Stone artefacts and human ecology at two rockshelters in Northwest Thailand

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To the best of my knowledge, the research presented in this thesis is my own except in cases where I acknowledge the work of other researchers. This thesis has not been submitted in any form for any other degree at this or any other university

Ben Marwick

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Abstract

This thesis documents the interaction of stone artefact technology and local environmental contexts during the late Pleistocene and Holocene at two rockshelters in the uplands of northwest Thailand. Previous work has been divided over the importance of environmental influences in human forager technology in mainland Southeast Asia. It has also been limited by the use of typological methods that are poorly suited to the flaked stone artefact technology of the region. Typological methods have not performed well because of the paucity of formal types in these assemblages. This has left a gap in our understanding of prehistoric human-environment relations. Advances in archaeology and human behavioural ecology have allowed for a more robust articulation between archaeological evidence and behaviours relating to environmental change. Three general models were developed from optimal foraging theory: a patch choice model, a central place model and an optimal dispersion model.

Developments in stone artefact analysis have produced reliable links between specific technological attributes of artefacts, behaviours relating to technological organisation and strategies of risk management. These advances were applied here to explore different dimensions of technological organisation by investigating the three foraging models. An experiment was conducted to test which variables are most indicative of risk reduction at the assemblage level for flaked stone artefacts in mainland Southeast Asia. These variables were then recorded from stone artefacts recovered from archaeological deposits at Ban Rai Rockshelter and Tham Lod Rockshelter. Although relatively close to each other, there are stark contrasts in the local availability of resources at these two sites because of the rugged landscape. These contrasts were used to refine the three models and produce synchronic hypotheses to test with the stone artefacts. A palaeoecological record was constructed by analyzing oxygen and carbon isotopes in freshwater bivalves recovered from the two sites. This allowed for further refinement of the three models and production of diachronic hypotheses about the relationship between stone artefact technological organisation and environmental change.

The result of the hypothesis testing suggested that people were simultaneously optimising their response to climatic conditions and local resource availability, but in a way that was not consistently predicted by the existing models. This inconsistency was

resolved by introducing a model of risk management and stone artefact reduction that includes a point of inflection so that environmental constraints can result in more than one optimum strategy. This work has vindicated previous claims that mainland Southeast Asian foragers were sensitive to environmental changes, especially over the Pleistocene-Holocene boundary. This work has found no support for previous claims that Pleistocene technologies were flake-based while Holocene industries were cobble-based. The results have important implications for understanding mainland Southeast Asian prehistory, including introducing of a suite of effective methods and techniques for human palaeoecology and stone artefact analysis, identifying potential causes and probable timing of technological and subsistence changes throughout the region as well as demonstrating the resilience and vulnerability of human groups to environmental variability.

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If we cannot usefully employ the stone tools, we cut out a very large part of our direct data from the past, data which provide many of the foundations of our more theoretically oriented upper stories. (White 1977: 13).

1. Introduction

Introduction

This thesis examines the relationship between human foragers and their environment through the lens of stone artefacts deposited over a 35,000 year period at two sites in northwest Thailand. The two sites, Tham Lod and Ban Rai, are located in an area typical of the extensive seasonal tropical forests and limestone karsts of mainland Southeast Asia. Despite an almost continuous tradition of archaeological research in these environments since the 1960s, very little has been discovered about how human foragers organised their stone artefact technology under varying environmental conditions. Although statements have frequently been made about technological change and climate change during the Pleistocene and Holocene in mainland Southeast Asia, no study of direct links between these two variables has been reported. This represents a serious gap in the knowledge required for understanding global variation in non-agricultural human societies.

The organisation of flaked stone artefact technology refers to the choices that human foragers make when solving the problems of maintaining a constant supply of stone to do useful work when the availability of stone is discontinuous. The technological and subsistence practises resulting from specific choices of individual foragers can be difficult to unambiguously identify. However, when the outcomes of large numbers of these choices are considered as an aggregate, through the measurement of assemblage-level reduction, then it is possible to infer time-averaged patterns of decision-making. For the two sites investigated here, employing stone to do work involves the reduction of cobbles through the detachment of flakes. Resharpening and reshaping of flakes do not appear to have been important strategies at these sites. The costs involved in the reduction process, in terms of consuming artefacts by using them and the costs of provisioning stone to make artefacts, vary according to the constraints and opportunities at any given time. For example, where the cost of provisioning is high, such as when sources of stone are remote, it is advantageous for people to adopt a strategy that emphasises efficiency. This might include techniques that extend the amount of work that can be done per unit of stone.

While the organisation of stone artefact technology may reflect social, psychology and political mechanisms, investigation of the role of the environment has emerged as a very productive area of inquiry into stone artefact technology. In particular, previous work has established that stone artefact technology is sensitive to variation in group mobility, prey abundance and quality and risk related to resource availability and scheduling (Bamforth 1986, Barton 1988, Bleed 1986, Clarkson 2007, Hiscock 2002a, Kelly 1988, Kuhn 1995, Nelson 1991, Parry and Kelly 1987, Torrence 1989). This project was motivated by the success of these previous investigations to apply their concepts to the explanation of assemblage variability in mainland Southeast Asia. Mainland Southeast Asia is a largely unknown region on the map of global variation in stone artefact technology. Surrounding regions such as India, China and Indonesia have a long history of productive research into stone artefact technology (Madsen et al. 2001, Moore and Brumm 2007, Pappu 2001). However, the current research focus in mainland Southeast Asia is on the emergence of agriculture and urbanism (Evans et al. 2007, White and Bouasisengpaseuth 2007). This has left undocumented the deep prehistory of a large area with distinctive seasonal tropical forest environments and historical trajectories.

Stone artefacts have not been completely neglected in mainland Southeast Asia, but previous approaches have relied on concepts and methods that were either inappropriate or incorrect. This has resulted in an apparent stasis in the study of stone artefacts in mainland Southeast Asia. Much previous work has been concerned with how the term 'Hoabinhian' is best defined and what diagnostic traits can be abstracted from the typically amorphous stone artefact assemblages (Hutterer 1977). To be fair, the difficulty in analysing mainland Southeast Asian flaked stone artefacts is a common theme in previous work and tentative efforts have been made to replace unproductive typological methods (Matthews 1964, White and Gorman 2004). This project was motivated by these efforts to attempt to formulate a systematic and comprehensive approach to explore variation in the amorphous stone artefact assemblages characteristic of pre-agricultural mainland Southeast Asia societies.

The choice of study area and sites for this project was opportunistic. To undertake an excavation large enough to produce the necessary stone artefact assemblage sizes to make reliable statements about technology and the environment was beyond the limits of this project. Consequently, a current field program was sought out where large

excavations were already underway. This led to the excavations at Tham Lod and Ban Rai that were conducted by a large Thai archaeological project directed by Rasmi Shoocongdej of the University of Silpakorn. These sites were chosen by Shoocongdej because they are located in an upland region of very high biodiversity that has been a focus of archaeological research. High biodiversity means that climate changes should leave more pervasive and detectable signals and the previous archaeological work, conducted by Gorman (1971b) in the 1960s demonstrates that the study area already has a reputation for shaping the construction of mainland Southeast Asian prehistory.

Aim and structure

The aim of this project is to explore the organisation of flaked stone artefact technology under varying climatic conditions during the Pleistocene and Holocene at two sites in the uplands of northwest Thailand. To achieve this aim, four questions will be addressed.

1. What is the most productive conceptual framework to employ in the analysis of technological organisation in mainland Southeast Asia?

Chapter two describes relevant previous work and concludes that although it has attempted to address questions of ecology and technology, it has generally been undertheorised and lacks convincing and testable links between observations and explanations. In chapter three is it argued that evolutionary theory is well suited to this task and three styles of evolutionary archaeology are examined. Human behavioural ecology is concluded to be the most suitable given the problems of the other two styles and the constraints of the available evidence. Ecological theory is an attractive source of concepts because of three important methodological challenges shared between ecology and archaeology. First, many ecological systems have long time scales. Second, many ecological systems are difficult to replicate and replicates are rarely perfect. Third, control over all aspects of an ecological experiment is difficult because many variables are difficult to identify and measure (Hilborn and Mangel 1997). These factors make it hard to get clear, unambiguous results in ecological experiments and observations (Shrader-Frechette and McCoy 1992). This is also often the case for archaeologists working on prehistoric human foragers. The success of ecology in dealing with these challenges has inspired the approach taken here. Three foraging models are presented as tools creating a bridge from behavioural ecological theory to testable predictions about technological organisation. Chapter four identifies risk as a

general quality that explains a substantial amount of variation in prehistoric technology and adapts Kuhn's (1995) spectrum of provisioning systems to link the foraging models to technological strategies of risk management.

2. How should variation in technological organisation in mainland Southeast Asia assemblages be measured most reliably and validly?

In other words, what is the best way to test the predictions of the three foraging models using flaked stone artefact assemblages? A reliable measurement is one that yields concordant results when repeated and is synonymous with accuracy and consistency. Validity is the extent that an instrument measures what it is intended to measure (Carmines and Zeller 1979). This question is motivated by the problems encountered by previous work using typological methods to identify and describe patterns of variation in stone artefact technology. Chapter four examines the issue of artefact classification and finds that typological methods are inappropriate for mainland Southeast Asian assemblages, and measurements of assemblage reduction are more valid. To be precise, people do not reduce assemblages, they reduce individual pieces of stone but the reliable reconstruction and analysis of these individual events is very rare because they are difficult to identify in a large assemblage of artefacts. In this project, 'assemblage reduction' refers to an average state of reduction derived from a combination of numerous individual reduction events occurring relatively close in space and time. This averaging results from the relatively long periods of time that the assemblages examined here represent (a single excavation unit can span up to 1000 years) compared to a single reduction event which may last only a few minutes. Chapter five presents the results of an experiment that identified a suite of variables to reliably measure stone artefact assemblage reduction.

3. What is the climatic history that forms the backdrop of human forager activity in the northern Thai uplands?

To make reliable statements about the relationship between human foragers and their environment it is necessary to have reliable environmental data. Reconstructing climate history is challenging because of the complex ways that proxies archive climatic conditions. The seasonal tropics are especially challenging because previous work has shown that proxies such as pollen and phytolith sequences tend to most strongly reflect very local conditions and vary in chronological resolution, making them problematic as regional signals. Chapter seven discusses these problems in detail

and offers a solution in the form of oxygen isotope sequences derived from freshwater bivalves. The bivalves were recovered from excavations at the same two sites that produced the stone artefact assemblages. The reliability of the oxygen isotope sequences is demonstrated by comparison to similar records from speleothems in China. The isotope sequences establish a climate history directly relevant to, and at the equivalent chronological resolution of the stone artefact sequences under investigation.

4. To what extent are climatic conditions related to technological organisation over time and space in the northern Thai uplands?

Previous work has documented only relatively short cultural sequences and the amount of detail presented for these sequences has made it difficult to detect patterns within and between sites. The two sites described here are unique in providing a large sample of flaked stone artefacts spanning 35,000 years. As such, they offer an unprecedented opportunity to examine the rates and scales of continuity and change in technology. Although the two sites are relatively close to each other, they are also unique in allowing comparison between two substantially different local habitats. Chapter six describes the local context of the sites, showing that Tham Lod is located in semi-evergreen forest adjacent to a river and a large source of stone suitable for artefact manufacture. Ban Rai, on the other hand, is located high above the same river, on the side of a ridge distant from sources of stone and in more open forest. These two different local contexts provide a convenient laboratory-like situation to test the influence of variation in climatic conditions relative to differences in the local availability of resources.

The analysis of the stone artefact assemblages from each site is presented in chapter eight and is organised around the three foraging models presented in chapter three. The predictions deriving from the models are refined in chapter six in light of the specific environmental contexts of the two sites, and further predictions are presented in chapter seven in light of the climate histories of the sites. These competing predictions are evaluated in chapter eight which shows that there are substantial differences between the two sites that reflect technological adjustments to the shift from dry Pleistocene conditions to wet Holocene conditions. There are also millennial scale changes in technology at both sites, some of which are related to climatic variation and others that have non-climate mechanisms.

Conclusion

In answering the four questions posed above, this project will establish its importance by generating new momentum in the study of mainland Southeast Asian flaked stone artefacts. It aims to contribute a sense of dynamism into the region's prehistory and show how one of the most ubiquitous kinds of material remains can give insight into substantive issues of mainland Southeast Asian archaeology.

2. Approaches to Flaked Stone Artefact Archaeology in Thailand: A Historical Review

Introduction

The previous chapter introduced the general aim of this project as an examination of the relationship between human foragers and their environment from the stone artefacts evidence. In this chapter a sample of representative previous work is surveyed to show the potential and limitations of the record. The purpose of this chapter is to identify what is already known about flaked stone artefact technology in mainland Southeast Asia by briefly describing some previous analytical and theoretical approaches to stone artefact archaeology in Thailand. This historical review will identify the important contributions of these analyses and identify topics deserving further attention. Finally, some observations will be made about the areas where progress in understanding flaked stone artefact technology might be possible. A slightly shorter version of this chapter has been published in the *Silpakorn University International Journal* (Marwick 2007a)

Research into stone artefact archaeology has a long history in Thailand and has made significant contributions to our understanding of Southeast Asian prehistory. Since the 1960s there has been a series of archaeological projects by foreign and Thai archaeologists that include substantial studies of stone artefacts. The focus in this chapter is on flaked stone artefacts from excavated cultural deposits because they open a window into technologies of the past that undated surface sites cannot. Archaeologists in Thailand are among the most advanced and productive in Southeast Asia and although the examples here are limited to Thailand, they exemplify the trends and problems of work throughout mainland Southeast Asia. Although there is some Thai language literature available on this topic, this chapter focuses on English language publications because these are the most widely available and influential sources. To understand the earliest work in Thailand I briefly discuss influential work in Vietnam and Myanmar to provide some context to archaeology in Thailand (Figure 2.1). Then I discuss a selection of the most detailed and important studies from Thailand.

Colani and the Hoabinhian of Vietnam

The earliest writings on the stone artefact archaeology of Thailand were strongly influenced by work on either side of the country, with French archaeologists in Vietnam and American archaeologists in Myanmar. French archaeologists working in the northern Vietnamese province of Hoa Binh in the 1920s and 1930s argued for the presence of distinctive archaeological assemblage that they called 'Hoabinhian' (Colani 1927). As a result of this work the First Congress of Prehistorians of the Far East in 1932 agreed to define the Hoabinhian as

> a culture composed of implements that are in general flaked with somewhat varied types of primitive workmanship. It is characterised by tools often worked only on one face, by hammerstones, by implements of sub-triangular section, by discs, short axes and almond shaped artefacts, with an appreciable number of bone tools (Matthews 1966).

Despite the general terms of the definition, Colani's Hoabinhian is an elaborate typology as indicated by the 82 artefacts from Sao Dong that she classified into 28 types (Matthews 1966). Despite this complex system, most Hoabinhian sites are identified simply by the presence of sumatraliths (White and Gorman 2004), which are river cobbles that are flaked around the complete circumference but on one surface only, so that when the cobble is turned over only the original rock surface, known as cortex, is visible (Figure 2.2). The chronology of Hoabinhian artefacts was assumed by Colani and others - working before radiocarbon dating methods appeared in the 1950s - to be Holocene because of the absence of extinct ice-age fauna. The validity of the Hoabinhian as a chronological or cultural concept in Southeast Asia is a subject of ongoing and lengthy debate (Shoocongdej 1996a). As will be shown, it has been variously used as a label for an ethnic group, time period, a form of subsistence economy and a technology of making stone tools.

Movius and the Chopper-Chopping Tool Complex of Myanmar

From his work in the Irrawaddy Valley of southern Myanmar in the 1930s Movius (1943, 1944) suggested that a technological line existed separating the unifacial (with flaking only on a single surface) "chopper-chopping tool" tradition of eastern Asia from the bifacial (with flaking on a both upper and lower surfaces) "handaxe" tradition

of western Asia, Africa and Europe. Movius (1949: 36) defined chopping tools (Figure 2.3) as

> core implements usually made on pebbles, or rough, more or less tabular, chunks of rock, with a cutting edge that has been worked from both sides. This edge is usually markedly sinuous, since in the majority of cases it is produced by alternate flaking, or rather by the intersection of alternating flake scars. This results in the formation of an edge that is in the form of a broad 'W'.

These types of artefacts were attributed to the Pleistocene because of the association of similar forms with *Homo erectus* at Zhoukodian in China and other pre-modern hominids in Europe and Africa. The difference between the chopper-chopping tool complex and assemblages from elsewhere in the world is explained by Movius as a result of differences in raw materials and ethnicity. Although an important early step in understanding Southeast Asian stone artefact technology, Movius' concepts have made less impact than Colani's Hoabinhian, and have been criticized for assuming that absence of evidence (of bifacial artefacts) is evidence of absence (Boriskovsky 1971), for ignoring bifacially worked artefacts in east Asia (Hutterer 1977) and for not allowing for the diversity and complexity of east Asian assemblages that have subsequently been described (Yi and Clark 1983).

The first contributions from Thailand

The earliest published work on stone artefacts in Thailand was on some excavations of caves and rockshelters south of Chiang Mai and in the west-central of Thailand at Ratchaburi (Sarasin 1933). Sarasin described the stone artefacts as amorphous and generally without any indication that they were intentionally manufactured except for two or three cobbles with unifacial flaking. Sarasin did not discuss his finds in detail, but these artefacts were later interpreted by Heider (1958) as 'probably either of the Palaeolithic chopper-chopping tool tradition or of the Mesolithic Hoabinhian tradition.' This statement reflected a common view in Southeast Asian archaeology that the Chopper-Chopping Tool Complex is a Pleistocene assemblage and the Hoabinhian is a Holocene assemblage, and also reflects the absence of clear differences between the two stone artefact assemblages. It is noteworthy that Heider identified the Thai assemblage with both Vietnamese and Burmese assemblages, suggesting a large homogenous culture area for prehistoric Southeast Asia.

Van Heekeren's work at Sai Yok 1960-1962

In 1948 van Heekeren published a brief account of his archaeological discoveries in Kanchanaburi Province, west-central Thailand. His account describes a small number of artefacts encountered while working on the Thai-Myanmar Railway as a Japanese prisoner of war in 1943-44. He identified these as a local expression of the Chopper-Chopping Tool Complex which he named the "Fingnoian". The age of these artefacts is uncertain because it is based only on their location in a gravel bed assumed by van Heekeren to have been formed during the Pleistocene (van Heekeren and Knuth 1967). Eight stone artefacts were also recovered from a cave near Wan Po and described by van Heekeren as Hoabinhian from the Holocene period because of their association with un-mineralised animal bone and molluscs.

Van Heekeren's finds of flaked and polished stone artefacts in surface assemblages during the 1940s (in addition to Heider's (1958) collection of over one hundred artefacts from surface sites in the same area) encouraged him to return in 1960 with a team of Danish and Thai specialists. The most important result of this work is the publication of the excavation at Sai Yok rockshelter in Kanchanaburi. Over 50 square metres were excavated between 1960 and 1961, some sections to a depth of 425 cm below the surface. No radiocarbon dates were obtained apparently because no datable material was found, but the maximum age is estimated by the excavators to be about 10,000 years before the present (BP) because of the associated extant fauna. The 1,500-odd stone artefacts, mostly made from quartzite, were classified by 'visual inspection' according to a typology devised by van Heekeren (1967) (Figure 2.4). Three major categories of artefacts were recognised, 'massive high-domed tools, sturdy choppers with a minimum of trimming, and proper Hoabinhian implements' and were further subdivided (van Heekeren and Knuth 1967). Using an analogy to Australian Aboriginal ethnographic data, they suggest that the Sai Yok artefacts were used for skinning and dismembering game and manufacturing hunting tools of wood and bamboo. Several hundred flakes and flake fragments were also found throughout the deposit but are not described in detail. No data about artefact dimensions or attributes are presented in the publications but van Heekeren (1967: 107) observed that

> …generally the later tools tended to grow smaller and finer and there was a greater discrimination in selecting the raw material, i.e. smaller, more shapely and more suitable pebbles were chosen as raw material

> in the later periods of occupation. At the same time, however, it must be admitted that there was an extraordinary slow rate of technical development in tool manufacture and that tools of the simplest and crudest type continued to be found in the more recent layers. Lines of demarcation of types, if they could be drawn at all, would in no way correspond to those separating upper from lower strata. This suggests that the pebble tool industry went through an uninterrupted period of hardly any change. The term 'pre-ceramic pebble tool industry' therefore is used to cover the entire collection.

The unchanging nature of the artefacts is attributed to their suitability to the tropical forest environment and the availability of wood and bamboo as raw materials for implements (van Heekeren and Knuth 1967). Like Movius, van Heekeren notes that evidence from Sai Yok supports finds from Myanmar, Malaya, India and China in suggesting that Southeast Asian Pleistocene assemblages do not contain bifacial, prepared core or standardised blade technologies like those found in Africa, Europe and west Asia. Van Heekeren (1967: 107-111) explains this difference as a result of environmental differences, with Southeast Asia 'characterised by a tropical climate with heavy rainfall and there were perhaps no major climatic and faunistic changes at the termination of the Pleistocene period.' He also suggests that Southeast Asian stone technology may have developed in isolation from other parts of the world because of 'a lack of initiative and creative activity.'

This work is an excellent reflection of European archaeology from the 1960s with the strict typological approach to the stone artefacts (Lyman et al. 1997, Trigger 1989). The concern with culture-historical themes is also typical, such as the problem of the absence from Southeast Asia of the typological sequences and chronological markers found in Europe, Africa and west Asia. The inferred stagnation of Southeast Asian lithic assemblages over long periods is also a concern. The most important limitations of the work were noted shortly after its publication by Gorman (1969b) who criticised the absence of radiocarbon dates or pollen analyses that could have provided the chronological and palaeoecological data to support van Heekeren's conclusions. Gorman also found that this work was difficult to compare with other Southeast Asian sites because of the ambiguity of stratigraphic continuity, the lack of supporting evidence for many statements concerning prehistoric behaviours and the minimal detail presented in the stone artefact analysis.

Matthew's analysis of Sai Yok stone artefacts 1964

As part of his PhD research at the Australian National University, Matthews (1964) analysed some metric and technological attributes of flaked cobble artefacts from Sai Yok. His aim was to determine if Hoabinhian artefact types were 'real' types or an arbitrary system of types imposed by Colani on a continuum of forms. His method was to test if the artefact types could be defined as clusters of constantly recurring metric and non-metric attributes. Matthews' analysis supported van Heekeren's conclusions that the unifacially flaked cobbles became smaller as the depth of deposit decreased and that there were no marked changes in the assemblage over time. However, the most significant conclusion of Matthews' work was that he could not define Colani's Hoabinhian types in terms of constantly recurring attributes. In other words, Hoabinhian types did not exist at Sai Yok and Hoabinhian artefacts simply reflect a continuous blend of shapes and sizes. Van Heekeren (1967: 38) had similarly suggested that 'no hard and fast rules can be made to differentiate the many types of implements, as some types almost imperceptibly merge into others'. Matthews' more objective statistical study lends some empirical support to van Heekeren's observation.

Matthews (1966: 88) later published some of his critical assessment of Colani's work that defined the Hoabinhian and concluded that

> Colani has neither defined a satisfactory typology for the collections of Hoa Binh province, nor has she isolated three chronological phases based on the stratification of the excavated deposits. However, it appears that the flaked artefacts, which presumably served as simple cutting and scraping tools, were larger in the lower parts of the deposits and that the diminution of size with decreasing depth was a gradual process.

This statement summarises the knowledge of Southeast Asian stone artefacts in the 1960s. Despite the publication of elaborate and well-illustrated typological classifications, Matthews shows that these typologies do not accurately reflect the range of variation in the assemblages. The only robust conclusion from Sai Yok and the northern Vietnamese sites is that flaked artefacts tend to get smaller in more recent times. His work shows that Southeast Asian stone artefact assemblages need to be analysed in a framework that recognises observational units (such as the sumatralith type) as a commonly occurring shape on a continuum of gradually changing shapes

rather than the traditional framework of discrete and immutable types proposed by the early French archaeologists.

Matthews' conclusions about typological methods have been validated by more recent work outside of Thailand which argues that essentialist typologies hide much of the variation found in stone artefact assemblages that is important for explanations of cultural change (Dunnell 1982, Lyman et al. 1997) and mask many of the underlying processes of artefact manufacture, use and discard (Kuhn 1992a, Schiffer and Skibo 1997). Chapter four explores these concerns in more detail. The main limitation of Matthews' work is that it seems to have been exclusively methodological and he made little contribution to understanding how changes in the artefact assemblages related to the life and history of the people who produced them. In addition, Matthews did not publish a detailed account of his analysis and results, so his most important findings are not widely known and have had little impact.

Gorman's work at Spirit Cave 1965-1971

Gorman (1969a) recognised that Matthews' work implied that stone artefacts could not uniquely define Hoabinhian cultures (with the methods available at the time) so he chose to focus on the human ecology of the Hoabinhian at Mae Hong Son Province, northwest Thailand. As part of his PhD work at the University of Pennsylvania he excavated a series of one metre squares at Spirit Cave to a depth of about one meter. Fourteen radiocarbon samples were submitted and the results indicated that most of the excavated materials were deposited at 12,000-7,500 BP (Gorman 1969a). Although Gorman's (1972: 80) main aim was to 'argue for the importance of the humid tropics as hearths of early plant and animal domestication', and much of his analysis is dedicated to organic materials, he made several important contributions to the analysis of Southeast Asian stone artefacts.

Gorman followed the framework of Matthews and based his approach on Peter White's (1969:22) work in New Guinea where he concluded that 'it is probably more accurate to regard a stone implement as the record of a series of discrete processes which have acted on it than as an attempt to create a specific formal type.' Gorman (1971b: 30) analysed artefacts from Spirit Cave using 'technological criteria (i.e. technique and area of preparatory flaking, length, width, breadth, weight of the implement etc.), and usewear criteria (edge damage patterns such as step-flaking, chipping etc.).' Following his analysis, Gorman (1972) proposed that the frequent use

of the Eurocentric terms 'Palaeolithic', 'Mesolithic' and 'Neolithic' to describe Southeast Asian archaeology was inappropriate because the defining characteristics of those periods were not present (Figure 2.5). Gorman, like van Heekeren, suggested that the absence of any significant changes in stone artefact technology probably resulted from the apparent continuity of environmental conditions from the terminal Pleistocene to the Holocene (Gorman 1972).

Preliminary results published in 1970 show two cultural levels at Spirit Cave, the older level (c. 12,000-9,000 BP) containing a Hoabinhian assemblage of 'large unifacially worked cobble cores, grinding stones and retouched and utilised flakes' and the younger level (c. 9,000-7,000 BP) containing this Hoabinhian assemblage plus 'flaked and quadrangular adzes, small ground and polished slate knives and cord-marked and burnished ceramics' (Gorman 1972: 95). Gorman's (1972: 95) microscopic edge-damage analysis indicates that many artefacts were used, with sumatraliths having 'severe step flaking' and striations, abrasions and use-fractures are present on edges of about 30% of retouched and utilised flakes. Most of the stone artefacts at Spirit Cave were made from readily available coarse-grained quartzite river cobbles.

These lithics formed a small part of Gorman's analysis, which included ceramics, animal and plant remains. These data led him to redefine the Hoabinhian from a simple description of stone artefacts to include ecological dimensions (Gorman 1972: 82):

> 1. A generally unifacial flaked tool tradition made primarily on water rounded pebbles and large flakes detached from these pebbles;
>
> 2. Core tools ("Sumatraliths") made by complete flaking on one side of a pebble and grinding stones also made on rounded pebbles, usually in association with iron oxide;
>
> 3. A high incidence of utilized flakes (identified from edge-damage characteristics)
>
> 4. Fairly similar assemblages of food remains including remains of extant shellfish, fish, and small-medium-sized mammals;
>
> 5. A cultural and ecological orientation to the use of rockshelters generally occurring near fresh water streams in an upland karstic

topography (though Hoabinhian shell middens do indicate at least one other ecological orientation);

6 Edge-grinding and cord-marked ceramics occurring (though perhaps as intrusive elements), individually or together, in the upper layers of Hoabinhian deposits

Gorman's work is notable because it included a number of important redefinitions relevant to Hoabinhian stone artefacts that encourage recognition and explanation of its unique qualities. As with the work of others, the weaknesses of Gorman's publications are the absence of detailed discussions or data about the stone artefacts. This is probably due to Gorman's interest in agricultural origins at Spirit Cave and the importance of botanical and zoological remains in his project.

White and Gorman's work on Tham Phaa Chan 1972-1979

Following from his work at Spirit Cave, Gorman returned to Mae Hong Son and excavated Tham Phaa Chan (also known as Steep Cliff Cave) and Banyan Valley Cave. The cultural deposit at Tham Phaa Chan dated from 7,500 BP to 5,100 BP and about 200 cobble artefacts and numerous flakes and other pieces were recovered (White and Gorman 2004). In 1979 Gorman and Joyce White, then a graduate student under Gorman's supervision at the University of Pennsylvania, presented a conference paper (published unaltered in 2004) arguing against claims that Hoabinhian stone artefact assemblages were disappointingly amorphous and unpatterned. They intended to demonstrate the standardization of Hoabinhian manufacturing and curating procedures and outline a sequence of stages in the reduction of river cobbles into flaked artefacts at Tham Phaa Chan. Influenced by Collins' (1975) work in North America, White and Gorman proposed a lithic reduction model with five behaviour sets that have distinctive effects on stone artefacts: raw material acquisition, decortication, an edge modification cycle (use, trimming, rejuvenation, shaping), bifacial flake removal, and dorsal cortex removal.

White and Gorman sampled 417 flakes, recording a series of metric and technological variables for each flake. They analysed flakes because they wanted information about each stage in the manufacturing process rather than just the final stage represented by the flaked cobble. This focus on flakes is a major departure from the cobble-based analyses of previous stone artefact studies in Thailand and Southeast Asia generally.

White and Gorman (2004: 437) suggest that the Hoabinhian reduction sequence at Tham Phaa Chan has three major stages:

> (1) the systematic selection of locally available raw materials, namely somewhat flattened ovaloid quartzite river cobbles, and continuing with (2) the cobbles' systematic modification by flaking beginning with initial shaping by unifacial circumferential decortication, followed by (3) various differentiated shaping and resharpening activities repeated as needed throughout the tool's use-life (with the majority of flakes struck circumferentially from a single cortical surface).

They concluded that flakes were produced to resharpen the cobble rather than for use as flake-tools because they believe the average size of flakes was too small for tool-use.

Gorman and White's study represents a significant turning point in stone artefact analysis in Southeast Asia for two reasons. Firstly, their study shows that previous statements about the primitive and inscrutable character of Hoabinhian stone artefacts are not accurate and that these assemblages do exhibit discernable patterns. Secondly, they demonstrate that flakes may be more useful than flaked cobbles for understanding Hoabinhian artefacts. For its time, the study used a progressive and relatively complex method involving metrical and technological variables for recording stone artefacts in a materialist framework. The main limitations of the study are the unclear definitions of stone artefact attributes which make it difficult to understand the differences between the patterns identified. Further limitations include the absence of any theoretical framework for interpreting the patterns in terms of what behaviours they represent and how they change over time. Like Matthews, White and Gorman did not publish their findings in a timely manner, depriving subsequent workers of its important innovations.

It is worth noting that 28 cobble tools from Tham Phaa Chan were analysed by Bannanurag (1988) for traces of usewear using low-power magnification (20-100 magnifications). The presence of steep edge angles, microscopic polish and micro-flake scars suggested to Bannanurag that the artefacts were probably used for working wood and bone rather than meat or soft vegetable matter. Bannanurag (1988) appropriately cautions that her findings are only tentative because of the absence of relevant comparative experimental work and the small sample analysed.

Pookajorn's work at Ban Kao District 1977-1979

In the late 1970s Surin Pookajorn led a team of Thai archaeologists from Silpakorn University to excavate three rockshelters in Kanchanaburi, Western Thailand. This work was published in English after Pookajorn completed graduate studies on material from the sites in the United States and Germany. The aim of the work was to use ethnographic information from the Mlabri hunter-gatherers of northern Thailand to interpret the archaeology of the Hoabinhian and to determine if the Hoabinhian is more accurately considered a culture or a 'technocomplex' (1984, 1988, 1990, 1992, 1996). These definitions are based on Clarke's (1968) taxonomy of archaeological time and space units. Clarke (Clarke 1968: 188) defined culture as a 'polythetic set of specific and comprehensive artefact-type categories which consistently recur together in assemblages within a limited geographical area'. The term 'technocomplex' refers to a vaguer entity and has been used for broadly similar sets of stone artefacts that are widely distributed across Europe and Africa. The similarities are thought to result from similar responses to common environmental problems at a regional and inter-regional scale (Gamble 2004: 130). The three cultural layers of Khao Talu, Ment and Heap caves were dated from 11,000 to 2,000 BP (Pookajorn 1990). The oldest cultural level is labelled as Early Hoabinhian (10,000-4,500 BP) with large flaked cobbles and flakes, the second cultural level is distinguished by the addition of pottery and called the Late Hoabinhian (4,500-2,000 BP) and the third cultural level is called the transitional Neolithic-Bronze Age level (2,500-1,000 BP) and in addition to similar material from the previous levels, includes ground-edge stone artefacts, some new kinds of potsherds and beads (Pookajorn 1990).

Pookajorn (1988) recovered 3,000 stone artefacts from the three sites and analysed 86 of these by recording some metric and non-metric variables. Differences in artefact shape were used to classify flaked cobbles into four types and flakes into six types. The 86 pieces were further classified into six types according to edge angles. Low power microscopic inspection of some of the artefacts apparently suggested that they were used for woodworking but it not clear what attributes were considered to be diagnostic of this. From his analysis and the absence of undefined 'hunting implements' in the assemblages, Pookajorn (1990) concludes that the stone artefacts were not used directly to extract subsistence recourses but used for tool maintenance purposes, such as making wood and bamboo implements.

According to Pookajorn, the stone artefact data indicates that the Hoabinhian is a 'technocomplex …defined by the environment in which the sites are situated, and by the resources available to prehistoric communities there' (1990). He updates Gorman's six traits for the Hoabinhian with evidence from the Ban Kao sites, showing that bifacially flaked cobbles appear with the more ubiquitous unifacially flaked cobbles when fine grained raw material such as chalcedony and chert are available, and that used flakes may not always be as abundant as Gorman suggested (Pookajorn 1990). The stone artefacts from Pookajorn's Ban Kao sites were later investigated in two undergraduate theses and one MA thesis (Auetrakulvit 1995) from Silpakorn University but these findings have not been published. More recently, Moser (2001) published a brief analysis of stone artefacts from Moh Khiew and found that the assemblage was generally unretouched flakes made from coarse-grained raw materials. He concludes that the cobble tool typology does not show chronological variation.

The stone artefact analysis appears to have been a minor component of Pookajorn's work compared to the floral and faunal analyses and the ethnographic descriptions (which do not include stone artefacts, the Mlabri use only organic and metal tools). The main limitation of the work is the absence of supporting metric, technological and usewear data in any of the publications which means that many of his statements about the Ban Kao assemblages are unconvincing because they lack supporting evidence. It also makes it very difficult to compare the Ban Kao assemblages with any other assemblages (Bulbeck 2003). This criticism also applies to Pookajorn's (1996) later work at Moh Khiew and Sakai Caves, Krabi Province, where the emphasis is on past environmental reconstruction rather than the stone artefact assemblages. In general, Pookajorn's approach to the stone artefacts at Ban Kao appears anachronistic with its formal typological focus, lack of detailed data and its concern with definitions of the Hoabinhian rather than questions of human behaviour and history.

These criticisms might be considered unfair in light of Glover's (1993) observations that the aims and motives of Thai and western archaeologists frequently differ with Thai archaeologists showing 'rather little interest in generalized explanations couched in terms of evolutionary processes, and not very much in comparative archaeology outside Thailand' (Glover 2001:45). However, Pookajorn's papers in journals such as *World Archaeology* (1985) and in an edited volume with western scholars (1996) suggest

that he intended his work to be consumed by an international audience, so international standards of criticism are appropriate.

Anderson's work at Lang Rongrien 1983-1984

The aim of the Anderson's excavation was to 'trace the archaeological, biological and geological history of southwestern Thailand, or more broadly speaking, the northwesternmost edge of the Sunda Shelf' (Anderson 1990). To achieve this aim Anderson excavated Lang Rongrien rockshelter at Krabi and revealed a stratified deposit with one of the oldest cultural sequences in Southeast Asia. The occupational layers date from >38,000 BP to about 7,500 BP, with a rooffall level at about 27,000 BP (Anderson 1997). The sequence is divided into three phases: late Pleistocene, dating between 27,000 and >38,000 BP; early Holocene, between 9,600 and 7,500 BP; and middle Holocene, probably between 4,000 and 3,500 BP. The Pleistocene archaeological assemblage is mostly small, unifacially retouched flake tools (Figure 2.6). The early Holocene assemblage differs because it is dominated by large heavy, unifacially and bifacially flaked core tools typical of the Hoabinhian industry (Figure 2.7). The middle Holocene deposits include four burials with pedestal pots and small cord-marked vessels (Anderson 1987). The most unique and important result of this work is the suggestion that Southeast Asian Pleistocene assemblages may be flake industries rather than cobble-based industries as initially suggested by Movius.

Anderson's (1990:38) stone artefact classification system is a typology derived from van Heekeren's work at Sai Yok and is based largely on artefact shape, size and presumed function. Although some comments are made about retouch and inspection of artefact use-edges by low power magnification, there are no data in the publications. Metric and technological variables do not appear to have been part of Anderson's stone artefact analysis.

Anderson's interpretation of the stone artefact data is an attempt to explain the geographic spread and time span of the Lang Rongrien assemblage. He compares the artefact types in the Pleistocene layers of Lang Rongrien to other Pleistocene assemblages in Vietnam, Malaysia, Philippines, South Sulawasi and southern China. He notes a series of differences but emphasises that all assemblages are characterised by flake tool assemblages with high proportions of amorphous flakes with steep unifacial retouch and very low proportions of cobble artefacts (Anderson 1990:66). Anderson (1990) interprets this regional pattern of Pleistocene flake assemblages as

evidence that Movius' Chopper-Chopping Tool Complex is not an accurate label for Southeast Asian assemblages because cobble chopping artefacts are not common, and the label emphasises wide-area homogeneity and cultural conservatism that is contradicted by the available evidence. Anderson also notes that despite the amount of archaeological research conducted since Movius' time, the apparent Pleistocene antiquity of the Movius' Irrawaddy cobble assemblages remains unproven (cf. Hutterer 1985).

Anderson similarly compares the frequencies of types in the Holocene layers of Lang Rongrien assemblage to a number of mainland and insular Southeast Asian sites and shows that the Lang Rongrien assemblage is most similar to the Malaysian Hoabinhian because of the low proportions of sumatraliths (Lang Rongrien has none) and because 'nearly all of the flake tools from the middle levels of Lang Rongrien have flat retouch, a feature that sharply distinguishes them from the Hoabinhian assemblages of Vietnam' (Anderson 1990:46).

Anderson suggests an ecological explanation for the origins of the Hoabinhian at Lang Rongrien, suggesting that the change from Pleistocene flake assemblages to Holocene cobble assemblages at Lang Rongrien is a response to reduced seasonality, increased precipitation and warmer temperatures during the Holocene. Anderson suggests that the Pleistocene flake assemblage was used by hunters who exploited open savannas and animal movement patterns that were made predictable by the use of valleys as refuges from the low air temperatures. During the Holocene the increased precipitation caused the open savannas to disappear and the warmer temperatures reduced the need for biogeographical refuges. He proposes that the cobble assemblages may be related to agricultural tasks such as forest-clearing or ground-breaking or shellfish procurement, but acknowledges that 'the evidence is not strong' (Anderson 1988:56). This interpretation contrasts with Gorman and van Heekeren who believe that there were no substantial changes in technology and climate at the terminal Pleistocene and early Holocene.

Anderson's work is important because Lang Rongrien has a long cultural sequence and his interpretation of the material is an unusually detailed engagement with historically and anthropologically significant themes in Southeast Asian archaeology. However, it is problematic that his conclusions about the Pleistocene flake industry are based on only 58 artefacts (47.9% of the Pleistocene assemblage) which may be the result of a

series of isolated short episodes rather than reflecting a long term pattern (Bulbeck 2003). The most important problems with his work, like those before him, are the absence of detailed stone artefact data and the failure to acknowledge contemporary developments in hunter-gather anthropology and archaeology. At the time Anderson was working, there were important debates in hunter-gatherer archaeology by American and European archaeologists about interpreting sites and stone artefacts which resulted in new approaches and methods (Binford 1980, Binford and Binford 1966, Bordes and de Sonneville-Bordes 1970, Dibble 1987, Rolland 1981). As an American scholar, Anderson might have been expected to have engaged more with this work and perhaps have used Lang Rongrien as an opportunity to test these new methods and concepts.

Reynolds' work on Tham Khao Khi Chan and Banyan Valley Cave, 1989-1992

Reynolds' work is unique in mainland Southeast Asian archaeology because he brings experience in European stone artefact archaeology from his PhD research before working on stone artefacts from two sites in Thailand. First, he analysed and described stone artefacts from Tham Khao Khi Chan, Surat Thani Province in southern Thailand, excavated by the Tharapong Srisuchat and the Thai Fine Arts Department for a salvage project in 1985 (Reynolds 1989). The site was excavated to a depth of 2.6 metres and four radiocarbon dates span 6,100 BP to 4,700 BP (Reynolds 1989:42). The second site Reynolds (1992) analysed stone artefacts and other material from was Banyan Valley Cave in the northwest province of Mae Hong Son, excavated by Gorman in 1972 (Figure 2.8). The final depths of the excavation were not recorded but were probably little more than the lowest hearths at 80-90 centimetres below the surface. Two radiocarbon dates indicate that the site was used between 900 BP and 5,300 BP and six thermoluminescence dates on ceramics fall within this period. Reynolds classifies the artefacts using his own typology. Like previous typologists such as van Heekeren, Reynolds' method of analysis is to compare the frequency of types in different layers.

In his publication about Tham Khao Khi Chan Reynolds (1989) makes a number of important arguments about stone artefacts and human behaviour. First, he argues against White and Gorman's proposal that the majority of utilised flakes in Hoabinhian assemblages are the result of core resharpening or reshaping. White and Gorman suggest that usewear on flakes derives from use of the core from which the flake is detached, but Reynolds notes that usewear on the utilised flakes from Tham Khao Khi

Chan occurs on the lateral margins of the flakes which would not have been exposed while the flake was still attached to the core. Similarly, Reynolds argues that the high ratio of 'plain' flakes to utilised flakes suggests that the production of flakes is often independent of core resharpening. The second observation is that although flakes outnumber cores in each of the three analytical units, the single conjoin found and the low ratio of numbers of negative flake-scars on cores to numbers of flakes suggests to Reynolds that many flakes are missing from the rockshelter and that stages of the reduction sequence occurred off-site. The third observation is that there are no major technological changes associated with an increase in the proportion of artefacts made from fine-grained raw materials (which have more predictable flaking characteristics) in the upper unit. Reynolds (1989:42) concludes that the Tham Khao Khi Chan assemblage

> …appears to be a fairly typical Hoabinhian for southern Thailand, with many steep-edged core tools retouched in such as way as to retain cortex adjacent to the flaked edge. Flakes are an important part of the assemblage both technologically and functionally. The reduction strategy employed was generalised and not aimed at producing specific blank forms. Rather such pieces as were suitable were selected from a range of flakes. Resharpening flakes were rare. Differential use of raw materials does not appear to have been significant, but further study of the raw materials and replicative experiments would be most informative.

Reynolds' (1992:84) observations on the stone artefacts from Baynan Valley Cave are less detailed because of plans to publish them in more detail in the future (in 2007 no further publications were available). Differences in the stone artefact assemblage suggest that the four stratigraphic units recorded by Gorman can be grouped into Hoabinhian and non-Hoabinhian layers. The upper, or younger, two non-Hoabinhian units 'lack the pebble tool element, flakes are thinner, and they have fewer step-flaked dorsal surfaces' and have a higher proportion of ground edge artefacts (Reynolds 1992:85). Only the lower two units contained small numbers of 'sumatraliths (unifacially flaked discoids), short axes, steep-edged pieces [unifacially and bifacially flaked] and axes, all of which are characteristic of the Hoabinhian technocomplex in Thailand' (Reynolds 1992:85).

Like White and Gorman, Reynolds made a significant and progressive contribution to stone artefact studies in Southeast Asia. Reynolds goes beyond White and Gorman because he shows how the analysis of technological attributes can be used to reconstruct behaviours relating to reduction intensity and how they changed over time. He also shares their limitations, including the absence of detailed metric data and the lack of discussion of the wider anthropological implications and regional significance. Reynold's arguments are weakened by a lack of application of fracture knowledge to describing the assemblages. At the time Reynolds was working on these two assemblages fracture dynamics were familiar to archaeologists from a number of publications (cf. Bamforth 1986, Cotterell and Kamminga 1987, Dibble and Whittaker 1981, Phagan 1985, Speth 1972) and it is unclear why Reynolds did not draw on this literature.

Shoocongdej's work at Lang Kamnam, 1989-1996

For her PhD thesis at the University of Michigan, Rasmi Shoocongdej (1996a) worked on the material from a series of 2.5 metre deep excavations at Lang Kamnan rockshelter, Kanchanaburi to study mobility organisation of hunter-gatherers in tropical seasonal environments during Late and post-Pleistocene periods. She defined mobility organisation as 'the way foragers arrange their camp movements in relation to subsistence activities in relation to environmental variability' (Shoocongdej 1996a:11). Her interpretive framework was based on the work of Binford (1980) and Kelly (1992) who argue from ethnographic evidence that mobility organisation is an environmental adaptation exerting strong influences on hunter-gatherer cultural processes and social organisation. To evaluate mobility organisation and investigate temporal change, the excavated sequence at Lang Kamnan was divided into three analytical units based on radiocarbon dates, stratigraphy and archaeological remains: Late Pleistocene (c. 27,000–10,000 BP), Early Holocene (c. 10,000–7,500 BP) and the Middle Holocene (c. 7,500–2,500 BP). The only significant change in the stone artefact assemblage appears to be the introduction of ground-edge artefacts in the Middle Holocene unit.

Shoocongdej's aim for the lithic analysis was to determine if the assemblage technology is expedient (where artefacts are made with a minimum of production effort and discarded after a relatively brief use-life) or curated (where artefacts have a relatively long use-life and are repeatedly repaired and resharpened). This distinction is based on Binford's (1986) now-famous classification of hunter-gatherers along a spectrum of

mobility from foragers (hunter-gatherers who exploit resources by moving residential camps to the resource locations) to collectors (hunter-gatherer groups who do not move residential camps as often, but organize task groups to exploit resources at remote locations, often in bulk, and bring these resources back to the residential base camp for the entire group). In their analysis of ethnographic and archaeological studies, Binford (1980), Kelly (1992), Shott (1986) and others found a strong positive correlation exists between mobility frequency and the curated component of lithic assemblages and an inverse relationship between technological diversity and residential mobility. In brief, they conclude that 'the more you move, the less you carry and the more you conserve what you carry' (Shott 1989b:221).

To fulfil this aim, Shoocongdej created a typology similar to Reynolds' by classifying stone artefacts into types according to technological characteristics thought by Shoocongdej to relate to the artefacts' manufacture, use, maintenance and discard. The proportions of these types were then compared to understand the level of curation in tools found at Lang Kamnan. Shoocongdej also collected metric data from the artefacts and flakes were examined at 10-40x magnification in an attempt to identify traces of use.

Shoocongdej recovered 874 stone artefacts from Lang Kamnan and classified them into ten categories. Quartzite is the most common raw material throughout the assemblage. She interprets a relatively high ratio of flakes to cores and a relatively high ratio of tertiary to primary flakes as evidence of tool production. Similarly, the small proportions of 'resharpened cores' and flakes suggest to Shoocongdej (1996:260-282) a relatively minor tool maintenance component. According to these variables, the assemblage apparently changes very little over time.

The dominance of unprepared cores, the small number of retouched flaked and the apparently unsystematic production and use of flakes at Lang Kamnan suggested to Shoocongdej an expedient assemblage that is typical of a residential mobility strategy (1996a:280-2, 2000:28). As proposed by many previous researchers (eg. Boriskovsky 1971, Pope 1989), Shoocongdej explains residential mobility as an adaptation to the ready availability of lithic raw materials and organic raw materials (such as shell, bamboo and bone) from which more lightweight, portable, flexible and ephemeral tools can be made. However, determination of mobility strategy was based only on arbitrary criteria for expediency and Shoocongdej does not examine relative changes in

the extent of artefact production, use and retouching. In fact there are no absolute criteria for the two extremes of Binford's mobility spectrum and the most reliable interpretation of residential or logistical mobility depends on comparisons in specific contexts. It is unlikely that any mainland Southeast Asian assemblage would be considered to be typical of a logistical strategy, given the definition that Shoocongdej uses. For example, Shoocongdej's (2000) definition of a logistical signature includes 'a strong bias in the proportional representation of different body parts' and 'a high level of diversity of functionally specialized tool types'. Previous work has demonstrated that these two qualities are absent from assemblages produced by human forgers in mainland Southeast Asia – and many other places also – so it is inappropriate to test a model that relies on the possibility of these qualities being present.

That said, Shoocongdej's work represents a watershed in stone artefact analysis and archaeology generally in Thailand for two reasons. Firstly, she used a research strategy directed to answering timely questions explicitly about human behaviour, rather than about artefact classification, and then systematically developed and tested relevant hypotheses. This contrasts with the more inductive and descriptive character of earlier work on stone artefacts. Secondly, she interpreted the data in an explicitly anthropological framework that focused on explaining the human behaviours that produced the archaeological material. This indicates a greater awareness of recent developments in archaeological explanation than is evident in any previous work in the region.

However, Shoocongdej's stone artefact methods are similar to Reynolds' and are similarly uninformed by contemporary methodological work on artefact attributes, especially analysis of artefact reduction as a measure of the level of assemblage curation (e.g. Barton 1988, Dibble 1987, Dibble and Pelcin 1995, Kuhn 1990). Other limitations of this work include a lack of detailed discussion of temporal and spatial change in the lithic assemblage, except to note that the shift from flake-based to cobble-based assemblages from the Pleistocene to the Holocene observed at Lang Rongrien was not apparent at Lang Kamnan. The reluctance to discuss temporal change may be due to some problems with the site's chronology. Some radiocarbon dates come from snail shells lacking cultural contexts and some of the dates are out of sequence (Bulbeck 2003).

Shoocongdej does not engage with specific problems of Hoabinhian technology raised by White and Gorman (2004) and Reynolds (1989, 1992) about whether the majority of flakes result from core resharpening or other behaviours and why stages of the reduction sequence seem to be missing from some rockshelter assemblages. Quantitative analysis of the metric data is limited and claims that the artefacts were used to process fauna are not supported by evidences such as cut marks on the bone or identification of residues and usewear on the artefacts.

Shoocongdej's work at Tham Lod and Ban Rai, 1998-present

Following from her PhD work, Shoocongdej (2004) began a project in Mae Hong Son to develop a cultural and environmental history and study the relationship between humans and their environment from the Pleistocene to recent times. The project also aims to create opportunities for training and professional development of Thai archaeologists. Two rockshelters have been excavated with cultural sequences dating to the late Pleistocene. Ban Rai was excavated to a depth of about two and a half metres and has eight radiocarbon dates spanning 10,600-7,250 BP. The deepest of the three areas excavated at Tham Lod has a depth of about five metres and has four radiocarbon and two thermoluminescence dates spanning 32,400-12,100 BP (Shoocongdej 2004). Data collection and analysis is ongoing for Ban Rai and Tham Lod and so far over a dozen Thai-language technical reports have been prepared (eg. Shoocongdej and Staff 2003a, 2003b) and one popular book has been recently published (Shoocongdej 2005) as well as an edited volume of conference papers, both in Thai (Shoocongdej 2006b). One preliminary report on Ban Rai was recently published in English (Treerayapiwat 2005). Treerayapiwat (2005) follows Shoocongdej's methods but does not present any details of the stone artefacts from Ban Rai beyond numbers of artefacts in each stratigraphic layer, only noting that 'the entire spectrum of production, repair, and use, with the inclusion of utilized cores and flakes, wasted cores and flakes, hammers, and resharpening flakes' were found.

