Understanding changes in mobility & subsistence from terminal Pleistocene to Late Holocene in the highlands of New Guinea through intensity of lithic reduction, changing site types, and paleoclimate

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ABSTRACT

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Chair of the Supervisory Committee:

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Anthropology

Why did people in the highlands of New Guinea move from a hunter-gatherer lifestyle and subsistence pattern, and develop a subsistence pattern centered on root and tree crop agriculture? How did the ancient residents of the highlands actually move around the landscape in the late Pleistocene, and how did that change though the Holocene? The research presented in this dissertation addresses these questions through and analysis of intensity of reduction of stone tools, paleoclimate reconstructions, and statistical analyses of regional radiocarbon dates. Competing models of processes driving change are compared against the accumulated evidence, with precipitation and other climate phenomena determined to be the mechanism with the strongest effect driving changes in site use, subsistence, and related technology.

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Dedication:

This work is dedicated to Chris Nygaard, and Tomyris and Tycho Huff Nygaard, who have made this all worthwhile.

Chapter 1. Introduction

In the broadest sense, the research presented in this dissertation is an effort to understand where highland New Guinea archaeology fits into general global models of processes of cultural and technological change. This research employs bodies of theory and analytical methods that have emerged in the decades since the original research on the sites excavated by David Cole in the Eastern Highlands, and the general heyday of highland archaeology in the 1960s and 1970s. The original research was conducted by Cole in cooperation with Virginia Watson and the University of Washington Microevolution Project. This research uses these new bodies of theory and methods to re-evaluate an existing collection that is held in trust by the Burke Museum for the Papua New Guinea National Museum and Art Gallery and the people of Papua New Guinea (PNG) in order to glean new insight into the processes that structure the archaeological record of highland PNG.

Even though the highlands of New Guinea are an independent center of plant domestication, a process of considerable interest to archaeologists (e.g. Bellwood 2005; Denham, et al. 2007; Harris 1996; Kennett and Winterhalder 2006; Yasuda 2002 amongst many others), the archaeological record of highland PNG is relatively poorly understood relative to other portions of the world. This situation is due to a variety of factors ranging from individual research agendas to geopolitics to national and local PNG governmental processes. The consequence of this gap in knowledge is a difficulty in evaluating if and how the trajectory of the PNG archaeological record articulates with models of global processes. As a result, the archaeological record of highland New Guinea is sometimes ignored in discussions of models of the transition to agriculture (e.g. Yasuda 2002) . When it is discussed only the culture history aspects of the development of agriculture, but no explanatory model or mechanism is provided (e.g. Barker 2009).

The pace of new excavations in the New Guinea highlands is profoundly slow, in no small part due to the logistical issues faced in working in the region. However, existing collections – often excavated decades ago – can provide a source of new data and analyses, whether it is through analyzing components not examined by the original researcher (e.g. Mountain 1991), or by applying new methods and new theoretical paradigms that have emerged since the time of the original analyses (e.g. Evans 2000; Evans and Mountain 2005; Gaffney, Summerhayes, et al. 2015). As the archaeological record is a finite, non-renewable resource, re-analysis of existing collections is an ethical act allowing the extraction of more information from cultural materials that have already been removed from the depositional context and adding value to collections that remain the cultural patrimony of descendant populations even if they are held in trust at foreign institutions (Barker 2003). The re-analysis of existing collections and meta-analyses of published data are an effective strategy to "data-mine" existing resources and broaden understanding of the past without putting a shovel into the ground.

The bulk of archaeological investigations for the highlands of New Guinea were conducted in the post-WWII to mid-70s period (a partial list includes: Bulmer 1964; Bulmer 1966; Bulmer 1975; Christensen 1975; Golson and Hughes 1980; Golson, et al. 1967; Watson 1976; Watson and Cole 1977; White 1967, 1969, 1972, 1977; White and Thomas 1972 and others). These pioneers were responsible for laying the foundations of understanding the culture history of the region. Archaeological research in this region is confounded by the poor preservation of organic artifacts typical of high-rainfall tropical areas (e.g. Cronyn and Robinson 1990; Kibblewhite, et al. 2015). As a result, the full scope of socio-economic activity for the region, especially as it pertains to plant materials and also faunal remains at open sites, is still not well understood. Lithic artifacts are one of the main sources of information about the archaeological past of highland New Guinea. Typology – of artifact or of attribute – was the dominant method for lithic analysis during the time period of the original analyses (Bulmer 1966; Bulmer 1975; Evans 2000; Watson 1976, 1995; Watson and Cole 1977; White 1967, 1968, 1969, 1972, 1977; White and Thomas 1972) . As Evans (2000:99) notes, typology in the different iterations in which it was deployed has been a less than satisfying tool for drawing out past patterns of artifact variability, and consequently, it has been difficult to link changes in the archaeological record to larger patterns of subsistence, mobility, cultural change, etc.

The research presented here seeks to test a model of linear gradient of "settling down" versus models of mobility and sedentism that reflect a relationship to environmental changes and constraints in the archaeological record of highland Papua New Guinea from the late Pleistocene (~20kya) through the Holocene. These alternative models are constructed using different lines of paleoclimate data and the concept of risk as a motivator for changing mobility as a part of changing subsistence and other demands. These models are evaluated with lines of evidence drawn from data from a new quantitative analysis of the lithic assemblages from three different sites in the Eastern Highlands province of Papua New Guinea, and with the results of a summed probability distribution (*SPD*) analysis of changing site types based on radiocarbon dates from all of the highlands. This research explores three lines of evidence: a meta-analysis of published radiocarbon dates, a synthesis of recent paleoclimate data, and a new analysis of three archaeological assemblages that were excavated in the 1960s from the Eastern Highlands of PNG by Cole, and which are held in trust for Papua New Guinea by the Burke Museum.

Structuring explanation and research questions:

Three key questions form the structure by which the data and models presented in this research are evaluated. In the opening chapter of the edited volume *Hunter-Gatherer Behavior: Human response during the Younger Dryas*, Eren proposes three questions that need to be answered in order to make a robust argument for environmental change to be demonstrated to be a determining factor in the behavior of past peoples (2012). While Eren's work specifically focuses on hunter-gatherers and the Younger Dryas, the questions are of a nature to be broadly applicable to a variety of lifeways and subsistence practices. The questions are:

1. If … climate change is influencing culture change, then there should be evidence of both environmental and culture change.
2. Assuming evidence of climate and cultural change is demonstrated, if … climate change is influencing cultural change, there should be tight temporal covariance of climatic/environmental events with behavioral changes.
3. Assuming the covariance of … climate and culture change is demonstrated, if climate change is influencing culture change, then there should be evidence falsifying other possible influences of culture change. (excerpted from Eren 2012:13-17)

These questions are not limited to questions of subsistence, and can be employed to benchmark a variety of theoretical approaches in material culture change relative to environmental change. Moreover, these questions are particularly straightforward to apply as a framework for understanding human-landscape interactions that drive changes in the archaeological record of highland PNG, understanding that humans are agents of some types of environmental change (Haberle 1993, 1996, 1998, 2007; Haberle and David 2004; Haberle, et al. 2001; Haberle, et al. 2012) , and the relationship between people and the landscape they inhabit is an iterative one. In the concluding chapter, the models defined below will be assessed using the data presented in subsequent chapters using these questions to determine which model has the most robust explanatory power for changes in site use, subsistence, and related technology in the highlands of Papua New Guinea from the terminal Pleistocene through the Holocene.

Risk and uncertainty as mechanisms of change in the archaeological record of highland PNG:

Risk can be a mechanism driving change in behavior and therefore patterning of the archaeological record. However, before risk can be used to generate models of potential outcomes, it must first be defined. The plain language definition is the "possibility of loss or injury" (Merriam Webster 2015b). However, there have been more specific definitions relative to models of the archaeological record offered that are necessary to understand for the construction of robust models. Winterhalder et al. define risk as an "unpredictable variation in the outcome of a behavior, with consequences for an organism's fitness or utility" (1999:302). Drawing on behavioral ecology, these authors use dietary shortfalls for example as negative outcomes that will drive adaptation of behavior to minimize the probability of the negative outcome (of presumably starving to death). Winterhalder et al. specify that *risk* is a *distribution of probability of outcome.* For example, if a hunter is trapping rabbits they probably have a good idea of the range of the sizes of rabbits they are likely to trap during a given part of the year, but they don't know exactly what size rabbit they will catch in any specific single trapping event. The nature – range, central tendency, the population size, etc. – of that distribution may be better known or more poorly known; this lack of knowledge about the true range of the distribution of outcomes (rabbits in our example) is defined as *uncertainty*. The *risk* – the distribution of the outcome – can be better understood through tactics such as gathering information (is there lots of good rabbit forage nearby? have other rabbits recently trapped been large or small? have traps been often successful, or have there been few rabbits caught?) that reduces *uncertainty* about the range of the distribution, but that *risk* – the distribution of possible outcomes – remains until some event (e.g. the rabbit is trapped) occurs, wherein the distribution of possibilities collapses into an outcome – in our example either the hunter traps a rabbit, or perhaps starves to death (1999).

In his discussion of mechanisms driving technological change, Fitzhugh uses a similar definition of *risk* as "variance in outcomes due to uncontrolled parameters" although the inclusion of negative outcomes or "*probability of loss"* in this definition is rejected (2001:134). In service of his exploration of invention versus innovation in which his discussion of the definition of *risk* is embedded, Fitzhugh seeks to separate out the sources of variability in technology from evaluations of the adaptive utility of various choices in technology once they are invented. Bamforth and Bleed note that technology is featured heavily as an adaptive response to risk whether by reducing costs or especially by reducing failure possibilities (1997). Torrence includes the individual human's perception of a problem for which technology is a solution, not just the variability in opportunities as defined by environmental constraints (1989). She employs a stochastic variability in outcomes of a behavior in the definition of *risk* employed in her discussion about lithic technology, and directly links subsistence risk to "failing to meet dietary requirements" (1989:59). Additionally, Torrence asserts that "subsistence patterns are geared to the variation in time and space of desired resources" and that "(t)he extent to which each type of subsistence pattern can successfully control variability in the availability of resources defines the quantity and quality of risk involved" (1989:58). Torrence goes on to directly link the "form and severity of the risk" associated with subsistence strategies to variability in stone tools (1989:58).

Many of these discussions of risk employ the same sigmoid curve describing the risk-proneness or risk-adverseness of a hypothetical actor, with risk-proneness falling on the lower concave portion of the curve, with an inflection point to risk-averseness on convex portion of the curve where needs are met with a high level of predictability. For the models presented in my study, "reducing the likelihood of negative outcomes" is a good working definition of *risk mitigation*, even if it does not capture the fine-grained differentiation between the mechanisms of invention, innovation, and adoption explored in Fitzhugh 2001.

The lack of capacity to explore invention, innovation, and adoption is a practical constraint due to the coarse-grained and geographically spotty nature of the known archaeological record in the highlands of PNG. The absolute first instance of a major subsistence change such as “adoption of agriculture” has probably not been captured in the total of two known agricultural archaeological sites (e.g. Denham, Golson, et al. 2004; Denham, Haberle, et al. 2004; Denham, et al. 2003; Golson and Hughes 1980; Golson, et al. 1967; Muke and Mandui 2003). That the very first and oldest agricultural behavior has probably not been captured yet is not an indictment of the rigor of the scholars who have contributed so much knowledge on the subject, but rather an observation about the rate of destruction of archaeological sites and the statistical unlikelihood that the one known site with significant time depth – Kuk – is actually the very first expression of agricultural behavior ever. While there is abundant evidence for management of the landscape for example through burning that predates and continues after the regional invention of agriculture (Denham, et al. 2003; Haberle 1993, 1996, 1998, 2007; Haberle and David 2004; Haberle, et al. 2001), it would be extremely surprising for there to be major chronological revisions to the earliest signals of cultivation and agriculture relative to the timeline established at Kuk.

A major driver of variability in resource availability in the highlands of New Guinea is, like in many places, climate, specifically precipitation, but also other El Niño Southern Oscillation (ENSO) effects such as frosts that can damage plants important to subsistence. While Pacific basin phenomena such as the Pacific Decadal Oscillation (PDO) has some secondary effects affecting ENSO, ENSO itself is the strongest climate cycle affecting not just Pacific climate, but global climate regimes (Mantua and Hare 2002; Rasmusson and Wallace 1983). ENSO droughts cause a multitude of negative effects, including the possibility of death from dehydration from water scarcity. Droughts in the highlands related to ENSO activity are known to cause substantial economic upheaval and public health catastrophes including failed crops, displacement of people due to food shortages, the destruction of wealth in the form of extermination of domesticated animals (i.e. pigs) which can neither be maintained nor turned loose as they will compete for now-essential wild resources, disease and mortality of people due to food and water scarcity, and others (Haberle 2000; Nicholls 2000; Allen 2000; Bourke 2000). Droughts cause direct hazards – water scarcity – and indirect increases in risk – the increased likelihood of crop failure. Currently there is a huge international scientific effort to more accurately model the variabilities of frequency and intensity of ENSO events. While there is currently a large and growing body of literature on cultural flexibility and limits to accommodations to climate change (e.g. Adger, et al. 2009; Adger 2003; Jolly and Berkes 2002) , we cannot fully retrodict what cultural resources and limitations past people would have brought to bear to dealing with ENSO events. Oral history would have provided some information regarding the range and variability in environmental conditions over a few lifetimes that would form the data used to estimate risk of frosts and droughts that then construct the risk associated with resource availability, or the direct risk of water shortages driving the risk of associated disease and death (with likely a high level of *uncertainty* regarding any particular annual cycle).

Models:

Drawn from an overview of existing research, the first model of change in subsistence – with attendant changes in site use, mobility, and technology – is a generic gradual model of "settling down." This model may be appealing for describing the chronological variability in the very coarse-grained archaeological record, from high mobility forager (*sensu* Binford) lifestyle giving way to decreased residential mobility and eventually the adoption of agriculture, but it relies on implicit assumptions of the benefits of reduced residential mobility, resulting in evolutionist circular reasoning: People adopted the adaptations of reduced residential mobility and resource intensification because they are advantageous (Binford 1980). They are demonstrated to be advantageous by the fact that people adopted these strategies. While perhaps being useful for a general description, the gradual model is devoid of any explicit explanatory mechanisms addressing *why* any given change in behavior is more or less advantageous. The forcing mechanism of the gradual model may implicitly be population growth, demic pressure, and associated territorial circumscription, but these factors should be supported by explicit positive evidence of population growth to construct robust explanation from this model. According to this model, we should see no major inflection points in changes in sites of different types, and subsistence and related technology should gradually change without any major transitions.

Flowing from observations about ecological changes, a second model can be hypothesized: that subsistence change followed major ecological shifts. From this model, changes in site use, subsistence strategy, and associated technology should closely trail major ecological changes that would constitute major changes in resource opportunities – plant and/or animal resources on the landscape. Through decades of palynological reconstructions, Haberle and others have developed a chronology of changes in the vegetative landscape (synthesized in Haberle 2007) through which they have also interpreted changes in the temperature and precipitation regimes (e.g. Haberle 1998, 2007). Through anthropogenic burning, expanses of closed forest have been converted to grasslands, with implications for increased sedimentation in the valley floors and transitions in valley floor vegetation regimes (Haberle 1993, 1996, 1998, 2007; Haberle and David 2004). This model links changes in subsistence and attendant changes in mobility and technology to resource opportunities, but it is somewhat unsatisfactory because the lack of robust archaeobotanical material in the archaeological record (versus the ecological record), and limited archaeofaunal evidence (e.g. Mountain 1991) – both linked to preservation issues – leaves an open question as to what the specific plant or animal food resource constraints were. Nonetheless, this model provides an environmental mechanism altering the opportunity and risk landscape that generates the impetus for change.

A third model posits that changes in precipitation dramatically changed the risk landscape with periods of reduced overall precipitation driving changes in subsistence-related behavior. This third model differs from the second model in that the second model is contingent on shifting ecological communities based on larger trends in climate; the mechanism of the third model is that people responded to seasonal crises linked to desiccated landscapes and critical food source failures due to ENSO-driven frosts and droughts. This model differs from the ecological shift model in that change in human behavior is not a response to the slow pinch of shifting landscapes, but rather a problem-solving strategy for coping with catastrophic seasons of inadequate drinking water and decimated resources. Dewar (2003) hypothesized that the availability of domesticated root and tree crops would reduce risk driven by rainfall variability, which in turn drives the availability of critical resources. This model has the added benefit of a more specific mechanism for change – water shortages and wild plant failures – when compared to the other models. While there is still a paucity of data on the wild plants that constituted the diet of past highland residents, the impact of droughts and frosts from ENSO events on modern plant and animal populations both wild and domesticated are well-known (e.g. Allen 2000; Bourke 2000; Haberle 2000; Nicholls 2000), and failure of these same plant types in the past in similar conditions can be assumed. In this model, changes in site use, subsistence strategy, and associated technology should be tightly chronologically linked to changes in precipitation.

Predictions and tests:

No single line of evidence is conclusive for testing our models against each other. It requires bringing the multiple lines of evidence together to conclusively differentiate between the proposed models (see table 1-1). These will be revisited in the concluding chapter to evaluate the models.

Table 1-1: table of predictions for evaluating models.

MODEL PREDICTIONS	**model 1 - gradual change**	**model 2 - ecological change**	**model 3 - climate change**
lithics			
NFX	highly mobile, general purpose site	highly mobile, general purpose site	residentially sedentary, general purpose site
NBZ	highly mobile, special purpose site	highly mobile, special purpose site	highly mobile, special purpose site
NFB	residentially sedentary, general purpose site	residentially sedentary, general purpose site	residentially sedentary, general purpose site
SPD	EITHER no change in proportions of site types OR site type proportions change with no relationship to ecological or climatological changes	a) proportions of site type use change AND b) changes are closely associated with ecological changes as determined by palynological record	a) proportions of site type use change AND b) changes are closely associated with climatological changes esp. changes in ENSO, general drying
other lines of evidence	any changes have no chronological relationship to ecological or climate changes	any changes are closely associated with ecological changes as determined by palynological record	any changes are closely associated with climatological changes esp. changes in ENSO, general drying

There are two major lines of evidence presented here that are relevant to questions of mobility: patterns of site types through time, and patterns in the lithic assemblages of the three sites explored in this research. Changes in mobility are relevant to understanding how people respond to shifting opportunities and the possibility of poor outcomes. Moving to a location with more favorable circumstances is a primary method for mitigating risk. As Kelly notes, “mobility is universal, variable, and multi-dimensional” (1992:43). While there are any number of dimensions to mobility, and associated models and bodies of theory to understand them, when considering the low-resolution data of the archaeological record of the highlands of New Guinea, one of the earliest robust models – Binford's forager-collector spectrum – is a useful tool (1980; also Fitzhugh and Habu 2002).

The central premise of Binford's collector/forager spectrum is to differentiate between groups who move around the landscape as a whole, who "map onto" the available resources from groups who are tethered to a specific resource or location for their primary residential location, but who send logistical groups out onto the broader landscape to bring resources back to the main camp (1980). Kelly describes this as a difference between moving the consumer to the resource, or the resource to the consumer (1992). Different rates or modes of mobility and different site uses will impact the structure of the attendant tool kit and the archaeological records of the sites in question (Binford 1980).

The forager/collector spectrum was never intended by Binford to be a typology, rather it is intended to help the archaeologist think about how mobility and sedentism structure the archaeological record (Binford 1980; Kelly 1992). Kelly explores many of the dimensions of mobility, and potential archaeological correlates such as the distribution over large geographic areas the differential concentration of formal tool types (1992). Unfortunately most of these correlates are not available in the highlands of New Guinea either because of the coarse-grained nature of the archaeological record, or because of the very few formal tool types (e.g. adzes and axes) that are available for this sort of regional analysis. However there are some behavioral correlates especially around site types that are available. Large open sites with large round circles of poles with hearths inside and ceramic remains are easily understood to be houses with fairly long-term occupations based on the nature of the archaeological assemblage contained in the site (e.g. Watson and Cole 1977). Sites that consist of mounds, ditches, and manuports proximal to these features that are located in swamps are not understood to be living sites as they lack domestic refuse. They do have features that would indicate managing irrigation and other microclimate features that would encourage the growth of specific plant species, and can therefore be understood to be agricultural sites (e.g. Denham, Golson, et al. 2004; Denham, Haberle, et al. 2004; Denham, et al. 2003; Golson and Hughes 1980). However, the nature of the residence tenure and use of rockshelters and of open sites without obvious house structures is less obvious and requires careful analysis to make an effective argument about their position in the cultural and subsistence patterns of past groups.

The Binfordian forager/collector paradigm is especially useful in the case of highland PNG because it can be used to generate predictions about changes in the patterns in the archaeological record that are durable in the tropical setting – especially around the production of stone tools. Kuhn (1990, 1991, 1993, 1994) and Clarkson (2002, 2004) have developed and implemented measures of intensity of reduction related to mobility, personal provisioning, place provisioning. Debitage analysis (e.g. Hiscock 2007; Veth, et al. 2005) has also been deployed effectively in the Near Oceania region. In short, all other things being equal, highly mobile people only carry what they expect to use themselves and minimize carrying materials not expected to be useful, whereas places with long-term occupations will have raw materials brought to the site. As a result of these two different strategies, assemblages from highly mobile people will have lower overall sizes especially of high quality material and lower variances as material is consistently "used up", reduced to the smallest potential useful artifact and used before discard. Retouched artifacts will have steep edge angles that approach the end of the mechanical properties of the material to be resharpened (Kuhn 1990, 1991), or have invasive retouch scars (Clarkson 2002) Conversely, locations with long term occupations will have a larger mean size of artifact, and a larger variance as objects will be at all states of reduction, not just the final, smallest, most "used-up" pieces. These criteria will be used to determine the type of mobility, or changes in mobility that occur at the sites of NFX. NBZ, and NFB (see table 1-2 below for specific predictions).

Table 1-2: predictions of lithic assemblage based on mobility type

mobility type	high residential mobility/logistical site use	low residential mobility/sedentism
provisioning strategy	personal provisioning	place provisioning
predictions	raw material: mixed assemblages; high quality exotic material supplemented by lower quality local material	raw material: all high quality material
	Intensity of reduction (various measures): high overall intensity of reduction; low mean average size of artifacts; artifacts discarded after further reduction no longer mechincally possible; low variance in artifact size, indices of intensity of reduction	Intensity of reduction (various measures): low overall intensity of reduction; higher average mean size of artifacts; artifacts in a variety of stages of reduction; high variance in artifact size, indices of intensity of reduction
	% cortex low	% cortex high
	few cores present; exhausted cores discarded	cores in all stages of reduction, cached raw materials

To determine which model best fits the archaeological record of highland PNG, the analysis of multiple lines of evidence was undertaken. A summed probability distribution (*SPD*) analysis of all of the published radiocarbon dates for the highlands of PNG was created in order to identify patterns in changing site use. As Andrefsky notes stone tool technology is "intimately linked to land-use practices" (2009:66). Therefore a quantitative analysis of intensity of reduction for the lithic assemblages of three sites spanning 20,000 years of occupation was undertaken as a direct measure of mobility to test the predictions in Table 1-2 (following Hiscock 2007; Kuhn 1991, 1992, 1993, 1994). These two analyses are combined with a synthesis of several paleoclimate proxies. Finally these lines of evidence are all brought together to evaluate the competing models of the transition to residential sedentism and related subsistence practices such as the development of agriculture using Eren's questions as a framework for assessment.

A note about place names: Watson and Cole, the original scholars to work with the assemblages discussed here refer to sites using the three-letter site designations assigned by the University of New Guinea (e.g. NFX, NAE, NBZ) (Watson and Cole 1977). Other researchers (e.g. White 1972) subsequently refer to sites mainly by their place names. This might cause some confusion in the case of NBZ as it is discussed in Watson & Cole 1977, which is the same site as Kafiavana which was subsequently excavated by Peter White (1972). I have provided both site names as they are frequently used in the literature in hopes of increasing clarity.

Chapter 2 provides an overview of the geological setting, recent history, and summaries of the previous analyses of the sites of NFB, NBZ (Kafiavana), and NFX. Explanation and synthesis of numerous relevant paleoclimate proxies are presented in Chapter 3. A new radiocarbon date for NFX and the results of the *SPD* analysis are discussed in Chapter 4. Chapter 5 presents the results from the lithic analysis. Finally these lines of evidence are brought together in the concluding Chapter 6 where the results of the *SPD* and lithic analyses are compared with a reconstruction of precipitation based on paleoclimate proxies as well as other paleoclimate reconstructions to evaluate the competing models for greatest explanatory power.

Chapter 2. Background

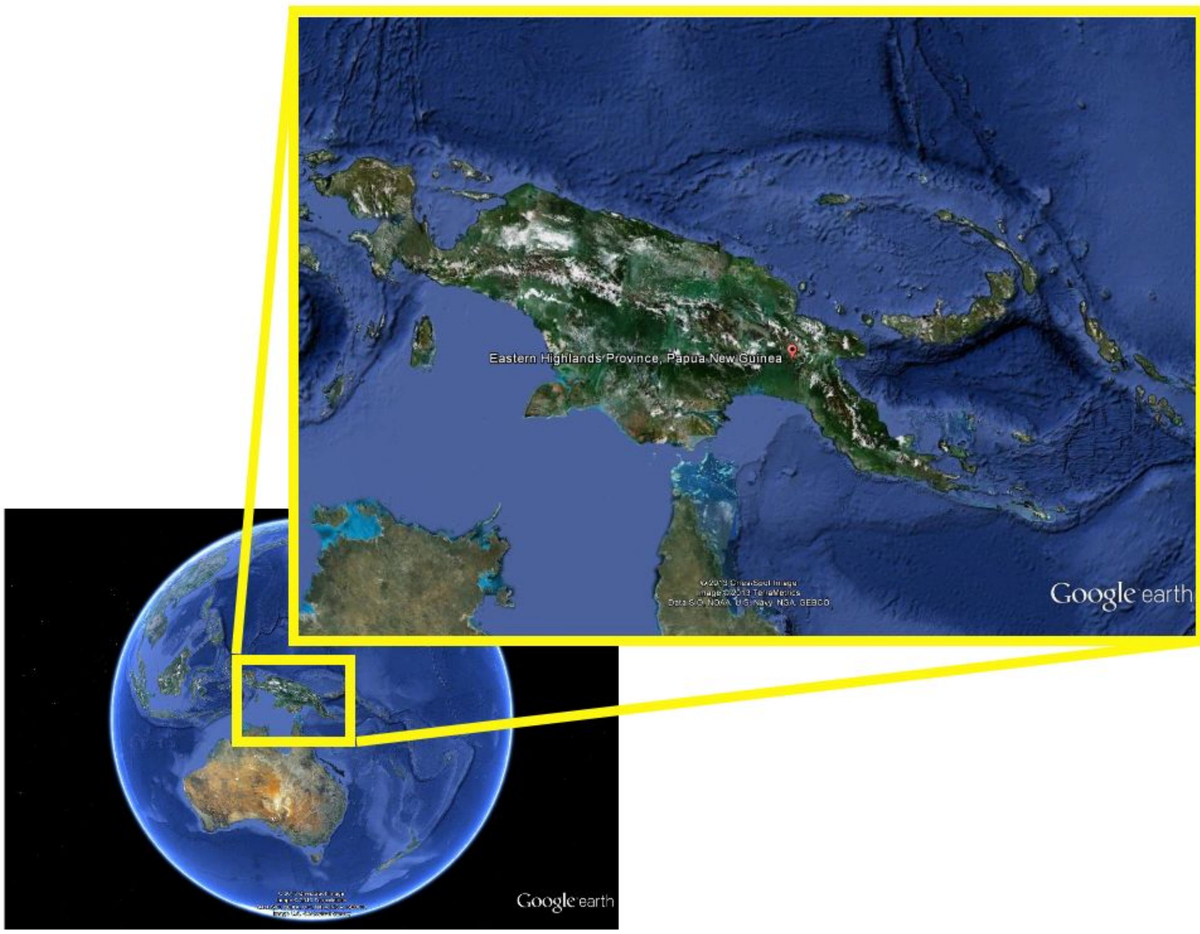

Figure 2-1: New Guinea. Eastern Highlands located by marker in pop-out. (Google Earth 2013)

Introduction:

At current sea levels, New Guinea is the second largest island in the world, and humans have lived on the New Guinea landscape for at least ~43,000-49,000 cal years (Summerhayes et al. 2010). The island lies between approximately 2°-10° south of the equator just to the north of Australia across the shallow Arafura Sea, Torres Strait, and Coral Sea (see fig. 2-1). Formerly the province of Irian Jaya, the west half of the island constitutes the Indonesia provinces of West Papua Province (Propinsi

Papua Barat) on the peninsula referred to as the Bird's Head, and Papua (Propinsi Papua). The eastern half of the island is united with the Bismarck Archipelago, the Louisiade Archipelago, Bougainville Island in the Solomon Islands, and other assorted surrounding islands in the nation of Papua New Guinea. These modern political boundaries reflect European colonial boundaries with the Dutch controlling the western side of the island, and the German and the British controlling the eastern side of the island (C.I.A. 2016; Strachan 1888).

Political organization and people in New Guinea:

Figure 2-2: Political divisions of the island of New Guinea. Green parts are provinces of Indonesia; beige parts outlined in red are the nation of Papua New Guinea. (GoogleMaps 2016)

As late as the early 20th century, only the low-lying coastal areas were known to European colonist (Murray 1920). These areas were sparsely populated, but were a source for copra (indigenous), rubber, and hemp (both introductions) that were valuable to European colonial powers (Murray 1920; Pratt 1906; Radford 1987). It was only in the 1930s that the prospect of gold led Europeans to ascend the central cordillera mountains and explore the highlands (Radford 1987; Standish 1982). The highlands had previously been assumed to be too rugged to be populated – European explorers were surprised to find millions of people living in the highlands practicing subsistence agriculture and pig husbandry (Murray 1920, 1929; Radford 1987). Through the 1930s it was mostly gold prospectors and Christian missionaries who ventured into the interior (Radford 1987). Not unlike the American West, the exploration of the central portions was of New Guinea spurred stories of great adventurers “discovering” a landscape that had been occupied by humans for tens of thousands of years (Crittenden and Schieffelin 1991). Christian missionary activity was encouraged and supported by colonial powers who were engaged in efforts to impose European morality structures in support of European-style political and legal systems, albeit in a racially defined and explicitly colonialist structure (e.g. Murray 1920; Murray 1929).

During WWII, European colonial presence contracted while the Japanese attempted to exercise some control over the various holdings. After WWII, the European colonial powers shifted, with the now Netherlands still retaining control of the western side of New Guinea until the early 1960s, while the German northern portion was absorbed into the British holdings, the control of which was shifted to Australia (Biskup, et al. 1973; Browne 1998; Indonesia. Departemen Luar 2005; Jinks, et al. 1968). In 1969 Indonesia took control of the western side of the island (see fig. 2-2 for current political boundaries) (Browne 1998; Indonesia. Departemen Luar 2005). In the 1975 Papua New Guinea gained independence (C.I.A. 2016). Currently 85% of the highland residents engage in subsistence agriculture, while some engage in wage labor at various economic interests in the region (Bourke 2000; C.I.A. 2016).

Although the Bismarcks have been inhabited for at least 40,000 years (Torrence, et al. 2004), a wave of Neolithic colonists who probably spoke an ancient Austronesian language and landed on the shores of these islands to the north and east of New Guinea approximately 3500 years ago (Bellwood 1997; Denham, et al. 2012; Spriggs 1984), and on the shores of New Guinea proper at least 2000 years ago (Allen, et al. 2011) to 2500 years ago (McNiven, et al. 2011). The ethnogenesis of the Lapita cultural complex is still a subject of substantial discussion (see Green 2003 for summary and discussion of existing models). Lapita was once defined simply as a pottery style of distinctive shapes with elaborate dentate stamping, but now encompasses a western Melanesian culture that spanned from approximately 3500bp to 2500bp with the oldest sites in the Bismarck Islands, and the spreading east into Polynesia. Lapita people employed Neolithic subsistence practices that included agriculture, domesticated animals, and advanced sailing techniques that permitted expansion from the Bismarcks into previously uninhabited islands in the western portion of remote Oceania (Bellwood 1997; Spriggs 1984, 2006). While it is beyond the scope of this research to explore competing hypotheses for the origins of Lapita culture and the relationship to Austronesian language (e.g. Bellwood 1997; Soares, et al. 2016; Szabo and O'Connor 2004; Terrell, et al. 2001), it is worth noting that Austronesian languages are spoken in several coastal areas and throughout much of the southern Huon Peninsula – the New Guinea peninsula closest to the Bismarck Islands, and the Markham River valley area directly south of the Huon Peninsula (Ross 2005).

Geology:

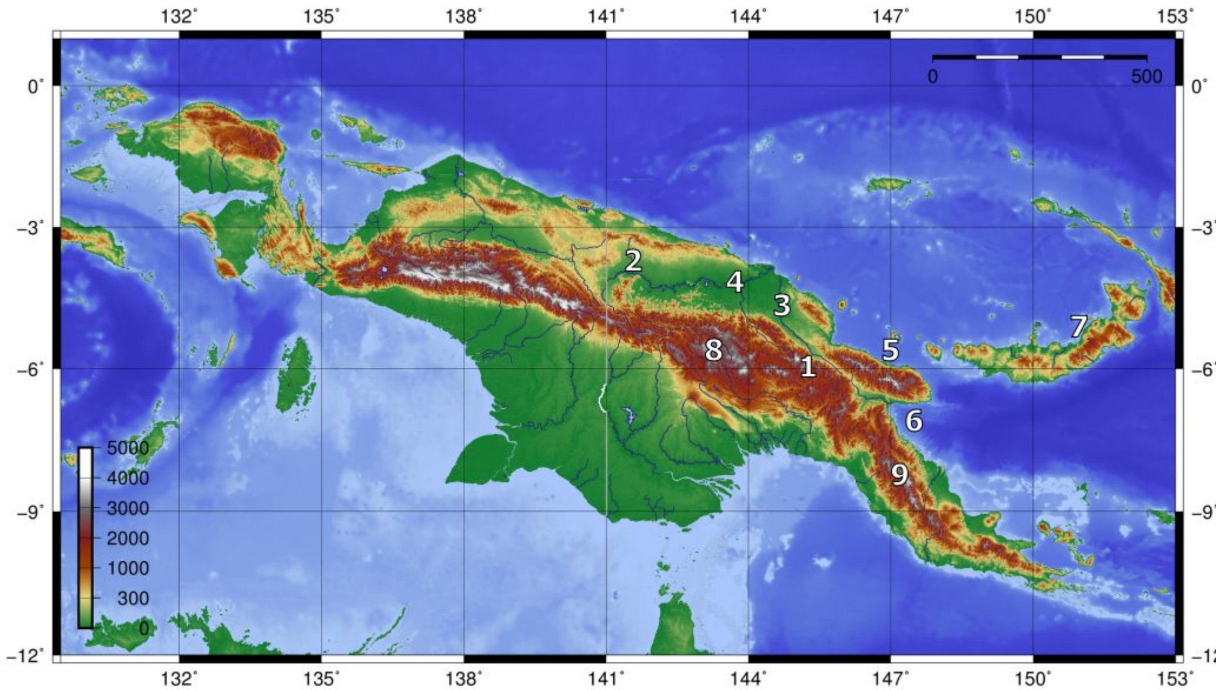

Figure 2-3: map of New Guinea showing elevation. 1. Study area, 2. Sepik River, 3. Ramu River, 4. Sepik-Ramu Basin, 5 Huon Peninsula, 6. Markham River valley, 7. The Bismarck Islands, 8. Central Cordillera, 9. Owen Stanley Range. (base map: Zamonin 2016)

Familiarity with the complex geology of New Guinea is important for understanding the archaeological record of New Guinea, and different geologic zones are used as units of study because of the internal similarities, and the remarkable differences between regions such as between the highlands and the coastal swamp forests. As noted previously, New Guinea is the second largest island in the world, and is located in the tropics a few degrees south of the equator, and a short distance across shallow seas above the continent of Australia. Its topology is dominated by the Central Cordillera (see fig. 2-3), a chain of mountain ranges that bisect the island along a northwest to southeast angle. In the 1930s that Europeans became interested in the possibility of gold and other valuable minerals in the highlands. Throughout the early colonial period, several patrols explored the highlands on the behalf of colonial governments (e.g. Crittenden and Schieffelin 1991; Souter 1970). In the 1930s, geological mapping was conducted by prospectors who tended to keep their findings private, and state-sponsored explorers. In the 1940s, New Guinea was a front in the Pacific theater of WWII as part of the Kokoda Track campaign as Allied forces fought to stop Japanese advance to Port Moresby (Anderson 1992; Drea 1993). From the 1950s through to the end of colonial rule in the late mid-1970s, mapping was conducted by an Australian colonial development ministry in Papua New Guinea, and returned to a geologic focus for economic development purposes, and the major landforms and structures were identified during this time (e.g. Dow and Plane 1965; Dow 1964; Dow 1972; MacGregor 1967; MacGregor and Read 1967; Mackay 1955; McMillan and Malone 1958). From the late 1970s forward, mapping in Papua New Guinea generally and in the Eastern Highlands specifically has been for assessment or promotion of specific economic development opportunities such as hydro-electric dam-building or gold mining (e.g. 2014; 2015a; Furstner 1975). While this is a wealth of information, the available geologic data frequently does not have the content or the resolution relevant for many archaeological questions.

