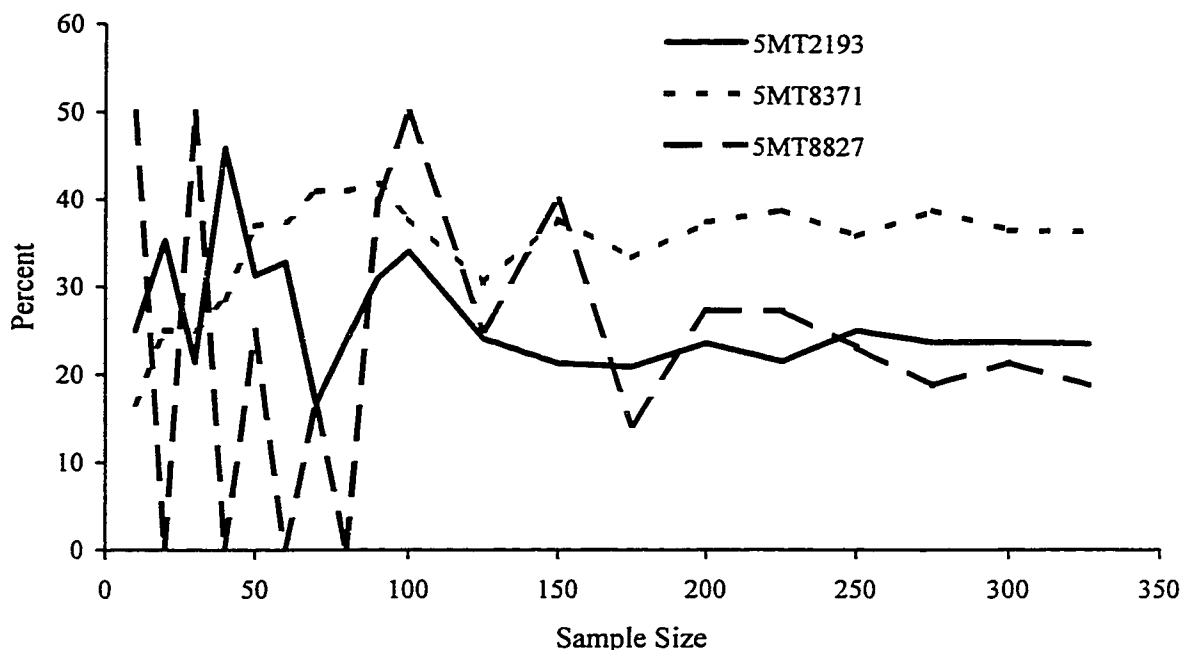


Figure 50. Change in the percentage of nonrandom fracture patterns in plain-surfaced pottery with increasing sample size for the assemblages from 5MT2193, 5MT8371, and 5MT8827.

Pottery Firing Data

The relative frequencies of core color patterns stabilized after a sample size of 150 - 200 sherds in the three smaller assemblages (Figure 53). Some of the more rare color patterns continue to fluctuate slightly in samples greater than 200 sherds, but the proportions appear to be reliably characterized by the total samples. The presence of fire clouds on the exterior and interior surfaces of pottery shows a relationship to samples size that is similar to that seen in the core

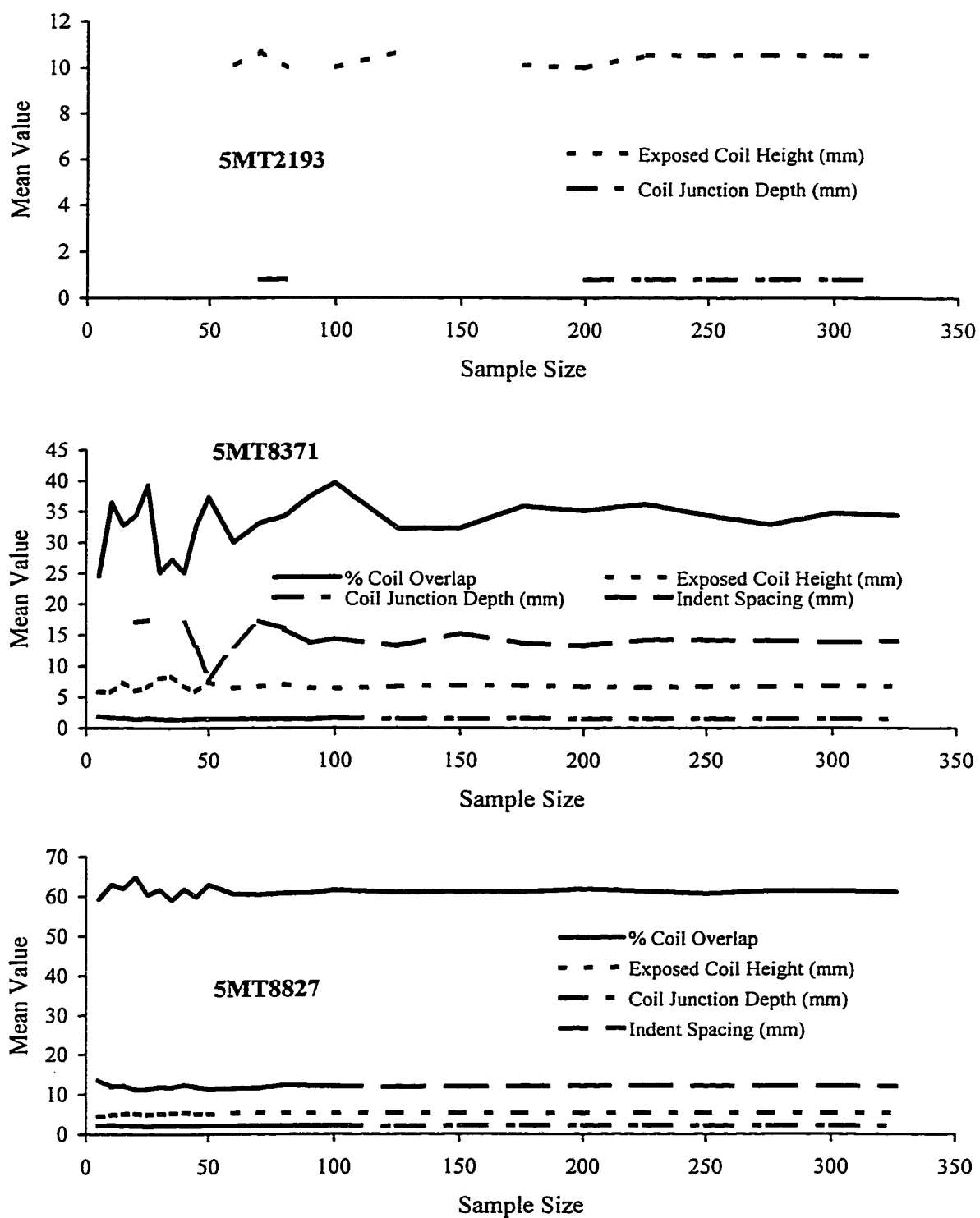


Figure 51. Changes in the mean value of metric attributes of exposed coils plotted against increasing sample size for assemblies from 5MT2193, 5MT8371, and 5MT8827.