Conclusion

Despite the variation in aims and methods, these case studies suggest a basic and familiar (Reynolds 1990a) outline of culture-history from the stone artefacts. First, the earliest record is a Pleistocene assemblage of flakes from Lang Rongrien, possibly used by mobile hunter-gatherers in a highly seasonal environment. The Hoabinhian and Chopper-Chopping Tool Complex do not seem to be important in Thailand during the

Pleistocene. Second, in the late Pleistocene – early Holocene period the classical Hoabinhian cobble artefacts appear, possibly in response to denser forest environments and less seasonal climates, although recent work has shown that terminal Pleistocene environments were more complex and diverse than previously thought (White et al. 2004). Many more sites are occupied for the first time, but the assemblages are still dominated by flakes, mostly unretouched. The cobble artefacts may have been used by mobile hunter-gatherers for woodworking, particularly for making other tools out of hard wood and bamboo. There seems to be a lot of variation in assemblages from this period. Finally, in the later Holocene the cobble artefacts become less important and disappear from some sites to be replaced by polished-edge artefacts and ceramics. These new forms are usually associated with horticultural populations rather than hunter-gatherers (Higham 2002:29-30). The task now is to add detail to this basic outline, refining the chronology, determining the specific characteristics of the technological changes, their behavioural implications, and their relationship to local and regional environmental changes.

The progress observed in work discussed here suggests a few themes deserving of future attention. First, chronology has been a weak point in previous work. As might be expected, the apparent absence of chronological change in the stone artefacts has not stimulated interest in dating the archaeological deposits. In addition sites have been difficult to date because of poor preservation of organic remains. When dates are available they have not been integrated into a critical account of the chronology of site formation. This thesis aims to redress this weakness through a systematic analysis of chronology and site formation at the two sites under examination. Second, the use of typological classification methods does not appear to have advanced knowledge substantially. Chapter four expands on this problem, but it can be noted here that the amorphous quality of Hoabinhian assemblages has frustrated previous attempts to build explanations based on the division of assemblages into groups of visually distinctive forms. This thesis departs substantially from previous typological methods and instead offers a reduction-based approach to stone artefact analysis.

Finally, interest in the relationship between human foragers and their environment has been an important motive for previous work. This focus has emerged from the limitations of the amorphous, unretouched stone artefact assemblages typical of mainland Southeast Asia to inform on other questions such as social and political

organisation. Interest in human-environment relationships is one of the few common themes running through the previous work, which is otherwise relatively disconnected. This thesis builds on previous work by taking a systematic approach to understanding human-environment relationships. Despite the pervasiveness of past interest in environmental mechanisms, it is unfortunate that they appear to have been employed as a default mechanism when no other can be demonstrated. An important symptom of this is the absence of reliable links between the claim that the environment was influential and the details of how the archaeological record supports this claim. This is a notable weakness that is common in the previous work discussed here. This thesis is motivated by the endurance of the environmental mechanism theme and the need for reliable links between theory and data. As a first step in building these links, the following chapter presents a new conceptual framework to investigate the relationship between people and their environment using stone artefact assemblages from mainland Southeast Asia

Figure 2.1. Map showing sites discussed in the text. Major waterways are shown in dashed grey lines.

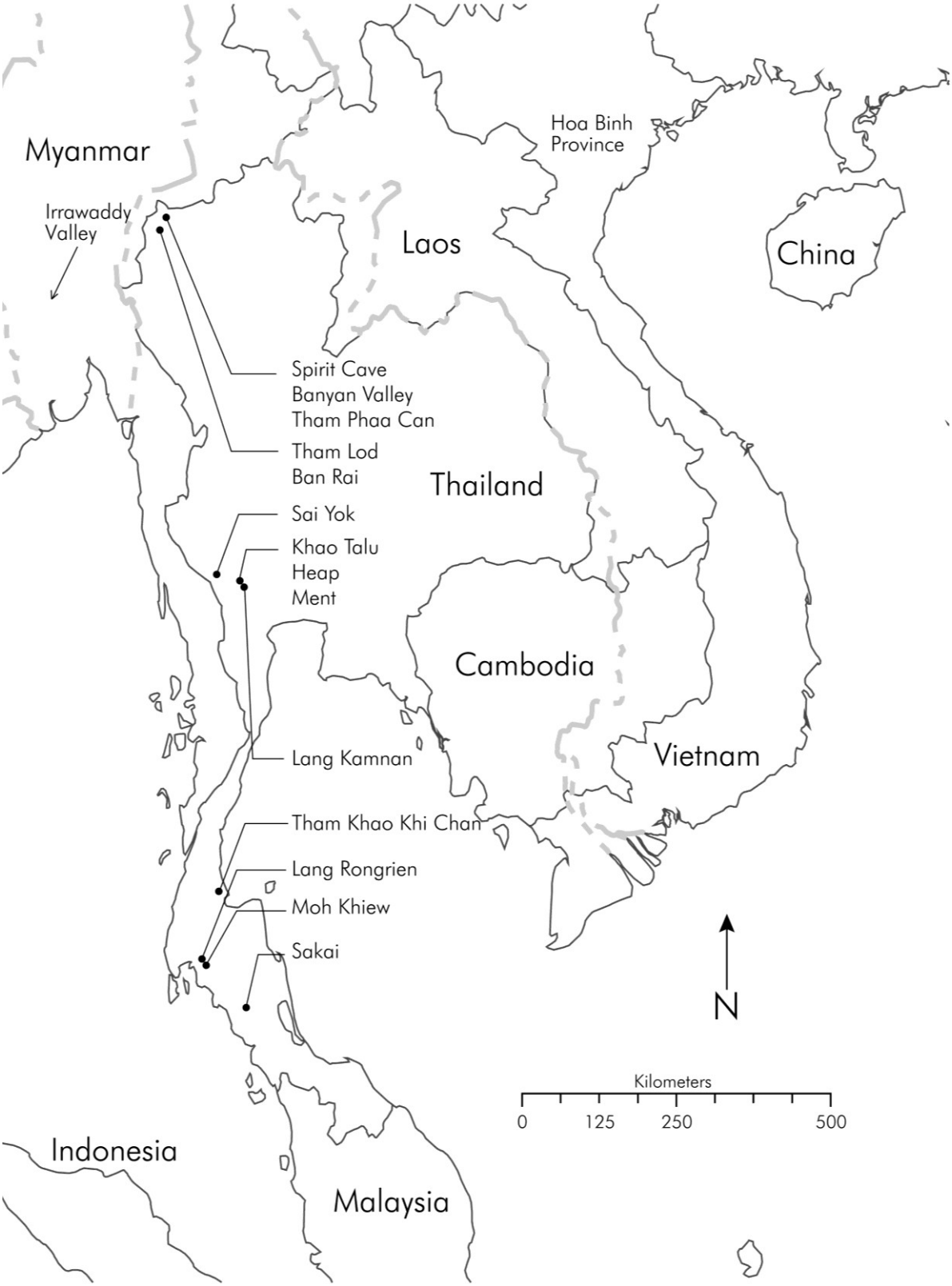


Figure 2.2. Typical sumatralith from Jeremie and Vacher (1992). Scale bars are centimetres.

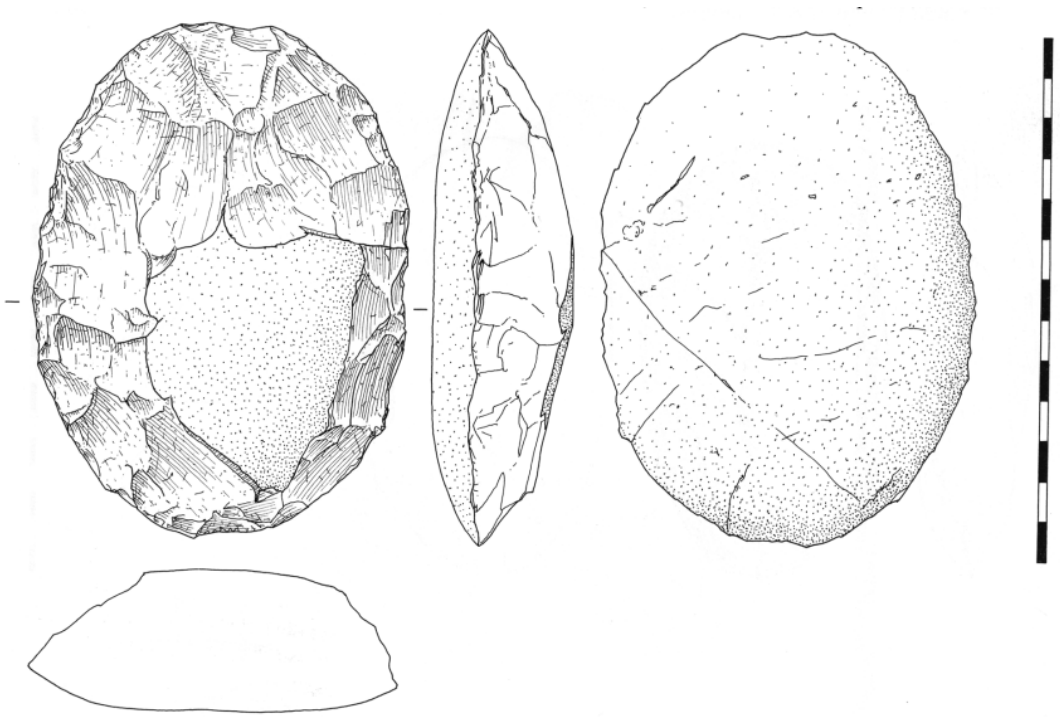


Figure 2.3. Movius' chopping tools from Myanmar. From Movius (1949)

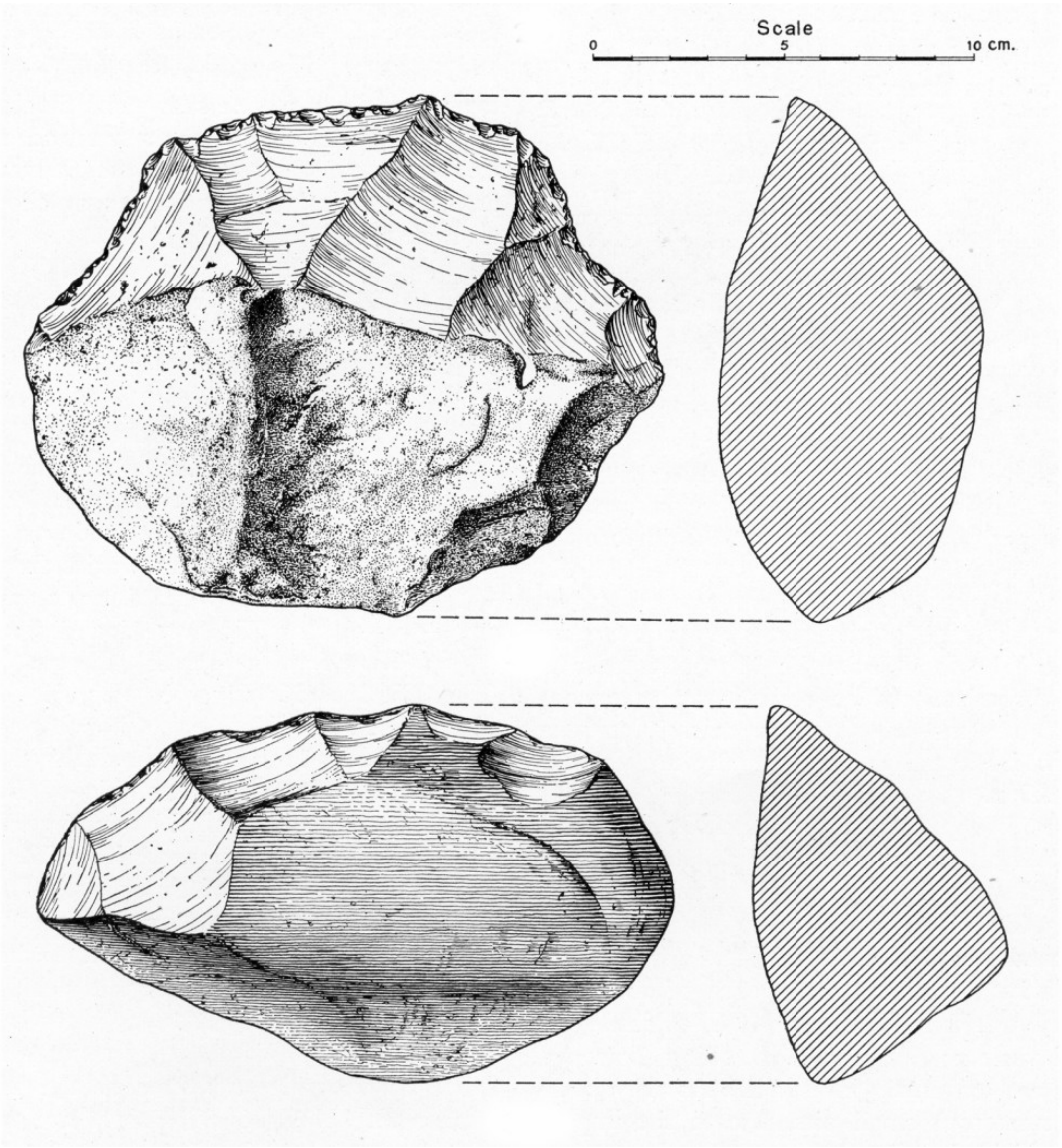


Figure 2.4. Artefacts from Sai Yok. From van Heekeren and Knuth (1967). No scale in original.

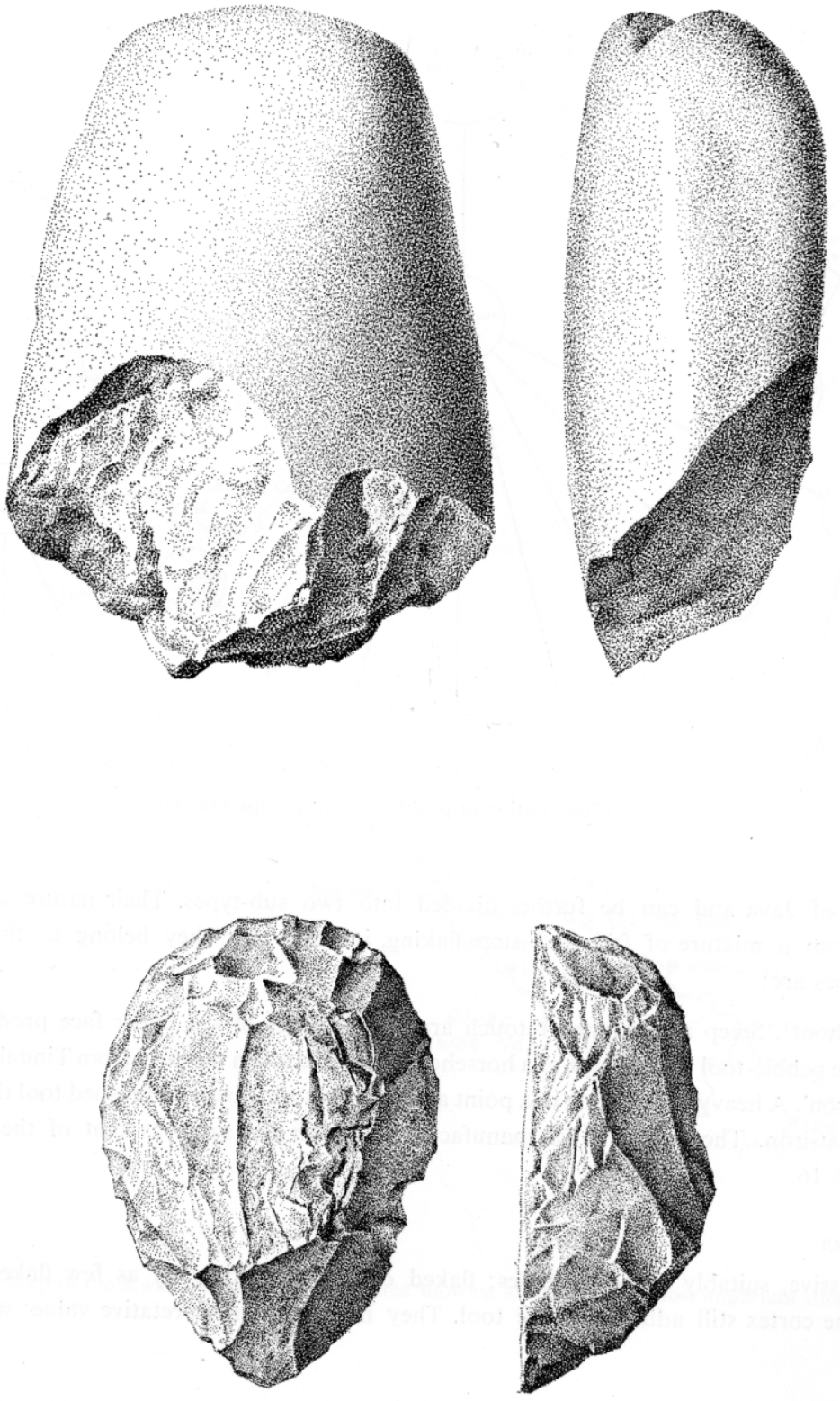


Figure 2.5. Stone artefacts from Spirit Cave. From Gorman (1971b)

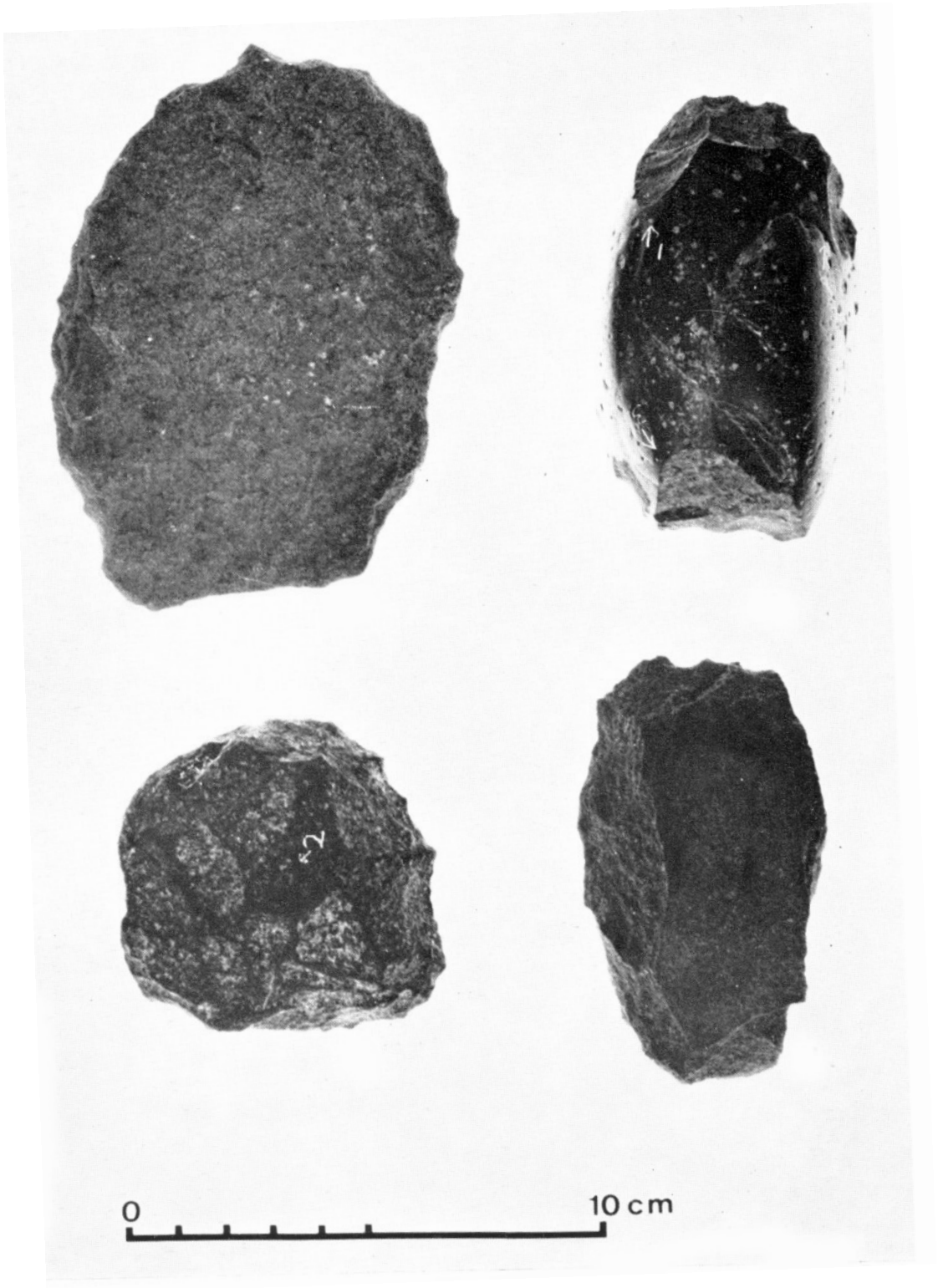


Figure 2.6. Pleistocene artefacts from Lang Rongrien. From Anderson (1990)

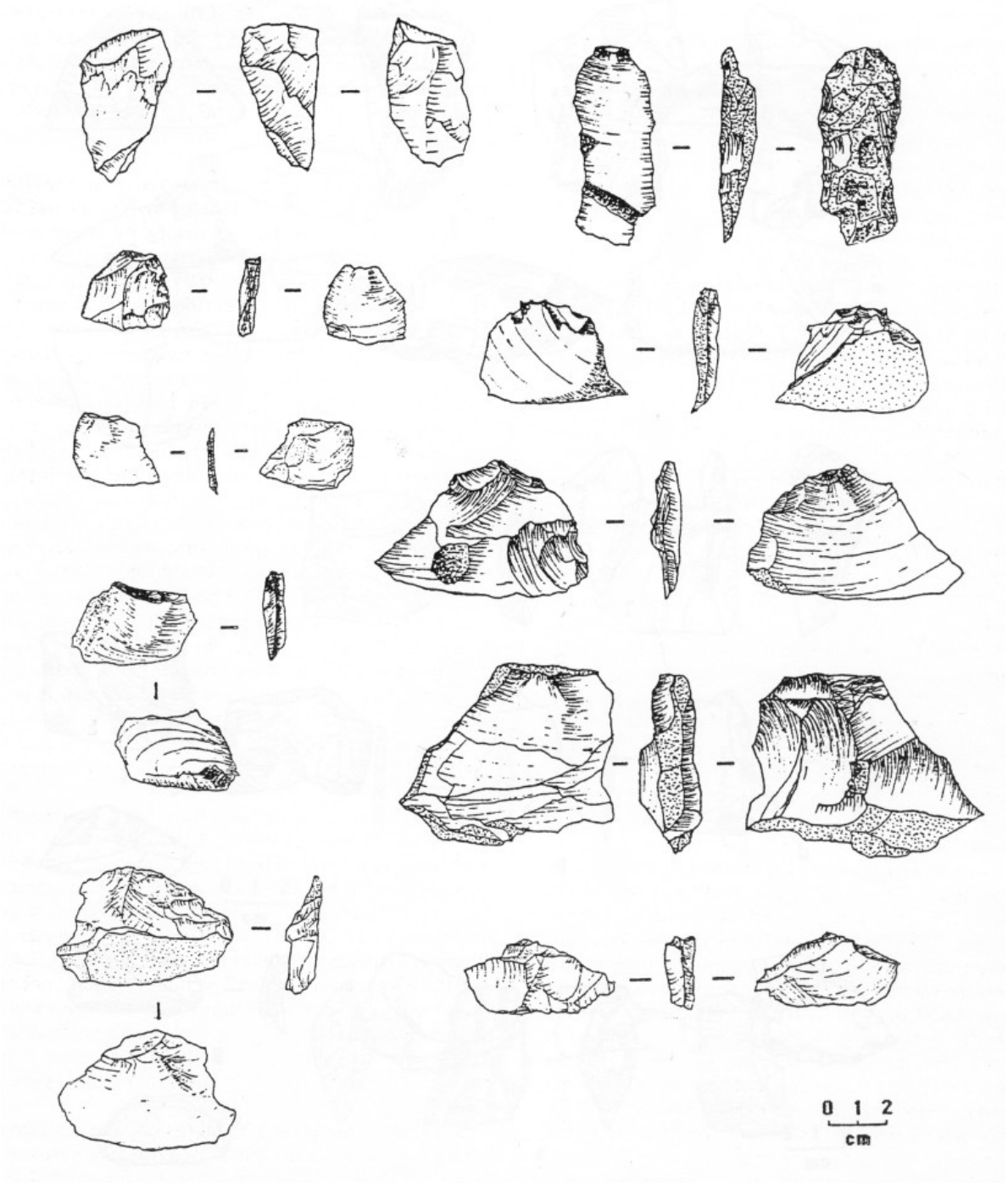


Figure 2.7. Typical Hoabinhian cores. From Van Tan (1994)

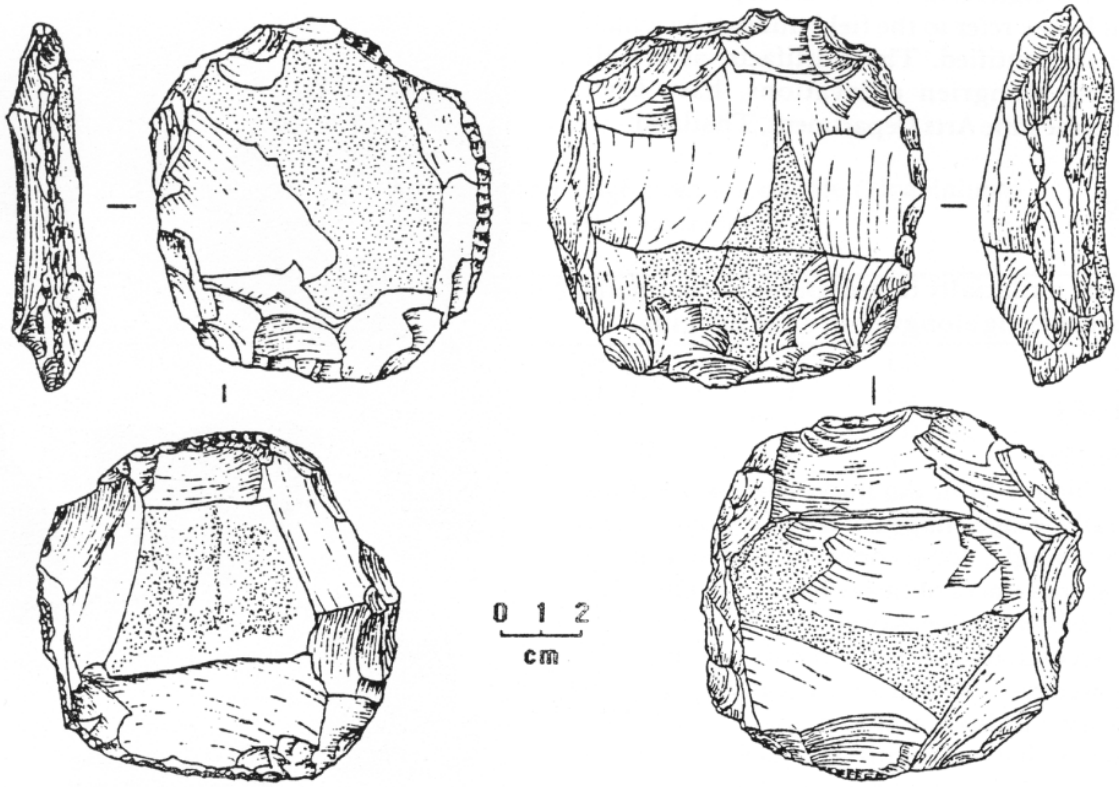
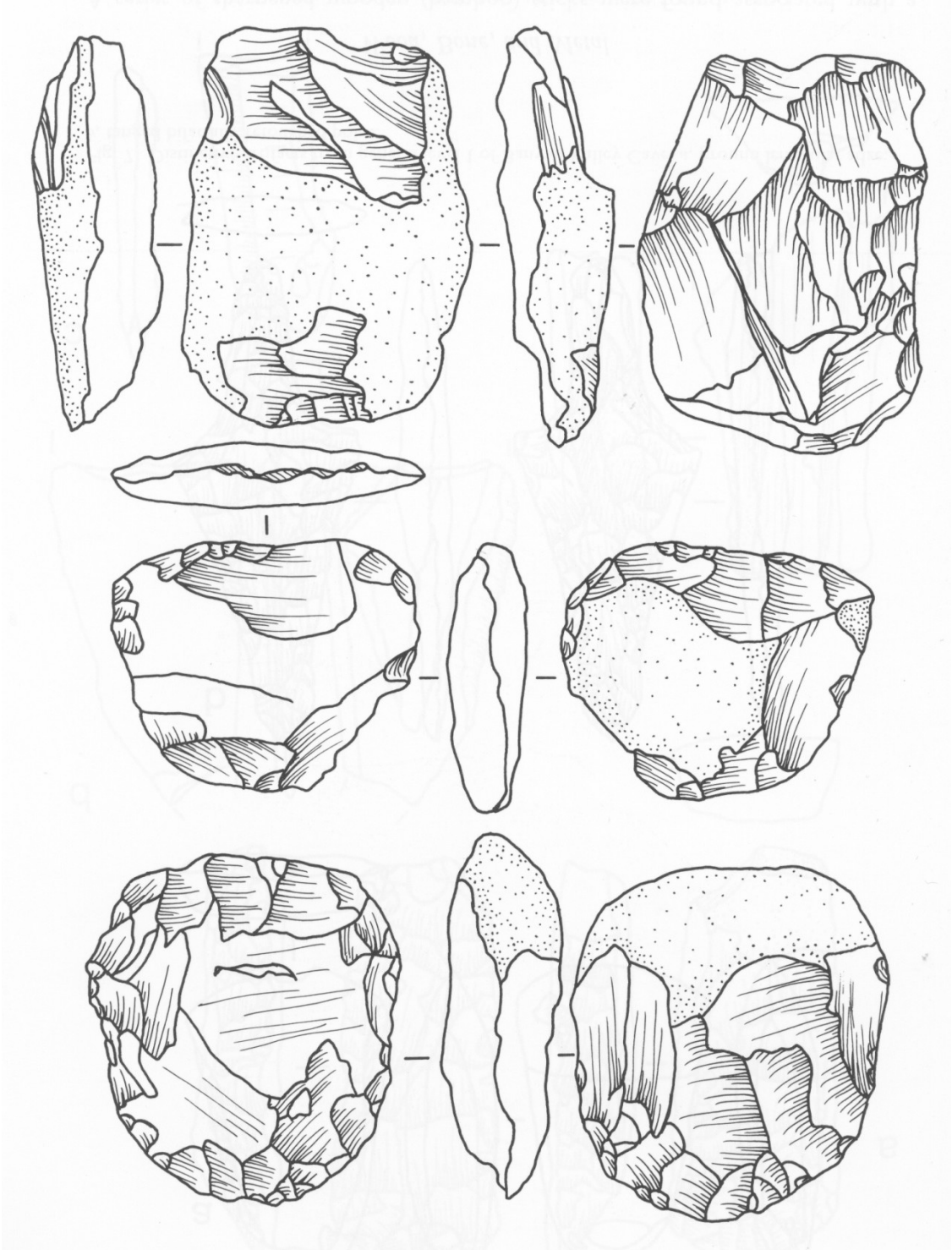


Figure 2.8. Artefacts from Banyan Valley Cave. From Reynolds (1992). No scale in original.



3. Human Behavioural Ecology, Foraging and Lithic technology

Introduction

The previous chapter surveyed earlier archaeology work on flaked stone artefacts in mainland Southeast Asia and identified a need for a conceptual framework that links flaked stone artefacts to the relationship between human foragers and their environment. The aim of this chapter is to explore conceptual frameworks suitable for making this link. First, the problems and requirements of a good conceptual framework are discussed. Second, the case is made for an evolutionary framework and three styles are evaluated. Finally, human behavioural ecology is argued to be the most suitable and three specific models are presented as a way of describing and interpreting the data presented in the following chapters. Chapters four and five continue this development of the link between theory and data.

Finding a Good Conceptual Framework: Conditions and Localities

As noted earlier, the aim of this thesis is to answer questions about people-artefact-environment interactions and to understand how people, in solving activity-related problems, create variability and change in the human-made world of things, namely, technology (cf. Schiffer 2002). Deciding on a good conceptual framework from which to derive the questions to ask is a difficult task, especially as the tools of inquiry are constantly evolving amidst shifting and diverse theoretical landscapes. A starting point is the recognition that the framework must have a commitment to formulate claims about human behaviour in the past, make efficient use of available evidence, be open to revision in response to new evidence, be exposed to a wide range of critical challenges, have internal coherence and external consistency (e.g. compatibility with well-established knowledge and reliance on plausible background assumptions) and have explanatory power, generality and simplicity (Dupré 1993, VanPool and VanPool 1999, Wylie 2000). Wylie (2000) notes that simultaneously satisfying all of these principles is very difficult and trade-offs need to be calculated according to local requirements. In this thesis there are two 'localities' to draw guidelines for practice. First is the previous work specific to the period and region, namely hunter-gatherer

archaeology in mainland Southeast Asia and second is the kind of evidence used and body of methods employed; the technological analysis of stone artefacts.

The previous chapter reviewed some of the most important contributions to human forager archaeology in mainland Southeast Asia. It concluded that although it is neither a substantial consumer of, nor contributor to, contemporary archaeological practice, some loose conventions have emerged. For example, Gorman, Anderson and Shoocongdej organised their work around human-environment interactions and approached questions from a North American context of empiricism and normative theory. Social interpretations were predictably absent (cf. Killick 2004), since the range and quality of the supporting material evidence is strongly limited by poor preservation. It is possible to make social arguments from single categories of evidence such as stone artefacts (e.g. Morris 2004) but this does not allow the 'tacking' between scales and lines of evidence that is necessary for compelling explanations (Wylie 1989). Interest in the relationship between human foragers and their environment was identified as an enduring theme in previous mainland Southeast Asian archaeological work. This particular historical context of research, resembling, as it does, a blank slate with human ecological tendencies, allows for great freedom of choice in plotting trajectories for future work. In addition, the relatively low density of research (for example, in terms of publications per decade) on this period and region means that the boundaries of inquiry are not well defined, resulting in few constraints in the selection of conceptual frameworks.

The second 'locality', that of stone artefact technological analysis, is altogether different, with a long history and wide variety of approaches that have been worked out in detail. Odell's (2001) survey of these approaches shows that although questions about sociopolitics and ritual have been convincingly addressed by lithic analyses, the bulk of work has been focused on technological organisation. Questions of technological organisation typically refer to human mobility, subsistence, and adaptations to risk and stress. These are questions of human behavioural ecology, asking how human interactions with environments are mediated and demonstrated by lithic technology. Bleed (1997) argues that this materialist focus derives from the practicalities of technological decision-making. He writes that technological processes are more accessible to the archaeologist than many other cultural processes because they involve tasks that produce concrete material results that present themselves in a

limited number of ways (since artefacts have no memory or intention [but see Gosden (2005) and Gell (1998) for different views]).

Following from this concreteness of technological decision-making is Bleed's (1997) second important point that technical actions have better potential to return immediate and direct feedback about the success or failure of those actions. Other cultural behaviours such as social or ideological activities produce less concrete results and the success or failure of these activities is more difficult to detect in the archaeological record. With most technological activities, failure has material consequences that quickly informs the people involved and allows for archaeologically detectable technological adjustments in response to the failure. In this way, technological change is analogous to Darwinian selection, where technological variants compete for selection as the most successful instrument or action under the pressures of specific tasks (Basalla 1988, Fleck 1992, Ziman 2000b).

The analogy between technological change and Darwinian evolution has received much attention from archaeologists (Bamforth 2002). The theory of evolution by means of natural selection is the most powerful tool available for explaining diversity in the biological world. Because humans are also biological entities, evolutionary processes are considered by some to be essential to any complete explanation of human behavior (Winterhalder and Smith 1992: 4). The typically low temporal resolution of archaeological studies of human technology is better suited to the time scale of biological processes rather than psychological or cognitive processes. That said, there are more general arguments that Darwinian evolution might provide all of the disciplines in the social sciences with similar explanatory power as it has to the biological sciences (Dennett 1994, Hull et al. 2001, Mesoudi et al. 2006).

Three Darwinian approaches have been explored in the analysis of stone artefacts: selectionist archaeology, dual inheritance theory and evolutionary ecology (Preucel 1999). Each of these approaches is based on a universal or generic Darwinist perspective of cultural change, where culture is argued to exhibit variation, competition, inheritance, and the accumulation of successive modifications over time (Mesoudi et al. 2004). Despite this shared perspective, the three approaches differ in their explanatory aims and in their definitions of key details such as where variation comes from, what is under selection and how selection occurs. Although there is a voluminous literature of programmatic statements from proponents of these

approaches (e.g. Boone and Smith 1998, Lyman and O'Brien 1998, O'Brien and Lyman 2002, Winterhalder and Smith 2000), it is more instructive to evaluate their implementation in archaeological case studies to see how they actually work. The operational details of the three styles have important implications for their suitability as conceptual frameworks for mainland Southeast Asian lithic analysis because of the specific character of the evidence.

Selectionist Archaeology and Lithic Analysis

Selectionist archaeology, also known as evolutionary archaeology, is represented here by a case study of Palaeoindian projectile points from the southeastern United States. O'Brien et al. (2001) aim to use cladistic methods to develop hypotheses about the historical relationships between different kinds of points. They hold that items of material culture, such as stone artefacts, are part of the human phenotype (or sum total of the observable characteristics of an individual organism) (O'Brien and Lyman 2000). This means that artefacts are subject to evolutionary processes just like organic parts of the phenotype (such as eyes, hair, skin, etc.). While information about the organic parts is transmitted via genes, information about the artefacts is transmitted via culture (for example, social contexts of teaching and learning). Continuity of transmission results in the inheritance of artefact forms, over time this leads to the tool traditions or lineages that O'Brien et al. (2001) identify as the different kinds of points. The source of new kinds of artefacts is errors in the transmission of information. They note that they are unsure how to distinguish unintentional random variation from variation directed by deliberate attempts by people to solve problems (Lyman and O'Brien 1998).

The objects of selection in this example are the functional traits of the stone points (O'Brien and Lyman 2000: 375), although it is not clear from O'Brien et al. (2001) how these functional traits were distinguished from non-functional traits. Elsewhere, selectionists have claimed that functional traits are those under selection because they directly affect the Darwinian fitness of the populations that are transmitting the trait (Dunnell 1978). Distinguishing non-functional traits from functional traits is done by analysing their frequencies over time. Functional traits tend to follow logistic frequency curves, where the initial stage of frequency increase is approximately exponential, then as competition arises from other traits, the increase slows, and may finally decline (O'Brien and Holland 1990, O'Brien and Holland 1992). Non-functional traits tend to follow Markovian distributions, where variation drifts without selective

pressures and the frequency of traits is largely determined by their previous states. Markovian distributions can resemble the classical battleships curves produced by artefact seriation (Neiman 1995, O'Brien and Holland 1990, O'Brien and Lyman 2000: 318-319).

The separation of functional and non-functional traits is not undertaken by O'Brien et al. (2001: 1126) in their study of points. Instead they focus on artefact design and refer to literature on point technology and mechanics that suggests the point traits that are likely to have been directly related to functional efficiency. The cladistic method orders the different kinds of points according to the number of differences in traits so a relative chronology of trait changes is created. Points that are more similar are proposed to be closer chronologically than points with few traits in common. Ancestor-descendant relationships are proposed for the different kinds of points, based on sequences of trait changes. The outcome is that the different kinds of points are ordered in time, based on the assumption that variation in the points comes from errors and recombinations during the social transmission of manufacturing instructions (O'Brien et al. 2001). This method was developed and is widely used by paleobiologists to reconstruct relationships between extinct species. It has also been employed with some success by cultural anthropologists and linguists to reconstruct family trees of culture and language groups (Mace et al. 2005). To date there have been few applications of cladistics to material culture (Tehrani and Collard 2002, Tëmkin 2004) and there is skepticism that traditional phylogenetic analyses have only limited application to cultural materials except in situations where traditional transmission is strong but intercultural exchange is relatively weak, as is the case in the few published studies. In their phylogenetic analysis of musical instruments, Tëmkin and Eldridge (2007) conclude that the intricacy of cultural historical patterns means that cultural systems are more complex than biological systems and additional methodological and theoretical development is required.

The selectionist case study is intuitively appealing because of its adherence to Darwinian evolutionary concepts, such as its explicit concern with the relationship between fitness maximization and engineering design and performance characteristics of material culture. However, there are two problems that make this case study an incomplete conceptual framework for future work. First, the link between changes in functional traits of the stone points and changes in the fitness of the makers is not

made; it rests on unstated and undemonstrated assumptions about how technological change affects human reproductive fitness (Preucel 1999, Wylie 1995). The case study has an inferential void that substantially weakens its internal coherence.

Second, the selectionist approach is problematic because it does not make any claims about human behaviour in the past. This is not an accidental omission but a deliberate epistemological gambit by selectionists. As part of their claim to be uniquely scientific, they state that inference from archaeological to behavioural contexts is fatally insecure because past behaviours are inaccessible to archaeologists. For selectionists, epistemic security can only be ensured for identifying variability in the archaeological record and monitoring it over time; they are interested in the material of the archaeological record, not in the behaviours that contributed towards its formation (1978, 1980, Dunnell 1989: 45). A related selectionist case study describing the increasing diversity of Great Basin projectile points at Gatecliff Shelter, Nevada is similarly agnostic about behaviour. Lyman and O'Brien (2000) outline a history of points at the site, but do not attempt to explain why these changes occurred. They reject behavioural reconstruction on the grounds that 'there is no deterministic relation between the behavioral terms of reconstruction and the debris of the archaeological record' (Dunnell 1992: 16). Wylie (1995: 208) notes that this is paradoxical because in order to provide compelling explanations for the adaptive advantages of specific variations in artefact design, selectionists must depend on behavioural reconstruction to establish exactly how a specific variation favoured human reproduction under specific conditions. In other words, they need to link people to stone points rather than simply undertaking a palaeobiology of material culture.

Dual Inheritance Theory and Lithic Analysis

A more coherent application of evolutionary principles to archaeological explanation can be found in case studies that employ Boyd and Richerson's Dual Inheritance Theory (DIT). This theory asserts that there are Darwinian evolutionary forces acting on the cultural transmission of information that are unique and independent of genetic evolution. While selectionists see change in material culture as the result of only selection and drift during cultural transmission, DIT holds that there are specific biases arising from human psychology that can affect cultural transmission at the population level. These include directed or content-based bias (when the content of one variant is easier to learn, remember and transmit than another variant), frequency-based bais

(when the commonness or rarity of a variant is the criteria determining its transmission), model-based bias (when a variant is transmitted because of its association with a suite of other attributes associated with individuals exhibiting the variant) and guided variation (when individuals copy existing behaviours and modify them by trial and error) (Boyd and Richerson 1985). The operation of these biases has been demonstrated by ethnoarchaeological and experimental studies.

Bettinger and Eerkens (1997, 1999) use metric analyses of late Holocene stone artefact assemblages from the Great Basin of western North America to explore the consequences of different cultural evolutionary processes. In their 1997 study they analyse a large sample of projectile points (n = 5285) to test predictions about the effects of different biases of cultural transmission on metric variability. They expect that guided variation and content-based bias will be important during times of low population densities and techno-organizational complexity because competing variants are easily compared by field testing and individual experience. When the population grows and/or technology becomes more complex they expect frequency-based and model-based biases to be more important because individual field testing of variants is inefficient compared to relying on social transmission of pre-tested variants.

These expectations allow them to hypothesize that complex point shapes will have less metric variation than simple forms, that arrowheads will be less variable than dart points and that long-lived forms will be more variable than briefly appearing forms. These expectations receive only equivocal support from the data. As predicted, complex point forms show less metrical variation than simple forms, and arrowheads show less variation than dart points. However, 81% of metric variation is strongly correlated with artefact size (r = 0.899), meaning that differences in types of cultural transmission have only a small effect. Inspired by Bettinger and Eerkens, Shott (1997) undertook a similar test of these social transmission models using metric attributes of stone points from late Holocene contexts of the North American Midwest and found that differences in cultural transmission have an even smaller effect on lithic variation than observed by Bettinger and Eerkens.

Shott's findings are not surprising, given Boyd and Richerson's (1992: 90) observation that analyses of archaeological records tends to show that 'forces like direct bias and guided variation are relatively weak, and that the uncritical transmission of cultural traditions is a strong effect'. More encouraging results come from Bettinger and

Eerkens' (1999) study of changes in metric variables of stone points during the introduction of bow and arrow technology to eastern California and central Nevada at around AD 300–600. Using an approach similar to their earlier study, they equate guided transmission with high metric variation and low correlation between different metric attributes (such as mass and basal width). Lithic assemblages with metric variables that are less variable and more highly correlated are equated with model-based bias. Their analysis shows that assemblages from eastern California have poor correlations of basal width and mass, suggesting that bow-and-arrow technology was probably introduced and spread by guided variation. Conversely, in central Nevada, the new technology was probably introduced and maintained by indirect bias because the metric attributes are strongly correlated. Bettinger and Eerkens interpret this data to mean that eastern Californian groups acquired the bow and arrow from distant and unfamiliar neighbours, and with limited contact they had to develop and customise the bow and arrow technology largely by trial and error. The opposite seems to be true for central Nevada where the appearance of bow and arrows was probably a result of faithful copying, suggesting closer social contacts with the donor group. They further conclude that these differences in social transmission indicate substantial differences in social organisation and hunting behaviours in the two regions. The success of this case study is partly due to the absence of a direct relationship between the attributes that vary and mechanical constraints and processes related to point manufacture and use. As O'Brien and Lyman observe (2002) there is no reason why basal width and mass should be correlated or mechanically constrained, so it is likely that some other force is responsible for patterns in their variation.

These archaeological applications of DIT show some similarities with the selectionist case study in their shared focus on artefact design traits and the recognition that selective pressures act on information about artefact design and manufacture. Significant differences in DIT include the primary selective role attributed to transmission biases and the decoupling of selective processes and the biological fitness of the artefact makers. Richerson and Boyd (2000) argue that cultural transmission biases evolved during the Pleistocene when they conferred adaptive advantages in rapidly fluctuating environments. Their models show that social learning is a useful adaptation in situations where climatic variation is not fast enough for individual discovery of adaptive behaviours by trial and error to be effective but not slow enough for adaptive behaviours to be genetically encoded. Under these conditions natural

selection shaped our psychology so that it uses short-cuts - transmission biases – to improve the efficiency of social learning by reducing costs and errors (Richerson and Boyd 1992). The result is that transmission bias 'is a culling process analogous to natural selection' acting on socially transmitted information (Richerson and Boyd 1992: 67). Selection resulting from transmission bias may not always optimise genetic fitness, since genetic reproduction is not required for cultural reproduction (for example, information can be transmitted to non-kin) (Richerson and Boyd 1992: 75-85). This biologically non-adaptive potential establishes culture and biology as two separate, but interacting evolutionary systems, in a similar way that Brighton et al. (2005) have argued that language is a third separate interacting evolutionary system.

The most important advantage of DIT over selectionist archaeology is that it is a conceptual framework that links people to the stone points. The case studies discussed here show that Dual Inheritance Theory provides description and explanation that include details of artefact design, reconstruction of cultural behaviours (such as contexts of learning) and incorporate historically specific conditions known from other sources. These qualities make DIT an excellent candidate for a conceptual framework because it explains human behaviour in the past, has internal coherence and external consistency.

Evidential Constraints in Mainland Southeast Asian Assemblages

The main failing of DIT, in context of current knowledge about mainland Southeast Asian lithic assemblages, is that it does not make efficient use of available evidence. The DIT case studies are not good analogues for the evidence available from mainland Southeast Asia. The Great Basin assemblages are based on large numbers of visually distinctive forms of stone artefacts in collections that have accumulated after decades of intensive fieldwork. Claims (for example, by Colani) for visually distinctive flaked stone artefacts analogous to points being present in mainland Southeast Asian assemblages have been unconvincing for two reasons. First, the existence of discrete artefacts forms has been questioned by Matthews' work showing the metrical continuity between different forms. Second, subsequent work in mainland Southeast Asia has failed to usefully employ any kind of classification based on visually distinctive flaked artefacts to describe geographical distributions or chronological phases.

Even if mainland Southeast Asian assemblages did have comparable visually distinctive artefact forms, the use of DIT assumes that similarities between assemblages can be interpreted as being phylogenetically homologous (i.e. due to common technological ancestry via cultural transmission) as opposed to being homoplasic (i.e. due to convergent technological evolution via adaptation). In favour of the idea of convergent technological evolution, there is an extensive body of literature demonstrating that morphological variation in retouched stone artefacts is most strongly related to the amount of reduction that the artefact has undergone (Bamforth 1986, Hiscock 2006, Hiscock and Attenbrow 2005, Kuhn 1994, 1995, Torrence 1983, 1989). This view holds that the shape and size of artefacts in many assemblages is substantially controlled by processes of edge and tool maintenance rather than a desire by the knapper to produce discrete shapes. The degree of maintenance is explained in terms of the performance of the artefact within the economic context that the ancient foragers operated in, rather than the biases of information transmission.

Another way to explain this problem is by comparing the degree of intentionality that can be deduced from artefact form. Intentionality is used in typological frameworks to explain why assemblages appear to contain artefacts with similar shapes and sizes. Hiscock (2007) has identified four traits that are often used by typological analysts to infer intentionality: repeated shapes, regular (usually symmetrical) form, morphological features in excess of performance requirements and extensive modification by retouching. When these traits appear very prominent in stone artefacts some analysts, such as Bettinger and Eerkens, argue that the form of the artefact is dependent on socially learned information is high. Conversely, if the form of the artefact is more strongly controlled by other factors, such as mechanical constraints of the raw material, then explanations based on biases in the transmission of social information receive less support. Hiscock's four traits are all present for assemblages of Great Basin points. For example, the numerous flake scars on Great Basin points reflect a high degree of effort invested in shaping the points, suggesting that a predefined form has influenced the shaping of the raw material. Similarly, the low coefficients of variation of metric variables on different forms gives the appearance of knappers working with a mental template of the final products (Eerkens and Bettinger 2001). These details, combined with ethnographic accounts, have been used to support typological claims that a high degree of intentionality is present in point forms, making them an ideal artefact for investigating cultural transmission.

On the other hand, mainland Southeast Asian assemblages have no analogous artefact forms with similar corroborating evidence of effort to impose form or work from a mental template. Invoking an explanation for artefact form based on social transmission of information – in mainland Southeast Asia or the Great Basin – risks committing the 'finished artefact fallacy' described by Davidson and Noble (1993). They claim that it is 'a fallacy to assume that the form in which a stone artefact is found is a product of an intention to produce that form'. In this context the most relevant element of the fallacy is that knapping involves the application of simple mechanical principles and constraints and the results of these should not confused with prior intentions of the knapper (Davidson 2002). Given the failure of typological systems and the absence of convincing evidence of intentionally shaped pieces in mainland Southeast Asian assemblages, artefact form is likely to be more dependent on raw material properties such as flaking mechanics and abundance or scarcity. The role of biases in information transmission on artefact form is likely to be very difficult to convincingly demonstrate. When there is no risk of mistakenly committing the finished artefact fallacy, such as when dealing with constructed (as opposed to reduced) artefacts such as ceramic vessels, textiles and baskets, DIT analyses are highly productive (Bentley and Shennan 2003, Collard and Shennan 2000, Collard and Tehrani 2005, Jordan and Shennan 2003, Shennan and Wilkinson 2001).