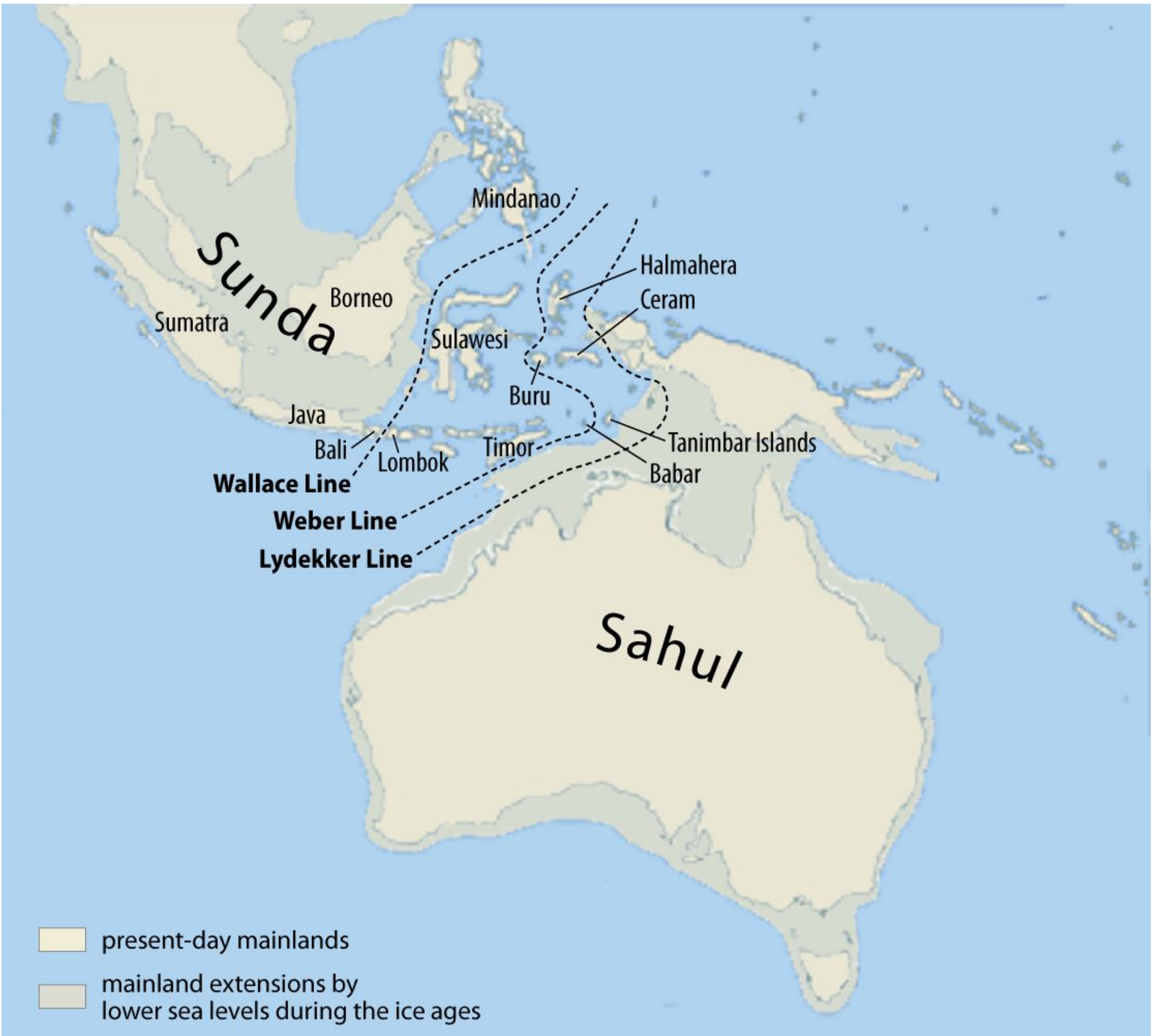

Figure 2-4: The Pleistocene sea-level low-stand continents of Sahul and Sunda with lines drawn by several biogeographers defining limits of ecological communities (Wikimedia Commons 2015)

The geographical continuity of Australia and New Guinea is important for understanding the ecological community of New Guinea. During glacial periods when sea levels are lowered due to water being locked up in ice sheets, New Guinea, along with several smaller island groups such as the Aru Islands, is joined to Australia across the Torres Strait and Arafura Sea to form a single landmass known as Sahul (see fig.2-4). The native fauna is Australasian and includes marsupials such as tree kangaroos and cuscus; a limited number of placental mammals such as varieties of fruit bat; as well as cassowaries. The archaeological record also contains the now-extinct species of macropods *Protemnodon nombe* and *P. tumbuna*; tree kangaroos *Dendrolagus noibano*; and marsupial wolf *Thylacine cynocephalus* (e.g. Bulmer 1966; Mountain 1991). What is less obvious from maps of Sahul is that significant portions of the New Guinea lowlands are extremely recently created landforms. Post-LGM, the Sepik-Ramu Basin (see fig. 2-3) formed an inland sea which started infilling around the mid-Holocene high stand at 6-7kya, and completely filled in by 4kya (Swadling, et al. 1989). Likewise, there is substantial Holocene-era progradation on the southern coast (Parker, et al. 2008).

In geologic time, the whole of New Guinea is a very young landform. The Central Cordillera, a group of formations over 2500 km long, are capped at over 3000m asl with Tertiary limestone formations. Through the Jurassic and Miocene, this region was seabed (Page 1976). The cordillera is still extremely tectonically active (Dow 1972; Drechsler 1990; Drechsler, et al. 1988; Page 1976). The Eastern Highlands are located to the south and west of the Huon Peninsula, a landmass that is still experiencing rapid uplift (Chappell, et al. 1996; Chappell and Thom 1977). In most of the eastern highlands, earthquakes of an intensity of 6 on the Modified Mercalli (MM) scale are expected on average every 25 years; in the northeast corner of the Eastern Highlands where the Kainantu Valley is located, MM7 earthquakes are expected on average every 25 years (Drechsler 1990; Drechsler, et al. 1988).

Sites analyzed in this research:

NFB, NFX, and NBZ (also known as Kafiavana) are some of dozens of archaeological sites identified by Cole during his work with the University of Washington's Micro-evolution Project. Cole's field work took place between 1966-67, and was conducted with the assistance of Rosemary Cole, Keith Weigel, R.J. Scarlett, and a number of local field crew members trained by the project (Watson and Cole 1977:viii, 169). Archaeological investigations conducted by the Cole expedition included extensive survey around the portion of the Kainantu Valley currently inhabited by the Tairora people, and the excavation of selected sites identified through survey. The goal of this project was to establish a basic chronology for the archaeology of the region. After returning from the field, Cole experienced health issues, and the laboratory analysis of the excavated materials was conducted by Watson in consultation with Cole (Watson and Cole 1977:5).

While Cole excavated a number of sites, only 3 sites were selected for this analysis. These sites, NFB, NFX, and NBZ were selected because they individually had the longest time depths and taken together almost continuously span a period from ~20kya to a few hundred years ago. Both NFB and NFX are open sites in the greater Kainantu Valley. NBZ is a rockshelter in the adjacent Asaro Valley to the west, but as discussed below there are no major geological obstacles between the sites, and the distance between these sites as a whole is not particularly great. NFX is the oldest site discussed here, with radiocarbon dates ranging from ~18-11.5kya. NBZ falls between NFX and NBZ with dates from ~10-5kya, although excavation with cultural material-bearing levels continue below the lower end of the bulk date. It is possible that NBZ may contain older material (White 1972:91), a position that this research tentatively supports, although more absolute dating is required to confirm that as a finding. Finally, NFB is an open site on the edge of the Norikori Swamp, and dates from 3.8kya-300ya.

Overall, the soil in the region is described as having a pH of approximately 6.0 (Pataki 1965:29; Watson and Cole 1977:11), which being acidic contributes to poor organic preservation consistent with well-drained tropical soils (e.g. Cronyn and Robinson 1990; Kibblewhite, et al. 2015), although detailed information on the exact pH and variability within sites is not available. None-the-less, while there is variable amounts of charcoal at each site, and the preservation of at least one wood artifact that was subsequently used for dating at NFX, the vast majority of artifacts at each site are lithic, and eventually ceramic once that technology arrives. Following her previous ethnographic work, the Watson lithic analysis sets up a quantitatively-defined typology on different portions of stone artifacts (Watson 1976, 1995; Watson and Cole 1977; also see: White 1969). A consequence of this analytical strategy is that a single object may have several 'tools' on it, reflecting the complexity of analysis of expedient lithic tools where very few single-purpose objects are ever created.

As noted in the Introduction, three-letter site names are not abbreviations or acronyms, but rather the site designation assigned by the University of New Guinea at the time of research. All archaeological sites in the highlands have these three letter designations (see Appendix A for list of sites and radiocarbon dates that include the three letter designations associated with other sites). The NBZ/Kafiavana site was originally excavated by Cole with just a few test pits, the materials from which will be discussed in detail in this research. Later, Peter White conducted more extensive excavations. Cole uses the NBZ designation, and that is used throughout the Watson & Cole monograph (1977), whereas White uses a local name – Kafiavana – in his analysis, creating a small amount of confusion about this location. NBZ and Kafiavana both refer to the same site, and which I try to use Kafiavana parenthetically to remind readers more familiar with White's analysis than the Watson and Cole work, since I am working with the Cole Collection, I feel that it is appropriate to adhere to the conventions of the original analysis.

NFX, NBZ, and NFB

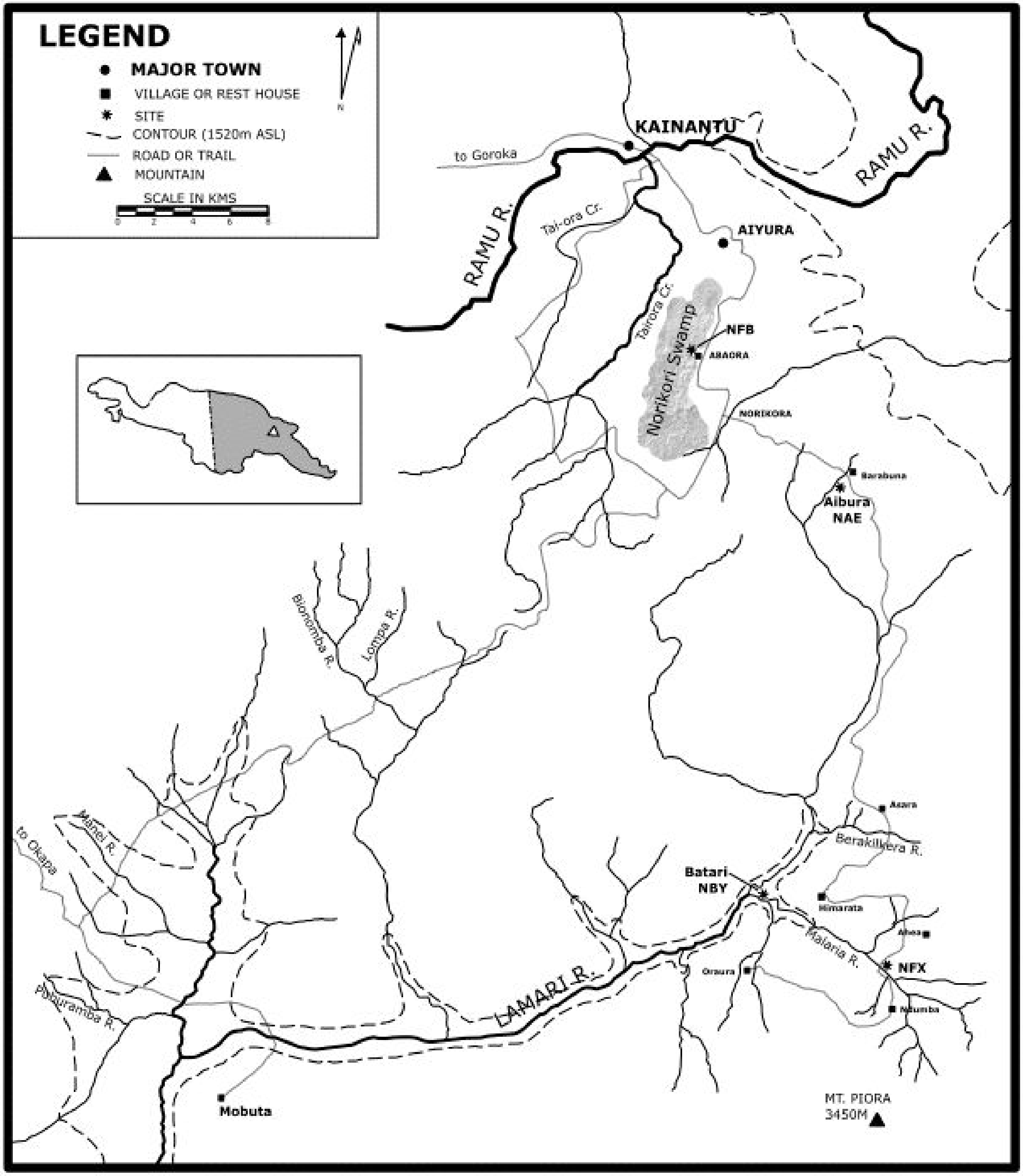

Figure 2-5: map of the UW Microevolution study area with relevant archaeological sites (NFB, Aibura (NAE), Batari (NBY), and NFX. Kafiavana (NBZ) is not pictured here, but lies approximately 40km east from the Microevolution study area (Watson and Cole 1977:143).

NFX:

NFX, the oldest of the sites (~18-11.5kya uncalBP) is an open site located on a rise over the Malaria River, a tributary to the Lamari River (Watson and Cole 1977). The Lamari River drains into the Purari River which meets the southern coast to the east of the Fly-Strickland delta and estuary zone. NFX is the far south of the Kainantu Valley area, and the northern portion of the valley drains via the Ramu River. NFX is approximately 41.5km south by southeast of the town of Kainantu, and just under 30km south by southeast of the NFB site. NFX is located 25m above the river on ridge and ravine landforms consisting of non-calcareous mixed or undifferentiated sedimentary rocks (Löeffler 1974). NFX lies in the extensive Lamari Conglomerate formation, which contains volcanic conglomerate, tuffaceous sandstones, basic volcanic rocks, and limestone (Bain 1974; Dow and Plane 1965). The Lamari Conglomerate is dated to the Tertiary f1-2 stage (middle Miocene) (Bain 1974; Dow and Plane 1965). The Lamari Conglomerate overlies the Omaura Greywacke formation (Tertiary stage e [upper Oligocene to lower Miocene]), and the Lamari river cuts steeply through the Lamari Conglomerate to the Omaura Greywacke in many parts of the Lamari river valley (Bain 1974; Dow and Plane 1965). The Omaura Greywacke formation contains fine to medium grained greywacke, siltstone, limestone, pebble conglomerate, and arkose (Dow and Plane 1965).

Figure 2-6: view of NFX facing south – Roll 4 #3 (Burke Museum Archives 1979; Watson and Cole 1977)

While geoarchaeological analysis of the NFX site was not conducted, Watson and Cole describe it as having a black organic horizon that is 15-35cm deep overlying clay loam of variable composition and color containing concretions. This deposit in turn lies over humic gley (Watson and Cole 1977:35). This description suggests a recent long period of pedogenesis preceded by a period of deposition by alluvial deposits. NFX was excavated using natural stratigraphy including levels identified within the alluvial clay deposits (Burke Museum Archives 1979). The profile is simplified in the Watson and Cole monograph to the three units of topsoil, clay, and humic gley (1977:36).

NFX is an open site currently located in the grasslands that extend around and beyond all three of the sites considered in this analysis. NFX is located on a rise above a river, and while there is not as much chronometric control as is desirable, it was occupied from ~18kya-~11.5kya uncalBP. The closest trees to this site are currently approximately 5km, but that is not an indicator of composition of the environment around the site was during the time of its occupation (see fig. 2-6). This site was extensively excavated by Cole in the late 1960s (Watson & Cole 1977). Notably, the site contains numerous postholes (see fig. 2-7). Cole interprets these as house supports or otherwise part of a structure (Burke Museum Archives 1979).

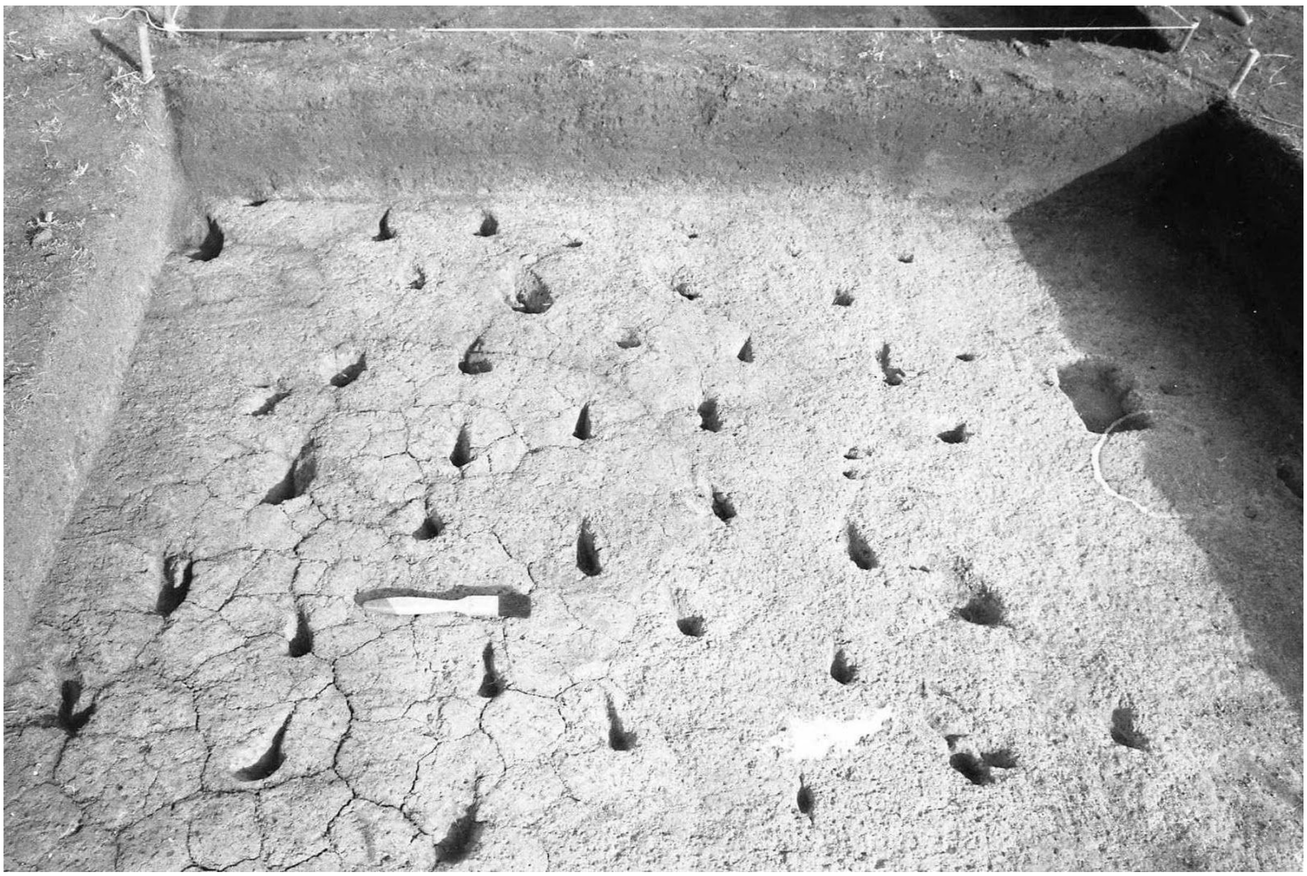

Figure 2-7: postholes at NFX plate: TA1 20 Code A Roll 2/1 (Burke Museum Archives 1979)

While Watson was unable to confirm Cole's interpretation of the postholes relating to some sort of structure using solely the excavation maps and notes (Burke Museum Archives 1979; Watson and Cole 1977), the postholes, if related to a structure, would have constituted the oldest known structures at the time of analysis, although building structures have since been pushed back to ~44kya with Neanderthals building with mammoth bones in Eastern Europe (e.g. Demay, et al. 2012). While Cole was able to identify oval patterning to the postholes (Burke Museum Archives 1979), determination of confirmation that these features were part of a structure, and if so what was those structures' purpose is beyond the scope of the research presented here. The most important aspect of these postholes is the recovery of a piece of wooden post that was used in the original dating of the site (sample #RL 370 18,050 +/- 750bp Watson and Cole 1977:194). While Watson expressed reservations about the validity of this date (Burke Museum Archives 1979; Watson and Cole 1977:194), the antiquity of NFX dating to the LGM has been confirmed by new radiocarbon dating that is presented in detail in Chapter 4: Dating.

While the nature of the postholes themselves are still unclear, the NFX site overall is interpreted as a general purpose habitation site, with multiple habitation surfaces identified during excavation by Cole. There was small amounts of charcoal that could be used for further dating. The overwhelming proportion of artifacts found at NFX were expedient flaked stone tools made from chert. A few pieces of ochre, some ground stone tools including an adze fragment, and surprisingly three pottery sherds from the upper layers were also part of the assemblage. Watson and Cole assign this to the Mamu Phase, Nanoway Tradition, a period of open site occupations, slow technological change, and little direct evidence towards subsistence but assumed to be a forager lifestyle (Watson and Cole 1977:131-132; Watson 1979).

NBZ (Kafiavana):

NBZ is a rockshelter located in the southern end of the Asaro Valley approximately 40m above the eastern bank of the Fayantina River, a tributary of the Waghi River, which ultimately drains on the south coast of New Guinea as the Purari River (White 1972). This part of the Asaro Valley is situated in the New Guinea Mobile Belt, and is consequently tectonically active (Bain 1974). The site and Koyagu hill where it is located is situated in a middle Miocene deposit provisionally named the Daulo Formation or Daulo Volcanics (Bain 1974; McMillan and Malone 1958; White 1972). Koyagu Hill is a sheared mass of calcareous siltstone with good territorial view in most directions, shade in the dry season although sun comes in about 1m past the drip line during the rainy season (White 1972). The Daulo Formation is adjacent to exposed areas of the Omaura Greywacke which probably underlie the Daulo Formation; some Quaternary alluvial deposits are also close to the site (Bain 1974). The Daulo Formation has substantial igneous constituents as it contains andesitic to shoshonitic agglomerate with lava and ash-flow tuffs, It also contains volcanolithic conglomerate, sandstone, greywacke, tuff and calcarenite (Bain 1974). This region is defined as the Yonki Formation by Haanjens et al., and describe it as rugged hills of grandiorite, some greywacke, siltstone, and colluvial soils (Haantjens, et al. 1970). However, White describes the immediate vicinity of NBZ as limestones, shales, greywacke, as well as conglomerate, so it is likely that the Daulo Volcanics are interfingered with the Yonki Formation in the vicinity of NBZ (White 1972:83). The Bismarck Mountain geologic zone begins a few (<5) kilometers from the site and extends along a northwest axis in one direction and a due easterly axis in the other direction above the Kainantu region. Moderately rugged to rugged hills, colluvial soils, mixed forest, grasslands, and swamps lie between NBZ and the Kainantu region and NFB connecting the Asaro and Kainantu valleys (Haantjens, et al. 1970). MacMillan and Malone describe these as “gently hilly uplands” (1958:6). NBZ is approximately 46km west of Kainantu township, and a road connecting Kainantu and Goroka passes close by the NBZ site.

Figure 2-8: a portion of the rock art painting from NBZ – Roll 2 #15 (Burke Museum Archives 1979)

NBZ is a rockshelter also located in what is now a grassy and hilly area overlooking a river. There are extensive paintings on the rock walls of NBZ, one portion of which is presented in fig. 2-8. Test pits were excavated by Cole in 1964; Peter White went to NBZ (referred to as Kafiavana in his publications) on the recommendation of Cole (Burke Museum Archives 1979; Watson and Cole 1977; White 1972). This site is not well dated, with a few low-precision bulk samples indicating occupation from at least 10kya to 5kya uncalBP (White 1972:91). While NBZ is a rockshelter, and is therefore expected to have a different site use than an open site like NFX or NFB, it bridges the time between the abandonment of NFX and the occupation of NFB. There is some highly fragmentary faunal remains in from the lowest levels in the assemblage. This research did not undertake analysis of this faunal material as it was only present in the lowest levels. A cowrie shell recovered from the lowest level excavated by Cole shows connection with coastal areas from the earliest occupation of this site (see fig 2-9). Whether this is direct trade, down-the-line trade or some other form of exchange is not clear from the small amounts of material available.

Figure 2-9: cowrie shell, unidentified snail shell and cuscus mandible from level 14 of NBZ

White indicates that he believes that the use of NBZ may extend into the Pleistocene, and based on the stratigraphy, with levels containing substantial artifactual remains underlying the older bulk dates, there is reason to believe that is accurate (White 1972:91). This analysis addresses the material from the Cole test pits, but relies heavily on White's analysis for ecological context, dating, and other supporting evidence. The lithic assemblage from NBZ is largely expedient stone tools, with some ground stone as well. There are a number of extremely large chert flakes (see fig. 2-10) that could be blanks for adzes, but are equally likely flake cores that have been cached for future use, based on the presence of flakes with platforms the with similar morphology to the large flakes (see fig. 2-11). The ambiguity of the future tool forms from these large chert flakes reflects the flexible approach towards the expedient lithic technology that characterizes all of the assemblages discussed in this research (also see: Watson 1995; White and Thomas 1972). The volume of flaked stone tools through time indicate that NBZ was used extensively, reinforced by the caching of large flakes especially in the lower levels. The middle levels contain a small ground stone with red ochre residue, suggesting that some of the extensive cave painting may have been happening during this time. Close to water, NBZ is interpreted as a frequently used camp where symbolic activity also occurred (White 1972). Watson and Cole do not assign it to a phase or tradition.

Figure 2-10: large chert flake core

Figure 2-11: flake tool with extensive retouch on distal end, large platform and bulb of percussion.

NFB:

NFB is an open site located at 6° 24' S, 145° 54' E on the eastern edge of the Norikori Swamp. It is 12.5km south of the township of Kainantu, almost 53km east by southeast of NBZ, and approximately 30km north by northwest of NFX. The larger region surrounding NFB is Yonki Formation, however the site of NFB and the Norikori Swamp sit in a mid to late Pleistocene deposit known as the Kainantu Formation (Dow and Plane 1965; Haantjens, et al. 1970; Mackay 1955). The Norikori Swamp is drained by the Ramu River, which cuts through the Bismarck Mountains to the north, then travels west to join the Sepik River to create the Ramu-Sepik Basin on the north coast of New Guinea.

The Kainantu Formation consists of lacustrine deposits of clay, sand, gravel, and boulders (MacKay 1955). The lacustrine sediments overlie a bed of conglomerate of older igneous, metamorphic, and sedimentary boulders, cobbles, and pebbles from various deposits in the region including from the Bena-Bena formation and other older formations of diorite and granodiorite (MacGregor and Read 1967). Pleistocene lakes sedimented in areas in the north of the Kainantu Valley and the adjacent Arona Valley that lies to the east of Kainantu Valley, then were drained by the Ramu River cutting through the Paleozoic Bena-Bena Formation, creating eroded streambeds in the Kainantu Formation region up to 30ft deep, exposing Omaura Formation bedrock at the base (McMillan and Malone 1958). The cobbles in the conglomerate beds in the Kainantu Formation contain quartz, quartzite, diorite, gneiss and other hard igneous and metamorphic rocks (McMillan and Malone 1958). The Kainantu Formation was dated in two locations providing ages of 36,900 ±2000 yrs uncalBP (CR 1767) and >54,000 yrs uncalBP (CR. 2012). Both dates come from organic material from the basal conglomerate level. The 36.9kya date comes from a drill hole of a depth of 116 ft. (35.4m); the >54kya date from organic material bedded in the conglomerate collected from the base of a cliff beside the Ramu River (MacGregor 1967; Rogerson and Haig 1982). The basal conglomerate beds are overlain by up to 90m of fine-grained deposits containing tephra with occasional thin lenses of conglomerate (Dreschler 1990; MacGregor 1967; Rogerson and Haig 1982). This landform receives new alluvial deposits from higher landscapes, and is eroded into the tributaries of the Ramu River. It is notable that the Pleistocene lakes in the Kainantu and Arona valleys are also known ethnographically (Watson 1997). There is currently no data regarding when in the late Pleistocene the Kainantu and Arona valley lakes drained.

The site of NFB is located on a rise between streambeds projecting into the Norikori Swamp (Watson and Cole 1977). The stratigraphy is described as a complex series of clay loam deposits of variable thickness in the Watson and Cole monograph (1977:13), although a closer inspection of the field notes and associated maps reveal a more complex stratigraphy (Burke Museum Archives 1979; Huff in press) (see figs 2-12 & 2-13).

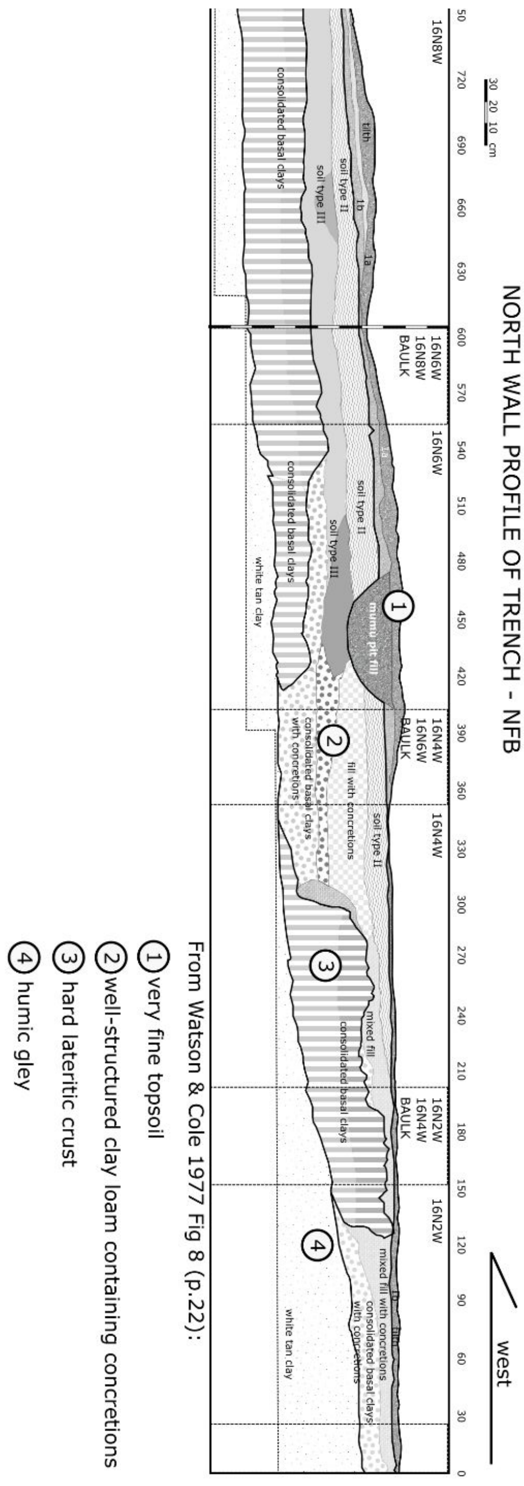

Figure 2-12: section of NFB trench stratigraphy

Figure 2-13: Cole and crew excavating at NFB – plate # TA1 1A(18) (Burke archives)

NFB is an open site located on a rise on an interfluve projecting into the Norikori Swamp (see map fig 2-5). This site was excavated thoroughly by Cole in the late 1960s (see fig 2-13). It is dated from 3.9kya to less than 200 years ago. While no excavation of the adjacent swamp was conducted that would be comparable to Denham's excavations at Kuk (2004a, 2004b), it can reasonably be inferred from the proximity of this site and the NGG site on the western side of the Norikori Swamp (dated to ~3.3kya uncalBP with a single C^{14} date, not part of this analysis) (Watson and Cole 1977:193) that exploitation of swamp resources were a focus for residents of this site. The presence of ceramics throughout the stratigraphy support a long-term occupation with low residential mobility (Huff in press). Watson & Cole are circumspect about the meaning of presence of pottery in the lower levels, but there are several pieces of pottery that are associated with the oldest radiocarbon dates for the site (Huff in press). Through geoarchaeological analysis was not conducted, Cole was able to identify several features such as habitation surfaces, hearths, and mu-mu pits (earth ovens) (see fig.s 2-14 & 2-15), and there is no evidence that the habitation sufaces were left intact while a turbation process moved pottery sherds and other artifacts differentially.

Figure 2-14: profile of earth oven at NFB plate: Color Slides/TA11A (Burke Archives)

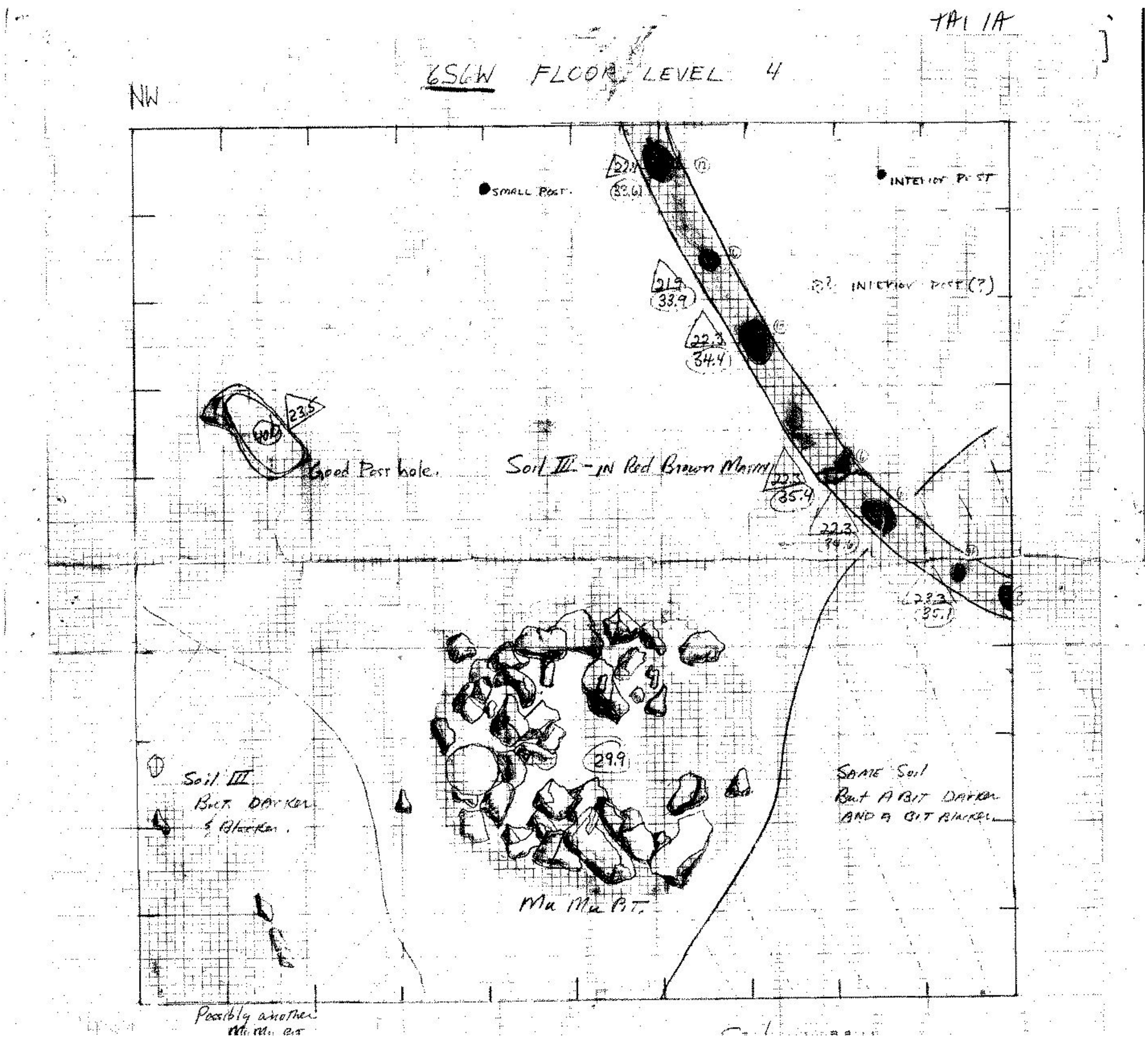

Figure 2-15: plan of level 4 in unit 6W6S. The line of postholes in the upper righthand corner are part of a large circle spanning several units defining a house structure. (Burke Archives)

Watson and Cole largely assign the NFB assemblage to the later Tentika Phase of the Nanoway Tradition, which is associated with earth ovens, rectangular (instead of circular) hearths, monoliths, some sort of substantial structures, ceramics, possible pig husbandry, and sedentism (1977:133-134; Watson 1979)

Summary of highlands archaeology:

As Fairbairn et al. note, there are currently "gaping holes in the archaeological and paleoenvironmental records" for the New Guinea highlands (2006:381). The trends in archaeological have tended to focus on first occupation (e.g. Summerhayes, et al. 2010; White 1972) and general description (e.g. Bulmer 1966; Watson and Cole 1977). Once the independent development of agriculture was established; the timing of the transition to agriculture was a central theme (e.g. Bulmer 1975; Christensen 1975; Golson 1984, 1991; Golson and Hughes 1980; Golson, et al. 1967; Gorecki 1986; Watson and Cole 1977).