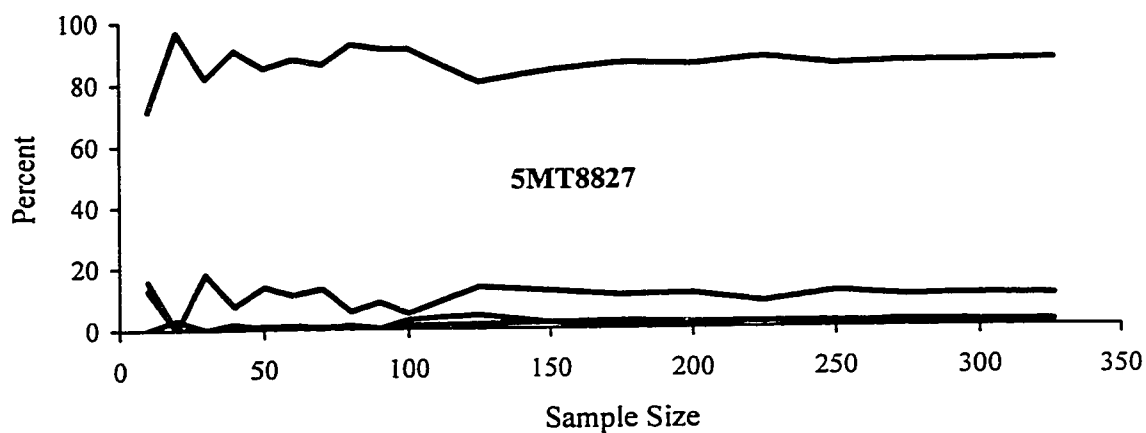
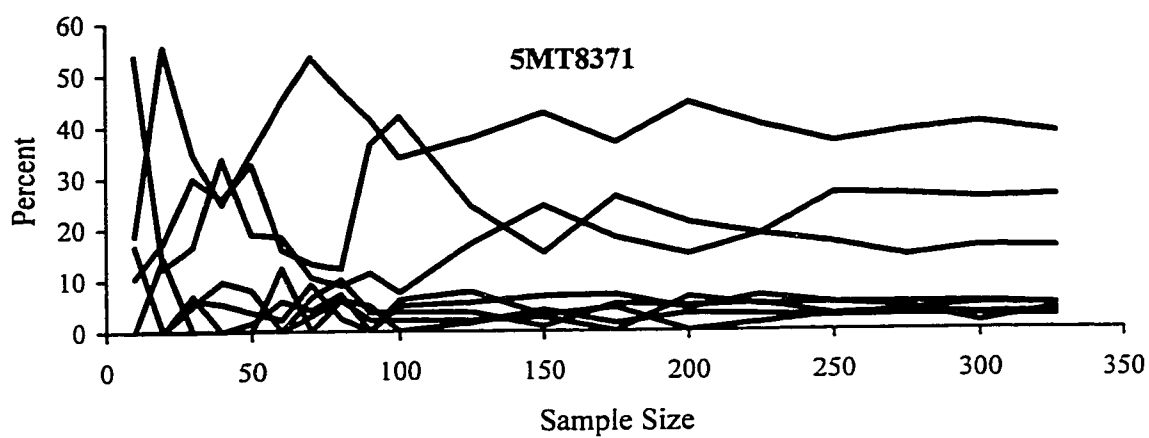
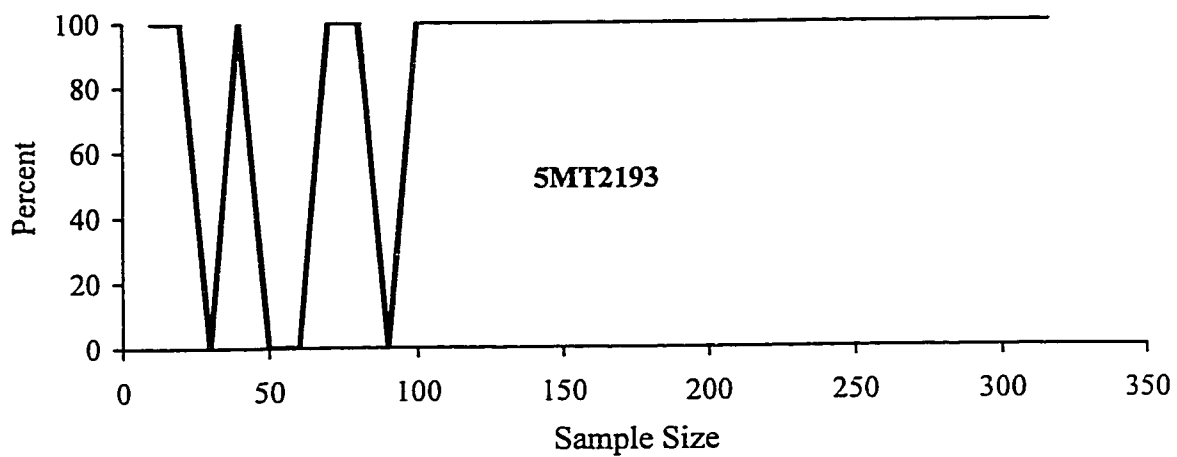


Figure 52. Changes in the percentages of exposed coil classes with increasing sample size for assemblages from 5MT2193, 5MT8371, and 5MT8827.