Clarkson's (2004) attempt to track changes in transmission bias in an assemblage of retouched flakes is an instructive example of the difficulties of identifying cultural evolutionary processes in assemblages where intentionality in shaping artefacts is less evident, compared to the Great Basin points. He observes that after 3,000 BP there are apparently co-ordinated increases in the central tendencies and decreases in variation of metric and retouch variables of artefacts from four excavated rockshelters in the Wardaman Country on the edge of the semi-arid zone in northern Australia. This change is interpreted as stochastic variation followed by directional selection or direct bias transmission (Clarkson 2004: 258). It is important to note that Clarkson includes both a selectionist interpretation and a DIT interpretation of the lithic data. Clarkson recognizes the selectionist interpretation of a mode shift and reduction in variation in artefact assemblages as 'directional selection', one of the three classical patterns of natural selection in biological populations (the others being stabilising selection [variation reduction, no mode change] and disruptive selection [mode split into two]). Similarly Clarkson acknowledges that the same data would be explained by DIT as a

result of direct bias transmission, which occurs when individuals adopt a variant based on direct knowledge and evaluation of the variant itself. Clarkson (2004: 282) explains his reluctance to choose between the two interpretations as a result of the limitations of theoretical modeling rather than to any problem with the data. This reflects the problem of equifinality — in this case where more than one kind of evolutionary explanation is suitable for the available lithic data. However the data may have some relevance since the variables he considers (indicators of shape, size and retouch type) are arguably more relevant to the performance of the artefacts and thus their maker's fitness rather than sensitive indicators of non-adaptive transmission biases. Indeed, Clarkson's (2004: 258) main argument is that the results are 'what would be expected if natural selection were operating to optimize technologies and design features in periods of increased risk and resource depression.'

The difference between Clarkson's two candidate interpretations is subtle and highlights the operational difficulties with these two approaches. The difference relates to the perception of changes in mode and variation resulting from fitness-optimizing natural selection (the selectionist view) or rational decision making in relation to proximate goals (the DIT view). This is an unsolved empirical problem, although the bulk of work to date has focused on transmission studies and concludes that pattern-generating transmission biases can emerge in contexts where biological fitness optimization is probably not a significant variable (Mesoudi 2005). Similarly, when dealing with cultural materials that have very limited variation that is independent of performance characteristics, it is difficult to make the case that non-adaptive transmission biases can be reliably measured. Despite these problems, there is some consensus that the two approaches are broadly complementary and that the most important difference is simply one of temporal scale. O'Brien and Lyman (2002) and Mesoudi et al. (2006) have suggested the selectionist approach is macroevolutionary, with its focus on reconstructing lineages and evolutionary relationships of artifacts and stated interest in the relationship between artefact engineering and biological fitness (and disinterest in explaining behaviour). Conversely, they suggest that explanations based on social transmission of information are targeting microevolutionary processes where unique evolutionary dynamics are generated by transmission modes (e.g. horizontal, oblique) and biases (e.g. directed, frequency-based) with no obvious biological parallels. In a similar way, Flannery (1999) has noted that the relationship between the two influential explanatory concepts of process and agency can be

described in terms of long term evolutionary processes resulting from palimpsests of behaviours by multiple agents.

Choosing between the two evolutionary approaches depends on what temporal scale is the priority, and indeed, what scale is analyzable given the evidence and methods available. In addition to its epistemological problems noted above, selectionism fails to qualify as a good conceptual framework for this project because it does not include a commitment to explaining human behaviour in the past. Approaches derived from DIT are more suitable because their findings can be related to behaviour, but have very strict data requirements – namely complex artefacts with variation in attributes that are not exclusively linked to mechanical performance properties or constraints. The microevolutionary scale qualifies as a likely explanatory framework, but unfortunately the data requirements cannot be satisfied by mainland Southeast Asian assemblages because they have very small proportions of pieces that can confidently be described as intentionally shaped. It has been shown that evolutionary theory can be productively employed on stone artefact assemblages with certain specific qualities, but the question now is how can evolutionary theory do something interesting with assemblages of unretouched flakes and cores?

Human Behavioural Ecology and Lithic Analysis

A parsimonious approach to interpreting assemblages dominated by non-tool components, often called debitage or waste, is to consider them as representative of behavioural patterns and adaptive strategies, rather than conglomerates of selected and transmitted information. In fact, assemblages of this kind of fundamental technology are ideal for examining adaptation. Since there are no retouched pieces, there is no modification of artefacts that could be considered unrelated to their performance of life-sustaining functions and very little avenue for non-adaptive variability to interact with transmission biases. The transmission biases could have an effect on functional attributes, but as Clarkson observed, it is difficult to distinguish this from variation resulting from biological fitness-enhancing selection. It could be argued then that every attribute in a debitage assemblage is performance related and thus directly related to fitness and adaptation. But since there is currently no satisfactory method for connecting changes in functional features directly to biological fitness, another model must be invoked to relate the assemblage attributes to evolutionary processes. What is required is an evolutionary model that shifts the

evidential demands and theoretical limitations away from selection and towards adaptation. Fortunately there is a third style of evolutionary archaeology that is well-suited to assemblages that have none of Hiscock's (2007) traits suggestive of purposive design.

Human behavioural ecology (HBE) studies human behaviour as adaptations to local environments. It is a field of study applying theory from evolutionary ecology, which examines how the evolutionary history of organisms influences their responses to selective pressures in the environment, to anthropological questions. This theory developed from ethological studies that asked why certain patterns of animal behavior emerged and persist and sought answers from the ecological contexts of these behaviours (Shennan 2002a). Behavioral ecology has inspired many who study adaptation in ecological context because of its employment of simple models as heuristic tools for understanding relationships between environmental variables and behaviour (Gremillion 2002).

Most often, the methods of behavioural ecology that are applied to anthropological problems are optimal foraging models (OFM), one of the most widely employed suite of behavioural methods in ecology (Sih and Christensen 2001). These models are instruments of prediction or investigation, where a complex system or process involving biologically significant resources is scaled-down to isolate key variables (Winterhalder 2002). The usefulness of models is assessed by testing situation-specific predictions generated from the models and iteratively refining the model until a good fit is obtained between predicted and observed (or archaeologically inferred) behaviour. Mismatches between observed and expected results are used to redirect the model (cf. Bliege Bird et al. 2001). Bird and O'Connell (2006) observe that for many models the predictions pertain to fitness-related goals of behavior, decision variables associated with achieving those goals, trade-offs connected with the decision variables, currencies to evaluate those trade-offs, and constraints that define or limit the actor's situational response. All of these are based on the assumption that foraging behaviour is fitness-enhancing when food requirements are met as quickly as possible, freeing time for other fitness-related activities. To avoid the selectionists' problem of not knowing how to relate material culture to fitness-enhancing behaviours, human behavioural ecologists often use energetic or economic efficiency as a rough proxy for biological fitness (Bettinger et al. 1997, Kuhn 2004a: 562).

Mackay's (2005) study of lithic debitage assemblages in archaeological sites in Cape York, northeastern Australia is a good example of a study of debitage assemblages using concepts derived from human behavioural ecology models. Although Mackay does not explicitly organize his investigation to test predictions derived from a model, he asks how people solved the problem of maintaining a constant supply of stone artefacts under varying degrees of mobility and with discontinuous distributions of raw materials. This question could be recast from a behavioural ecological perspective as asking how people made decisions to optimize their use of technology, given constraints of mobility necessary to obtain subsistence resources and unevenness in the patches of raw materials. This question, in various guises, has long been common in studies of hunter-gatherer technological organisation (e.g. Binford 1979, Torrence 1989). What makes Mackay's study relevant here is that he answers the question using debitage assemblages, unlike other work that uses assemblages of formal tools analysed using typological methods. Mackay's methods measure economic efficiency by comparing the relative amounts of effort invested in assemblages to extend the use-lives of artefacts. Other studies have similarly examined debitage assemblages (Cowan 1999) but Mackay's is notable because of the wide range of variables that he measures and the complete absence of formal tools from his assemblages (unlike Cowan who has bifaces in his assemblages).

Mackay's work is a useful prototype for an evolutionary study of mainland Southeast Asian lithic assemblages because he successfully explains how environmental contexts provide constraints and opportunities relating to the organisation (or decision rules) of a relatively informal lithic technology. His questions and methods are relevant to mainland Southeast Asia but further work is necessary to explain why optimization models are useful to an evolutionary explanation of lithic assemblage variation. The role of evolutionary processes in HBE is quite different from selectionist and DIT approaches that explicitly refer to selection and transmission as controls on artefact variation. In classical optimal foraging models the role of selection is to produce a phenotype with the cognitive flexibility to weigh the costs and benefits of particular strategies. Behavioural strategies are general decision categories (for example, what prey? which location?) that are distinct from behavioural tactics that specify the particular techniques of foraging. The strategies themselves, or the information that generates them, are not considered to be under strong selection. Instead, the most important selection remains at the lowest levels as defined for biological evolution; a

process that acts on genotype variation (Cronk 1991: 28). Natural selection maximizes gene survival, and individuals, as temporary vehicles for genes, should behave in ways that maximize reproductive fitness. So natural selection supplies the capacity to generate a range of behavioural strategies, but the particular strategy employed depends on the specific environment. Variation in behavioural strategies results from environmental variation because natural selection has produced a phenotype with sufficient flexibility to track environmental variation optimally (Boone and Smith 1998: S145).

This link between genes and behaviour is known as the 'phenotypic gambit' and has the advantage of allowing the details of the inheritance process to be ignored and instead focus on behaviour with the working assumption that it represents an adaptation produced by decision rules, which are under selection (Shennan 2002a). This is one of the key differences between behavioural ecology and other evolutionary approaches to archaeology; behavioural changes result from phenotypic flexibility rather than selective processes. In archaeology, the phenotypic gambit departs slightly from the classical optimal foraging models because in addition to genes, culture is another system of inheritance that affects behavioural strategies (Jeffares 2005). This means that there could be a role for DIT in HBE as 'rules of thumb' to improve the efficiency of information processing (Jochim 1983) or as a source of alternative hypotheses when adaptive predictions are not satisfied, because cultural transmission biases can result in non-adaptive behaviours (Shennan 2002b). In the context of debitage assemblages, this detail of multiple inheritance systems is of little importance because, as suggested above, the effect of DIT will be very difficult to detect. A related implication is that OFT models are based on individual selection and archaeological assemblages are predicted to reflect the average foraging behaviour for optimisng individual fitness. This does not imply that other levels of selection are impossible, just difficult to deal with analytically. For example, group selection would be more important in the analysis of an assemblage with a strong signal of cultural transmission bias (for example if the assemblage was decorated pottery). In any case, the priority of HBE is to focus on behavioural adaptation without having to tackle the hard problem of demonstrating and explaining heritability in material culture.

Criticisms and Limitations of Optimal Foraging Models

Although optimality models allow the heritability problem to be side-stepped -- a major advantage when dealing with debitage assemblages -- there are two special issues that it raises when applied to human behaviour. Sterelny (2004) has suggested that the good fit between animal behaviour and OFM is because animals have simple heuristics with low decision loads that lead to near-optimal behaviour. Humans are different, according to Sterelny (2004), because the trade-offs relating to our survival are far more complex and have much higher decision loads. DIT provides some of the heuristics to reduce this load, but Sterelny's point is that trade-offs related to information processing need to be incorporated into OFM. This is not a fatal issue, since modeling is deliberately simplifying and the history of success in anthropological applications of OFM suggest that simplifying or glossing over information processing is not a critical compromise (Bird and O'Connell 2006). A second issue raised by Sterelny (2004: 253) is that the incompleteness of the archaeological record and ambiguities involved in reconstructing behavioural strategies mean that models can only be tested for qualitative consistency of the predictions of the model and patterns of inferred behaviour. This is a more significant limitation because an important outcome of modeling is predictive failure, revealing unexpected constraints, currencies and decision rules (Smith 1991). Qualitative models offer less resolution about where predictive failures occur, for example they cannot provide specific threshold values for variables where predictions fail.

Sterelny's first criticism may have some relevance for more developed applications of OFM to ethnographic and zooarchaeological studies (e.g. Bird and Bliege Bird 1997, Broughton 1994, Hawkes et al. 1982, O'Connell and Hawkes 1981), but is premature for lithic archaeology where formal models are in their infancy. Only a small number of formal mathematical models of behaviours relating to stone artefacts have been developed (Brantingham and Kuhn 2001, Elston and Brantingham 2002, Kuhn 1994, Metcalfe and Barlow 1992) and only one of these has been tested with archaeological data (Surovell 2003). It is hardly surprising that Surovell's work is on Folsom and Goshen assemblages in Wyoming and Colorado, chronologically and geographically adjacent to where O'Brien et al. (2001) and Bettinger and Eerkens (1999) obtained data for their evolutionary studies. When dealing with the archaeology of less intensively examined areas where fewer assumptions can be reliably justified, Torrence (1983: 14) has suggested that application of formal models to technology are 'not necessary or

appropriate although the formation of more specific models should be the ultimate goal'. Similarly, Metcalfe and Barlow (1992: 352) conclude that formal modeling of lithic technological organisation 'require[s] estimating the various parameters of the model with a level of precision unlikely ever to be available from the archaeological record.

Jochim (1989) has highlighted an important reason why formal modeling seems to work so well for zooarchaeology and ethnographic studies of subsistence but has been less useful for lithic studies. He attributes the difference to the fundamental difficulty of quantifying stone artefacts as a fitness-related resource. The energetic and nutritional requirements of humans are relatively easily predicted from experimental data and measured either directly during subsistence activities or by reliable archaeological proxies such as prey body-size (e.g. Grayson and Delpech 1998, Gremillion 2002). On the other hand, there is no 'recommended daily intake' for stone artefacts (Shea 1991), especially in environmental contexts such as the tropics where organic materials fail to preserve and organic tool use is likely but not identifiable archaeologically. In addition to the absence of reliable predictors of lithic requirements, there are also no general methods for measuring intake or consumption of stone artefacts. For example, Kuhn (1994) has calculated that the optimum length of transported artefacts is 1.5 to 3 times the minimum usable size. However, determining the absolute value of these optimum lengths in lithic assemblages with very few or no tools (the smallest of which might be assumed to be at their minimum usable size) is complicated by a variety of other affecting variables such as raw material nodule size, raw material scarcity, manufacturing costs, mobility costs, frequency of use and frequency of discard (Jochim 1989: 108).

Like Sterelny, Bird and O'Connell (2006) similarly conclude that the main limitation affecting behavioural ecological approaches to technology is difficulties in quantifying key variables relating to costs and benefits of different technological strategies. One way to work around this limitation is to shift from using ratio or interval data that animal ecologists use as inputs to using ordinal data (Elston and Brantingham 2002: 112, Simms 1987). As Sterelny noted, ranking of inputs is better suited to the quality of most archaeological data, but the downside is a sacrifice in the precision of modeling and reduction in the potential for insightful predictive failure. Instead of predicting day-to-day behaviour, model with ordinal inputs investigate the general rules and

constraints that characterise foraging behaviours over multiple generations (Simms 1983). Although precision is reduced, there are two advantages to less specific models.

First is that a ranking method bypasses the dilemma of measuring optimizing versus satisficing, a concept that describes individuals behaving as if to satisfy a minimum requirement or having to choose behaviours when information processing or time constraints limit the ability to make an optimal decision (Ward 1992). Models based on ranking show which strategies will 'do better' than others in specific contexts. This position is more compatible with ethnographic hunter-gatherer societies where trade-offs that are not fossilized in debitage assemblages (such as those explained by costly signaling theory) can result in behavioural strategies that are inconsistent with predictions derived from models (Hawkes et al. 1995). Under these conditions it is more reasonable to look for instances when one strategy is doing better than another, rather than expect optimal strategies to be reflected in the palimpsest of shifting goals, currencies and constraints that is compressed into the archaeological record. All things being equal, a strategy of 'doing better' or meliorising (Dawkins 1982) will tend to approach the optimal strategy (Mithen 1988).

Second, a relaxing of precision means that the models are less bound by their more problematic assumptions. For example, the prey choice models assume that foragers search at random through the patches of their habitat, an assumption that is improbable for foragers of any species (Durham 1981: 220). Ignoring this assumption means that the distribution of prey encounters need not follow a Poisson distribution, which would be unlikely if foragers are manipulating their environment to make prey encounters more uniform or highly aggregated (Zeleznik and Ian 1991). Similarly, some optimal dispersal and group size models make the unlikely assumptions that foragers do not share information with each other and have no memory of foraging locations between trips (Durham 1981). Discarding these assumptions makes little difference to qualitative tests of these models, attesting to their robustness as behavioural heuristics (Heffley 1981).

Three Optimal Foraging Models for Lithic Debitage Assemblages

Despite these limitations and compromises, qualitative model testing has proven to be a fruitful archaeological research strategy that generates explanations that have a good fit with data (e.g. Clarkson 2006, Yesner 1981). The complexity of prehistoric decision-making is broken down by OFM into four discrete dimensions: prey choice (or diet

breadth, *what* resource to seek); patch choice (*where* to seek the resource); time allocation (*how long* to spend seeking for each alternative); and social foraging (with *whom* to forage or *share* resources and information) (Smith 1983). Debitage assemblages are not suitable for answering questions about prey choice because this relates specifically to what is included in a forager's diet and usually requires information about the energetic return rates of resources which are often equated to the biological species exploited (Grayson and Delpech 1998, Kaplan and Hill 1992, Stephens and Krebs 1986, Winterhalder and Goland 1997). Sources of lithic raw materials could be conceived of as 'prey' but they are better modeled as patches rather than prey because their location is usually static over the long term. However, debitage assemblages are well suited to questions about patch choice, time allocation and social organization. These three dimensions are modeled for hunter-gatherers below.

Patch Choice Models

Patch choice models attempts to explain how foragers select the patches or environments they exploit and how much time they should spend in each patch. Patch models predict that potential foraging locales will be exploited in order of the return rates expected from searching for and handling resources within each, adjusted for the costs of traveling (MacArthur and Pianka 1966). The marginal value theorem is a formal expression examining how long a forager should remain in a patch, taking into account declining return rates over the time that foragers exploit a patch (Charnov 1976). Two of the several predictions following from this model are particularly interesting. First, the optimal forager should leave any patch when it is depleted to the point where foraging elsewhere will yield higher returns, taking travel costs into account. Second, since time allocation to any patch is a function of average yields for all utilized patches, as the overall productivity of a set of patches rises less time should be spent in any one patch and conversely (declining productivity increases optimal patch-stay times) (Smith 1983). In archaeological terms, these predictions simply suggest that areas or periods of higher patch yields will have evidence of more intensive human occupation as people exploit a reliable and abundant resource.

Central Place Models

The central place model will predict how people's foraging behaviours given certain travel costs, transport costs and resource returns (Orians and Pearson 1979). A general central place model predicts that as travel and transport costs increase then so should

the resource return. A more specific formulation, the field processing model, predicts that as travel and transports costs increase then so should the amount of pre-processing of resources to optimize the delivery of useful material at the central place (Barlow and Metcalfe 1996, Bettinger et al. 1997, Bird and Bliege Bird 1997, Metcalfe and Barlow 1992). This model focuses on in-field processing or pre-processing of artefacts before they arrive at their final destination. For example assemblages with pieces that show signs of extensive cortex removal and less than expected pieces with cortex might reflect the in-field detachment of unwanted material to reduce weight and increase the artefact's utility prior to transport (Clarkson 2006).

Models of Optimal Dispersion and Group Size

Models of optimal dispersion predict optimum forager settlement patterns under different environmental conditions, assuming they are minimizing round-trip travel costs from resource to settlement location. These models predict that as resources become more mobile and clumped, foragers will increasingly aggregate into larger groups and when resources are more stable and evenly distributed, foragers will increasingly disperse into smaller groups (Horn 1968). In anthropological terms, the model predicts that foragers will increasingly adopt a residential settlement pattern in stable/evenly dispersed environments because small frequently-relocating settlements will always be near resources. On the other hand, a logistical settlement pattern is a better strategy in mobile/clumped environments, with larger settlements from which small groups of people venture out to collect resources at distant or constantly shifting patches (Binford 1980, Harpending and Davis 1977, Heffley 1981). In archaeological terms, a residential settlement will show signs of a relatively low investment in economising technology because the group can easily relocate to new stone sources, while a logistical settlement will show signs of higher investment in efficiency because the group cannot easily relocate and the availability of stone sources is less predictable.

Conclusion

This aim of this chapter has been to determine the most suitable conceptual framework for investigating links between lithic assemblages from mainland Southeast Asia and the relationship between human foragers and their environment. The case was made for pursuing an evolutionary framework. Three distinct evolutionary approaches to lithic archaeology were considered and HBE was found to be the most appropriate. The limitations and assumptions of HBE were discussed and qualitative model testing

was argued to be the best way to make use of HBE. Three models are presented and their predictions outlined. These models resemble classical models of economic behaviour and rely less on selection than the other two approaches. This is an advantage for HBE because identifying the action of selection in lithic assemblages can be difficult, especially if the assemblage is mostly debitage. In HBE, evolutionary theory has an ontological role, explaining how the economic preferences came to be. The presentation of these models glossed over complex issues because generality was preferred to precision. The following chapter looks more specifically at linking HBE to testing the general predictions of these three model using flaked stone artefact assemblages. Chapter five then examines the specific methods suitable for testing the general predictions. The general predictions are refined into specific predictions in chapters six and seven following the description of relevant contextual environmental and climatic data.

4. Analysing Technological Organisation

Introduction

The main finding of the previous chapter was that foraging models developed by human behavioural ecologists are likely to be productive when using stone artefacts to examine the relationship between human foragers and their environment. The aim of this chapter is to develop a bridge between the general HBE models and methods for testing the predictions of these models. The first step is to find some quality that is specific enough to be robustly measured in lithic assemblages but general enough to be inserted into the models explaining behavioural strategies. Finding this quality is known as the 'currency problem' because of the difficulty in identifying the variable that has the greatest influence on behavioural strategies across the broadest range of contexts and is convenient for analysis (Jeffares 2002: 122-125, Winterhalder 1981: 21). This quality is identified here as risk and Kuhn's (1995) spectrum of provisioning strategies is adapted to measure technological investment in risk reduction. The second step is to review how best to classify the assemblage in preparation for determining their position along Kuhn's spectrum. It is concluded that typological classifications are inappropriate and a nominalist approach based on the measurement of attributes is more suitable. Chapter five completes the link between theory and measurement by detailing the particulate attributes on the artefacts that are most sensitive to risk reduction.

Linking Lithics to Models

A good method for finding the most general qualities relating to variation in lithic assemblages is to survey the technological strategies practised by a large sample of cultural groups living in a diverse range of environments. In this case, technology is broadly defined as a society's 'customary means of manipulating the physical environment' (Bleed 1997). There are four main hypotheses proposing a general quality that strongly influences technological strategies: Oswalt's (1976) hypothesis that the nature of the food exploited is the key variable, Torrence's hypothesis that it is risk of subsistence failure (Torrence 1989), Shott's (1986) hypothesis that it is residential

mobility and Shennan's (2001) hypothesis that population size is the primary variable controlling technological diversity and complexity.

Oswalt (1976) analysed the toolkits and diets of 36 hunter-gatherer groups. He classified technologies into five types, from the least complex (an 'instrument' such as a digging stick) to the most complex (a 'complex untended facility' such as a snare). For 20 groups he observed a relationship between the degree of reliance on mobile food resources (especially aquatic animals) and toolkit complexity and concluded that exploiting mobile prey is more difficult than stationary foods (such as plants) and therefore requires more complex technology. Oswalt claimed that it was the nature of the food available that was responsible for this relationship. Torrence (1983) used a similar functional classification and similar sample of forager groups to test the hypothesis that time stress was a key component related to technological organisation.

Torrence proposed a model that predicted increased reliance on mobile foods equating to increased time stress because of the increased search and handling time required compared to stationary foods. Relatively simple technologies (such as Oswalt's instruments) do little to reduce time stress because they require continuous and direct operation to acquire food resources (for example, digging for tubers). A middle category such as weapons reduce time and energy inputs when seeking mobile prey because they reduce the distance between the locations where the prey is spotted and captured (Torrence 2001: 79). Finally, more complex technologies such as snares reduce time stress further still by freeing up people to pursue other tasks at the same time that the snare is working. Like Oswalt, she looked at the relationship between technology and reliance on mobile food resources (using latitude as a proxy for the proportions of plants and animals available for consumption, with fewer plants available further from the equator because of shorter growing seasons). Torrence found a positive and significant correlation between toolkit complexity, toolkit diversity and latitude, strongly supporting her hypothesis.

Torrence (1989) later refined her interpretation of the correlation, suggesting that time stress was only a proximate cause for variation in technology. Time stress caused by limitations in the duration of prey availability is just a specific case of stress related to the probability and cost of failing to capture prey, which Torrence proposes is the ultimate cause of technological variation. The probability of prey capture failure and the costs of this failure are two important variables that contribute to the suite of risks

that hunter-gatherers manage with various behavioural strategies (Torrence 2001: 77). In their discussion of risk, Bamforth and Bleed (1997) extend Torrence's analysis further to determine the relative importance of probability and cost of failure to technological organisation. Using partial regression methods, their analysis suggested that after sampling bias is removed from Oswalt's data, increasing latitude relates primarily to toolkit diversity rather than complexity, which is mostly controlled by the degree of dependence on aquatic resources. They also note that probability of failure seems to be the main variable operating on the cross-cultural analysis. Failure costs probably make a contribution also, but this is difficult to accurately evaluate across different technologies and environments.

Shott (1986) proposed that the key variable for technological organisation was mobility because carrying costs limit the number of tools available. Ethnographic research suggests that highly mobile groups will have less complex tools than more sedentary groups because the tools they carry must be suitable for a wider range of tasks (Ebert 1979, Kelly 1988, Kelly 1992). Shott examined correlations between technological diversity and complexity and a range of mobility variables (including frequency and magnitude) for 14 hunter-gatherer groups. Toolkit diversity and mobility frequency were found to be significantly negatively correlated, as predicted. Other variables were not significantly correlated. For example, relationships between toolkit diversity and total mobility magnitude, toolkit complexity and frequency of moves or average distance per move and territory size and toolkit diversity or complexity, were not significant (Shott 1986).

Shennan's approach to identifying the primary variable in technological organisation is rather different from that of Oswalt, Torrence and Shott. He adapted a mathematical model of mutation and selection used in population genetics to investigate the effect of population size on the extent to which cultural innovations ('mutations') are advantageous to the biological fitness of human populations and their attractiveness as models for imitation. Specifically, Shennan models the transmission of craft traditions, such as toolkit production, because of the specific transmission characteristics of this kind of information (i.e. craft traditions) are passed from a parent or adult of the parent's generation to the same gender offspring once per generation during childhood and very rarely learned from peers (Shennan and Steele 1999). The results of the modeling show that members of larger populations are on average both substantially

biologically fitter and more attractive as models for imitation while smaller populations suffer the persistence of innovations which are less beneficial reproductively and less attractive to imitate. The implication for technology is that rates of successful technological innovation are likely to be correlated with population sizes and densities, so bigger populations have more complex and diverse technologies.

To identify which of these four hypotheses used to explain toolkit variation is the most general and most important, Collard et al. (2005) conducted a stepwise multiple regression analysis of technological, ecological, subsistence, mobility and population data from 20 hunter-gatherer groups worldwide (the same used by Oswalt and Torrence). Their results supported Torrence's hypothesis that risk of resource failure is the primary influence on hunter-gatherer technology. The only variables that significantly influenced toolkit complexity and diversity were effective temperature (which they use instead of latitude as a similar proxy for length of growing season) and net above-ground productivity (reflecting the increase in plant biomass during the growing season). They did not find any significant correlations supporting the hypotheses of Oswalt, Shott and Shennan. Like Bamforth and Bleed (1997), Collard et al (2005) caution that risk buffering is less well correlated with toolkit structure for hunter-gatherer groups with a substantial aquatic resource component in their diet. They cite two examples of groups exploiting aquatic foods with complex toolkits that would otherwise be unexpected, given their relatively low risk environments (the Calusa of southern coastal Florida and the San groups occupying the floodplains of the Botletli River in the northern Kalahari). These exceptions are of limited significance in the analysis of lithic assemblages because aquatic foraging toolkits are typically made from ephemeral organic materials with few lithic components. If aquatic toolkits are widely used, they are likely to be underrepresented by lithic assemblages and therefore unlikely to substantially distort lithic assemblage complexity and diversity as robust measures of risk minimisation.

Risk is a useful concept to articulate general technological strategies with behavioural ecological models (Hiscock 1994). The problem of risk is ubiquitous in animal foraging systems (where it is defined as 'variance' rather than 'probability of failure', although these can be considered equivalent in this context) and there is a substantial literature on optimal foraging modelling and empirical testing of how animals respond to risk

(Caraco 1981, Kacelnik and Bateson 1996, 1997, Real and Caraco 1986). Important results from this work are three general principles that predict how animals respond to risk. First, animals whose average expected foraging returns are above survival requirements tend to be risk-averse and animals whose average expected returns are not, tend to be risk-prone. Second, when variance is in amount of returns, animals are more usually risk-averse, whereas when variance is in delay of returns, animals are almost universally risk-prone. Third, direction and magnitude of risk-sensitive preferences may be influenced by the number of options available in the choice set (Bateson 2002). Ecologists have observed a variety of behaviours for minimising risk including torpor, group foraging, food sharing and storage (Winterhalder et al. 1999).

A similar suite of responses to risk has been documented by anthropologists examining human groups, highlighting the universality of the problem of risk. In their survey of ethnographic literature, Winterhalder et al. (1999) list some of the frequently observed risk-minimising strategies, including diversification of food resources (e.g. crop types or herd composition), diversification of resource collection locations (e.g. field dispersion, increased foraging mobility), food transfers and sharing and storage. More specific human responses to risk sensitivity include information storage (e.g. encoding of survival information in oral tradition), exchange relationships and, of course, technology (Minc and Smith 1989, Sobel and Bettles 2000, Wiessner 1982). These responses can be generalised into four strategies that minimise risk by spreading exposure to it (1) across multiple individuals, (2) over time, (3) over space and (4) across economic activity types (Winterhalder et al. 1999: 339).

Although highly variable, humans are similar to most large omnivores, in being generally risk-averse (Winterhalder et al. 1999: 338). As noted above, human technology mostly operates to spread risk over time and space by reducing time stress related to foraging. However, Fitzhugh (2001) has suggested that in the special case of technological innovation, humans can change from risk-averse to risk-prone. He proposes that when groups begin to experience resource yields below minimum requirements they should become risk-prone by exploring new technologies in the hope of improving resource yields. Fitzhugh suggests that increased innovation and variation can be expected in response to heightened risks when groups encounter unfamiliar environments (through migration or climate change), resource depression (especially of high-yielding prey) or social-political competition.

It should be no surprise that the risk-averse responses listed by Winterhalder et al. (1999) resemble some of the predictions of the three optimal foraging models presented in the previous chapter. For example, the patch choice model predicts that individuals will stay longer in a patch when in a more profitable patch relative to other patches, as the distance between patches increases and when the environment as a whole is less productive. Staying in a patch for longer is equivalent to minimising risk by minimising exposure to other patches that probably yield less. The central place model predicts that the further a forager goes the more they will bring back. This is equivalent to minimising risk by spreading it over time and space; by increasing the load with distance the forager maintains an average return rate given the travel and transport costs for all trips and smooths out variation in returns for trips of different lengths.

These similarities between risk reducing strategies and optimising strategies suggest that risk reduction, or minimizing the likelihood of a shortfall, can be employed as a currency for optimal foraging models (Stephens 1990). Winterhalder (1990) demonstrates this when examining trade-offs between rate-of-return maximisation strategies and risk-minimisation strategies in subsistence practises and risk management for pre-modern agriculturalists in central England and hunter-gatherers of the Kalahari in Southern Africa. Using diet breadth models, he shows that for both examples the model predicts similar outcomes for rate-of-return maximisation and risk-minimisation. In the case of the archaeological record of technological organisation other influential factors, for example those related to social and historically contingent contexts, cannot be ruled out, so it is unlikely that a risk minimisation strategy will always be optimal. However, for models with maximum generality, risk is clearly the most useful variable and will be highly influential even if people are satisficing instead of optimising.

Measuring Risk Minimisation

If risk seems to be a suitably general quality explaining variation in prehistoric technology, including lithic assemblages, and for use as a currency for optimal foraging models, then the next step is to determine how risk minimising strategies can be identified in the particular lithic assemblages under consideration here. There has already been considerable work done on identifying risk minimising strategies in stone artefact technology. This work is based on the assumption that conflation of archaeological deposits and palimpsest formation do not obscure the signal of short

time scale activites repeated over long time periods. One influential example is Bleed's (1986) categorisation of tools as 'maintainable' (readily repairable) and 'reliable' (unlikely to break while in use). Maintainable tools are described as relatively simple, generalised, light and portable, being suitable for quick and easy repair during use. Reliable tools are more complex and specialised, with redundant design elements to minimise unscheduled repair time and requiring more effort and time to produce and repair (and thus more costly when they fail). Assemblages that are relatively abundant in both reliable and maintainable tools reflect an investment to minimise a relatively high exposure to risk, in a similar way that the more complex and diverse assemblages discussed above correlate with more challenging environments.

Bleed's approach has proven very productive in a variety of archaeological studies (Bleed 2001, Bousman 1993, Bousman 2005, Hiscock 2006, Myers 1989, Neeley and Barton 1994) but is limited by its dependence on visually distinctive and relatively complex tools as the objects of analysis and the reality that reliable and maintainable tools are not mutually exclusive. The conventional idea of a tool is a specimen that has at least one of the four attributes identified by Hiscock (2007) to hypothesise implement design (repeated shaped, regular form, morphological features in excess of performance requirements and extensive retouch). This is a crucial limitation in this context because the assemblages considered here, like many flaked stone assemblages from mainland Southeast Asia, are almost entirely unretouched flakes and cores; there are no tools, conventionally defined. Similarly the approach used by Torrence et al. in the above discussion of toolkit complexity and diversity is also not suitable for assemblages of unretouched stone artefacts because they constitute only a single dimension of diversity and complexity, so comparing two or more assemblages from the same region will always produce the same result. This is not to say that unretouched flakes were not used, only that tools cannot be unambiguously distinguished from tool-making debris. Similarly, the stone component may represent only part of the whole implement, so analysis of tool design is limited to one small, often simple and cheap component. Bleed and Torrence have proposed special cases of a theory for connecting risk to stone artefacts, but what is needed here is a more general theory that connects risk to the largest part of stone artefact assemblages in mainland Southeast Asia – the unretouched flakes and cores. This is a difficult task since without tools it is necessary to generalise beyond well-understood dimensions of

tool design such as standardisation, flexibility and use-life (Hiscock 2006, Nelson 1991, Surovell 2003, Ugan et al. 2003).

To begin the derivation of this general theory it is necessary to return to the three optimal foraging models outlined in the previous chapter and consider how to test their predictions. The patch choice model is the simplest, stating that the higher the value of the patch the longer a forager will remain there. The archaeological correlate of this is simply more and larger sites with higher artefact densities in high value patches. A minor consideration is to ensure that technological changes alone are not responsible for higher densities, this can be dealt with first by analysing artefact technologies and second by examining discard rates of other cultural materials. Similarly, the predictions of the central place model can be tested by measuring the relative degrees of pre-processing of lithic raw material prior to entering the site. The methodological challenge here is distinguishing pre-processing from on-site processing. This can be done by analysing core and flake ratios and metrics in assemblages recovered from archaeological sites and identifying pieces that appear to be missing from the assemblage. For example, cores are present in the assemblage but certain size classes of flakes appear to be absent then it is possible that those flakes were detached form the core off-site during a pre-processing event. More complicated are testing the predictions of the model of optimal dispersion, which describes when people will adopt logistical or residential settlement patterns. The problem here is that it is difficult to identify these differences in settlement patterns in unretouched lithic assemblages. More specifically, an approach is needed that shows how foragers solved the problems of maintaining an adequate supply of stone artefacts at different points on a spectrum of high to low residential mobility.

The most productive approach to making the connection between lithic assemblages and residential mobility are the two 'provisioning strategies' described by Kuhn (1992b, 1995, 2004b). Individual provisioning describes a strategy of keeping individual foragers supplied with the artefacts and raw materials they need as they move through the landscape. Place provisioning refers to strategies that involve supplying artefacts and raw materials to places where activities are likely to be carried out. Like Bleed's scheme, Kuhn's system has been most commonly employed in the analysis of tools rather than unretouched pieces. Kuhn's system is here adapted for assemblages of

unretouched flakes and cores, following the example of Mackay (2005) who modified it to suit an assemblage with no formal components.

Individual Provisioning

The main limiting factor in provisioning mobile individuals with technology is transport cost, so artefacts should be designed to supply a satisfactory amount of potential utility given these transport costs (Kuhn 2004b: 432). The exact method for obtaining this satisfactory amount varies across different lithic technologies (Goodyear 1989, Kuhn 1994, Morrow 1995, Nelson 1991, Roth and Dibble 1998, Shott 1986). Amongst this diversity of methods the general trend is for mobile individuals to provision themselves with artefacts that have undergone some processing and are ready for use rather than less- or un-processed raw material nodules, which would involve carrying mass that is not contributing to the artefact's function. This strategy is most directly relevant to testing the predictions of the central place model, since the predictions of that model hinge on travel and transport costs. When foragers have to travel further to obtain resources, the field processing model predicts that pre-processing of resources should increase to optimise the delivery of useful material given travel and transport costs. In the case of lithic assemblages, the correlate of increased travel and transport costs is increased individual provisioning.

In particular, the expected characteristics of an assemblage resulting from individual provisioning are pieces that have reduction potential and, more importantly, pieces that have had that potential extended, realised and/or exhausted. Reduction potential refers to the degree that an artefact can be modified and repaired to prolong its useful life, making less raw material do more work (Macgregor 2005, Shott 1989a). Identifying reduction potential of tools is difficult and problematic despite several ingenious methods (Clarkson 2002, Eren et al. 2005, Kuhn 1990, Shott 1995), and for assemblages without tools at all a different approach is required. Hiscock (2006) has suggested that instead of looking for reduction potential, assemblages can be examined to identify technological decisions that resulted in reducing the rate at which artefacts need to be resupplied, thus reducing procurement and transport costs. Hiscock (2006: 81) calls these decisions to reduce procurement and transport costs an 'extension strategy' and notes that it is characterised by fewer and smaller artefacts that have attributes suitable for extended flaking, use and resharpening. Examples of these attributes include

higher quality raw materials (Goodyear 1989) and cores with multiple platforms (Macgregor 2005). When employing this strategy foragers are investing relatively more energy in a smaller number of artefacts for the return of use over an extended period.

Perhaps the most useful link provided by the concept of individual provisioning is between lithic assemblages and the predictions of the optimal dispersion model. The paradigmatic mobile individual is one who makes lengthy logistical foraging trips from a base camp, but foragers as a group are all mobile individuals when the residential camp is a small frequently relocating settlement. This means that a signal of individual foraging in an assemblage can reflect high logistical mobility during conditions of mobile and clumped resources or high residential mobility in stable/evenly dispersed environments if foraging activities are out of phase with raw material provisioning opportunities. Local factors, such as the availability of raw material and the nature of particular foraging resources are the key to disentangling the two possibilities. For example if a residentially mobile group is foraging in an area of relative raw material abundance then the signal of individual provisioning in the assemblage should be weak. On the other hand, foragers involved in logistical movements are always likely to adopt an individual provisioning strategy, according to the predictions of the central place model.

Place Provisioning

Where the signal of individual provisioning is weak then a different provisioning strategy, place provisioning, is likely to be operating. Place provisioning occurs when transport costs do not strongly constrain technological choices. The relaxation of these constraints means that people will tend to amass quantities of raw material at more permanently or more frequently occupied locations. These locations will tend to be provisioned with raw material in various states of manufacture including unworked nodules and less reduced specimens (Parry and Kelly 1987). This strategy is optimal under three conditions: abundant raw material, low residential mobility or short range logistical movements.

The identification of place provisioning strategy as the opposite of individual provisioning provides a more robust link between optimal foraging models and lithic assemblages. In reality, the two strategies are not polar opposites but will both be present in an assemblage to different degrees depending on the particular habitat. Place provisioning strategies will be predicted by the patch choice model when

foragers are in an area or period of high patch yields. Similarly, place provisioning is predicted by the central place model when travel and transports costs are relatively low or logistical movements are short. Finally, place provisioning is predicted by the optimal dispersion model when resources are patchy/mobile but near to the residential camp or stable/evenly dispersed when raw material provisioning is in phase with substance resource acquisition. Once again, determining the mix of factors influencing technological provisioning choices requires knowledge of the local habitat.

These two provisioning strategies, when linked with the optimal foraging models described in the previous chapter, can be ultimately regarded as responses to varying degrees of exposure to risk. There are two specific kinds of risk that these provisioning strategies should be most effective at lessening. First is subsitence risk, or the risks associated with procuring food. This is the kind of risk that Torrence's work refers to, and is likely to be relevant in the discussion any mobile technology of human foragers. Elston and Raven (1992: 33-34) describe this as contingency risk, which is the probability of not having enough toolstone to meet subsistence needs. This risk increases as toolstone supply diminishes and suggests that people will increasingly invest effort in monitoring and managing stone consumption to avoid insufficiency. However, the flake and core assemblages examined here are likely to have been used for other tasks in addition to food procurement, such as processing materials for shelters and repairing tools for other purposes. A second kind of risk, technological risk, may be more important for this kind of assemblage which cannot be exlusvely linked to food procurement. Technological risk refers to the risk of running out of usable tools or raw material and being unable to perform key activities. This kindof risk is more general because it does not require knowledge of how the artefacts were used. Instead it depends on the assumption that making and maintaining stone artefacts incurs an opportunity cost by diverting time from time sensitive activities such as pursuing mobile resources or travelling between patches. Elston and Raven (1992: 33-34) describe this as venture risk, which is the probability that the procurement and opportunity costs of seeking stone resources will exceed the benefits of any stone resources gained. These different kinds of risks are not quantified in detail here, but serve a heuristic purpose in linking stone artefact technology and risk management. This taxonomy of risk illustrates the sorts of risks that stone arteafact technology can minimise through the choice of an individual or place provisioning strategy.

In general, individual provisioning will be adaptive in high risk environments while place provisioning is suitable for low risk environments where time and energy can be diverted to tasks other than technological provisioning. That said, an individual's technological decisions are likely to be influenced by risk on a variety of scales from personal momentary risk to population-level generational risk. This means that a lithic assemblage will include a combination of individual and place provisioning strategies and analysis of provisioning strategies will only reflect a response that is an average of several different responses conflated together during the formation of the archaeological deposits. Consideration of the minimum chronological resolution of analytical units is important for interpreting this average response.

In using these two provisioning strategies and related behavioural ecological models to answer archaeological questions, much previous work has focussed on partitioning a typology into categories along the spectrum between place and individual provisioning (e.g. McCall 2006). While this approach generally works because of an occasional correspondence between typology and artefact reduction intensity in assemblages from certain times and places, it is necessary to consider an alternative philosophy of classification for assemblages that are not readily amenable to typological classification. This is a typical problem of mainland Southeast Asian lithic assemblages, largely due to the very small numbers of retouched pieces and the relatively indistinct patterns of core reduction.

Approaches to Artefact Classification

Classification is an enduring and central concern of archaeology, as it is in many other disciplines. In particular, biology has a long tradition of working at the general problem of how to arrange phenomena to do useful analytical work. Since biologists have been thinking about this for much longer than archaeologists, it might be instructive to see how they have confronted the problems of grouping entities. Also, the processes of change in a flaked stone artefact over its use-life suggest that there is good reason to look to biology for ideas about classification. The nature of change for a flaked stone artefact is the flake-by-flake removal of mass that changes the size and shape of the artefact (Flenniken 1984, Steffen et al. 1998). Although the flakes removed are discrete units, these flakes are typically much smaller than the artefact from which they are removed (for example a core or retouched flake) so the process of change of a stone artefact can be viewed as a continuous reduction of mass and morphological

possibilities. This process of change by continuous reduction can be compared to natural selection of variation in a biological population. The artefactual equivalent to a biological population is an assemblage, when a group of artefacts in the same place from the same time are under consideration.

The process of natural selection in biological populations is reductive because variation in a biological population is reduced when less successful variants are removed from the population by their failure to reproduce. Other processes such as mutations, genetic drift and genetic recombination generate biological variation. The sources of variation in stone artefact assemblages and biological populations are, of course, very different but I suggest that the mechanisms of change in lithic assemblages and biological populations are conceptually similar. Morphologies of both assemblages of flaked stone artefacts and biological populations change because of a process of continuous reduction. Even if an artefact is used by multiple people over different times and locations, morphological and size change of that piece can only occur through the flake-by-flake removal of mass. A direct analogy between natural selection and stone artefact reduction is problematic because stone reduction does not remove unsuccessful variants from the assemblage like natural selection does. However, the more abstract concept of gradual change by reduction of variation is shared by stone artefacts and biological populations and has implications for archaeological classification.

This conceptual equivalence of the processes of change is significant because it means that the philosophical and methodological work of biologists on classification is relevant to archaeologists dealing with flaked stone artefacts. For example, Ernst Mayr (1959), identified two basic philosophies that underlie attempts to define concepts of biological species: 'typological' thinking versus 'population' thinking (Figure 4.1). Mayr's 'typological' thinking is similar to what archaeologists mean when they refer to typologies. It presumes the existence of discoverable and discrete kinds of things. Things are of the same kind because they share real and fixed 'essences' — and these essential properties dictate whether a specimen is of kind A or kind B (Lyman and O'Brien 2002). This approach to classification was dominant in biology from Plato and Aristotle until Darwin. Modern biologists are generally critical of this essentialism (Sober 1980), with Hull (1965a, 1965b) arguing that it was responsible for 2000 years of

stasis in the development of the science of biology, and Popper (2003: 11) similarly writing that

> the development of thought since Aristotle could, I think, be summed up by saying that every discipline as long as it has used the Aristotelian method of definition has remained arrested in a state of empty verbiage and barren scholasticism, and that the degree to which the various sciences have been able to make any progress depended on the degree to which they have been able to get rid of this essentialist method.

Essentialism and stone artefact archaeology

Should essentialism also be criticised by archaeologists working with Southeast Asian stone artefacts? In this context there are three criticisms of essentialism. First, essentialism results in a method that uses only a very small fraction of the available sample. Typological thinking in stone artefact studies results in methods that classify assemblages into discrete groups of artefacts according to their shapes and sizes. The shapes and sizes of artefacts are explained by typologists as the result of an intentional design in the mind of the artefact maker to produce tools for specific purposes (Dibble 1995: 32, Hiscock and Attenbrow 2005). This results in a focus on the most visually striking artefacts in an assemblage, usually only a small proportion of most archaeological assemblages (Hiscock 2007). In the earliest published description of a typology Southeast Asian flaked stone artefacts, Colani (1927) writes that over 1000 artefacts were recovered from the excavations at Sao Dong, Vietnam, of which 82 artefacts were classified into 28 types. Similarly, in Pookajorn's (1988) excavation of over 3000 artefacts from three rockshelters at Ban Kao, central Thailand, he classified 86 of those artefacts into 10 types. Excavations at Laang Spean, western Cambodia, recovered 8502 stone artefacts, of which 34 were classified into seven types (Mourer 1977). In these three examples the analysed samples are rather small for reliable statistics and convincing interpretation (cf. Shennan 1988) and there are a large number of artefacts that are not contributing to the analysis. Even if the unanalysed pieces really were waste from prehistoric tool-making, it is widely accepted by stone artefact analysts in other parts of the world that this kind of debitage has considerable analytical value (Andrefsky 1998: chapter six, Clarkson and O'Connor 2005, Collins 1975). This suggests that the typological approach to Southeast Asian stone artefact analysis results in an inefficient use of the available data.

A second criticism of essentialist approaches is that they hide or compress variation into a small number of groups. Artefacts that do not appear to fit comfortably into the typology are explained by the typologist as imperfections, flawed realisations of the ideal mental image or the result of variation in skill and raw materials that is usually viewed as having no explanatory value (Dunnell 1986, O'Brien and Lyman 2000:33). Colani (1927:56) dismisses the large number of artefacts that she does not analyse as 'among the rudest ever made by human hands.' Later archaeologists working in Vietnam have been similarly nonplussed by the 'great number of indefined [sic] tools' in Hoabinhian assemblages and are 'puzzled with the idea of how to find a suitable type for them' (Chung 1994).

In Thailand, van Heekeren observed that 'the overwhelming majority of the flakes from [Sai Yok] displayed no signs of edge-chipping from use or from planned retouch and typological examination of the flakes does not indicate intended production of any predetermined shapes. They may therefore be labelled as waste products' (van Heekeren and Knuth 1967:23). The Sai Yok lithic assemblage was later revisited by Matthews (1964:188) who undertook a detailed and systematic analysis of the flaked stone artefacts, motivated by a concern that the Hoabinhian types focussed on by other archaeologists were 'an arbitrary selection… being made from a continuous range of shapes'. Matthews was influenced by Spaulding's (1953) argument that types can be discovered in archaeological assemblages by using statistical tests such as chi-square to identify distinctive differences between groups of artefacts with similar combinations of attributes. Although Spaulding's approach cannot discover 'natural' types because the types discovered by statistical analysis ultimately depends on the choices made in the selection and weighting of variables (Dunnell 1971), Matthews was able to use Spaulding's method to test the idea that the Hoabinhian assemblage from Sai Yok contained the discrete types described by Colani.

Matthews (1964:230) analysed the Sai Yok assemblage to test his claim that Colani's Hoabinhian typology was not justified and resulted in 'individual [artefacts] from continuous ranges [being] given typological significance they did not deserve.' Matthews collected data from the Sai Yok artefacts using measurements of continuous variables to see if different artefact types would identify themselves by showing different and discrete modes in the results. On each artefact he recorded a suite of metric dimensions as well as observations about the quantity and distribution of flake

scars and cortex as well as the shape of the artefact (Matthews 1964:150-3). Matthews' conclusion is unequivocal; the Sai Yok assemblage does not contain discrete types but only kinds of artefacts with measurements and attribute states that overlap on a continuum with other kinds. Figure 4.2 shows that metric variables for flaked cobble artefacts vary continuously rather than having discrete peaks. The same continuous variation is evident in flake scar numbers and edge angles or cores (Figure 4.3) and metric variables on flakes (Figure 4.4). This result demonstrates that, in the case of the Hoabinhian, typological analysis ignores variation in lithic assemblages and instead focuses on a few forms that are not representative of numerically and technologically important aspects of the assemblage. Despite Matthews' early demonstration of how typological analysis compresses and neglects variation, typological methods have continued to be used in mainland Southeast Asian archaeology (eg. Pookajorn 1990, Santoni et al. 1990). Had Matthews presented his results more directly by stating that Hoabinhian types are not necessarily final products but visually distinctive forms resulting from different stages of reduction with overlapping attribute variation then his results may have had a more immediate impact.

Matthews' study indicates that essentialist approaches to Southeast Asian stone artefacts are problematic because they are inefficient in their use of data and they fail to incorporate the full range of assemblage variation. In addition to these two specific issues, there is a third and more general problem with essentialist approaches, one that is common to the analysis of all kind of artefacts. This problem is that because typological analyses cannot measure gradual change in artefacts over time (because continuous morphometric variation is not tracked), only the difference between kinds of artefacts can be measured (Lyman and O'Brien 1997). If a kind of thing (such as a stone artefact type) is based on discrete and exclusive essences, then for that thing to change it must drop one essence and take on another, so it must undergo a transformational step-like change rather than a gradual and continuous change (Mayr 1982). This means that a typologist can produce sequences of kinds of artefacts, showing that there are differences over time, but this sequence does not allow them to measure gradual change leading to empirical historical relationships with clear ancestor-descendant relationships (Dunnell 1980:38, O'Brien and Lyman 2000:35). Measuring historical change in artefact lineages is an increasingly important concern in artefact analysis with the growing interest in evolutionary theory in archaeology

(Boone and Smith 1998, Lyman and O'Brien 2006, Lyman and O'Brien 1998, Marwick 2006)

An example of this problem in Southeast Asia is the numerous lithic industries named by Vietnamese researchers, such as the Sonvian, Bacsonian and Da But, that are defined according to the frequencies and presence or absence of certain lithic types, and the geography of site location (Huu Nga 1994, Khac Su 1994, Van Tan 1997). These different industries are equated with cultures, for example the Sonvian and the Hoabinhian are regarded by Khac Su (1994:26-27) as 'independent, separated cultures' with some 'cultural interrelation'. The typological differences between the lithic industries are relatively clear but the historical relationships between these industries are unclear. For example, we do not know if they are divergent lineages from a common ancestor, ancestor-descendant industries or if the two industries really represent two points on continuum of a single industry where the changes in the lithic assemblages are best explained as adaptations to different ecological conditions (cf. Nishimura 2005).