There have been some attempts at synthesis through time including Feil (1986), Watson (1979), Bulmer (1975). Feil, a social anthropologist, focuses on the gradient in precipitation, with rain being more continuous towards the west, and more seasonal in the Eastern Highlands. He attributes the early development of agriculture in the wetter western Kuk as a result of the preferable conditions for growing taro, and goes so far as to call the eastern highlands an "agricultural 'backwater'" (1986:626) until the arrival of the sweet potato (*Ipomena batatas*) fairly recently, although conceding that there are species such as *Pueria lobata* that are under cultivation today, and would have been suitable in the past assuming that the environment is relatively comparable to that of today. Watson (1979) focuses on a chronology of the eastern highlands, reiterating the chronology defined in the Watson and Cole monograph (1977:131-136), and incorporates other nearby sites such as Aibura and Batari into her scheme. As her chronology is dependent on the lithic typology she developed, and asserts that through more rigorous lithic analysis (adhering to her methodology) is necessary for more comparison between highlands regions. Bulmer also is hesitant to draw grand conclusions about overall inter-regional patterns, but focuses on her chronology, that there was intensification of resource production (i.e. agriculture) from 6,500 years ago, and increasing economic complexity with more modern (by the paleoclimate reconstructions available at the time) since ~5000ya (1975:67-68). The paucity of evidence overall unquestionably skews the interpretation of the archaeological record. We currently do not have any evidence from more geographically extensive excavations in other swamps to compare the antiquity of Kuk or the relative timing of spread of agricultural practices. The oldest sites are in the Owens Stanley Range to the east, but the Arona Valley to the east of the Kainantu Valley has few identified sites, and none of significant antiquity (Swadling 1973 in Bulmer 1975, Watson & Cole 1977). While precipitation gradients likely affected the subsistence and cultural development of various people across the highlands, the Feil synthesis – ambitious for its era – might suffer from taking the absence of evidence as the evidence of absence. Watson and Bulmer both hew more closely to the evidence, and stick to supporting their models with the available evidence while acknowledging the limitations of what the evidence can actually prove.

As noted above, currently Kosipe and the Ivane Valley in the Owens Stanley Range (see map fig. 2-3), at high elevation but separated from the main highlands by the Ramu Valley, are where the oldest known sites in all of New Guinea are located at 43-49 kya cal (Summerhayes, et al. 2010). Only Ivane Valley sites (Summerhayes et al. 2010) and Nombe (Evans 2000; Evans and Mountain 2005; Fairbairn, et al. 2006; Mountain 1991; White 1972) are known before the LGM. During the LGM the number of archaeological sites expands significantly (e.g. Bulmer 1964; Bulmer 1966; Bulmer 1975; Watson and Cole 1977; White 1972). Overall, the numbers of sites that have been excavated and analyzed are low, in no small part due to the changes from a colonial Australian government and subsequent changes in governance; and the general logistical complexity of conducting new fieldwork in the highlands, as well as the research interests of members of the scientific community. Therefore it cannot be argued that the highlands were virtually empty during the pre-LGM late Pleistocene, when there has been very little new excavation has been conducted since the fluorescence of highland archaeology in the 1960s and early 1970s (e.g. Denham, Golson, et al. 2004; Denham, Haberle, et al. 2004; Denham, et al. 2003). Without more thorough investigation, arguments about population are under-determined. However, from thoroughly considering the analyses that have been conducted, it can be determined on the basis of tool raw material type and residue analysis (Fullagar, et al. 2006; Summerhayes, et al. 2010), faunal analysis (Mountain 1991), and assemblage-level lithic analysis (Evans and Mountain 2005; Gaffney, Ford, et al. 2015) that the early inhabitants of the highlands were very mobile people.

After the Pleistocene/Holocene transition, the focus of archaeological analysis is on the timing of the adoption of agriculture. Figure 2-16 shows a comparative summary of models of transition to agriculture in the highlands.

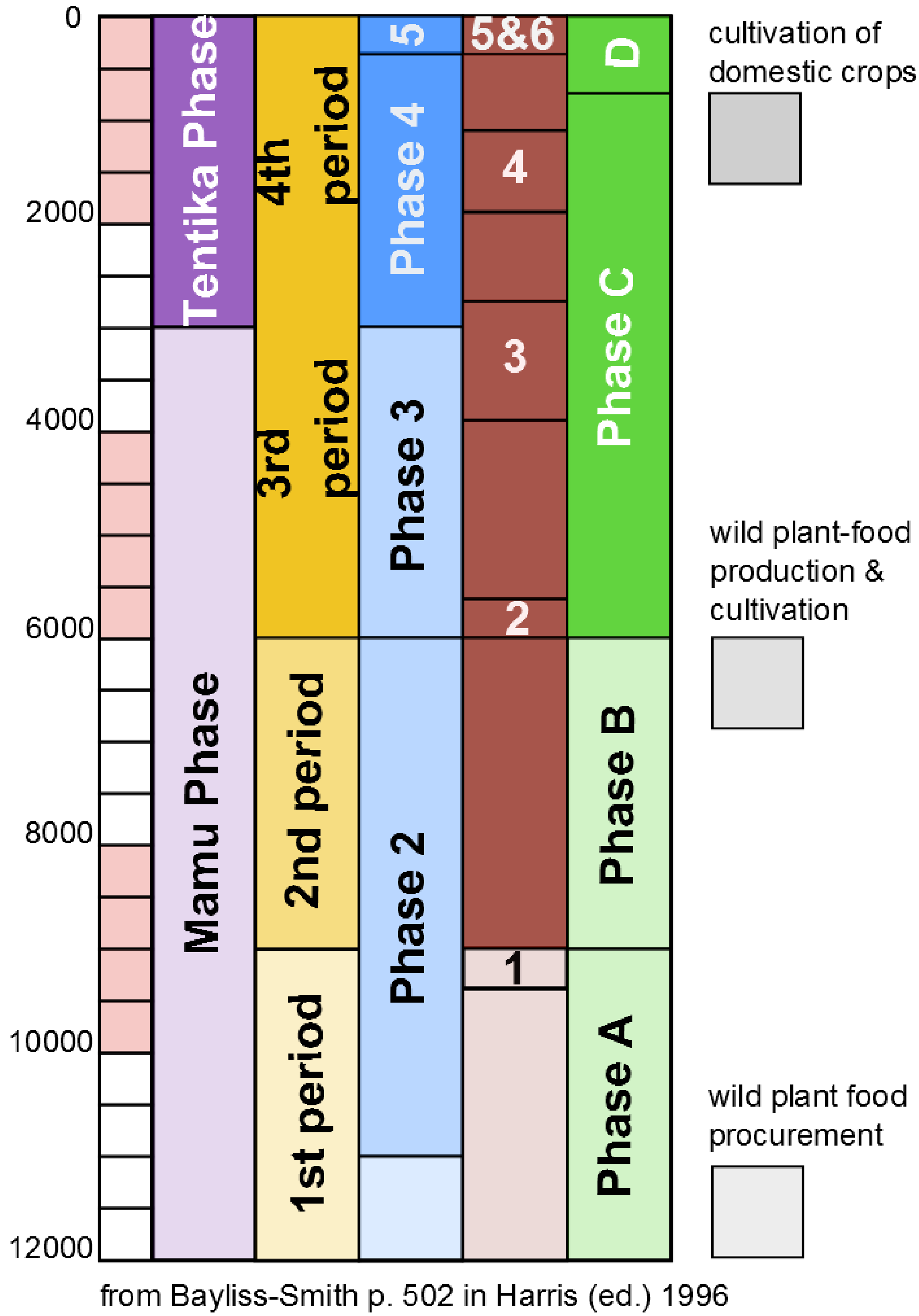

Figure 2-16: Comparative models of timing of settled agriculture. Watson & Cole phases in purple; Christensen phases in yellow; Bulmer phases in blue; Golson, Hughes and Yen phases in red; Gorecki phases in green. From Bayliss-Smith p. 502 in Harris (ed) 1996. The gray boxes on the far right serve as a generic key linking color intensity to the subsistence practices

described by the original authors. Lightest color intensities are wild plant food procurement (only); darkest color intensities are the cultivation of domestic crops. Not all models contain intermediate stages.

Current with the era in which these analyses were conducted, typology of stone tools is a heavily utilized method (e.g. Bulmer 1966; Bulmer 1975; Watson and Cole 1977; White 1972). Working off ethnographic studies (e.g. Watson 1995; White 1968; White and Thomas 1972) there is general agreement that the highlanders generally used an expedient bipolar technology. Consequently an approach of analyzing each worked edge as a type on an object was employed (e.g. Watson and Cole 1977; White 1972), although this approach still fell victim to the many limitations of applying typology to an expedient assemblage (e.g. Bradbury and Carr 2012; Hiscock 2015; Shott 1989, 1999).

All of the approaches in fig. 2-16, and Denham's research significantly extending Golson's work at Kuk Swamp (e.g. Denham and Haberle 2008; Denham and Ballard 2003; Denham, Golson, et al. 2004; Denham, Haberle, et al. 2004; Denham, et al. 2003) employ a gradual and often an evolutionist framework. The explanations are usually centered on a pull explanation: that settling down and adopting a sedentary lifestyle has obvious inherent benefits that people slowly incorporated into their subsistence patterns.

Against these prevailing models, NFX is occupied from the LGM to the Pleistocene/Holocene boundary, and pre-dates even the earliest signals of agriculture. As a group, the NFX, NBZ and NFB sites represent a virtually continuous record from the LGM to the 18th century. Both NFX and NFB bear the hallmarks of being residential occupation sites, whereas NBZ as a rockshelter is a logistical site, and possibly also a ritual site when the rock paintings are taken into consideration. NFX provides a benchmark for what a residential site in the terminal Pleistocene pre-agriculture looks like, against which the assemblages of NBZ and NFB can be compared.

Chapter 3. Paleoclimate of New Guinea

Intro:

The island of New Guinea is located a few degrees south of the equator on the Sunda shelf separated from Australia by the shallow Torres Strait at the closest point, the Coral Sea to the southeast, and the Arafura Sea to the southwest. The average temperature is 10°-15°C (50°-60°F) with cloud cover, and temperatures that range up to above 33°C (90°F) in the open sun. Temperatures dip down to 5°-9°C (40°s F) with frosts sometimes occurring especially in El Niño years where temperatures have been recorded as low as -2.3°C (29°F) (Allen 2000; Pataki-Schweizer 1980; Pataki 1965). The high altitude forested regions receive 5-10m of rainfall in a year, while the lowland areas only receive 2-3m of precipitation annually (Brunskill 2004). While they are humid year-round, the eastern highlands have a seasonal gradient, with rainfall heaviest in December-March, while May-October is the dry season (Tachikawa, et al. 2011). Seasonality of rain is largely controlled by the Intertropical Convergence Zone (ITCZ) with inter-annual variability driven by El Niño Southern Oscillation (ENSO) events (Aldrian and Dwi Susanto 2003; Russell, et al. 2014; Tachikawa, et al. 2011). These two inter-related climate phenomena – the ITCZ and the ENSO – are the controlling factors for climate for the highlands both currently and for time periods relevant for understanding landscape opportunities for past populations represented by the archaeological record (Aldrian and Dwi Susanto 2003; Liu, et al. 2014; Russell, et al. 2014; Tachikawa, et al. 2011).

Intertropical Convergence Zone (ITCZ)

The ITCZ is a global climate feature that roughly circles the equator. Sometimes colloquially known as the “doldrums”, it is formed as an effect of the planet’s rotation which in turn drives the dominant wind directions for different latitudinal zones. Specifically, the ITCZ is formed when the southwesterly-traveling northern hemisphere trade winds and northwesterly-traveling southern hemisphere trade winds converge at the equator (fig. 3-1).

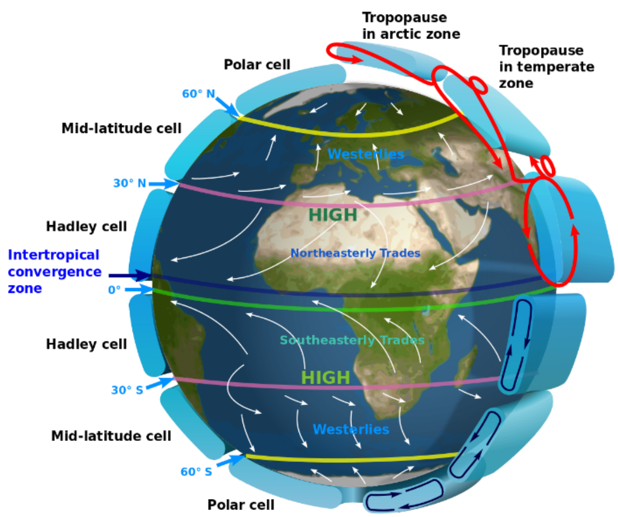

Figure 3-1: global wind patterns including trade winds converging and the ITCZ (Kaidor 2013)

Observational data has demonstrated a seasonal north-south shifting of the ITCZ, with the ITCZ moving towards the hemisphere currently experiencing summer (fig 3-2). This gradient is exaggerated by the unequal distribution of continental landmasses and the higher albedo of the northern hemisphere continents relative to the southern hemisphere oceans (Böll, et al. 2014; Broccoli, et al. 2006; Philander, et al. 1996).

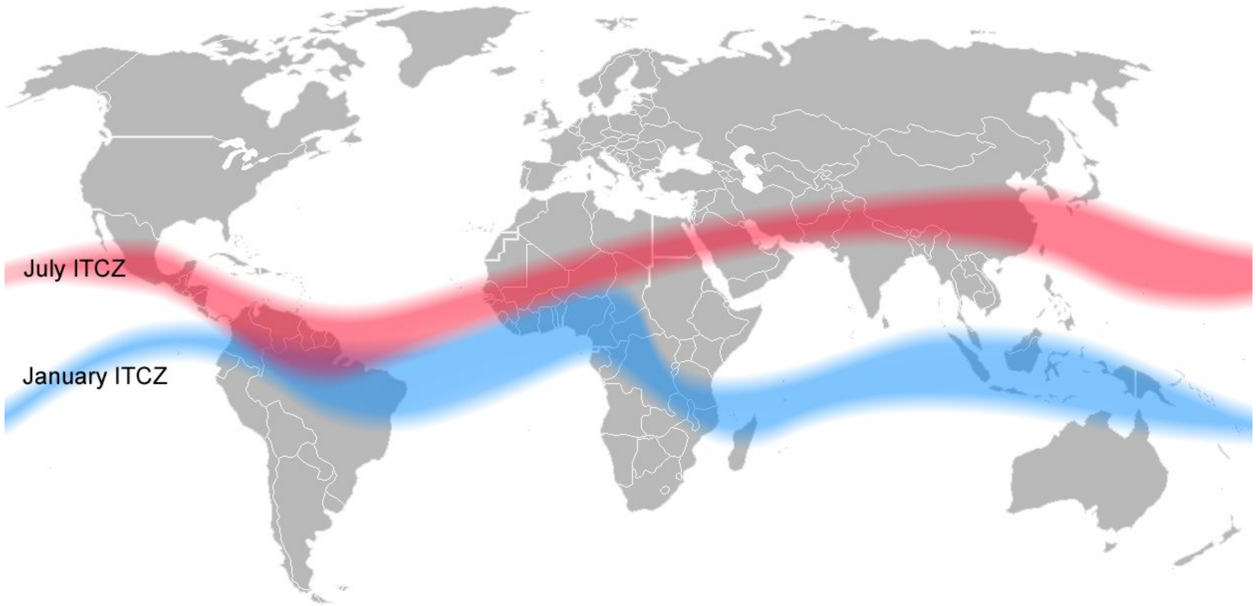

Figure 3-2: global map showing idealized seasonal tracks of the ITCZ (Halldin 2006)

The intensity of the Asian-Australian winter monsoon and the latitudinal location of the ITCZ determines the quantity of wet-season precipitation in the Indo-Pacific region including the eastern highlands of Papua New Guinea (Leduc, et al. 2009; Russell, et al. 2014; Tachikawa, et al. 2011; Yancheva, et al. 2007). The inversely-correlated variability in the Indian summer monsoon and the Asian-Australian winter monsoon is linked with north-south variability in the ITCZ (Böll, et al. 2014; Böll, et al. 2015; Gupta, et al. 2003; Tachikawa, et al. 2011; Yancheva, et al. 2007). The ITCZ has shifted southward over the Holocene due to increases in austral summer insolation and consequent decreases in northern hemisphere summer insolation as a consequence of eccentricities in the position of the Earth relative to the Sun known as the Milankovitch cycle (Gupta, et al. 2003; Haug, et al. 2001; Leduc, et al. 2009; Tachikawa, et al. 2011; Wang, et al. 1999; Wanner, et al. 2011). Southward movement of the ITCZ has also been correlated with North Atlantic cold events such as Heinrich events (Böll, et al. 2015; Goswami, et al. 2006; Leduc, et al. 2009; Russell, et al. 2014), and with Northern hemisphere glaciation events(Broccoli, et al. 2006; Russell, et al. 2014; Wanner, et al. 2011). It is also notable that the ITCZ shifts southward during El Niño events (Haug, et al. 2001).

El Niño Southern Oscillation (ENSO)

ENSO refers to the variability in sea surface temperatures (SST) and atmospheric patterns in air pressure in the tropical Pacific Ocean region. El Niño events and La Niña events are a suite of climatological phenomena including changes in precipitation and atmospheric temperature throughout the Pacific Basin that often accompany extreme values in the SST variability. El Niño events are especially important to the highlands of Papua New Guinea, as they often cause extreme droughts in the highlands and in the general Western Pacific Warm Pool (WPWP also known as the Indo-Pacific Warm Pool or IPWP) area and the Indo-Pacific writ large. In the PNG highlands El Niño events are frequently implicated in anomalously cold temperatures that can drop below freezing causing destructive frosts. Droughts and frosts have caused crop failures in the highlands and destruction of wild food sources, with serious public health consequences for modern populations (Allen 2000; Bourke 2000; Haberle 2000; Nicholls 2000). Droughts from modern El Niño events have also created the conditions for extensive forest fires in the highlands, with attendant destruction of property, gardens, and ecosystem (Haberle 2000); and have been implicated in lowered success in hunting wild foods (Bourke 2000). With the devastating consequences El Niño events have had on modern populations, understanding the variability in strength and frequency of the ENSO cycle is critical for understanding changing landscape opportunities for past populations of the PNG highlands.

Under normal conditions, warm water accumulates on the western side of the Pacific Ocean, especially in the region of the north coast of New Guinea and the greater area. This is called the Western Pacific Warm Pool (WPWP) or Indo-Pacific Warm Pool (IPWP) (see fig.3-3).

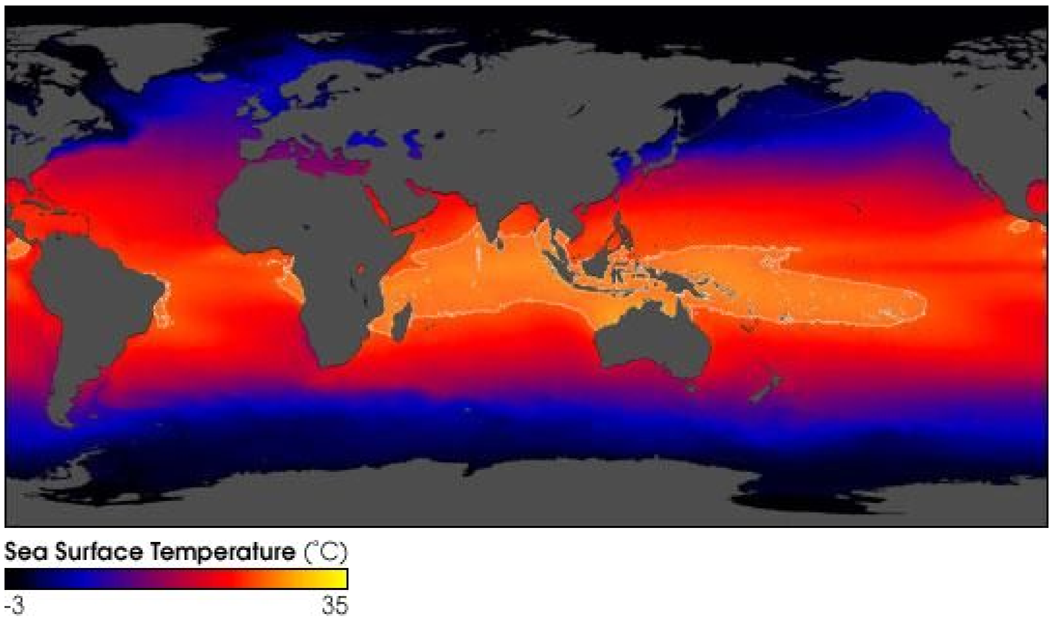

Figure 3-3: Western Pacific Warm Pool (WPWP). Orange area around ISEA are the warmest SST. (NASA 2016)

In El Niño years, the warm pool stretches east across the Pacific basin towards the equatorial regions of South America. The atmosphere generally has low pressure over warm water due to evaporation and convection, and high pressure over colder water. In normal years, the warm water, the low pressure and the atmospheric moisture stays in the western Pacific resulting in the austral summer wet season in the highlands of PNG and the general region. In El Niño years, as the warm water moves eastward, the low atmospheric pressure and the precipitation travel with it, resulting in extreme wet conditions in parts of the west coast of the Americas, and droughts and exceptionally cold weather in the WPWP region generally and the highlands of PNG specifically (see fig. 3-3, 3-4).

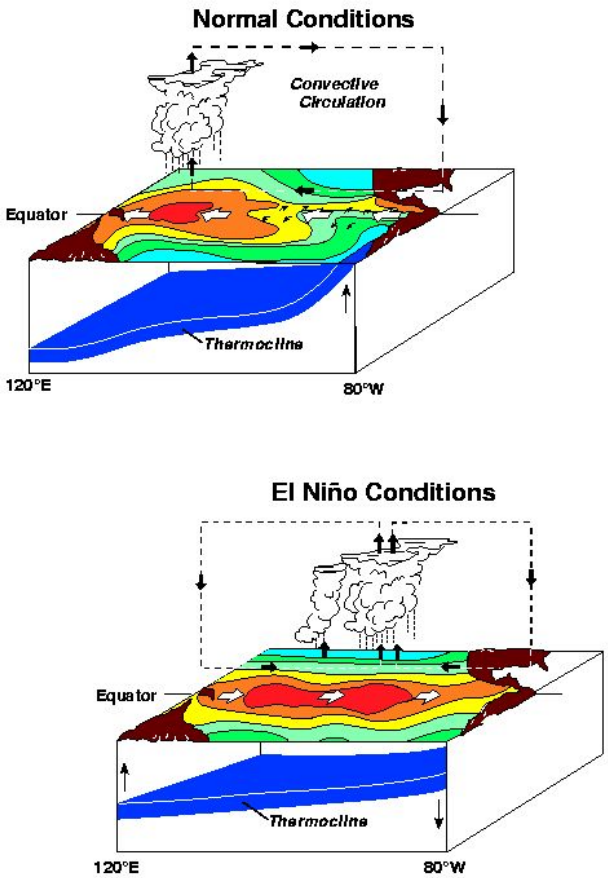

Figure 3-4: Illustration of normal vs. El Nino conditions with the migration of the warm pool eastward and attendant precipitation patterns (TAO_Project_Office 2016)

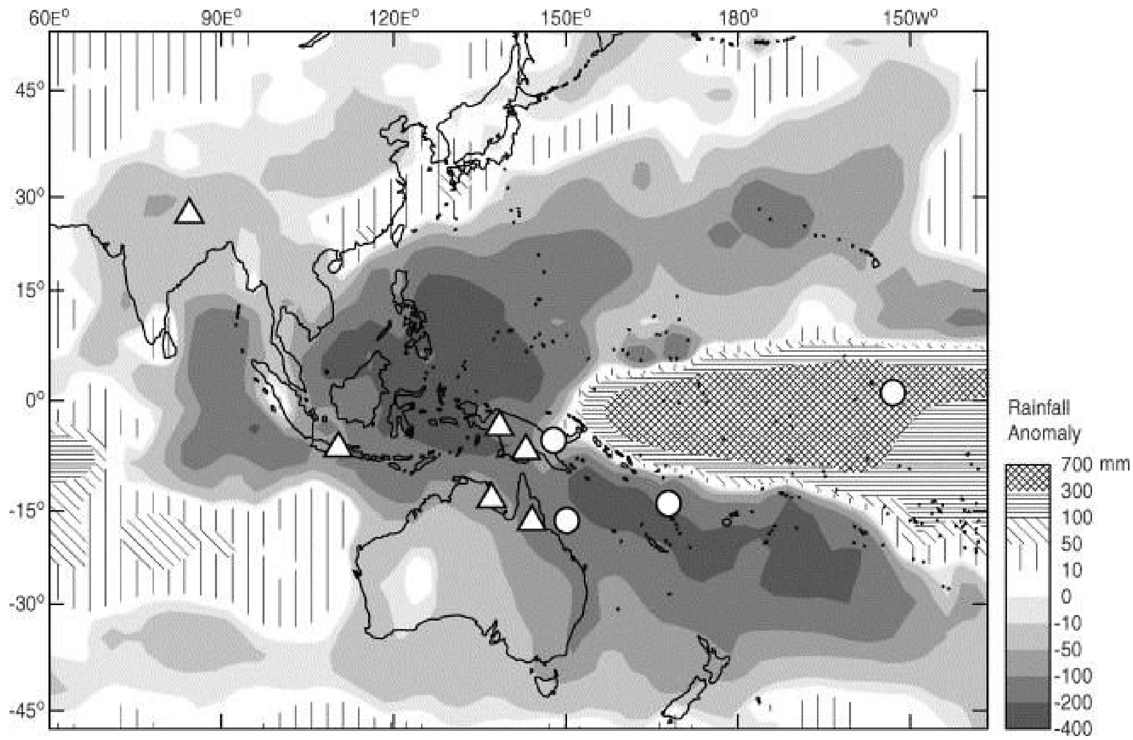

Figure 3-5: Precipitation anomalies (mm) associated with moderate-strong El Niño events from 1900 to 1998. Dark areas have precipitation deficits, hatched areas have increased precipitation. Triangles and circles represent terrestrial and oceanic paleoclimate records respectively. (Gagan, et al. 2004)

ENSO has been a major global climatic feature (fig. 3-4, 3-5) for hundreds of thousands of years (Tachikawa, et al. 2011; Tudhope, et al. 2001). However, due to the limited time depth of various paleoclimate proxies, and uncertainty about the impact of lowered sea level and consequent exposure of the Sunda and Sahul continental shelves on Pacific circulation, ENSO research tends to focus on the period from the Last Glacial Maximum forward (e.g. Carré, et al. 2014; Gagan, et al. 2004; Liu, et al. 2014).

Variations in sea surface temperatures (SST) as recorded in the differential update of strontium and other isotopic analyses of banded corals (e.g. Deng, et al. 2009; Wei, et al. 2007) or as recorded in the alkenone unsaturation and isotopic concentrations of foraminifera in marine sediments (e.g. Schwab and Sachs 2009). These have been some lines of inquiry into the frequency and amplitude of ENSO events. Varved sediments from the eastern Pacific have also been used to interrogate the ENSO record (e.g. Haug, et al. 2001; Moy, et al. 2002), as well as the isotopic composition of fossil bivalves from Peru (e.g. Carré, et al. 2014). Recently isotopic analysis of marine sediments from the WPWP area has been applied to the issue of understanding ENSO (e.g. Tachikawa, et al. 2011). There have been many analyses that aggregate several proxies and (e.g. Donders, et al. 2008; Gagan, et al. 2004; Liu, et al. 2014; Tudhope, et al. 2001; Wanner, et al. 2011). While this list is not all-encompassing of the methods and results for investigating the ENSO pattern and associated changes in SST, salinity, and direct measures of precipitation in various parts of the ENSO range, it provides a broad foundation of data and analyses to employ in understanding the archaeological record of places such as the highlands of New Guinea that are substantially impacted by these climate phenomena.

Precipitation:

In that precipitation in the highlands of PNG is affected by the latitudinal position of the ITCZ and by the frequency and amplitude of ENSO events – phenomena that are inter-related but that are not synonymous – it is particularly useful that some direct measurements of precipitation in the WPWP have recently been developed. Tachikawa et al. (2011) use x-ray fluorescence (XRF) of marine sediment cores to identify variable abundances of iron (Fe), titanium (Ti), potassium (K), silicon (Si), and calcium (Ca) in tandem with mass spectrometric analysis of the marine cores to understand the changing sediment loads from the Sepik-Ramu river system from island New Guinea through a 400kya time span. Ti is an especially useful indicator for coarse, refractory and heavy minerals that are a constituent of river sediments. The marine sediment cores were collected from the Bismarck seafloor from two locations somewhat north and west of the Sepik-Ramu basin outlet. While the

Tachikawa et al. (2011) analysis was specifically focused on understanding the role of precession and obliquity in the hydrological processes of the WPWP over a 400ky time span, their results reveal patterns in sediment outwash from the Sepik-Ramu basin that are relevant to understanding precipitation from highlands that sit at the Ramu River headwaters. While the dataset that would provide precise chronology has not yet been published, general trends are identifiable from existing publications. Marine isotope stage (MIS) 4 (71-57kya) shows an increased contribution of coarse river sediments. MIS 3 (57-29kya) is extremely variable with a substantial drop in sediments early in the stage, and increasing through time. MIS 2 (29-14kya) demonstrates a substantial drop through the stage and continues into MIS 1 (14kya-present), increasing sometime in the Holocene.

Another analysis of the coarse refractory sediment products of outwash is the Russell et al. (2014) analysis of sediments from Lake Towuti on Sulawesi. While there is some geographic distance between the New Guinea highlands and Sulawesi (approximately 2732km straight line distance from Kainantu, PNG to Lake Towuti on Sulawesi), these two regions experience similar seasonal precipitation regimes, with the bulk of their rainfall occurring from November through March (Aldrian and Dwi Susanto 2003; Russell, et al. 2014).

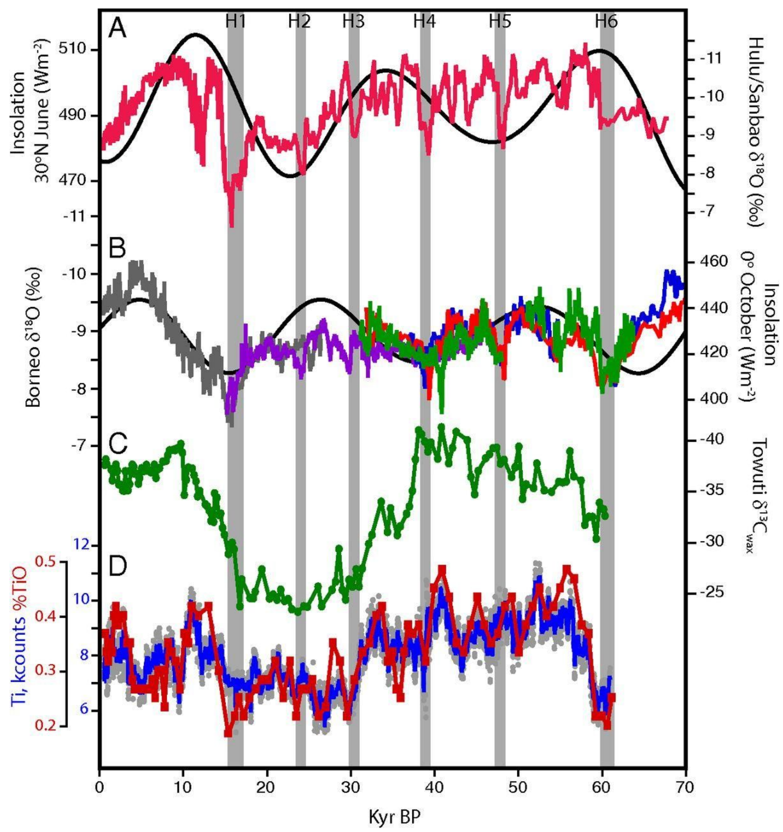

Figure 3-6: A comparison of proxy data from Lake Towuti to paleoclimate records from nearby regions. Vertical gray bars indicate the timing of Heinrich events 1–6 (from Russell, et al. 2014).

Lake Towuti data is presented in figure 3-6. Ti content is very low at the beginning of the record during Heinrich event 6 (H6) at approximately 60kya, indicating reduced precipitation and minimal river sediment contribution. There is a steep increase then a general trend downwards with no change in sedimentation during H5 (45kya). There are peaks in sedimentation directly before both H4 (38kya) and H3 (31kya) with an overall downward trend through this period. There is a period of variable but overall reduced precipitation between H3 and H1 (16.8kya) with no real change in behavior at H2 (24kya). This trend in reduced precipitation matches the drop in precipitation from the Tachikawa et al. (2011) record during MIS2. The Russell et al. (2014) record shows a steep increase in precipitation directly following the Last Glacial Maximum (24-19kya, not represented on this graph) so that the dry period extends from ~33-16kya, followed by a steep decrease in precipitation going to the beginning of the Holocene (11.7kya, not represented on this graph). This pattern also has good agreement with the Tachikawa et al. record (2011) which shows a final dip in precipitation in the Holocene with an increase towards the mid and late Holocene.

It is also notable that these patterns in precipitation have good agreement with many ENSO, ITCZ and monsoon proxies. Liu et al. (2014) note a weakening of ENSO events in the Bølling-Allerød interstadial (BA) (~14.5kya) and an increase in ENSO events in the Younger Dryas (YD) (~12.9-11.7kya). Donders et al. (2008) find reduced ENSO activity 6-5kya, substantially increased El Niño events from 4.5-3.5kya, with a decrease towards modern ENSO activity from 3.5kya forward. Carré et al. (2014) note several cold events in coastal Peru 6.7-7.5kya indicating ENSO activity, and the establishment of modern ENSO behavior at approximately 3-4.5kya. Significant El Niño activity is recorded at Laguna Pallcachoa in southern Ecuador at 7kya (Moy, et al. 2002). Extremely wet conditions linked to ENSO in the Cairiaco Basin on the west coast of the Americas are observed from 10.5-5.4kya (Haug, et al. 2001). SST records from the Arabian Sea also support a southward movement of the ITCZ through the Holocene linked to increased insolation, and correlated with increased ENSO activity from 2.4kya forward (Böll, et al. 2014; Böll, et al. 2015). Soil analysis from NBZ (Kafiavana) demonstrates a dry period during the main occupation phase of 10-5kya based on the chemical composition and particle size of aeolian deposits (White 1972: Appendix A)

Pollen:

There have been several pollen cores of varying timespans collected from the New Guinea highland swamps (e.g. Haberle 1996, 1998; Sniderman, et al. 2009). The longest and most complete pollen core comes from Haeapugua in the Tari Basin of Papua New Guinea (located close to the marker for the Central Cordillera in fig. 2-3) (Haberle 2007). While the Tari Basin is relatively more central than the eastern highlands, this paleoecological record still offers significant insight into past precipitation regimes.

Table 3-1: Description of pollen zones from Haeapugua in the Tari Basin, PNG. Key indicators of swamp forest biodiversity are Myrtaceae, *Dacrydium*, *Pandanus*. From Haberle 2007 p. 223.

Pollen Zone Description	palynological richness	key indicators
zone H3 (>30kya-18kya)	low to high	present
Nothofagus-rich montane forest on valley floor		
zone H4 (18kya-8.5kya)	low	present
grassland dominates with high fire incidence followed by an expansion of mixed montane forest taxa after 14.5kya		
zone H5 (8.5kya-1.7kya)	high	dominant
mixed montane swamp forest dominated by Myrtaceae until around 3kya when increased disturbance of swamp forest leads to increased dominance of *Dacrydium* and *Pandanus*		
zone H6 (1.7kya-present)	low	declining
grass and sedge dominated swampland with loss of swamp forest taxa resulting from burning and the initiation of artificial drainage of section of the swamp near the site for agricultural purposes. The increased abundance of Casuarina after 900 ya may reflect deliberate planing in nearby gardens		

In the original article on the Tari basin, Haberle employs 19 radiocarbon dates and two know tephra events to define the timescale of the Haeapugua Basin palynological record, with 13 of the ^{14}C dates and both tephra dates coming directly from the core that was analyzed for pollen (1998). The Tari Basin drains to the Tagali River, which ultimately drains out to the south coast (as opposed to the Sepik-Ramu system on the north coast), and it is located approximately 350km west and slightly north of Kainantu and the Norikori Swamp. The actual precipitation measured in the heavy fraction of sediment for the Tagali River system is not part of this analysis, and the central highlands where the Tari Basin has a different precipitation regime than the eastern highlands that is generally wetter more even throughout the year. However, Haberle synthesizes data from the Tari Basin with palynological analyses from basins around New Guinea including the Norikori Swamp in defining the ecological successions (2007). The Tari Basin is one location, but the data that inform the sequence is comprehensive across the highlands and is supported by a substantial number of dates are in good stratigraphic order. It could be argued that ecological transitions may not happen at the same time across the highlands, especially where anthropogenic burning is a major driver of plant regime change, but the comprehensive nature of Haberle's work and the strong stratigraphic control make the Haeapugua sequence the best available measure of ecological change for the New Guinea highlands.

The Haeapugua record (table 3-1) doesn't start until a few thousand years into the dry period from the Lake Towuti precipitation record with zone H3 (Haberle 2007; Russell, et al. 2014). *Nothofagus*, also known as the southern beech, inhabits the valley floors. Trees being long-lived species (as opposed to herbaceous species or grasses) are more tolerant of precipitation variability. Also the valley floors would have more moisture relative to the slopes of the valleys. Zone H4 begins at the end of the LGM with a high fire incidence. This would be consistent with droughts and generally dry conditions as indicated by the precipitation records and the observed incidence of wildfires during modern El Niño-associated droughts (Haberle 2000; Russell, et al. 2014; Tachikawa, et al. 2011). During H4 there is a shift towards mixed montane forest taxa. This would be consistent with increased precipitation and reduced El Niño activity during the BA reducing constraints on species diversity (Liu, et al. 2014). The emergence of zone H5 corresponds with the dry period associated the early Holocene Warm Period and El Niño activity. The pollen community in zone H5 changes at ~3kya, which corresponds with the establishment of modern El Niño behavior (Carré, et al. 2014; Donders, et al. 2008; Haberle 2007).

Summary:

Altogether, the precipitation patterns for the highlands of New Guinea as inferred or observed from a number of lines of evidence show that this landscape experiences generally abundant but highly variable including occasionally catastrophically low rates of rainfall. Droughts present problems for people that range from adequate drinking water supply, water for processing resources like sago, and complications to hunting wild game. Additionally droughts are often accompanied by frosts that kill useful plants, both domesticated and wild. The time from first human occupation of the highland landscape at approximately 47kya to 33kya was a period of highly variable precipitation (Russell, et al. 2014; Summerhayes, et al. 2010). Drier conditions began at 33kya and continued through the Last Glacial Maximum, after which there was an amelioration, followed by another dry period during the early Holocene Warm Period, ending in the mid-Holocene with a return to highly variable ENSO activity, with variability reduced at around 3.5-2kya. Changes in plant ecology as recorded in the pollen record of the highlands of New Guinea demonstrate changes in species frequency that chronologically correlate with changes in precipitation and El Niño activity from several proxies.