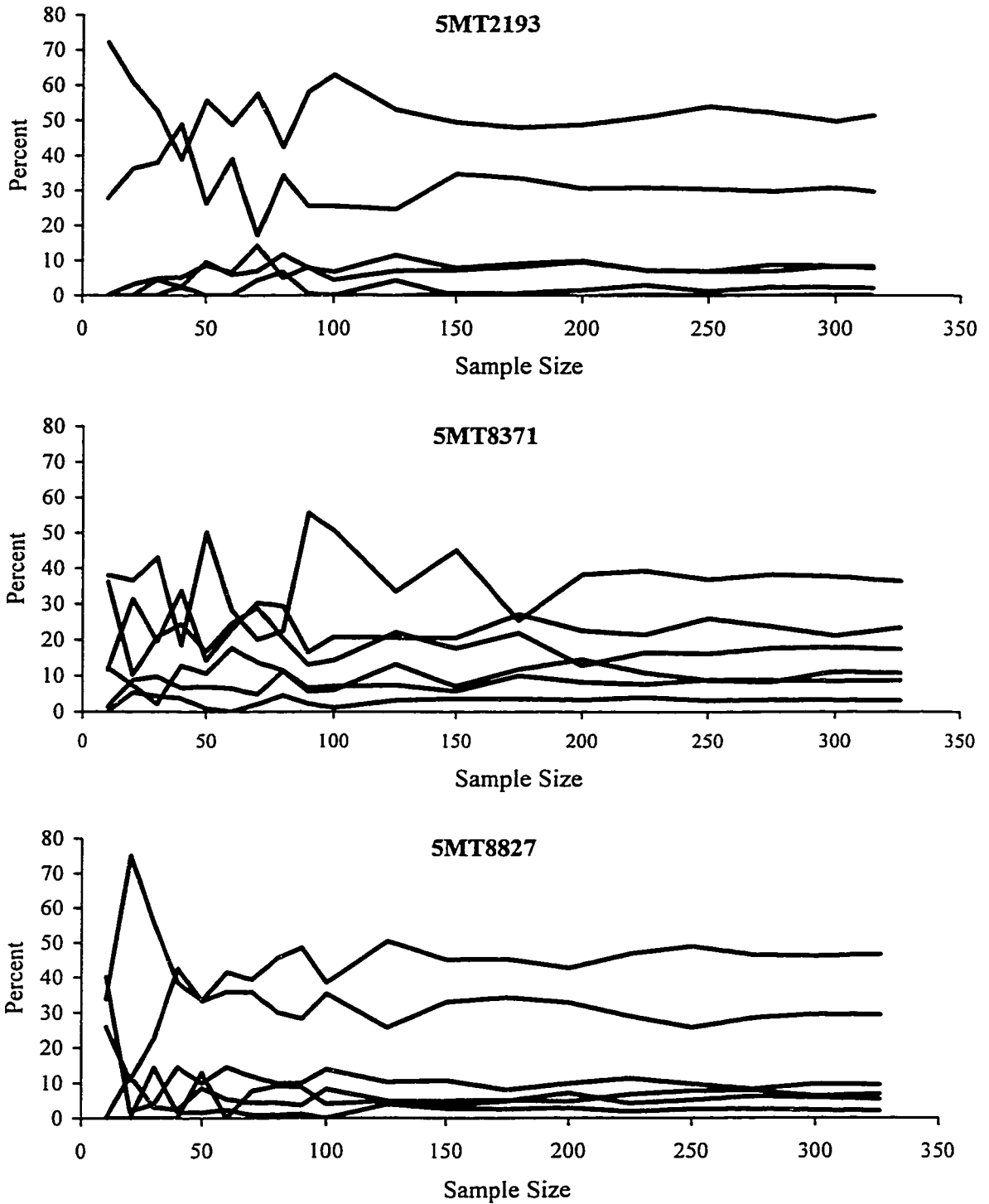


Figure 53. Changes in the percentages of different core color patterns with increasing sample size for assemblages from 5MT2193, 5MT8371, and 5MT8827.

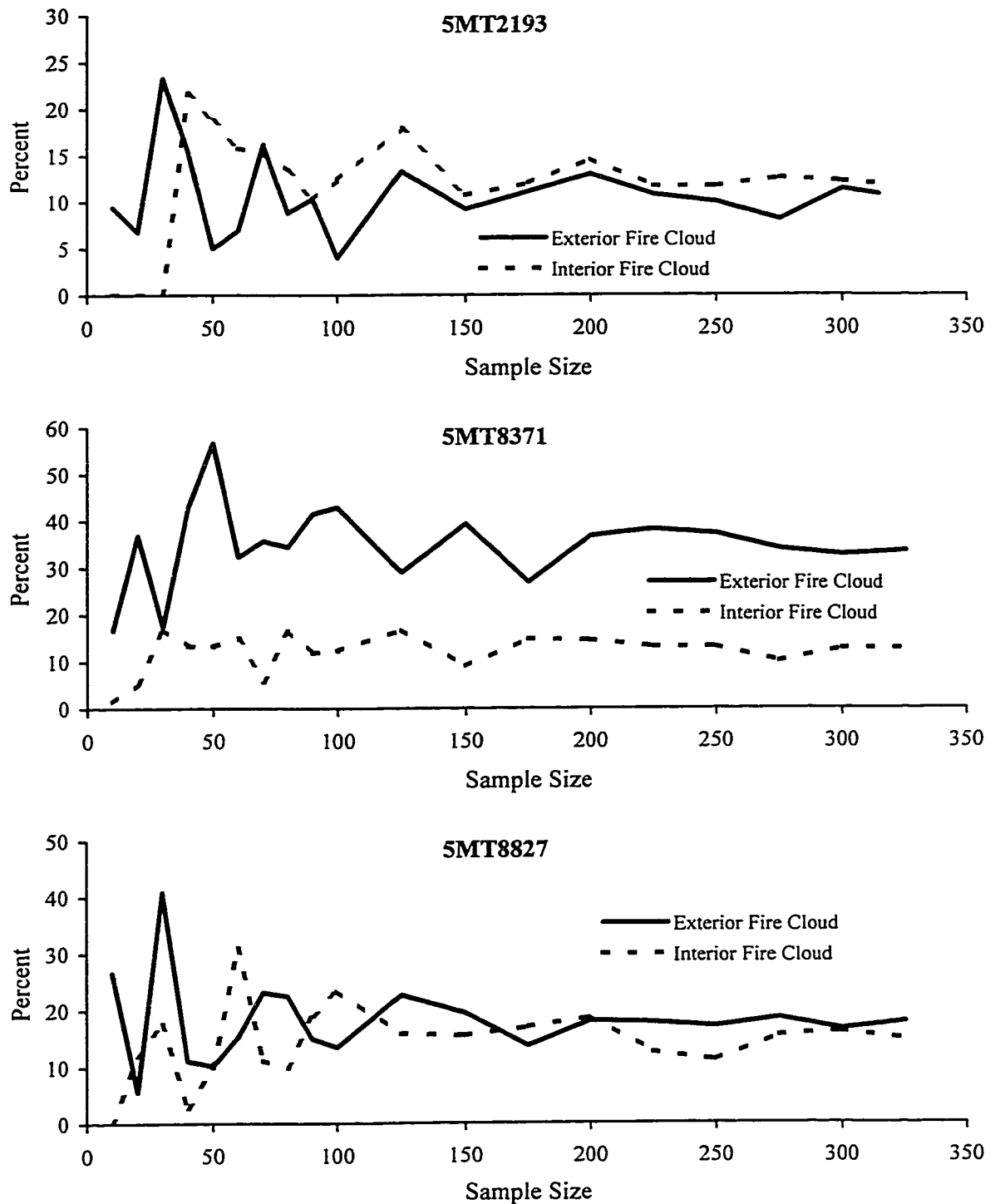


Figure 54. Changes in the percentages of fire clouds with increasing sample size for assemblages from 5MT2193, 5MT8371, and 5MT8827.

color patterns (Figure 54). The proportions of fire clouds become fairly stable in samples greater than 200 sherds, although some slight fluctuations continue. Overall, the effects of sample size on the reliability of the firing data appear to be minimal, except in reducing the reliability of the percentages observed for rare classes.

Pottery Use Data

Information on the use of pottery comes from vessel morphology and use-related alterations. Evidence of the shape and size of vessels is most readily obtained from rim pieces. Consequently, only a small subset of sherds in any sample actually provides useful information on vessel morphology. This can make vessel morphology data particularly susceptible to sample size effects. Only three assemblages, 5MT2193, 5MT4671, and 5MT3868, contained a variety of vessel forms. Only one vessel form occurred in the other three assemblages making sample size effects inconsequential given the large number of sherds analyzed. For the three assemblages with a variety of vessel forms, I compared the relative abundance of different vessel forms to sample size using the two ways of quantifying vessel shape: sherd weight and degrees of rim arc. Subsamples with zero percent for all vessel form categories included no sherds for which vessel form data were generated. Figure 55 presents the results for 5MT2193, Figure 56 for 5MT4671, and Figure 57 for 5MT3868.