To summarise, the use of essentialist approaches in Southeast Asian archaeology has three significant criticisms: first, it is an inefficient method, with large numbers of artefacts ignored because they do not fit into type categories; second, continuous morphometric variation at the assemblage level is largely ignored in favour of ideal specimens, despite the empirical reality that these ideal types are not representative of the assemblage; and third, that typological analyses cannot explain historical change in artefact lineages. That said, we should not completely abandon essentialism because typological thinking still has value as a system of classification for archaeologists. Metal, ceramic and many other kinds of artefacts, for example, often have discrete forms with no continuity between shape and size between different classes of artefact. These kinds of artefacts are built up from a plan, such as a metal cast or coil and slabs of pottery (1987, Schiffer and Skibo 1997) and resharpening or repair need not involve the one-way reduction of mass like stone artefacts (Shott 2005, Steffen et al. 1998). Broken metal artefacts can be melted and recast and broken ceramic vessels can be ground up and recycled as temper (Deal and Hagstrum 1995), rather than gradually moving through a spectrum of utility and changing morphology like flaked stone artefacts. Typological classifications of ceramic, metal and other constructed (as opposed to reduced) artefacts can be valid and useful for answering a variety of

questions about past human behaviours. These kinds of artefacts (and related attributes such as decorations) are especially well suited to analysis using frequency seriation, where the quantities of various kinds are tracked together over time (O'Brien and Lyman 2000:271-300). This often results in 'battleship curves' (also known as Markovian structures) that can be analysed to discover biases in the social transmission of artefact-related information and answer fundamental questions about the spread and persistence of cultural traits (Bentley and Shennan 2003, Neiman 1995). In addition to the analytical value of typological thinking, it is also a useful system for assemblage curation and public education, where things need names so that stories about them can be told, as well as having to be organised and displayed within discrete spaces.

Nominalism and the reduction thesis

If typological approaches to flaked stone artefacts in Southeast Asia are problematic, then how can the opposing philosophy of classification – Mayr's 'population' thinking – be employed in stone artefact analysis? This approach to classification holds that phenomena cannot exist as discrete entities because they are always in the process of becoming something else. No two things are ever exactly alike because similar things do not share an essence, they are just at similar points in the process of becoming something else. The nominalist sees individual things that are composed of unique features and when these things are grouped together they form populations that are described by statistical abstractions such as mean and measures of variation (Mayr 1959). Like essentialism, nominalism is a way of viewing the world that was familiar to the ancient Greeks as well as ancient Arab and Chinese authors (Bowler 2003), but was an unpopular philosophy until Darwin. Darwin's contribution is significant because he replaced typological thinking with population thinking through his collection of evidence supporting gradual rather than sudden change in animals and his proposal of natural selection as a mechanism for this gradual change.

The nominalist approach to stone artefact analysis recognises that morphological variation in stone artefacts reflect different stages along a continuum of change rather than the intentional creation of discrete types. This approach is supported by ethnographic studies that have recorded how tool morphology changes as the tool undergoes continuous resharpening throughout its use-life (Gallagher 1977, Gould et al. 1971, Hayden 1977, Hayden 1979). This approach is known as the 'continuum model' or the 'reduction thesis' (Hiscock and Attenbrow 2003, Shott 2005). Nominalist

analyses are well-suited for classifying flaked stone artefacts because each flake that is removed, either during the manufacture, use or resharpening of an artefact, is a small step in the process of the artefact becoming a different shape and size. Over the life of an artefact, this flake-by-flake change resembles a continuous process that can be measured with continuous measurement variables. Following from this, an assemblage of artefacts is a group of individual pieces that were in the process of becoming something else (through morphometric change resulting from use, reduction, breakage, discard, etc.) at the time they entered the archaeological record. Although individual artefacts may have noteworthy histories of manufacture and use, it is only when they are considered together at the assemblage level that meaningful statements about technological patterns can be made. Extrapolating technological schemas from single pieces risks confusing unique stochastic events with longer-term patterns of behaviour that are of greater archaeological interest.

Measuring the degree of this change in artefact shape and size is the focus of nominalist analyses (Clarkson and O'Connor 2005). Shott (2005) presents a catalogue of methods developed in the last twenty years for measuring artefact reduction in assemblages, including Dibble's (1987) comparison of relative numbers of Middle Palaeolithic scraper types, Kuhn's (1990) geometric index of unifacial reduction, Barton's (1988) perimeter retouch index and Clarkson's (2002) index of invasiveness. These methods are yet to be tested with assemblages from mainland Southeast Asia. Despite having been very illuminating elsewhere, they may be of limited use with mainland Southeast Asian assemblages because of the relatively low proportions of intensively reduced artefacts (White and Gorman 2004).

A more productive method is likely to be diacritical analysis, which includes all flakes and cores in an assemblage and ranks individual flake reduction according to simple changes in individual flake morphology that logically follow from changing core morphology as reduction intensity increases (Sellet 1993: 108). In this way, the assemblage can be described in terms of statistics based on the population of individual artefacts. For example, although technological attributes interact in complex ways, a reasonable expectation is that as an assemblage is reduced, the average number of flake scars on flakes and cores will often increase, and the average amount of cortex will correspondingly decrease. Similarly, proportions of artefacts with overhang removal (the presence of a series of overlapping flake scars less than about 5 mm long

at the intersection of the striking platform and the dorsal surface) may also increase as the knapper adjusts the core platforms to prepare them for the more difficult blows required to detach flakes from smaller cores (Macgregor 2005). The following chapter develops this approach further and presents experimental evidence in support of a set of variables for measuring artefact reduction at the assemblage level for Hoabinhian assemblages.

There are three specific and significant advantages for the nominalist approach when dealing with flaked stone artefacts. The first is that it allows the analyst to jettison assumptions about the knapper's mental goals and functional desires when describing and analysing the assemblage (Hiscock and Attenbrow 2005: 33). Adopting a nominalist approach shifts the criteria of classification from the unknowable mental states of the knapper inferred by the typologist to the attributes of fracture surfaces which have the obvious advantage of being objectively described. As a result, a nominalist analysis includes all products of the knapping 'waste' (for example unretouched flakes and amorphous cores), not just the sample that appear to have been used or designed for use. One reason to do this is because the fracture surfaces of the waste material preserves information about earlier states of the cores, thus documenting manufacturing processes that are not preserved in intensively reduced cores that would otherwise be the exclusive object of analysis in a typological system.

A second reason to prefer the nominalist approach of using the entire assemblage rather than only pieces assumed to have been tools is that there is yet to be a convincing demonstration of the claimed associations of tool form and function that Hoabinhian typological systems rely on (Bannanurag 1988, Kim Dzung 1994).

Finally, the nominalist approach is advantageous because variation in assemblage reduction can be interpreted as a reflection of variation in behavioural responses to the conditions of lithic production and discard. This interpretation is possible because lithic production is not simply a technical act, but a process of supplying functional tools at the same time as solving problems related to risk, cost, and efficiency in systems of time budgeting, mobility and land use (Bleed 2001, Clarkson and Lamb 2005, Hiscock 1994, Kelly 1988, 1992b, 1994, Kuhn 1995). From this embeddedness of technology in other systems, the distribution of assemblages at different stages of reduction over space and time can be seen as a reflection of variation in planning, land

use and settlement and subsistence patterns in everyday life of hunter-gatherers (Binford 1979, Kuhn 1995, Nelson 1991).

Summary

This chapter has identified risk as a quality that is general enough be used with the foraging models and important in the explanation of technological variation. Kuhn's spectrum of provisioning systems was adapted to link the idea of risk reduction to behavioural strategies involving stone artefacts. Finally, a review of artefact classification systems argued that a nominalist system based on the measurement of artefact attributes is best suited to the investigation of risk reducing behaviours using flaked stone artefacts. The next chapter shows specifically which artefact attributes are the most reliable indicators of risk reducing strategies.

Figure 4.1. Schematic representation of essentialist and nominalist approaches to classification. The peaks represent kinds of artefacts in a hypothetical assemblage, with the height of peaks indicating their numerical dominance in the assemblage.

Figure 4.2. Matthews' metric analyses of flaked cobble artefacts from Sai Yok (n = 100). Redrawn from Matthews (1964).

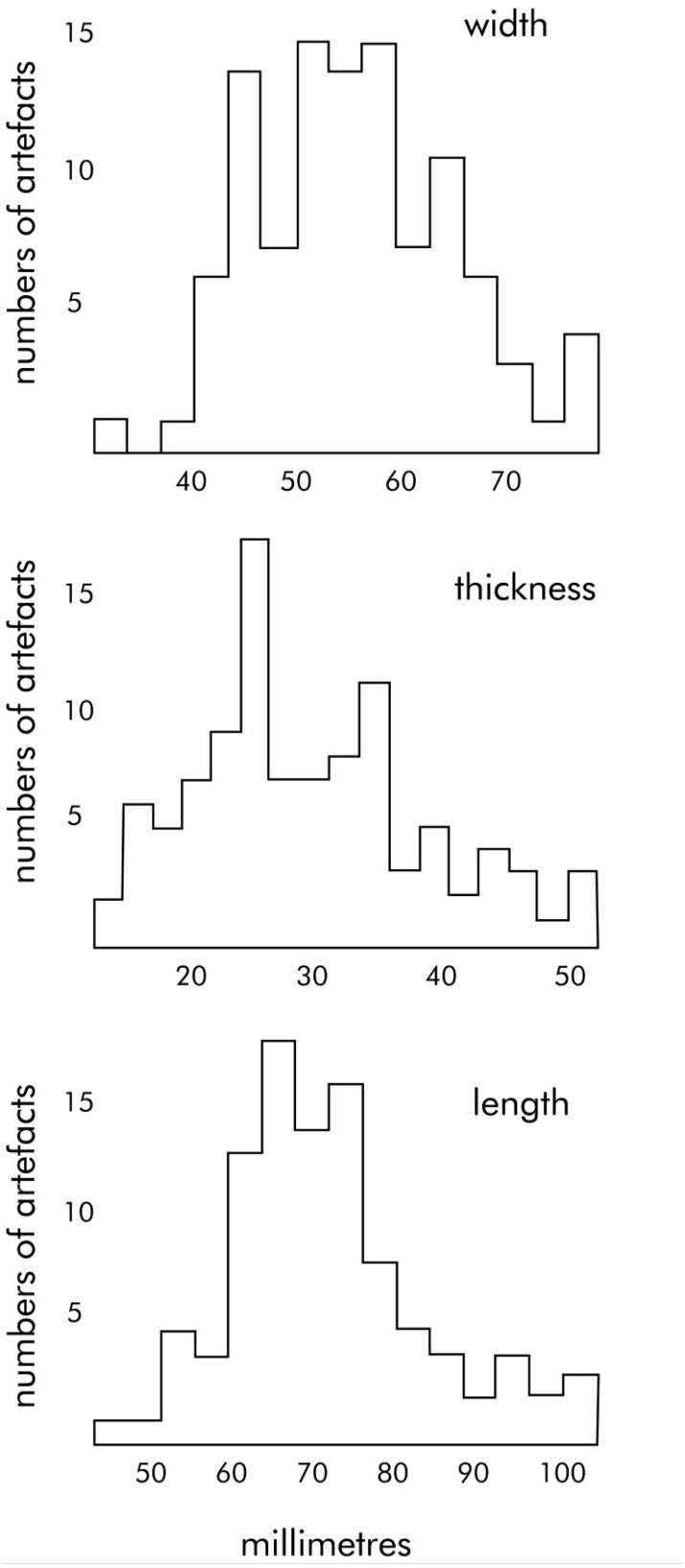


Figure 4.3. Matthews' analyses of flake scar numbers and edge angles on pebble tool artefacts from Sai Yok (n = 183). Redrawn from Matthews (1964).

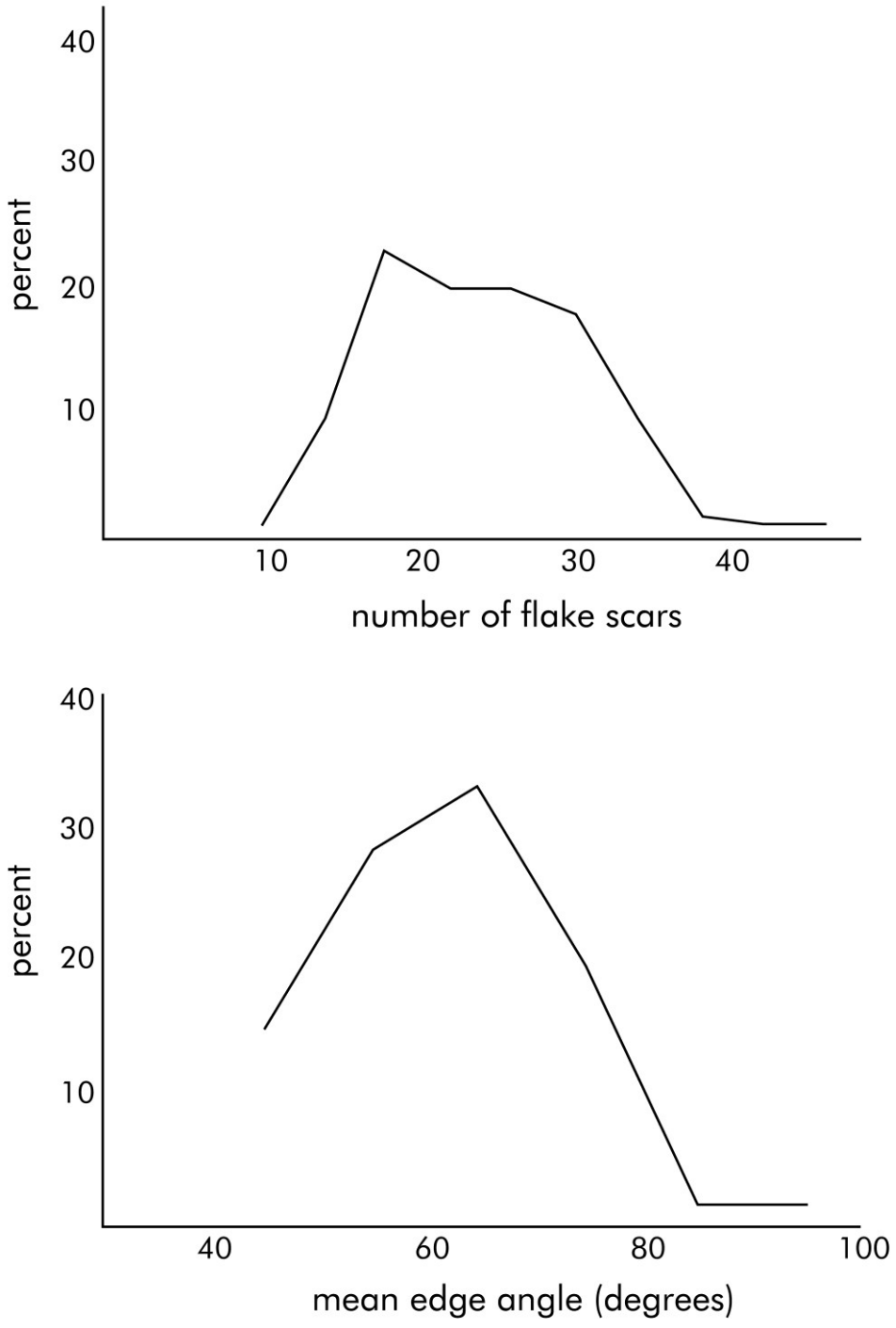
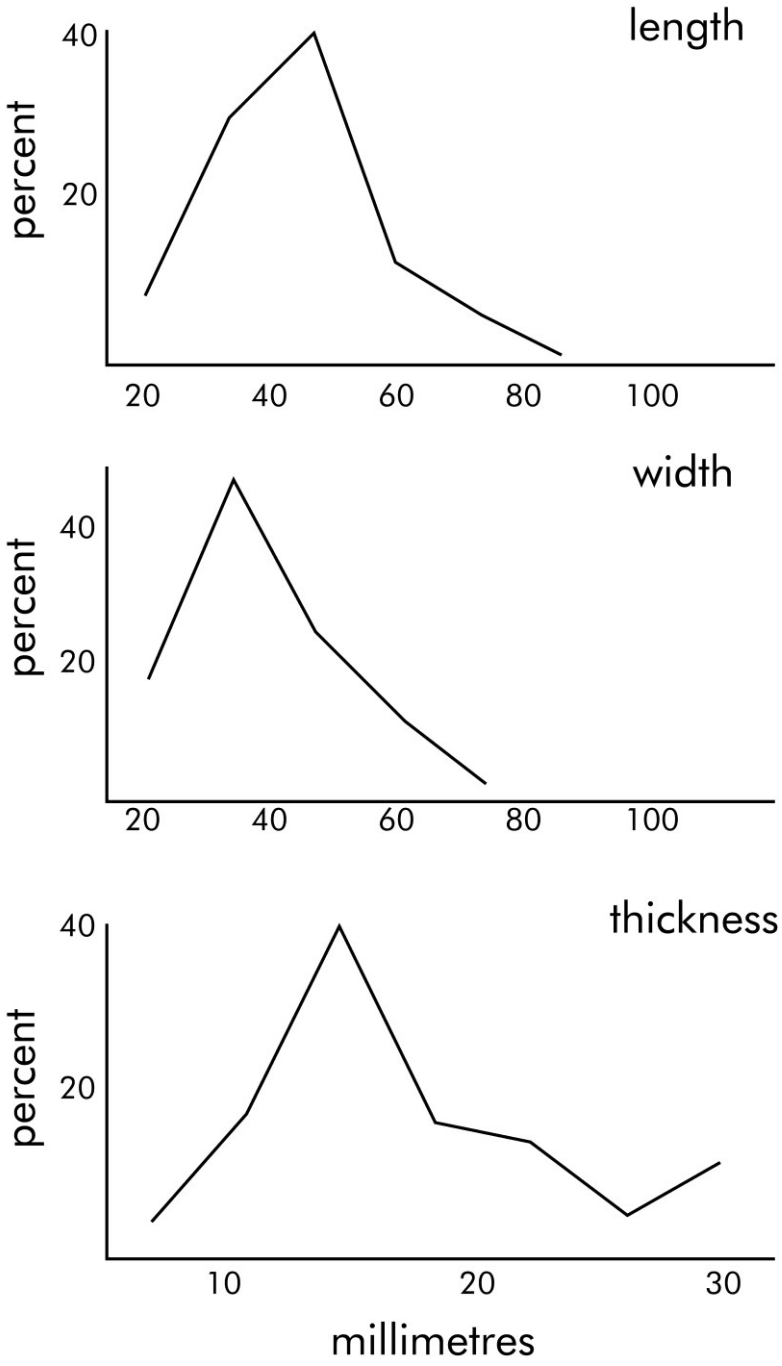


Figure 4.4. Matthews' metric analyses of flakes from Sai Yok (n = 100). Redrawn from Matthews (1964).



5. A General Model for Quantifying Lithic Reduction in Hoabinhian Assemblages

Introduction

Now that the problem of the most appropriate approach to the classification of artefacts has been addressed, the next step is to determine the most relevant variables for quantifying lithic reduction at the assemblage level, rather than for specific specimens. These variables are the key to a general theory connecting risk to stone artefacts because they allow direct measurement of the degree that risk reducing strategies have influenced assemblage formation. The aim of this chapter is to describe the specific techniques for measuring risk reducing strategies in flaked stone artefact assemblages. The first part of this chapter is a brief review of artefact definitions and general statistical and graphical techniques. The second part presents the results of an experiment designed to identify the most reliable attributes for measuring assemblage reduction intensity as a proxy for investment in risk reduction. A slightly shortened version of the second part of this chapter has been accepted for publication in the *Journal of Archaeological Science* (Marwick 2007b).

Defining and identifying artefacts

The previous chapter described the nominalist philosophy of classification as the most suitable approach to analysing flaked stone artefacts. The implication of following this approach is that the most parsimonious and robust division of flaked lithic specimens is into four classes: cores, flakes, retouched flakes and flaked pieces. These classes are defined by simple empirical qualities, namely macroscopic scar form and superimposition, and are independent of functional and mental assumptions (Hiscock 2007). While additional subdivisions are possible, for example unifacial and bifacial cores or retouched flakes, these subdivisions are undesirable at this high level of classification because they impose discontinuities on the assemblage that may obscure or conflate relationships with other technological properties important for understanding sequences of manufacturing actions. This simple four class system has the advantages of clarity, efficiency and objectivity over previous Hoabinhian

classification schemes which have had limited success because of their complexity and subjectivity.

Core

In this classification a core is defined as specimen with one or more negative conchoidal flake scars and no positive flake scars. A negative flake scar is a fracture surface that has negative impressions of one or more of the following; ring crack, cone, bulb, concentric ripples or fracture termination (Cotterell and Kamminga 1987, Crabtree 1972). Further description and information on the mechanics of the formation of flake scars can be found in Phagan (1985), Whittaker (1994) and Macgregor (2005). No distinction was made between complete and broken cores because the coarseness of the lithic material and the relatively high frequency of internal faults in the rock made distinguishing core fragments from unbroken cores difficult. Quantification of cores is simply given as a total count of specimens.

Flake

A flake is defined here as a specimen with one or more positive conchoidal flake scars (i.e. one or more ventral surfaces). A positive conchoidal scar can be identified using one or more of the following properties: ring crack, cone, bulb, concentric ripples or fracture termination. A flake may also have negative flake scars, but this property is irrelevant to its membership of the class.

Flakes are the most numerous kind of artefact in this project and describing their different states of fragmentation is necessary to accurately calculate the abundance of flakes and to distinguish complete from broken specimens. The distinction between complete and broken specimens is important for accurate technological interpretations of many flake attributes. For example it would be spurious to analyse flake lengths and include length measurements from transversely broken flakes where the length of the original intact flake cannot be measured.

Four kinds of flake fragment were recognised here, following Hiscock (2002b). Longitudinally broken fragments occur when a flake has broken along the percussion axis and split the flake so that the broken fragments include part of the striking platform, fracture initiation and termination. Transversely broken flakes occur when the flake is broken along an axis perpendicular to the percussion axis. Transversely broken pieces include portions of both lateral margins but not necessarily the platform

or fracture initiation (unless it is a proximal fragment), and termination (unless it is a distal fragment). Marginal fragments occur when a piece of the flake margin breaks away, these fragments have only portions of one lateral margin and no termination or initiation. Surface fragments are pieces that are a portion of ventral or dorsal surface, with no initiation, termination or margins present.

Although technological analysis is undertaken only on complete flakes, these different fragmentation classes can be used to estimate the abundance of flakes in an assemblage. Influenced by studies of taphonomy and zooarchaeological quantification, Hiscock (2002b) has proposed a formula for calculating minimum numbers of flakes (MNF) from complete and fragmented flakes. The formula sums the number of complete flakes, the largest category of transverse fragments (proximal or distal, excluding medial), the largest category of longitudinal fragments without a transverse break (left or right) and the largest category of transversely and longitudinally broken fragments (right/proximal, left/proximal, right distal, left/distal). Minimum numbers of flakes must be calculated separately on different raw materials because their different mechanical properties mean that their susceptibility to fragmentation varies.

Retouched flake

A retouched flake is defined here as a flake on which scars have been produced after the formation of the last ventral surface. This is identifiable by the presence of one or both of these two properties: the flake has scars that encroach onto the ventral surface (and were created after that surface) and/or the flake has scars that originate from the ventral surface (and were created by striking that existing ventral surface) (Hiscock and Attenbrow 2005: 34). This is a polythetic class because is it based on the specimen having at least one of the properties of the flake class and one of these two retouch properties. Very few retouched flakes were recorded so no further analyses of these were undertaken.

Flaked piece

Although the previous three classes will capture the great majority of artefacts in an assemblage, an additional class is necessary to classify specimens that cannot be classified as cores or flakes. The flaked piece class is for specimens where the definite identification of positive or negative flake scars is impossible because of fragmentation, weathering or encrustations. This class makes the classificatory framework exhaustive

so that all specimens can be classified as well as reducing observer bias induced by guessing the classification of ambiguous specimens.

Statistics and Graphs

Now that the basic classes of artefacts have been defined, it is important to explain the approach and theory relating to the exploration of relationships in the data obtained from these classes. The focus of the analytical methods here is on continuities of variations in the stone artefact assemblages, so it is important to have appropriate, consistent and explicit statistical methods to describe patterns and test the predictions of the models outlined in chapter three.

Descriptive statistics

These methods include basic statistics to describe the numerical qualities of a class or any of its attributes. *Sample size* or *batch size* is depicted as 'n' and refers to the number of observations made for any particular class or attribute. *Mean* is one measure of central tendency of a sample and is calculated by the sum of measurements divided by the number of measurements. *Median* is the value in the sample that is below half of the values when they are ordered by rank. Where there is an even number of values then the median is the average of the two middle values. The median and the mean are both measures of the central tendency of a sample, but the median is less sensitive to extreme values and skew than the mean. *Standard deviation* is a measure of the spread or dispersion of values around the mean. It is calculated by taking the square root of the sample variance, where variance is the sum of the squares of the differences between a value and the sample mean divided by one less than the sample size.

Significance testing

Null hypothesis significance testing (NHST) is a widely used and conventional approach for inferring patterns and relationship from data. However, ecologists and psychologists have debated the usefulness of NHST as a valid approach for scientific inference (Carver 1993, Gill 1999, Gliner et al. 2002, Johnson 1999, Shaver 1993, Thomas 2001, Thompson 2004, Vacha-Haase 2001). There has been similar concern about the usefulness of this approach in archaeological research, but perhaps less progress towards a better framework for inference (Chibnik 1985, Christenson 1979, Clark and Stafford 1982, Cowgill 1977, Scheps 1982, Thomas 1978). Di Stefano et al. (2005) have identified five main points in the debate. First is that NHST is used mechanistically as

if it was an objective rule that provided an unambiguous and rigorous answer (Stewart-Oaten 1995). Second, NHST tends to focus effort on testing a single uninformative null hypotheses; that there is no difference between a parameter (such as the mean) measured on two or more samples (Anderson et al. 2000, Johnson 1999). The reason why this is uninformative is because as sample sizes increase it is inevitable that a test of the difference between the two samples will result in increasingly small *p* values, such that a very small difference between the samples becomes a statistically significance difference although it might not have any scientific importance (Berkson 1938, Royall 1986, Yoccoz 1991). A more informative approach would provide the statistic for the two samples, the difference between the statistics from the two samples and the error associated with the estimates.

The third theme in the criticism of NHST is an over-reliance on *p* values without including necessary information such as effect sizes or error estimates. In their survey of 347 journal articles published in the *Journal of Wildlife Management* and *Ecology* over the period 1978-1999, Anderson et al. (2000) found that 47% of *p* values did not include estimates of means, effect sizes or error estimates. Effect sizes are important because they represent a standardized difference between the means of two samples or a standardized measure of association, and have the potential to reveal whether a statistically significant result reflects a scientifically meaningful difference rather than a trivial difference (Maxwell et al. 1981, Maxwell and Delaney 1990). Error estimates provide information about the degree of accuracy of a statistic, giving an estimation of how close it is to its true value. This is important for assessing the reliability of a comparison of two samples and the impact of sample size, for example, smaller samples will have higher error estimates than large ones so less confidence can be placed in the results of a significance test (Nix and Barnette 1998).

The fourth point is that the use of NHST results in uninformative and misinterpreted *p* values. For example, knowing the magnitude of difference between two samples and the accuracy of this measurement is more informative than simply knowing that they are different, yet *p* values only state whether or not there is a difference. Similarly, *p* values do not indicate the probability that the observed effect is due to chance, the probability that the null hypothesis is true, the reliability of the result or effect and error sizes (Di Stefano et al. 2005, Nickerson 2000). The *p* value represents the probability of the observed data, or more extreme data, given that the null hypothesis is

true and certain other conditions hold (Johnson 2005). The final objection noted by Di Stefano et al. (2005) is that the use of NHST has a tendency to encourage arbitrary inferences, especially the use of 0.05 as a cut-off for significance (Johnson 1999).

In response to these five criticisms and other more philosophical objections (Gill 1999, Nickerson 2000) some authors take an extreme view that NHST should be abandoned entirely in favour of other approaches (Anderson et al. 2000). These other approaches include Bayesian statistics (where rejection or acceptance of hypotheses is fundamentally linked to previous beliefs and assumptions) and Information Theoretic techniques (where competing models are ranked according to how well they approximate the process that generated observed data) (Johnson and Omland 2004, Stephens et al. 2007a).

Bayesian statistics constitute a different way of doing science, not just an alternative statistical tool (Dennis 1996). The two distinguishing features of Bayesian methods are the quantification of estimates of how likely each explanation is believed to be and the input of these estimates into probabilistic models. There has been some application of these methods in archaeological dating, chronologies and artefact seriation (Buck et al. 1996, Buck and Sahu 2000, Christen and Litton 1995, Dellaportas 1998, Halekoh and Vach 2004). Although Bayesian methods have been encouraged because they formalise previous beliefs and assumptions and because it gives the probability of the hypothesis given the data (which is what researchers usually really want to know), the method is still relatively obscure in archaeology, probably due to the difficulties of implementing the computation (Aldenderfer 1998: 110, Baxter 1994: 222) and difficulties in representing qualitative archaeological data as quantitative probabilities (Reece 1994). Since this project is not primarily a computational study and the modelling is only semi-quantitative as discussed in the previous chapter, Bayesian statistics are not a suitable alternative to significance testing here.

Advocates of Information Theoretic (IT) techniques claim that NHST is relatively uninformative because it tests only a single hypothesis while IT methods simultaneously evaluates multiple working hypotheses and rank models according to how much the goodness of fit of the models with the data (Anderson et al. 2000, Hilborn and Mangel 1997). IT methods are philosophically attractive because of the claims that it searches for the best model rather than the true model, the high value it places parsimony and simplicity, its advocacy of the concept of multiple working

hypotheses and its focus on quantifying strength of evidence rather than providing arbitrary dichotomies like NHST (Burnham and Anderson 2002). As a relatively recently developed statistical method, there has been little formal use of model-evaluating IT techniques in archaeology although there has been scattered employment of more general concepts of IT analyses in assemblage diversity studies (Justeson 1973, Kent 1992, Kintigh 1984) Although the theory underlying IT inferential procedures is robust, the novelty of the method means that there is still uncertainly about which of the possible model-evaluating criteria is most suitable under given conditions (Guthery et al., Kass and Raftery 1995), how it responds to small samples sizes (Richards), what the 'rules of thumb' are for interpreting differences in criteria values for competing models (Stephens et al. 2007b) and doubt that IT techniques entirely overcome the criticisms of NHST (Stephens et al. 2005). IT methods are easier to calculate than Bayesian methods but have a similar requirement for fully quantitative models because of the need for maximum likelihood estimators in IT calculations. This need for fully quantitative inputs and the uncertainties in interpreting the results preclude IT techniques from being suitable here.

Confidence Intervals

Having now reviewed some of the problems with NHST and the two alternatives, Bayesian methods and IT methods, as suitable quantitative methods for comparing samples, what options remain for alternative approaches to comparing samples? Fortunately, critics of NHST are almost unanimous in recommending the use of confidence intervals in place of significance tests (Cowgill 1977, Cumming and Finch 2001, Fidler et al. 2006, Gardner and Altman 1986, Thompson 1999, Thompson 2002, Wonnacott 1987). Confidence intervals (CIs) are an established component of conventional statistical methods that are intervals or ranges of plausible values for some quantity or population parameter of interest; they are a set of parameter values that are reasonably consistent with the observed sample data. Cumming and Finch (2001) offer four reasons for using CIs. First, CIs give point and interval information that is accessible and comprehensible, especially through the simple visual display of data, enabling substantive understanding and interpretation. Second, there is a direct link between CIs and NHST: noting that an interval excludes a value is equivalent to rejecting a hypothesis that asserts that value as true — at a significance level related to the CI percentage (usually 95%). Third, CIs are useful in the accumulation of evidence over multiple experiments, supporting meta-analysis and meta-analytic thinking

focused on estimation. Finally, CIs give information about precision that may be more useful and accessible than a statistical power value.

Despite the advantages of CIs over NHST and more complex approaches, they are not yet widely used in archaeology or other disciplines (Ely 2001, Fidler et al. 2004a, 2004b), so it is necessary to explain how they are calculated and how to correctly interpret the results and graphical depictions. Confidence intervals are most commonly calculated at 95%, indicating the range of values that gives a 95% probability of including the population parameter being estimated (usually the mean). The computation uses probability theory to take account of sampling error, formally expressed as: mean ± t x SE, where SE denotes the standard error of the mean, SD/√n, where SD is the standard deviation and n is the size of the sample. The t value is determined from the t-distribution according to the degrees of freedom of the sample under investigation (calculated as n-1). The main prerequisite for the use of this calculation is that the distribution of the sample data resembles a Gaussian, or normal, curve (Cumming and Finch 2001). This t-based approach is not very robust under extreme deviations from normality (Boos and Hughes-Oliver 2000).

The distribution of data from lithic assemblages, especially metric data, is not well understood so the existence of normal distribution, a prerequisite of this approach, cannot be assumed. Early experimental work described the size distribution of lithic debitage produced during biface manufacture as an exponential distribution (Ahler 1986, Baumler and Downum 1989, Patterson 1990, Patterson and Sollberger 1978). Stahle and Dunn (1982) also examined debitage from an experimental biface assemblage of Afton projectile points, a dart point from the North American mid-continent. Unlike Patterson, Stahle and Dunn interpreted the cumulative relative frequencies of flake size categories as a Weibull distribution. Shott and Sillitoe (2004, 2005) have also used the Weibull distribution to model ethnographic data on stone artefact use-life durations from highland New Guinea and reduction of an archaeological assemblage of Palaeoindian flakeshavers from the Bull Brook site in the northeastern United States. The Weibull distribution has some theoretical appeal because of its usefulness as a model for analysing failure (including the fracture of brittle solids) and death data in engineering, ecology and medicine (Iii et al. 1978). However, Shott's archaeological example only included a single kind of artefact and Stahle and Dunn (1982) were not able to use the Weibull distribution to accurately

model assemblages of a mixture of flakes from a variety of biface reduction stages. Since most lithic assemblages are palimpsests, a mixture of reduction stages and different artefact forms is more likely to reflect archaeological reality.

For mixed lithic assemblages Shott (1994) suggested that artefact size distributions could be modelled by the log skew Laplace function because this function has been successfully used to model particle sizes of complex mixed cave sediments (Fieller et al. 1992a, 1992b). Unfortunately Shott does not present any detailed empirical results of using the log skew Laplace function so it is difficult to evaluate its usefulness. Similarly inspired by research in engineering and geology, Brown (2001, Brown et al. 2005) has argued that fractal distributions are appropriate and useful for size-frequency distributions of lithic debitage. Fractal models have been successfully applied to analyse the fragmentation of rocks and soils (Borodich 1997, Perfect 1997). These models are well developed in geology and geophysics, with many natural phenomena exhibiting fractal distributions (Radlinski et al. 1999, Turcotte 1997). Brown (2001) found that ten previously published experimental lithic assemblages could be modelled as fractal distributions, as well as six archaeological assemblages from Late Postclassic Mayapan in Mexico. In these assemblages the fractal dimension closely and systematically corresponded to the degree of assemblage reduction. However, Brown also noted that many other assemblages from Mayapan approximated a normal distribution and he attributed this to floor cleaning and re-deposition of lithic debris.

The diversity of probability distributions that have been proposed to model lithic debitage suggests that variation across different lithic technologies cannot be robustly described by a single distribution. None of the distributions appear to have properties that maintain their robustness when recovery techniques vary, for example when different sized sieves are used or when artefacts are identified by people with different levels of skill. However, the four proposed distributions reveal two important general features of lithic assemblages. First, is the obvious detail that they are generally not Gaussian or normal (with the exception of a those noted by Brown (2001)), so the conditions for employing traditional hypothesis tests (such as the chi-square and *t*-tests) and the common CI calculation are not satisfied. Second is that these distributions reflect the typically skewed shape of the sample distribution, where most values cluster to the lower extreme of the sample's size range.

The textbook correction for the non-normality and skewness is the use of transformation functions such as taking the square root, inverse or logarithm of the sample values (Drennan 1996: 56-59). Transformation is a versatile and robust method for preparing data for statistics requiring a normal distribution but is inappropriate for some distributions, such as those with multiple modes. There have been some claims that transformations are problematic because very sensitive to variations in the minimum values of a sample (Osborne 2002), they make confidence intervals difficult to interpret because they standardise the variances of samples (Bland and Altman 1996) and testing the mean on transformed scales is not always equivalent to testing on the original scale (Zhou et al. 1997). These claims do not invalidate transformation as a statistical method (a common transformation, the Z-score is used in this project), but the overall approach chosen here explores an entirely different approach to statistics based on theoretical distributions, which is what transformations are often preparation for.

Bootstrap methods

In this situation where confidence intervals are desired but the sample distribution is unknown and transformations are undesirable, computer-intensive resampling methods such as the bootstrap can be used in place of classical mathematical methods (Diaconis and Efron 1983, Efron and Tibshirani 1991). Classic mathematical methods rely on theoretical distributions, which require strong assumptions of both the sample and the population. When these assumptions are not met, computer-intensive resampling methods can replace analytically difficult or ambiguous distribution theory. The basic idea of the bootstrap is that the distribution of the observed data is the best guide to the distribution of the population from which that data derives. The bootstrap is thus a 'distribution free' method because it does not depend on the distribution of the sample data resembling a known distribution. Point values and estimates are then calculated from a distribution generated out of the observed data (Boos 2003).

Bootstrapping consists of a few simple steps repeated a large number of times. First, random sample values are taken or 'resampled' from the original set of observed data to create a new set the same size. The values in the original set are usually denoted as (x_1, x_2,..., x_n) and the new set as (x_1*, x_2*,..., x_n*). The new set of values is known as the 'bootstrap sample'. The randomly sampled values from the original set of observed

data are 'replaced' back in the original set after they are sampled, this means it is possible that one value might appear multiple times in the bootstrap sample even though it only appears once in the original sample. The statistic of interest, such as the mean, median, correlation coefficient or any other function (usually denoted as $\hat{\theta}$ or theta-hat and the corresponding parameter of the population is simply θ or theta) is then calculated on the bootstrap sample (that statistic from the bootstrap sample is represented as θ^* or theta-star). The two steps of random resampling with replacement and calculating θ^* on the resulting new sample are then repeated a large number of times, usually 1000 or more so that there are 1000 or more values for θ^*, this is known as the sampling distribution of θ^*.

The recommended number of repetitions varies from 25 upwards (Efron and Tibshirani 1993) and a number of rules have been proposed for determining the necessary number (Booth and Hall 1994, Hall 1986). However, Chernick (1999: 114) suggests that debates about numbers less than 5000 are irrelevant because of the ubiquity and speed of modern computers. A practical approach suggested by Lunneborg (2000) is that the number of repetitions be incremental increased until successive SE estimates of (x_1*, x_2*,..., x_n*) vary by less than 1%. These large numbers of repetitions are quickly and easily accomplished by modern desktop computers, but early investigations into the bootstrap occurred in the 1970s when computing resources were not as powerful or affordable, so the bootstrap was considered a 'computer-intensive' method in comparison to classical mathematical methods using lookup tables (Efron 1979). In the calculations performed here and in the following chapters, 10,000 repetitions were conducted for all implementations of the bootstrap.

Once the sampling distribution is obtained then confidence intervals can be calculated to represent the accuracy of θ^*. Because of its conceptual simplicity and its freedom from restrictive assumptions the bootstrap is popular amongst statisticians for calculating CIs. As a result of this popularity a daunting variety of different bootstrap methods have been developed for calculating CIs (DiCiccio and Efron 1996, Diciccio and Romano 1988, Efron 1987). The simplest bootstrap method is percentile CI, where the values of θ^* are ordered from smallest to largest and then the θ^* values at the 2.5th and the 97.5th percentiles are taken as the upper and lower limits of the 95% CI. This method is appealing because of its clarity and simplicity (Wood 2004). However, the percentile bootstrap does not work well for small samples or skewed distributions

(Chernick 1999: 53, Manly 1997: 50, Shao and Tu 1995: 132, 166) and Hall (1988) offers theoretical arguments against the use of percentile methods. Similarly, empirical simulation studies comparing alternative bootstrap methods show that the percentile method is less accurate than other bootstrap methods (Hoyle and Cameron 2003, Kelley 2005, Ukoumunne et al. 2003). This means that percentile CIs will include the true value of the unknown parameter less often than 95% and will include more erroneous values of the unknown parameter than is desirable (Good 2005: 90).

The relative newness of bootstrap methods means that they are still evolving and there are currently no clear reasons for favouring one method over another. In this context, two criteria can be introduced to aid in choosing between the numerous other bootstrap methods for producing CIs. First is to focus on methods with demonstrated suitability for skewed distributions that resemble the size-frequency distributions noted above for lithic assemblages. Second is to prefer less mathematically complex methods to keep implementation of the method straightforward and preserve the conceptual appeal of the bootstrap as a robust but simple method for non-normal data.

Hoyle and Cameron (2003) compare six different methods for calculating nonparametric bootstrap confidence intervals on estimates of recreational fishing catches obtained from telephone and diary surveys. This data is highly skewed with most respondents reporting a small catch size and just a few reporting large catches. The six methods were normal bootstrap (where the SD of the bootstrap distribution is the estimate of the sample SE and then used for common CI calculations), two percentile bootstrap methods, bias corrected bootstrap (a variation of the percentile method that adds a correction derived from difference between $\hat{\theta}$ and θ^*), bias corrected and accelerated bootstrap (a variation of the percentile method that corrects for skewness by introducing a constant) and bootstrap-*t* (where the bootstrap distribution is of a statistic that is a ratio of the random variable to its SE). The simulation was based on 4000 sub-samples of 100 values (catch sizes) taken from a total of 2844 values and each of the 4000 sub-samples was resampled 4000 times to generate the bootstrap distribution according to one of the six methods. The results of the simulations were then compared to the sample of 2844 values to see how well the simulated CIs represented the catch rate and total catch sizes of the larger sample. Their results showed that the bootstrap-*t* method produces the most correct and least

biased coverage, with the skewness of the data handled poorly by the other methods (Hoyle and Cameron 2003: 104).

Zhou and Dinh (2005) conducted simulations calculating CIs on log-normal and gamma distributions to test the performance of normal (non-bootstrap) *t*, bootstrap-*t*, bias corrected and accelerated bootstrap and three methods of transforming the normal *t* statistic. Like the data used by Hoyle and Cameron (2003), the log-normal and gamma distributions are highly skewed. They created CIs using the different methods for 27 variants of the log-normal distribution and 28 variants of the gamma distribution, running 10,000 simulated samples for each variant (to keep sampling variation small) and 1000 bootstrap samples for each generated dataset. Zhou and Dinh (2005) found that the bootstrap-*t* and two of the three transformation methods gave similar results and better coverage than the bias corrected and accelerated bootstrap. Similarly, Manly (1997: 66-68) examined the performance of the same seven bootstrap methods tested by Hoyle and Cameron (2003) on a computer-generated pseudo-random sample of 20 values with an exponential distribution. Each of the seven methods was used to find 95% CIs of the mean using 1000 bootstrap replications from the sample of 20 values. He found that the bootstrap-*t* method provided the best coverage of the true 95% CI. The bootstrap-*t* CI coverage was 95.2% with the coverage of the next best method, the bias-corrected and accelerated method, at 92.4%.

These simulations are far from the final word on which bootstrap method is definitively superior, but they suggest that the bootstrap-*t* method outperforms other methods for skewed sample distributions. Other empirical studies show that the CIs from bootstrap-*t* methods perform well in terms of coverage accuracy compared to other bootstrap methods in more general situations (Canty et al. 1996, Davison and Hinkley 1997: Example 5.7 and Section 5.7, Hall 1988, Shao and Tu 1995: Section 4.4.4, Ukoumunne et al. 2003). Hall (1989) has also used theory to demonstrate that bootstrap-*t* has exceptionally good CI coverage properties for regression functions. However, it has also been noted that bootstrap-*t* methods can give unstable and wide CIs when complex functions and small samples are involved (Efron and Tibshirani 1993: 162, Kilian 1999).

The success of the bootstrap-*t* is encouraging because it is second in simplicity to the simple percentile method CI, while the other bootstrap methods are considerably more complex (Chernick 1999: 59, Manly 1997: 65). Although the case that has been made

here for bootstrap-*t* is based on its advantages with skewed non-normal distributions, its more general advantage of being a robust and simple distribution-free statistical method means that wider applications are also appropriate. Confidence intervals of regression variables can also be estimated using bootstrap-*t* methods. Evaluation of the strength of covariation between two variables is undertaken here by calculating the Pearson Correlation Coefficient, a measure of the linear association of the two variables. The coefficient ranges from -1 to 1 with positive values indicating that the two variables change in the same direction and negative values indicating inverse relationships. Squaring the coefficient value gives a general indication of the strength of the covariation. Bootstrap methods were used to create bootstrap distributions of coefficient value by resampling observations. Confidence intervals for the coefficient can then be determined from the bootstrap distributions. Bootstrapping the coefficient value improves the reliability of the value under conditions when it is difficult to be sure that the assumptions of linear regression have not been violated (independence of values, independence of errors and homogeneity of variance). In a situation like this, cross-validation of the regression model can be undertaken by bootstrapping the regression statistic (Chernick 1999: 70-88). Incidentally, confidence intervals for correlation statistics incorporate standard null hypothesis significance tests; if the interval includes zero then the correlation is not significant.

Bootstrap methods may have the appearance of being a statistical panacea because of their apparent robustness, their departure from classical techniques and the combination of computational intensiveness with theoretical simplicity. However, like all methods, bootstrapping has important limitations, the most significant being that these limits are not well understood because theoretical work is relatively recent. There are three reasonably well understood limitations of the bootstrap. First is that bootstrap methods are tools for producing inferential statistics (such as confidence intervals), not point estimates of parameters (Mooney and Duval 1993: 60). Point estimates produced by bootstrapping merely reflect the bias of the statistics involved rather than alleviate these biases, although more complex approaches such as the bias corrected and accelerated bootstrap attempt to compensate for this. The second limitation is the assumption that the sample is representative of all the possible distinct values of the population (Mooney and Duval 1993: 60). As sample size decreases, the likelihood of all the relevant values of population being represented decreases also. This can be especially problematic for bootstrap CIs because they rely heavily on the extreme

values in the tails of the sample distribution. However, experimental data reported by Mooney and Duval (1993) indicates that the asymptotics that the bootstrap relies on improves accuracy before the central limit theorem does during multiple runs with incremental increases in sample size. Like Chernick (1999: 150), they found that bootstrap CIs outperformed parametric intervals on a variety of tests with small samples (n = 14-50). Finally, the third significant limitation of bootstrap is that the sample reflects a random sample from the population. The theoretical justification of the bootstrap depends on the assumption that the empirical distribution of the sample is a good estimator of the population distribution (Mooney and Duval 1993: 60). If the validity of this assumption is threatened by data that was not collected using simple random sampling then more complicated adjustments need to be made to the bootstrap method. These limitations are less restrictive than traditional methods based on known distributions, but they indicate that careful substantive reasoning remains necessary for the appropriate application of bootstrap methods.

In the results of stone artefact analyses that follow, the bootstrap-*t* method was used to calculate 95% CI on various statistics such as the mean and correlation coefficient. Results are expressed as a point value with the 2.5th percentile and 97.5th percentile in square brackets following the point value. A number of software implementations of bootstrap methods are available, including several for Microsoft Excel (Christie 2004, Good 2005, Meineke 2000, Wood 2005). This would be the simplest technique but the performance of the Excel's random number generator in standard tests of randomness has been criticised as inadequate (McCullough and Wilson 2005). The quality of random number generation is important because bootstrap methods rely heavily on random numbers to resample the original sample. Instead, the S-Plus Resample Library for S-Plus 8.0 was chosen as the most suitable implementation with the advantage of having a built-in routine for bootstrap-*t* CIs and bootstrapping regression CIs (Insightful Corporation 2002). In the S-Plus implementation the bootstrap-*t* CIs of sample means, for example, are determined by (1) calculating the means and standard deviations for each column of the original data and bootstrap samples, (2) calculating the *t* statistic for each bootstrap sample: (bootstrap means - means of original data)/(bootstrap standard errors), (3) calculating quantiles of the bootstrap distribution of the *t* statistic (4) inverting those quantiles to obtain confidence limits. This bootstrap-*t* procedure is similar for other statistics.

Graphical representations

Three major forms of graphical representations of data are used here for the visual display of quantitative information about patterns and relationships between variables. First are dot charts, where one or more variables are depicted (usually on a common continuous measurement scale) across multiple categories (usually positioned on the y-axis). Values on dot plots are judged by their position along the horizontal axis (cf. Figure 8.1). These are a less familiar form of graph that are advocated by Cleveland and McGill (1984a, 1984b, 1985) as a replacement for more common bar charts. Cleveland and McGill's (1985, 1987) experiments on the visual perception of information encoded in graphs demonstrated a hierarchy in the accuracy of decoding for different forms of graphs. They found that points positioned along a common scale (such as the dot chart) are consistently interpreted most accurately, while graphs based on length and area (such as bar graphs) are harder to compare visually and interpret accurately. Other advantages resulting from the emphasis on points positioned along a common scale is that they do not require a zero baseline as bar charts do and they have a highly efficient ratio of data to ink because most of the ink in the graph is non-redundant ink arranged in response to variation in the numbers represented (Gillan and Richman 1994, Tufte 1986).

The second form of graph is the confidence interval graph which plots several kinds of statistical information in a single graph (cf. Figure 5.3 for example). The vertical lines indicate the region of the 95% confidence interval for the mean values of each category on the x-axis. The mean value is depicted as a point on the CI line. These graphs show the direction and magnitude of changes in the values of point estimates between categories. They also allow comparison of shape of the distributions of measurements of some variable for different categories. A special feature of 95% CI graphs is that they have a direct link to familiar null hypothesis significance tests, as noted above (Cumming and Finch 2001). For example, the values of points in the region of the CI give p values of >0.05 for the null hypothesis and points outside of the CI give p values of <0.05. When comparing two or more CIs, it is possible to determine p values from the lengths and overlap of the CI lines. Cumming and Finch (2005) offer a rule of thumb for reading p values from 95% CI graphs: when n > 10 (they can be quite different) and CI lengths do not differ by more than a factor of two, an overlap of 0.5 of the CI length for two independent categories results in $p \approx 0.05$ and when the CI lines

touch but do not overlap, $p \approx 0.01$. This feature supports quick visual inference without relying on arbitrary p values.

The third major form of graph is a conventional time series graph. In these graphs the horizontal axis represents time values (such as thousands of years) and the vertical axis represents a value that is being examined for change over time (for example, Figure 6.8). A variety of common bar, line and dot charts are also used throughout.

Quantifying lithic reduction

Numerous studies have documented general measures of core reduction in assemblages showing that core reduction exerts considerable influence upon various attributes of lithic assemblages (Dibble et al. 1995). Analysis of Eurasian assemblages show that as core reduction increases, the number of blanks per core and extent of core preparation also increase (Bar-Yosef 1991, Marks 1988, Montet-White 1991). Similarly, as core reduction increases in Eurasian assemblages, average core size, flake size, flake platform area, and cortex area on the cores and flakes decrease (Henry 1989, Marks et al. 1991, Newcomer 1971). Studies of Hoabinhian assemblages make limited use of these general indicators of core reduction intensity (Reynolds 1989, 1992, Shoocongdej 2000, White and Gorman 2004). These indicators are used only as assemblage descriptors while the overall assemblage interpretation is still based on typological analyses (Shoocongdej 1996b). The limited use of these core reduction indicators in Hoabinhian assemblages may be because there has been little experimental work to demonstrate their relevance.