Chapter 4. Dating

Intro:

In the course of this research, two major issues regarding radiocarbon dating chronology of the archaeological record of highland Papua New Guinea needed to be resolved. The first question regards the date of oldest occupation of NFX. The other question regards the position of NFX, NBZ, and NFB in the overall distribution of sites and radiocarbon dates linked with occupations throughout the archaeological record of the PNG highlands. The first of these issues was resolved by the identification of appropriate datable material from a unit adjacent to the unit that provided the 18,050 ±750 uncalBP date originally published in Watson & Cole (p. 194; 1977). The latter of these issues was addressed by aggregating a database of all published radiocarbon dates associated with archaeological materials for the highlands of PNG and analyzing patterns of site type and other site attributes.

New radiocarbon date for NFX:

Figure 4-1: Artifact # 147, sample of wood post used for RL 370 radiocarbon date 18,050 ± 750 uncalBP plate: Tai 20 Code B Roll 1/5 (Burke Museum Archives 1979)

In the original Watson & Cole monograph, a date of 18,050 ± 750 uncalBP is published for a "sample of mineralized charcoal post." See fig. 2-17 for a picture of the post in situ during excavation. Due to what was at the time surprising antiquity of age, Watson expressed significant concerns to the contracted dating researchers about the validity of this date as well as other dates (e.g. UW 260 and 261) (Burke Museum Archives 1979). At the time these samples were dated, the state of the art of radiocarbon dating had switched from a solid-state ionization counting system originally developed by Libby, to a gas-based system (Taylor and Bar-Yosef 2014:290). Radiocarbon dating at the time was not a particularly well-understood process by most archaeologists, and two major complications were the need for large samples of organic material (10-12g) which were hard to find in archaeological

contexts, and the establishment of the need for a calibration curve based on differential concentrations of radiocarbon in the environment in the past (Taylor and Bar-Yosef 2014). Watson expressed concerns in correspondence to various researchers about changes in the water table potentially bringing older carbon up into the archaeological sites in question or other issues of contamination (e.g. July 11, 1973 letter from Wastson to J. Buckley at Teledyne Isotopes, Burke Museum Archives 1979). Corresponding researchers explained any relevant pre-treatment processes (e.g. the removal of carbonate), and the unlikelihood of a sample appearing older than an accurate date (e.g. Aug. 5, 1974 letter to Watson from C. Tucek of Radiocarbon, LTD.; Burke Museum Archives 1979; also see Tucek 1971 for description of sample pre-treatment and dating methods).
None-the-less, Watson's conservative approach towards what would have been surprisingly old dates at the time of publication is reflected in the cautionary comments made about several dates including RL 370 (18,050 ± 750 uncalBP) in the discussion of radiocarbon dates in the Watson & Cole monograph (1977:193-195). No geoarchaeological evidence is provided to support disturbance, and extensive dating that would have been able to identify disturbed contexts was not available at the time of the original research. The equivocal and conservative approach to these dates by the original authors has created ambiguity about the validity of these dates in the larger archaeological community, and re-dating of this site is necessary to clarify the oldest habitation of this site.

In order to validate or correct the oldest occupation at NFX, a significant portion of organic material was identified from the unit adjacent to the unit which provided the material for the original LGM from a level underlying the level that contains post hole fill and the artifact numbered #147 which rendered RL 370 (18,050 ± 750 uncalBP) (Burke Museum Archives 1979).

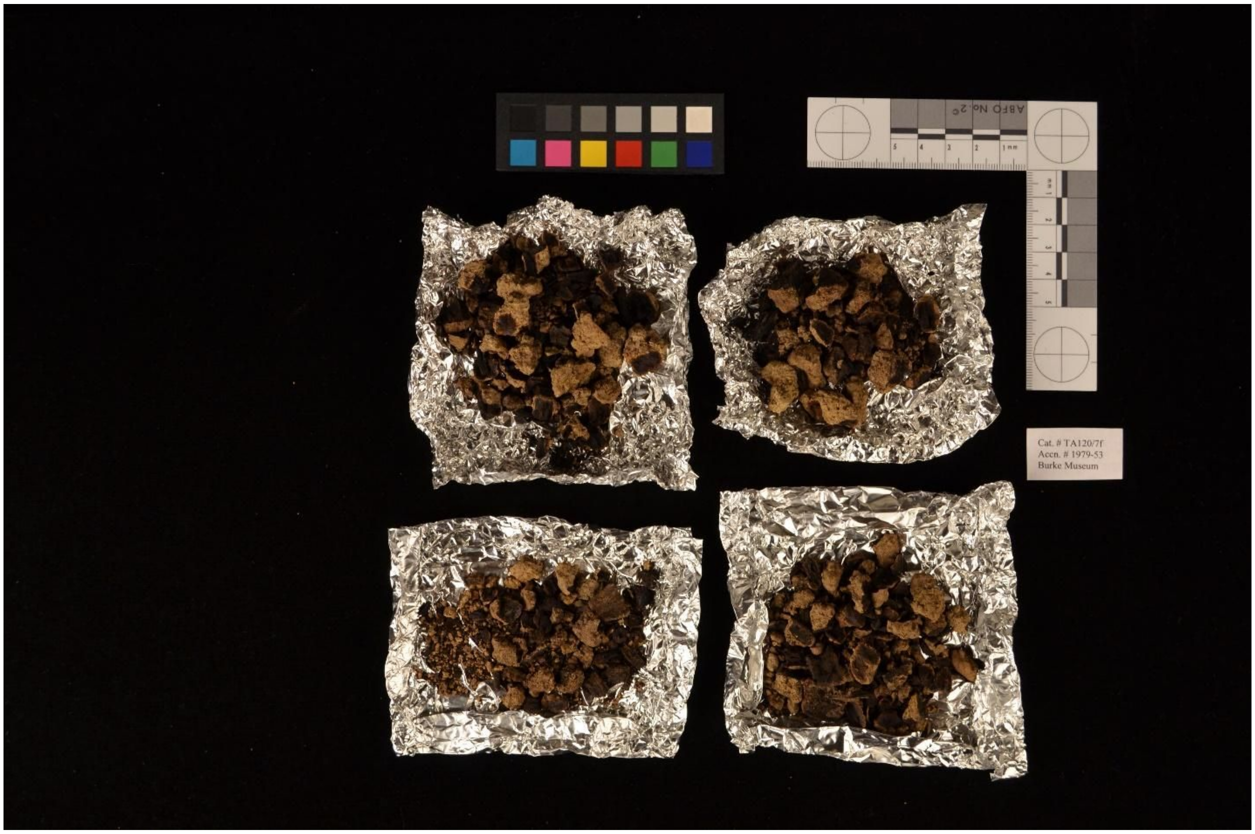

Figure 4-2: charcoal samples from NFX sample OxA-26323 17065 +/- 80bp

Cole describes the level below the postholes in 3N14W as containing significant charcoal scatter and numerous lithic artifacts in the NE portion of the unit (NFX 3N14W fieldnotes, Burke Museum Archives 1979). It is this material that was dated to clarify the validity of the ~18kya date from the 1977 publication (see fig. 4-2 for dated material) (Watson and Cole 1977).

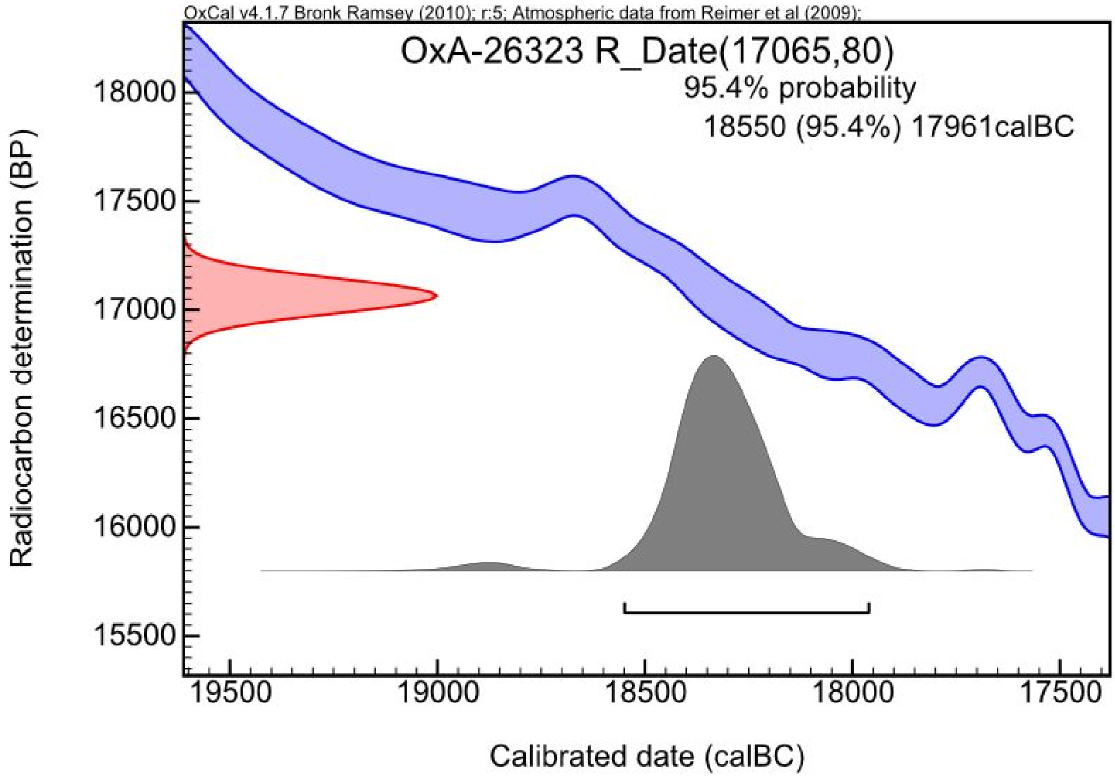

Figure 4-3: calibration of OxA-26323 using OxCal. The red distribution indicates the uncalibrated date; the grey distribution indicates the calibrated date with a 2 σ bar; blue indicates the calibration curve (using IntCal 2009) (Reimer, et al. 2011).

The sample sent in for dating was charcoal from a scatter from the adjacent unit to the ~18kya date. Species of tree was unidentified. The charcoal scatter was collected from the level below the post holes. It was associated with a small scatter of chert flakes. The new date should be considered a *terminus post quem* date for the postholes and is the earliest date for human activity at the site. The entire contents of the sample was submitted to maximize the likelihood of a result (see Bronk Ramsey, Higham, Bowles, et al. 2007 for pretreatment methods). The sample was dated using AMS (see Bronk Ramsey, Higham and Leach 2007; Bronk Ramsey, et al. 2002 for AMS methods). The radiocarbon sample derived from the contents of TAI20/7f was designated sample number

OxA-26323 and returned an uncalibrated radiocarbon date of 17,065 ± 80 years before present using the 5568 half-life (see fig. 4-3).

Using the OxCal calibration tool (Bronk Ramsey 2010a) and the IntCal 2009 (Reimer, et al. 2011) calibration curve, the new OxA-26323 provides a calibrated date of 20,471-20,701calendar years ago. This date falls within the range calibrated date for RL-370 (18,050 ± 750 uncalBP) of 20,067-23,713 calBP (see fig. 4-4). As the ~18kya date has a large margin of error, and the new ~17kya date, with a significantly smaller error margin due to improved dating methods. As both samples are from the basal archaeological levels of adjacent units, and of similar depth, the new date of ~20kya cal BP is a more accurate date for the earliest occupation of NFX.

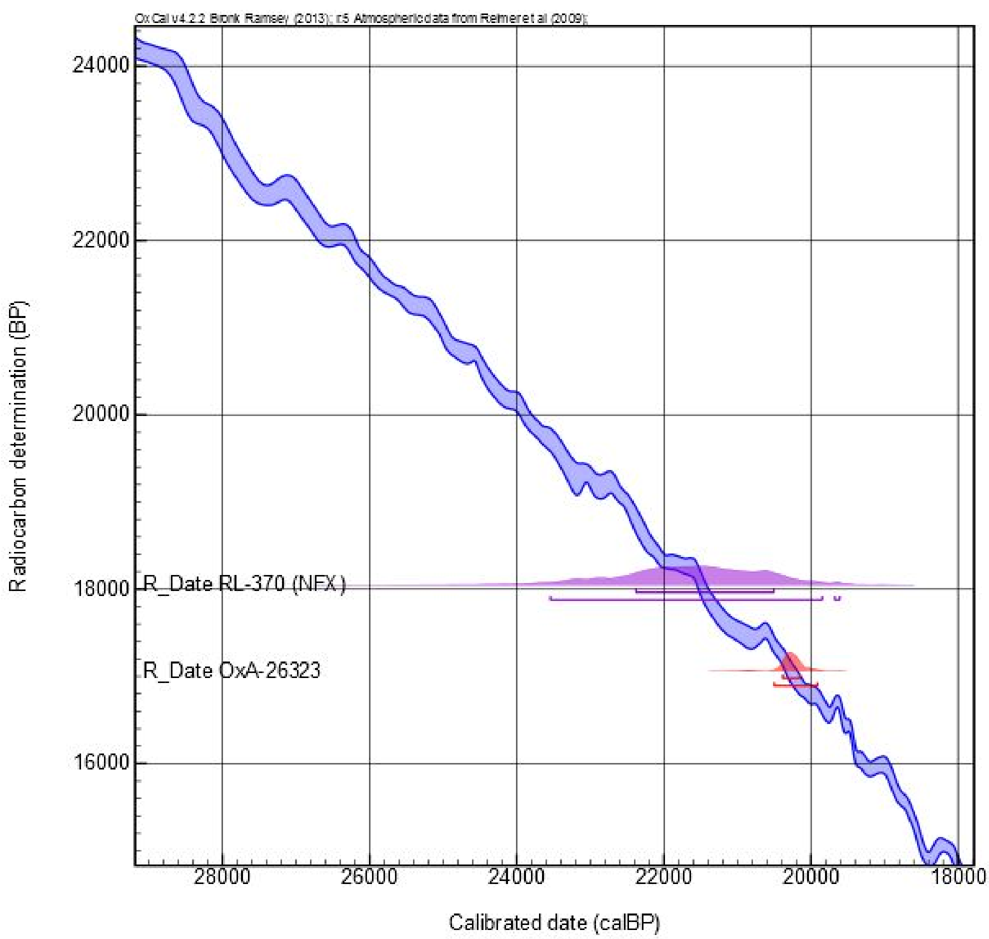

Figure 4-4: Calibrated comparison of original date of 18,050bp to new date of 17065bp (Reimer, et al. 2011).

Analysis of published dates from archaeological sites:

In order to understand the role of the sites excavated by Cole in relation to patterns of site use throughout the archaeological record of highland PNG, I aggregated a database of all published radiocarbon dates associated with archaeological material. In the case where there were discrepancies between aragonite and collagen dates for faunal material, the date asserted by the original author to be the more accurate was the date added to the database (e.g. Mountain 1991:3.13). Dates that were from archaeologically sterile basal units and not associated with any artifactual remains were not included in the database (e.g. Mountain 1991: Appendix 1). Sites were classified by a simple taxonomy of site types:

a) Open sites that contained general habitation artifacts and had features such as hearths that indicate domestic activities. There are no indications of agricultural activities at these sites.
b) Rockshelters that were sites of either general or specialized use but that were located in small caves.
c) Agricultural sites that were located in swampy areas and contained features that indicated agricultural activities such as mounds, ditches, or other small earthworks relevant to regulating moisture for plants.

All sites types contain chipped stone tools with usewear indicating several different activities and with food residues (e.g. Fullagar, et al. 2006).

This database of radiocarbon dates was analyzed using OxCal to generate uniformly calibrated dates and a graphical representation of the dates for visual comparison with various paleoclimate reconstructions both regional and global (see Appendix A for list of sample numbers, uncalibrated and calibrated dates, source publications and other details) (Bronk Ramsey 2010b).

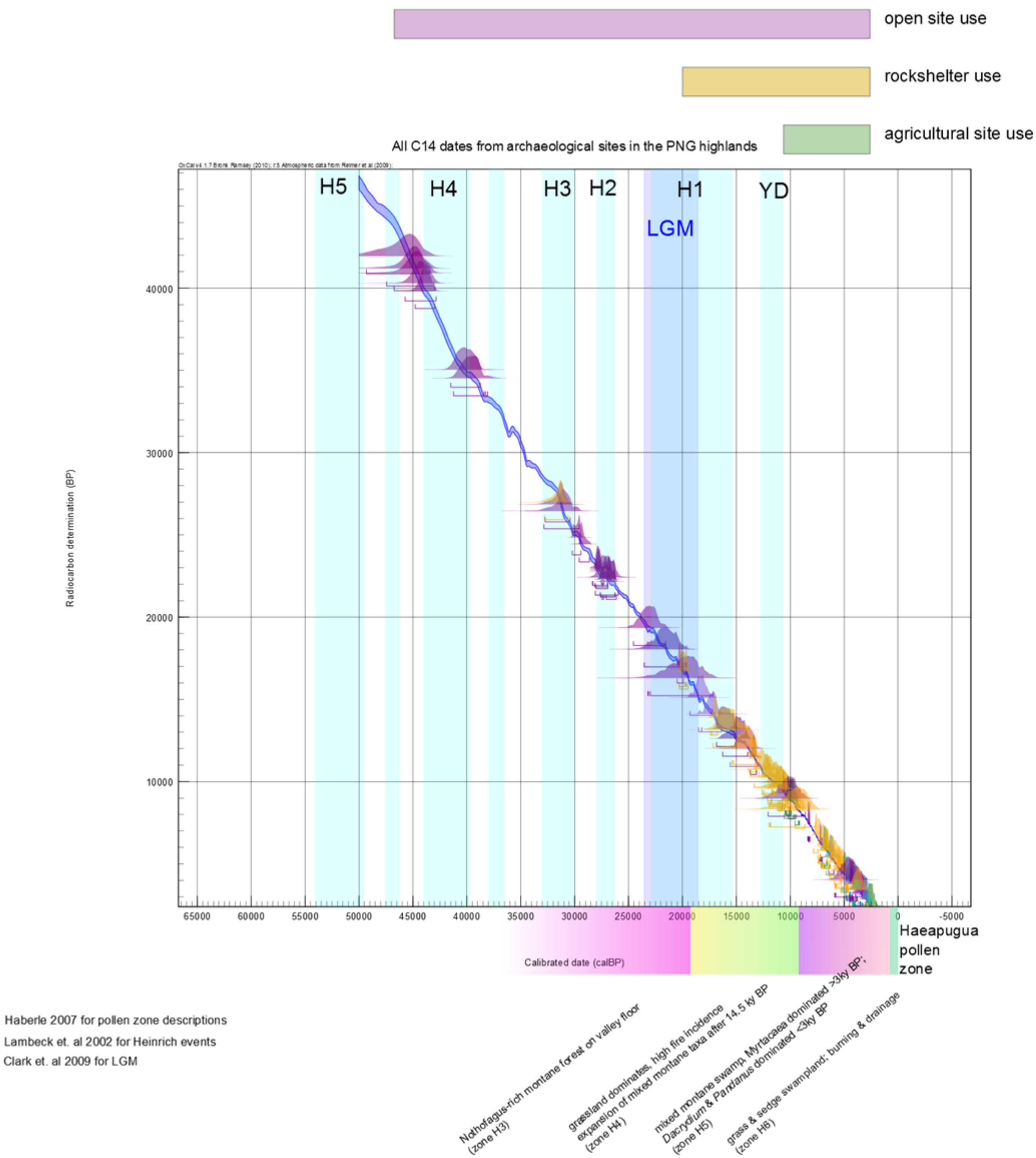

Figure 4-5: All radiocarbon dates from archaeological deposits from highland PNG calibrated using OxCal and the IntCal 2009 calibration curve. Bars at the top of the calibration show the time span for different site types. Blue bars on the main

calibration graph represent major global climate cold events. The bar below the calibration graph shows the major ecological regimes based on pollen cores from the Haeapugua Swamp (Haberle 2007).

This visual matching of radiocarbon data with global and regional climate data suggests a correlation between major climate events and shifts in site use with a possible gap around the Heinrich 4 (H4) event, the beginning of continuous use of rockshelters in the LGM (with first use of rockshelters in the H3 event), and the advent of agricultural sites at the end of the Younger Dryas. Anthropogenic fire may drive a transition from closed canopy forest to grassland very quickly, while large scale climate alterations from warmer to cooler, or wetter to drier affect plant species composition more slowly. Tropical trees generally grow quickly due to the abundance of water, although there is variability between species (Bazzaz and Pickett 1980; Nicholas 1985). The palynological ecological reconstructions (i.e. Haeapugua pollen stages) are lagging indicators, with global climate trends (e.g. LGM, YD, etc.) and archaeological site use change preceding the palynological changes see figure 4-5 above). As one might expect archaeological site use change to follow changes in ecological communities of desirable plants and animals, this was a surprising finding, indicating that a different environmental constraint was at play with the patterning of site use. Validating these possible relationships was a key target of the *SPD* analysis.

One important outcome of the comparison of all radiocarbon dates with global climate data is to establish that there was indeed an LGM occupation of the PNG highlands, contra Summerhayes et al. 2010. The dates of the LGM are defined by Clark et al. 2009 as spanning from 26.5-19kya at its maximum in the northern hemisphere. Sites in PNG that fall within this time period include AER in the Ivane Valley, NFX in the Kainantu Valley, JAO also known as Wañlek, and NAC or Nombe. The Clark et al. (2009) dates are generated from 4443 radiocarbon dates from samples, calibrated with CALIB ver. 5.02 for dates less than ~24kya, and dates with the Fairbanks calibration for dates older than ~24kya (see Clark, et al. 2009 supporting online materials for further details). The Fairbanks curve dates fall within the IntCal 2005 curve for the period of time relevant to the LGM (Fairbanks, et al. 2005;

Reimer, et al. 2011). The IntCal 2009 curve was largely an extension of the IntCal 2004 curve that only calibrated to ~26kya (Reimer, et al. 2004; Reimer, et al. 2011). The CALIB calibration program uses the IntCal curve for calibration. The new date provided above (fig. 4-3) from NFX ~20kya cal. falls within the date range of the LGM, as does the previously published oldest date from NFX from the Watson and Cole monograph ~22kya cal as well as the other dates mentioned above (Watson and Cole 1977). Haberle (2007) does not comment on his calibration strategy, but Golson (2005:231) notes that several highland PNG researchers use an unpublished table developed by Haberle for calibration, and that this table is based off of the CALIB ver. 3.1 program and presumably an early version of the IntCal calibration curve. Without further clarifying information, it is assumed here that this is the method used for calibrations in Haberle's publications.

Testing hypotheses with *SPD*

In order to test hypotheses about the relationship of changing site types and global climate phases, the radiocarbon dates in the aforementioned database were analyzed again, this time using summed probability distributions (*SPD*) and kernel density estimates (KDE). Working with William Brown of University of Washington, a number of analyses were produced. Statistical methods used are described in Brown 2015, and original R code written by Brown was used to produce these analyses. These analyses, while promising, are also provisional due to the limitations of the small number of dates available and the demand for larger sample sizes for robust results. Robust *SPD* preferably uses over 500 sites, whereas the available dataset had only approximately 130 dates total, which summed to 76 actual dates used in the analysis. Because of the sample size limitations, no demographic arguments can be made with this dataset (see Attenbrow and Hiscock 2015 for a fuller discussion of the limitations of *SPD* for demographic change). As we are not seeking to make a demographic argument but rather one of variability in site use, the results of this analysis have proven to be useful in understanding patterns in changing site types through time. Earlier in the Pleistocene, changes in proportions of site types look quite extreme, but this is an artifact of the low number of dates in this time range and may not reflect the actual population. Proportions are more reliable in the very terminal Pleistocene and through the Holocene as this is where the density of dates lies and sampling error will be less of a problem.

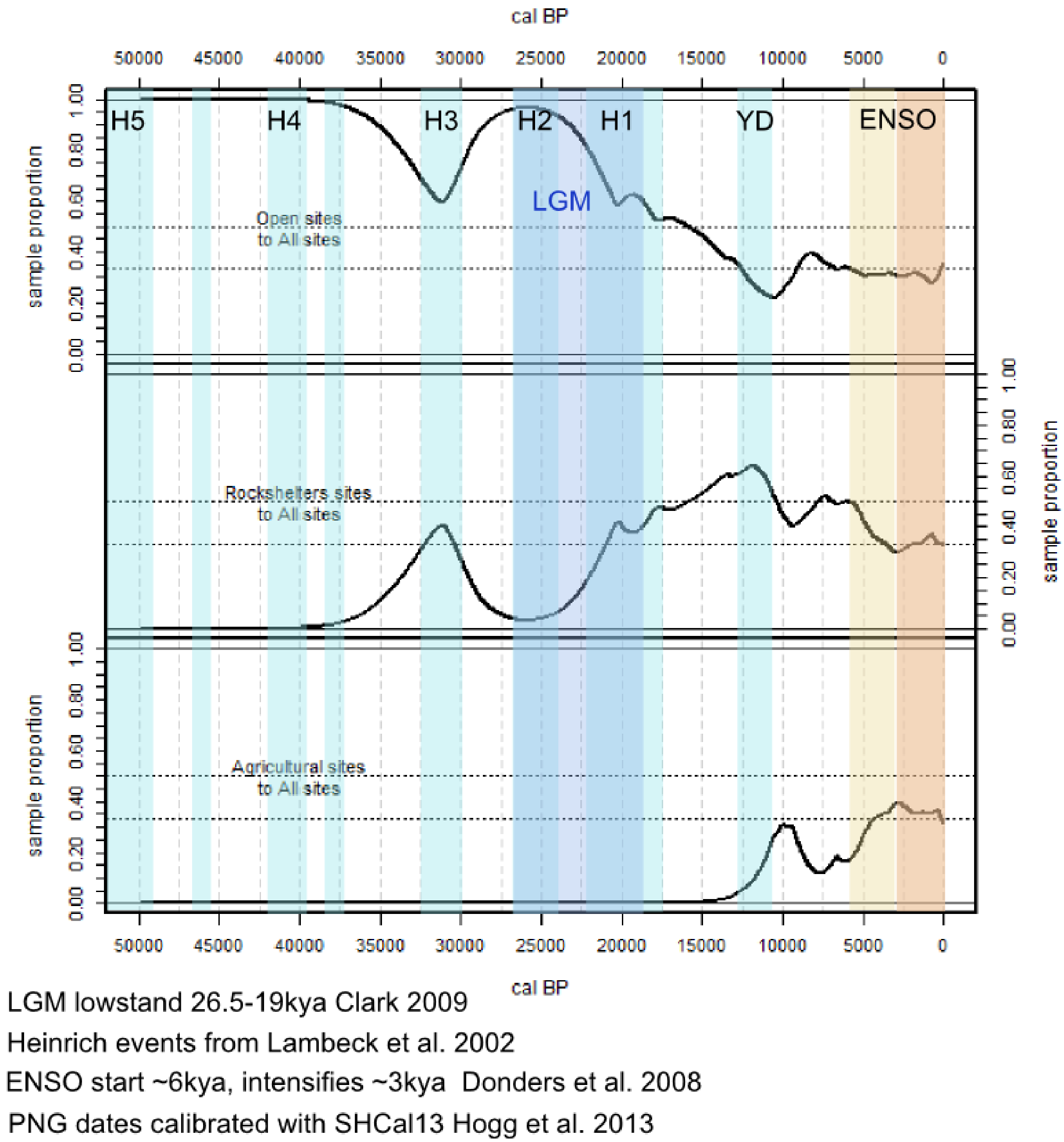

Figure 4-6: Secular variation in type-to-type proportions calculated using kernel density estimates (KDE) that have been rescaled to subset sample size. This shows the changing proportions of site types (open sites, rockshelters, and agricultural sites) as determined by all published radiocarbon dates for archaeological contexts for the highlands of Papua New Guinea. Use of logistical sites (rockshelters) begins ~33kya, intensifies after the LGM. Blue bars represent global climate cold events. Yellow and orange bars represent the onset and intensification of mid to late Holocene ENSO activity. The dates of global climate events are supported by hundreds of radiocarbon dates from various sources, details in the supporting materials of the articles.

Through the lens of *SPDs* of specific types as a ratio of all sites of all types, patterns in changing frequency of site types is confirmed. Looking at fig. 4-6, there is an initial use of rockshelters in the H3 phase (at Nombe; Evans & Mountain 2005) that is not continuous, but re-emerges in the Last Glacial Maximum when the continuous use of rockshelters begins. Open sites gain in proportion to other site types at the end of the Younger Dryas, as agricultural sites emerge, and rockshelters lose importance. Rockshelters have a steep decline in importance as agricultural site use increases in intensity in the early mid-Holocene as ENSO activity kicks up, while the proportion of open domestic sites stays relatively steady through this period. The proportions of sites (fig. 4-6) during the Pleistocene are likely distorted by the very low number of dates in this range, but the analysis becomes more robust in the very terminal Pleistocene and Holocene due to the increasing number of dates (see fig 4-7 for histogram of dates, and Appendix A for radiocarbon date data set).

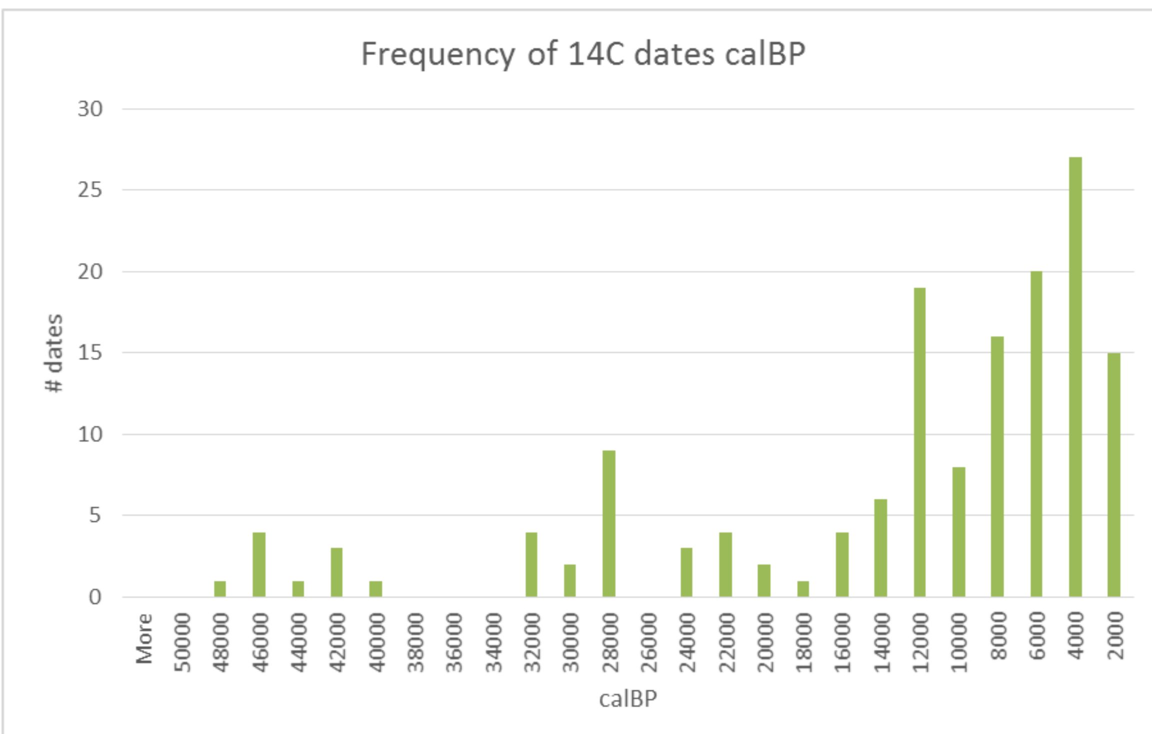

Figure 4-7: histogram of number of calibrated 14C dates used in this analysis. See Appendix A for complete details of data set.

Summary:

Through the radiocarbon analysis of organic archaeological material associated with lithic artifacts and from a similar depth in an adjacent unit, the LGM occupation of NFX is confirmed with a date of 17,065 ±80 uncalibrated radiocarbon years, or 20,701-20,471 calibrated calendar years. This new data point was incorporated into a database of all published radiocarbon dates associated with archaeological materials in for the highlands of PNG. This dataset was calibrated with OxCal using the IntCal 2009 calibration curve and compared to a number of paleoclimate datasets both regional and global. It should be noted that additional radiocarbon dates for Wañelek have been published (Gaffney, Summerhayes, et al. 2015) since the radiocarbon date database was aggregated, but it is not expected that these dates will significantly alter the final analysis of changing ratios of site types. Dates from several sites in the highlands including the new NFX date fall within the established timespan of the LGM. Additionally, this visual comparison gives rise to questions whether changing site type use is linked to larger climatic changes as opposed to local ecology. Towards evaluating the models presented in Chapter 1, the shifting importance of different site types and global climate phases are explored through a provisional summed probability distribution analysis of sites by type, and changing rates of the ratio of different site types to the whole established in relation major climate trends. Major climate changes – especially the LGM, the Younger Dryas, and the mid-Holocene increase in ENSO activity – is closely associated with changes in the proportion of site types. The use of rockshelters increases from the LGM to the YD, when agricultural sites start building in importance relative to rockshelters, while the proportion of open sites remains fairly even from the YD forward.

Chapter 5. Artifact Analysis

Introduction:

Between 2010 and 2015, I measured, quantified, and otherwise described over 2,000 unmodified flakes, 75 amorphous cores, a handful of bifacially reduced tools, and 81 unifacially reduced tools. I also cataloged hundreds of other non-lithic artifacts with some quantitative or nominal data about these objects. These objects came from the assemblages of the eastern highland Papua New Guinea archaeological sites of NBZ (Kafiavana), NFX and NFB (see fig. 5-1 for locations of sites).

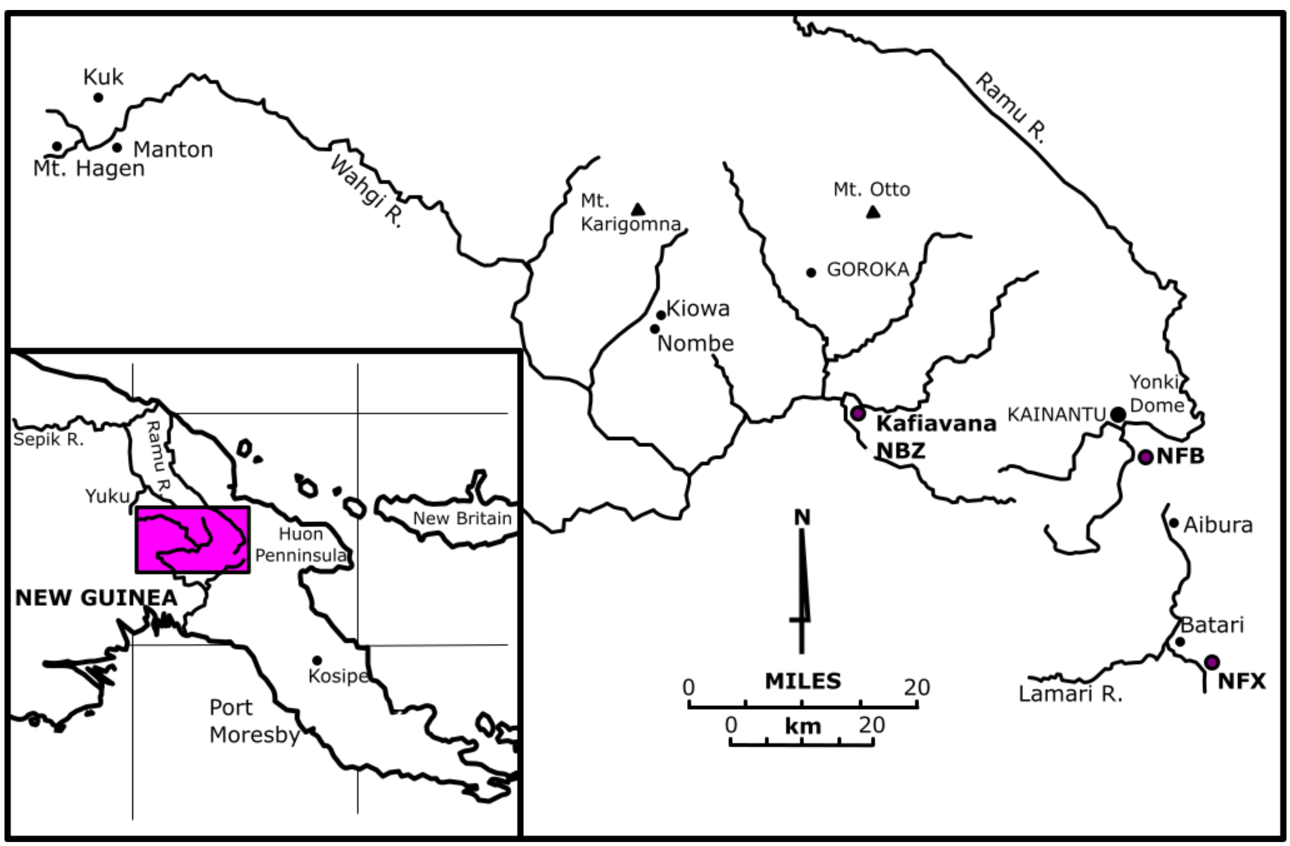

Figure 5-1: Map of archaeological sites in the eastern highlands.