The relatively small assemblage from 5MT2193 shows considerable fluctuation in the relative frequencies of vessel forms for both quantification methods throughout the range of sample sizes. In this case, the total sample size does not adequately document the abundance of vessel forms in the assemblage, and consequently, the relative frequencies of different vessel forms are unreliable. However, the rank order of different vessel forms is probably accurately documented because, although the values continue to fluctuate, the lines do not cross one another. The other two assemblages, with much larger total sample sizes, did reach redundancy resulting in reliable relative frequency data. The percentages of vessel forms in the assemblage from 5MT4671 stabilized above sample sizes of 600 sherds, and the values from 5MT3868 stabilized after samples of 1000 to 1100 sherds.

I used the estimated radius of the arc of vessel rims to measure the size of vessels and the degrees of arc covered by the rim segment to quantify abundance. I estimated rim radii in 1 cm intervals with actual values falling between 3 and 22 centimeters. Figure 58 shows changes in the relative frequencies of wide-mouth and indeterminate jars in each of the 1-cm radius intervals with increases in sample size for the assemblages from 5MT2193 and 5MT4671. Figures 59 and

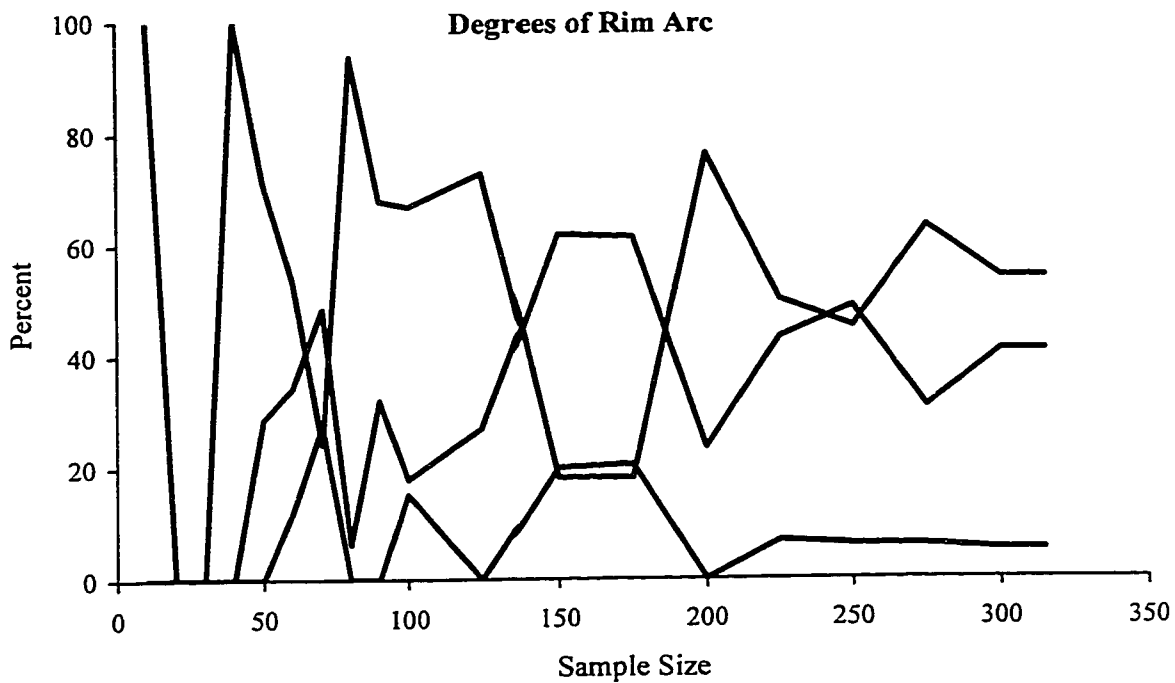


Figure 55. Changes in the percentages of different vessel forms, using two quantification techniques, with increasing sample size for the assemblage from 5MT2193.

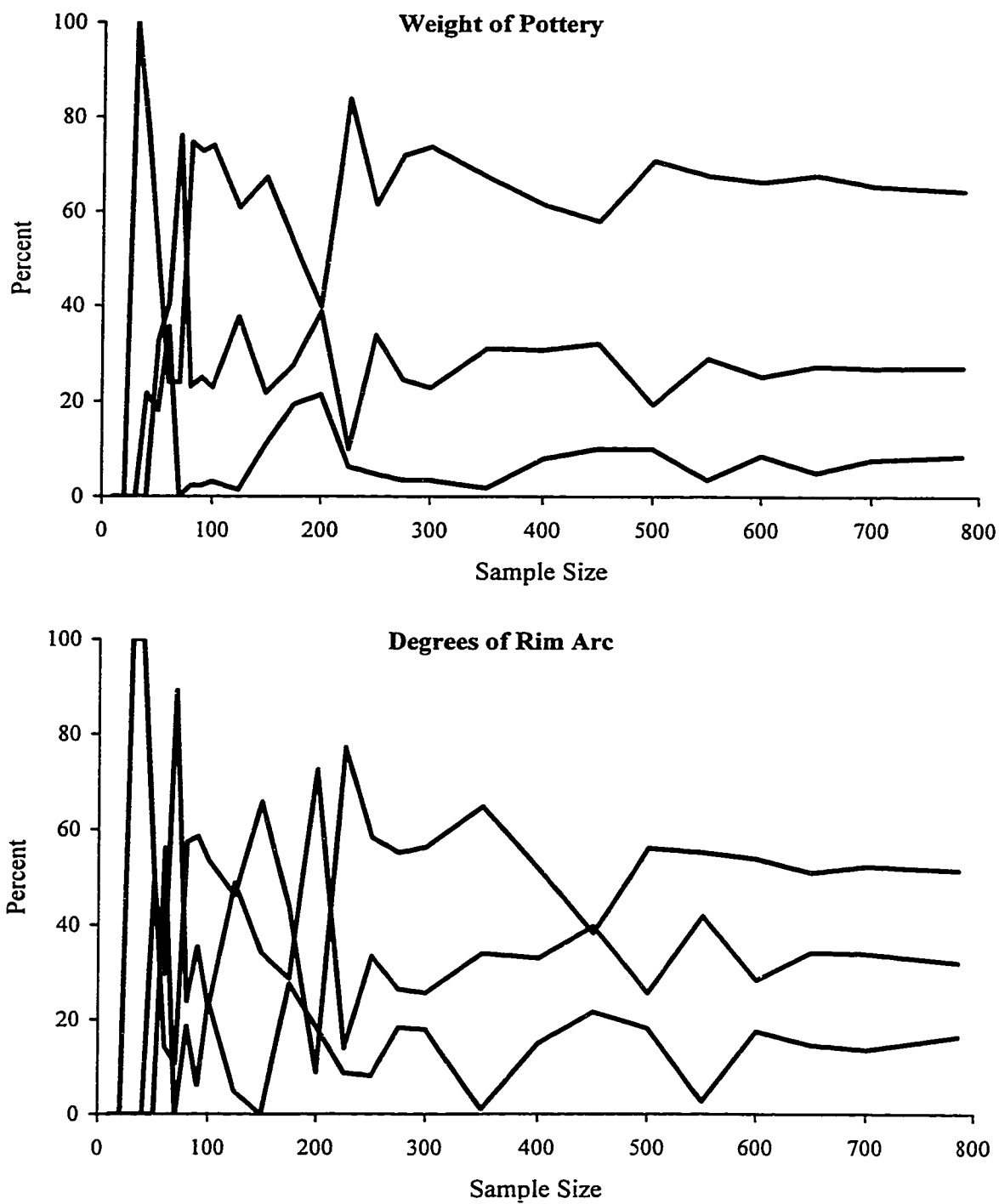


Figure 56. Changes in the percentages of different vessel forms, using two quantification techniques, with increasing sample size for the assemblage from 5MT4671.