In addition to measuring core reduction, a variety of methods have been developed for quantifying flake reduction for assemblages around the world (Clarkson 2002, Dibble 1987, Kuhn 1990). These methods are based on flake cross-section geometry, flake retouch perimeter, flake retouch height, flake retouch invasiveness, flake allometry and typological comparisons. These methods have been examined in detail by Hiscock and Clarkson and they conclude that the flake retouch height and invasiveness measurements are the most effective metrics (Clarkson 2002, Hiscock and Clarkson 2005a, 2005b). Unfortunately most of these methods are poorly suited for analysing Hoabinhian assemblages because these assemblages typically have very low proportions of retouched flakes and few or no artefact forms with clear discontinuities in morphology and size (Matthews 1964, Reynolds 1989, 1992, Shoocongdej 1996a, White and Gorman 2004). A customised and standardised method for measuring

reduction in Hoabinhian assemblages would provide the necessary data for comparing relative reduction intensity within and between assemblages from different contexts.

Previous contributions towards understanding Hoabinhian technology

The method proposed here builds on three previously published studies of Hoabinhian lithic reduction. First, White and Gorman (2004) analysed variation in technological variables of flakes from Tham Phaa Can in northwest Thailand. Their study demonstrated that two sequences of flake production could be discerned in the assemblage, and that the conventional assumption of the Hoabinhian as an amorphous technology requires rethinking. White and Gorman's study is significant because it is the first to consider the analytical potential of Hoabinhian flake technologies rather than core and tool typologies. A second technological study is Reynolds' (1989) analysis of a small assemblage of lithics (n = 385) from Tham Khao Khi Chan rockshelter in southern Thailand, where he produces a typology based on technological attributes of flakes and cores. He makes some brief observations about the ratio of cores to flakes and flake dorsal cortex types (primary, secondary and tertiary) as indicators of reduction intensity. The main limitation of these two studies is that they do not supply an interpretative framework to link the descriptions of flake technology to an explanation of human behaviours.

In his comparison of core and flake attributes from two cave assemblages from northern Vietnam, Nishimura (2005) similarly focuses on the technological attributes of flakes. He arbitrarily defines a series of flake attributes as indicators of expedient or curated assemblages and interprets assemblage variation as a direct reflection of frequency of site use. The more expedient assemblage (Bung rockshelter) is interpreted as a temporary camp and the more curated assemblage (Xom Trai) as a base camp that was more frequently visited. Nishimura suggests that the intensity of site use may be explained by the environmental context of the sites, since he considers Xom Trai to be in an ecologically richer location than Bung rockshelter. This interpretation associating expedient technology with low frequency of site occupation is difficult to reconcile with ethnographic and ethnoarchaeological work indicating that expedient artefacts are usually associated with longer durations of site occupation (Kelly 1995, Parry and Kelly 1987) and the provisioning of places rather than of mobile individuals (Kuhn 1995).

An experimental approach to quantifying Hoabinhian reduction

These descriptions of previous studies suggest that there is still a pressing need for robust measures of Hoabinhian assemblage reduction. Shocoongdej (1996a) has noted that the lack of systematic lithic production experiments using river cobble material in Southeast Asia makes it difficult to measure assemblage reduction with confidence. In an attempt to help assuage this problem, the experiment described here was designed, following Amick et al. (1989), with two objectives in mind. First, to observe how a large number of flake variables change over the course of core reduction, and second, to identify the most responsive variables for use in archaeological analysis.

A simple experiment was designed to record changes in 28 metric and technological variables of flakes struck by the author from 30 river cobbles by hard-hammer percussion. Cobbles of a variety of different sizes and shapes were collected from the Lang River, adjacent to the Tham Lod rockshelter archaeological site in northwest Thailand (Shoocongdej 2004). The raw materials of the cobbles were orthoquartzite (n = 25), sandstone (n = 3) and andesite (n = 2). These raw materials have similar mechanical properties and were not separated for analysis. Detached pieces over 5 mm with unambiguous positive scars (having evidence of a bulb of percussion or bending initiation) were recorded as flakes. The order of each flake was recorded as they were struck and flaking continued until flakes could no longer be detached using freehand percussion. Although the cores are not discussed here, core mass was recorded after each flake detachment and the final state of the core was also recorded.

The experimental cobble reduction was carried out in order to create a variety of typical Hoabinhian typological forms (cf. Colani 1927, Forestier et al. 2005), simulating a range of possible reduction sequences, until the cobble could no longer be held for flaking. Although it is difficult to generalise about typical Hoabinhian assemblages because the number of well-described assemblages is small and many pieces are unretouched and amorphous (especially flakes), they have historically been characterised by the presence of sumatraliths (ovoid cobbles flaked unifacially and invasively around the entire circumference), short axes (sumatraliths broken along the short axis of the cobble) choppers (ovoid cobbles flaked unifacially and invasively along half of its circumference following the long axis of the cobble) and other variations of unifacially flaked cobbles. Bifaces are rare in Hoabinhian assemblages from mainland Southeast Asia but they have been described from the Malay Peninsula

and island Southeast Asia (Bulbeck 2003). To date there is no convincing evidence of systematic reworking of retouched tools and the preparation of core forms for standardised products in Hoabinhian assemblages.

This experiment was undertaken at the same time and place as the collection of data from the stone artefact assemblage at Tham Lod (described in chapter eight), so the experimental flaking was modelled on the range of cores and flakes found in this archaeological assemblage as well as those described in publications of other sites (e.g. Forestier 2000, van Heekeren and Knuth 1967). Moser (2001) observes that Hoabinhian flakes are produced by hard hammer percussion, so cobbles were used here as hammerstones. After a core was completely reduced, every flake was given an individual percentile ranking reflecting its position in the sequence of all flakes removed from that core. To analyse the data, flakes from all 30 cores were ordered together by their individual percentile ranking and then arbitrarily divided into ten ranked classes to form a continuum of reduction intensity from early reduction (1) to late reduction (10). This means that all cores and therefore a variety of reduction sequences contributed flakes to each of the ten ranks of the reduction intensity continuum. The raw data from this experiment are available by contacting the author via the Department of Archaeology and Natural History, Research School of Pacific and Asian Studies, The Australian National University.

Results of the experiment

The thirty cobbles produced a total of 625 flakes and 159 flaked pieces. The average number of flakes per cobble is 21 with a maximum of 72 and most cobbles producing less than 30 flakes (Figure 5.1, Figure 5.2). Figure 5.2 shows two modes in the distribution of the numbers of flakes per core. The first mode indicates that most cores produced less than the average number of flakes, with 11 cores producing between two and eleven flakes. A second mode occurs at about 36 flakes per core. The two cores producing 66 and 72 flakes each are considered to be outliers.

As a first step to understanding how flake morphology and attributes vary through the reduction sequence, a series of basic attributes are examined here. A simple model of reduction intensity of flaked cobble assemblages can be employed to generate predictions about which variables are most likely to reflect reduction. The geometry of the ovoid cobbles typical of Hoabinhian assemblages suggests that variables relating to dorsal cortex and dorsal flake scars are likely to have simple linear or curvilinear

relationships with reduction intensity. Interior platform angle and overhang removal are also likely to be related to reduction because they are sensitive to the size and inertia of the core. Flake mass is unlikely to correlate with reduction intensity because the oblate spheroid geometry of the cobbles will probably result in short early reduction flakes made by acute, glancing blows on the perimeter of the cobble, followed by mid-reduction flakes that are as long as the maximum thickness of the cobble and finally followed by late-reduction flakes that are small because most of the mass of the cobble has been already removed. The following analyses test these predictions of this simple model.

Mass

Flake mass is used as a general measure of flake size and has been observed as a reliable indicator of reduction for biface manufacture (Amick et al. 1988, Magne and Pokotylo 1981). For this experiment, flake mass does not significantly vary according to the extent of reduction (r = 0.017 [-0.036, 0.071]) and is not a useful reduction indicator. Maudlin and Amick (1989) also observed that size variables were poor indicators of reduction and suggested it was probably because of the small flakes that are continuously produced throughout the reduction process. In this case the oblate spheroid model appears to be a good explanation of the distribution of flake lengths.

Overhang removal

Overhang removal (OHR), also known as platform trimming or platform preparation, is defined here as the presence of a series of overlapping small (an arbitrary scar length of <15 mm is used here) step-terminated flake scars initiated from the platform surface onto the dorsal surface of a flake (Clarkson and O'Connor 2005). These scars are often interpreted as the removal of a lip left on the platform by earlier flake removal and are presumably generated to maintain a certain core morphology for the predictable removal of flakes as core size decreases and platform angles increase (Clarkson and O'Connor 2005). In this case however OHR was also noted to occur as a result of accidental platform edge shattering as well as platform maintenance, suggesting that it results from both intentional and unintentional behaviours. As predicted, this experiment shows a strong and significant positive correlation between the presence of OHR and increasing intensity of cobble reduction (r = 0.892 [0.698, 1.085] Figure 5.3).

Interior platform angle

As suggested by the model, the increase in the percentage of flakes with OHR is probably a result of shifting core geometry and size as flake removal progresses. Interior platform angle (IPA) was measured on flakes as the angle between the striking platform and the ventral surface with a goniometer. Despite a number of studies of platform angles showing that it is difficult to measure reliably (Dibble and Bernard 1980), in this experiment there is a significant correlation between IPA and extent of reduction (r = 0.307 [0.231, 0.368]). The IPAs of the early reduction flakes are typically less than 90° and then in the later stages of reduction the values cluster around 90-100° (Figure 5.4). The 90-100° values are probably asymptotic because it is difficult to remove flakes at higher angles without risking aberrant hinge and step terminations that alter the morphology of the core's free face and reduce its useful life (Macgregor 2005, Whittaker 1994). An interesting result of this experiment is that the increasing percentage of OHR and the increasing IPA appear to be directly linked. Increases in flake IPA result in more acute platform angles on the core, creating lips on the platform that are removed when the core is prepared for another flake removal, leaving traces of OHR.

Percentage of dorsal cortex

The amount of cortex (the skin on the outer surface of the cobble formed with chemical or mechanical weathering) on the dorsal surface of a flake is another important indicator of an assemblage's extent of reduction (Cowan 1999, Morrow 1984, Odell 1989). The popularity of this variable is based on the simple assumption that flakes with a high percentage of cortex come from the outer surface of the core and once that outer surface has been completely removed, all subsequent flakes will be noncortical. Thus, the model predicts that the more extensive the core reduction, the higher the proportion of noncortical flakes in an assemblage (cf. Dibble et al. 2005). In this experiment the percentage of flake dorsal cortex (measured in intervals of ten percent for each flake) is significantly correlated with the extent of cobble reduction (r = -0.491 [-0.551, -0.429]). The mean percentage of dorsal cortex for the experimental assemblage is 25% and the standard deviation is 32%. Although there is a good statistical correlation for the overall reduction sequence, Figure 5.5 shows that dorsal cortex is most sensitive to variation in the early stages of core reduction. In the later half of the reduction process the average percentage of dorsal cortex is low but the small variation

between the later stages suggests the influence of some stochastic effects. These results support the predictions of the model and corroborate those of earlier studies suggesting that cortex percentage is most useful as an indicator of early reduction (Dibble et al. 1995, Dibble et al. 2005, Magne and Pokotylo 1981, Mauldin and Amick 1989).

Dorsal flake scars

Closely related to the percentage of dorsal cortex is the number of flake scars on the dorsal surface of flakes. In this experiment the number of flake scars per flake ranged from 0 to 8 with a mean of 1.72. The number of dorsal flake scars per flake is significantly correlated with reduction intensity (r = 0.308 [0.239, 0.377], Figure 5.6). However, Maudlin and Amick (1989) note that dorsal flake scars can also be highly correlated with flake size and in this case the correlation with flake mass is stronger (r = 0.424 [0.344, 0.503]) than the correlation with reduction intensity. On the other hand, there are weak but significant correlations between standardised numbers of flake scars per flake and reduction intensity (standardised by dividing by mass or by flake surface area, mass: r = 0.193 [0.125, 0.261], flake surface area: r = 0.293 [0.221, 0.360]). Figure 5.6 suggests that this variable becomes asymptotic as reduction increases, probably because the constant size of flakes limits the maximum number of visible flake scars to about two. These results provide only equivocal support for the model's predictions, suggesting that the number of dorsal flake scars may be a less reliable indicator of reduction intensity than the other variables discussed here.

Dorsal cortex location

Nishimura (2005) has suggested that the location of dorsal cortex in flakes in Hoabinhian assemblages in northern Vietnam may indicate stages of tool making. He noted that early stages are characterised by flakes with 100% dorsal cortex (primary flakes) and flakes with a crescent-shaped distribution of dorsal cortex (cortex extending from the platform, around one margin and contacting the distal end). He notes that the later stages of 'resharpening or otherwise rejuvenating an edge [on a core tool]' results in flakes with cortex on the distal end of the flake and flakes without any dorsal cortex (tertiary flakes) (cf. Jeremie and Vacher 1992, Nishimura 2005). This cobble reduction experiment demonstrates that Nishimura's four classes (Figure 5.7) are an exhaustive classification because they describe more than 98% of flakes (Figure 5.8).

Cortex location has been used to distinguish between multidirectional core reduction, bifacial reduction and dart production (Tomka 1989) but does not appear to have been systematically investigated as an indicator of reduction intensity. This experiment shows that numbers of flakes with 100% cortex and crescent patterned cortex significantly decrease as reduction continues while numbers of flakes with distal cortex and no cortex increase significantly (Table 5.1). Table 5.1 also shows that the four classes are relatively insensitive to flake size, making them more reliable indicators of reduction than counts of dorsal flake scars. Figure 5.9 shows how the majority of flakes change from primary to tertiary very early in the reduction process, supporting the earlier observation that major changes in dorsal cortex occur during the early stages of reduction. The important detail in this figure is that it shows the middle stages of reduction can be identified in the region with <10% crescent-pattern flakes and >20% distal-patterned flakes. The usefulness of these two flake classes as indicators of mid-reduction is also indicated by their good correspondence with two other reliable indicators of reduction intensity, dorsal cortex percentage (Figure 5.10) and IPA (Figure 5.11).

The reason that these flake classes are good indicators of reduction is probably because unifacial cobble reduction typically begins with removal of primary and crescent-patterned flakes as flakes are removed from the circumference of the cobble, followed by the appearance of distal-pattered flakes as flake removal begins to overlap previous scars around the circumference of the cobble and invade towards the centre of the cobble. Distal-patterned and tertiary flakes become more abundant when flake removal is increasingly invasive and core rotation increases so that flake scars intersect with previous scars.

Although this four class system has yet to be used to interpret any archaeological assemblages, it can be shown to have some advantages over other methods of recording dorsal cortex. Firstly, the four class system has stronger correlations with reduction intensity (Table 5.1) and weaker correlations with flake size than the popular primary-secondary-tertiary system (secondary flakes and reduction intensity: r = -0.232 [0.161, 0.303], secondary flakes and flake mass: r = 0.265, [0.200, 0.341]).

Secondly, Sullivan and Rosen (1985) note that the primary-secondary-tertiary system is problematic because of false assumptions and inconsistent definitions across different analysts. Although all the analyses presented here were undertaken by a single person,

the wider utility of this method for other analysts and projects with multiple analysts can be evaluated by an inter-observer error experiment. To assess the level of inter-observer reliability available with the four flake classes a series of simple blind tests were undertaken. Ten people with a range of experience in lithic analysis classified thirty flakes into the four cortex classes plus an 'other' category. Their results were compared to the author's and the average difference was 10.6%. Two of the more experienced participants had no errors in their classification, suggesting that with more training and familiarity, error levels can be very low or zero. These results mean that inter-observer error in the use of these four classes is relatively low (cf. Clarkson 2002) and unlikely to be greater than other measurements (Fish 1978).

Finally, the distal cortex class provides valuable resolution for the later stages of the reduction process. Although flakes with distal cortex have a low correlation with overall reduction (Table 5.1), they are useful markers of intensive reduction because they are most abundant in the second half of the reduction process, compared to tertiary flakes that become abundant relatively early in the reduction process. This feature of the distal cortex flakes is especially relevant in assemblages where flakes are transported out of the assemblage or partially worked cores are introduced and reduced further so that the proportions of primary and tertiary flakes no longer accurately represent the extent of reduction occurring at the site.

Cores

The initial masses of the 30 cores ranged from 190 g to 1737 g with an average mass of 735 g. The final masses ranged from 92 g to 1040 g with a mean of 316 g. The percentage mass lost during flaking ranged from 5% to 81% with a mean of 54%. There is a moderate positive correlation between initial nodule mass and final core mass (r = 0.673, [0.413, 0.932]). This suggests that although the end points of the cores were determined by when they could no longer be held for flaking, this quality is not readily identifiable as a threshold minimum core mass (which would be expected to produce a distribution with most points close to an asymptote). It is likely that in addition to an inertia threshold below which the material is not suited to freehand reduction – in this case probably at about 100 g – the geometry of the core also influences core use-life duration.

As expected, larger cores tend to produce more flakes. However initial core mass appears to have only weak positive correlations with the amount of flakes produced,

with the correlation between initial nodule mass and flake count at $r = 0.488$ [0.102, 0.875]. The correlation between final core mass and flake count is 0.162 [-0.176, 0.502], suggesting that final core mass is a poor indicator of the productivity of the core prior to discard. Similarly, change in core mass is weakly correlated with flake productivity ($r = 0.162$ [-0.166, 0.503],). Change in core mass is also weakly correlated with initial core mass ($r = 0.254$ [-0.132, 0.641]). These consistently weak correlations suggest that final core mass gives little insight into the life of the core before discard (cf. Braun et al. 2005). This highlights the importance of data from flakes in accurately understanding lithic reduction in Hoabinhian assemblages.

Discussion

This experiment was designed to reproduce the particular qualities of Hoabinhian assemblages, especially the unifacial circumferential, centripetal reduction of ovoid cobbles (Forestier 2000). The results presented here support the predictions of a simple model of assemblage reduction and suggest that there are a number of simple technological attributes of flakes that are robust indicators of the intensity of reduction in Hoabinhian lithic assemblages. Analysis of the experimental data showed that the most important variables for measuring reduction intensity are the presence of overhang removal, interior platform angle and percentage of dorsal cortex. These attributes have the advantages of being well understood and widely used by lithic analysts as well as being easily recognisable, allowing rapid and accurate data collection. In addition to these familiar attributes a new method of classifying flakes according to dorsal cortex location has been proposed. This new method was shown to be similarly useful for measuring assemblage reduction intensity and its reliability is demonstrated by relatively low inter-observer error.

A further advantage of the attributes discussed here is that they can be used to produce summary ratios describing an assemblage for comparison with other assemblages. These ratios represent a continuous measurement of assemblage variation without imposing arbitrary stages or events onto the reduction process. Summary ratios of flake attributes can be used to describe the extent of cobble reduction even when cores have been removed from the assemblage.

Limitations and potential sources of error

One possible objection to this interpretation of the strong correlations of reduction with the key flake variables is the problem of multicollinearity. Multicollinearity occurs when two or more independent explanatory variables in a model have strong linear correlations. The presence of multicollinearity is a problem because collinear variables contribute redundant information and can cause other variables to appear to be less important than they really are. Multicollinearity also makes it difficult or impossible to reliably estimate their individual correlation values. For example, it could be possible that there is a strong negative correlation between the percentage of dorsal cortex and the number of dorsal flake scars. This might occur because higher numbers of flake scars are likely to remove a greater area of the dorsal surface than smaller numbers of flake scars on the same sized flake. However, it is also possible that large numbers of small flake scars will remove less dorsal cortex than one or two large flake scars. Figure 5.12 shows the correlations between four of the key flake variables described above. The relatively low correlations between the variables, compared to their correlations with reduction intensity stages described above, suggest that multicollinearity is not a problem here. This interpretation is supported by a more formal measure of multicollinearity, the variance inflation factor (VIF). The VIF is a scaled version of a multiple correlation coefficient between one variable and the rest of the independent variables (Neter and Wasserman 1996). For the four variables in Figure 5.12, the VIFs are overhang removal = 1.072, interior platform angle = 1.191, dorsal scars = 1.272 and dorsal cortex = 1.137. Variance inflation factor values of 30-100 are considered to indicate moderate to strong collinearities (Belsley et al. 2004, Velleman and Welsch 1981). These low VIF values confirm that multicollinearity is not a problem in this analysis.

As an additional demonstration of the usefulness of these variables as independent measures of reduction, it is possible to show that these variables are roughly similar in their sensitivity to reduction intensity. Table 5.2 shows the Z-score transformations for the maximum and minimum values of each of those four variables in the ten reduction levels. Z-scores were calculated with a simple standardising transformation that subtracts the sample mean from each data point and divides the result by the sample standard deviation. The result is set of dimensionless values that indicate the standardised deviations from the sample mean (Abdi 2006). The main advantage of the Z-score is its dimensionless quality, enabling meaningful comparison between

variables with different measurement units such as numbers of dorsal flake scars and interior platform angle. The table shows the range of each of those four variables in terms of standard deviations, illustrating the spread or variability of values for each variable. The maximum variability here is about 1.5 to 2 standard deviations with none of the variables showing unusually high or low variation. This suggests that these variables are roughly equivalent in their sensitivity to change as reduction intensity changes.

Shott (1996) has noted that it is not easy to design experiments that depict how ancient stoneworking actually proceeded. This experiment has tried to simulate the defining characteristics of Hoabinhian assemblages, such as unifacial, centripetal and circumferential cobble reduction. However, it is likely that Southeast Asian lithic assemblages represent a range of raw material procurement and core reduction strategies (Forestier et al. 2005, White and Gorman 2004). Until future work describes these different reduction strategies we cannot know how well this experiment approximates the range of variation in the Hoabinhian. Nevertheless, most of the variables identified here are reliable indicators of reduction in a range of technological systems, including biface manufacture, so the variation within Hoabinhian technologies is unlikely to compromise the robustness of these measures. Finally, taphonomic and recovery processes will influence assemblages in complex ways that may influence inter- and intra-site comparisons of the technological variables discussed here. Breakage of flakes may distort the proportions of complete flakes representing different stages of reduction in ways that are difficult to discern from the recovered archaeological assemblage. This highlights the need for detailed descriptions of deposits and excavation methods to accompany the interpretation of lithic assemblages.

Summary

This chapter has completed the link from a general theory of understanding the relationship between humans and their environment via flaked stone artefacts. A series of definitions have been provided to support a nominalist classification of an assemblage. A review of statistical methods indicated that computer-intensive resampling techniques are best suited to analysing lithic assemblages where a theoretical distribution cannot be assumed to accurately represent the distribution of variables in the assemblage. Confidence intervals were argued to be an appropriate

method to evaluate differences in the central tendancies of variables. Incidently, for the article describing this experiment published in the *Journal of Archaeological Science* all of the regression results were presented with conventional *p* values rather than bootstrapped confidence intervals, because of the relative unfamiliarity of resampling methods. In this case the outcomes were the same, but it argued there that resampling methods have stronger support from theory when analysing stone artefacts. Analysis of the experimental assemblage identified five key attributes for measuring assemblage reduction intensity, as a proxy for energy invested in risk reduction. These are: overhang removal, interior platform angle, dorsal cortex, dorsal flake scars and the distribution of dorsal cortex. An unexpected finding was the insensitivity of core attributes to changes in reduction intensity. This suggests that flake attributes are the most reliable and valid indicators of reduction and core attributes. These methods will be used to analyse the assemblages from the two sites described in the next chapter.

Figure 5.1. Artefacts from the experimental assemblage. Top row: two unifacially flaked cores. Bottom row: view of dorsal surfaces of two flakes.

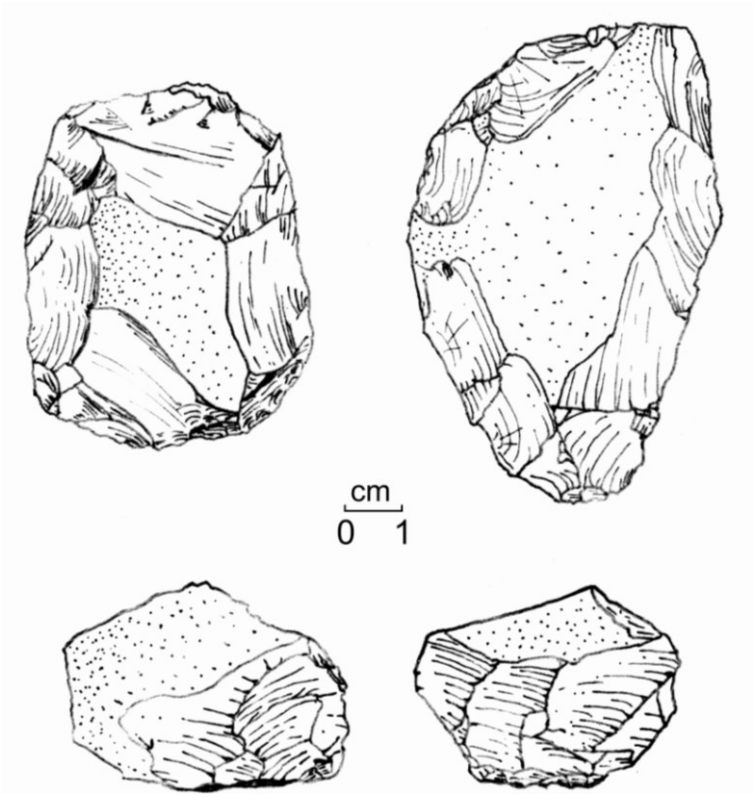


Figure 5.2. Frequency distribution of flakes per core in the experimental assemblage.

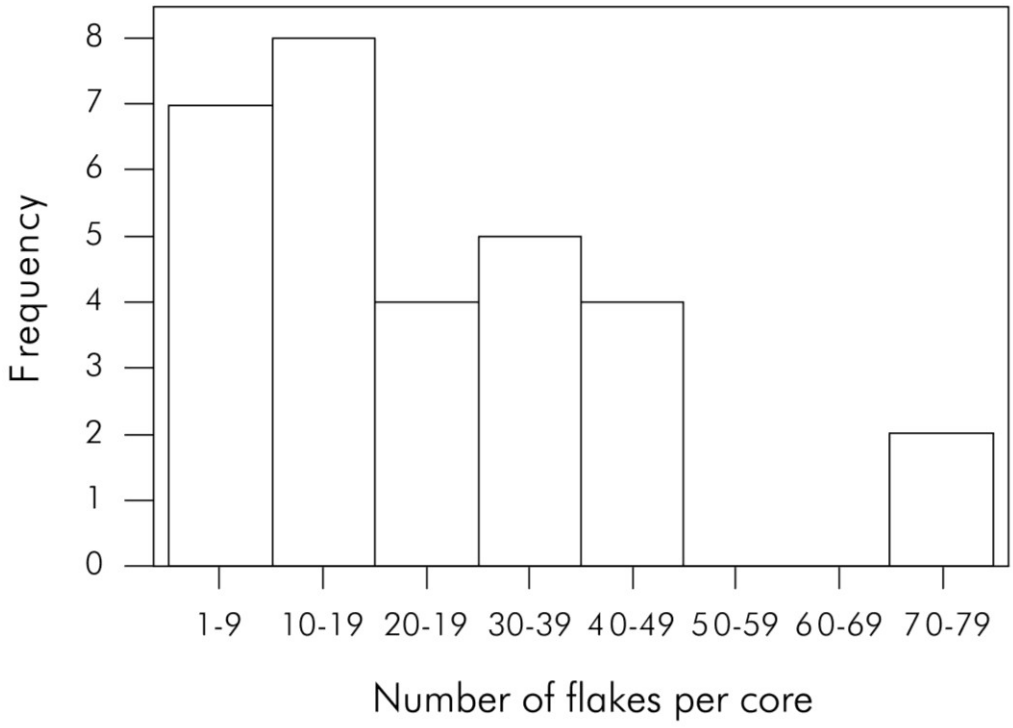


Figure 5.3. Plot of changes in the mean proportion of flakes with overhang removal and increasing reduction. Error bars show 95% Confidence Interval of mean.

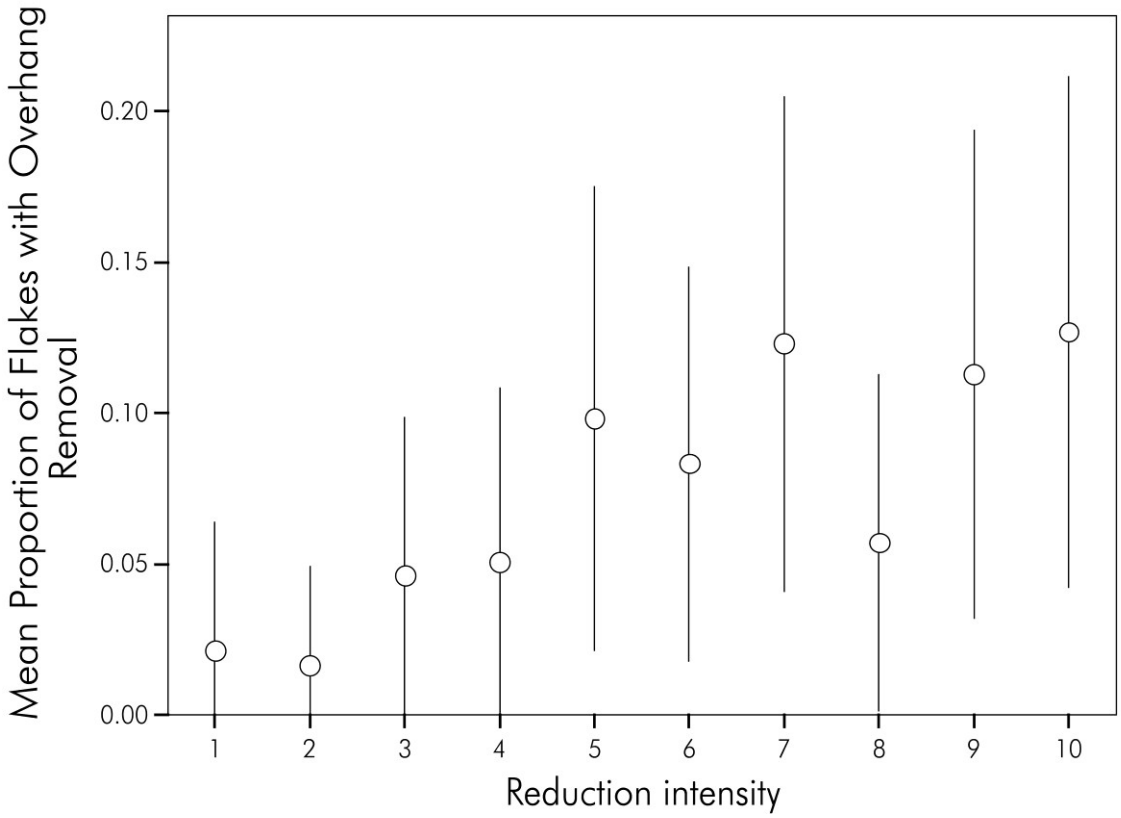


Figure 5.4. Plot of changes in mean flake interior platform angle with increasing reduction. Error bars show 95% Confidence Interval of mean.

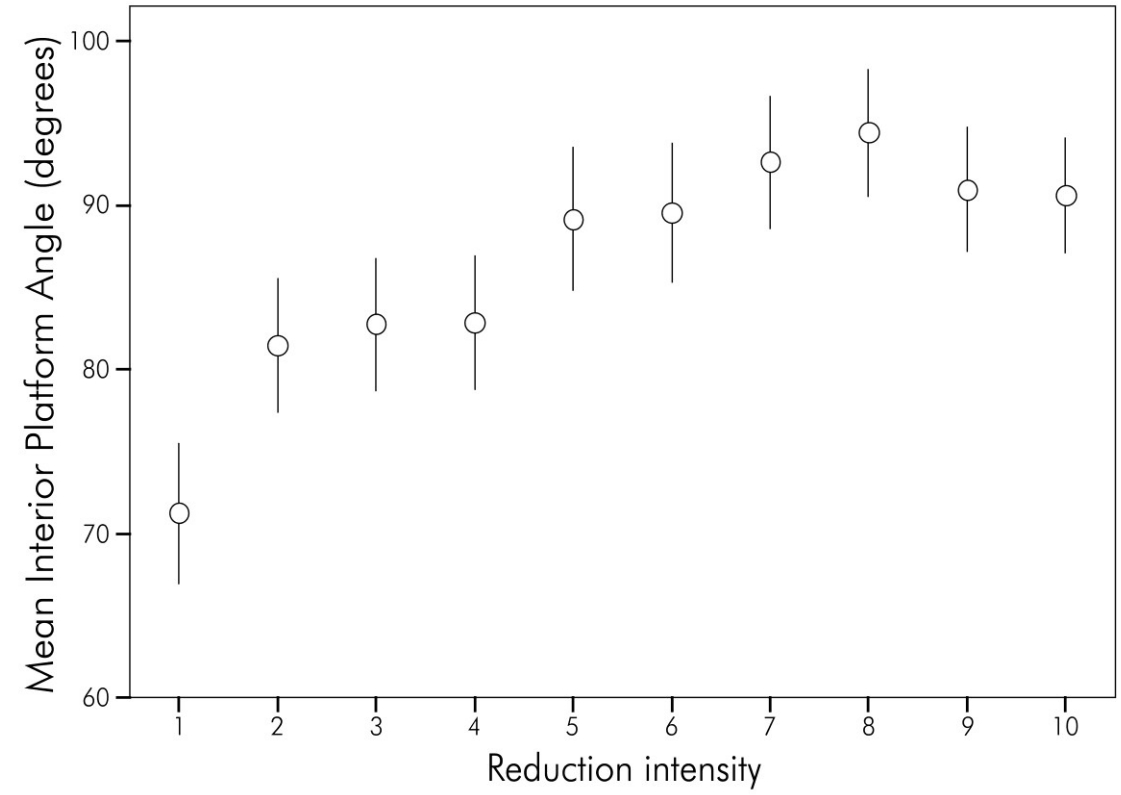


Figure 5.5. Plot of changes in mean percentage of flake dorsal cortex with increasing reduction. Error bars show 95% Confidence Interval of mean.

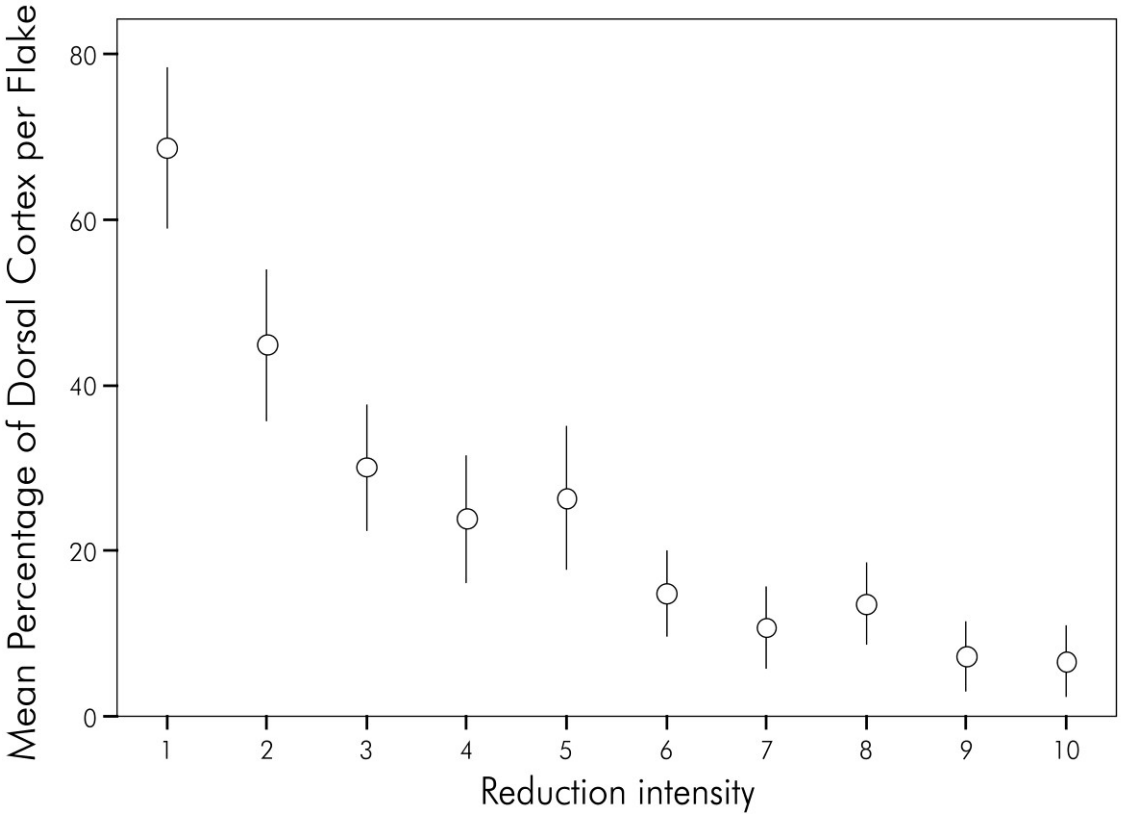


Figure 5.6. Plot of changes in the mean number of flake scars on the dorsal surface on flakes with increasing reduction. Error bars show 95% Confidence Interval of mean.

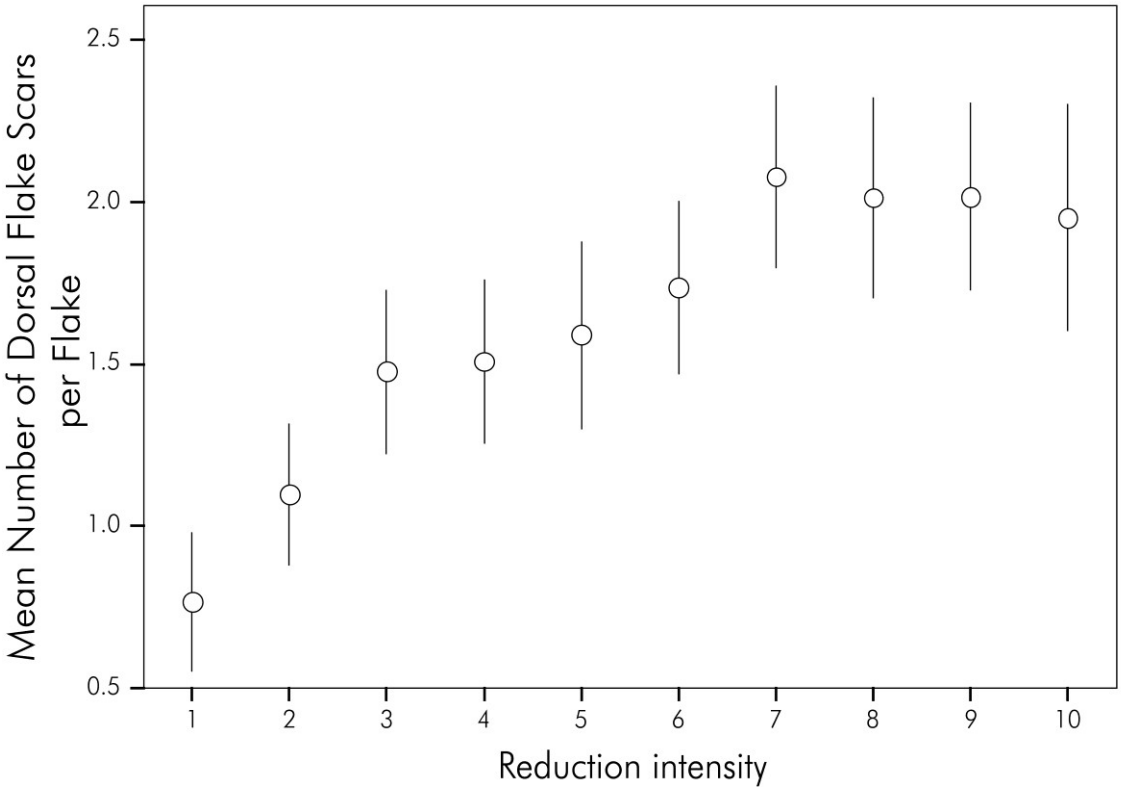


Figure 5.7. Four classes of dorsal cortex location identified by Nishimura (2005). Modified from Jeremie and Vacher (1992).

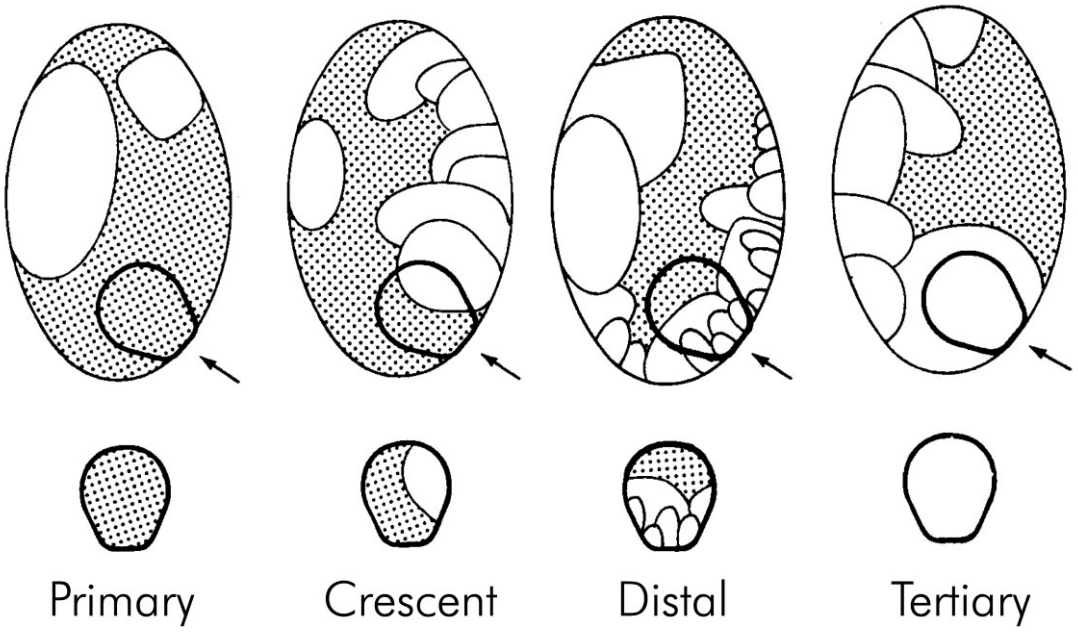


Figure 5.8. Frequency distribution of the four classes of dorsal cortex location.

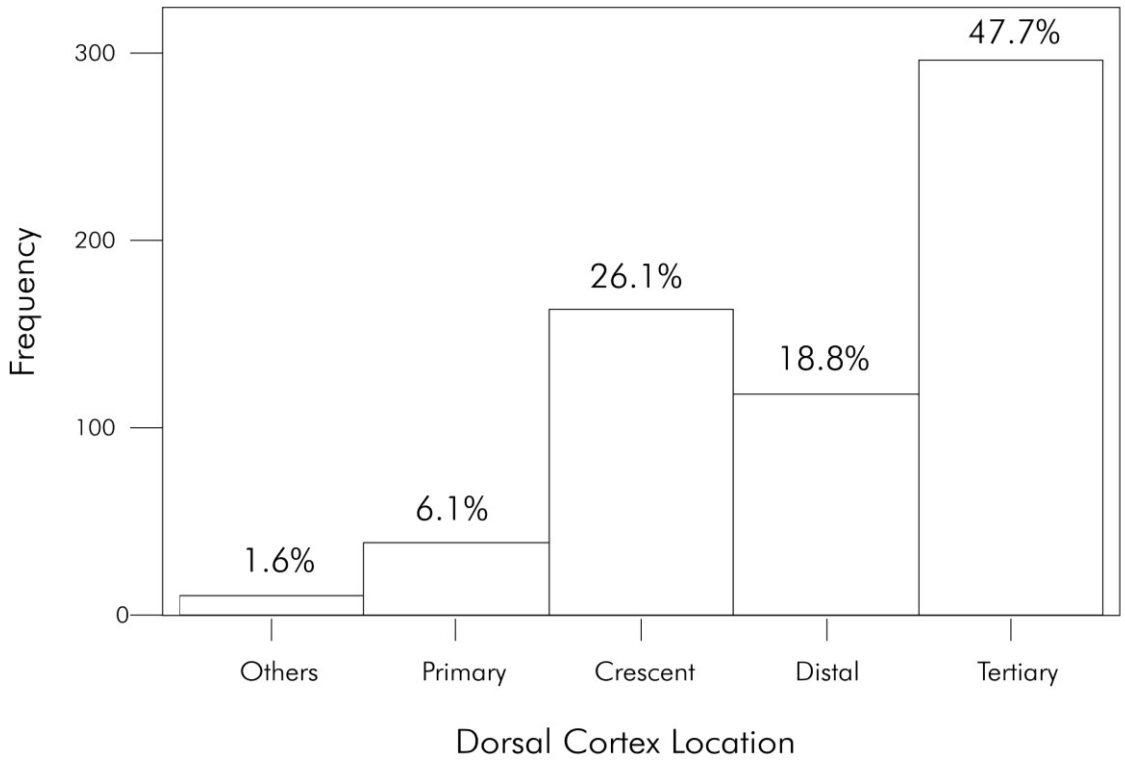


Figure 5.9. Changes in the proportions of the four classes of dorsal cortex distribution with increasing reduction.

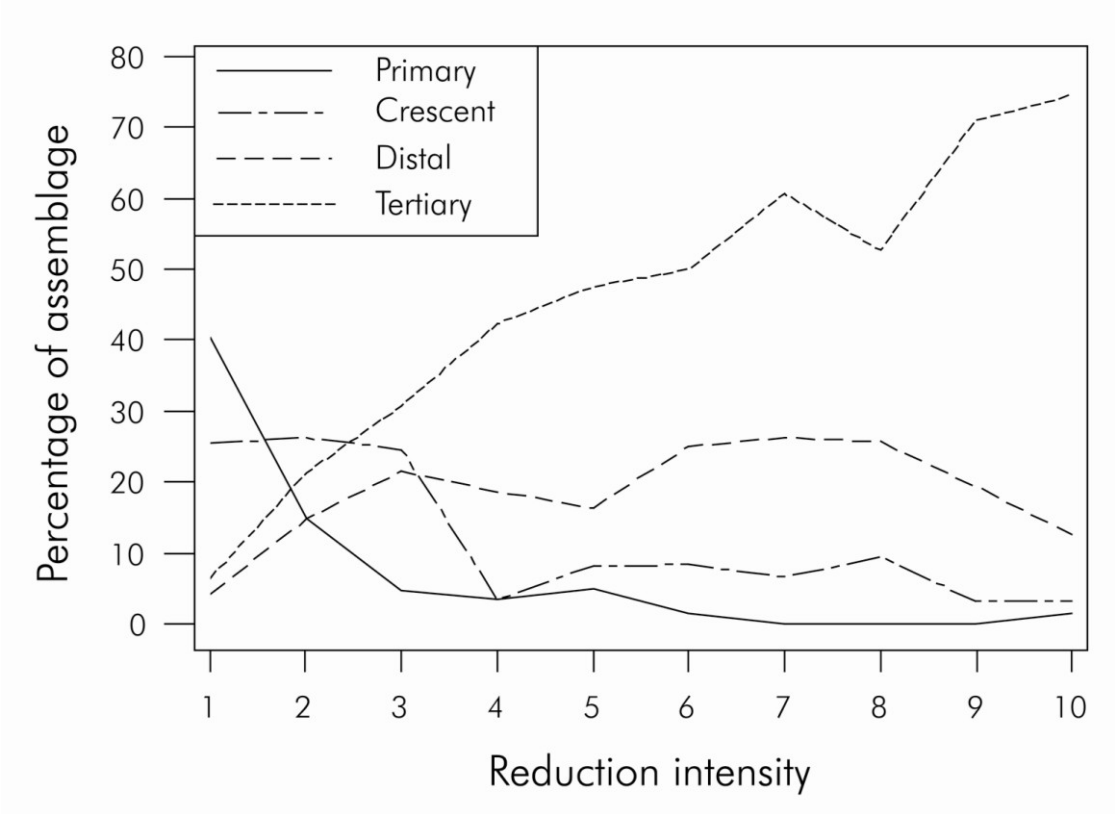


Figure 5.10. The relationship of dorsal cortex location to percentage of dorsal cortex. For example, for all flakes that have 10% dorsal cortex, 80% of those flakes have that cortex located on the distal region.

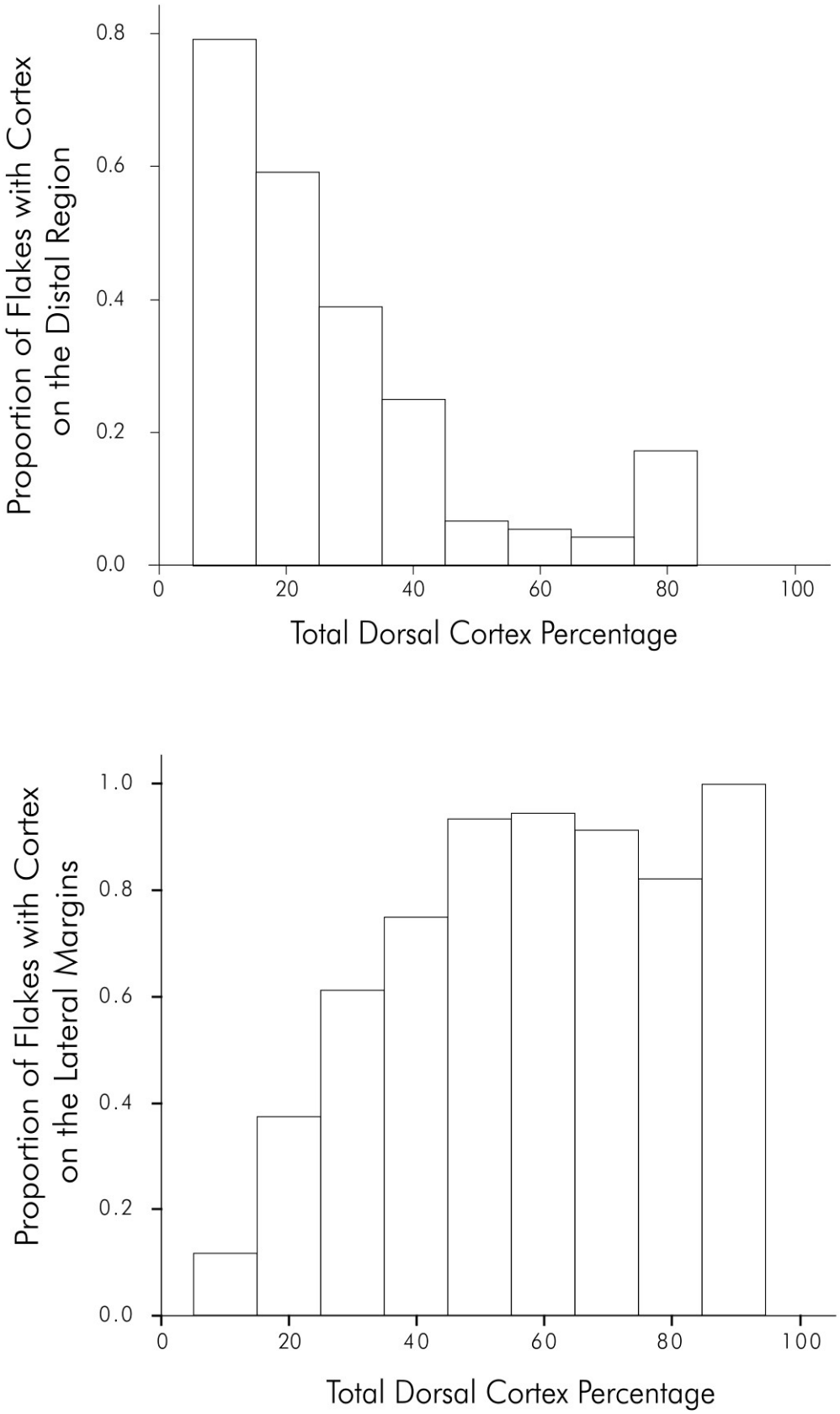


Figure 5.11. The relationship of dorsal cortex location to interior platform angle. For example, for all flakes that have an interior platform angle of 40 degrees, 40% of those flakes have 100% dorsal cortex.