I used a flexible approach towards sampling to balance between representation of assemblages and practical limitations on time. As the assemblage was quite large, I used a 10% sampling of the assemblage from NBZ. I examined a total n=1,312 artifacts from NBZ, with 1,150 of them being unmodified flakes alone. The number of artifacts in the full assemblage was not recorded, but would fall somewhere above 10,000 artifacts. At NFX the assemblage was much smaller, so I used a 100% sample of excavated materials (N=497, with expedient or unmodified flakes being 467 of that assemblage). I sampled a smaller proportion of debitage bags from NFB (n=105; levels 1-8 represented), and a 100% sample of artifacts that had been identified in the Watson/ Cole analysis of the NFB material (n=724 artifacts identified by Watson & Cole; n=829 total). Generally Watson and Cole identified lithic artifacts with evidence of usewear visible to the naked eye or with some retouch or other sort of secondary reduction. Watson and Cole also identified non-chipped stone artifacts such as raw quartz crystals, ochre, animal bone, plant samples, and pottery sherds. In the statistical analysis, I only used expedient flakes with usewear. Debitage that had not been used as a tool would be underrepresented at NFB due to limitations of sampling of the level bags that contained artifacts that were collected but not individually cataloged in the original Watson and Cole monograph (1977). I examined and recorded a total of 2,638 artifacts in the course of this project.

Results from the lithic analysis:

The original data collection design for the lithic assemblage included both a general debitage analysis strategy, and data points that were targeted at measuring intensity of reduction to be used as a proxy for mobility of past populations. Generally, the assemblage can be described as consisting of a large number of irregularly-shaped and relatively small flakes. There are also a number of bipolar reduction objects that are interpreted as bipolar cores. There are significant methodological and theoretical complexities to understanding the role of bipolar cores, variously known as scalar pieces, *pieces esquilles*, wedges, splintered pieces to name a few (e.g. Bradbury and Carr 2012; Hiscock 2015; Leblanc 1992; Shott 1989, 1999). This analysis was not designed with the intent of understanding the role of bipolar reduction in the assemblages at hand, but rather to understand retouched pieces. Between the theoretical and methodological complexities and the different research questions that shaped the analysis strategy, what can be said about the bipolar reduction strategy is fairly limited. There is also very little that can be said about the measures of reduction (GUIR and Clarkson's index of invasiveness) due to the uneven distribution of relevant artifacts in two of the sites (NFX and NFB). Bipolar reduction is the dominant strategy for reduction based on the small, irregular, expedient flakes that dominate the three assemblages considered here. Due to the ambiguity of the role of bipolar objects in the reduction sequence as either core or tool (Shott 1989, 1999), and due to the frequent presence of edge damage indicative of usewear, bipolar objects were included in the unmodified flakes dataset as they had identifiable ventral surfaces or were otherwise identifiable as the product of a chipped stone technology as opposed to being produced by natural processes.

Size and weight, as well as amount of cortex are used as measures of reduction to reveal if patterns in mobility can be detected. Sites with a large variability and a higher mean in size of artifacts are interpreted as long-term residencies, which have been provisioned with raw material, and therefore material at all stages of reduction should be present (Binford 1979; Kuhn 1991, 1993, 2004; Nelson 1991). Sites with lower means and lower variances are interpreted as sites where there is a high level of mobility, as high-quality material will be thoroughly reduced into small pieces (Binford 1979; Kuhn 1991, 1993, 1994). Likewise, sites with more cortex are interpreted as provisioned, long-term occupation sites where all stages of reduction occur; camp sites of highly mobile people will have little to no cortex as only the highest quality material will be transported in frequent moves around the landscape (Binford 1979; Nelson 1991).

Quantitative, nominal, and qualitative data about the shape and other characteristics of the lithic assemblages of NBZ, NFX and NFB was collected into a series of Microsoft Access 2010 databases. Lithic artifacts comprised the bulk of these archaeological assemblages. Data about the frequency of other artifact types was also collected. Data was exported to Microsoft Excel 2010 spreadsheets. Some analysis was conducted in Excel. Data was also imported into SPSS 19, and analysis was conducted with that application as well. All datasets as well as other electronic products such as scanned notes, digitized maps, etc., will be archived with the Burke Museum of Natural History and Culture at the University of Washington in Seattle, WA, USA.

Descriptive statistics on flakes with usewear:

Supplementary data regarding graphs and charts presented here can be found in Appendix B.

Maximum length of flakes with usewear:

Table 5-1: descriptive statistics for the max length of unmodified flakes with usewear

Max Length in mm Descriptive Statistics	*NFX*	*NBZ*	*NFB*
Mean	24.6	20.0	20.7
Standard Error	1.3	0.7	0.5
Median	22.8	18.6	19.8
Mode	13.1	14.4	15.9
Standard Deviation	11.0	8.8	7.5
Sample Variance	121.8	78.0	56.1
Kurtosis	14.8	1.2	7.2
Skewness	3.0	1.1	1.7
Range	77.7	43.8	58.6
Maximum	87.6	51.1	65.5

Minimum	10.0	7.3	6.8
Sum	1718.8	3223.4	5555.8
Count	70.0	161.0	268.0
Geometric Mean	22.9	18.3	19.6
Harmonic Mean	21.5	16.8	18.5
AAD	7.2	6.8	5.6
MAD	5.3	5.7	4.5
IQR	10.3	11.1	9.1

The boxplot (see fig. 5-2) is a useful tool for visualizing the differences in sample populations. The boxplot shows quartiles, with the transition between colors in the solid box representing the mean of that distribution. See Appendix C for quartile transitional values for boxplot. The long upward tail of the lengths of the expedient flakes with usewear is to be expected since there is a lower limit in which a) people are able to use a tool, and b) that researchers will be able to collect using standard excavation methods such as screening with hardware cloth. Moreover, stone tool production is a reductive technology – smaller tools are made out of larger ones. This is especially true of the expedient collections here where every object is recycled without specific constraints to shape, and the distinction between “core” and “tool” is largely irrelevant.

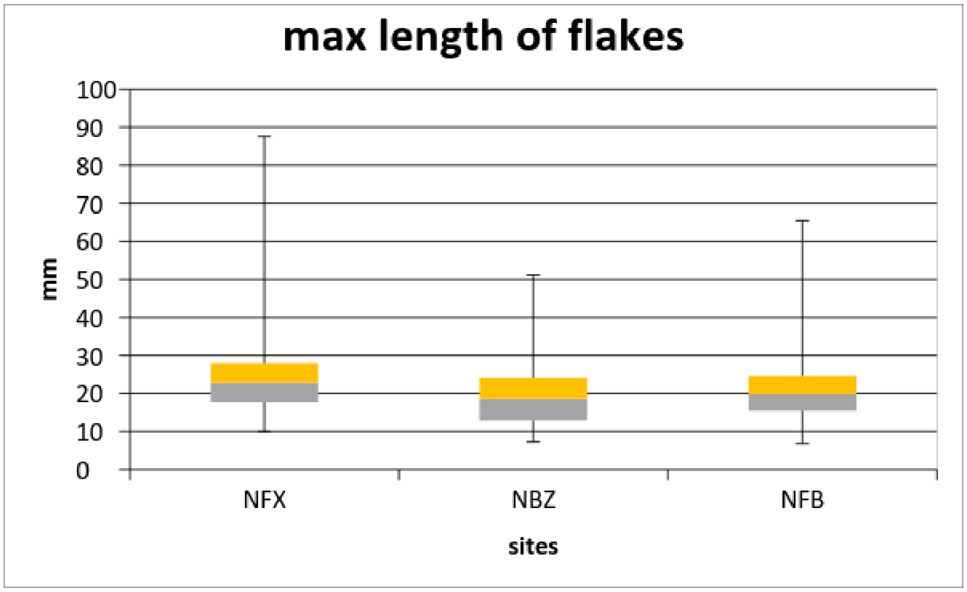

Figure 5-2: Sites are ordered oldest to youngest. ^{14}C dates indicate NFX was occupied from ~18kya-11.5kya; NBZ from ~10kya-5kya; NFB from ~3.8kya-185ya. This is graphical boxplot of distribution of values for maximum length in mm of flakes with usewear. Transitional values can be found in Appendix C.

ANOVA, or Analysis of Variance, is a statistical strategy to compare multiple populations at the same time instead of only a pairwise comparison. ANOVA does not analyze variance, but rather the means of several sample sets simultaneously to determine whether or not they come from the same population. An F test score that is substantially higher than 1 indicates that there are substantial differences in the means of the sample sets, and they are determined to not being from the same underlying population. A low P-value indicates that the likelihood of getting the F test score when the null hypothesis (that the sample sets come from the same population) is extremely unlikely, supporting the falsification of the null hypothesis. ANOVA is robust against violations of the assumption of normal distribution, so skew (table 5-1) in this case is not a problem (Drennan 1996; Ramsey, et al. 2001).

Table 5-2: ANOVA analysis of distributions for values of maximum length of unmodified flakes in mm with usewear. High F value and low P value confirms that differences in means are not random.

ANOVA: Single Factor								
DESCRIPTION					Alpha	0.05		
Groups	*Count*	*Sum*	*Mean*	*Variance*	*SS*	*Std Err*	*Lower*	*Upper*
NFX	70	1718.79	24.55414	121.7583	8401.324	1.01634	22.5266	26.58169
NBZ	161	3223.35	20.02081	78.02228	12483.56	0.670155	18.69732	21.3443
NFB	268	5555.76	20.73045	56.10123	14979.03	0.519422	19.70776	21.75313
ANOVA								
Sources	*SS*	*df*	*MS*	*F*	*P value*	*F crit*	*RMSSE*	*Omega Sq*
Between Groups	1057.362	2	528.6808	7.311685	0.000742	3.013899	0.286761	0.024673
Within Groups	35863.92	496	72.30628					
Total	36921.28	498	74.13911					

As the ANOVA (table 5-2) shows us that the length of unmodified flakes with usewear from all three sites don’t come from the same parent population, a set of T-tests are used to determine where the difference lies. The T-test is robust to skewed distributions when the numbers are large (Ramsey, et al. 2001).

Table 5-3: T-Test for distributions of maximum length of unmodified flakes between NFX & NFB. High t-stat and low p-values indicate that these assemblages represent different populations.

comparing the max length of NFX & NFB									
T Test: Two Independent Samples									
SUMMARY			Hyp Mean	0					
Groups	*Count*	*Mean*	*Variance*	*Cohen d*					
NFX	70	24.55414	121.7583						
NFB	268	20.73045	56.10123						
Pooled			69.58438	0.458382					
T TEST: Equal Variances				Alpha	0.05				
	std err	*t-stat*	*df*	*p-value*	*t-crit*	*lower*	*upper*	*sig*	*effect r*
One Tail	1.11969	3.414959	336	0.000358	1.649401			yes	0.18315
Two Tail	1.11969	3.414959	336	0.000716	1.967049	1.62121	6.026181	yes	0.18315
T TEST: Unequal Variances				Alpha	0.05				
	std err	*t-stat*	*df*	*p-value*	*t-crit*	*lower*	*upper*	*sig*	*effect r*
One Tail	1.395972	2.739092	86.28436	0.003742	1.662765			yes	0.282836
Two Tail	1.395972	2.739092	86.28436	0.007484	1.987934	1.048595	6.598795	yes	0.282836

As the variances (table 5-3) between NFX and NFB are fairly dissimilar (without performing an F-test), the lower part of the table for T-TEST: Unequal Variances should be used. In both cases (one-tail and two tail) the *t-stat* is greater than the *t-crit*, and the *p-values* are quite low (<0.05), and the null hypothesis that the means are statistically the same is rejected. NFX and NFB have different means to their distributions.

Table 5-4: T-Test for distributions of maximum length of unmodified flakes between NBZ & NFB. High p-values indicate that these populations are statistically the same.

comparing the max length of NBZ & NFB									
T Test: Two Independent Samples									
SUMMARY			Hyp Mean	0					
Groups	*Count*	*Mean*	*Variance*	*Cohen d*					
NBZ	161	20.02081	78.02228						
NFB	268	20.73045	56.10123						
Pooled			64.3152	0.088487					
T TEST: Equal Variances				Alpha	0.05				
	std err	*t-stat*	*df*	*p-value*	*t-crit*	*lower*	*upper*	*sig*	*effect r*
One Tail	0.79966	0.887428	427	0.187674	1.64843			no	0.042906
Two Tail	0.79966	0.887428	427	0.375348	1.965535	-2.2814	0.862119	no	0.042906
T TEST: Unequal Variances				Alpha	0.05				
	std err	*t-stat*	*df*	*p-value*	*t-crit*	*lower*	*upper*	*sig*	*effect r*
One Tail	0.833033	0.851876	295.0871	0.197487	1.650035			no	0.04953
Two Tail	0.833033	0.851876	295.0871	0.394974	1.968038	-2.34908	0.9298	no	0.04953

Table 5-4 demonstrates that under all conditions (one-tail, two-tail; equal variance, unequal variance) the means of the sample populations between NBZ and NFX are statistically the same.

Table 5-5: T-Test for distributions of maximum length of unmodified flakes between NFX & NBZ. Low p-values indicate that these assemblages represent different populations.

comparing the max length of NFX & NBZ										
T Test: Two Independent Samples										
SUMMARY			Hyp Mean	0						
Groups	*Count*	*Mean*	*Variance*	*Cohen d*						
NFX	70	24.55414	121.7583							
NBZ	161	20.02081	78.02228							
Pooled			91.20039	0.4747						
T TEST: Equal Variances				Alpha	0.05					
	std err	*t-stat*	*df*	*p-value*	*t-crit*	*lower*	*upper*	*sig*	*effect r*	
One Tail	1.367233	3.315702	229	0.000531	1.651535			yes	0.21403	
Two Tail	1.367233	3.315702	229	0.001063	1.970377	1.839372	7.227299	yes	0.21403	
T TEST: Unequal Variances				Alpha	0.05					
	std err	*t-stat*	*df*	*p-value*	*t-crit*	*lower*	*upper*	*sig*	*effect r*	
One Tail	1.491313	3.039828	109.15	0.001482	1.658953			yes	0.279377	
Two Tail	1.491313	3.039828	109.15	0.002963	1.981967	1.577601	7.48907	yes	0.279377	

Table 5-5 demonstrates that under no circumstances are the means between NFX and NBZ the same. Returning to the ANOVA (table 5-3), this means that the sample population that does not match the others is NFX. The mean length of unmodified tools at NFX is statistically different (larger) than the means for the other sites.

Medial width of flakes with usewear:

Table 5-6: descriptive statistics for the maximum width of unmodified flakes with usewear

medial width in mm Descriptive Statistics			
	NFX	*NBZ*	*NFB*
Mean	18.3	16.2	14.9
Standard Error	1.3	0.62	0.3
Median	16.9	14.8	14.3
Mode	29.1	18.2	11.4
Standard Deviation	11.0	7.9	5.3
Sample Variance	120.6	62.7	27.8
Kurtosis	13.7	2.6	2.6
Skewness	2.9	1.4	1.1
Range	74.6	45.9	34.3
Maximum	79.8	50.9	38.8

Minimum	5.2	5.0	4.5
Sum	1284.5	2611.8	4016.7
Count	70	161	269
Geometric Mean	16.1	14.6	14.1
Harmonic Mean	14.3	13.2	13.2
AAD	7.1	6.0	4.1
MAD	5.5	4.5	3.3
IQR	10.2	9.1	6.6

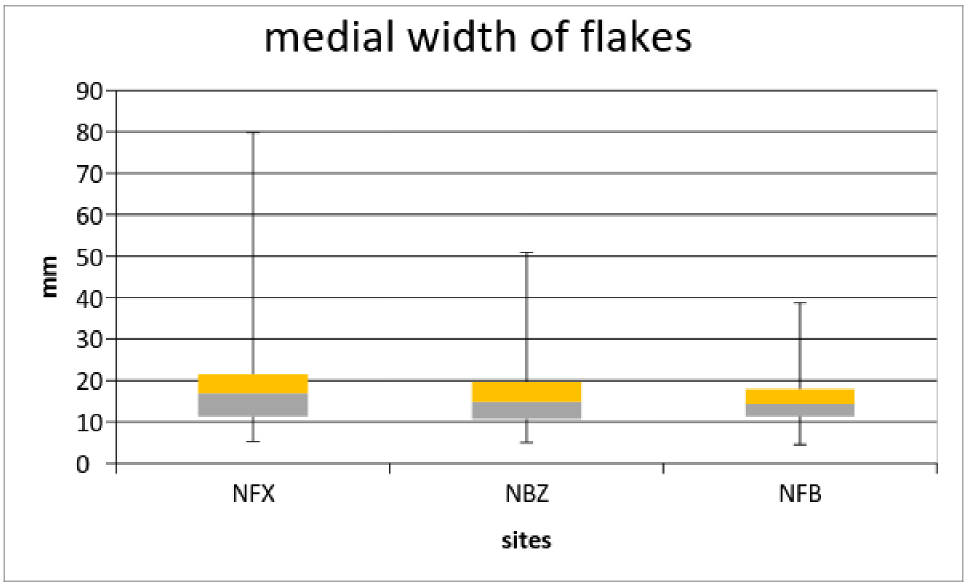

Figure 6-3: graphical boxplot of distribution of values for medial width of flakes with usewear

Numeric data (table 5-6) and boxplots (fig. 5-3) for the distribution of medial width of unmodified flakes with usewear. Visually, NFX appears to be different. See Appendix C for table of quartile transitional values for boxplot.

Table 5-7: ANOVA analysis of distributions for values of medial width of unmodified flakes with usewear. High F value relative to F-crit and low P value confirms that differences in means are not random.

medial width in mm
ANOVA: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*

NFX	70	1284.49	18.34986	120.596
NBZ	161	2611.81	16.22242	62.74127
NFB	269	4016.71	14.93201	27.7699

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	686.182	2	343.091	6.608628	0.00147	3.013862
Within Groups	25802.06	497	51.91562			
Total	26488.24	499				

The ANOVA analysis in table 5-7 demonstrates that the means are not equal, or that the sample sets do not come from the same parent population.

Table 5-8: T-Test for distributions of medial width of unmodified flakes between NFX & NFB. High t-statistic values and low p-values indicate that these assemblages represent different populations.

comparing the medial width of NFX & NFB									
T Test: Two Independent Samples									
SUMMARY			Hyp Mean	0					
Groups	*Count*	*Mean*	*Variance*	*Cohen d*					
NFX	70	18.34986	120.596						
NFB	269	14.93201	27.7699						
Pooled			46.77584	0.499738					
T TEST: Equal Variances				Alpha	0.05				
	std err	*t-stat*	*df*	*p-value*	*t-crit*	*lower*	*upper*	*sig*	*effect r*
One Tail	0.917668	3.724496	337	0.000115	1.649388			yes	0.198835
Two Tail	0.917668	3.724496	337	0.000229	1.967028	1.612771	5.222928	yes	0.198835
T TEST: Unequal Variances				Alpha	0.05				
	std err	*t-stat*	*df*	*p-value*	*t-crit*	*lower*	*upper*	*sig*	*effect r*
One Tail	1.351308	2.529289	77.44541	0.00673	1.664885			yes	0.276227
Two Tail	1.351308	2.529289	77.44541	0.013461	1.991254	0.727051	6.108648	yes	0.276227

Table 5-8 shows that there is a difference in the means between NFX and NFB in all cases; they do not come from the same parent population.

Table 5-9: T-Test for distributions of medial width of unmodified flakes between NFX & NBZ. Using the TTEST for unequal variances, the low t-statistic and high p-value indicates that these two populations have statistically the same mean.

comparing the medial width of NFX & NBZ									
T Test: Two Independent Samples									
SUMMARY			Hyp Mean	0					
Groups	*Count*	*Mean*	*Variance*	*Cohen d*					
NFX	70	18.34986	120.596						
NBZ	161	16.22242	62.74127						
Pooled			80.17349	0.237597					
T TEST: Equal Variances				Alpha	0.05				
	std err	*t-stat*	*df*	*p-value*	*t-crit*	*lower*	*upper*	*sig*	*effect r*
One Tail	1.281916	1.659575	229	0.049184	1.651535			yes	0.109014
Two Tail	1.281916	1.659575	229	0.098369	1.970377	-0.39842	4.653292	no	0.109014
T TEST: Unequal Variances				Alpha	0.05				
	std err	*t-stat*	*df*	*p-value*	*t-crit*	*lower*	*upper*	*sig*	*effect r*
One Tail	1.453443	1.46372	101.5063	0.07318	1.65993			no	0.143773
Two Tail	1.453443	1.46372	101.5063	0.14636	1.983495	-0.75546	5.010333	no	0.143773

Keeping in mind that there are large differences between the variance of NFX and NBZ, the T-test for unequal variances is the appropriate test to examine here (table 5-9). The p-values exceed our significance of 0.05, so it cannot be stated that the means of these two populations are different.

Table 5-10: T-Test for distributions of medial width of unmodified flakes between NBZ & NFB. Using the TTEST for unequal variances, there are contradictory results between the one-tailed and two tailed test. Using the two-tailed, test, a t-statistic value lower than t-crit but a p-value greater than 0.05 means we cannot reject the null hypothesis that these means come are from the same parent population at a 95% level of confidence.

comparing the medial width of NBZ & NFB									
T Test: Two Independent Samples									
SUMMARY			Hyp Mean	0					
Groups	*Count*	*Mean*	*Variance*	*Cohen d*					
NBZ	161	16.22242	62.74127						
NFB	269	14.93201	27.7699						
Pooled			40.84331	0.201915					
T TEST: Equal Variances				Alpha	0.05				
	std err	*t-stat*	*df*	*p-value*	*t-crit*	*lower*	*upper*	*sig*	*effect r*
One Tail	0.636804	2.026393	428	0.021672	1.648422			yes	0.097483
Two Tail	0.636804	2.026393	428	0.043344	1.965522	0.038763	2.542067	yes	0.097483
T TEST: Unequal Variances				Alpha	0.05				
	std err	*t-stat*	*df*	*p-value*	*t-crit*	*lower*	*upper*	*sig*	*effect r*
One Tail	0.702091	1.837961	245.7045	0.033638	1.651071			yes	0.116457
Two Tail	0.702091	1.837961	245.7045	0.067275	1.969654	-0.09246	2.673291	no	0.116457

The results of table 5-10 require a bit of consideration. The one-tailed test for unequal variances does provide a significant result that the mean of NBZ is indeed larger than the mean of NFB. However, the two-tailed test is more appropriate here since the question that is being asked is whether the sample sets reflect the same underlying population of artifact proportions. While the t-stat value is lower than the t-crit value, the p-value is greater than 0.05, and therefore the null hypothesis that these two sample populations are similar is supported.

Maximum thickness of flakes with usewear:

Table 5-11: descriptive statistics for the maximum width of unmodified flakes with usewear

max thick in mm Descriptive Statistics	*NFX*	*NBZ*	*NFB*
Mean	7.3	5.3	7.4
Standard Error	0.7	0.4	0.3
Median	5.9	3.7	6.5
Mode	#N/A	3.5	6.5
Standard Deviation	5.9	5.3	4.1
Sample Variance	35.3	28.4	17.0
Kurtosis	9.4	50.8	0.4
Skewness	2.5	5.9	0.9
Range	36.2	54.7	20.4
Maximum	37.7	55.8	21.7
Minimum	1.5	1.1	1.2
Sum	508.2	859.3	1981.4
Count	70	161	269
Geometric Mean	5.6	4.2	6.3
Harmonic Mean	4.5	3.5	5.2
AAD	4.1	3.0	3.3
MAD	2.6	1.4	2.6
IQR	5.4	3.8	5.3

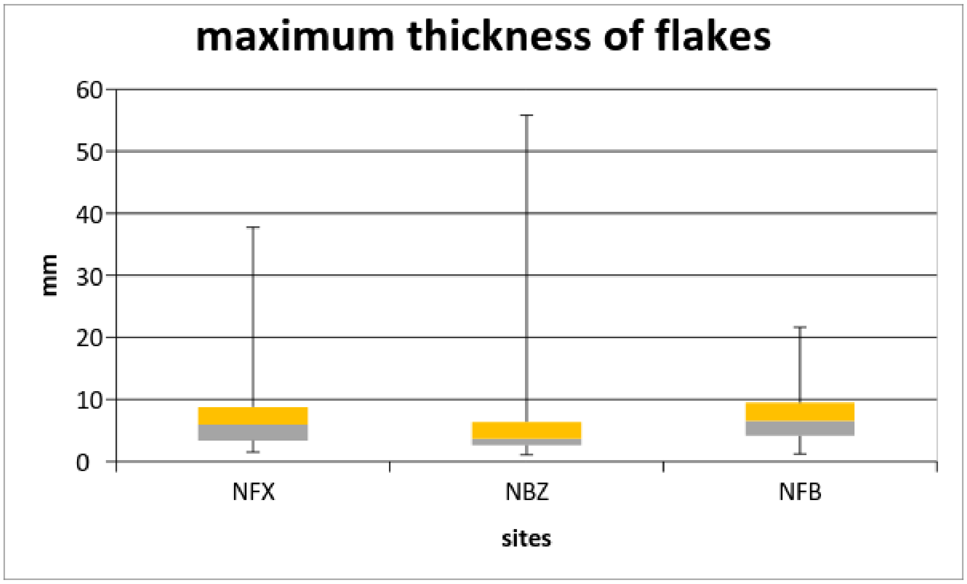

Figure 5-4: graphical boxplot of distribution of values for maximum thickness of flakes with usewear

The boxplot (fig. 5-4) of maximum thickness shows that NBZ has the most extreme value for this measurement, but if the descriptive statistics (table 5-11) are considered, NFX has a larger standard deviation. NBZ has a lower mean than NFX does, and NFB has the smallest range of thickness and the lowest standard deviation, but the highest mean values, although the mean is comparable to NFX.

Table 5-12: ANOVA analysis of distributions for values of maximum thickness of unmodified flakes with usewear. High F value and low P value confirm that the distributions are statistically different and these differences are not random.

ANOVA: Single Factor								
DESCRIPTION					Alpha	0.05		
Groups	*Count*	*Sum*	*Mean*	*Variance*	*SS*	*Std Err*	*Lower*	*Upper*
NFX	70	508.19	7.259857	35.25042	2432.279	0.575581	6.111604	8.40811
NBZ	161	859.32	5.337391	28.38723	4541.957	0.379527	4.587863	6.08692
NFB	269	1981.41	7.365836	16.98309	4551.469	0.293616	6.787749	7.943923
ANOVA								
Sources	*SS*	*df*	*MS*	*F*	*P value*	*F crit*	*RMSSE*	*Omega Sq*
Between (	440.1255	2	220.0628	9.489328	9.03E-05	3.013862	0.237093	0.032842
Within Gr	11525.7	497	23.19055					
Total	11965.83	499	23.97962					

The extremely high F score relative to F-crit, and the extremely low p-value indicate that these three means do not come from the same underlying population (table 5-12).

Table 5-13: T-Test for distributions of maximum thickness of unmodified flakes between NFX & NFB. Low t-statistic values and high p-values indicate that these populations are statistically the same.

comparing the distributions of max thickness for NFX & NFB									
T Test: Two Independent Samples									
SUMMARY			Hyp Mean	0					
Groups	*Count*	*Mean*	*Variance*	*Cohen d*					
NFX	70	7.259857	35.25042						
NFB	269	7.365836	16.98309						
Pooled			20.72329	0.02328					
T TEST: Equal Variances				Alpha	0.05				
	std err	*t-stat*	*df*	*p-value*	*t-crit*	*lower*	*upper*	*sig*	*effect r*
One Tail	0.610807	0.173507	337	0.431179	1.649388			no	0.009451
Two Tail	0.610807	0.173507	337	0.862357	1.967028	-1.30745	1.095495	no	0.009451
T TEST: Unequal Variances				Alpha	0.05				
	std err	*t-stat*	*df*	*p-value*	*t-crit*	*lower*	*upper*	*sig*	*effect r*
One Tail	0.752802	0.14078	87.03358	0.444185	1.662557			no	0.015089
Two Tail	0.752802	0.14078	87.03358	0.888369	1.987608	-1.60226	1.390297	no	0.015089

NFB and NFX have virtually identical means, and this is confirmed by the T TEST for unequal variances (Table 5-13).

Table 5-14: T-Test for distributions of maximum thickness of unmodified flakes between NFX & NBZ. High t-statistic values and low p-values indicate that these populations are statistically different, with the mean for NFX being statistically larger.

comparing the distributions of max thickness for NFX & NBZ									
T Test: Two Independent Samples									
SUMMARY			Hyp Mean	0					
Groups	*Count*	*Mean*	*Variance*	*Cohen d*					
NFX	70	7.259857	35.25042						
NBZ	161	5.337391	28.38723						
Pooled			30.45518	0.34836					
T TEST: Equal Variances				Alpha	0.05				
	std err	*t-stat*	*df*	*p-value*	*t-crit*	*lower*	*upper*	*sig*	*effect r*
One Tail	0.790086	2.433235	229	0.007866	1.651535			yes	0.158754
Two Tail	0.790086	2.433235	229	0.015731	1.970377	0.365698	3.479234	yes	0.158754
T TEST: Unequal Variances				Alpha	0.05				
	std err	*t-stat*	*df*	*p-value*	*t-crit*	*lower*	*upper*	*sig*	*effect r*
One Tail	0.824558	2.331511	119.4613	0.010701	1.657759			yes	0.208622
Two Tail	0.824558	2.331511	119.4613	0.021402	1.9801	0.289759	3.555173	yes	0.208622

The t-stat in all cases shows a significant difference between NFX and NBZ (table 5-14). Comparison of NBZ and NFB is omitted here, since NFX and NFB are statistically from the same population, and NFX and NBZ are statistically from different populations. Therefore NBZ and NFB will also statistically be from different populations.

Weight in g of flakes with usewear:

Table 5-15: descriptive statistics for the weight in grams of unmodified flakes with usewear

Weight in g Descriptive Statistics	*NFX*	*NBZ*	*NFB*
Mean	5.8	2.4	2.9
Standard Error	2.1	0.3	0.2
Median	1.9	0.8	1.7
Mode	0.5	0.3	1.8
Standard Deviation	17.7	4.1	3.4
Sample Variance	312.2	17.0	11.3
Kurtosis	56.8	13.1	5.6
Skewness	7.3	3.4	2.2
Range	144.4	24.5	18.4
Maximum	144.4	24.5	18.5
Minimum	0	0	0.12
Sum	405.3	384.9	780.8
Count	70	161	269
AAD	6.5	2.5	2.4
MAD	1.5	0.6	1.1
IQR	4.4	2.0	2.9

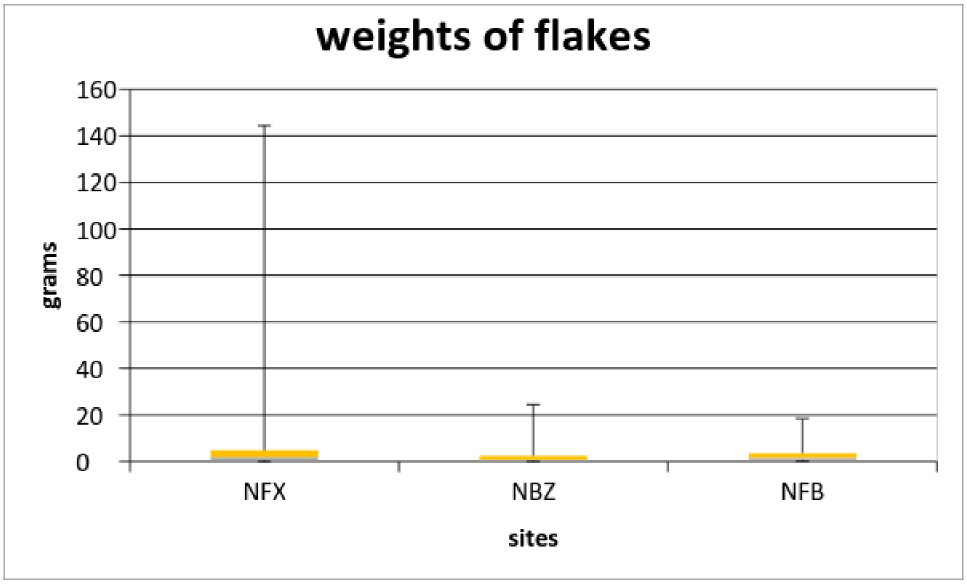

Figure 5-5: graphical boxplot of distribution of values for weight of flakes with usewear

NFX has extreme values for weight of flakes. NFX also has the lowest number of artifacts (table 5-15), so these extreme values are likely dragging up the mean and standard deviation.

Table 5-16: ANOVA analysis of distributions for values of weight of unmodified flakes with usewear. High F value and low P value confirm that the distributions are statistically different and these differences are not random.

ANOVA: Single Factor								
DESCRIPTION					Alpha	0.05		
Groups	*Count*	*Sum*	*Mean*	*Variance*	*SS*	*Std Err*	*Lower*	*Upper*
NFX	70	405.27	5.789571	312.1628	21539.24	0.885755	4.022539	7.556604
NBZ	161	384.92	2.390807	17.00971	2721.553	0.58405	1.237367	3.544248
NFB	269	780.82	2.902677	11.32134	3034.12	0.451842	2.013065	3.792288
ANOVA								
Sources	*SS*	*df*	*MS*	*F*	*P value*	*F crit*	*RMSSE*	*Omega Sq*
Between Groups	596.9323	2	298.4662	5.434628	0.004626	3.013862	0.247272	0.017429
Within Groups	27294.91	497	54.91933					
Total	27891.84	499	55.89547					

The high F-value relative to F-crit and the low P-value shows that these means are not reflective of the same population (table 5-16).

Table 5-17: T-Test for distributions of weight of unmodified flakes between NFX & NFB. Using the TTEST for unequal variances, the low t-statistic and high p-value indicates that these two populations have statistically the same mean.

comparison of weights for NFX & NFB									
T Test: Two Independent Samples									
SUMMARY			Hyp Mean	0					
Groups	*Count*	*Mean*	*Variance*	*Cohen d*					
NFX	70	5.789571	312.1628						
NFB	269	2.902677	11.32134						
Pooled			72.91797	0.338075					
T TEST: Equal Variances				Alpha	0.05				
	std err	*t-stat*	*df*	*p-value*	*t-crit*	*lower*	*upper*	*sig*	*effect r*
One Tail	1.145756	2.519643	337	0.006105	1.649388			yes	0.135979
Two Tail	1.145756	2.519643	337	0.012209	1.967028	0.633161	5.140628	yes	0.135979
T TEST: Unequal Variances				Alpha	0.05				
	std err	*t-stat*	*df*	*p-value*	*t-crit*	*lower*	*upper*	*sig*	*effect r*
One Tail	2.121687	1.36066	70.30693	0.088984	1.666914			no	0.160179
Two Tail	2.121687	1.36066	70.30693	0.177967	1.994437	-1.34468	7.118466	no	0.160179

As the variances are extremely different, the T TEST for unequal variances is used here (table 5-17), and surprisingly there is no significant difference between NFX, which has extreme values and a higher mean.

Table 5-18: T-Test for distributions of weight of unmodified flakes between NFX & NBZ. Using the TTEST for unequal variances, the low t-statistic and high p-value indicates that these two populations have statistically the same mean.

comparison of weights for NFX & NBZ									
T Test: Two Independent Samples									
SUMMARY			Hyp Mean	0					
Groups	*Count*	*Mean*	*Variance*	*Cohen d*					
NFX	70	5.789571	312.1628						
NBZ	161	2.390807	17.00971						
Pooled			105.9423	0.330207					
T TEST: Equal Variances				Alpha	0.05				
	std err	*t-stat*	*df*	*p-value*	*t-crit*	*lower*	*upper*	*sig*	*effect r*
One Tail	1.473597	2.306441	229	0.01099	1.651535			yes	0.150674
Two Tail	1.473597	2.306441	229	0.02198	1.970377	0.495222	6.302306	yes	0.150674
T TEST: Unequal Variances				Alpha	0.05				
	std err	*t-stat*	*df*	*p-value*	*t-crit*	*lower*	*upper*	*sig*	*effect r*
One Tail	2.136614	1.590724	72.29062	0.058018	1.666294			no	0.183901
Two Tail	2.136614	1.590724	72.29062	0.116036	1.993464	-0.8605	7.658026	no	0.183901

The difference in variance in the distributions of weight in grams of unmodified flakes with usewear between NFX and NBZ is extreme, therefore the T TEST for unequal variances is the appropriate test to evaluate these sample populations (table 5-18). While NFX has extreme values, its mean is still statistically similar to the mean of the population at NBZ. This result is somewhat contradictory to the results of the ANOVA as NFX with the higher mean and extreme values driving a larger variance has no significant difference from the means of either of the other sites in a pairwise comparison using the T TEST.

Table 5-19: T-Test for distributions of weight in grams of unmodified flakes between NBZ & NFB. Using the TTEST for unequal variances, the low t-statistic and high p-value indicates that these two populations have statistically the same mean.

comparison of weights for NBZ & NFB									
T Test: Two Independent Samples									
SUMMARY			Hyp Mean	0					
Groups	*Count*	*Mean*	*Variance*	*Cohen d*					
NBZ	161	2.390807	17.00971						
NFB	269	2.902677	11.32134						
Pooled			13.44783	0.139583					
T TEST: Equal Variances				Alpha	0.05				
	std err	*t-stat*	*df*	*p-value*	*t-crit*	*lower*	*upper*	*sig*	*effect r*
One Tail	0.365402	1.400837	428	0.080994	1.648422			no	0.067557
Two Tail	0.365402	1.400837	428	0.161987	1.965522	-1.23008	0.206337	no	0.067557
T TEST: Unequal Variances				Alpha	0.05				
	std err	*t-stat*	*df*	*p-value*	*t-crit*	*lower*	*upper*	*sig*	*effect r*
One Tail	0.384366	1.331724	285.7895	0.092006	1.650199			no	0.078532
Two Tail	0.384366	1.331724	285.7895	0.184012	1.968293	-1.26841	0.244676	no	0.078532

Table 5-19 demonstrates that there are no cases where there is significant difference in the means of these populations.