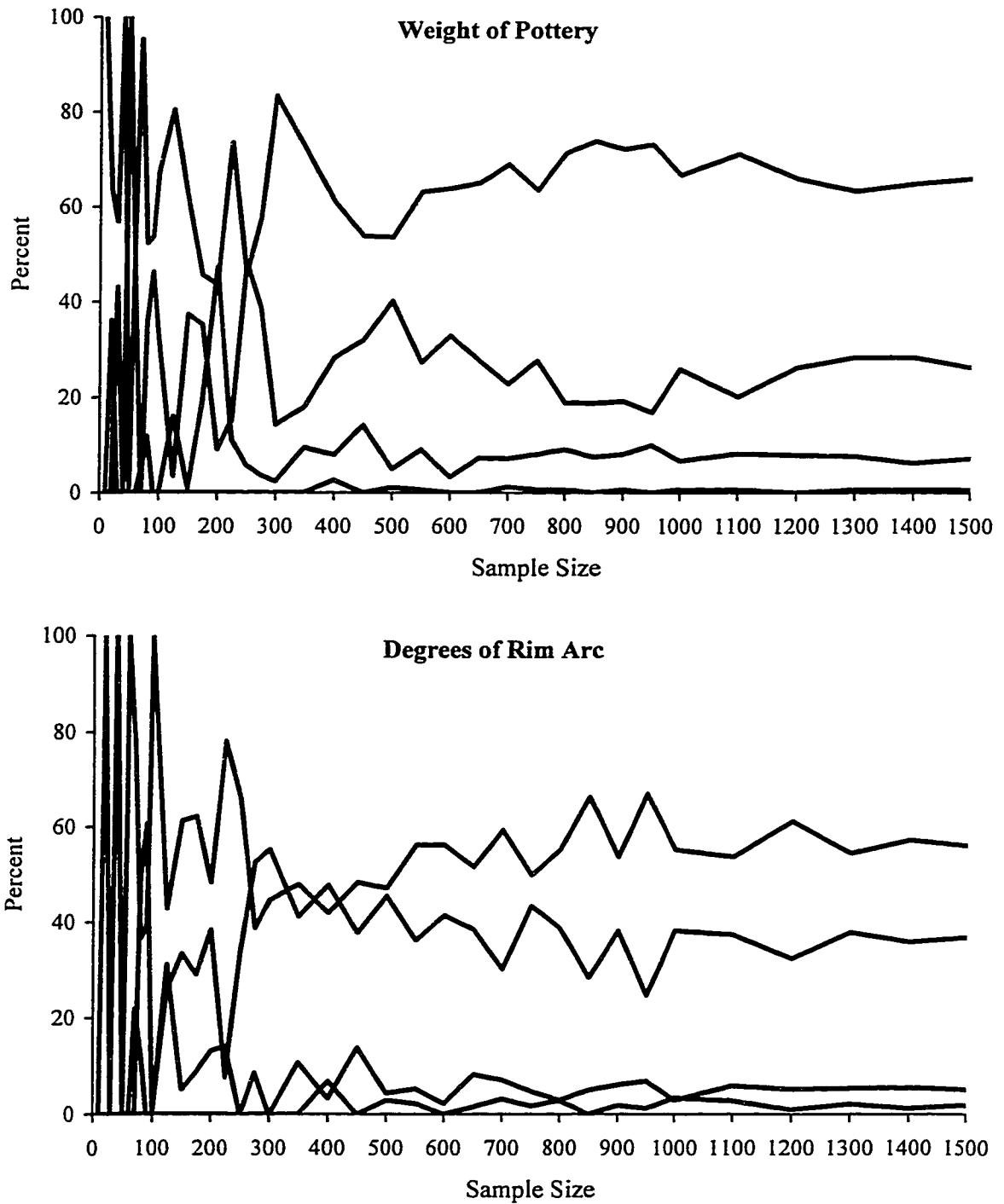


Figure 57. Changes in the percentages of different vessel forms, using two quantification techniques, with increasing sample size for the assemblage from 5MT3868.

60 present the same data for the assemblages from 5MT3868 and 5MT8371, and 5MT1786 and 5MT8827, respectively. In the smaller assemblages, the relative frequencies of different vessel sizes continue to fluctuate over most of the range of sample sizes. Only as resample size come close to the total sample size do the values begin to stabilize. These results indicate that the percentages of pottery in different vessel sizes may be unreliable. However, another possibility is that the 1 cm interval is too fine and falls below the precision of the measurement technique. Consequently, the fluctuations in percentages derive from a combination of sample size effects and measurement error. In two of the larger assemblages, 5MT3868 and 5MT4671, the vessel size values did stabilize, but values from 5MT1786 did not reach redundancy until almost the entire sample was included. Taken together, these results suggest that the data on the relative frequencies of vessel sizes should be used with caution, but the rank orders of different sized vessels is probably fairly reliable.

Finally, the relative frequencies of three forms of use-related alterations—spalling, interior surface pitting—and soot accumulation, are reliably documented with the current sample sizes. Figure 61 shows the changes in percentages of these three attributes with increasing sample size for the three smaller assemblages, 5MT2193, 5MT8371, and 5MT8827. The values in each assemblage stabilized in samples above about 200 sherds.