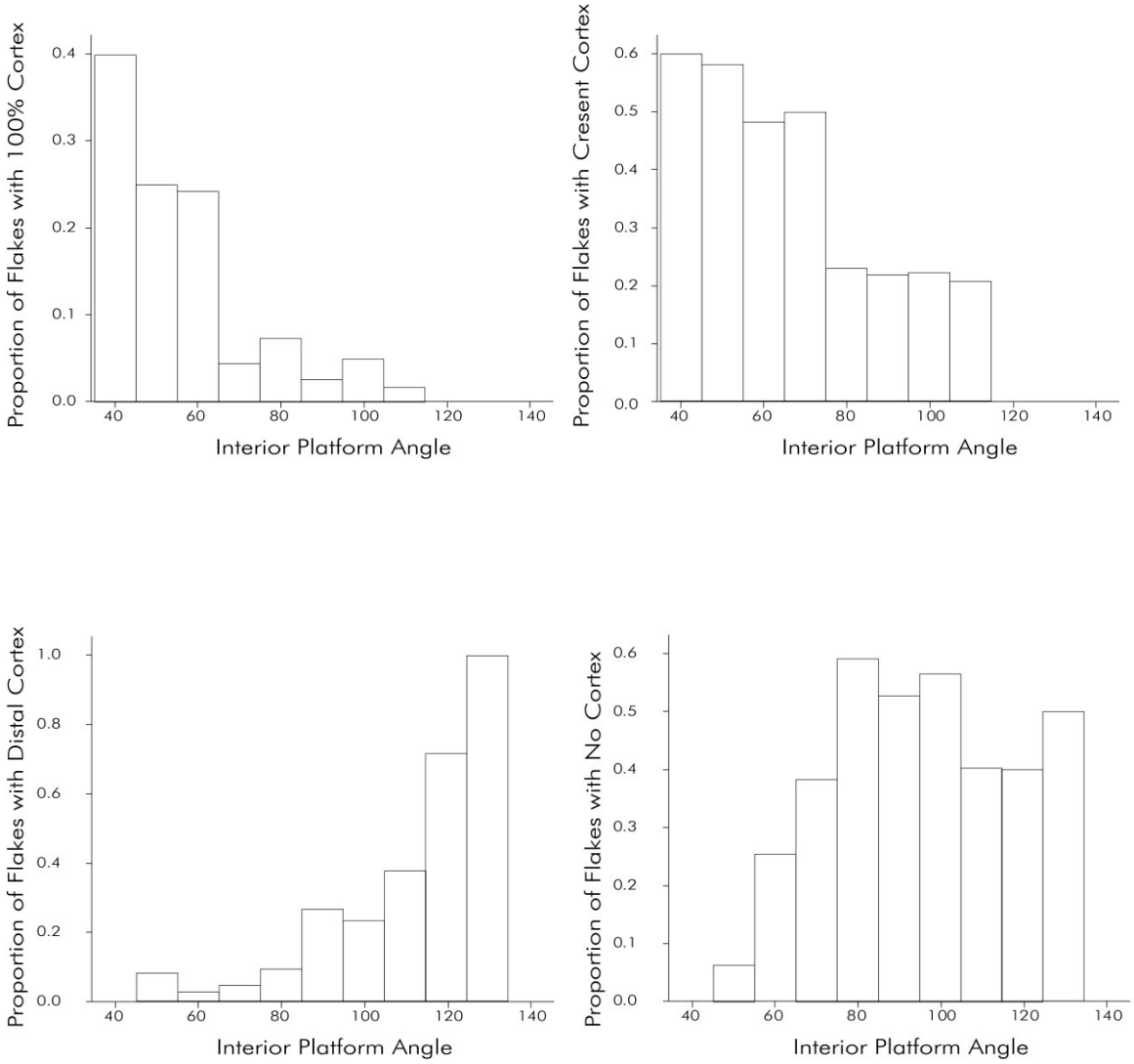


Table 5.1. Correlations of four classes of dorsal cortex location with reduction intensity and flake mass. Confidence intervals that include zero indicate a correlation that is not statistically significant.

Class	Reduction Intensity	Flake Mass
100% Cortex	-0.349 [-0.418, -0.281]	0.015 [-0.054, 0.085]
Crescent	-0.319 [-0.399, -0.238]	0.056 [-0.026, 0.139]
Distal	0.101 [0.019, 0.181]	0.287 [0.192, 0.382]
No Cortex	0.373 [0.296, 0.451]	-0.271 [-0.316, -0.225]

Figure 5.12. Scatterplot matrix showing correlations for four of the key flake variables in the experimental assemblage. Data points have been jittered to reduce overlapping. Jittering involves the addition of a small amount of random data to each point to reduce overlapping where many points have the same value.

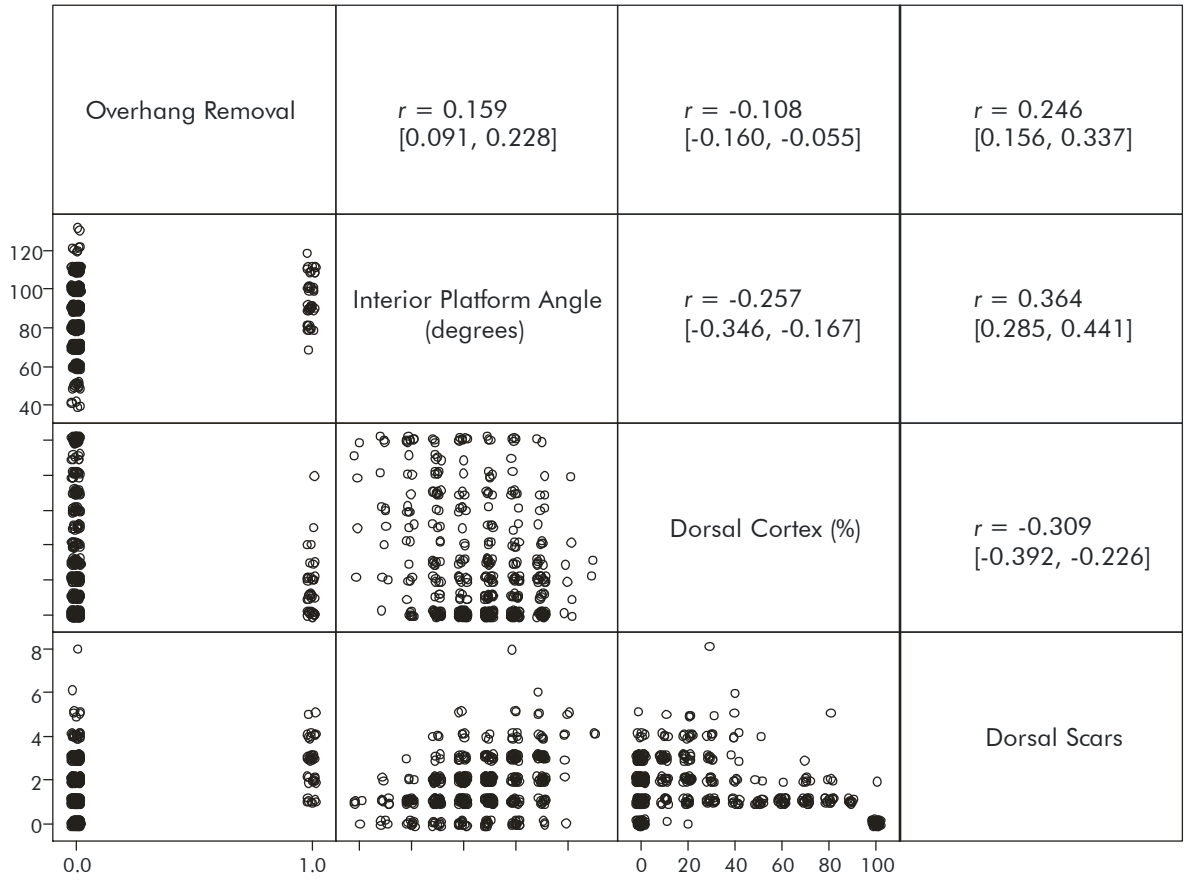


Table 5.2. Spread or variability of values for each variable, measured in standard deviations.

	Interior Platform Angle	Dorsal Cortex (%)	Overhang Removal	Dorsal Scars
Z-score maximum	1.16	2.25	1.30	0.99
Z-score minimum	-2.18	-0.93	-1.45	-1.99

6. The Sites and their setting: Ban Rai and Tham Lod

Introduction

The previous three chapters have outlined the analytical approach that is being employed in this project. A framework based in human behavioural ecology has been established and links have been made down to the specific attributes to be measured on the stone artefacts. In this chapter some of the specific ecological qualities relevant to analysing the assemblages are reviewed. Winterhalder (1980) has argued that when testing hypotheses about ecological adaptation it is necessary to go beyond normative descriptions that gloss over spatial heterogeneity and temporal fluctuations. The aim of this chapter is to go beyond normative description and identify the particular constraints and opportunities relevant to human foragers that derive from the physical environment of the study area. It will describe the current landscape and climate in terms of a habitat for human foragers. These habitat variables are used to build testable hypotheses from the models presented in chapter three. The relevance of this current information is based on the assumption that differences between modern and past conditions are largely related to range and distribution of modern taxa and water sources, with minor changes in taxonomic composition and geomorphology, rather than major taxonomic turnovers and catastrophic geomorphological shifts. The current climate and resource parameters are discussed in order to set the stage for reconstructing the past conditions of prehistoric hunter-gatherers' habitats. Chapter seven then discusses the history environmental conditions in more detail.

Overview of the Region

The Study Area

Although the two rockshelters examined here are both on the Lang river, activities at these locations are likely to have been influenced by conditions elsewhere in the area that people moved through. To capture some of the variation and diversity that might be typical of the home range of the prehistoric human foraging groups that used the two sites, the study area is expanded beyond the two sites to the boundaries of Pang Mapha District, an area of some 1,120 km^2 (Shoocongdej 2006a). This area is within the range of variation for total areas of forager mobility (Kelly 1995: 114-5) and about half

the area calculated from the movements of the Northern Thai Mlabri foragers by Pookajorn (1985, 1988). Pang Mapha District is located about 150 km northwest of Chiang Mai. It is part of the southern extension of the Shan mountain ranges (Santisuk 1988: 11), which in turn are part of a series of discontinuous limestone outcrops following the north-south alignment of mountain ranges extending from Malaysia to Myanmar (Dunkley 1985). The boundaries to the north and west are shaped by the drainage for the Salaween River which marks the border between Thailand and Myanmar. The south and east boundaries of the district follow long walking paths on high ridges. These ridge-top paths are probably ancient as they are the most effective way to travel in this area because of the abundant rugged peaks, dense valley vegetation and seasonal swelling of rivers that make walking through valleys and across slopes difficult.

The main access to the area today is the highway from Chaing Mai to Mae Hong Son, on which the main town of Soppong is located. Although the district is one of the least populated areas in Thailand, Pang Mapha has a high diversity of ethnic groups, mostly living in isolated small villages that have been established in the last few generations (Kernmel-Torrès 2004). These groups include the Shan, Lisu, Lahu, Karen, Hmong and smaller numbers of other groups. The Shan are the most numerous, as a relic population of the eastern margin of the Shan State. The Shan language is in the Tai-Kadai family and is closely related to Thai. The Shan State is presently a state in the Union of Myanmar that shares the border with Pang Mapha. Before the Thai-Myanmar border was formally determined, Pang Mapha was largely controlled by the Shan State. The Karen also derive from homelands along the Thai-Maynmar border, especially the Karen State, Kayah State and southern Shan State. The Karen language is classified in the Tibeto-Burman group of the Sino-Tibetan family and is not similar to Thai. Most Karen groups in Pang Mapha are refugees from oppressive treatment by the military dictatorship in Rangoon that opposes Karen autonomy within Myanmar. These Karen have settled in Pang Mapha within the last two or three generations. Immigration of Shan and Karen people is continuous in Pang Mapha as people take advantage of the difficulties in controlling the border in the rugged terrain to escape persecution in Myanmar. The Lisu and Lahu are ethnic groups from southern China who speak languages in the Loloish family of the Tibeto-Burman group. They probably arrived in Pang Mapha as part of the diaspora of ethnic minorities leaving south China during the civil unrest in the early days of the Republic of China (i.e. after 1912),

although some may have arrived in earlier migrations during the late Qing Dynasty (1644-1912). The Hmong also trace their origins to southern China and probably arrived in Pang Mapha under similar conditions to the Lisu and Lahu. None of these groups claim any connection with prehistoric remains found in Pang Mapha.

Geology and geomorphology

The uplands of far Northwest Thailand are a formation of hills and mountains with prominent and very steep pinnacles and ridges of limestone (Figure 6.1, Figure 6.2). The geomorphology of this area was examined and recorded during six speleological expeditions conducted over 1983-1986 by members of the Australian Speleological Research Council (Dunkley and Brush 1986). The landscape that contains the two archaeological sites examined here covers an area of about 1000 km^2 which is described as extremely rugged with 47% of the landscape area consisting of slopes over 60% (Dunkley 1985).

The limestone that dominates the landscape is of Permian age and is comparable in lithology and structure to carbonates of similar age in the Sino-Burman mountains (Kiernan 1991b). The folding and faulting that dominates the structural geology trends north-south and dates from the pre-Cretaceous Kimmeridgean Orogeny to the west in the Shan States of Burma. Later epeirogeneric uplift caused the area to become more exposed to erosion and deposition, a process that continued throughout the Tertiary and Quaternary (Kiernan 1991b). Partially as a result of this uplift, the Permian limestone karst currently rises up to 1000 m above the valley floors and accordant summits (possibly representing ancient erosion surfaces) are prominent especially at about 1100 m. Drainage in the karst systems determined the formation of extant caves (as underground streams) and rockshelters (though sinkhole evolution). Even today, drainage is mostly underground and as the landscape has evolved and eroded, numerous deep caves and cliffs have become exposed and left hanging above the valley floor. This drainage is very extensive, with the region containing two of the most extensive underground cave systems known in mainland Southeast Asia. The surface flow of the few waterways in the region is also a feature of the underground drainage, with most streams ending in a drop into a limestone sinkhole. The exposure of cliffs and caves generally accompanies valley incisions into non-carbonate sedimentary rocks that underlie the folded limestone.

Surrounding these karstic features are Quaternary sediments including recent slopewash sediments, rockfall talus and travertine that appear to be the product of relative landscape stability (Kiernan 1991a). Kiernan (1991b) suggests that the current surface sediment deposits largely result from anthropogenic erosion caused by swidden agricultural activity and burning on the valley slopes during the Holocene. He also notes that many extant gravels and sediments amongst the karst result from Pleistocene processes (Kiernan 1991b). The high relief of the area results in considerable potential energy from water flow, facilitating erosion by catastrophic events and strong relationships between landscape evolution and regional climate change. For example, slope stability in this highly rugged region is greatly influenced by vegetation cover. Changes in climate result in changes in the density of vegetation that insulates and protects biomass and substrate from mobilisation by surface water flow. Changes in seasonality have the most extreme effects on climate-mediated landscape evolution. For example, when the magnitude of difference between the wet and dry seasons is great, warm and wet conditions during wet seasons will foster luxuriant plant growth that favours chemical weathering and the development of soils that insulate the ground from mechanical processes. During the dry season much of this vegetation will recede and expose the soils for removal by the first monsoonal rains. The resulting lowering of soil surface on the slopes corresponds with higher sediment loads in surface water and increased alluvial sediment deposition on river terraces (Kiernan 1991a). This interaction of climate and landscape suggests that the prehistoric climate change is likely to have had pervasive influences beyond changes in the ranges of floral and faunal taxa.

Current Climate and Seasonality

Pang Mapha currently has a seasonal tropical climate with three highly distinct seasons: cool and dry (November to February), hot and dry (March to May) and warm and wet (May to October). Prehistoric climates for the study area are discussed in chapter seven. Current seasons in the study area, like much of the tropics and subtropics, are controlled by the location of the Inter Tropical Convergence Zone (ITCZ), a low pressure weather system that moves over mainland Southeast Asia in a northerly direction during May, and in a southerly direction during September. This results in two major air streams affecting the climate of the study area: the northeast monsoon and the southwest monsoon (Manisan 1995). The northeast monsoon brings cool and dry air from the Siberian anti-cyclone over major parts of Southeast Asia. The

monsoon commences in November and lasts until February. During this time the study area is in a winter season, characterized by relative aridity combined with low air temperatures. The summer season can be considered to be a transition period, from mid-February to mid-May, as primary influence shifts from the northeast to southwest monsoon. The hottest month is usually April. The southwest monsoon, which begins in mid-May and ends by mid-October, brings air of high humidity originating from the Indian Ocean towards Thailand. This southwest monsoon corresponds with the rainy season in the study area. Rainfall peaks occur during the retreat of the monsoon, generally from August to September. Abundant rainfall from tropical cyclones also occurs from August to October.

Detailed climate records for Pang Mapha Province are not available, but a weather station in the district capital, Mae Hong Son, has been collecting temperature and rainfall data since 1951. Average annual rainfall in Mae Hong Son is 1277 mm, but may be closer to 2000 mm in Pang Mapha (Richardson 2003), with 90% falling between May and October (the monsoon season). This is typical of most of northern Thailand, although the mountainous location of Pang Mapha causes heavier rainfall that is spread over a longer period of time relative to lower altitude areas (Poussart and Schrag 2005).

The annual variation in mean temperatures in Mae Hong Son is relatively narrow, from 29°C in April to 21°C in January. A better indication of the variability comes from the mean monthly maximum and minimums, since it is the extremes that impose limits on bioproductivity. Temperatures range from mean maximums of 36°C in April to 28°C in December and mean minimums of 24°C in June and 14°C in January. During the coldest months the temperature in Pang Mapha frequently falls below 10°C and ground frosts have been reported (Richardson 2003).

Hydrology

The high variation in seasonal rainfall in the study area means that potable water distribution varies greatly over the landscape between the wet and dry seasons. During the dry season water is restricted to small but continuous flows of the four permanent rivers that run through the study area. Springs are present in some deep narrow gorges. The rivers run in deep troughs running north-south, with three of the four waterways (Khong River, Pong Saen Pik Stream and Lang River) draining into the Pai River to the south which flows west and joins the Salween River in Myanmar.

Although the course of all four waterways occasionally follows subterranean routes, Lana River is notable because it actually drains into an underground system. The two archaeological sites discussed here are both adjacent to the Lang River which goes underground for about 600 m near Tham Lod rockshelter (Figure 6.1).

During the wet season these four main waterways become dramatically swollen with rainfall and runoff. They carry a large sediment load that reshapes the river banks each season with sediment erosion and deposition. Current sediment loads are likely to be greater than prehistoric conditions because modern swidden agricultural activities on the steep hillsides result in greater soil erosion than erosion from forest floors (Kiernan 1987). Away from the rivers a network of numerous small tributaries appears during the wet season. Most of these are ephemeral, only flowing after rain but holding pools of water for several days after flow ceases. During the wet season the distribution of potable water extends to steeply elevated ridges (c. 300 m) about the rivers and in the rocky gullies draining them, with pools and soaks forming in areas that otherwise have no potable water. Underground water flows are common in the study area, especially to the south between Lang River and the Pai River, but these are not easy to access. In this area there are no significant perennial streams because drainage is entirely underground (Dunkley 1985). The extensive underground drainage throughout the study area, combined with the high relief promoting surface drainage, means that standing pools of water are usually short-lived except during the peak of the wet season.

The Distribution and Quality of Raw Materials for Stone Artefacts

The distribution of non-carbonate lithologies in the study area is closely related to hydrological activity (Figure 6.3). Waterways erode through the limestone to expose non-carbonate sedimentary rocks, as well as carrying gravels from long distance upstream sources. Most streambeds in the study area are mantled by clasts from gravels (2-64 mm diameter) to cobbles (64–256 mm diameter, most being 100-150 mm) which in turn are partially covered by sandy silts. Cobbles in particular have mostly been reworked from pre-existing bank and bed deposits (Kiernan 1991b). These stream deposits are composed of quartzite and metaquartzite (50%) with smaller proportions of sandstone (20%) mudstone (20%) and other sedimentary and metamorphic lithologies (10%) (Kiernan 1991b). Similarly composed deposits are also found on terraces up to 15 m above the current river levels although these are generally overlain

by 0.5 m to 1 m of sandy loam. Hillside alluvial gravels and cobbles are apparent when surface infiltration has been inhibited by thick surface covers or poor soil development. These hillside deposits tend to be composed of sandstone and mudstone with no quartzite. They include high terrace deposits and relict cobbles probably representing lag clasts from very ancient terrace sediments that have been extensively dissected and reworked (Kiernan 1991b). Compared to streambed and terrace deposits, clasts in hillside deposits are very weathered and rarely intact since they are highly susceptible to erosion causing blocky disintegration. Average weathering depth of rinds on sandstone clasts in these assemblages is 3.4 mm, compared to 1.1 mm for rinds on the low terraces (Kiernan 1991b).

There are two major implications of this distribution of non-carbonate lithologies for prehistoric people seeking raw materials for making stone artefacts. First is that fine grained sedimentary raw materials such as chert and silcrete are extremely rare in the landscape of the study area, with coarser-grained raw materials such as quartzite and sandstone abundant instead. Mineralogical structure, especially grain or crystal size, is an important factor influencing many variables of stone artefact manufacture (Brantingham et al. 2000). Fine-grained rocks, or those with small crystal sizes, tend to flake predictably and a high degree of control over the flaking process is possible. When a blow is applied to a fine grained rock, the force travels through the mass relatively uninterrupted because the rock is homogenous and isotropic. This means that fine grained materials are highly plastic; their shape and size can be relatively easily transformed by reduction to a variety of forms (Goodyear 1989). On the other hand, when a blow is applied to a coarser grained rock, the propagation of force is more likely to be interrupted and redirected as it travels around the grains. This makes flaking less predictable, resulting in irregular fractures and severe, irreparable errors during reduction (Brantingham et al. 2000). As a consequence, coarser grained raw materials are less plastic and their reduction results in a relatively restricted range of forms. In summary, the choice of raw materials is limited in the study area, and the particular raw materials available further limit artefact manufacturing options.

The second implication of the distribution of lithologies is that the quality of rock declines as distance from a waterway increases. Cobbles found in streambeds have been size- and quality-sorted by water flow. For example, clasts with internal weaknesses will tend to break into smaller pieces during reworking and be carried by

water flow to lower energy locations. This means that cobbles in high-energy locations, where the water volume is relatively large, will tend to have few internal weaknesses and flaws. There is a gradual change in the proportions of raw materials as deposits increase in distance from waterways. Streambed and low terrace deposits are up to 50% quartzite, while high terrace and hillside deposits tend to have high proportions of sandstone and mudstone and no quartzite. Of these three types of rock, quartzite is most desirable for making stone artefacts because the grains in quartzite are most tightly bound, making it relatively tough and able to hold a more durable working edge over a variety of edge angles and over a longer use-life, compared to mudstone and sandstone. This is because quartzite is a metamorphic rock, formed by heat and pressure applied to quartzite-rich sandstone, fusing the quartz crystals into dense matrix with an even texture (Pellant 1992). Sandstone and mudstone, on the other hand, are sedimentary rocks with a less dense matrix that has not been compressed by heat and pressure. The texture of sandstone and mudstone is characterised by pore spaces between the grains. These pore spaces reduce the contact between grains, reducing the toughness of the rock and making it relatively easy to break (Pellant 1992). This lower toughness means that the morphological possibilities for durable working edges are limited to very obtuse angles and these edges have relatively short use-lives because the rock abrades relatively quickly during contact.

The Distribution of Floral and Faunal Resources

Another suite of resources of importance to human forager groups are the plants and animals that they share the landscape with and consume as subsistence resources. As with stone, the distribution of these is correlated with water availability. Additional variables in the distribution of flora and fauna are climate, soil type and parent rock materials. Although the interaction of these variables creates complex ecological patterns, elevation can be used as a proxy for these variables when describing the local ecology in the study area (Figure 6.4). This is possible because the extreme ruggedness of the topography results in relatively large differences in elevation between the valley floors and the ridge tops, with corresponding differences in soil, parent rock and water availability (Santisuk 1988). The high variability in elevation in the study area means that the study area is a mosaic of forest types over short distances, grading in taxonomic composition and structure from dense and moist forests of the valley floors to the more open evergreen forests on the ridges. That said, the distribution of vegetation in the study area in either horizontal or vertical directions does not follow a

simple pattern, with overlapping distributions of the different forest types (Santisuk 1988). In general the vegetation below 1000 m above mean sea level (amsl) can be called 'lowland vegetation' and the vegetation above 1000 m amsl is 'montane vegetation', both of which can be subdivided into several sub-types according to the dominant taxa and structure.

Starting with the lowest of the lowland vegetation, the river banks of the Lang River are typical of the lower parts of the study area with semi-evergreen forest spreading from the sheltered moist valleys of low hill ranges up to about 900 m amsl (Santisuk 1988). The habitat of semi-evergreen forests is characterised by about 5-6 dry months and 1400-1800 mm of rainfall. This type of lowland forest is also known as 'dry evergreen forest', 'seasonal rain forest' or 'mixed deciduous forest' and is composed of a mixture of a deciduous canopy trees (usually less than one third) and evergreen taxa in the canopy and lower stories (Santisuk 1988: 27). Along larger water courses, such as the Lang River, semi-evergreen forest forms a narrow strip of galley forest characterised by dense tall stands of evergreen dipterocarps, especially *Ditperocarpus turbinatus*. The density of trees ranges from 170 to 713 per hectare (Rundel and Boonpragob 1995). The forest is structurally three-tree layered, with an upper layer at around 22-35 m, a middle layer at 10-22 m and a lower layer at <10 m (Santisuk 1988: 28). The lower layer also includes a well developed shrub layer with abundant woody climbers and palms. The richness of the understory means that horizontal visibility is often less than 20 m (Rundel and Boonpragob 1995). Bamboo is relatively uncommon because it is not suited to limited light that penetrates canopy, so it only appears in open areas. In the past it is likely that this forest also included *Tectona grandis* (teak) as a dominant species but human activities such as logging and village construction have heavily disturbed the forests of the study area, and teak is now relatively rare (Rundel and Boonpragob 1995).

A second type of forest, dry dipterocarp forest, overlaps with semi-evergreen forest in its upper ranges and extends up to about 1000 m amsl. Dry dipterocarp forest is a relatively low and open forest dominated by deciduous trees, ranging from a nearly closed canopy to an open woodland structure. Its habitat is characterised by 5-7 dry months and 1000-1500 mm of rainfall, a slightly drier habitat than the lower semi-evergreen forests. Dominant species include *Dipterocarpus obtusifolius, Shorea Optusa, Shorea siamensis* and the legumes *Xylia kerrii* and *Pterocarpus macrocarpus* (Rundel and

Boonpragob 1995). The canopy and story structure of dry dipterocarp forests is similar to semi-evergreen forests, but the tree density of dry dipterocarp forests is lower at 20 to 88 per hectare (Rundel and Boonpragob 1995). Bamboo is relatively common in more open areas.

At the highest elevations in the study area a distinctive montane vegetation pattern appears, characterised by the presence of tall pines such as *Pinus merkusii* and *Pinus kesiya* as well as *Quercus* sp. and *Castanopsis* sp. This type of forest appears from about 1000 m amsl and is called 'hill evergreen forest' or 'lower montane pine-oak forest'. It is best developed along ridges and moderate to steep slopes at 1000-1400 m amsl (Santisuk 1988). Few statistics are available for hill evergreen forests, but they are known to be an open woodland forest type characterised by widely spaced trees with a dense canopy that limits development of the lower stories and shrubs (Santisuk 1988).

To summarise these vegetation patterns, there is a trend in forest structure from high tree density and developed undergrowth in humid lower elevations to more open woodland in drier and more elevated contexts. Although the taxonomic composition does not change greatly and transitions between the different forest types are not sharp, there is a substantial gradient of decreasing biomass density as distance from the river and elevation increases. The significance of this gradient for human forager populations is that while generally similar kinds of food resources are available in each kind of forest, the ease of walking and stalking prey through the understory varies substantially. The density of the lowland vegetation, combined with the ruggedness of the terrain, imposes limits on the magnitude of human mobility. On the other hand, people moving through the montane forests on ridges and hill sides were less impaired because the woodlands were more open and less filled with lower story growth. These differences would have been especially stark during the wet season when the deciduous vegetation of the lowland forests are covered in leaves and biomass density is at its highest.

The correlation between elevation, dryness and forest types means that estimating vegetation patterns during past climates is relatively straightforward. Wetter conditions will allow the lowland vegetation to expand its range to higher elevations, so far as the soil is sufficiently well drained. Similarly, the lowland forests will retract towards the waterways under drier conditions, with a concomitant increase in the range of the montane forests. These changes in forest distributions are likely to have

influenced how human forager populations organised their mobility strategies and technology. For example, it could be suggested that during wet conditions people preferred habitats in montane forests because the density and humidity of the lowland forests made travelling less efficient. Abundant precipitation means that water is available in adequate quantities on the ridges and slopes away from the lowland waterways. Similarly, during dry conditions people might be expected to concentrate their activity at lower forests near waterways because the less developed lowland forest is more habitable than the typical semi-evergreen forest and reduced precipitation means than water is less available on the ridges and slopes away from the waterways.

The fauna of the study area are less well known than the vegetation because they have been more heavily impacted by human activities such as hunting, logging and farming. Surveys of modern village inhabitants in the Lang River basin indicate that 67 mammal species have been observed in the study area in the last 15 years. (Lao Yi Pa and Tacumma 2000, Srikosamart et al. 1999, Wangwacharakul et al. 2000). Those known to have been eaten in the historical period are listed here. Of the larger mammals, these include *Elephas maximus* (Asian elephants), *Bos gaurus* (gaur*), Bos javanicus* (banteng), *Panthera tigris* (tiger), *Panthera pardus* (leopard or panther), *Muntiacus muntjak* (common barking deer), *Cervus unicolor* (sambar dear), *Naemorhedus sumatraensis* (Southern serow), *Naemorhedus caudatus* (long-tailed goral), *Sus scrofa* (Eurasian wild pig), *Arctonyx collaris* (hog badger), *Macaca* sp. (macaque) and *Macaca mulatta* (rhesus macaque). Some of these large mammals have become locally extinct during the last 15 years, especially *Elephas maximus*, *Bos gaurus*, *Bos javanicus*, *Panthera tigris*, and *Panthera pardus* (Lao Yi Pa and Tacumma 2000). Smaller bodied mammals include *Presbytis* sp. (langur), *Hylobates* sp. (gibbon), *Hylobates lar* (white-handed gibbon), Viverridae (civets), *Paradoxurus hermaphroditus* (common palm civet), Felidae (medium and small wild cats), Muridae (rats and mice), Sciurinae (squirrels), *Cynocephalus variegatus* (sunda colugo), *Tupaia belangeri* (northern tree shrew), and Chiroptera (bats). The most abundant mammals during historical times have been *Macaca mulatta*, *Hylobates lar*, *Paradoxurus hermaphroditus*, *Sus scrofa*, *Muntiacus muntjak*, *Cervus unicolor*, and *Naemorhedus sumatraensis* (Wangwacharakul et al. 2000). Many of these have been identified in the faunal records from Tham Lod and Ban Rai, but the generally poor condition of the faunal assemblage strongly limits its analytical potential.

The Two Rockshelters

The two sites described here were excavated by the Highland Archaeology Project in Pang Mapha (HAPP). This project was directed by Rasmi Shoocongdej, an Associate Professor of archaeology at Silpakorn University, Bangkok and staffed by students and specialists from Silpakorn and other institutions in Thailand. The project began in 2001 and concluded in 2007. Excavations at Tham Lod and Ban Rai were conducted by the HAPP in 2002 and 2003. I joined the project in 2004 when the HAPP were engaged in post-excavation analysis. In the following account, descriptions of the excavation methods and stratigraphy have been derived from published accounts such as Shoocongdej (2006a) and Treerayapiwat (2005) as well as more detailed unpublished Thai-language reports produced by the HAPP (Shoocongdej and Staff 2003a, 2003b).

Tham Lod

Site context

Tham Lod rockshelter is about 250 m away from the Lang River and about 15 m above current high water levels. This means that prehistoric occupants would have had easy access to the river and related resources such as abundant materials for making stone artefacts. It is on the edge of a relatively flat area surrounded by steep low hills and karst formations (Figure 6.5). The overhang of the rockshelter is part of a long cliff that has been interpreted by Khaokiew (2004) as a circular collapsed doline about 100 m in diameter. The current floor of the rockshelter rises about nine metres above the level of the flat area in front of it, indicating that sediment accumulation is connected to geomorphic process on the slopes above and to the sides of the rockshelter. The elevation of the rockshelter is about 640 m amsl (Shoocongdej 2006a). As is typical of this elevation, the surrounding vegetation is a mix of semi-evergreen forest and dry dipterocarp forest. About twenty years ago the vicinity of the rockshelter was developed into a forest management and education station and there are several small buildings and small playing fields in the area. This has obscured the natural topography and vegetation of the area, probably making the shelter more exposed than in the past.

Site description

The rockshelter is roughly straight and faces north (Figure 6.6). The maximum extents of the level area where the excavations were located is 30 m east-west by five metres

north-south. The east-west dimensions are defined by large boulders to the east and an uneven surface to the west. The height of the overhang is about 20 m and the slope from the floor of the rockshelter down to the flat area in front of the rockshelter is about 30 degrees. No rock art is visible on the rockshelter but wide pink stains run down the height of the shelter. These stains probably result from minerals dissolved in water that runs down the rock during the wet season rains, indicating that water regularly enters the rockshelter and either drains off the surface, or seeps through the sediments.

Excavations

Three discrete areas were excavated by the HAPP at Tham Lod (Figure 6.6). The first area abuts the rear of the shelter and is four metres long and between 1.2 m and 2 m wide, depending on the shape of the back wall. The second excavation area is located further down the slope and consists of an 8 x 8 m square and an adjoining 2 x 2 m square. The third area is further still down the slope and is a trench of 9 x 2 m. Although the initial excavation method for the three areas was proposed to follow natural layering of the sediments, the homogeneity of the sediments meant that in practice excavation units were roughly horizontal arbitrary units 10 cm deep. This has an important implication for the usefulness of the excavated materials from areas two and three.

These two areas are located on the slope, and although the initial excavation units followed the level of the ground surface, the lower units were horizontal because of the difficulty of following the ground surface at depth. This means that the horizontal excavation units most likely cross-cut layers of sediments deposited at different times. For example, a horizontal excavation unit on the slope will result in the downslope section recovering younger material relative to the upslope section, because sediments in the downslope section are closer to the ground surface and overlay the sediments in the upslope section. As a result, excavation areas two and three were excluded from the analysis here because of uncertainly about the contemporaneity of artefacts within excavation units. Excavation area one was considered unproblematic because the ground surface is relatively level, and assuming the lower levels are also level, any cross-cutting effects should be relatively minor. All excavated materials passed through sieves with a 1.5 mm mesh.

Stratigraphy

The homogeneity of sediments at Tham Lod, probably caused by water flow from the cliff face, makes it difficult to discern depositional units (Figure 6.7). The discussion here focuses on identifying excavation units that are disturbed to exclude them from the analysis.

The top three to four centimetres of excavation area one consists of a fine red-brown clayey sand with dispersed ash and charcoal and small pieces of limestone detached from the cliff face. Material recovered includes animal and human bone, shell, stone artefacts, ceramic pieces, seeds and other plant matter as well as obviously recent metal items such as coins and glass. Excavation unit one begins immediately below this layer and includes two post holes about 20 x 20 cm extending 14-46 cm below the surface. Surrounding the postholes is a continuation of the loose red-brown clayey sand with small limestone pieces and scattered ash and charcoal along with increased quantities of animal bone and teeth, shell, ceramic, plant matter and stone artefacts. Some glass beads were found but also modern items such as iron and plastic, indicating that mixing had occurred in these levels. Except for a having two features that are discrete areas of charcoal, ash and burnt sediment, excavation unit two has similar qualities including modern metal and glass objects. River pebbles and cobbles, as well as similar sized pieces of caliche (also known as calcrete, a hardened deposit of calcium carbonate), appear in these upper levels and are abundant throughout. Units three and four are also similar.

In unit five there is a burial indicated by the presence of a human tibia and femur as well as dispersed cranial fragments. An unusually large river boulder (30 cm diametre) was found overlying these bones. About 20 cm below this burial a second burial was uncovered, also with unusually large river boulders and limestone rock. A human radius, ulna and some teeth were identified. Bones from both burials were very fragile and only denser bone remained intact. Both burials are interpreted as having the body interred in a flexed position. Difficulty in discerning the intrusive burial feature from the surrounding sediments means that only limited confidence can be placed in the association of the dates with the burials. It is possible that the dates provide ages for the sediment that the body was placed in, rather than the time that the burial occurred. Bones from the burial have not been dated.

Below the burials the loose red-brown sediments continue, but in unit six, 50-60 cm below the surface, there is a denser than usual accumulation of limestone boulders and cobbles ranging in size from 5 to 30 cm in diameter. This is interpreted by Wattanapituksakul (2006a) and Khaokiew (2004) as a roof fall episode, possibly caused by earthquakes. A large number of human bone fragments were also recovered amongst the rock. Stone artefacts, shells, animal bones continue to be recovered, but plant remains, ceramic, metal and glass no longer appear. The proportion of limestone rocks in the sediment seems to drop slightly in the units below 60 cm from the surface, but remains higher than any units above the main roof fall concentration. In these lower levels an intrusive rock appears in the east wall of the excavation. The intrusion of this rock increases with depth until at the base of the excavation nearly half of the area is occupied by the rock. To compensate for this intrusion, volume calculations for each excavation unit (for calculation of artefact discard rates) were based on surface areas derived from plan drawings of each excavation unit. The plan drawings showed the extent of intrusion of the rock into each excavation unit and allowed volume to be calculated from the surface area of excavated sediment of each unit multiplied by the depth of the unit.

This combination of limestone rocks mixed with red-brown sediment and pieces of caliche continues down to unit 32 (310-320 cm below the surface) when large quantities of river cobbles also appear. The quantity of river cobbles decreases by unit 42 (410-420 cm below the surface) and is absent in units below. The presence of cobbles in these units is interpreted by Khaokiew (2004) as evidence that the rockshelter was once part of an ancient stream terrace. Only small amount of faunal remains and no artefacts were recovered from the river cobble bearing units. In the final 30 cm of excavation below the river cobble bearing units, no artefacts or faunal material were recovered.

To summarise the stratigraphy of Tham Lod, excavation units between the ground surface and unit six are highly likely to have been disturbed by the two burials and recent activity that has intruded modern objects into the sediments. The units below the roof fall in unit six show no signs of major disturbance, although the homogeneity of the sediments makes this difficult to detect. The absence of major stratigraphic units or areas of disturbance suggests no need to aggregate excavation units to form analytical units that reflect the history of depositions or to avoid disturbed contexts. Evidence of occupation appears to be absent below unit 32, suggesting that occupation

began around that time. The first occupation of Tham Lod is probably related to a change in the local hydrology, with the stream moving away from the rockshelter and creating a dry area suitable for habitation.

The presence of caliche throughout the entire deposit (except the river cobble bearing units) is an important indicator of preservation conditions. Although the sediments are described as loose, the caliche results in a semi-concrete texture throughout the strata, with rocks, stone artefact and animal bone fragments often tightly bound in a carbonate matrix. The cause of this is not well understood at Tham Lod, but it probably results from carbonic acid derived from carbon dioxide dissolved in the water as it passes through the sediments (Goldberg and MacPhail 2006: 178). This acid dissolves animal bones and calcium carbonate in the surrounding limestone then during neutral or alkaline conditions the carbonate precipitates out of solution to form a solid. This probably explains why the faunal remains are in such poor condition, combined with the likely gnawing and fragmenting action of Hystricids (Zeitoun et al. 2005). The stone artefact assemblage is less affected by this geochemistry, but it suggests that an analysis of residues on the stone artefacts would not be productive because any residues may have been dissolved or washed off the edge of the artefact.

Chronology

Establishing the chronology of sediment accumulation at Tham Lod was challenging because of the poor organic preservation in most units and other problems. For example, two samples of 500 g each of animal bone were sent to the Waikato Radiocarbon Laboratory for dating but the amount of datable carbon was below the level of instrument error. Three thermoluminescence samples were unable to be exported due to bureaucratic difficulties and a sample of shell was tested for U-Th dating but contained insufficient concentrations of uranium. Twelve age determinations were obtained for area one (Table 6.1) and no attempt has been made to relate these to dates from areas two and three because stratigraphic continuity between the areas cannot be demonstrated (although it is worth noting that dates from the other areas are all within the range of the area one dates). All radiocarbon dates were converted to calendar ages using the CALPAL2001 calibration curve in the CALPAL_A software (Weninger et al. 2007). Interpolation of ages for each excavation unit was obtained by deriving an age-depth curve from a regression equation relating the dates to their excavation unit (as a proxy for depth below the ground surface). A linear

model is used because there are no changes in the stratigraphy that suggest substantial nonlinear changes in the rates of accumulation. Prior to calculating this regression, two dates that were more than 10,000 years younger that the dates stratigraphically above them were identified as major anomalies and excluded from the sample. The relationship between the age and depth of the remaining 10 samples is strongly positively correlated (r = 0.884 [0.694, 1.074]). A simple linear regression using the least-squares method can be defined as

Age = (791.40 x Excavation Unit) + 9599.67

The regression is not forced through the origin because disturbance in the upper undated layers is likely to have altered sedimentation rates. This equation gives an r^2 value of 0.782 [0.585, 0.940], indicating a good fit (Figure 6.8). Inspection of standardised residuals means that cases that depart the most from the model can be easily identified In this case, no outliers were identified (values exceeding two standard deviations from the calculated value) so no further refinement of the model was necessary.

This high correlation and r^2 values implies a relatively constant rate of sedimentation during the Pleistocene at Tham Lod. Each excavation unit represents about 791 years. However, the sequence of dates still contains inversions and the period 15,000-20,000 BP is unrepresented. This may represent a slowing of sedimentation rates that slowed the accumulation of datable material. Alternatively sediments and datable material may have been removed by erosion during this period. With the current data it is not possible to be sure of the cause of the absence of dates in the period 15,000-20,000 BP. This suggests that some uncertainty is justified for the regression equation, although in the absence of further data it will be used here to interpolate ages for all excavation units. It is possible that there is a small Holocene signal from Tham Lod but disturbance of the upper layers means this cannot be reliably identified. In any case, the most substantial occupation at Tham Lod is clearly during the Pleistocene, so the available sample is probably representative of the overall pattern.

Ban Rai

Site Context

In stark contrast to Tham Lod, Ban Rai is perched high up on the southern side of a steep valley (Figure 6.1). It is about 10 km from Tham Lod in the same river valley.

However, the distance from the river to the site is about 200 vertical metres for Ban Rai, taking over an hour to make the difficult ascent from the river to the site. To the west of the site the river drains into a sinkhole. The site is located about 760 m amsl, 120 m higher than Tham Lod. The vegetation immediately surrounding the site is semi-evergreen, similar to Tham Lod, but with a greater bamboo component and just upslope from the rockshelter is an ecotone where a mix of dry dipterocarp and montane forests occur. Above the shelter in these montane forests is a long open ridge that is currently an important walking trail between villages. This ecotone is important because it means prehistoric occupants of Ban Rai were well situated to access montane environments, which are likely to have been a focus of occupation given the distance to the river and difficulty of access.

Site Setting

The rockshelter is a north-facing open circle about 105 x 42 m with a cliff height of about 30 m (Figure 6.9, Figure 6.10). The dimensions are defined by the cliff walls and the steep slope dropping away from the front of the shelter. Sediment accumulation appears to result from limestone decay and alluvial and aeolian sediments introduced from upslope from the shelter. The rockshelter was formerly a cave and the remnants of roof collapse are evident across the floor of the rockshelter and especially out near where the cave entrance would have been. The floor of the rockshelter is relatively even, making it a significant feature on the surrounding steeply sloping valley side. The level area appears relatively well sheltered from the weather and there are no mineral stains on the cliff race indicating high volumes of water flow. A small amount of rock art is faintly visible in red monochrome on the east side of the rockshelter. At the time of excavation remains of about 15-20 log coffins were scattered across the floor of the rockshelter. About six of these were still standing with upright posts and elevated platforms that presumably held corpses. A small number of human teeth were found associated with these coffins.

Excavations

Three discrete areas close to the back of the rockshelter were selected for excavation (Figure 6.10). Area one was situated to focus on the log coffin activity and was a trench of 14 x 2 m between a pair of large wooden posts and a smaller coffin structure close to the rockshelter wall. The location of area two targeted the highest mound at the site with excavations covering an area of about 6 x 2 m. Area three (4 x 4 m) was located

near the rock art and in an area where flaked stone artefacts had been found on the surface.

Of these three areas, area three was chosen as the focus for this project. According to HAPP data, area three has a substantially larger stone artefact sample (n = 9462) compared to areas one (n = 757) and two (n = 922). Also, area one is described by Treerayapiwat (2005) as disturbed and area two has a similar problem with a 30 cm pit containing a flexed burial. As a result, area three was judged to be most suitable for this project because it is the least disturbed excavation and has the largest sample of flaked stone artefacts. All excavated materials passed through sieves with a 1.5 mm mesh.

Stratigraphy

As at Tham Lod, excavation began with the intention of following major features and natural stratigraphy. However these were elusive after a few centimetres below the surface so sediment was removed in arbitrary approximately 10 cm deep units (Figure 6.11). The sediment was a fine brown sand with pebble sized limestone pieces. These upper units contained stone artefacts, animal bone, shell, ceramics and an iron artefact. The units in the upper 30 cm contain some signs of disturbance such a post hole from a log coffin structure and plant leaves throughout the matrix. In excavation unit three (35-40 cm below the surface) a small thin circular feature of ash and animal bone was identified. In unit five a small thin circular feature of red sediment and ash appears, probably the result of a campfire. This unit appears to the be the lowest level where ceramic pieces were found, with only stone artefacts, faunal remains and shell continuing into the lower layers. Additional minor features of ash and charcoal with minor variations in sediment colour occur throughout the lower layers. These features were not excavated separately from the excavation units.

The amount of limestone rock in the sediment appears to increase with depth. For example by unit 22 (195-205 cm below the surface) it was necessary to use an iron bar to loosen the rock-sediment matrix for removal. Below this unit the quantity of artefacts drops substantially, although faunal remains and shell continue. Concomitant with this increase in limestone and decrease in artefacts is a gradual change from the fine brown sand of the upper units to a yellow sand that extends to the base of the excavation in unit 32 at 305 cm below the surface. Stone artefacts remain present but only in very small numbers until unit 28 and then disappear from the sequence.

To summarise the stratigraphy of Ban Rai, there is little in the available descriptions that casts doubt on the integrity of the deposit. Sediment accumulation at Ban Rai appears relatively straightforward compared to Tham Lod. Sediments probably originate from the surrounding slopes. The sediments at Ban Rai are consistently fine and sandy and there are no signs of extensive water flow such as the caliche and semi-concrete sediments at Tham Lod. Despite this, the faunal remains are similarly small and fragmented like at Tham Lod, indicating that carnivore action may be largely responsible for this. The absence of large pieces of limestone in the deposit suggests that the cliff face is relatively stable and no major weathering or rockfall occurring during the time represented by the excavation. The yellow sediment in the lower units suggests low concentrations of ash and organic material, confirming the low intensity of occupation suggested by the sparse artefact signal. However, bedrock was not reached and there was no indication of any change in sediments such as the cobble-bearing units at Tham Lod, so it is possible that human occupation occurred in the unexcavated layers below the yellow sediments.

Chronology

Seven radiocarbon dates were available for area three of Ban Rai (Table 6.2). These radiocarbon dates were converted to calendar ages using the CALPAL2001 calibration curve in the CALPAL_A software (Weninger et al. 2007). As for Tham Lod, interpolation of ages for each excavation unit was obtained by deriving an age-depth curve from a linear regression equation relating the dates to their excavation unit (as a proxy for depth below the ground surface). The relationship between the age and depth of the seven samples is strongly positively correlated (r = 0.774 [0.417, 1.132]). Removing the date from unit three which is anomalous because it is older than dates in unit ten and 12 improves the correlation slightly (r = 0.883 [0.469, 1.269]). A simple linear regression using the least-squares method on these six dates can be defined as

Age = (160.51 x Excavation Unit) + 5807.92

This equation gives an r^2 value of 0.780 [0.464, 0.806], indicating a good fit (Figure 6.12). Inspection of the standardised residuals revealed no outliers. The high correlation and r^2 value for this equation suggests that this model is a good fit for the depth-age relationship at Ban Rai. Each excavation unit represents about 160 years, providing much greater chronological resolution than Tham Lod. On the other hand, the stone artefact sequence only spans from the beginnings of occupation at about 9700 BP to

6200 BP, much shorter than the 30,000 years represented by Tham Lod. Interestingly, Ban Rai is typical of other rockshelter sequences known in the study area, with similarly brief early Holocene occupation signals at Spirit Cave and Tham Phaa Chan, also in the highlands of Mae Hong Son Province. The timing of the beginning of occupation at Ban Rai is notable, since it coincides with the start of the Holocene period. Two dates from areas one and two also suggest earliest occupation at the Pleistocene/Holocene boundary (Treerayapiwat 2005). The sterile yellow layers below the occupation deposit suggest that this date for earliest occupation is very reliable, although it is possible that a hiatus separates a much earlier occupation from these Holocene deposits.

Little geological data are available for the archaeological sediments at Ban Rai and Tham Lod. The dominant depositional processes appear to be alluvial and aeolian transport of sediment, but it has not been possible to identify changes in the contributions of these processes. Similarly, although there appears to be no major hiatuses at a macroscopic scale it is not possible to be equally certain that finer scale interruptions have not occurred, for example in the deposition and removal of sediment on decadal scales. As a result, the interpretations that follow here assume that at the highest resolution, the stone artefact assemblages represent an average of roughly 500-1000 years and fluctuations in depositional contexts more frequent than 1000 years were unable to be detected with the material available.

Building testable hypotheses

In chapter three I argued that the most productive approach to analysing typical mainland Southeast Asian flaked stone artefacts is by using them to test predictions from three optimal foraging models. I described the patch choice model, the central place model and the model of optimal dispersion and group size. In chapters four and five I discussed the method and theory linking these models to flaked stone artefact assemblages. Now that some details are known about the environmental parameters of the study area and the two sites it is possible to be more specific about the predictions that can be made about the sites. The predictions presented here are synchronic, without reference to chronology. In the following chapter, when climate history is reconstructed for the study area, the predictions will be further refined to include a diachronic dimension.

The patch choice model predicts that areas of higher patch yields will have evidence of more intensive human occupation as people exploit a reliable and abundant resource. Under current conditions it might be expected that the environs of Tham Lod have a higher yield than Ban Rai because of Tham Lod's close proximity to the river. Ban Rai is also near montane forests which have a lower biomass than the semi-evergreen forests surrounding Tham Lod. All other things being equal, the patch choice model predicts a greater density of stone artefacts might be expected at Tham Lod compared to Ban Rai.

The central place model predicts that as travel and transports costs increase then so should the amount of pre-processing of resources to optimize the delivery of useful material at the central place. Given that in this landscape the river banks are the main source of the highest quality material for making stone artefacts, the difference in distance from the river is likely to be a substantial influence on travel and transport costs at the two sites. Tham Lod is adjacent to the river while Ban Rai is much further away and requires a steep ascent to travel from the river to the site. Under current conditions, it can be predicted from the central place model that pre-processing of stone will be substantially more frequent in the Ban Rai assemblage compared to Tham Lod. The main prediction here is that the Ban Rai assemblage will be 'incomplete' with evidence of stages of stone reduction missing from the assemblage, having taken place off-site.