Analysis of unmodified flakes with usewear:

While there are very few trends here to discern, it is notable that NFX trends towards the larger range of measurements, while NFB trends to the smaller range. NBZ somewhat surprisingly has the largest range of thicknesses, but a very small range of weights. This probably indicates shatter from trampling, since NBZ is a rockshelter and activities would have taken place repeatedly in the same constrained space. Ethnographically, access to quarries and watercourses is controlled by discrete kin groups. It is not clear how far into the archaeological past this practice of control of natural resources extends, but differential access to raw materials for sites on different parts of the landscape raises an issue of equifinality when attempting to establish and interpretation for the differences in raw material use between these sites. Nonetheless, greater variance in intensity of reduction is a signal of place provisioning and therefore lower residential mobility (Andrefsky 2005; Barton and Riel-Salvatore 2014; Binford 1979; Binford 1980; Kuhn 1994; Kuhn 1996; Nelson 1991). Therefore the overall trends in the data for unmodified flakes with usewear at the sites in question can be interpreted as: place provisioning and residential sedentism at NFX; personal provisioning and substantial shatter from trampling at the NBZ rockshelter; and restricted access to raw materials at NFB.

Unmodified flakes and the incidence and percentage of cortex:

"Cortex" is the chemical or mechanical alterations to the outside of a rock as it resides in its natural environment (Andrefsky 2005). It is often a different color than the rock's interior, and sometimes has different mechanical properties when being flaked (Andrefsky 2005). Core reduction of a new nodule of chert often (but not always) begins with the removal of all of the cortex, and therefore can be used to understand whether the core was prepared elsewhere, and only the most desirable (defined as sharpest-flaking, most predictable) material was brought to a location. It should be noted that there is a large variability in the many techniques and orders of operation that can be used to reduce a core to manufacture the desired tools. The size of source material also has a large impact on reduction strategies, with smaller pieces of source material often not being decortified as there would also be a substantial loss of raw material (Andrefsky 2005; Root 2004). Generally speaking, even with tool production strategies where the cortex is not removed from the core before flaking, the cortex is all gone by about halfway through the core reduction (Andrefsky 2005; Root 2004). Measures of presence or absence of cortex are strategies for understanding intensity of reduction, transport and provisioning of a site (Binford 1979; Dibble, et al. 2005; Kuhn 1991; Marwick 2008; Nelson 1991). What follows is the analysis of data collected regarding the frequency and percentage of cortex at the different archaeological sites in question.

χ^2 analysis of flakes with usewear regarding the presence of cortex:

A χ^2 analysis of presence or absence of cortex on utilized unmodified flakes was conducted to identify differences between the site assemblages. Supplementary tables with the expected and observed values can be found in Appendix C.

Table 5-20: results of a Chi-squared test of frequencies of presence or absence of cortex on unmodified flakes with usewear

Chi-Square Test					
SUMMARY		**Alpha**	0.05		
Count	*Rows*	*Cols*	*df*		
500	3	2	2		
CHI-SQUARE					
	chi-sq	*p-value*	*x-crit*	*sig*	*Cramer V*
Pearson's	4.937268	0.0847	5.991465	no	0.099371
Max likelihood	5.159314	0.0758	5.991465	no	0.101581

As the test statistic does not exceed the critical value, we do not reject the null hypothesis that the observed frequency distribution is no different from the theoretical distribution. Or more plainly, the

χ^2 analysis of all flakes with usewear failed to detect any difference in the proportion of presence/absence of cortex on flakes that were used as tools across all three sites (table 5-20).

χ^2 analysis of all flakes regarding the presence of cortex:

Supplementary tables with the observed and expected values can be found in Appendix C.

Table 5-21: results of a Chi-squared test of frequencies of presence or absence of cortex on all unmodified flakes

Chi-Square Test					
SUMMARY		**Alpha**	**0.05**		
Count	*Rows*	*Cols*	*df*		
2028	2	3	2		
CHI-SQUARE					
	chi-sq	*p-value*	*x-crit*	*sig*	*Cramer V*
Pearson's	3.048453	0.217789	5.991465	no	0.038771
Max likelihood	2.99386	0.223816	5.991465	no	0.038422

Once again, the test statistic did not exceed the critical value; there is no ascertainable difference between the rates of presence or absence of cortex between the sites for all flakes whether or not they had usewear on them (table 5-21). This accounts for all of the waste debitage as well as objects that were used as tools.

Descriptive statistics on unmodified flakes with cortex at all sites:

While there was no discernable difference in the proportion of presence/absence of cortex on unmodified flakes, differenced in the percentage of cortex on flakes that have cortex may reveal differences in the usual reduction sequences at different sites. The following are descriptive statistics for the percentage of cortex on unmodified flakes at all sites. As noted earlier, there was not a 100% analysis of flakes labeled as 'debitage' by the Watson & Cole analysis, otherwise unanalyzed, and sorted into level bags by the original researchers. However, there was an analysis of 105 of these flakes from levels 1-8 from a number of different units. Following the rule of large numbers, this sub-sampling is assumed to represent the underlying population. Therefore all flakes with cortex, both with usewear and without from all units have been included here.

Table 5-22: descriptive statistics for the distribution of percentage of cortex on all unmodified flakes with cortex

Descriptive Statistics	*NBZ*	*NFB*	*NFX*
Mean	31.2	24	27.8
Standard Error	1.2	2.1	1.6
Median	30	20	25
Mode	50	10	20
Standard Deviation	16.1	17.2	15.4
Sample Variance	258.1	297.5	238.4
Kurtosis	-1.4	0.2	-0.03
Skewness	-0.2	0.9	0.5
Range	55	79	75
Maximum	60	80	80
Minimum	5	1	5
Sum	5499	1656	2450
Count	176	69	88

Geometric Mean	25.8	17.8	23.1
Harmonic Mean	19.5	11.7	18.0
AAD	14.3	14.3	13.0
MAD	15	10	10
IQR	30	30	25

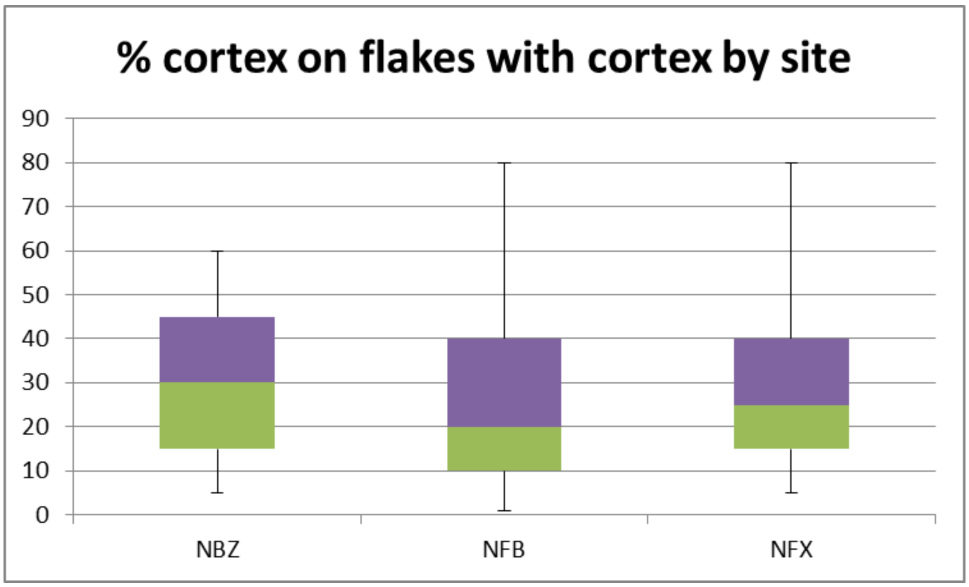

Figure 5-6: graphical boxplot for the distribution of the percentage of cortex on all unmodified flakes with cortex

The descriptive statistics (table 5-22) and the boxplots (fig. 5-6) demonstrate some differences in the distribution of the percentage of cortex, with both NFB and NFX having some artifacts with very high values. NBZ, the rockshelter, has the highest mean, but the smallest range.

Table 5-23: ANOVA analysis for the distribution of the percentage of cortex on all unmodified flakes with cortex. High F value and low P value indicate that these distributions are statistically different.

ANOVA: Single Factor								
DESCRIPTION					Alpha	0.05		
Groups	*Count*	*Sum*	*Mean*	*Variance*	*SS*	*Std Err*	*Lower*	*Upper*
NBZ	176	5499	31.24432	258.1057	45168.49	1.217839	28.84078	33.64786
NFB	69	1656	24	297.5294	20232	1.945009	20.1188	27.8812
NFX	88	2450	27.84091	238.3882	20739.77	1.722284	24.41768	31.26414
ANOVA								
Sources	*SS*	*df*	*MS*	*F*	*P value*	*F crit*	*RMSSE*	*Omega Sq*
Between Groups	2721.613	2	1360.806	5.213196	0.005902	3.023093	0.224329	0.02468
Within Groups	86140.27	330	261.0311					
Total	88861.88	332	267.6563					

The ANOVA analysis (table 5-23) compares the means of the sample sets from the three sites. The F statistic is much higher than the F-crit value, and is accompanied by a very low P-value. This indicates that the means do not all come from the same parent population, and that this finding being a false positive is extremely unlikely, therefore there is confidence in this finding.

Pairwise comparison (T-test) between the distributions of amount of cortex on all flakes for all sites:

Table 5-24: T-test for NBZ and NFB for the distribution of the percentage of cortex on all unmodified flakes with cortex. High t-stat values and low p-value indicate that the means of these distributions are statistically different and NBZ is higher.

T Test: Two Independent Samples									
SUMMARY			Hyp Mean	0					
Groups	*Count*	*Mean*	*Variance*	*Cohen d*					
NBZ	176	31.24432	258.1057						
NFB	69	24	297.5294						
Pooled			269.1378	0.441581					
T TEST: Equal Variances				Alpha	0.05				
	std err	*t-stat*	*df*	*p-value*	*t-crit*	*lower*	*upper*	*sig*	*effect r*
One Tail	2.330180382	3.108909	243	0.001051	1.6511484			yes	0.195585
Two Tail	2.330180382	3.108909	243	0.002102	1.9697744	2.654389	11.83424783	yes	0.195585
T TEST: Unequal Variances				Alpha	0.05				
	std err	*t-stat*	*df*	*p-value*	*t-crit*	*lower*	*upper*	*sig*	*effect r*
One Tail	2.40385732	3.013622	116.8661	0.001583	1.65798166			yes	0.26853
Two Tail	2.40385732	3.013622	116.8661	0.003166	1.9804476	2.483605	12.00503164	yes	0.26853

The ANOVA (table 5-24) demonstrates that in all cases, there is a significant difference between the means of NBZ and NFB.

Table 5-25: T-test for NBZ and NFX for the distribution of the percentage of cortex on all unmodified flakes with cortex. Using the TTEST for unequal variances, there are contradictory results between the one-tailed and two tailed test. Using the two-tailed, test, a t-statistic value lower than t-crit and a p-value greater than 0.05 indicate that these assemblages have statistically the same mean.

T Test: Two Independent Samples									
SUMMARY			Hyp Mean	0					
Groups	*Count*	*Mean*	*Variance*	*Cohen d*					
NBZ	176	31.24432	258.1057						
NFX	88	27.84091	238.3882						
Pooled			251.5583	0.214583					
T TEST: Equal Variances				Alpha	0.05				
	std err	*t-stat*	*df*	*p-value*	*t-crit*	*lower*	*upper*	*sig*	*effect r*
One Tail	2.070730566	1.643579	262	0.050731	1.65069028			no	0.101021
Two Tail	2.070730566	1.643579	262	0.101463	1.96905972	-0.67398	7.480801229	no	0.101021
T TEST: Unequal Variances				Alpha	0.05				
	std err	*t-stat*	*df*	*p-value*	*t-crit*	*lower*	*upper*	*sig*	*effect r*
One Tail	2.043395773	1.665565	180.408	0.048768	1.65336301			yes	0.123061
Two Tail	2.043395773	1.665565	180.408	0.097536	1.97323082	-0.62868	7.435500614	no	0.123061

As with the discussion of table 5-10, the two-tailed test for unequal variances is the important test here (table 5-25). The t-stat does not exceed the t-crit, therefore no difference between the means of the sample populations can be established with significance.

Table 5-26: T-test for NFB and NFX for the distribution of the percentage of cortex on all unmodified flakes with cortex. High t-stat values and low p-value indicate that the means of these distributions are statistically the same.

T Test: Two Independent Samples									
SUMMARY			Hyp Mean	0					
Groups	*Count*	*Mean*	*Variance*	*Cohen d*					
NFB	69	24	297.5294						
NFX	88	27.84091	238.3882						
Pooled			264.334	0.236242					
T TEST: Equal Variances				Alpha	0.05				
	std err	*t-stat*	*df*	*p-value*	*t-crit*	*lower*	*upper*	*sig*	*effect r*
One Tail	2.614330401	1.469175	155	0.071906	1.65474377			no	0.117194
Two Tail	2.614330401	1.469175	155	0.143812	1.97538713	-9.00522	1.32340554	no	0.117194
T TEST: Unequal Variances				Alpha	0.05				
	std err	*t-stat*	*df*	*p-value*	*t-crit*	*lower*	*upper*	*sig*	*effect r*
One Tail	2.649712662	1.449557	137.7762	0.074727	1.65597038			no	0.122564
Two Tail	2.649712662	1.449557	137.7762	0.149455	1.97730354	-9.0802	1.398377141	no	0.122564

In all cases, there is no statistical difference between the means of the sample sets from NFB and NFX (table 5-26).

Analysis of flakes with cortex:

The χ^2 analysis shows that there is no difference between the number of flakes per site with the presence of cortex in relationship to the number of flakes without cortex for flakes with usewear for all sites. This is best explained by the process of bipolar flaking and the desired properties of the objects that ultimately are selected for use by their makers (see Watson 1995: for ethnographic notes that these reduction strategy was indeed in use in the Eastern Highlands; see White 1968: for description of the process by Western Highlands New Guinea group Duna).

When considering the statistical tests of the distribution of percentage of cortex on all flakes between sites, NBZ stands out as having lower ratios of cortex to total surface area than the other sites. The ANOVA analysis (table 5-23) demonstrates that the distributions of all 3 sites do not come from the same underlying population. Viewing the boxplot graph (figure 5-6), NBZ has both a more constrained range and a higher mean of cortex to surface area. The paired T-tests show that NBZ is indeed an outlier, and the distributions of NFX and NFB are from the same statistical population. This is again best explained by NFX and NFB being residential sites that have been provisioned with raw materials and contain the full range of reduction for objects to be utilized in a range of activities being produced there, whereas a logistical site such as the NBZ rockshelter will have only raw material with high utility (e.g. prepared elsewhere to have reduced cortex) transported there (Binford 1979; Binford 1980; Kuhn 1994; Kuhn 1996; Nelson 1991; Riel-Salvatore and Barton 2004). The higher overall mean of cortex to surface area for NBZ is best understood as a function of the low overall surface area and volume of the objects at NBZ as demonstrated in the metric analysis of their dimension above.

Analysis of other types of lithic artifacts:

It was the original intent of this analysis to use measures of intensity of reduction to understand changes in mobility of past inhabitants of the terminal Pleistocene and the Holocene highland New Guinea landscape. While analysis of the assemblage from NBZ (the first site analyzed) was initially promising, neither NFX nor NFB delivered an adequate number of appropriate cores, unifacially, or bifacially-reduced artifacts for analysis.

χ^2 analysis of other lithic artifacts from all sites:

Frequency and χ^2 of the remainder of the lithic assemblages from all three sites are listed below (table 5-27). Cores are defined as amorphous cores that are consistent with the expedient and frequently bipolar lithic technology employed. Tables of observed and expected values can be found in Appendix C.

Table 5-27: results of chi-squared test of frequencies of other chipped stone artifacts by site. The observed frequencies are not determined to be different between sites.

Chi-Square Test					
SUMMARY		**Alpha**	0.05		
Count	*Rows*	*Cols*	*df*		
176	3	3	4		
CHI-SQUARE					
	chi-sq	*p-value*	*x-crit*	*sig*	*Cramer V*
Pearson's	4.914164	0.296219	9.487729	no	0.118155
Max likelihood	5.093544	0.277833	9.487729	no	0.120293

As the test statistic does not exceed the critical value, we do not reject the null hypothesis that the observed frequency distribution is no different from the theoretical distribution. Other than the much larger number of objects at NBZ, there are no discernible differences between the frequencies of other classes of lithic artifact between the sites.

Non-chipped stone artifacts:

Frequency of the presence or absence of non-chipped stone artifacts was recorded, as were some notes about the artifacts in question. These counts do not reflect the totals for charcoal at NFX or NFB. The assemblages of both of these sites contain significant quantities of charcoal material, especially collected from hearths (table 5-28). Histograms of the frequency of non-chipped stone artifacts by individual site can be found in Appendix C.

Table 5-28: frequencies of other (non-chipped stone) artifacts at all sites.

	NBZ	NFX	NFB
shell	1	0	0
bone	11	0	20
plant	6	0	21
ochre	17	11	18
mixed shell & bone	13	0	0
sediment	1	1	0
ground stone	8	4	42
manuport	18	0	2
other	2	8	20
pottery sherd	0	3	277
FCR	0	2	0
hammer stone	0	1	0
	NBZ	NFX	NFB

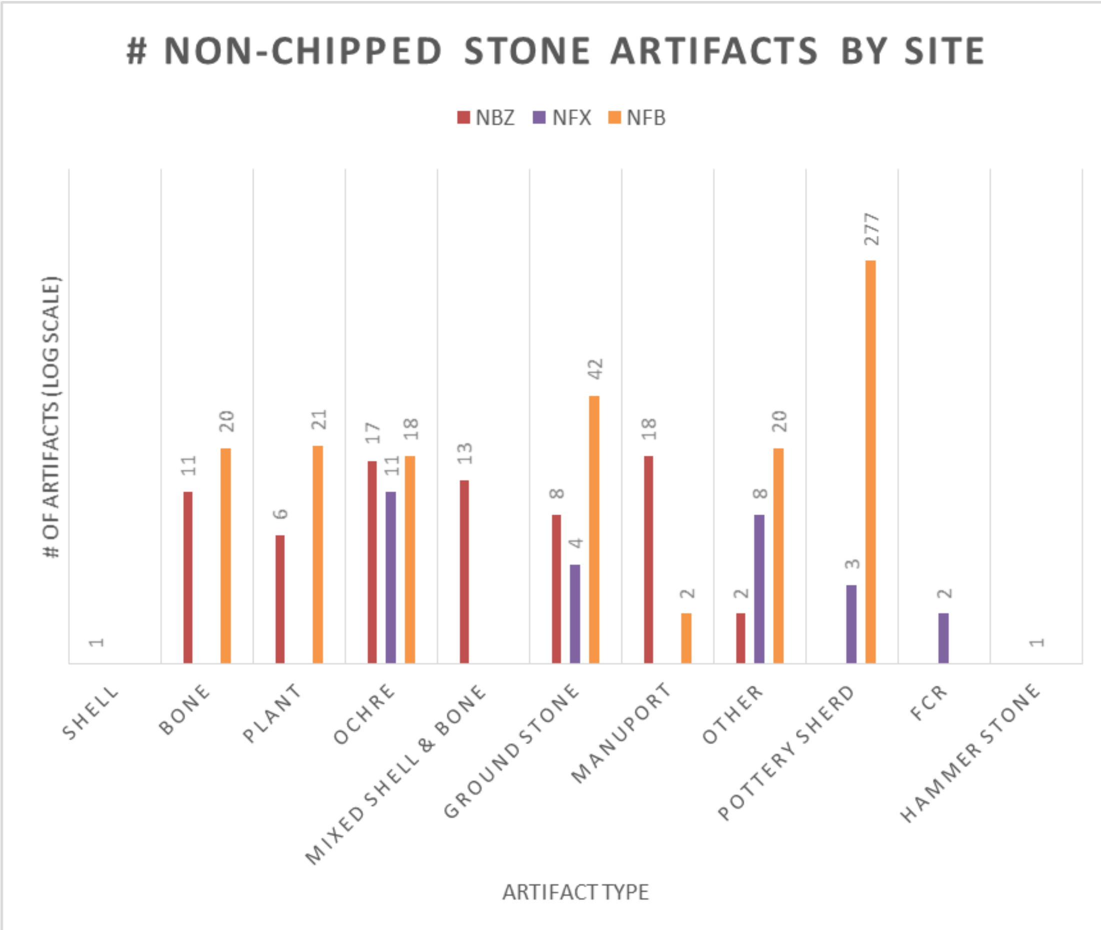

Figure 5-7: histogram of frequencies of other (non-chipped stone) artifacts at all sites grouped by site. Logarithmic scale used.

Several classes of non-chipped-stone artifacts are present at all sites. There is no organic material (other than the charcoal not represented here) at NFX. This is not surprising due to the age (~11-18kya) of the site and the generally poor preservation of organic material due to acidity in tropical soils (Cronyn and Robinson 1990; Kibblewhite, et al. 2015; Pataki 1965). Notable at NFX is the presence of 3 pottery sherds. These sherds come from levels that lie directly above the youngest radiocarbon date (11.5 +/-140), which provides a *terminus post quem* (*TPQ*) date for the sherds but does not provide further data regarding them. Also notable is the presence of a piece of shell at NBZ. It is a piece of cowrie, a marine species, and indicates that there is some kind of contact between highland and coastal groups (see fig 2-9). This object comes from the deepest layer excavated by Cole, currently dated to approximately 10kya by association with level depths from White's excavations (1972).

SUMMARY:

The overall picture from the analysis of chipped stone artifacts is one of continuity. There are marked similarities between NFX and NFB that are best explained by these sites being long-term residential sites. The differences between NBZ and the other sites are best explained with the fact that NBZ is a rockshelter and not an open site, and is therefore most likely a logistical site, not a long-term residential site. Any differences in the lithic materials between NFB and NFX are best explained by differential access to raw materials. All sites are dominated by cryptocrystaline silicates frequently referred to as 'chert'. Non-chipped stone artifacts do provide some insight into changing technology through time, especially with the rise of pottery use. The presence of pottery in levels dated to ~3.2-3.8kya uncalBP. suggests the need for direct dating and other analyses of these artifacts (see Huff in press: for expanded discussion).

The artifactual evidence supports that NFX, dated from 18 kya uncalBP. to 11.5 kya uncalBP., is an open residential site in a system of long-term residential sedentism and logistical foraging sensu Binford (1980) NBZ, date from at least 10kya uncalBP to 5kya uncalBP is a logistical site in the foraging system that also includes early agriculture such as that observed at Kuk (e.g. Denham, Golson, et al. 2004; Denham, et al. 2003; Golson 1984). NFB, located on the eastern site of the Norikori Swamp, is also a long-term open residential site, in a subsistence system that includes intensified agriculture and the use of pottery. Bipolar reduction of lithic raw materials to create usable objects is demonstrated to be a very stable technology throughout the period from the Last Glacial Maximum forward.

Chapter 6. Conclusion

Intro:

The Introduction to this dissertation established a general research question: how do we understand changes in mobility and sedentism in the archaeological record of highland Papua New Guinea in relation to variations in the environment? Some criteria for establishing robust environmental explanations as defined by Eren (2012) were reviewed, and three possible models – a generic gradual model, transitions linked to ecological changes recorded in the palynological record, and transitions linked to changes in precipitation – were discussed especially in relation to concepts of risk. Some middle-level theory linking behaviors and archaeological correlates were discussed to link the models presented in the introduction to actual archaeological observations. In Chapter 2, a general overview of the geographic setting and the recent history of the country of Papua New Guinea was considered. The general geology of the highlands was discussed, and specific geologic settings of the sites of NFX, NBZ, and NFB were explored. A quick overview of the archaeology of the highlands was reviewed to provide a setting for the new research presented in subsequent chapters.

Chapter 3 provides an overview of the major global-scale climate systems most relevant to the local climate of highland PNG: the Intertropical Convergence Zone (ITCZ), and the El Niño Southern Oscillation (ENSO). These major weather systems are discussed with specific consideration of their impact on precipitation on highland precipitation. A number of paleoclimate proxies relevant to ITCZ, ENSO, and direct measures of precipitation are discussed, especially the heavy fractions of sediments for Lake Towuti (Russell et al. 2014) and the Sepik-Ramu drainage basin (Tachikawa et al. 2001).

The activities undertaken to construct the relevant archaeological data are discussed in their respective chapters. In Chapter 4 there was a short discussion of the summed probability distribution analysis of all published radiocarbon dates that was conducted cooperatively with William Brown (Huff and Brown in prep). Additionally in Chapter 4, a new radiocarbon date for the NFX site confirming its LGM age was provided, securing that site's length of occupation. The site typology used in the analysis of all radiocarbon dates was defined, and site types were compared with both global climate trends such as Heinrich events, the Last Glacial Maximum, and mid-to-late Holocene ENSO intensity. The site typology was also compared with palynologically-defined ecological stages in an effort to identify correlations. Figure 5-6 provides a graphical representation of the changing ratio of site types as summed probability distributions. This changing ratio is also compared against major global climate events. Major trends in the *SPD* analysis are the adoption of rockshelters during the LGM, and the advent of an agricultural site (Kuk) at the end of the Younger Dryas, accompanied by the decreasing frequency of rockshelters relative to other site types through the Holocene.

In Chapter 5, methods of and data from the lithic analysis was presented. As noted by Bellwood, "technology seems to have changed very little before, during, or after the advent of agriculture in New Guinea" (2005:134). The data presented here confirms this assessment. There are no clear trends in artifact size or variability based on the collections examined in this project. Watson and Cole did identify changing frequencies of types using the edge as the unit of tool. While these changing frequencies of edge types may indeed exist, the whole artifacts as measured in this analysis showed a remarkable stability in size, shape, and raw material type through time at all sites considered here. Other non-lithic artifacts of note include the presence of marine (cowrie) shell in the deepest level at NBZ excavated by Cole (1977) and correlated with a date of approximately 10kya based on comparable depth in White's more extensive excavations (1972). The marine shell suggests that trade or travel between the coastal areas and the highlands existed at NBZ at least at the beginning of the Holocene. Also notable is the presence of 3 pottery sherds at NFX, which lay in levels slightly above the earliest radiocarbon date of ~11.5kya. As these sherds are above the radiocarbon date, they suggest continued occupation or reoccupation of the site, but require further analysis.

Evaluating the models:

Bringing all of these lines of evidence together, the three models presented in the introduction can be evaluated.

The gradual change model can be discarded when the ratio of different site types is considered (fig. 5-6). While the curve in this graph is noisy due to low number of data points despite the smoothing that was part of the *SPD* process, there are steep inflection points. Rockshelters generally suffer less from destruction from taphonomic processes relative to open sites (Surovell, et al. 2009). It is surprising that the visible use of rockshelters doesn't start until well into the occupation of the highlands. The earliest sites (Kosipe and Ivane Valley), which do fall in the Owens Stanley Range rather than the Central Cordillera, are open sites. Rockshelter use at Nombe significantly to the west follows more than 10,000 years later. While sampling bias from low numbers of known sites over all of the highlands could account for workers just not discovering older rockshelters yet, the pattern as it exists is that the highlands had a highly mobile lifestyle with frequent long-term use of the Ivane Valley sites for an extensive period of time (Ford 2011). There is a rapid shift to the extensive use of rockshelters in addition to open sites at the beginning of the LGM, signaling a change in the use of the landscape in the subsistence round. Then again at the Younger Dryas, the use of rockshelters decreases significantly as a proportion to all site types while agricultural sites increase dramatically as a proportion until all three site types are roughly equal in proportion over the last few thousand years. An argument could be made about the coarse nature of the known archaeological record and what 'gradual' in the longue durée actually means. However, these are significant changes in the proportion of site types relative to each other, suggesting a rather rapid change in subsistence practice. This change could be using a variety of ecological niches available at various elevations as opposed to only using valley floor resources (Evans and Mountain 2005; Ford 2011), followed some time later by the adoption of extensive then intensive food production practices (e.g. Denham, Golson, et al. 2004; Denham, et al. 2003; Golson 1984).

The plant ecology model, that site use changes follow the major plant community trends that would drive the availability of fruit and vegetable resources as well as faunal resources is belied by the observation that site use changes precede the progression of ecological stages (e.g. Haberle 2007). Figure 6-5 shows that the adoption of new site types happens before a major ecological transition, not following it. While of course the transition of plant populations, especially tree populations is generally fairly slow, so conceivably the subsistence patterns of past peoples were so fragile that they could not tolerate early small alterations in their ecology, the model of plant ecology stages driving subsistence and therefore site use and mobility change is unsatisfying due to the lack of actual mechanism. It is the change in availability of unspecified hypothesized resources, rather than an identifiable resource driving change.

Finally, there is the climate hypothesis, in which precipitation and variability in climate linked to ENSO such as droughts and frosts created high risk (and high uncertainty) situations to which humans responded with strategies that would minimize both risk – variability in outcome – and uncertainty – knowledge about likely range of outcomes. As discussed in Chap. 3 the Lake Towuti paleorainfall data shows a period of reduced and variable rainfall between H3-H1 (31kya-16.8kya) (Russell, et al. 2014). These data were in good agreement with the Sepik-Ramu precipitation data (Tachikawa, et al. 2011). The increased use of temporary rockshelters and long-term open sites close to water during this period is consistent with the change to tethered mobility from a free-roaming forager lifestyle (e.g. Binford 1979). The mobility of the group as a whole would be tethered to proximity to reliable water supplies, with rockshelters being used as very short-term campsites for small task groups hunting and possibly conducting ritual activities based on the extensive paintings in many of these sites (e.g. NBZ).

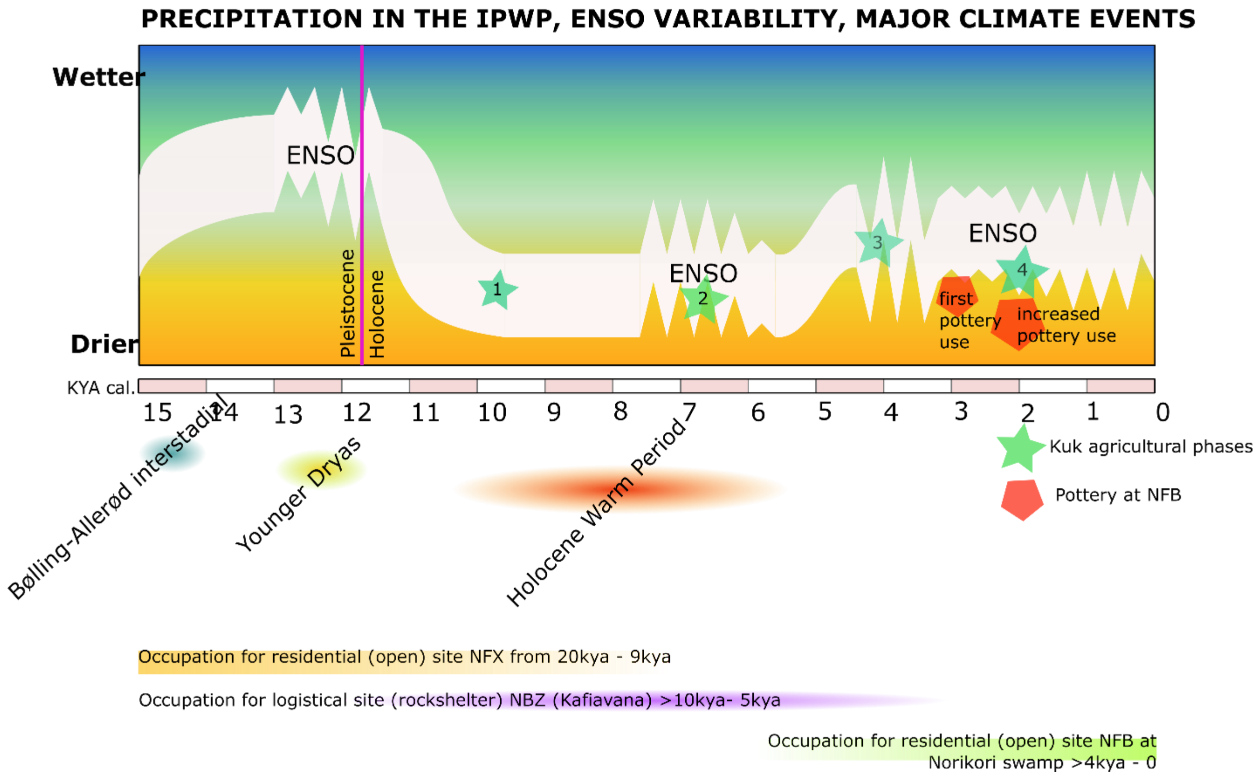

Figure 7-1: aggregated paleoclimate data modeling precipitation and ENSO variability changes from the terminal Pleistocene through the Holocene. Also included are phases of agriculture at Kuk Swamp (green stars), occupations of NFX, NBZ and NFB, and the dates of ceramics based on stratigraphic relationships at NFB (Huff in prep). Dates are given in calibrated years. The vertical position of the white band reflects the overall average annual precipitation. The jagged sections represent periods of intensified ENSO activity, with relative intensity represented by the changes in amplitude with greater amplitude representing increased intensity. This is a graphical summary of the data presented in Chapter 3.

As we move forward in time, it is easier to link changes in subsistence and site use to changes in precipitation simply because there is both more abundant paleoclimate data and archaeological data. Looking at fig. 7-1, there is a substantial drop in precipitation at approximately 10kya. At the same time the first signals of extensive, low-intensity food production at Kuk also begin (Denham, Golson, et al. 2004; Denham, et al. 2003; Golson 1984). These archaeological signals are mounds that indicate optimizing an environment for a plant species, and a variety of stone tools in association with the mounds. Swamps are a wet landscape, and would have water and nutrients available for transplanted useful plants; mounding could be a strategy for optimizing moisture to be consistent but not excessive. The presence of translocated useful plants is supported by the starch and phytolith evidence found on the associated stone tools (Fullagar, et al. 2006). Fullagar et al.(2006) state unequivocally that there is conclusive evidence for *Dioscorea* and *Colocasia* in the earliest Phase 1 at Kuk swamp, supporting Denham's and Golson's and other co-authors' (Denham, Golson, et al. 2004; Denham, Haberle, et al. 2004; Golson 1984, 1991) argument that the multicomponent complexes of Phase 1 of mounds, trenches, and postholes were constructed in support of planting and cultivating water-intolerant crops as low level food production (Smith 2001). It is also notable here that Haberle's zone H4-H3 transition happens at 8.5kya, trailing both the change in precipitation and the adoption of low-level food production observed in Phase 1 at Kuk (see 6-1 for definitions of zones from Haberle 2007).

Managing the moisture levels of soils in a swamp environment became substantially more extensive in Phase 2 at Kuk swamp, a period that correlates with a period of increased ENSO variability, meaning that while overall the precipitation rate on a millennial scale would be comparatively low, on the annual scale there would be some extremely wet years, and some years that were both catastrophically dry and accompanied by frosts. Investing more energy into moisture management of soils to maintain and expand the predictable production of plant crops to mitigate environmental variability would pay dividends in reduced risk and reduced uncertainty. The selection of multi-year crops such as tuber and corm producing plants is part of this risk and variability reduction; one season crops like cereals would have a high failure rate in bad years, although there is some evidence in *Saccharium* and other grass plants being utilized during the Phase 1, Phase 2 transition based on usewear and residues on stone tools from Kuk (Fullagar, et al. 2006). Latinis (2000) notes that arboreal resource systems are by nature diverse. Additionally he provides an compilation of all evidence of arboreal resources recovered from archaeological contexts in island southeast Asia and near Oceania (including the PNG highlands) from research published to date; there is evidence of useful arboreal species from at least ~12kya in the highlands (Latinis 2000:52-53). The long term investment of arboreal resources – which do require some maintenance – would be both useful for a relatively residentially sedentary (tethered) forager in the long term and risk and uncertainty reducing because of the inter-annual hardiness of the plant. Denham specifically identifies the topology of the paleosurface would be optimal for cultivating a broad variety of plants with different soil and moisture requirements (Denham, et al. 2003:167), supporting this diversified strategy as a risk mitigation technique.

The next major phase transition (Phase 3) at Kuk happens at approximately 4.5-2.6kya (Denham, et al. 2003:159), a period of increased rainfall, commencing at the same time (4.5-3.5kya) of strong and frequent ENSO events (Donders, et al. 2008). The occupation of NFB also begins with the onset of this high ENSO variability period (Watson and Cole 1977). As this period of extreme ENSO activity ends, the first pottery from both NFB (Huff in press) and Wañelek (Gaffney, Summerhayes, et al. 2015) occurs. As Ullah et al.(2015) note in their discussion of punctuated subsistence change, the state of moving from what they describe as a horticulturalist to a committed agriculturalist is more possible in the tropics than on other landscapes. Driven by ecological crises (reduced precipitation, drought, frost), but also by environmental amelioration – the reduction of ENSO activity and the advent of pottery use – the once highly mobile foragers of the New Guinea highlands have settled down. Low residential mobility and food production was not adopted out of any inherent advantage to sedentism and agricultural subsistence, but in a step-wise process to mitigate risk from environmental variability. Finally, at another less intense increase in ENSO activity, we see the transition to Phase 4 agriculture at Kuk, another step in a line of phases that reflect intensification of energy spent constructing ditches and mounds that would control the hydrology of the swamp agriculture.

Curiously, the stone technology throughout the 20,000 year sequence represented by NFX, NBZ and NFB is quite stable. It is possible that the methods used here are simply not the appropriate instruments for gaining further insight into the lithic collections of these eastern highland sites. However, Ford (2011), Evans & Mountain (2005), and Gaffney et al. (2015) have all had some success with various approaches that include quantitative and materialist-oriented strategies exploring variability in their various sites that is not reflected in the homogenous collections from these eastern sites. NFX and NBZ are situated in locations in close proximity to rivers or streams and may have had abundant, continual, proximal access to high quality cryptocrystalline sillicates in the river beds. Uninterrupted access to high-quality raw materials reduces the need to curate tools and to thoroughly reduce them, or “use them up”. It should be noted that there was evidence of caching at NBZ at certain levels, which would belie continuous access to high quality materials at that site. NFB does not have an adjacent source of raw materials, the closest source being located across Norikori Swamp (pers. comm. David Cole 2015), although presumably residents enjoyed continuous unfettered access to this resource – or a different unknown site – through their occupation. An important feature of the continuity of the lithic assemblage is that is supports the continuity of populations, as opposed to subsistence and cultural change being driven by practiced introduced through in-migration or diffusion of new ideas. Demonstrated by the cowrie shell in the terminal Pleistocene/Holocene boundary layers of NBZ, movement of people and/or ideas from the coast were possible along the exchange networks that brought exotic marine goods up to the highlands, but there is no specific line of evidence that these transitions were forced by the outside through demic expansions or the adoption of foreign technocomplexes, as opposed to being the independent inventions of the highland people.