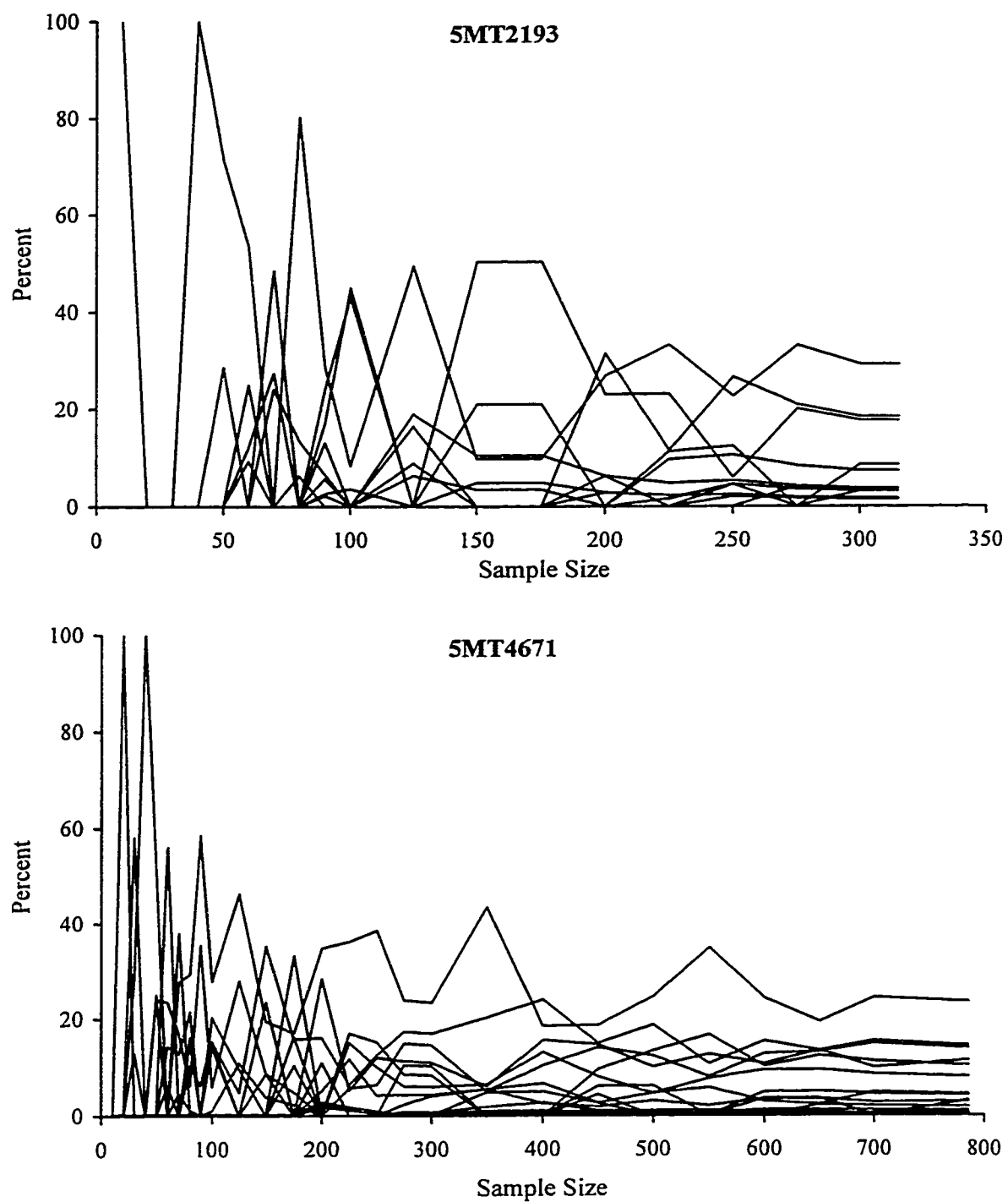


Figure 58. Changes in the percentages of rim radii with increasing sample size for the assemblages from 5MT2193 and 5MT4671.

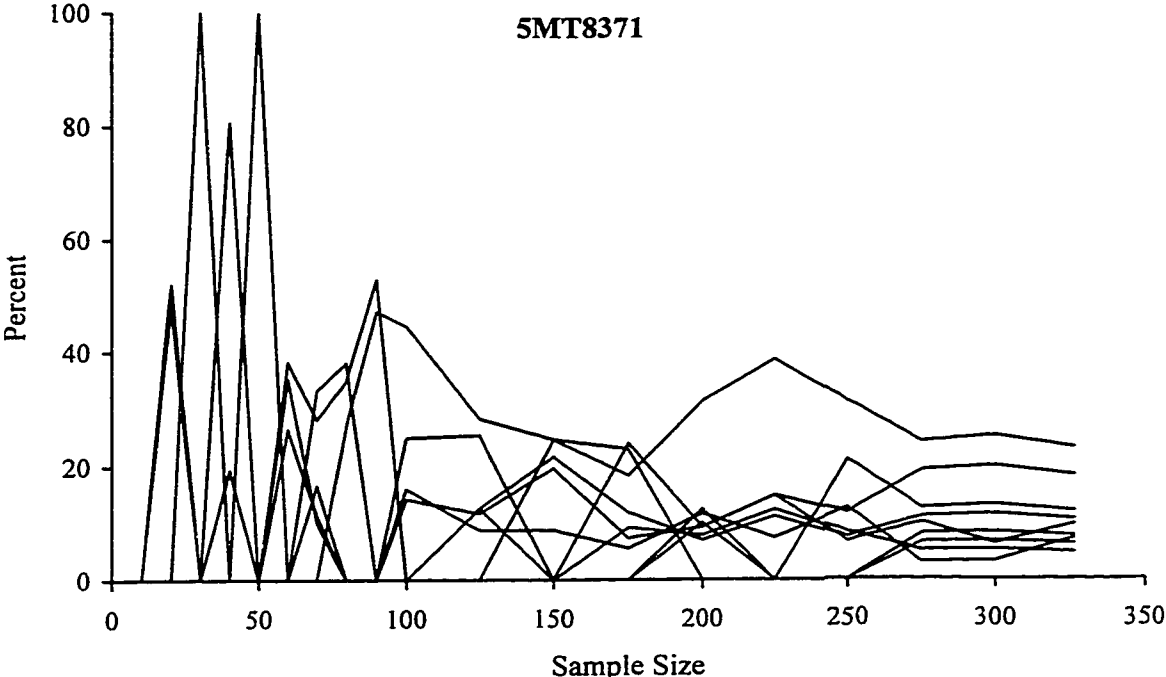
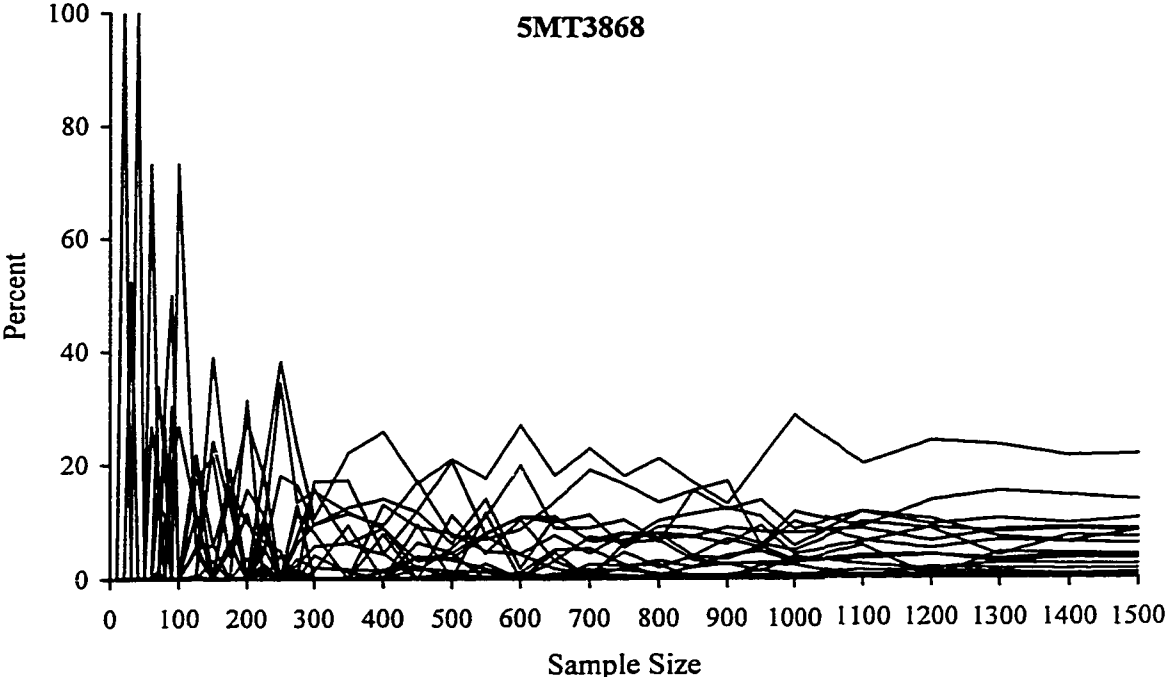


Figure 59. Changes in the percentages of rim radii with increasing sample size for the assemblages from 5MT3868 and 5MT8371.