The model of optimal dispersion and group size predicts that a residential settlement pattern is adaptive in stable/evenly dispersed environments and a logistical settlement pattern is a better strategy in mobile/clumped environments. This model has potentially interesting implications for predicting human responses to seasonal variation, but chronological resolution at the two sites is too low to test these predictions with confidence. At a more general scale, it can be predicted that Tham Lod is more suited to a residential settlement pattern because of its close proximity to the river and the high biomass of the surrounding semi-evergreen and dry deciduous forests. The density of these forest types constrains mobility and the abundance and closeness of resources, especially stone, means that high logistical mobility was probably unnecessary as well as inefficient. On the other hand, Ban Rai is likely to be more suited to logistical settlement because of its altitude. It is predicted that occupants of Ban Rai would have taken advantage of the relative openness of the montane forests

to engage in long range foraging trips. Similarly, the distance of Ban Rai from a reliable water source means that water is an unstable resource and foragers probably had to journey some distance to ensure access to water and resources that concentrate around upland water sources such as game. The distance of Ban Rai from reliable sources of stone suggests that people made targeted forays to ensure an adequate supply and were more selective about quality than occupants of Tham Lod. The main prediction of the optimal dispersion model is a relatively strong signal of greater assemblage reduction, as a result of individual provisioning, at Ban Rai compared to Tham Lod.

Summary

This chapter has surveyed the environmental settings of the two sites that are the focus of this project. The current climate and resource parameters have been presented and some initial predictions about the stone artefact assemblages have been developed. This information about current conditions will be used in the following chapter to reconstruct the past conditions of prehistoric hunter-gatherers' habitats. Then a more refined set of predictions will be presented for testing in chapter eight.

Figure 6.1. Local topography and hydrology of Tham Lod and Ban Rai

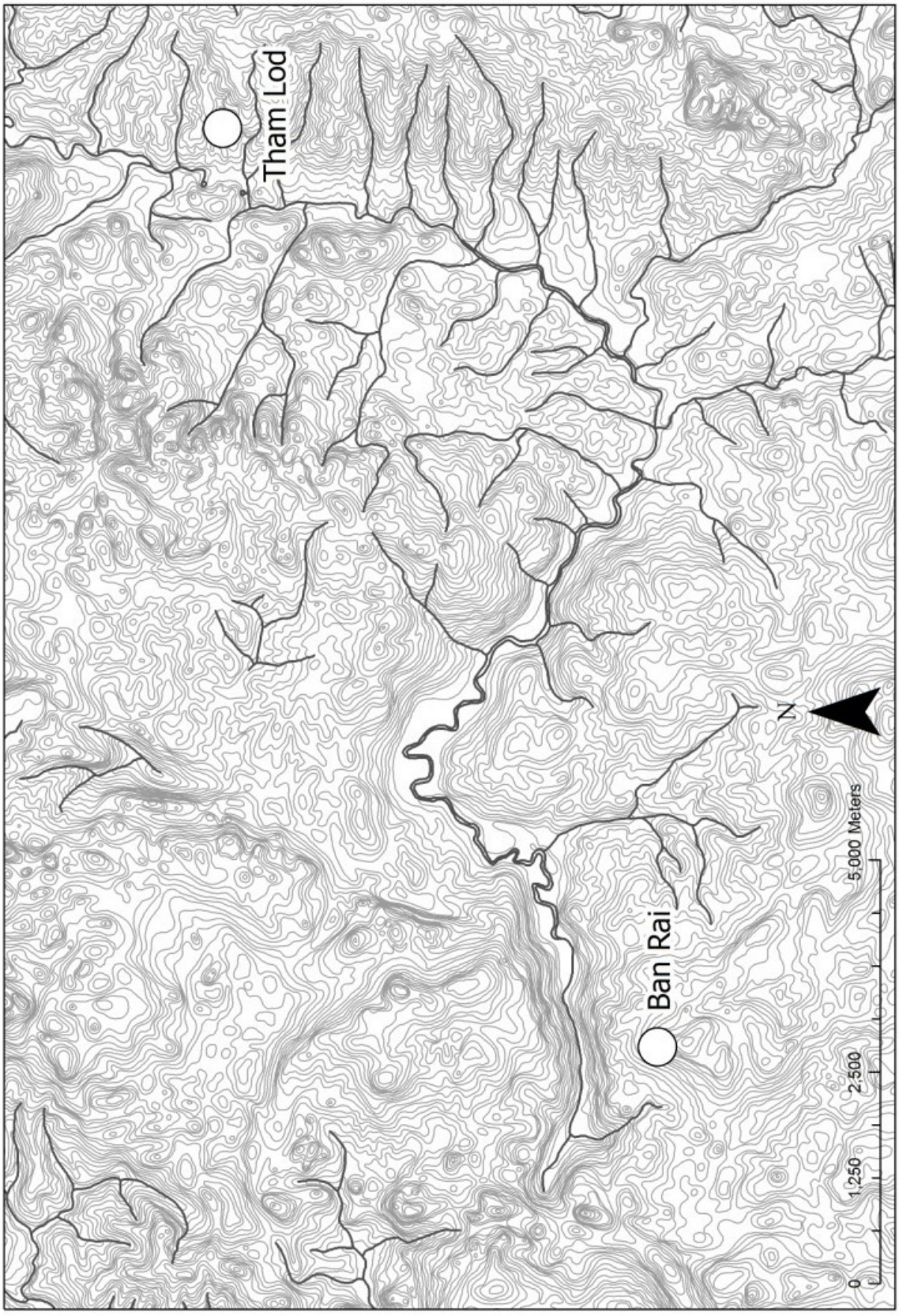


Figure 6.2. Typical view of the study area landscape from a high point near Tham Lod Rockshelter. Note the rugged topography and the cleared valley where modern agriculture and settlement is concentrated.

Figure 6.3. View of Lang River near Ban Rai. Note the relatively dense vegetation and the cobble river banks. From Shoocongdej et al. (2003a).

Figure 6.4. Schematic of the relationship between forest types, elevation and wetness in northern Thailand. Modified from Rundel and Boonpragob (1995).

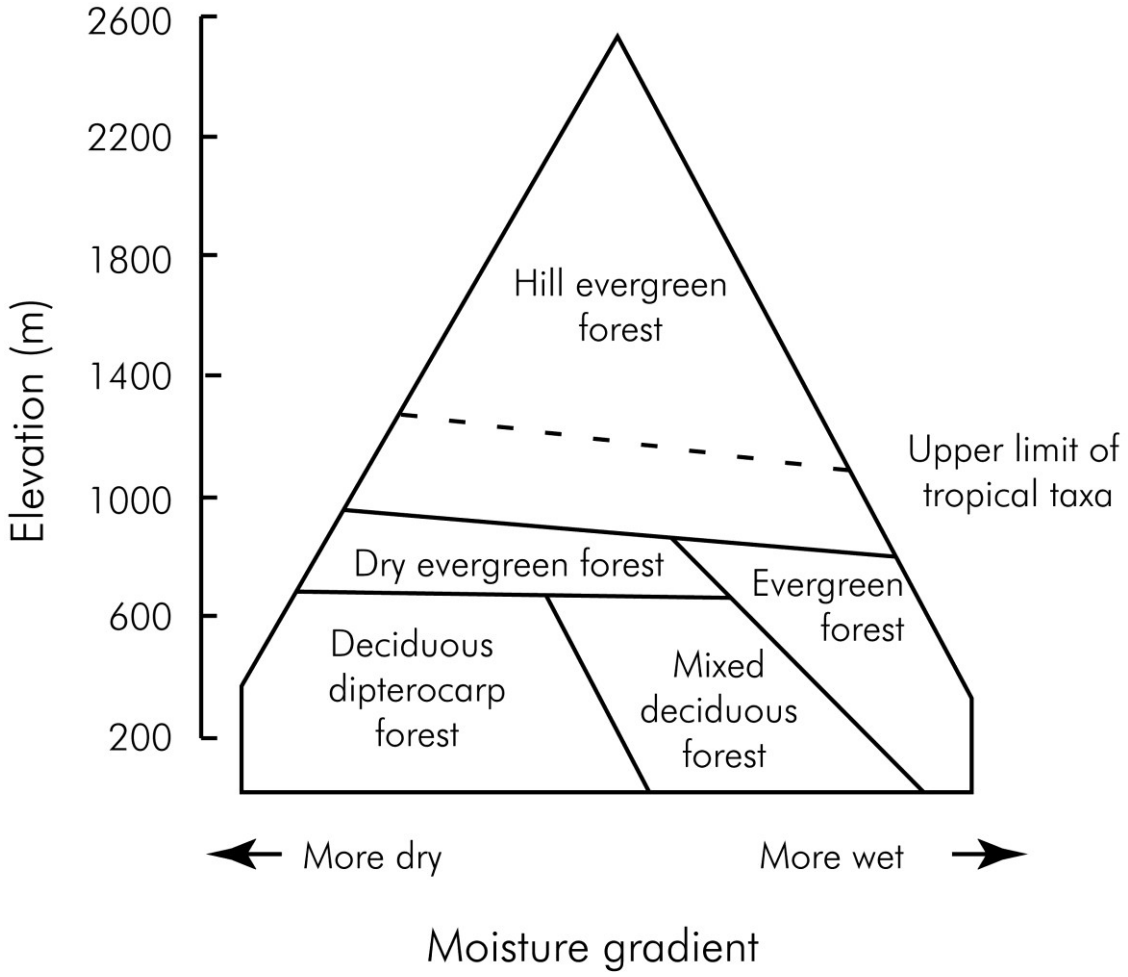


Figure 6.5. Views of Tham Lod

a) View to Areas 1-3, note the red vertical stains on the rockshelter wall. From Shoocongdej et al. (2003b).

b) View over Areas 2 (L front) and 3 (R back), both backfilled, from Area 1, note the flat area in front of the rockshelter (author photo)

c) Excavation in progress at Area 1. From Shoocongdej et al. (2003b).

d) Completed excavation at Area 1 (author photo)

Figure 6.6. Plan of excavations at Tham Lod. The contour lines show the height above the plain in front of the rockshelter. Modified from Shoocongdej et al. (2003b).

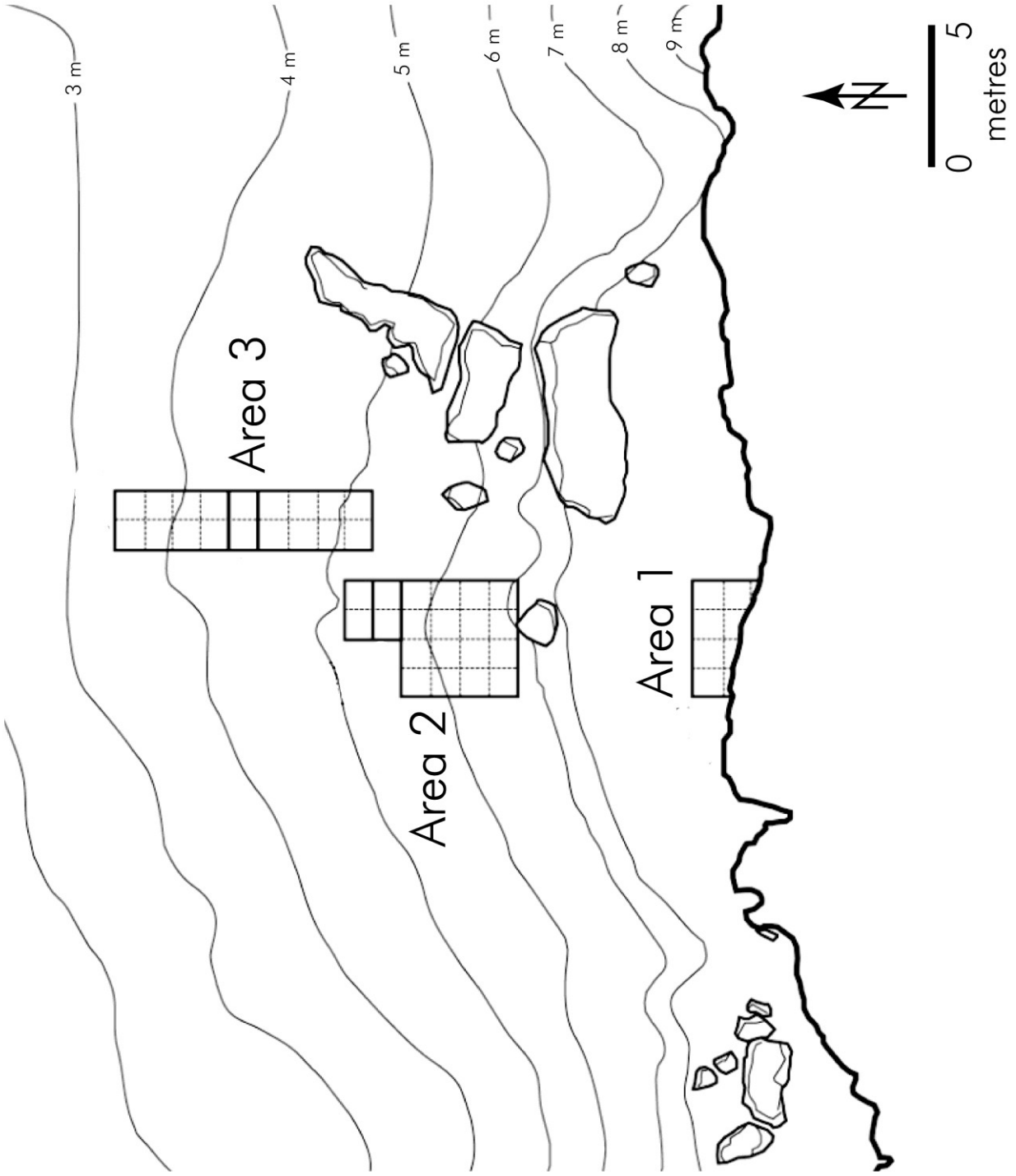


Figure 6.7. Stratigraphic section of Tham Lod Area 1. Modified from Shoocongdej et al. (2003b).

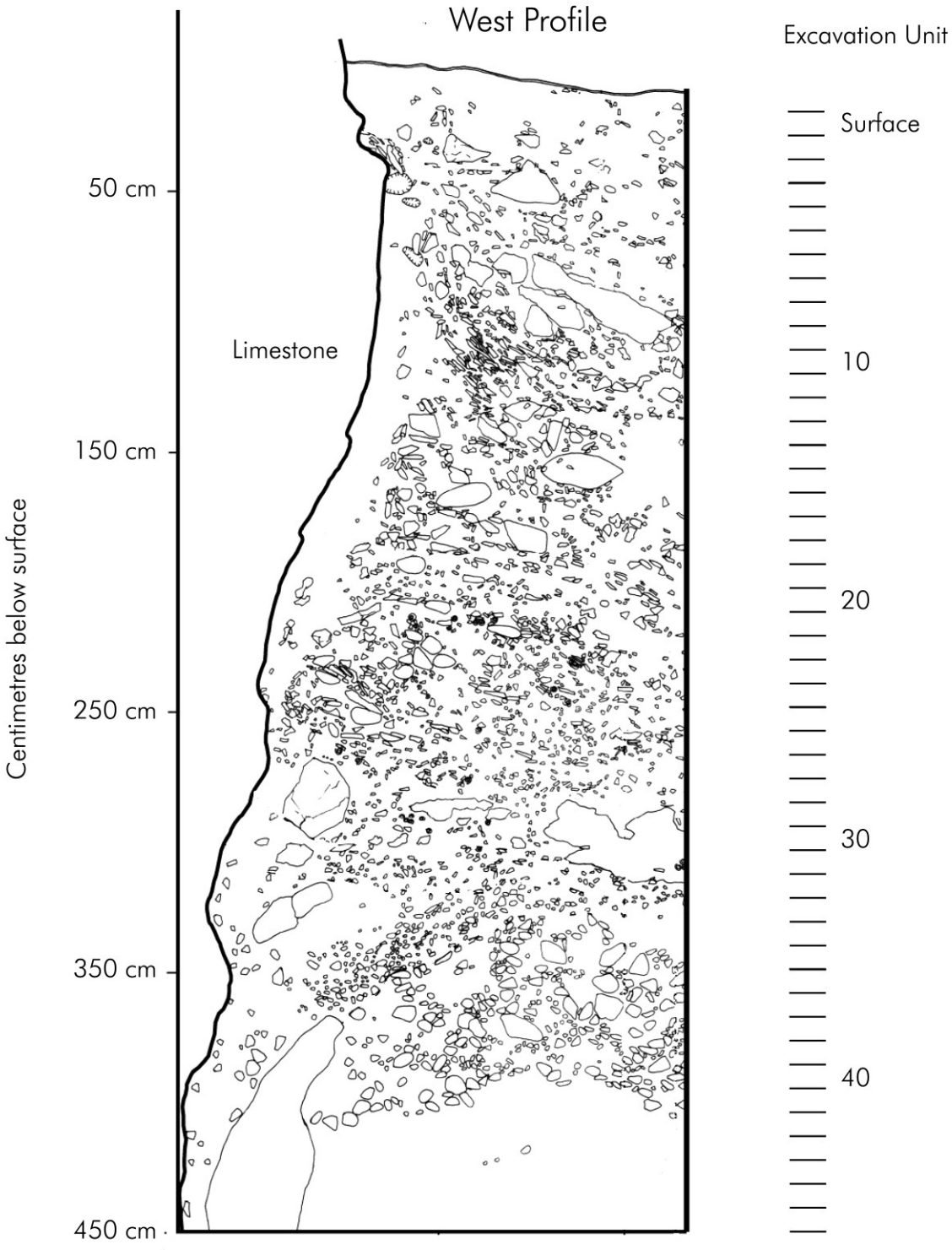


Table 6.1. Dates from Tham Lod Area 1. Dates without a SD for the calibrated age were determined by thermoluminescence methods, the remainder were determined by AMS radiocarbon methods. All ages are in years before the present.

Excavation unit	Age	1 SD for age	Calibrated age	1 SD for calibrated age	Dated material	Lab code
4	12,100	60	14,070	140	organic sediment	Beta-168223
7	13,640	80	14,764	60	organic sediment	Beta-168224
9	13,422	541	13,422		calcrete	Akita-TL7
17	24,920	200	29,910	270	charred material	Beta 194122
18	20,000	117	23,900	180	Margaritanopsis laosensis	Wk-20398
24	22,257	154	22,257		sedimentary quartz	Akita-TL12
27	29,318	336	34,500	500	Margaritanopsis laosensis	Wk-20399
28	22,190	160	26,740	400	shell (unspecified)	Beta-172226
31	32,380	292	32,380		organic sediment	Akita-TL10
32	34,029	598	39,960	1050	Margaritanopsis laosensis	Wk-20400

Figure 6.8. Age-depth plot for Tham Lod Area 1 with linear regression line and equation.

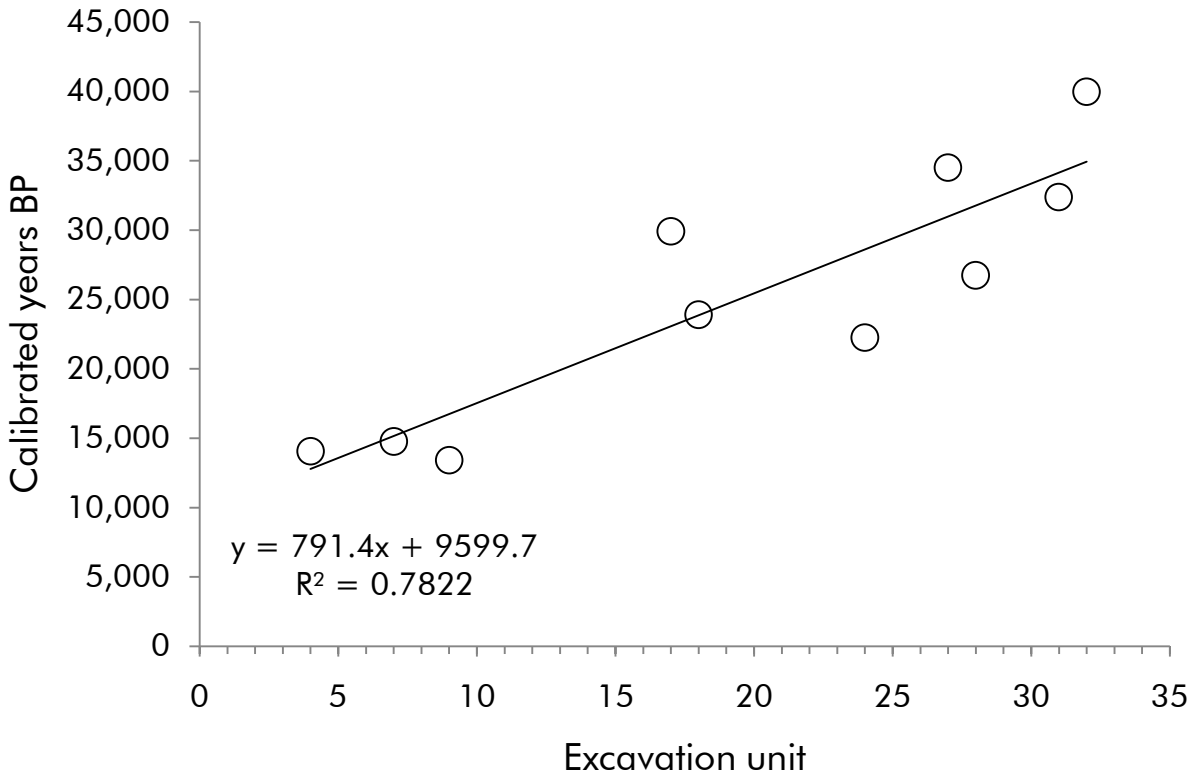


Figure 6.9. Views of Ban Rai

a) View across Ban Rai Rockshelter, shallow trenches are visisible in Area 3 on the left. From Shoocongdej et al. (2003a).

b) Excavations in progress at Ban Rai Area 3. Rulers are 1 m. From Shoocongdej et al. (2003a).

c) View of the deeper levels at Ban Rai Area 3. From Shoocongdej et al. (2003a)

Figure 6.10. Plan of excavations at Ban Rai. The surface is strewn with wood from log coffins. Modified from Shoocongdej et al. (2003a).

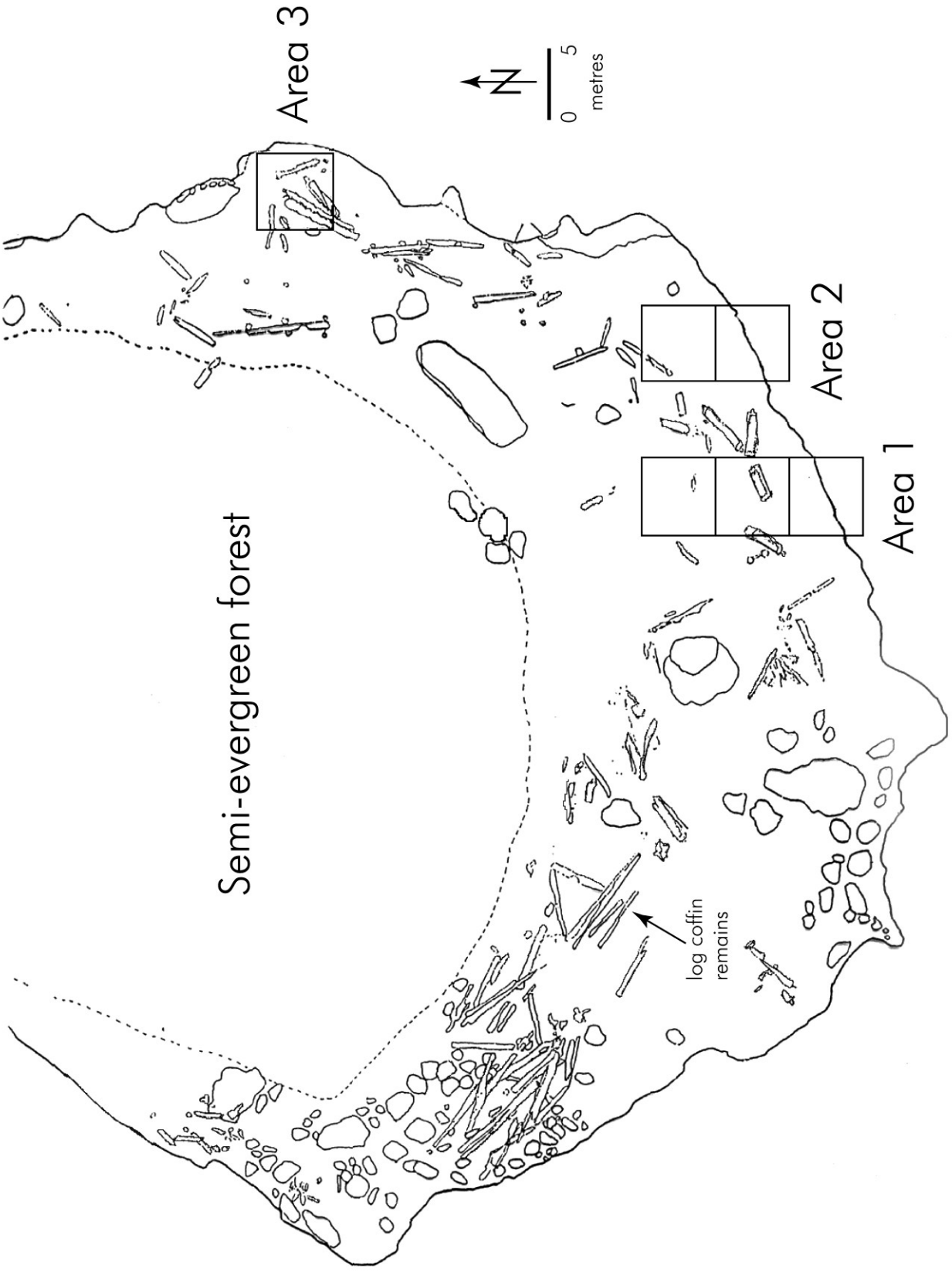


Figure 6.11. Stratigraphic section of Ban Rai Area 3. Modified from Shoocongdej et al. (2003a).

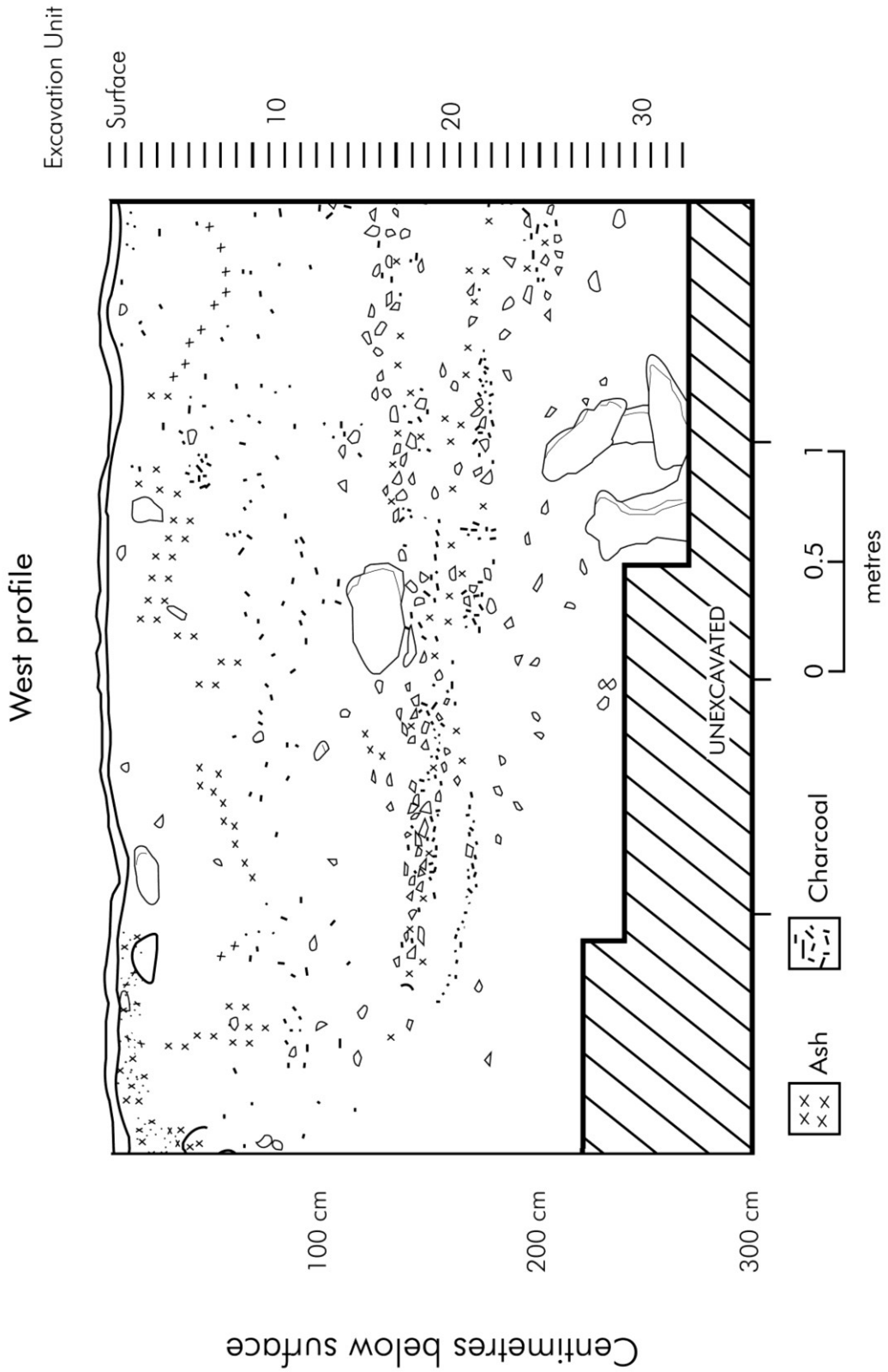
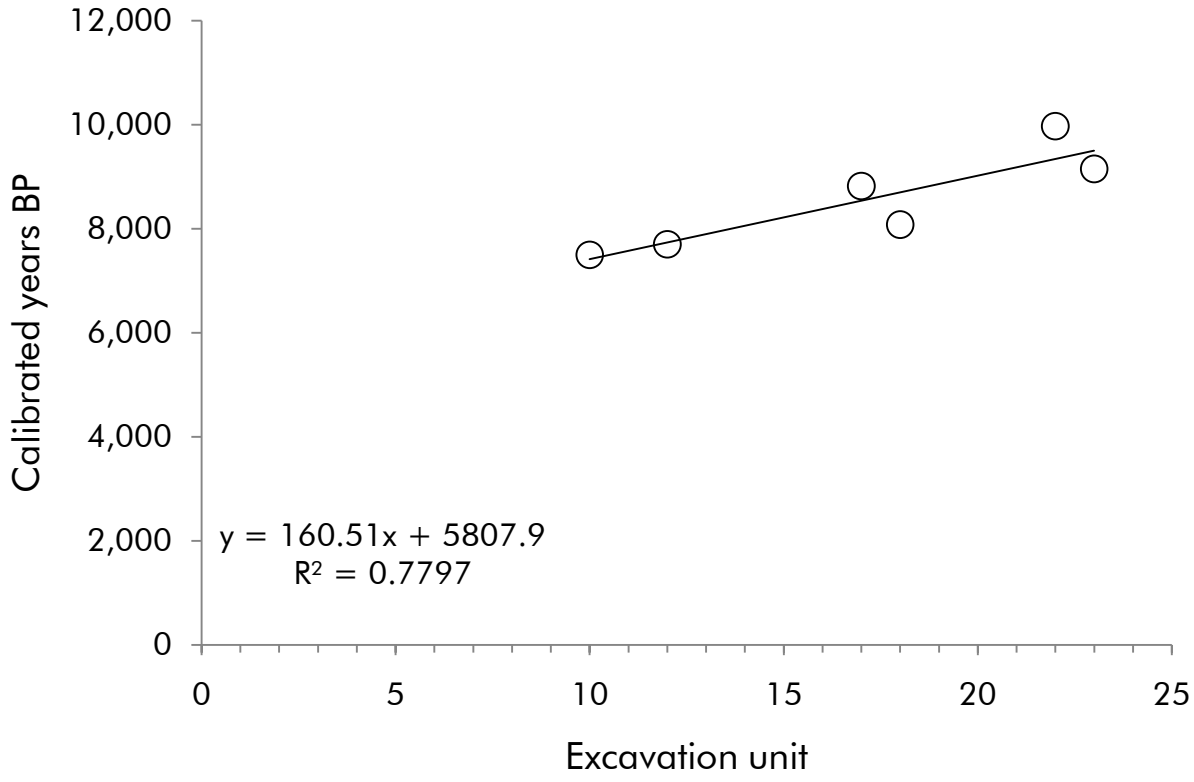


Table 6.2. Dates from Ban Rai Area 3. All ages are in years before the present.

Excavation unit	Age	1 SD for age	Calibrated age	1 SD for calibrated age	Dated material	Lab code
3	7040	60	7870	60	Margaritanopsis laosensis	OZJ686
10	6600	70	7500	50	Margaritanopsis laosensis	OZJ687
12	6850	70	7700	70	Margaritanopsis laosensis	OZJ688
17	7950	70	8820	130	Margaritanopsis laosensis	OZJ689
18	7250	40	8080	60	charred material	Beta-168220
22	8850	50	9970	140	charred material	Beta-168221
23	8190	50	9150	90	charred material	Beta-168222

Figure 6.12. Age-depth plot for Ban Rai Area 3



7. Palaeoecological Context of the Study Area

Introduction

In addition to the details of temporal variation presented in the previous chapter, to refine and reliably test hypotheses generated by the models proposed in chapter three it is necessary to have a palaeoecological record to provide inputs into the models. This chapter first surveys relevant previous work and refutes earlier arguments that the seasonal tropics show little difference between the climates of the Pleistocene and Holocene. To remedy some of the problems of previous work a highly localised, high resolution palaeoclimate study of oxygen isotopes was undertaken. For this study, freshwater bivalves were recovered from the archaeological excavations at Tham Lod and Ban Rai and sampled for isotopic analysis. The reliability and robustness of this isotope record is demonstrated and it is argued to be a suitable proxy for palaeoecological conditions during the prehistoric occupation of Tham Lod and Ban Rai. Interpretations of climate history during the period of human occupation at Tham Lod and Ban Rai are discussed and the predictions of the foraging models are further refined. The raw data that this chapter is based on are available by contacting the author via the Department of Archaeology and Natural History, Research School of Pacific and Asian Studies, The Australian National University.

Regional Climate Change and Variability

There are a variety of archaeological perspectives on regional climate change and variability in mainland Southeast Asia, highlighting the need for robust data. For example, Gorman (1971a) claims that global climatic events have had negligible impact on tropical environments. Gorman notes that eustatic sea level changes after 25,000 BP would have altered the preservation of coastal sites and the area of 'optimum' hunter-gatherer habitats. He cites extant fauna present in Niah Cave at 32,000 and continuity of plant taxa in a pollen core from Taiwan as evidence of generally similar climates from the late Pleistocene to recent times (Gorman 1971b: 59-62). In his review of Hoabinhian evidence from mainland Southeast Asia he does not suggest that these sea level changes might have been part of a wider suite of climate changes requiring any substantial modification of human behaviour or technology (Gorman 1971a).

On the other hand, Anderson (1988) argues that climatic events have influenced major cultural changes amongst SE Asian hunter-gatherer populations. As noted in chapter two, Anderson suggests that cooler and drier conditions during the Pleistocene created savannah conditions on the Malay Peninsula that made animal hunting a successful mode of subsistence. As a result the Pleistocene human occupants made small flake tools as hunting implements and the larger cobble artefacts only appear later when the climate becomes warmer and wetter and hunting implements become less important in human subsistence technology. Anderson's arguments are mostly based on global climate data indicating differences in average temperatures between the Pleistocene and Holocene.

In part, this discrepancy between Gorman and Anderson is due to Gorman working much earlier when fewer data were available. The environmental history of mainland Southeast Asia is poorly documented relative to the rest of the world (Penny 2001), but the number of studies has been steadily increasing. A review of current evidence shows that Anderson was more accurate but high variation between different records in mainland Southeast Asia means that only the broadest trends appear over wide areas. This variability emphasises the need for site-specific climatic records for describing robust relationships between human behaviour and climate. The work of Hastings and Liengsakul (1983) is notable because it is the first broad overview of Late Quaternary climate change for mainland Southeast Asia using data from that region. They interpret climatic conditions from nine radiocarbon dated stratified sediments throughout Thailand. They state that the period from 60,000 BP to 30,000 BP was cool and dry, followed by a warm and wet period until 20,000 BP, then returning to cool and dry conditions until about 11,000 BP at the beginning of the Holocene when warm and wet conditions resumed. Changes in swampy mangrove vegetation in a pollen core from Chanthaburi Province, southeast Thailand similarly suggests sea level regression at about 20,000 BP and sea level increases at about 8,400 BP (Pramojanee and Hastings 1983).

Pollen and other kinds of microflora are the main sources of evidence for more recent palaeoclimate studies in mainland Southeast Asia. Maloney(1992) describes sequences of pollen from 33 locations in mainland and island Southeast Asia including pollen from deep sea cores, archaeological sites and dry land pollen cores. He notes that most of these cores are only late Holocene sequences, many contain incomplete descriptions

of pollen taxa and many of them have no radiocarbon dates at all, limiting their usefulness for palaeoclimate reconstruction. His synthesis of these cores indicates that most dry land pollen cores only yield evidence for very localised vegetation changes within freshwater swamp forest or mangrove swamp, or a change from mangrove swamp to freshwater swamp (Maloney 1992).

More recently, flora microfossils have been described from four sediment cores extracted from three lakes in south, north and northeast Thailand (Penny 2001, White et al. 2004). The core with the oldest sequence, spanning 40,000 years, was taken from Nong Pa Kho (NPK), taken from a peat swamp on the Korat Plateau, northeast Thailand (Penny 2001). A 230 cm core was dated with five radiocarbon determinations in the following stratigraphic sequence: 6700±50 BP, 5970±60 BP, 12,350±60 BP, 11,540±90 BP and 38,300±600 BP (uncalibrated). The oldest date is unusual given the relatively short core length and the inversion at the third and fourth dates is difficult to explain but may result from growth of an intrusive root (Penny 2001). The Pleistocene sequence is remarkable because of its environmental stability, in contrast to high altitude sites where temperature changes seem to have resulted in large altitudinal migrations of plant taxa (Flenley 1979, 1998, Stuijts et al. 1988). From the base of the core to about 11,000 BP the record is dominated by a stable majority of Pine/Oak forest taxa such as *Pinus, Quercus,* and *Cyperacae* as well as relatively high proportions of charcoal. This suggests drier and cooler conditions that favoured an expansion of the range of montane forests and increased fire events. The stability of the Pine/Oak forest is at odds with local geomorphological evidence from Tung Kula Ronghai on the southern Khorat Plateau, northeast Thailand, where an organic sand unit dated to 34,000-20,000 BP is interpreted by Loëffler et al. (1983) to indicate a humid phase just before the last glacial maximum. Penny (2001) suggests that this disagreement is because the Pine/Oak taxa represented by the core have a wide ecological tolerance, strong tolerance for fire and egregious growth and profligate pollen production, leading to an exaggerated impression of community stability.

Nevertheless, cool-adapted species such as *Alnus, Ulmus* and *Artemisa* are prominent during the Pleistocene section of NPK, with *Alnus* peaking at 21,000 BP suggesting a subtle reduction in temperature around the glacial maximum. Similarly high values of these three species also occur between approximately 13,400 BP and 11,600 BP, suggesting cool and dry conditions again just before the Holocene. This is coincident

with an increase in the rate of dust accumulation in the Malan loess of central China, also suggesting a drop in temperature. This increase in dust accumulation occurs just before the Younger Dryas, which is manifest by a reduction in dust accumulation in the loess, suggesting a strengthening of the warm, moist summer monsoon (Zhisheng et al. 1993). The influence of the Younger Dryas is not evident at NPK.

The Holocene sequence from NPK indicates a rapid shift from Pine/Oak forest to tropical broad-leaf taxa, especially *Cephalanthus*, and ferns such as *Lygodium*, suggesting possibly swamp-forest or inundated riparian vegetation as a response to wetter and warmer conditions (Penny 2001). Changes in the Holocene taxa are extremely dynamic, but it is possible to discern a few important shifts. Modern vegetation appears at about 6300 BP. At about 5500 BP there is an increase in charcoal and at 4700 BP there is a decline in the abundance of many dryland taxa. Penny (2001) suggests that these changes might have resulted from increased burning and subsequent disturbance, but notes that the extent of these influences or their causes is not clear.

Also on the Khorat Plateau of northeastern Thailand is the lake Nong Han Kumphawapi (NHK), in Udon Thani Province, where two cores (1.41 m and 6.18 m) have been extracted (Penny 1999). Thirteen radiocarbon determinations are available for the two cores indicating sediment accumulation from about 14,350 BP to 2000 BP (uncalibrated). The short Pleistocene sequence has little pollen but is characterised by mottled sediments, suggesting periodic wetting and drying and a strong seasonal contrast in the climate (Penny 1999). The dominant taxa represented by the few spores present are *Pinus, Celtis* and *Uncaria*/*Wendlandia*, suggesting relatively open and dry conditions. The period 10,200-9500 BP is marked by high rates of sedimentation, suggesting high sediment mobility in the lake catchment probably due to increased precipitation from a stronger southwest monsoon with relatively open vegetation (Kealhofer 1996). After about 9800 BP taxonomic diversity increases considerably with *Altingia,* Combretacae/Melastomataceae, Dipterocarpaceae, *Elaeocarpus* and others suggesting an expansion of dry deciduous or semi-evergreen forests and more humid conditions than present (Penny 1999). At 6600-6400 BP many of these lowland taxa disappear and there is an increase in charcoal and a dramatic increase in *Pinus* and *Cephalanthus*. Penny (1999) suggests that this change might be due to the high tolerance of *Pinus* to frequent fires and exposed soils and their prolific pollen production. This

change might be a result of a termination of a strengthening of the summer monsoon, with temperatures and precipitation declining or anthropogenic disturbance. The cause is ambiguous because chronological resolution of the monsoon event and the NHK core is inadequate to be certain of a relationship, and there is no robust archaeological evidence for human activity on the Khorat Plateau at that time. These conditions persist until about 2800 BP when charcoal quantities decline, and secondary forest taxa such as *Trema* and *Macaranga* become more common, probably a result of changes in anthropogenic burning from widespread forest burning to more restricted burning areas (Kealhofer and Penny 1998). These Mid and Late Holocene changes at NHK highlight one of the weaknesses of microflora records, namely that the anthropogenic signal can interfere with the climate signal, making it difficult to discern the climate mechanisms that are interacting with human ecological systems.

To the west of NHK and NPK is Kwan Phayao, a lake in Phayao Province, northern Thailand. A 5.88 m core was extracted from the lake and dated with five radiocarbon determinations from about 19,000 BP to 640 BP (uncalibrated). The Pleistocene sequence is very short, with a date of 19,190±120 BP (Beta-099704) at 546-548 cm depth and a date of 9850±50 (Beta-106544) at 527-531 cm depth, only about 17-19 cm apart, suggesting very slow sedimentation or erosion during this time (White et al. 2004). The brief Pleistocene sequence is characterised by Pine/Oak woodland, suggesting cooler and drying conditions resulting in an expansion of this type of forest into lower areas than it currently occupies. Unusually, charcoal quantities are relatively low during this period, indicating that fires may have been relatively infrequent. Notable changes in the Holocene sequence include a decline in Dipterocarpaceae (*Hopea*/*Shorea* type, *Dipterocarpus* type), *Macaranga* and Fagaceae (*Lithocarpus*/*Castanopsis* type and *Quercus*) at around 4500-1700 BP, possibly reflecting the development of drier conditions related to a regional weakening of the southwest monsoon flow over Indochina (Maxwell and Liu 2002, White et al. 2004). Pine/Oak tax dominate the sequence throughout the Holocene, even though they only currently grow on slopes 470 m above the lake, highlighting the confounding effect of the prolific pollen production that is typical of these taxa. After 1860 BP there is an increase in charcoal quantities and regrowth taxa such as *Macaranga* and *Trema*, interpreted by White et al. (2004) as indicative of forest disturbance through burning, probably anthropogenic.

To the south of Thailand is the Nong Thale Song Hong (NTSH) core, a 3.8 m core taken from a closed basin lake in Trang Province, within 75 km of the archaeological sites Lang Rongrien and Moh Khiew. There are five radiocarbon dates for the core, but the two stratigraphically lowest ones are inconsistent with the upper three and have been rejected as inconsistent. The three accepted dates are 6330±50 BP, 10,820±50 BP and 21,170±90 BP, all uncalibrated (Maloney 1999). The phytolith sequence in the NTSH core shows relatively high percentages of burnt phytoliths and grass phytoliths during the Pleistocene period. During the Holocene these two groups decline substantially and arboreal phytoliths increase concomitantly (Kealhofer 2002). This suggests more frequent burning and more grassland with less forest during the Pleistocene, indicating drier conditions than the Holocene.

Pollen samples from NTSH are restricted to the Holocene levels, except for one sample with an interpolated age of about 17,500 BP. The single Pleistocene sample is dominated by *Castanopsis* sp., suggesting open forest but with enough standing water suitable for the aquatic plant *Nymphoides*. *Nymphoides* continues into the early Holocene and is joined by *Castanopsis indica* and *Lawsonia inermis*, suggesting a swamp forest community during conditions of high lake levels, perhaps related to a high groundwater table as sea levels transgress the continental shelf and annual rainfall increased with the strengthening of the southwest monsoon (White et al. 2004). These conditions persist until about 7600 BP when deciduous and evergreen taxa become dominant (Dipterocarpaceae, *Acacia*, Combretaceae and *Lagerstroemia*), probably indicating edaphic dryness (Maloney 1999). Increased locally dry conditions are also indicated at about 7000 BP with relatively high quantities of the regrowth tree *Macaranga,* the fern *Lygodium* and grass pollen as well as the disappearance of the palm *Borassodendron machadonis* after 4000 BP. After 4000 BP there are indicators of forest disturbance with increased charcoal quantities and secondary growth taxa (*Macaranga*, *Mallotus*, *Trema* and Urticaceae/Moraceae). At about the same time are increases in swamp forest taxa suggesting locally wetter conditions (*Elaeocarpus ruqosus, Carallia brachiata, Nymphoides* and *Lycopodium cernuum*). It is unclear how clearly the pollen record is reflecting regional climate change or human landscape modification in these Late Holocene samples, although the presence of the economic taxa *Palaquium, Piper and Areca* after 1500 BP strongly suggest human influence (Maloney 1999, White et al. 2004).

Although these pollen and phytolith records have substantial gaps and ambiguities in interpreting the taxonomic variation, it is possible to summarise some of the broad climatic trends that they represent. Cores from areas surrounding the study area, such as South Asia, East Asia and offshore generally show three major events in Late Pleistocene-Holocene climate dynamics: (1) a Pleistocene-Holocene transition from cool and dry conditions to warmer and wetter conditions, (2) an Early to Mid Holocene precipitation maximum and (3) and a Mid to Late Holocene transition to drier conditions, usually involving stronger seasonality (Maxwell 2001, Maxwell and Liu 2002). The Thai cores also include these elements, but not as a uniform, synchronous response. The Pleistocene seems to have been relatively drier and cooler than current conditions, with an increase in the modern range of Pine/Oak forests and increased burning events. This trend is comparable with evidence from cores in higher latitudes and altitudes in Yunnan (Shaomeng et al. 1986, Xiangjun et al. 1986). In general the Holocene sequences of the Thai cores are characterised by high variability over time and space. The timing and impact of the Pleistocene/Holocene transition varies, as does the timing and impact of the Early Holocene monsoon maximum. This variability has also been documented in northeastern Cambodia (Maxwell 2001). The Mid and Late Holocene climate record from the Thai cores is also clouded by possible anthropogenic forest disturbance, reducing robustness of the climate signal in the pollen record.

Paleoclimate Proxies at Tham Lod and Ban Rai

The key attribute of the pollen evidence is variation under the influence of local conditions. With none of the cores inside the study area or in similar upland environments, they are unsuitable as palaeoclimate proxies for the archaeological sequences from Ban Rai and Tham Lod, except as general indicators of contrasting conditions between the Pleistocene and Holocene for mainland Southeast Asia. Unfortunately this low level of spatial and chronological resolution adds little to what is already known about global climates, highlighting the importance of climate records generated from proxies recovered at or very near the archaeological sites. The highly rugged topography of the study area combined with its highly seasonal climate means that there are no lakes or swamps to provide ideal coring conditions. Dan Penny (personal communication) has examined sediments from Ban Rai and Tham Lod and found pollen grains and fern spores present, though the preservation is generally poor. He found that the number of taxa is relatively low and many samples contained no pollen. Those that contained pollen were characterized by upland high altitude wind-

pollinated plants, local grasses and ferns. The incompleteness of the pollen record means that it is not possible to discern change over time with any confidence.

Pumijumnon and Trikanchanawattana (2006) also investigated pollen records in the study area, taking samples from seven locations near Ban Rai and Tham Lod, as well as examining sediments from the two rockshelter excavations. Two dates were obtained for the non-rockshelter locations, giving relatively young ages of 280 BP and 650 BP. Like Penny, they found that sediments from the rockshelters contained insufficient pollen to make conclusions about prehistoric climates (Trikanchanawattana 2005). The relatively shallow time depth of the other samples similarly precludes any insights into palaeoclimate. Nevertheless, Pumijumnon and Trikanchanawattana (2006) state that past vegetation was similar to the present, but with a cooler climate indicated by higher quantities of *Pinus* and grasses with reduced quantities of *Circulisporites* and the plankton *Concentricystes* which suggest less humid conditions and less frequent flooding. However, this trend is not consistent, with some locations showing a trend towards increased dryness over time. This mosaic of changes over a relatively short time suggests that the pollen sequences reflect highly localized conditions. The causes of these changes are unclear, although it seems likely that anthropogenic disturbance is a significant influence since the pollen samples span a period of increasing population and agricultural activity in the study area. In any case they are of limited use as palaeoclimate proxies for the archaeological sequence at Tham Lod and Ban Rai because of their short time depth and non-synchronous patterns.

Another line of evidence comes from Wattanapituksakul's (2006a) identification and morphometric analysis of mammal teeth excavated from Tham Lod. He identified 2300 mammal teeth specimens, representing a minimum number of 218 individuals classed into 31 taxa, mostly Cervidae, *Sus scrofa,* Bovinae and Pecora. Most mammals represented in the sequence have wide habitat ranges and are not diagnostic of anything less than extreme changes in local vegetation or climate. Also, analysis of change over time is limited by the lumping of excavation units into five analytical units, reducing chronological resolution and resulting in a very high number and diversity of specimens in a single analytical unit. Like Pumijumnon and Trikanchanawattana, Wattanapituksakul concludes that, in general, past climates were similar to current conditions. Notable taxa represented in the mammal teeth assemblage are *Ursus tibetanus,* Rhinocerotidae, both large-bodied mammals, and

Naemorhaedus. Curiously, the habitat of Rhinocerotidae is dense forest and swamp, while *Ursus tibetanus* and *Naemorhaedus* typically prefer open montane habitats. All three of these taxa occur in Pleistocene and Holocene units, suggesting that taxonomic representation may be more indicative of human foraging ranges and strategies rather than changes in mammalian habitat ranges related to climate change.

One detail from the teeth assemblage that might reflect climate is a gradual reduction in the width of the first and second upper molars of *Naemorhaedus* from the Pleistocene to the Holocene. This reduction in molar width is argued by Wattanapituksakul (2006b) to reflect a reduction in body size of *Naemorhaedus* possibly in response to a decrease in the quality of food, the seasonal availability of food or a warmer climate. This supports the pollen and other data in suggesting that the Holocene was significantly warmer than the Pleistocene, but adds little in terms of magnitude or chronological resolution.

A New Palaeoclimate Proxy for Tham Lod and Ban Rai: The freshwater bivalve Margaritanopsis laosensis

To overcome the limitations of low chronological resolution, poor preservation and anthropogenic interference with the climate signal it was necessary to seek a proxy other than microflora or mammal teeth. Ideally this proxy would be present in all excavation units from Ban Rai and Tham Lod so that a chorological resolution equivalent to the stone artefact sequence could be achieved. This proxy was also required to archive climatic information in a way that was relatively independent of anthropogenic influence. The only material that met these conditions was the freshwater bivalve *Margaritanopsis laosensis,* the most abundant shell at both sites (99% mass of all shell at Tham Lod and 96% mass of all shell at Ban Rai) and the only taxa that occurs in more than 95% of the excavation units at both sites. In brief, the theory behind the choice of shell as a proxy is that while the shell organism is alive and growing the hard part of its shell, the isotopic properties of the shell will reflect the isotopic properties of the water it lives in, which varies according to climatic conditions.