Returning to the evidentiary standards set forth by Eren (2012), the models can be clearly evaluated. The first point, that if climate change is effecting cultural change, there should be measurable evidence of both climate and cultural change. The gradual model is agnostic to climate change, but it also serves here as the null hypothesis. There is indeed cultural change in the form of changing frequency of site types through time, the stepwise intensification of production of plant resources from low-level food production though to committed intensive agriculture, and the adoption of ceramic technology. And there is substantial climate change in variability of precipitation and the incidence of frosts as summarized in figure 6-1. There is also ecological change in transitions between ecological regimes as seen in chapter 3 table 3-1 taken from Haberle 2007.

The second point that Eren's model of explanation requires is that these changes be tightly correlated in time. In the case of the precipitation and ENSO variability, there is a tight correlation with the cultural changes listed above. Conversely, there is not a tight correlation between site use changes and ecological changes. These ecological transitions seem to trail the cultural changes rather than to be driving them, suggesting that they are also secondary effects of the climate changes that are the primary motivator for cultural change.

Finally, assuming the previous two criteria are met, then there should be evidence "falsifying other possible influences of culture change" (Eren 2012:17). This is a pretty steep standard of evidence, but the overall continuity of the lithic assemblages of the highlands generally, and the specific continuity of the sites of NFX, NBZ, and NFB over 20 millennia supports a local population changing in place. Without another line of evidence demonstrating an influx of immigrants, there is no evidence that changes in subsistence or technology were driven by new residents of the region bringing in knowledge and strategies from elsewhere, or causing demic pressure on existing residents. While assemblages from individual sites (e.g. Nombe, Wañelek, or Ivane Valley) may demonstrate learning about the availability of local raw material resources, there is no evidence such as the supplantation of local expedient styles with a formal assemblage associated with an outside group that would indicate a new and substantial cultural exchange or demic expansion into the highlands (Evans and Mountain 2005; Ford 2011; Gaffney, Ford, et al. 2015). Rather the lithic evidence supports continuity of people and technology in the highlands.

When all three of these criteria are considered, the model of precipitation and ENSO variability has the most robust support from the archaeological record of the highlands of PNG. It also has the added benefit of bringing the archaeological trajectory of the New Guinea highlands into a paradigm – managing risk in a highly variable environment – that is recognizably a global process, with the past people of New Guinea making selecting the species and strategies that were most suitable for addressing the challenges and opportunities they faced. In their introductory chapter to the edited volume exploring the breadth of agricultural behavior, Vrydaghs and Denham (2010) note that generally the study of agriculture and the transition to this mode of food production is framed in Eurasian, and often Eurocentric terms, using models derived from Eurasia, and expecting lines of evidence related to the climate, seasonality, plant and animal species available in that region. Arboriculture and the husbandry of multi-year non-cereal crops are difficult to understand in the Eurasian-centric context – the tropical plants aren't tied to a cereal cycle of spring-sowing, summer-growing, fall-harvesting, winter-storage. Tropical crops may not produce discernable pollen signals, and in the case of a mixed species swamp garden, tropical plants may not have any distinguishing morphological changes that would make them dependent on human intervention for propagation. In his popular book *Guns, Germs, and Steel*, Jared Diamond (1997) goes so far as to argue that the people of New Guinea just got a bad deal in terms of the native plants available for domestication along with other features of geography. But really, the trajectory of New Guinea archaeology is best understood not in how it fails to be European, but rather in how changes in the use of the landscape, in site use, and in plant resources served to mitigate changes in environmental variability that would have caused both significant risk and uncertainty for residents.

Future directions:

There is much that is not covered in the analysis presented here. Immediately, there is a need for the petrographic, typological, and luminescence dating analysis of ceramics from the Cole collection to refine chronometric control and to explore possible sources local or exotic of ceramic materials to gain insight into use and possible exchange systems visible within the late Holocene ceramic assemblages (see Gaffney, Summerhayes, et al. 2015; Huff in press). Additionally, further dating of materials from NBZ including a review of the materials excavated by Peter White would refine the chronology of that site, possibly extending its use back into the late Pleistocene.

More broadly, the socio-economic life and symbolic life in the highlands is still poorly understood. Residue analysis on ceramics and stone tools may provide more information about the resources those tools were used to process. Likewise microwear analysis of stone tools may contribute new information to the scope of resources and activities. There are many rockshelters with abundant vibrant paintings on the walls, but as of yet little work has been done to attempt to understand the geographic and chronological distributions of various motifs, or to link them to any curated local knowledge of the symbology and cosmography represented.

The timing of the introduction of pigs, central to exchange and prestige systems with modern populations, is still not well-understood, and consequently how pigs changed the socio-economic landscape is still unknown as well. A better understanding of the introduction of pigs, and whether through the translocation of wild or feral pigs, or through committed pig husbandry would contribute substantially towards understanding the time depth of current political structures and economic activities.

Of course simply more archaeological research needs to be conducted to answer these and other questions. The statistical analysis provided in the previous chapters would be substantially strengthened by the many more data points from many more sites. This analysis included data from the PNG/Indonesia border to the Owens Stanley Range in order to reach a level of statistical robustness, but this level of inclusiveness will also conceal inter-regional variability. Both the continued reanalysis of previously excavated collections, and new excavations at new sites will contribute substantially to resolving the currently coarse-grained archaeological record of the highlands into a fine-grained, nuanced view into the processed unfolding throughout the past of this region.

Bibliography

1979 Burke Museum Archives Accn # 1979-53 Cole New Guinea. Burke Museum of Natural History and Culture, Seattle.

2014 Reports from Australian National University Advance Knowledge in Geology (Linking high-grade gold mineralization to earthquake-induced fault-valve processes in the Porgera gold deposit, Papua New Guinea), pp. 667.

2015a Precious Metals Mining in Papua New Guinea to 2020 - A Focus on the Gold Industry. *Investment Weekly News*:418.

2015b risk. In *Merriam-Webster*. Risk. Merriam-Webster, Incorporated Springfield, MA.

Adger, W., S. Dessai, M. Goulden, M. Hulme, I. Lorenzoni, D. Nelson, L. Naess, J. Wolf and A. Wreford

2009 Are there social limits to adaptation to climate change? *Climatic Change* 93(3):335-354.

Adger, W. N.

2003 Social Capital, Collective Action, and Adaptation to Climate Change. *Economic Geography* 79(4):387-404.

Aldrian, E. and R. Dwi Susanto

2003 Identification of three dominant rainfall regions within Indonesia and their relationship to sea surface temperature. *International Journal of Climatology* 23(12):1435-1452.

Allen, B.

2000 The 1997-98 Papua New Guinea Drought: perceptions of disaster. In *El Niño: History and Crisis*, edited by R. H. Grove and J. Chappell. The White Horse Press, Cambridge.

Allen, J., G. Summerhayes, H. Mandui and M. Leavesley

2011 New data from Oposisi : implications for Early Papuan pottery phase. *Journal of Pacific Archaeology* 2(1):69-81.

Anderson, C. R.

1992 *Papua*. Washington, D.C. : U.S. Army Center of Military History : For sale by the U.S. G.P.O., Supt. of Docs., Washington, D.C.].

Andrefsky, W.

2005 *Lithics: A macroscopic approach 2nd ed.* Cambridge University Press, Cambridge.

Andrefsky, W.

2009 The Analysis of Stone Tool Procurement, Production, and Maintenance. *Journal of Archaeological Research* 17(1):65-103.

Attenbrow, V. and P. Hiscock

2015 Dates and demography: are radiometric dates a robust proxy for long-term prehistoric demographic change? *Archaeology in Oceania* 50:30-36.

Bain, J. H. C. M., D.E.

1974 Explanatory Notes on the Karimuri Geological Sheet, edited by D. o. M. a. Energy. vol. 58. Bureau of Mineral Resources, Geology and Geophysics; Australia, Canberra.

Bamforth, D. B. and P. Bleed

1997 Technology, Flaked Stone Technology, and Risk. *Archeological Papers of the American Anthropological Association* 7(1):109-139.

Barker, A. W.

2003 Archaeological Ethics: Museums and Collections. In *Ethical Issues in Archaeology*, edited by L. J. V. Zimmerman, K.D.

Hollowell, J.J. Society for American Archaeology. AltaMira Press.

Barker, G.

2009 *The Agricultural Revolution in Prehistory Why Did Foragers Become Farmers?* Oxford : OUP Oxford, Oxford.

Barton, C. M. and J. Riel-Salvatore

2014 The formation of lithic assemblages. *Journal of Archaeological Science* 46:334-352.

Bazzaz, F. A. and S. T. A. Pickett

1980 Physiological Ecology of Tropical Succession: A Comparative Review. *Annual Review of Ecology and Systematics* 11(1):287-310.

Bellwood, P. S.

1997 *Prehistory of the Indo-Malaysian archipelago*. revised edition ed. Academic Press, Sydney [N.S.W.]; Orlando, Fla.

Bellwood, P. S.

2005 *First farmers : the origins of agricultural societies*. Blackwell Pub., Malden, MA.

Binford, L. R.

1979 Organizational and formation processes: looking at curated technologies. *Journal of Anthropological Research* 35:255-273.

Binford, L. R.

1980 Willow Smoke and Dogs' Tails: Hunter-Gatherer Settlement Systems and Archaeological Site Formation. *American Antiquity* 45(1):4-20.

Biskup, P., H. Nelson and B. Jinks

1973 *Readings in New Guinea history*. Sydney, Angus & Robertson, Sydney.

Böll, A., A. Lückge, P. Munz, S. Forke, H. Schulz, V. Ramaswamy, T. Rixen, B. Gaye and K. C. Emeis

2014 Late Holocene primary productivity and sea surface temperature variations in the northeastern Arabian Sea: Implications for winter monsoon variability. *Paleoceanography* 29(8):778-794.

Böll, A., H. Schulz, P. Munz, T. Rixen, B. Gaye and K.-C. Emeis

2015 Contrasting sea surface temperature of summer and winter monsoon variability in the northern Arabian Sea over the last 25 ka. *Palaeogeography, Palaeoclimatology, Palaeoecology* 426:10-21.

Bourke, R. M.

2000 Impact of the 1997 Drought and Frosts in Papua New Guinea. In *El Niño: History and Crisis*, edited by R. H. Grove and J. Chappell. The White Horse Press, Cambridge.

Bradbury, A. P. and P. J. Carr

2012 Evaluating Early Archaic Blade and Bipolar Technologies In *Contemporary lithic analysis in the Southeast problems, solutions, and interpretations*, edited by P. J. Carr, A. P. Bradbury, S. E. Price, D. S. Miller, A. M. Smallwood and D. Sain. Alabama : University of Alabama Press, Tuscaloosa.

Broccoli, A. J., K. A. Dahl and R. J. Stouffer

2006 Response of the ITCZ to Northern Hemisphere cooling. *Geophysical Research Letters* 33(1):n/a-n/a.

Bronk Ramsey, C.

2010a OxCal. 4.1.7 ed, Oxford.

Bronk Ramsey, C.

2010b Oxford Radiocarbon Accelerator Unit: Research: OxCal4, pp. website. ver. 99 ed. vol. 2010. Research Laboratory for Archaeology and the History of Art, Oxford.

Bronk Ramsey, C., T. Higham, A. Bowles and R. Hedges

2007 Improvements to the pretreatment of bone at Oxford. *Radiocarbon* 46(1):155-163.

Bronk Ramsey, C., T. Higham and P. Leach

2007 Towards high-precision AMS; progress and limitations. *Radiocarbon* 46(1):17-24.

Bronk Ramsey, C., T. F. G. Higham, D. C. Owen, A. W. G. Pike and R. E. M. Hedges

2002 Radiocarbon Dates from the Oxford Ams System: Archaeometry Datelist 31. *Archaeometry* 44:1-150.

Browne, S. J.

1998 *Irian Jaya, 30 years of Indonesian control*. Irian Jaya. Clayton, Victoria, Australia : Monash University, Centre of Southeast Asian Studies, Clayton, Victoria, Australia.

Brunskill, G. J.

2004 New Guinea and its coastal seas, a testable model of wet tropical coastal processes: and introduction to Project TROPICS. *Continental Shelf Research* 24:2273-2295.

Bulmer, S.

1964 Radiocarbon dates from New Guinea. *The Journal of Polynesian Society* 73(3):327-328.

Bulmer, S.

1966 The prehistory of the Australian New Guinea Highlands : a discussion of archaeological field survey and excavations, 1959-1960, University of Auckland, [Auckland].

Bulmer, S.

1975 Settlement and economy in prehistoric Papua New Guinea: a review of the archeological evidence. *Journal de la Société des océanistes* 46(30):7-75.

C.I.A., U. G.

2016 The World Factbook.

Carré, M., J. P. Sachs, S. Purca, A. J. Schauer, P. Braconnot, R. A. Falcón, M. Julien and D. Lavallée

2014 Holocene history of ENSO variance and asymmetry in the eastern tropical Pacific. *Science* 345(6200):1045-1048.

Chappell, J., Y. Ota and K. Berryman

1996 Late Quaternary Coseismic Uplift History of Huon Penninsula, Papua New Guinea. *Quaternary Science Reviews* 15:7-22.

Chappell, J. and B. G. Thom

1977 Sea Levels and Coasts. In *Sunda and Sahul*, edited by J. Allen, J. Golson and R. M. Jones, pp. 275-291. Academic Press, London.

Christensen, O. A.

1975 Hunters and Horticulturalists: A Preliminary Report of the 1972–4 Excavations in the Manim Valley, Papua New Guinea. *Mankind* 10(1):24-36.

Clark, P. U., A. S. Dyke, J. D. Shakun, A. E. Carlson, J. Clark, B. Wohlfarth, J. X. Mitrovica, S. W. Hostetler and A. M. McCabe

2009 The Last Glacial Maximum. *Science* 325(5941):710-714.

Clarkson, C.

2002 An Index of Invasiveness for the Measurement of Unifacial and Bifacial Retouch: A Theoretical, Experimental and Archaeological Verification. *Journal of Archaeological Science* 29:65-75.

Clarkson, C.

2004 Technological Provisioning and Assemblage Variation in the Eastern Victoria River Region, Northern Australia: A Darwinian Perspective. PhD Thesis, School of Archaeology and Anthropology, Australian National University, Canberra.

Crittenden, R. and E. L. Schieffelin

1991 *Like people you see in a dream : first contact in six Papuan societies*. Stanford, Calif. : Stanford University Press, Stanford, Calif.

Cronyn, J. M. and W. S. Robinson

1990 *The elements of archaeological conservation*. London

New York, NY : Routledge, London

New York, NY.

Demay, L., S. Péan and M. Patou-Mathis

2012 Mammoths used as food and building resources by Neanderthals: Zooarchaeological study applied to layer 4, Molodova I (Ukraine). *Quaternary International* 276–277:212-226.

Deng, W.-F., G.-J. Wei, X.-H. Li, K.-F. Yu, J.-X. Zhao, W.-D. Sun and Y. Liu

2009 Paleoprecipitation record from coral Sr/Ca and [delta]18O during the mid Holocene in the northern South China Sea. *The Holocene* 19(6):811-821.

Denham, T., C. Bronk Ramsey and J. Specht

2012 Dating the appearance of Lapita pottery in the Bismarck Archipelago and its dispersal to Remote Oceania. *Archaeology in Oceania* 47(1):39-46.

Denham, T. and S. Haberle

2008 Agricultural emergence and transformation in the Upper Wahgi valley, Papua New Guinea, during the Holocene: theory, method and practice. *The Holocene* 18(3):481-496.

Denham, T., J. Iriarte and L. Vrydaghs

2007 *Rethinking agriculture : archaeological and ethnoarchaeological perspectives*. World Archaeological Congress. Left Coast Press, Walnut Creek, CA.

Denham, T. P. and C. Ballard

2003 Jack Golson and the investigation of prehistoric agriculture in Highland New Guinea: recent work and future perspecitves. *Archaeology of Oceania* 38:129-134.

Denham, T. P., J. Golson and P. J. Hughes

2004 Reading Early Agriculture at Kuk Swamp, Wahgi Valley, Papua New Guinea: the Archaeological Features (Phases 1-3). *Proceedings of the Prehistoric Society for ...* 70:259-298.

Denham, T. P., S. Haberle and C. Lentfer

2004 New evidence and revised interpretations of early agriculture in Highland New Guinea. *Antiquity -Oxford-* 78(302):839-857.

Denham, T. P., S. Haberle, C. Lentfer, R. Fullagar, J. Field, M. Therin, N. Porch and B. Winsborough

2003 Origins of Agriculture at Kuk Swamp in the Highlands of New Guinea. *Science (Washington)* 301(5630):189-193.

Diamond, J. M.

1997 *Guns, germs, and steel : the fates of human societies*. W.W. Norton & Co., New York.

Dibble, H., L. , U. Schurmans, A. , R. Iovita, P. and M. McLaughlin, V.

2005 The measurement and interpretation of cortex in lithic assemblages. *American Antiquity* 70(3):545-560.

Donders, T. H., F. Wagner-Cremer and H. Visscher

2008 Integration of proxy data and model scenarios for the mid-Holocene onset of modern ENSO variability. *Quaternary Science Reviews* 27(5):571-579.

Dow, D. B. and M. D. Plane

1965 Report No. 79: The Geology of the Kainantu Goldfields, edited by B. o. M. R. Department of National Resources, Geology and Geophysics. Bureau of Mineral Resources, Geology and Geophysics, Canberra.

Dow, D. B. D. F. E.

1964 *The geology of the Bismarck Mountains, New Guinea*. Commonwealth of Australia, Dept. of National Development, Bureau of Mineral Resources, Geology and Geophysics, Canberra.

Dow, D. B. T., G.A.M.

Denham, D.

1972 Geology, Volcanoes and Earthquakes of Papua New Guinea, edited by G. a. G. C. o. A. Department of National Development; Bureau of Mineral Resources. vol. 81. Bureau of Mineral Resources, Canberra.

Drea, E. J.

1993 *New Guinea*. Washington DC : U.S. Army Center of Military History : For sale by the U.S. G.P.O., Supt. of Docs., Washington DC.

Drechsler, M.

1990 An engineering geology zonation of the Eastern Highlands Province, Papua New Guinea. Port Moresby, Papua New Guinea: Geological Survey of Papua New Guinea, Port Moresby.

Drechsler, M., G. Geological Survey of Papua New, G. Papua New, M. Department of and Energy

1988 *Seismic risk assessment of 21 sites in Papua New Guinea*. Geological Survey of Papua New Guinea, Dept. of Minerals and Energy, [Port Moresby].

Drennan, R. D.

1996 *Statistics for Archaeologists: A Commonsense Approach*. Interdisciplinary COntributions to Archaeology. Springer, Pittsburgh.

Dreschler, M.

1990 An Engineering Geology Zonation of the Eastern Highlands Province, Papua New Guinea, edited by G. Geological Survey of Papua New.

Eren, M. I.

2012 *Hunter-Gatherer Behavior Human Response During the Younger Dryas*. Hunter-Gatherer Behavior. Walnut Creek : Left Coast Press, Walnut Creek.

Evans, B.

2000 A Technological Evaluation of the Chipped Stone Assemblage from Nombe, Papua New Guinea, Australian National University, Canberra.

Evans, B. and M. J. Mountain

2005 Pasin bilong tumbuna: archaological evidence for early human activity in the highlands of Papua New Guinea. In *Papuan Pasts: cultural, linguistic and biological histories of Papuan-speaking peoples*, edited by A. A. Pawley, R.

Golson, J.

Hide, R. Pacific Linguistics, Canberra.

Fairbairn, A. S., G. S. Hope and G. R. Summerhayes

2006 Pleistocene occupation of New Guinea's highland and subalpine environments. *World Archaeology* 38(3):371-386.

Fairbanks, R. G., R. A. Mortlock, T. C. Chiu, L. Cao, A. Kaplan, T. P. Guilderson, T. W. Fairbanks, A. L. Bloom, P. M. Grootes and M. J. Nadeau

2005 Radiocarbon Calibration Curve Spanning 0 to 50,000 Years B.P. Based on Paired 230Th/234U/238U and 14C Dates on Pristine Corals. *Quaternary Science Reviews* 24:1781-1796.

Feil, D. K.

1986 A Social Anthropologist's View of Papua New Guinea Highlands Prehistory. *American Anthropologist* 88(3):623-636.

Fitzhugh, B.

2001 Risk and invention in human technological evolution. *Journal of Anthropological Archaeology* 20:125-167.

Fitzhugh, B. and J. Habu

2002 *Beyond foraging and collecting : evolutionary change in hunter-gatherer settlement systems*. Fundamental issues in archaeology. Kluwer Academic/Plenum Publishers, New York.

Ford, A.

2011 Learning the lithic landscape: using raw material sources to investigate Pleistocene colonisation in the Ivane Valley, Papua New Guinea. *Archaeology in Oceania* 46(2):42-53.

Fullagar, R., J. Field, T. Denham and C. Lentfer

2006 Early and mid Holocene tool-use and processing of taro (Colocasia esculenta), yam (Dioscorea sp.) and other plants at Kuk Swamp in the highlands of Papua New Guinea. *Journal of archaeological science.* 33(5):595.

Furstner, J. M. M.

1975 Engineering geology of the Ramu 1 hydro-electric project in Papua New Guinea. *Bulletin of the International Association of Engineering Geology - Bulletin de l'Association Internationale de Géologie de l'Ingénieur* 14(1):71-77.

Gaffney, D., A. Ford and G. Summerhayes

2015 Crossing the Pleistocene-Holocene transition in the New Guinea Highlands: Evidence from the lithic assemblage of Kiowa rockshelter. *JOURNAL OF ANTHROPOLOGICAL ARCHAEOLOGY* 39:223-246.

Gaffney, D., G. Summerhayes, A. Ford, J. M. Scott, T. Denham, J. Field and W. R. Dickinson

2015 Earliest Pottery on New Guinea Mainland Reveals Austronesian Influences in Highland Environments 3000 Years Ago. *PLoS ONE* 10(9):e0134497.

Gagan, M. K., E. J. Hendy, S. G. Haberle and W. S. Hantoro

2004 Post-glacial evolution of the Indo-Pacific Warm Pool and El Niño-Southern oscillation. *Quaternary International* 118–119(0):127-143.

Golson, J.

1984 *Kuk and the development of agriculture in New Guinea : retrospection and introspection*. Dept. of Prehistory, A.N.U., Canberra.

Golson, J.

1991 The New Guinea Highlands on the eve of agriculture. *IPPA Bulletin* 11(1991):9.

Golson, J.

2005 Introduction to the chapters on archaeology and ethnology. In *Papuan Pasts: cultural, linguisitc and biological histories of Papua-speaking peoples*, edited by A. Pawley, R. Attenborough, J. Golson and R. Hide, pp. 221-234. Pacific Linguistics, Canberra.

Golson, J. and P. J. Hughes

1980 The Appearance of Plant and Animal Domestication in New Guinea. *Journal de la Société des océanistes* 69(36):294-303.

Golson, J., R. J. Lampert, J. M. Wheeler and W. R. Ambrose

1967 A note on carbon dates for horticulture in the New Guinea Highlands. *The Journal of Polynesian Society* 76(3):369-371.

GoogleMaps

2016. vol. 2013. Google, Inc.

Gorecki, P. P.

1986 Human Occupation and Agricultural Development in the Papua New Guinea Highlands. *Mountain Research and Development* 6(2):159-166.

Goswami, B. N., M. S. Madhusoodanan, C. P. Neema and D. Sengupta

2006 A physical mechanism for North Atlantic SST influence on the Indian summer monsoon. *Geophysical Research Letters* 33(2):n/a-n/a.

Green, R. C.

2003 The Lapita horizon and traditions - signature for one set of Oceania migrations. In *Pacific Archaeology, Assessments and Prospects: Proceedings of the International Conference for the 50th Anniversary of the First Lapita Excavation, Koné-Nouméa, 2002*, edited by C. Sand, pp. 95-120. Département Archéologie, Service des Musées et du Patrimoine de Nouvelle-Calédonie.

Gupta, A., K. , D. Anderson, M. and J. Overpeck, T.

2003 Abrupt changes in the Asian southwest monsoon during the Holocene and their links to the North Atlantic Ocean. *Nature* 421(6921):354.

Haantjens, H. A., J. R. McAlpine, J. C. Saunders, R. G. Robbins and E. Reiner

1970 No. 27 Lands of the Goroka & Mount Hagen Area, Territory of Papua and New Guinea. In *CSIRO Land Research Surveys*, edited by CSIRO, pp. 1-172. vol. 2010. Commonwealth Scientific and Industrial Research Organization, Australia.

Haberle, S.

2000 Vegetation Response to Climate Variability: a paleoecological perspective on the ENSO phenomenon. In *El Niño: History and Crisis*, edited by R. H. Grove and J. Chappell. The White Horse Press, Cambridge.

Haberle, S. G.

1993 Late quaternary environmental history of the Tari Basin, Papua New Guinea.

Haberle, S. G.

1996 Palaeoenvironmental Changes in the Eastern Highlands of Papua New Guinea. *Archaeology in Oceania* 31(1):1-11.

Haberle, S. G.

1998 Late Quaternary vegetation change in the Tari Basin, Papua New Guinea. *Palaeogeography, palaeoclimatology, palaeoecology.* 137(1-2):1.

Haberle, S. G.

2007 Prehistoric human impact on rainforest biodiversity in highland New Guinea. *Philosophical Transactions- Royal Society Of London Series B Biological Sciences* (1478):219-228.

Haberle, S. G. and B. David

2004 Climates of change: human dimensions of Holocene environmental change in low latitudes of the PEPII transect. *Quaternary International* 118-119:165.

Haberle, S. G., G. S. Hope and S. van der Kaars

2001 Biomass burning in Indonesia and Papua New Guinea: natural and human induced fire events in the fossil record. *Palaeogeography, palaeoclimatology, palaeoecology.* 171(3):259.

Haberle, S. G., C. Lentfer, S. O'Donnell and T. Denham

2012 The palaeoenvironments of Kuk Swamp from the beginnings of agriculture in the highlands of Papua New Guinea. *Quaternary International* 249:129-139.

Halldin, M.

2006 Intertropical Convergence Zone (ITCZ), edited by W. Commons.

Harris, D. R.

1996 The origins and spread of agriculture and pastoralism in Eurasia. *The origins and spread of agriculture and pastoralism in Eurasia*.

Haug, G., K. Hughen, D. M. Sigman, L. C. Peterson and U. Rohl

2001 Southward migration of the intertropical convergence zone through the Holocene. *Science* 293(5533):1304-1308.

Hiscock, P.

2007 Artefacts on Aru: Evaluating the Technological Sequences. In *The Archaeology of the Aru Islands, Eastern Indonesia*, edited by S. O'Connor, M. Spriggs and P. Veth. Terra Australis. vol. 22. ANU Press.

Hiscock, P.

2015 Making it small in the Palaeolithic: bipolar stone-working, miniature artefacts and models of core recycling. *WORLD ARCHAEOLOGY* 47(1):158-169.

Huff, J. A.

in press Revisiting NFB: New data indicating the presence of ceramic technology in the Eastern Highlands of Papua New Guinea at 3000 BP.

Huff, J. A. and W. Brown

in prep New Methods, New Models: re-evaluating patterns of site use and mobility in the highlands of PNG using novel statistical methods.

Indonesia. Departemen Luar, N.

2005 *Historical facts on Irian Jaya*. Jakarta : Dept. of Foreign Affairs, Republic of Indonesia, Jakarta.

Jinks, B., H. Nelson and P. Biskup

1968 *A short history of New Guinea*. Sydney Angus and Robertson, Sydney.

Jolly, D. and F. Berkes

2002 Adapting to Climate Change: Social-Ecological Resilience in a Canadian Western Arctic Community. *Ecology and Society* 5(2):18.

Kaidor

2013 English: Global circulation of Earth's atmosphere displaying Hadley cell, Ferrell cell and polar cell. Wikimedia Commons.

Kelly, R. L.

1992 Mobility/Sedentism: Concepts, Archaeological Measures, and Effects. *Annual Review of Anthropology* 21:43-66.

Kennett, D. J. and B. Winterhalder

2006 *Behavioral ecology and the transition to agriculture*. Origins of human behavior and culture, 1. University of California Press, Berkeley.

Kibblewhite, M., G. Tóth and T. Hermann

2015 Predicting the preservation of cultural artefacts and buried materials in soil. *The Science of the total environment* 529:249.

Kuhn, S. L.

1990 A Geometric Index of Reduction for Unifacial Stone Tools. *Journal of Archaeological Science* 17:583-593.

Kuhn, S. L.

1991 "Unpacking" reduction: Lithic raw material economy in the mousterian of west-central Italy. *Journal of Anthropological Archaeology* 10(1):76.

Kuhn, S. L.

1992 Blank Form and Reduction as Determinants of Mousterian Scraper Morphology. *American Antiquity* 57(1):115-128.

Kuhn, S. L.

1993 Mousterian Technology as Adaptive Response: A Case Study. *Archeological Papers of the American Anthropological Association* 4(1):25-31.

Kuhn, S. L.

1994 A Formal Approach to the Design and Assembly of Mobile Toolkits. *American Antiquity* 59(3):426-442.

Kuhn, S. L.

1996 The Trouble with Ham Steaks: A Reply to Morrow. *American Antiquity* 61(3):591-595.

Kuhn, S. L.

2004 Upper Paleolithic raw material economies at UcagIzlI cave, Turkey. *Journal of Anthropological Archaeology* 23(4):431-448.

Latinis, D. K.

2000 The development of subsistence system models for Island Southeast Asia and Near OceaniaL the nature and role of aboriculture and arboreal-based economies. *World Archaeology* 32(1):41-67.

Leblanc, R.

1992 Wedges, Pieces Esquillees, Bipolar Cores, and Other Things: An Alternative to Shott's View Of Bipolar Industries. *North American Archaeologist* 13(1):1-14.

Leduc, G., L. Vidal, K. Tachikawa and E. Bard

2009 ITCZ rather than ENSO signature for abrupt climate change across the tropical Pacific. *Quaternary Research* 72:123-131.

Liu, Z., Z. Lu, X. Wen, B. L. Otto-Bliesner, A. Timmermann and K. M. Cobb

2014 Evolution and forcing mechanisms of El Nino over the past 21,000 years.(RESEARCH: LETTER)(Report)515(7528):550.

Löeffler, E.

1974 No. 33 Explanatory Notes to the Geomorphological Map of Papua New Guinea. In *CSIRO Land Research Surveys*, pp. 1-39. 2010 ed. vol. 2010. CSIRO, Clayton.

MacGregor, J. P.

1967 Upper Ramu Hydro-electric scheme, New Guinea, edited by G. a. G. C. o. A. Department of National Development; Bureau of Mineral Resources. vol. 144. Bureau of Mineral Resources.

MacGregor, J. P. and J. R. L. Read

1967 Geological Investigations of the Goroka - Daulo Pass - Chuave Road, Eastern Highlands District, New Guinea, edited by G. a. G. C. o. A. Department of National Development; Bureau of Mineral Resources. vol. 25. Bureau of Mineral Resources, Canberra.

Mackay, N. J.

1955 Geological Report on a Reconnaissance of the Markham and Upper Ramu Drainage Systems, New Guinea, edited by G. a. G. C. o. A. Department of National Development; Bureau of Mineral Resources. Bureau of Mineral Resources, Canberra.

Mantua, N. and S. Hare

2002 The Pacific Decadal Oscillation. *Journal of Oceanography* 58(1):35-44.

Marwick, B.

2008 What attributes are important for the measurement of assemblage reduction intensity? Results from an experimental stone artefact assemblage with relevance to the Hoabinhian of mainland Southeast Asia. *Journal of Archaeological Science* 35(5):1189-1200.

McMillan, N. J. and E. J. Malone

1958 Geology of the Eastern Highlands of New Guinea, edited by G. a. G. C. o. A. Department of National Development; Bureau of Mineral Resources. vol. 92. Bureau of Mineral Reources, Canberra.

McNiven, I. J., B. David, T. Richards, K. Aplin, B. Asmussen, J. Mialanes, M. Leavesley, P. Faulkner and S. Ulm

2011 NEW DIRECTION IN HUMAN COLONISATION OF THE PACIFIC: Lapita Settlement of South Coast New Guinea. *Australian Archaeology* (72):1-6.

Mountain, M. A.

1991 The prehistory of the New Guinea Highlands, Australian National University, Canberra.

Moy, C. M., G. O. Seltzer, D. T. Rodbell and D. M. Anderson

2002 Variability of El Niño/Southern Oscillation activity at millennial timescales during the Holocene epoch. *Nature* 420(6912):162-165.

Muke, J. and H. Mandui

2003 In the shadows of Kuk: evidence for prehistoric agriculture at Kana, Wahgi Valley, Papua New Guinea. *Archaeology in Oceania* 38(3):177-185.

Murray, J. H. P.

1920 *Review of the Australian administration in Papua from 1907 to 1920*. Port Moresby, E.G. Baker, Government Printer, Port Moresby.

Murray, J. H. P.

1929 *Native administration in Papua*. Port Moresby : Walter Alfred Bock, Port Moresby.

NASA

2016 Reverberations of the Pacific Warm Pool. NASA.

Nelson, M. C.

1991 The study of technological organization. *Archaeological Method and Theory* 3:57-100.

Nicholas, V. L. B.

1985 Gap-Phase Regeneration in a Tropical Forest. *Ecology* 66(3):682-687.

Nicholls, N.

2000 What the Instrumental and Recent Historical Record Tells Us About the El Niño-Southern Oscillation. In *El Niño: History and Crisis*, edited by R. H. Grove and J. Chappell. The White Horse Press, Cambridge.

Page, R. W.

1976 Geochronology of igneous and metamorphic rocks in the New Guinea highlands. Canberra, A.C.T., Australia: Australian Geological Survey Organization, Canberra, A.C.T.

Parker, G., T. Muto, Y. Akamatsu, W. E. Dietrich and J. W. Lauer

2008 Unravelling the conundrum of river response to rising sea-level from laboratory to field. Part II. The Fly–Strickland River system, Papua New Guinea. *Sedimentology* 55(6):1657-1686.

Pataki-Schweizer, K. J.

1980 *A New Guinea landscape : community, space, and time in the eastern highlands*. Seattle : University of Washington Press, Seattle.

Pataki, K. J.

1965 *Shifting popuation and environment among the Auyana*

some considerations on phenomena and schema. Auyana. Thesis (M.A.)--University of Washington.

Philander, S. G. H., D. Gu, G. Lambert, T. Li, D. Halpern, N. C. Lau and R. C. Pacanowski

1996 Why the ITCZ Is Mostly North of the Equator. *Journal of Climate* 9(12):2958-2972.

Pratt, A. E.

1906 *Two years among New Guinea cannibals*

a naturalist's sojourn among the aborigines of unexplored New Guinea. 2d ed. ed. London, Seeley & Co., London.

Radford, R.

1987 *Highlanders and foreigners in the upper Ramu : the Kainantu area 1919-1942*. Carlton, Vic. : Melbourne University Press

Portland, OR : Exclusively distributed by ISBS, Carlton, Vic. : Portland, OR.

Ramsey, P. P., R. K. Smidt and D. M. Levine

2001 *Applied statistics for engineers and scientists : using Microsoft Excel and MINITAB*. Upper Saddle River, N.J. : Prentice Hall, Upper Saddle River, N.J.

Rasmusson, E. M. and J. M. Wallace

1983 Meteorological Aspects of the El Niño/Southern Oscillation. *Science* 222(4629):1195-1202.

Reimer, P. J., M. G. L. Baillie, E. Bard, A. Bayliss, J. W. Beck, C. J. H. Bertrand, P. G. Blackwell, C. E. Buck, G. S. Burr, K. B. Cutler, P. E. Damon, R. L. Edwards, R. G. Fairbanks, M. Friedrich, T. P. Guilderson, A. G. Hogg, K. A. Hughen, B. Kromer, G. McCormac, S. Manning, C. Bronk Ramsey, R. W. Reimer, S. Remmele, J. R. Southon, M. Stuiver, S. Talamo, F. W. Taylor, J. van der Plicht and C. E. Weyhenmeyer

2004 IntCal04 terrestrial radiocarbon age calibration, 0-26 cal kyr BP. *Radiocarbon* 46.

Reimer, P. J., M. G. L. Baillie, E. Bard, A. Bayliss, J. W. Beck, P. G. Blackwell, C. Bronk Ramsey, C. E. Buck, G. S. Burr, R. L. Edwards, M. Friedrich, P. M. Grootes, T. P. Guilderson, I. Hajdas, T. J. Heaton, A. G. Hogg, K. A. Hughen, K. F. Kaiser, B. Kromer, F. G. McCormac, S. W. Manning, R. W. Reimer, D. A. Richards, J. R. Southon, S. Talamo, C. S. M. Turney, J. van der Plicht and C. E. Weyhenmeyer

2011 *IntCal09 and Marine09 Radiocarbon Age Calibration Curves, 0-50,000 Years cal BP*. 2011.

Riel-Salvatore, J. and C. M. Barton

2004 Late Pleistocene Technology, Economic Behavior, and Land-Use Dynamics in Southern Italy. *AMERICAN ANTIQUITY* 69(2):257-274.

Rogerson, R. and D. W. Haig

1982 *Geology and Mineralisation of the Kainantu Area*. Geological Survey of Papua New Guinea.