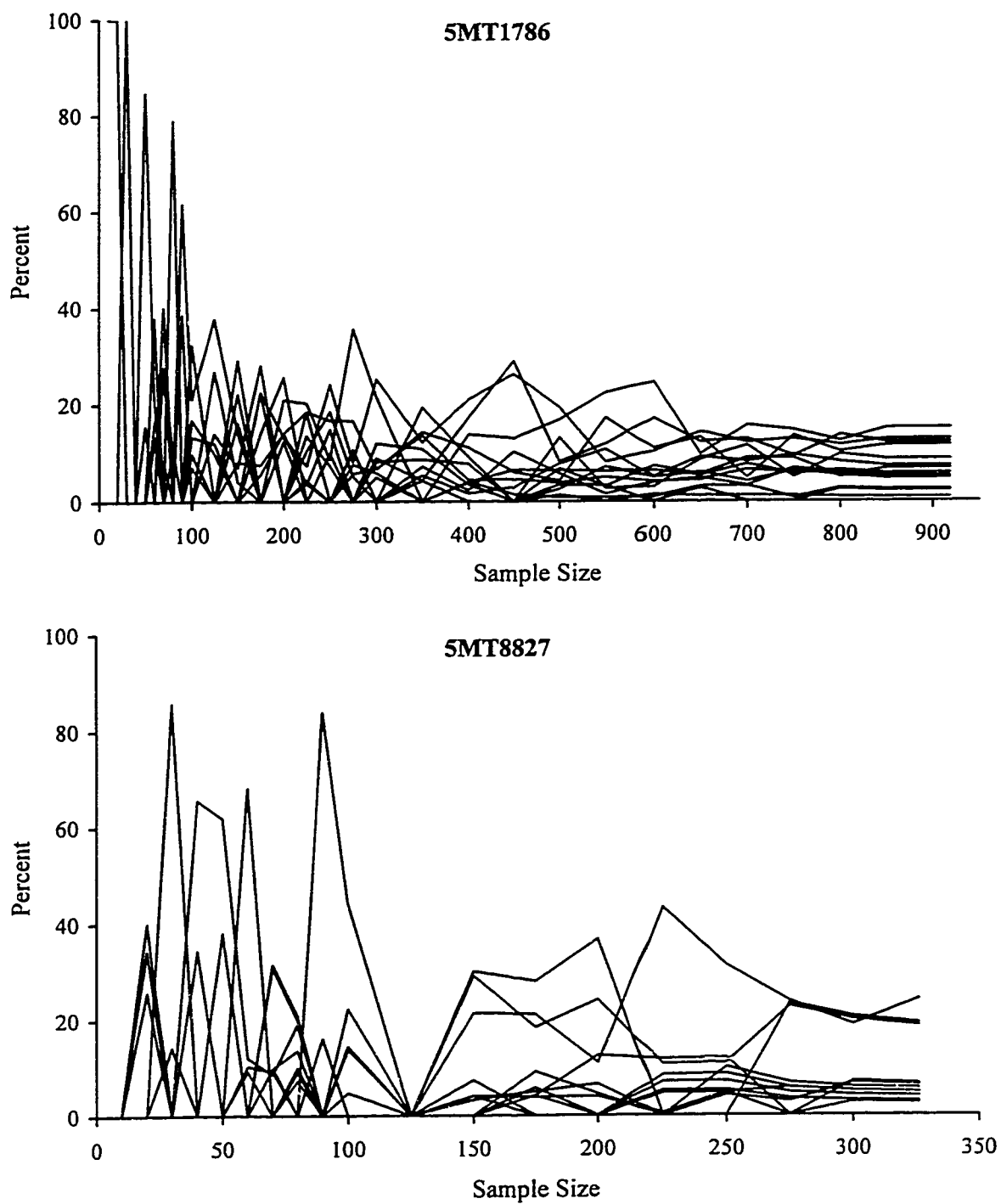


Figure 60. Changes in the percentages of rim radii with increasing sample size for the assemblages from 5MT1786 and 5MT8827.

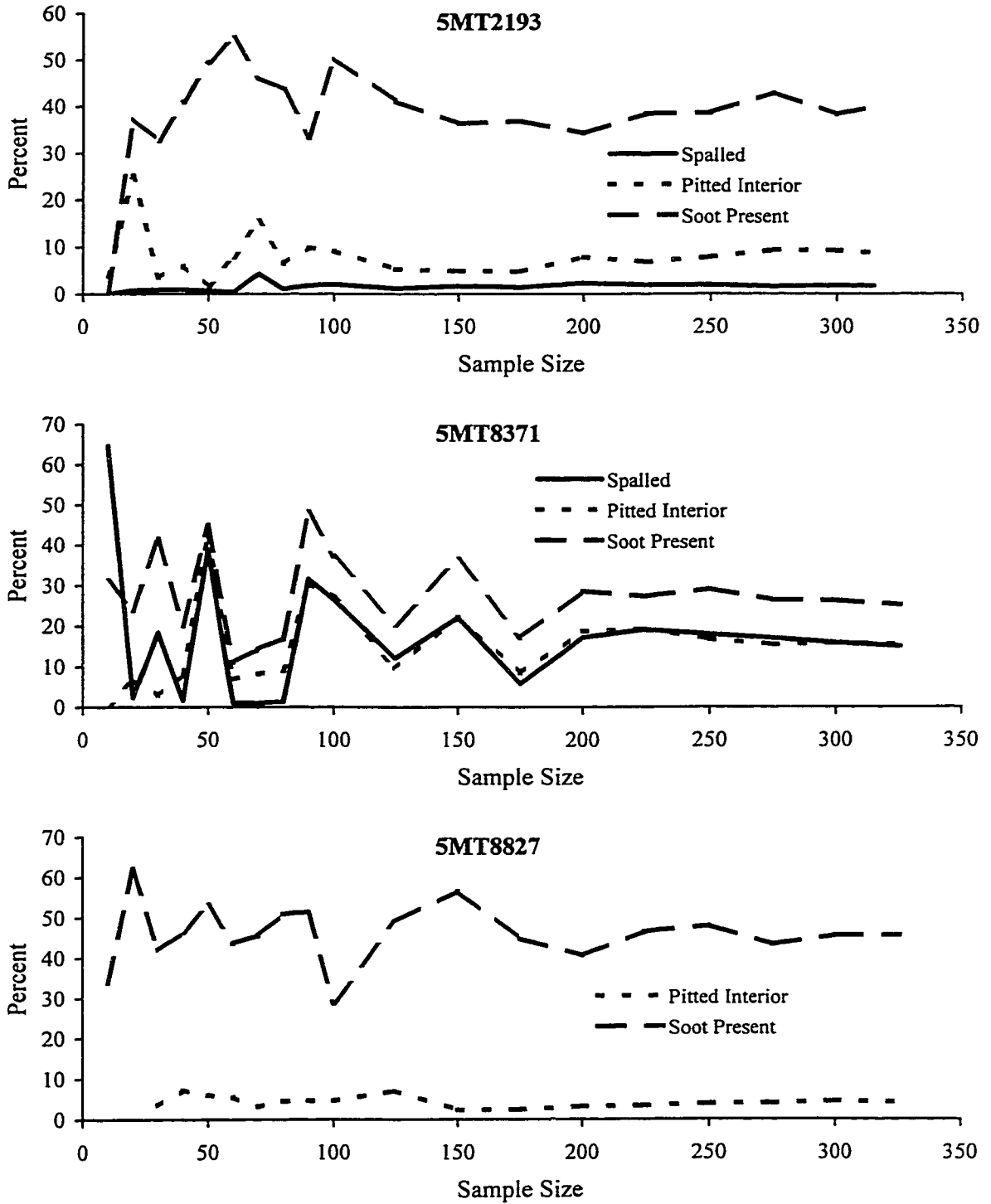


Figure 61. Changes in the percentages of different use-related alterations with increasing sample size for the assemblages from 5MT2193, 5MT8371, and 5MT8827.

VITA

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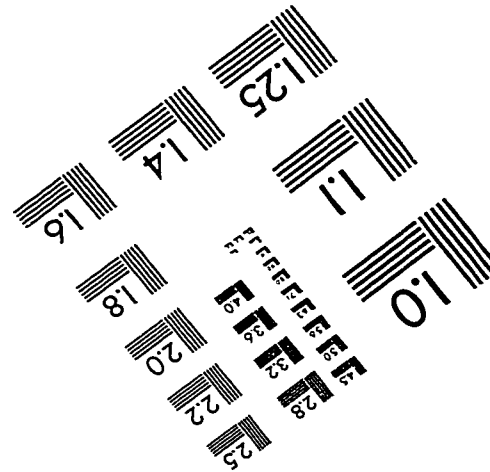
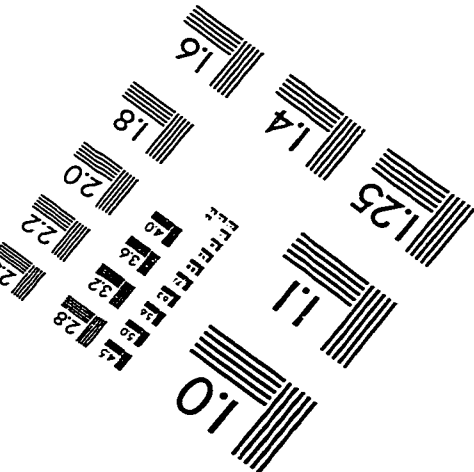
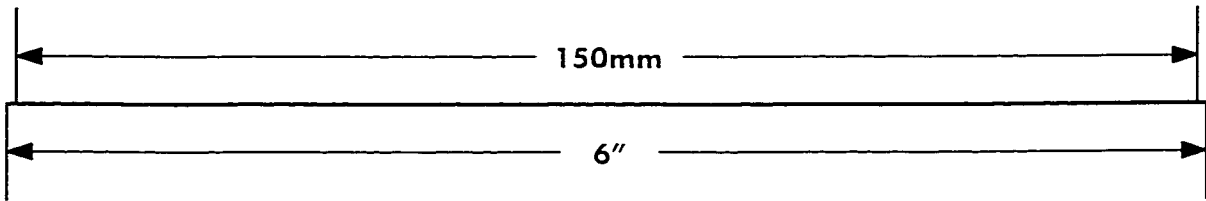
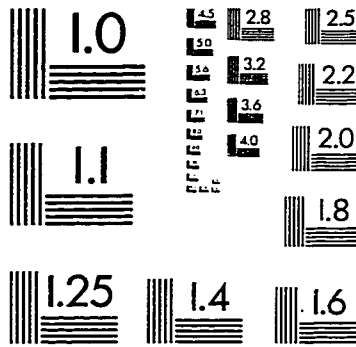
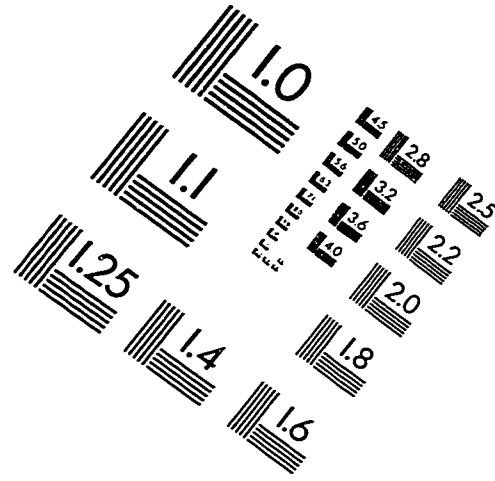
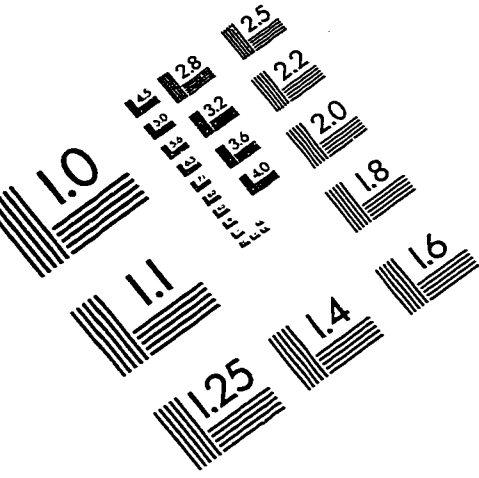
Education

- 1999 Doctor of Philosophy in Anthropology, University of Washington, Seattle.
- 1993 Master of Arts in Anthropology, University of Washington, Seattle.
- 1986 Bachelor of Arts with distinction, University of Nevada, Reno.
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- 1976 Los Gatos High School, Los Gatos, California.

Selected Publications

- 1998 Determining the Fuel Constituents of Ancient Hearth Ash via ICP-AES Analysis. *Journal of Archaeological Science* 25:493-503. (with K. Adams and J. Stewart).
- 1998 Theory, Measurement, and Explanation: Variable Shapes in Poverty Point Objects. In *Unit Issues in Archaeology: Measuring Time, Space, and Materials*, edited by A. F. Ramenofsky and A. Steffen, pp. 163-189. University of Utah Press, Salt Lake City, Ut.
- 1992 Effects of Pocket Gopher Burrowing on Archaeological Deposits: A Simulation Approach. *Geoarchaeology* 7(3):185-208.
- 1989 *Prehistoric Archaeology of the West Sinter Quarry, Cortez Mountains, Nevada*. Technical Report No. 61. Quaternary Sciences Center, Desert Research Institute, Reno, Nv. (with S. Livingston).
- 1988 The Density Dependent Method: Measuring the Archaeological Record in the Northern Southwest. *American Archeology* 7(1):38-48. (with C. Irwin-Williams, S. Durand and P. Hicks).

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