Root, M. J.

2004 Technological Analysis of Flake Debris. In *Aggregate Analysis in Chipped Stone*, edited by C. T. Hall and M. L. Larson. The University of Utah Press, Salt Lake City.

Ross, M.

2005 Pronouns as preliminary diagnostic for grouping Papuan languages. In *Papuan Pasts: cultural, linguisitc and biological histories of Papua-speaking peoples*, edited by A. Pawley, R. Attenborough, J. Golson and R. Hide, pp. 15-66. vol. 572. Pacific Linguistics, Canberra.

Russell, J. M., H. Vogel, B. L. Konecky, S. Bijaksana, Y. Huang, M. Melles, N. Wattrus, K. Costa and J. W. King

2014 Glacial forcing of central Indonesian hydroclimate since 60,000 y B.P. *Proceedings of the National Academy of Sciences of the United States of America* 111(14):5100.

Schwab, V. F. and J. P. Sachs

2009 The measurement of D/H ratio in alkenones and their isotopic heterogeneity. *Organic Geochemistry* 40(1):111-118.

Shott, M. J.

1989 Bipolar Industries: ethnographic evidence and archaeological implications. *North American Archaeologist* 10(1):1-24.

Shott, M. J.

1999 On Bipolar Reduction and Splintered Pieces. *North American Archaeologist* 20(3):217-238.

Smith, B. D.

2001 Low-Level Food Production. *Journal of Archaeological Research* 9(1):1-43.

Sniderman, J. M. K., J. Finn and T. P. Denham

2009 A late-Holocene palaeoecological record from Ambra Crater in the highlands of Papua New Guinea and implications for agricultural history. *The Holocene* 19(3):449-458.

Soares, P. A., J. A. Trejaut, T. Rito, B. Cavadas, C. Hill, K. K. Eng, M. Mormina, A. Brandão, R. M. Fraser, T.-Y. Wang, J.-H. Loo, C. Snell, T.-M. Ko, A. Amorim, M. Pala, V. Macaulay, D. Bulbeck, J. F. Wilson, L. Gusmão, L. Pereira, S. Oppenheimer, M. Lin and M. B. Richards

2016 Resolving the ancestry of Austronesian-speaking populations. *Human Genetics* 135(3):309-326.

Souter, G.

1970 *New Guinea: the last unknown*. Sydney, Angus and Robertson, Sydney.

Spriggs, M.

1984 The Lapita cultural complex: Origins, distribution, contemporaries and successors. *The Journal of Pacific History* 19(4):202-223.

Spriggs, M.

2006 The Lapita Culture and Austronesian Prehistory in Oceania. In *The Austronesians Historical and Comparative Perspectives*, edited by P. Bellwood, J. J. Fox and D. T. Tyron. ANU Press, Canberra.

Standish, W.

1982 Elite Communalism: The Highlands Liberation Front. In *Micronationalist Movements In Papua New Guinea*, edited by R. J. May, pp. 359-414. Political and Social Change Monograph. vol. 1. SOCPAC Printery, Canberra.

Strachan, J.

1888 *Explorations and adventures in New Guinea*. London : S. Low, Marston, Searle & Rivington, London.

Summerhayes, G. R., M. Leavesley, A. Fairbairn, H. Mandui, J. Field, A. Ford and R. Fullagar

2010 Human adaptation and plant use in highland New Guinea 49,000 to 44,000 years ago. *Science (New York, N.Y.)* 330(6000):78-81.

Surovell, T. A., J. Byrd Finley, G. M. Smith, P. J. Brantingham and R. Kelly

2009 Correcting temporal frequency distributions for taphonomic bias. *Journal of Archaeological Science* 36(8):1715-1724.

Swadling, P.

1973 *The human settlement of the Arona Valley, Eastern Highland District, Papua New Guinea: prepared by Pamela L. Swadling for Papua New Guinea Electricity Commission*. the Commission, Boroko.

Swadling, P., J. Chappell, G. Francis, N. Araho and B. Ivuyo

1989 A Late Quaternary Inland Sea and Early Pottery in Papua New Guinea. *Archaeology in Oceania* 24(3):106-109.

Szabo, K. and S. O'Connor

2004 Migration and Complexity in Holocene Island Southeast Asia. *World Archaeology* 36(4):621-628.

Tachikawa, K., O. Cartapanis, L. Vidal, L. Beaufort, T. Barlyaeva and E. Bard

2011 The precession phase of hydrological variability in the Western Pacific Warm Pool during the past 400 ka. *Quaternary Science Reviews* 30(25):3716-3727.

TAO_Project_Office

2016 El Niño and Normal, edited by D. Dr. Michael J. McPhaden. NOAA/Pacific Marine Environmental Laboratory.

Taylor, R. E. and O. Bar-Yosef

2014 *Radiocarbon Dating, Second Edition An Archaeological Perspective*. Radiocarbon Dating. Walnut Creek : Left Coast Press, Walnut Creek.

Terrell, J. E., K. M. Kelly and P. Rainbird

2001 Foregone Conclusions? In Search of "Papuans" and "Austronesians". *CURRENT ANTHROPOLOGY* 42:97-124.

Torrence, R.

1989 Re-tooling: towards a behavioral theory of stone tools. In *Time, Energy and Stone Tools*, edited by R. Torrence, pp. 57-66. University of Cambridge, Cambridge.

Torrence, R., V. Neall, T. Doelman, E. Rhodes, C. McKee, H. Davies, R. Bonetti, A. Guglielmetti, A. Manzoni, M. Oddone, J. Parr and C. Wallace

2004 Pleistocene colonisation of the Bismarck Archipelago: new evidence from West New Britain. *Archaeology in Oceania* 39(3):101-130.

Tucek, C. S.

1971 Radiocarbon, Ltd. natural radiocarbon measurements I. *Radiocarbon* 13(1):74-77.

Tudhope, A. W., C. P. Chilcott, M. McCulloch, E. R. Cook, J. Chappell, R. M. Ellam, D. W. Lea, J. M. Lough and G. B. Shimmield

2001 Variability in the El Niño-Southern Oscillation Through a Glacial-Interglacial Cycle. *Science* 291:1511-1517.

Ullah, I. I. T., I. Kuijt and J. Freeman

2015 Toward a theory of punctuated subsistence change. *Proceedings of the National Academy of Sciences* 112(31):9579-9584.

Veth, P., M. Spriggs and S. O'Connor

2005 Continuity in Tropical Cave Use: Examples from East Timor and the Aru Islands, Maluku. *Asian Perspectives* 44(1):180.

Vrydaghs, L. and T. Denham

2010 Rethinking Agriculture: Introductory Thoughts. In *Rethinking Agriculture*, edited by T. Denham, J. Iriarte and L. Vrydaghs, P. ebrary, general editor. Left Coast Press, Walnut Creek.

Wang, L., M. Sarnthein, H. Erlenkeuser, J. Grimalt, P. Grootes, S. Heilig, E. Ivanova, M. Kienast, C. Pelejero and U. Pflaumann

1999 East Asian monsoon climate during the Late Pleistocene: high-resolution sediment records from the South China Sea. *Marine Geology* 156(1-4):245-284.

Wanner, H., O. Solomina, M. Grosjean, S. P. Ritz and M. Jetel

2011 Structure and origin of Holocene cold events. *Quaternary Science Reviews* 30:3109-3123.

Watson, V.

1976 Classification in Prehistory. *Archaeology and Physical Anthropology in Oceania* 11:81-90.

Watson, V.

1995 Simple and Significant: stone tool production in highland New Guinea. *lithtech Lithic Technology* 20(2):89-99.

Watson, V.

1997 *Anyan's story : a New Guinea woman in two worlds*. Seattle : University of Washington Press, Seattle.

Watson, V. and J. D. Cole

1977 *Prehistory of the eastern highlands of New Guinea*. Anthropological studies in the eastern highlands of New Guinea, 3. University of Washington Press, Seattle.

Watson, V. D.

1979 New Guinea Prehistory: A Model of Regional Comparison. *Archaeology & Physical Anthropology in Oceania* 14(2):83-98.

Wei, G.-J., W.-F. Deng, K.-F. Yu, X. Li, W.-D. Sun and J. x. Zhao

2007 Sea surface temperature records in the northern South China Sea from mid-Holocene coral Sr/Ca ratios. *Paleoceanography* 22(3).

White, P. J.

1967 Taim bilong bipo investigations towards a prehistory of the Papua-New Guinea Highlands.

White, P. J.

1968 Fabrication, Outils ecailles on Scalar Cores? *Mankind: Official Journal of the Anthropological Societies of Australia* 7:658-666.

White, P. J.

1969 Typologies for some prehistoric flaked stone artefacts of the Australian New Guinea Highlands. *Archaeology and Physical Anthropology in Oceania* 4(1):18-46.

White, P. J.

1972 *Ol Tumbuna: archaeological excavations in the Eastern Central Highlands, Papua New Guinea*. Terra Australis, 2. Dept. of Prehistory, Research School of Pacific Studies, Australian National University, Canberra.

White, P. J.

1977 *A collection of stone axes and ethonographic data made by the late Ole Christensen in the central Highlands, Papua New Guinea*. Dept. of Prehistory, Research School of Pacific Studies, the Australian National University, [Canberra].

White, P. J. and D. H. Thomas

1972 What Mean These Stones? Ethnotaxonomic Models and Archaeological Interpretations in the New Guinea Highlands. In *Models in Archaeology*, edited by D. Clarke, pp. 275-308. Methuen, London.

Winterhalder, B., F. Lu and B. Tucker

1999 Risk-sensitive adaptive tactics: Models and evidence from subsistence studies in biology and anthropology. *Journal of Anthropological Research* 7(4):301-348.

Yancheva, G., N. R. Nowaczyk, J. Mingram, P. Dulski, G. Schettler, J. F. W. Negendank, J. Liu, D. M. Sigman, L. C. Peterson and G. H. Haug

2007 Influence of the intertropical convergence zone on the East Asian monsoon. *Nature* 445(7123):74-77.

Yasuda, Y. (editor)

2002 *The origins of pottery and agriculture*. New Delhi : Roli Books, New Delhi.

Zamonin

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Appendix A

site	site code	sample #	14C date estimate	standard error	citation author	citation year
Kosipe/Ivane Valley	AAXF	WK 27072	41951	1571	Summerhayes	2010
Kosipe/Ivane Valley	AAXF	WK 27074	41206	1173	Summerhayes	2010
Kosipe/Ivane Valley	AAXF	WK 27073	40922	1113	Summerhayes	2010
Kosipe/Ivane Valley	AAXE	WK 23354	40298	956	Summerhayes	2010
Kosipe/Ivane Valley	AAXD	WK 23356	39836	909	Summerhayes	2010
Kosipe/Ivane Valley	AAXD	WK 23355	36264	575	Summerhayes	2010
Kosipe/Ivane Valley	AER	WK 17901	35049	670	Summerhayes	2010
Kosipe/Ivane Valley	AER	WK 17900	34531	629	Summerhayes	2010
Kosipe/Ivane Valley	AER	ANU-191	26870	590	White	1970
Kosipe/Ivane Valley	AER	ANU-190	26450	800	White	1970
Kosipe/Ivane Valley	AAXE	WK 27080	24856	153	Summerhayes	2010
Kosipe/Ivane Valley	AAXE	WK 27076	24433	149	Summerhayes	2010
Kosipe/Ivane Valley	AAXE	WK 27077	22998	125	Summerhayes	2010
Kosipe/Ivane Valley	AAXE	WK 27079	22907	137	Summerhayes	2010
Kosipe/Ivane Valley	AAXF	WK 27069	22802	141	Summerhayes	2010
Kosipe/Ivane Valley	AAXE	WK 23352	22414	416	Summerhayes	2010
Kosipe/Ivane Valley	AAXE	WK 27075	22313	114	Summerhayes	2010
Kosipe/Ivane Valley	AAXC	WK 23359	22302	108	Summerhayes	2010

Kosipe/Ivane Valley	AAXE	WK 27078	22155	113	Summerhayes	2010
Kosipe/Ivane Valley	AER	GaK-624	19300	1200	White	1970
Kosipe/Ivane Valley	AER	GaK-625	19350	600	White	1970
NFX	NFX	RL-370	18050	750	Watson & Cole	1977
NFX	NFX	OxA-26323	17065	80	Huff - this publication	2013
NFX	NFX	I 7284-C	16210	270	Watson & Cole	1977
Wañlek	JAO	GX-3331	15100	450	Bulmer	1977
NFX	NFX	I 7284	12680	280	Watson & Cole	1977
Wañlek	JAO	GX-3328	11995	425	Bulmer	1977
NFX	NFX	UW 262	11510	140	Watson & Cole	1977
Kosipe/Ivane Valley	AER	ANU-189	8970	620	White	1970
Kosipe/Ivane Valley	AAXC	WK 23358	7489	32	Summerhayes	2010
Kosipe/Ivane Valley	AAXE	WK 23353	7417	32	Summerhayes	2010
Kosipe/Ivane Valley	AAXF	WK 27070	6240	30	Summerhayes	2010
Kosipe/Ivane Valley	AAXF	WK 27068	6070	32	Summerhayes	2010
Wañlek	JAO	I-6860	5455	105	Bulmer	1974
Kosipe/Ivane Valley	AER	ANU-21	4050	500	White	1970
NFB	NFB	RL-407	3960	170	Watson & Cole	1977
Kosipe/Ivane Valley	AAXC	WK 23357	3938	34	Summerhayes	2010
Kosipe/Ivane Valley	AAXC	WK 23348	3855	30	Summerhayes	2010
Wañlek	JAO	GX-3333B	3840	175	Bulmer	1977
NGH	NGH	UW 108	3780	120	Watson & Cole	1977
NFB	NFB	UW 260	3530	130	Watson & Cole	1977
Wañlek	JAO	GX-3326	3430	175	Bulmer	1977

NGG	NGG	UW 107	3300	150	Watson & Cole	1977
Wañlek	JAO	GX-3227B	3230	230	Bulmer	1977
Wañlek	JAO	GX-3330	3225	180	Bulmer	1977
Wañlek	JAO	GX-3332	3170	210	Bulmer	1977
NFB	NFB	UW 261	3070	95	Watson & Cole	1977
Wañlek	JAO	I-6859	2865	90	Bulmer	1974
Wañlek	JAO	I-6861	2840	90	Bulmer	1974
Kana		ANU-9487	2450	200	Muke & Mandui	2003
NFB	NFB	I 7285	2060	85	Watson & Cole	1977
NGM	NGM	RL-408	290	90	Watson & Cole	1977
NFB	NFB	I 7286	185	80	Watson & Cole	1977
Nombe	NAC	ANU-2578	27000	550	Mountain	1991
Batari	NBY	ANU-40	16850	70	White	1972
Nombe	NAC	ANU-2580	14700	180	Mountain	1991
Nombe	NAC	ANU-3683	13150	500	Mountain	1991
Yuku	MAH	GX-3112B	12100	350	Bulmer	1974, 1975, 1979
Nombe	NAC	ANU-2581	11900	130	Mountain	1991
Nombe	NAC	ANU-3681	11650	160	Mountain	1991
Nombe	NAC	ANU-2569	11400	190	Mountain	1991
Kiowa	NAW	Y-1366	10350	140	Bulmer	1964
Nombe	NAC	ANU-2579	10250	100	Mountain	1991
Nombe	NAC	ANU-2576	10250	250	Mountain	1991
Kiowa	NAW	Y-1368	9920	200	Bulmer	1964

Yuku	MAH	ANU358	9780	150	Bulmer	1974, 1975, 1979
Yuku	MAH	GX-3113B	9700	300	Bulmer	1974, 1975, 1979
Manim	MJJ	ANU-1375	9670	220	Christensen	1975
Nombe	NAC	ANU-3686	9560	230	Mountain	1991
Kiowa	NAW	Y-1367	9300	200	Bulmer	1964
Kafiavana	NBZ	NZ-1026	9290	140	White	1972
Nombe	NAC	ANU-3687	8320	840	Mountain	1991
Nombe	NAC	ANU-3688	6740	120	Mountain	1991
Nombe	NAC	ANU-3075	6410	60	Mountain	1991
Kiowa	NAW	Y-1370	6100	160	Bulmer	1964
Nombe	NAC	ANU-3076	5870	110	Mountain	1991
Nombe	NAC	ANU-3074	5810	180	Mountain	1991
Nombe	NAC	ANU-3684	5340	120	Mountain	1991
Nombe	NAC	ANU-3689	5090	220	Mountain	1991
Kiowa	NAW	Y-1371	4840	140	Bulmer	1964
Kafiavana	NBZ	ANU-42	4690	170	White	1972
Yuku	MAH	GX-3111B	4570	220	Bulmer	1974, 1975, 1979
Kamapul	MKK	ANU-1325	4340	100	Christensen	1975
Aibura	NAE	GaK-623	3800	110	White	1972
Nombe	NAC	ANU-2570	3450	310	Mountain	1991
Batari	NBY	ANU-38a	3470	60	White	1972
Tugeri	MJX	ANU-1321	2450	70	Christensen	1975

Etpiti	MJW	ANU-1323	2170	70	Christensen	1975
Nombe	NAC	ANU-3685	900	80	Mountain	1991
Batari	NBY	ANU-39	850	53	White	1972
Aibura	NAE	Gak-622	770	110	White	1972
Nombe	NAC	OxA-2541	320	95	Hedges et al.	1995
Nombe	NAC	OxA-2537	170	100	Hedges et al.	1995
Kafiavana	NBZ	OxA-2540	165	90	Hedges et al.	1995
Nombe	NAC	OxA-2538	100	95	Hedges et al.	1995
Kafiavana	NBZ	OxA-2539	80	95	Hedges et al.	1995
Nombe	NAC	ANU-3073	100.4	0.9	Mountain	1991
Nombe	NAC	OxA-2536	45	85	Hedges et al.	1995
Batari	NBY	ANU-38b	≥8230	190	White	1972
Kafiavana	NBZ	ANU-41B	≥10730	370	White	1972
Kafiavana	NBZ	ANU-20	>9500	n/a	White	1972
Kuk	MAB	ANU-11441	9390	40	Denham et al.	2003
Kuk	MAB	ANU-11071	9050	90	Denham et al.	2003
Kuk	MAB	ANU-11075	9040	80	Denham et al.	2003
Kuk	MAB	OZD928	9030	60	Denham et al.	2003
Kuk	MAB	ANU-11070	8840	240	Denham et al.	2003
Kuk	MAB	OZD929	8840	60	Denham et al.	2003
Kuk	MAB	ANU-11182	8800	100	Denham et al.	2003
Kuk	MAB	OZD922	8460	90	Denham et al.	2003

Kuk	MAB	ANU-1 057	5970	80	Denham et al.	2003
Kuk	MAB	ANU-1 196A	5950	80	Denham et al.	2003
Kuk	MAB	ANU-1 311	5790	100	Denham et al.	2003
Kuk	MAB	ANU-1 196B	5400	230	Denham et al.	2003
Manton/Kuk	MCS	ANU-4 4	4600	140	Golson et al.	1967
Kuk	MAB	ANU-1 1432	4380	40	Denham et al.	2003
Kuk	MAB	ANU-1 1183	4130	80	Denham et al.	2003
Kuk	MAB	OZF239	4000	30	Denham et al.	2003
Kuk	MAB	ANU-1 464A	3900	140	Denham et al.	2003
Kuk	MAB	OZF240	3780	50	Denham et al.	2003
Kuk	MAB	ANU-1 464B	3600	80	Denham et al.	2003
Kuk	MAB	ANU-1 315	3520	90	Denham et al.	2003
Kuk	MAB	ANU-1 815	3470	170	Denham et al.	2003
Kana		ANU-9 382	2970	70	Muke & Mandui	2003
Kuk	MAB	ANU-1 1185	2890	80	Denham et al.	2003
Kuk	MAB	ANU-8 055	2650	80	Denham et al.	2003
Kuk	MAB	ANU-8 056	2480	80	Denham et al.	2003
Manton/Kuk	MCS	ANU-4 3	2300	120	Golson et al.	1967
Kana		ANU-1 0964	1520	150	Muke & Mandui	2003
Kana		ANU-9 381	820	130	Muke & Mandui	2003
Kana		ANU-1 1230	360	70	Muke & Mandui	2003

APPENDIX B – ADDITIONAL DATA FROM CH.5 ARTIFACT ANALYSIS

Quartile transitional values for quantitative measures of unmodified flakes with usewear

Table B-0-1: table of transitional values for boxplot of distribution of values for maximum length of flakes with usewear

Box Plot	*NFX*	*NBZ*	*NFB*
Min	9.96	7.28	6.84
Q1-Min	7.695	5.65	8.6375
Med-Q1	5.15	5.71	4.3125
Q3-Med	5.1525	5.43	4.8325
Max-Q3	59.6625	27.04	40.8475

Table B-0-2: table of transitional values for boxplot of distribution of values for medial width of flakes with usewear

Box Plot	*NFX*	*NBZ*	*NFB*
Min	5.22	5.01	4.54
Q1-Min	6.1	5.62	6.8
Med-Q1	5.585	4.14	2.96
Q3-Med	4.6575	4.96	3.68
Max-Q3	58.2375	31.12	20.82

Table B-0-3: table of transitional values for boxplot of distribution of values for maximum thickness of flakes with usewear

Box Plot	*NFX*	*NBZ*	*NFB*
Min	1.54	1.08	1.22
Q1-Min	1.8325	1.55	2.94

Med-Q1	2.5575	1.04	2.38
Q3-Med	2.86	2.73	2.91
Max-Q3	28.94	49.4	12.2

Table B-0-4: descriptive statistics for the weight of unmodified flakes with usewear

Box Plot	*NFX*	*NBZ*	*NFB*
Min	0	0	0.12
Q1-Min	0.5825	0.37	0.69
Med-Q1	1.3275	0.43	0.84
Q3-Med	3.0275	1.6	2.02
Max-Q3	139.4225	22.12	14.81

Table B-0-5: table of transitional values for boxplot of distribution of values for weight in grams of flakes with usewear

Box Plot	*NFX*	*NBZ*	*NFB*
Min	0	0	0.12
Q1-Min	0.5825	0.37	0.69
Med-Q1	1.3275	0.43	0.84

Q3-Med	3.0275	1.6	2.02
Max-Q3	139.4225	22.12	14.81

Table B-0-6: transitional values for quartiles for the distribution of the percentage of cortex on all unmodified flakes with cortex

Box Plot			
	NBZ	*NFB*	*NFX*
Min	5	1	5
Q1-Min	10	9	10
Med-Q1	15	10	10
Q3-Med	15	20	15
Max-Q3	15	40	40

Supplementary tables for Chi-squared analysis of percentage of cortex:

Table B-0-7: observed values for frequencies of the presences or absence of cortex on all unmodified flakes

		NBZ	NFB	NFX	totals	total %
OBSERVED	#pieces with cortex	176	69	88	333	16.42%
	#pieces w/o cortex	973	343	379	1695	83.58%
	# of cases	1149	412	467	2028	

Table B-0-8: expected values for frequencies of the presences or absence of cortex on all unmodified flakes

Expected Values				
	NBZ	NFB	NFX	Total
#pieces with cortex	188.6672	67.65089	76.68195	333
#pieces w/o cortex	960.3328	344.3491	390.318	1695
Total	1149	412	467	2028

Table B-0-9: observed values for frequencies of the presences or absence of cortex on unmodified flakes with usewear

Observed Values		
	#cor+use	no cor + use
NBZ	23	138
NFB	62	207
NFX	15	55

Table B-0-10: expected values for frequencies of the presences or absence of cortex on unmodified flakes with usewear

Expected Values			
	#cor+use	no cor + use	Total
NBZ	32.2	128.8	161

NFB	53.8	215.2	269
NFX	14	56	70
Total	100	400	500

The relationship of quantitative variables by site:

The following figures show scatterplots of maximum thickness and weight of chipped stone artifacts with trend lines and R^2 scores showing the variability explained by the relationship between these variables. The dataset used here has been trimmed of the most extreme values so that the central tendencies are clearer.

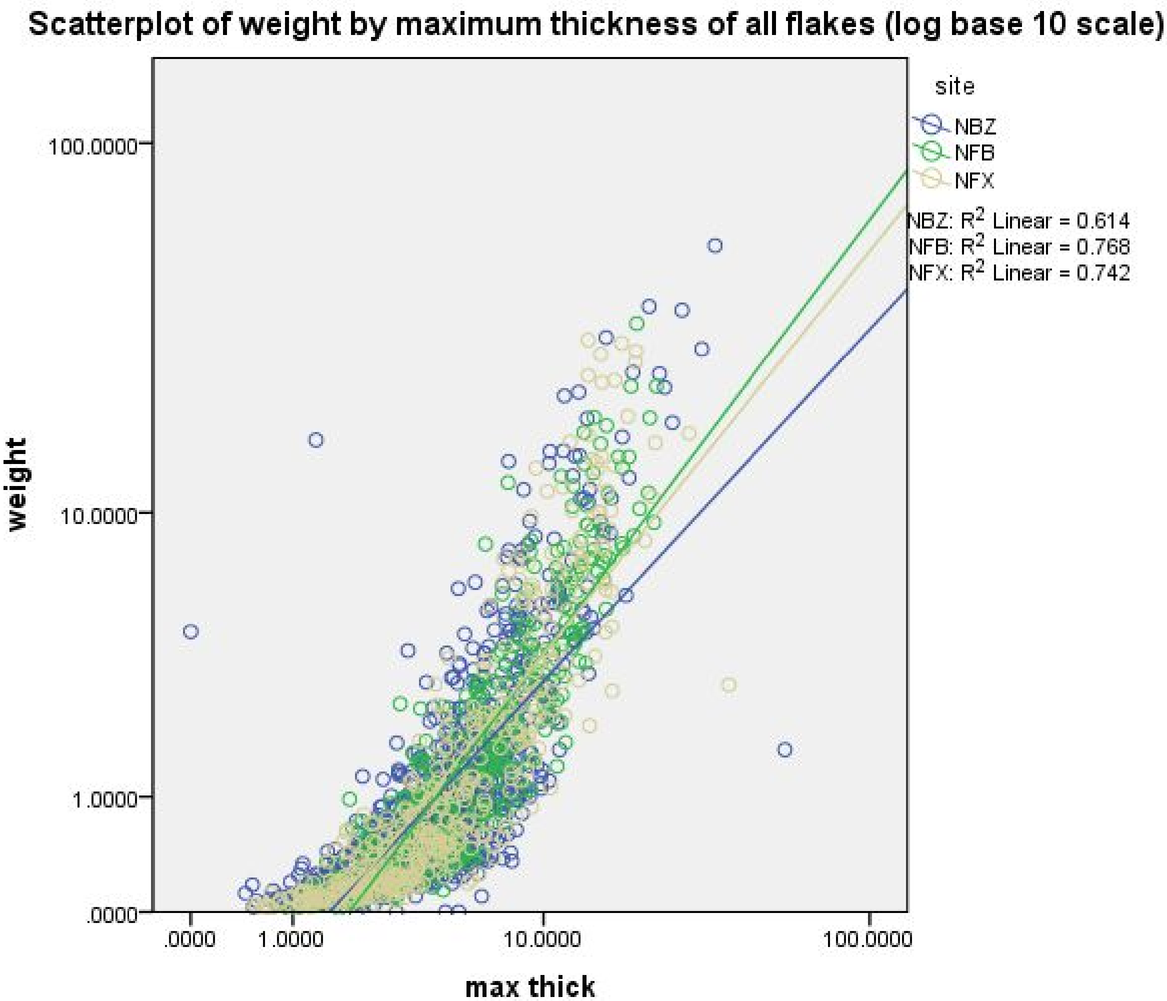

Figure B-1: scatterplot of values of weight and maximum thickness of all flakes grouped by site with linear regression.

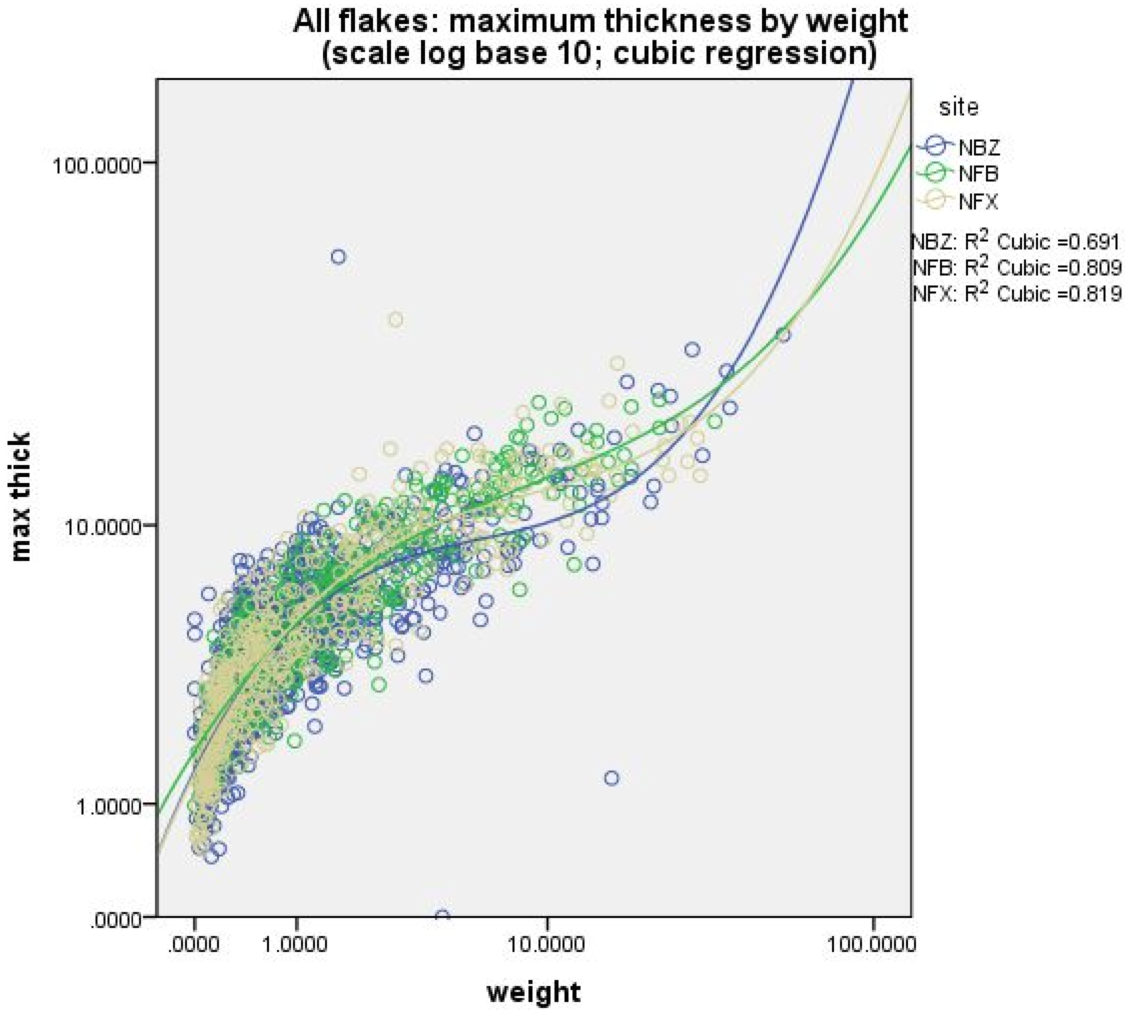

Figure B-2: scatterplot of maximum thickness and weight for all flakes grouped by site with cubic regression lines.

Figures B-1 and B-2 demonstrate the relationship between weight and thickness as strong predictors of the other variable. With either a linear or a cubic regression, this relationship is substantially stronger at NFB and NFX relative to the relationship between these variables at NBZ.

Supplementary tables for Chi-squared analysis of other chipped-stone artifacts

Table B-0-11: observed values of other chipped stone artifacts by site

Observed Values			
	cores	**unifacial**	**bifacial**
NFX	5	11	1
NBZ	57	56	8
NFB	13	24	1

Table B-0-12: expected values of other chipped stone artifacts by site

Expected Values				
	cores	**unifacial**	**bifacial**	**Total**
NFX	7.244318	8.789773	0.965909	17
NBZ	51.5625	62.5625	6.875	121
NFB	16.19318	19.64773	2.159091	38
Total	75	91	10	176

Histograms of other artifact types by site:

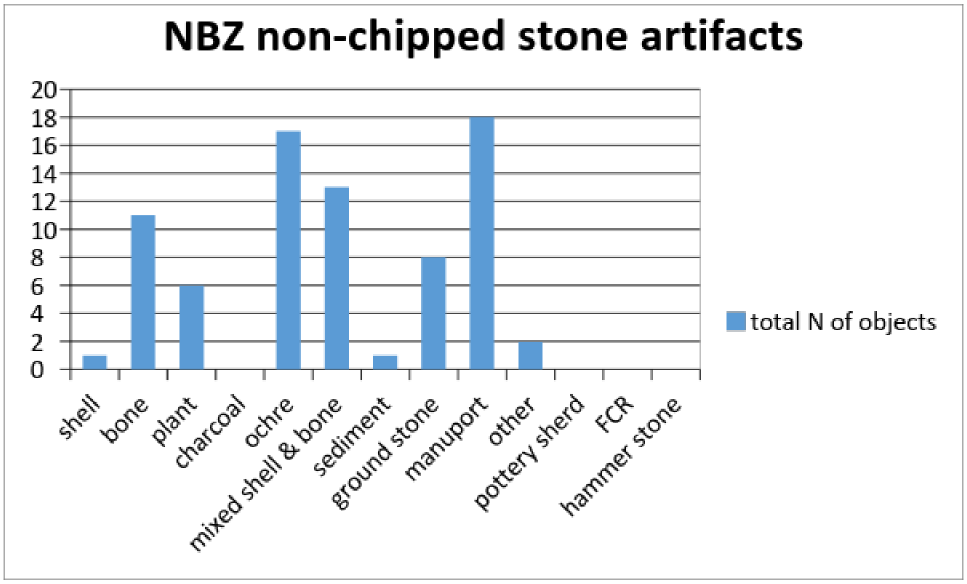

Figure B-3: bar chart of frequencies of other (non-chipped stone) artifacts at NBZ

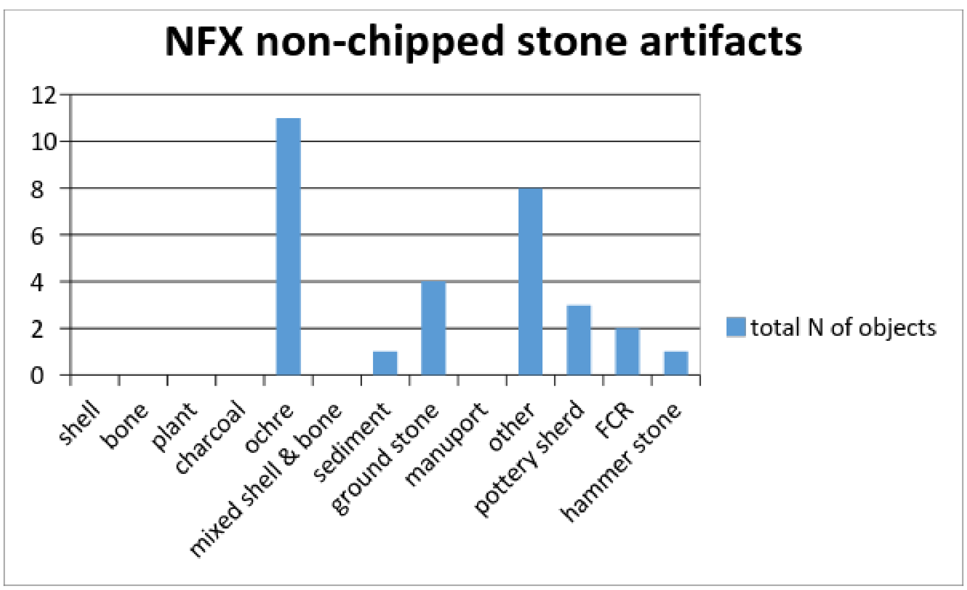

Figure B-4: bar chart of frequencies of other (non-chipped stone) artifacts at NFX

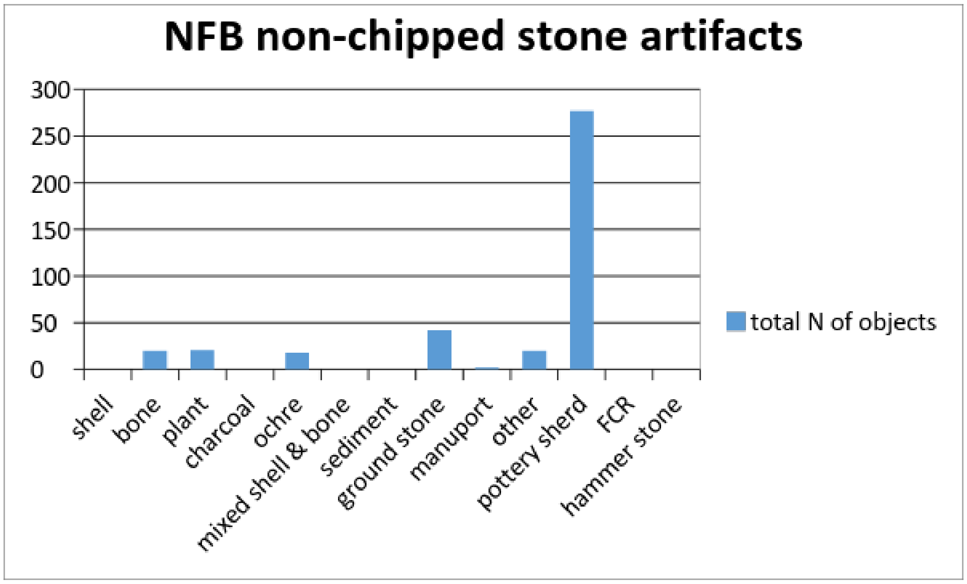

Figure B-5: bar chart of frequencies of other (non-chipped stone) artifacts at NFB