The main assumption here, as with the pollen and mammal teeth, is that the shells entered the archaeological site shortly after they died and stopped archiving climatic conditions. If the shells died long before they entered the site (ie. they were antiques) then their palaeoclimate signal will not be synchronised with the stone artefacts, and

will be of limited use for analysing relationships between the two records. The assumption that the death of the shells was contemporary with the strata they were recovered from is supported by the sequence of radiocarbon dates discussed the previous chapter. For both sites the materials dated includes *Margaritanopsis laosensis* as well as other organic materials and thermoluminescence analysis of sediments. The relatively high correlation coefficients for the depth-radiocarbon age relationship suggest that the deposition of the dated shells was contemporaneous with the rest of the material in the strata the shells are found in. This means that the association of shells and stone artefacts in excavation units is probably robust.

Stable Isotope Geochemistry and Freshwater Bivalves

The link between the shell and the climate that it lived in is complex, but relatively well understood by palaeoecologists. The key is the equilibrium between the oxygen isotopes shell carbonate in the water that the shell lives in. Atoms of a given element, such as oxygen, with differing numbers of neutron (but identical numbers of protons and electrons) are called isotopes. There are two types of isotopes, those that emit radiation and gradually decay into another element or isotope, and those that are stable (Hoefs 2004). Stable isotopes form during the decay of radioactive isotopes, although many also formed during the explosions of stars at earlier times in the history of the universe. Isotopes are important in geochemistry because they have similar chemical properties (because of the identical numbers of electrons) but slightly different physical properties because of their difference in mass (resulting from the different numbers of neutrons). This difference in physical properties causes slight differences in the reaction rates of molecules containing different isotopes (Hoefs 2004). For example, during water evaporation, the heavier water molecules composed of ^{18}O are slower to evaporate than the lighter ^{16}O because the ^{18}O molecules require more energy to change phase from liquid to vapour. Reactions that cause differences in isotope ratios include basic physical processes such as melting, freezing, crystallisation, condensation and evaporation, as well as more complex processes such as plant photosynthesis and animal metabolism. This variation in reaction rates results in variation in the ratios of commonly occurring isotopes, such as $^{18}O/^{16}O$, $^{13}C/^{12}C$ and $^{14}N/^{15}N$ in the skeletons and flesh of living organisms.

The processes that result in variation in isotope ratios are called fractionation. There are two kinds of fractionation, equilibrium fractionation and kinetic fractionation (Criss

1999). Equilibrium fractionation describes bidirectional isotopic exchange reactions that occur between two different phases of a compound at a rate where equilibrium is maintained, for example the transformation of water vapour to liquid precipitation. The temperature of the equilibrium reaction influences the degree of fractionation that occurs, with higher temperatures generally causing faster reactions and greater differences in isotope ratios. Kinetic fractionation is a unidirectional process where the lighter isotope reacts faster and becomes irreversibly concentrated in the products of the reaction. Examples of kinetic fractionation include biological processes such as photosynthesis and respiration as well as evaporation. Living organisms prefer lighter isotopes because of the lower energetic costs in reacting the lighter isotope compared to the heavier one (Hoefs 2004). This preference can result in substantial fractionations between the substrate (where the heavier isotope is more abundant) and the biologically mediated product (where the lighter isotope is more abundant).

Kinetic fractionation is responsible for the variation in stable isotope ratios in biogenic carbonate, such as from corals, molluscs and otoliths. Analyses of these carbonates have become an important tool for reconstructing past environmental and climatic conditions. There are three reasons why biogenic carbonates are useful palaeoclimate archives. First, the carbon and oxygen isotopic ratios in the shell or skeletal aragonite have a close relationship to the isotopic values of the water that the organism lives in. Oxygen isotopes are the more important of the two because oxygen isotopes from the water are incorporated into the shell carbonate. Carbon isotopes are also useful for palaeoclimate reconstruction because some shell carbon is derived from ambient dissolved inorganic carbon in the water. This dissolved carbon may come from plants that grow in different habitats in the study area. However, shell carbonate also derives from metabolic processing of carbon in the food digested by the shell organism (Geist et al. 2005). There is no simple relationship between carbon isotope ratios in river water and in shell carbonate (Dettman et al. 1999). This means that carbon isotope values of shells are less directly influenced by the isotopic values of the water that they grew in. However, the kinetic and metabolic effects on carbon isotope ratios are generally very small (Auclair et al. 2004, Carre et al. 2005), so carbon isotope ratios can cautiously be interpreted as an environmental signal.

A second reason why biogenic carbonates are useful is that they can survive thousands to millions of years of burial, so they can provide data for a variety of spatial and

temporal scales. Third, biogenic carbonate is generally deposited continuously during the lifetime of an organism, providing potentially very high resolution records for reconstructing past climates. More specifically, the isotopic signatures of oxygen and carbon of shell carbonates growing in freshwater reflect the temperature and isotopic concentration of the water in which the shell secretes its successive layers of calcium carbonate.

There are two models for interpreting isotope signatures of riverine bivalve shell carbonate (Dettman and Lohmann 1993). First is the 'temperature-dominated' model where variability in oxygen isotopes in shell carbonate is a reflection of changes in surface water temperature. This model is appropriate in fluvial systems that are dominated by groundwater input where variation in the isotopic concentration of meteoric water (rainfall) at seasonal scales is overwhelmed by the isotopic effects of seasonal changes in water temperature. Higher water temperatures result in higher metabolic rates, higher magnitudes of kinetic fractionation and greater differences in the ratio of isotopes. Similarly, lower temperatures result in correspondingly low metabolic rates and lesser differences in isotopic ratios. This model is suited to shells in habitats where the seasonality of rainfall is low.

In habitats where rainfall seasonality is marked, such as the study area considered here, a different model based on rainfall mediated isotopic changes is more appropriate. This second model is the 'water-based' model, where the effects of temperature-dependent oxygen isotope fractionation are greatly diminished relative to seasonal changes in the oxygen isotope ratios of precipitation. In this model the influence of regional climate on the isotopic composition of meteoric water is more substantial than temperature. Changes in the oxygen ratio in river water are driven by variations in the isotopic character of meteoric water, produced as atmospheric water vapour moves inland from its oceanic source (Kaandorp et al. 2003).

To interpret the oxygen isotope values from the shells from Ban Rai and Tham Lod, the 'water-based' model is most relevant because variation in the ecology of the Lang River, from which the shells were originally collected, is largely determined by precipitation. During the dry season the river is very shallow, flow is slow and the water is very clear. During the wet season high levels of precipitation increases the volume and flow rates by several multiples and the water becomes opaque with silt

and debris from runoff. Changes in surface water temperature, assuming they relate to air temperature, are less pronounced.

This is a result of the monsoonal climate of the study area with distinct wet and dry seasons resulting in high seasonal variation in precipitation. The northeast monsoon brings cool and dry air from the Siberian anti-cyclone over major parts of Thailand from November to February. During these months, eastern winds bring air of high humidity that has traversed the South China Sea towards the East Coast of peninsular Thailand. The southwest monsoon, which begins in mid-May and ends by mid-October, brings 90% of the annual rainfall and air of high humidity originating from the Indian Ocean (Khedari et al. 2002). Ideally, a year's worth of river water and *Margaritanopsis laosensis* specimens would have been collected as a control sample to establish the isotopic variation that these monsoonal systems are responsible for (Mannino et al. 2003). However, despite intensive searching and sampling kilometres of river banks, this project was unable to locate specimens of *Margaritanopsis laosensis*, and it is believed that the species is locally extinct due to pollution of the river from intensive agricultural activity.

In the absence of a modern control sample it was necessary to simplify the model for shells as palaeoclimate indicators. The initial plan was to sample single shells multiple times across the life of each shell for sub-annual resolution of isotope ratios (Jones et al. 2005). Without a control sample to interpret these sub-annual variations this plan was changed so that multiple samples from single shells were combined to produce an average isotope ratio for the life of each shell. To interpret these results, the model of the relationship between the shell and the climatic conditions it grew in is no longer based on seasonal changes but instead relies on variation at a multi-year scale (since shells of similar size have a typical lifespan of two to three years). More specifically the oxygen isotope values of meteoric water are likely to increase during periods of heightened aridity (when the water molecules containing the lighter ^{16}O evaporate leaving the heavier ^{18}O to become relatively concentrated in the water) and decrease during periods of increased precipitation (the effect of evaporation is much less and the $\delta^{18}O$ of the precipitation stays close to that of the source, the Indian Ocean). This model predicts that oxygen isotope ratios of *Margaritanopsis laosensis* will show relatively high ratios of ^{18}O during periods of reduced rainfall and increased evaporation and

relatively high ratios of ^{16}O during periods of increased rainfall and reduced evaporation.

Mineralogy and taphonomy of the shells

When shells for oxygen isotope analysis are recovered in areas where limestone geology is dominant it is critical that the carbonate produced by the shell when it is alive is aragonite rather than calcite. Aragonite and calcite are chemically identical forms of calcium carbonate, but with different structures, symmetry and crystal shapes. Shells can grow aragonite, calcite or both in alternating layers (Falini et al. 1996, Thompson et al. 2000). Calcite is the major component of limestone, so when the shell is made of calcite in limestone environments, it is impossible to be certain that the shell calcite is a result of skeletal growth in the shell or taphonomic processes that have displaced the biogenic mineral with calcite from the surrounding limestone. These taphonomic processes can include carbonate recrystallisation and isotopic exchange with the surrounding limestone. At Ban Rai and Tham Lod this is an important concern, not only because of the limestone geology, but also because the high volume of seasonal precipitation promotes dissolution and recrystallisation of carbonates in the sediments that the water drains through. If the skeletal carbonate of *Margaritanopsis laosensis* is calcite then it is unsuitable for isotopic analysis because the carbonate of the shell is indistinguishable from contaminating limestone carbonate resulting from taphonomic processes. This means that the oxygen isotope ratios of the shell carbonate will not reflect the isotope ratios of the water it grew in, but instead the isotope ratios of the surrounding limestone, which have no relation to the climate conditions prevailing while the shell was alive.

To assess the viability of *Margaritanopsis laosensis* for oxygen isotope analysis a series of small analyses were undertaken. Four specimens were selected from Ban Rai and four from Tham Lod, from the upper, middle and lower excavation units of each site, to investigate mineralogy and taphonomic alteration of the mineralogy. It was hypothesised that if the shells were primarily aragonite, then some or all of the aragonite in the older shells might have changed to calcite because of prolonged exposure to the influence of the surrounding limestone and because aragonite is an unstable mineral that slowly decays to form calcite. It was also hypothesised that taphonomic processes might differentially alter the shell, with the best preservation of the original shell mineral at the thickest area near the umbo.

As a qualitative mineralogical test, the shells were sawn in half from margin to umbo and stained with Feigl's solution which stains black in the presence of aragonite (Friedman 1959, Lewis and McConchie 1994). This confirmed that *Margaritanopsis laosensis* secreted aragonite but did not indicate if taphonomic processes had altered the amount. To investigate taphonomic alteration, a preliminary mineralogical study using X-ray diffraction (XRD) analysis was undertaken to quantitatively determine the mineralogy.

The eight shells were sampled in four locations per shell using a 0.35 mm or 0.5 mm drill bit to create a particulate sample. Prior to sampling, possible contaminants were removed by cleaning the shells with a wire brush and an abrasive disk attached to an electric rotary tool. The particulate sample was then ground finely in acetone using an agate mortar and pestle for three minutes and then transferred by pipette to a quartz sample plate and mounted in the XRD instrument. The samples were analysed at the ANU Department of Earth and Marine Sciences using a Siemens D501 Diffractometer (Copper target) and interpreted using computer software (database: PDF-2, search/match: DiffracPlusEva 10.0, quantitative analysis: Siroquant V3).

The results of the analysis of these eight shells showed that they are mostly aragonite with consistently small amounts of calcite. The percentage by mass of aragonite ranged from 99.9 to 90.4 and of calcite from 9.6 to 0.1. Lower values were found in the samples taken from the umbo compared to other parts of the shell. The average percentages of calcite to aragonite are 3.1% to 96.5% at Ban Rai and 4.2% to 95.8% at Tham Lod. Overall, there is an average of less than five percent calcite by mass in each shell. Surprisingly the amount of calcite appears to decrease with the depth of the deposit that the shell was recovered from and thus the age of the shell. The shell that returned the highest calcite value of 9.6% mass is notable because it had a different colour and texture to the other shells. This specimen was selected because it was thought to have been cooked or burnt because the shell was much denser than the others and had a blue-grey coloured exterior. The mineralogical analysis suggests that it was burnt, which could cause decay of the aragonite into calcite and thus explain the higher percentage of calcite.

Although these results come from only a small sample, they confirm that *Margaritanopsis laosensis* is an aragonite producing species and suggest that taphonomic processes probably have not substantially altered the mineralogy of the archaeological

specimens. These results suggest that *Margaritanopsis laosensis* specimens recovered from excavations at Ban Rai and Tham Lod are suitable for oxygen isotope analysis.

Interactions between mineralogy and isotope ratios

Before undertaking a detailed shell isotope study, it was necessary to ensure that there was no interaction between the slight variations in shell mineralogy and oxygen isotope ratios. If there is an interaction then shells sampled for isotope analysis need to have very similar ratios of calcite and aragonite in order to discard the calcite influence as a constant, substantially restricting the number of shells suitable for oxygen isotope analysis. If there is no interaction then some variation in ratios of calcite and aragonite is tolerable and sampling is not so constrained. This is important because although *Margaritanopsis laosensis* is the most abundant shell species at both sites, the majority of specimens are either burnt or broken - as might be expected if they were a food resource - with only small numbers of intact specimens (<5) per excavation unit. If it is necessary to sample only specimens with equivalent ratios of calcite and aragonite then the sample might be so small that it will be unreliable. Also, isotope analyses are a relatively expensive analytical procedure and instrument time was difficult to secure, so it was prudent to fully assess the viability of *Margaritanopsis laosensis* with smaller samples before conducting a larger scale analysis. To assess interaction between mineralogy and isotope ratios a further 23 specimens were sampled for XRD to determine the ratios of calcite and aragonite and for mass spectrometry to determine the oxygen and carbon isotope ratios. The sample size was determined by the capacity of a single automated run of the mass spectrometer and a smaller sample size was not possible.

Samples of shell carbonate were extracted by sawing the shell in half from margin to umbo and then drilling into the profile at the thickest part of the shell near the umbo. Similar to the XRD sampling, a 0.35 mm or 0.5 mm drill bit was used and the particulate matter was collected with subsamples of 180-200 μg weighed for delivery to the mass spectrometer. Microdrilling was chosen as the most appropriate technique because of the relatively low spatial resolution required (Spötl and Mattey 2006). The samples were analysed at the ANU Research School of Earth Sciences on a Finnigan MAT 251 using a Kiel Microcarbonate device, both computer-controlled using ISODAT software. Following convention, results are reported as delta (δ) values in parts per mil (‰). The delta value is an expression of the difference between the raw isotopic values

of the shell and a standard, in this case Vienna Peedee Belemenite (VPDB) (Criss 1999: 35). National Bureau of Standards NSB 19 was used as an equivalent of VPDB. The carbonate samples were reacted with two drops 105% phosphoric acid at a temperature of 90°C over a reaction time of 13 minutes. Water was removed from the H_2O-CO_2 gas evolved from this reaction by freezing and then vaporising CO_2 in a double trap system using liquid nitrogen. The pure CO_2 then entered the inlet system of the mass spectrometer for measurement (Ayling et al. 2006). The working gas used (KAZZA) was composed of $\delta^{18}O$ VPDB = - 1.88‰; $\delta^{13}C$ VPDB = 2.39‰. Data was corrected for ^{17}O interference using the method of Santrock et al. (1985) and normalised so that a sample of solid NBS 19 analysed by this method would yield the following results: $\delta^{18}O$ VPDB = - 2.20‰; $\delta^{13}C$ VPDB = 1.95‰. The working gas values and ion correction methods are reported here to allow comparison with data produced in different laboratories.

Analysis of these 23 specimens supported the findings of the previous analysis relating to mineralogy and depth and showed only very weak interactions between mineralogy and age and mineralogy and isotope ratios. The percentage of aragonite in the shell varied from 100% to 88.4% with a mean of 95.9% and standard deviation of 3.7%. The correlations between percentage aragonite and excavation depth (as a proxy for time of exposure to carbonate recrystallisation, isotopic exchange with the surrounding limestone or aragonite decay) are relatively weak (Tham Lod: r = -0.168, Ban Rai: r = -0.475). This suggests that the time that the shells have been buried in the archaeological deposits has had little effect on their mineralogy. Similarly, the variation in ratios of calcite and aragonite in the shells has little effect on $\delta^{18}O$ values (Tham Lod: r = -0.113, Ban Rai: r = -0.037) or the $\delta^{13}C$ values (Tham Lod: r = -0.240, Ban Rai: r = 0.176). These results suggest that there is little interference in the climate signal in these shells from taphonomic processes. The amount of calcite in the shell does not appear to substantially increase over time nor does it substantially interact with the oxygen and carbon isotopes of the shell. This makes variation in presence of calcite in the shell difficult to explain, since one shell gave a value of 100% aragonite it is unlikely that *Margaritanopsis laosensis* secretes calcite as well as aragonite (there appears to be no information available about shell formation and carbonate metabolism for this species). Similarly, with no strong relationship between calcite percentage and depth of recovery it seems that taphonomic processes contribute little to the percentage of calcite in the shells, unless it is an asymptotic relationship where the calcite percentage increases only to a certain point. Nevertheless, the main implication of these results is

that *Margaritanopsis laosensi*s is suitable for oxygen isotope analysis for palaeoclimate reconstruction.

Seasonal variation versus multi-year variation in isotope ratios

A final preliminary analysis was necessary to check that the isotopic variation between specimens was greater than the seasonal isotopic variation within a specimen. If isotopic variation between specimens was greater than the seasonal isotopic variation within a single specimen then a reliable multi-year climatic signal can be obtained. If the opposite is true and variation within a single shell is equivalent or greater than variation between specimens then the intra-annual seasonal signal is dominant and a multi-year climate signal cannot be reliably discerned. One specimen each from Ban Rai and Tham Lod was also intensively sampled across the profile of the shell to determine the seasonal range of variation in isotope values.

Thirty isotope samples were taken along the profile of the shell from Ban Rai and 22 samples from the Tham Lod shell, following cleaning and cutting the shell as described above. The samples were evenly spaced across the profile from umbo to margin, although the margins of both shells were damaged. The sequence does not represent a full spectrum of carbonate deposition because the most recently deposited layers were absent. The range of variation in $\delta^{18}O$ for the multiple samples from the individual specimens was 0.59‰ for the Ban Rai specimen (Figure 7.1) and 0.74‰ for the Tham Lod specimen (Figure 7.2). This is less than the range of values for the 23 specimens analysed for isotope-mineralogy interactions which have ranges of 1.47‰ (14 specimens from Ban Rai) and 2.49‰ (nine specimens from Tham Lod). These results show that variation in isotopic ratios is greater between individual specimens than within an individual specimen. This means that variation between specimens is likely to contain a reliable climate signal.

Verifying 30,000 years of climate change at Tham Lod and Ban Rai

Given the encouraging results of these small preliminary analyses, it was decided to select three shells from all excavation units where *Margritanopsis laosensis* is present to sample for isotopic analysis, with one of the three specimens also sampled for XRD analysis to check that no unusual taphonomic processes had occurred in each sampled excavation unit. Three was chosen because it was the maximum number of intact specimens in most of the excavation units. These data were combined with data from

the previous analysis to produce a total of 155 samples analysed for isotope ratios. Analytical precision for replicate measurements (n = 36) of $\delta^{18}O$ in NBS-19 was ±0.06‰ (2SD). Twenty-six excavation units at Tham Lod were sampled and 14 excavation units were sampled from Ban Rai. This gives a relatively detailed sequence of climate change spanning from about 6000 BP to about 35,000 BP.

Figure 7.3 shows the $\delta^{18}O$ values for Ban Rai and Tham Lod with interpolated age values on the horizontal axis determined by the regression equations described in the previous chapter. Before examining the record in detail, it is important to establish the reliability of the range and magnitude climate signal by comparing it to similar sources. This is important because the Holocene data come from Ban Rai and the Pleistocene data from Tham Lod with no overlap, so it is necessary to investigate the possibility that the different locations might distort or add noise to the climate signal. Although the shells at both sites come from the same river, there is a possibility that slight variations in local conditions in the river might have influenced isotopic fractionation in unpredictable ways (Shanahan et al. 2005).

No comparable data are currently available in mainland Southeast Asia. Further north at two locations in China there are two locations where comparable oxygen isotope data from speleothems have been analysed and published (Wang et al. 2001, Yuan et al. 2004, Zhao et al. 2003). Detailed chronological and oxygen isotopic data from these two locations was downloaded from internet archives at the World Data Center for Paleoclimatology, Boulder, Colorado, USA (http://www.ncdc.noaa.gov/paleo/). Carbon isotope data was not available. These records are significant because the cave speleothems grow in relatively constant temperature conditions (similar to the mean annual air temperature), so oxygen isotopic variation is mostly a function of the oxygen isotopic composition of cave drip water, which is closely related to mean local precipitation (McDermott 2004, Schwarcz 1986). This sensitivity to precipitation makes the speleothem data ideal to test the model of isotope variation in *Margritanopsis laosensis* as a function of precipitation and evaporation.

Wang et al. (2001) describe a very high resolution sequence of $\delta^{18}O$ from five stalagmites in Hulu Cave (also known as Tangshan Cave), 28 km east of Nanjing. The sequence was dated with 59 ^{230}Th dates with analytical errors of 150-400 years, spanning 75,000 BP to 11,000 BP. These data are useful for verifying the range and variation in the isotope values from Tham Lod since it represents the Pleistocene phase

of the sequence. The overlap of Hulu and Tham Lod starts at 34,000 BP and ends at 11,000 BP. During this time the maximum $\delta^{18}O$ values from both sequences are close at -4.70‰ from Hulu and -5.53‰ from Tham Lod, with the Hulu maximum occurring at about 16,100 BP and the Tham Lod maximum at about 15,100 BP (Figure 7.4). Wang et al. (2001) suggest that the sharp increase to this value represents Heinrich Event 1 (H1), one of six extreme events when large amounts of glacial ice were released into the North Atlantic ocean. The massive addition of fresh water and rock mass carried by the glaciers altered ocean circulation patterns and produced anomalous deposits of ice-rafted debris and high $\delta^{18}O$ values in ice cores (Hemming 2004, Meese et al. 1997). Zhao et al. (2003) have also observed this H1 event in another speleothem record from Hulu. The similarly sharp increase in $\delta^{18}O$ values at Tham Lod suggests that a signal from H1 may also be present in this sequence. However, the relatively low resolution of the Tham Lod sequence means that further work is required in Thailand to reliably demonstrate that peak dryness during the Last Glacial Maximum in northern China and northwest Thailand was synchronised.

The minimum $\delta^{18}O$ values of the two sequences are -8.67‰ from Hulu and -7.62‰ from Tham Lod. These minimum values are not synchronised with the Hulu minimum at about 32,700 BP and the Tham Lod minimum at about 23,000 BP. Wang et al. (2001) suggest that the Hulu minimum corresponds with a brief warm period recorded in the Greenland ice cores as Greenland Interstadial five (Meese et al. 1997). The sequence at Tham Lod does not appear to indicate this warm period, and the minimum value at Tham Lod occurs at the time of the second highest value at Hulu, so there does not appear to be any synchrony between the two records in documenting warm and wet periods. Similarly, the steep drop at Hulu from about 14,800 BP to 13,000 BP, indicating a rapid transition to warmer and wetter conditions, is not documented at Tham Lod. Wang et al. (2001) interpret this rapid warming at Hulu as evidence of the Bølling-Allerød Interstadial, a widespread warm period probably triggered by an exceptionally large melting event of continental ice sheets into the North Atlantic, causing an increase in sea levels and altering ocean circulation patterns (Weaver et al. 2003). The Bølling-Allerød Interstadial is also documented in a another stalagmite record from Hulu Cave (Zhao et al. 2003). The two $\delta^{18}O$ values at 11,200 BP and 12,700 BP at Tham Lod may indicate a signal of the Younger Dryas, the sharp increase in $\delta^{18}O$ at Hulu indicating a rapid return to glacial conditions after the Bølling-Allerød Interstadial, but the resolution of the Tham Lod sequence is too low to identify this with certainty.

It is unclear why there is the possibility of synchrony for the dry events but none at all for the wet events in these Pleistocene sequences. There is a substantial difference in elevation between the two sites with Hulu Cave only 100 m amsl (Yuan et al. 2004), compared to about 640 m amsl for Tham Lod. The standard deviation of values at Tham Lod is less than at Hulu (Hulu SD = 0.95‰, Tham Lod SD = 0.63‰), despite the Hulu sample being much larger. This means that it is possible that the rugged upland topography of Tham Lod creates orographic effects that dampen variation in the local signal during regional changes in wetness and dryness. It may also be relevant that the radiocarbon calibrations of Pleistocene dates at Tham Lod are difficult to make fine correlations with the TL dates from the Chinese speleothems because CalPal uses a hypothetical model for dates older than around 26,000 BP rather than actual calibrations (Ramsey et al. 2006).

Nevertheless, there is good overall agreement between Hulu and Tham Lod (Figure 7.4), such as the general upward trend towards Last Glacial Maximum out of slightly warmer and wetter conditions before 30,000 BP, as well as similar magnitudes and range of $\delta^{18}O$ values. This provides robust verification of the reliability of the Tham Lod sequence and is especially impressive given that the Hulu sequence comes from stalagmite carbonate and the Tham Lod sequence comes from shell carbonate. This suggests that the primary control on $\delta^{18}O$ values in both Pleistocene sequences is precipitation rather than atmospheric temperature effects, as predicted by the model for *Margritanopsis laosensis*. Kinetic effects from the secretion of biogenic carbonate by *Margritanopsis laosensis* appear to have a negligible effect on isotopic ratios at the scales examined here. If the net effect of temperature on aragonite $\delta^{18}O$ is likely to be small, then the $\delta^{18}O$ signal will be dominated by changes in the $\delta^{18}O$ of the seawater moisture source and the amount or types of monsoon precipitations (Dansgaard 1964, Schwarcz 1986). Variations in surface seawater $\delta^{18}O$ in the South China Sea, where the summer monsoon draws its moisture, are well known for this period (Wang et al. 1999) and are small relative to those observed in these Thai and Chinese isotope records. The summer monsoon in southeast China contributes 80% of annual precipitation, with $\delta^{18}O$ of the summer rainfall being 10‰ lower than the winter rainfall (Zheng et al. 1983). Equivalent data are not available for Thailand, but because the Thai climate is similarly dominated by summer monsoon rain (Khedari et al. 2002), it is reasonable to explain the $\delta^{18}O$ change in the Thai records in terms of changes in the ratio of summer to winter precipitations (Wang et al. 2001, Zhao et al. 2003).

A similar comparison for the Holocene sequence of $\delta^{18}O$ values Ban Rai is available from Dongge Cave, 18 km southeast of Libo, Guizhou Province. The elevation of Dongge Cave is comparable to Ban Rai at 680 m amsl (Yuan et al. 2004). A very high resolution sequence of $\delta^{18}O$ values was obtained from two stalagmites. The isotope sequence was dated by 66 ^{230}Th dates and spans from recent times to about 15, 600 BP, continues again from about 40,000 BP to about 65,000 BP and again from about 90,000 BP to about 160,000 BP. These data are useful for verifying the reliability of the sequence from Ban Rai, given that the Dongge sequence also overlaps with Hulu with very little difference in the overlapping sections of the two Chinese sequences. This continuity between the Chinese sequences is useful for evaluating the relationship between the Ban Rai sequence and the Tham Lod sequence, now that the reliability of Tham Lod has been established. The Dongge sequence overlaps the entire Ban Rai sequence, spanning from about 5,900 BP to 9,800 BP. The range of $\delta^{18}O$ values from Ban Rai fits within the Dongge range (Figure 7.5). The Dongge sequence ranges from -8.46‰ at 8,300 BP to-9.33‰ at 9,000 BP and the Ban Rai sequence ranges from 7.94‰ at 5,900 BP to -9.05‰ at 6,600 BP. There does not appear to be any synchrony in these maximum and minimum values.

A slight trend of increasing dryness is apparent over the duration of the Ban Rai sequence. This may reflect the end of the Middle Holocene Optimum, a warm-moist event caused by changes in the Earth's orbit that spanned 8,200–5,700 BP (Zhou et al. 2001). Yuan et al. (2004) do not identify this Optimum in the Dongge sequence, but it has been described in pollen sequences elsewhere in China (An et al. 2000, Liew et al. 2006, Wang et al. 2007, Zhuo et al. 1998). Despite the absence of clear climatic events in the Ban Rai sequence, the overall similarities in magnitude and variation with the Dongge sequence (Ban Rai SD = 0.30‰, Dongge SD = 0.22‰) suggests that the isotope sequence from Ban Rai provides a reliable climate signal and has not been substantially distorted by local effects.

Interpreting the isotopic records from Tham Lod and Ban Rai

Given that the oxygen isotope ratios from Tham Lod and Ban Rai are generally reliable indicators of past climatic conditions, it is now possible to examine these two sequences as histories of climate relevant to the archaeological record. At the broadest level there is a clear difference in isotope ratios between the Pleistocene and Holocene periods. The average $\delta^{18}O$ value for the period 6000 to 10,000 BP is -8.58‰ (SD =

0.30‰) and for the period 10,000 to 34,000 BP the average value is -6.61‰ (SD = 0.63‰). Without a modern control sample it is not possible to calculate a water temperature-isotope fractionation relationship to accurately predict past temperatures from the isotope values in this location. However, the relationship between temperature, $\delta^{18}O$ of water and $\delta^{18}O$ of biogenic aragonite has been empirically determined as

$$T°C = 20.6 – 4.34(\delta^{18}O_{aragonite} - \delta_{water})$$

where $\delta^{18}O_{aragonite}$ is the value of the shell and δ_{water} is the $\delta^{18}O$ value of the water minus 0.2‰ (Dettman et al. 1999, Grossman and Ku 1986). The subtraction of 0.2‰ from the $\delta^{18}O$ value reflects the different scales on which they are normally measured (PDB or VPDB for carbonate, SMOW or VSMOW [Vienna standard mean ocean water] for water) (Dettman et al. 1999). This means that in general, a change in $\delta^{18}O_{aragonite}$ of 1‰ is approximately equivalent to 4-5°C. For Ban Rai and Tham Lod the difference of average $\delta^{18}O$ values between the Pleistocene and Holocene is -1.97, suggesting that the Pleistocene was on average cooler than the Holocene in the range of 7.8°C to 9.8°C. This change from cooler to warmer temperatures corresponds with Wattanapituksakul's (2006b) interpretation of the reduction in molar width of *Naemorhaedus* as indicating a warmer climate in the Holocene.

The close correspondence between the Thai and Chinese sequences suggest that finer scale variations in the Thai sequences are most reliably interpreted as changes in monsoon precipitation, since the isotopic variation in the Chinese sequences is almost entirely explained by monsoon variability (Wang et al. 2001, Zhao et al. 2003). The Tham Lod sequence, starting at about 34,000 BP has a period of relatively wet but unstable conditions until about 20,000 BP. This instability is indicated by the high variability in mean $\delta^{18}O$ values during this time. The warm and wet period at 35,000-20,000 BP agrees with the stratified sediments described by Hastings and Liengsakul (1983) and the geomorphological evidence described by Loëffler et al. (1983). The variability in $\delta^{18}O$ values is at odds with the Nong Pa Kho pollen sequence that suggests environmental stability during the Pleistocene, supporting Penny's (2001) interpretation that the characteristics of the dominant Pine/Oak taxa result in an exaggerated impression of community stability.

From about 20,000 BP to about 11,100 BP conditions are at their driest, including the H1 event of local maximum dryness at about 15,600 BP. This is probably the local

signature of the Last Glacial Maximum, when local conditions were very dry and cool in response to global increases in ice sheet area. This generally agrees with pollen sequences from Kwan Phayao and Nong Han Kumphawapi suggesting dry conditions. The Tham Lod sequence ends at about 11,000 BP, leaving a gap until in the data until about 9,800 BP when the Ban Rai sequence begins. This gap, combined with the relatively low chronological resolution of the excavation units, is unfortunate because it means there is no data available to investigate the effect of the Younger Dryas, an event that is controversial as a proposed cause of shifts from hunter-gatherer to agricultural economies in west Asia (Bar-Yosef 2002, Moore and Hillman 1992, Richerson et al. 2001, Willcox et al.). The Younger Dryas does not seem to be evident at any of the Thai pollen cores.

The Ban Rai sequence, starting at about 9,800 BP, suggests consistently and substantially higher precipitation than preceding times. Variability is also reduced, compared to the Tham Lod sequence, although this may be an effect of the shortness of the Ban Rai sequence. Increased precipitation during the Holocene is also demonstrated by the pollen cores, but Holocene climate variability is argued to be higher than during Pleistocene, in contrast to the $\delta^{18}O$ records. As noted above, there is a slight trend towards increasing dryness until the Ban Rai $\delta^{18}O$ sequence ends at 5,900 BP, but the shortness and relatively low resolution of the sequence limits the reliability of further identifications of climate events.

Interpreting variation in the carbon isotope ratios is difficult because of the uncertainty about what controls them, not only in biogenic carbonates but also in speleothems also. Currently the only comparable carbon isotope sequence is from one stalagmite at Hulu dated from about 16,500 BP to about 10,700 BP (Zhao et al. 2003). Fluctuations in this record are interpreted as indicating the relative abundance of plants that use the C_3 photosynthetic pathway (mainly trees) versus those using C_4 photosynthesis (mainly tropical–subtropical grasses) or bioproductivity (that determines the amount of isotopically light organic matter released to the soil) in areas where C_4-type vegetation is not present (Dorale et al. 1998 , Goede 1994), combined with some contribution from inorganic processes acting on soil CO_2 (Baker et al. 1997). In the case of shell carbonate these mechanisms are also likely to be important because soil $\delta^{13}C$ influences river water $\delta^{13}C$ through surface runoff. Given the close relationship between precipitation and bioproductivity in monsoonal regions, it is reasonable to expect that $\delta^{13}C$ values

will become more negative during periods of higher precipitation, indicating a dominance of trees or generally greater bioproductivity.

At a broad level, this relationship between $\delta^{13}C$ and bioproductivity appears to explain the Thai isotope records. During the Pleistocene when $\delta^{18}O$ values suggest drier conditions, the $\delta^{13}C$ values indicate either dominance of tropical–subtropical grasses or lower bioproductivity (Figure 7.6). Similarly, the increase in summer monsoon rains suggested by $\delta^{18}O$ values during the Holocene is complemented by $\delta^{13}C$ values that indicate an expansion of forest vegetation or greater bioproductivity. At a finer scale, influences on $\delta^{13}C$ values are harder to discern with the available data and interpretation of the record becomes difficult. For example there is a sustained downward trend from 20,000 BP to about 11,500 BP, but this is difficult to explain as increased forest vegetation because it occurs at a time when oxygen isotopes suggest hightened dryness. This ambiguity in the $\delta^{13}C$ sequence from *Margritanopsis laosensis* means that the $\delta^{18}O$ sequence will be relied on as the primary palaeoclimate proxy.

Refining the hypotheses

Now that a climate history is available for the two sites it is possible to revisit the synchronic hypotheses proposed in the previous chapter and refine them by adding a diachronic dimension.

The patch choice model predicts that periods of relatively higher patch yields, lower variance in patch richness or smaller distances between patches will have evidence of relatively more intensive human occupation as people exploit a reliable and abundant resource. In this case it is predicted that during wetter times there will be higher densities of artefacts because the landscape can support more human activity. Linking human population size to stone artefact assemblages is fraught with uncertainty, but assuming all things are equal, a higher carrying capacity will result in more people engaging in more stone artefact making and repairing episodes. At the broadest level, it can be predicted that occupation during the Holocene will result in higher densities of stone artefacts that during the Pleistocene. This means that Ban Rai, with its Holocene sequence of occupation, is expected to have higher densities than Tham Lod, which is an entirely Pleistocene sequence. This is at odds with the synchronic hypothesis generated by the patch choice model which predicts the opposite, based on Tham Lod's favourable location relative to resources such as water and stone. Testing these competing hypotheses is an excellent opportunity to discern the relative

importance of proximity to resources versus climate in determining settlement patterns.

The central place model predicts that as travel and transports costs increase then so should the amount of pre-processing of resources to optimize the delivery of useful material at the central place. There is little reason to think that climate change at the scale described here would alter the distance of the sites from stone sources. However, it is likely that drier conditions would favour an increase in the range of open montane forests and a contraction of the denser semi-evergreen and dry deciduous forests. This increase in relatively low biomass environments would increase travel times for the collection of food resources. Similarly, travel time for procuring water would also be increased during drier conditions as the availability of water would be restricted because of higher evaporation and reduced precipitation. The prediction for the stone artefact assemblage is that during drier periods there will be greater assemblage reduction compared to wetter periods. During dry periods people are predicted to have minimised travel and transport costs by minimising the mass of stone that they carry, with more extensive preparation of artefacts before carrying them to other locations. At the broadest level, Tham Lod is predicted to have the most extensively pre-processed assemblage because of its Pleistocene occupation. Once again, this is at odds with the synchronic hypothesis that predicts Ban Rai to have higher assemblage pre-processing because of its greater distance to the stone source. These conflicting predictions present another opportunity to test the relative importance of climate and distance to resources.

Finally, the model of optimal dispersion and group size predicts that a residential settlement pattern is adaptive in stable/evenly dispersed environments and a logistical settlement pattern is a better strategy in mobile/clumped environments. From the available data it is difficult to discern how the structure and distribution of resources would have changed under different precipitation regimes. However, drier conditions will result in an expansion of the low density montane forests as well as making surface water less available. In this case, drier conditions can be equated with mobile/clumped environments, and therefore the expected signal is more intensive assemblage reduction than during wetter periods. At the broadest level, highest assemblage reduction is expected at Tham Lod compared to Ban Rai because of the Pleistocene aridity that characterises occupation at Tham Lod compared to the

increased precipitation during the Holocene occupation at Ban Rai. Like the previous two models, this prediction seems paradoxical given the opposite synchronic hypothesis derived from this model in the previous chapter. The question of what is the greatest influence of hunter-gatherer organisation of stone artefact technology, climate or resource availability, has profound implications for all three models under investigation here.

Summary

This chapter has reviewed previous work on palaeoclimate reconstruction relevant to the study area. It is noted that there has been ambiguity about the importance of climate change as an influence on human behaviour in mainland Southeast Asia. This previous work is argued to be limited because of the distance of the pollen cores from the study area, the importance of local influences on the pollen sequence and the extent of anthropogenic disturbance interfering with the climate signal. Currently available palaeoclimate data from the study area is similarly limited by poor preservation and low chronological resolution. In response to these limitations a new palaeoclimate proxy was developed by analysing oxygen isotope ratios in the freshwater bivalve *Margaritanopsis laosensis* which is ubiquitous in the excavated sequences at Tham Lod and Ban Rai. The theory of isotope geochemistry is presented, a model of isotopic variation in *Margaritanopsis laosensis* developed and the analytical methods and results are described. Surprisingly good verification of the isotope record at Tham Lod and Ban Rai comes from speleothem records from China. A broad interpretation of climate history at Tham Lod and Ban Rai is offered.

This new palaeoecological record has been used to make some refinements to the predictions derived from the three optimal foraging models presented in chapter three. Interestingly, at the broadest level the refined predictions incorporating the effects of climatic variation over a synchronic dimension are exactly opposite to the diachronic predictions derived from the same models in the previous chapter. This is largely a result of the discrete periods of occupation that the sites represent, with Ban Rai representing the Holocene and Tham Lod representing the Pleistocene. This unusual situation of conflicting hypotheses from the same models presents an excellent natural laboratory to examine the competing effects of climatic variation and proximity to resources on human technological organisation.

In addition to this broad level analysis, a high resolution analysis is described in the next chapter. The oxygen isotope sequence will be integrated with data from the flaked stone artefact assemblages at the level of the excavation unit, providing millennial scale resolution. This allows more detailed examination of the relationship between the organisation of stone artefact technology and inferred variation in precipitation and associated ecological changes.

Figure 7.1. Results of 30 samples taken from umbo to margin of a shell from Ban Rai excavation unit 11. Values on the vertical axis show maximum, mean and minimum.

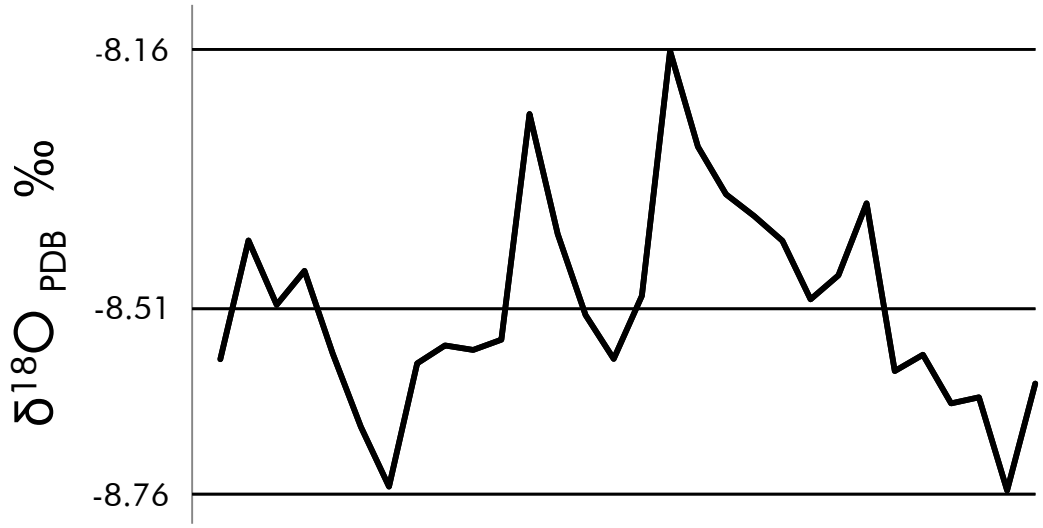


Figure 7.2. Results of 30 samples taken from umbo to margin of a shell from Tham Lod excavation unit 28. Values on the vertical axis show maximum, mean and minimum.

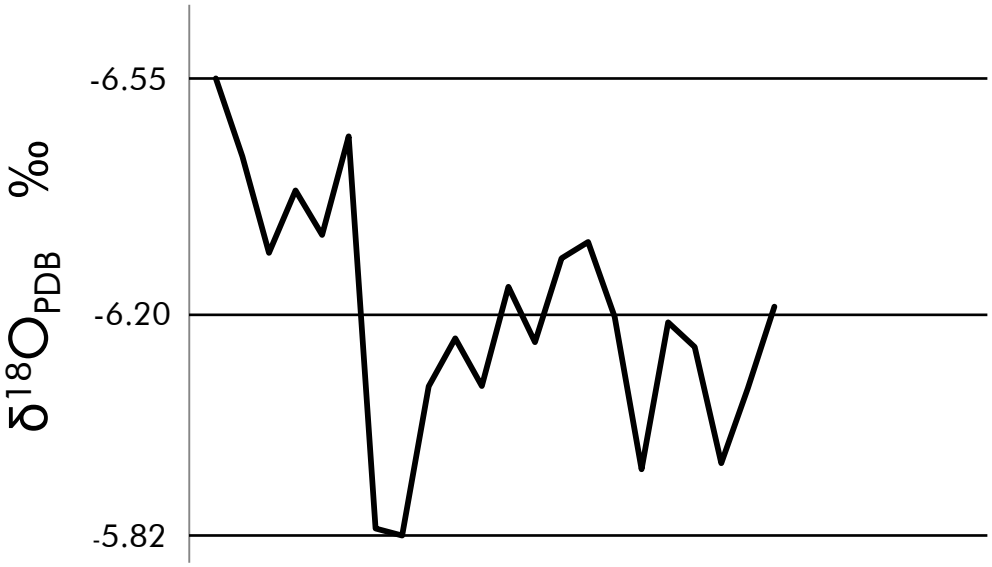


Figure 7.3. Results of oxygen isotope analysis of samples from Tham Lod and Ban Rai spanning 30,000 years. Data markers show mean and 95% confidence interval.

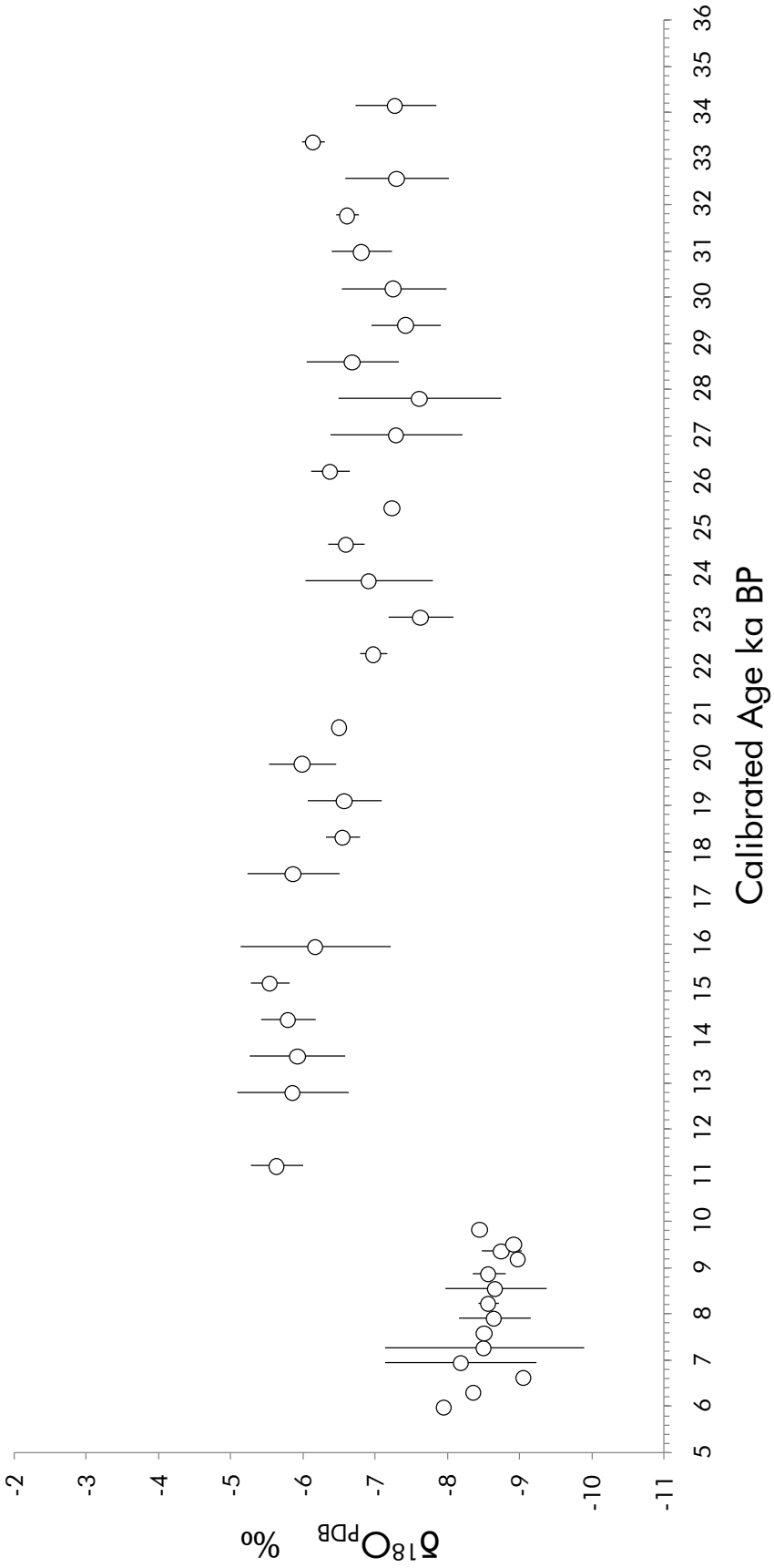


Figure 7.4. Pleistocene sequences of $\delta^{18}O$ from Hulu, China and Tham Lod. Data markers for Tham Lod show mean and 95% confidence interval.

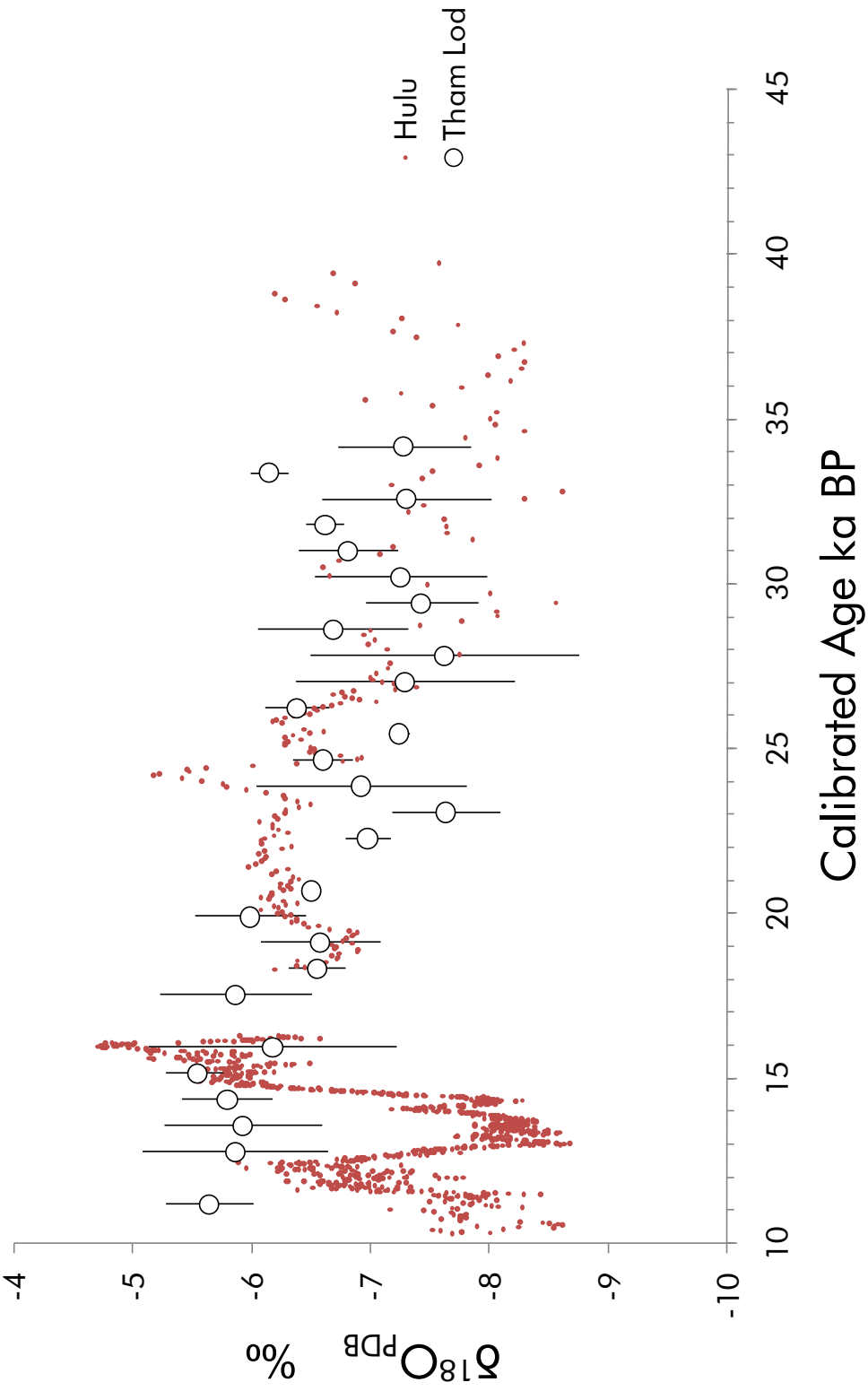


Figure 7.5. Pleistocene sequences of $\delta^{18}O$ from Dongge and Hulu, China and Ban Rai. Data markers for Ban Rai show mean and 95% confidence interval.

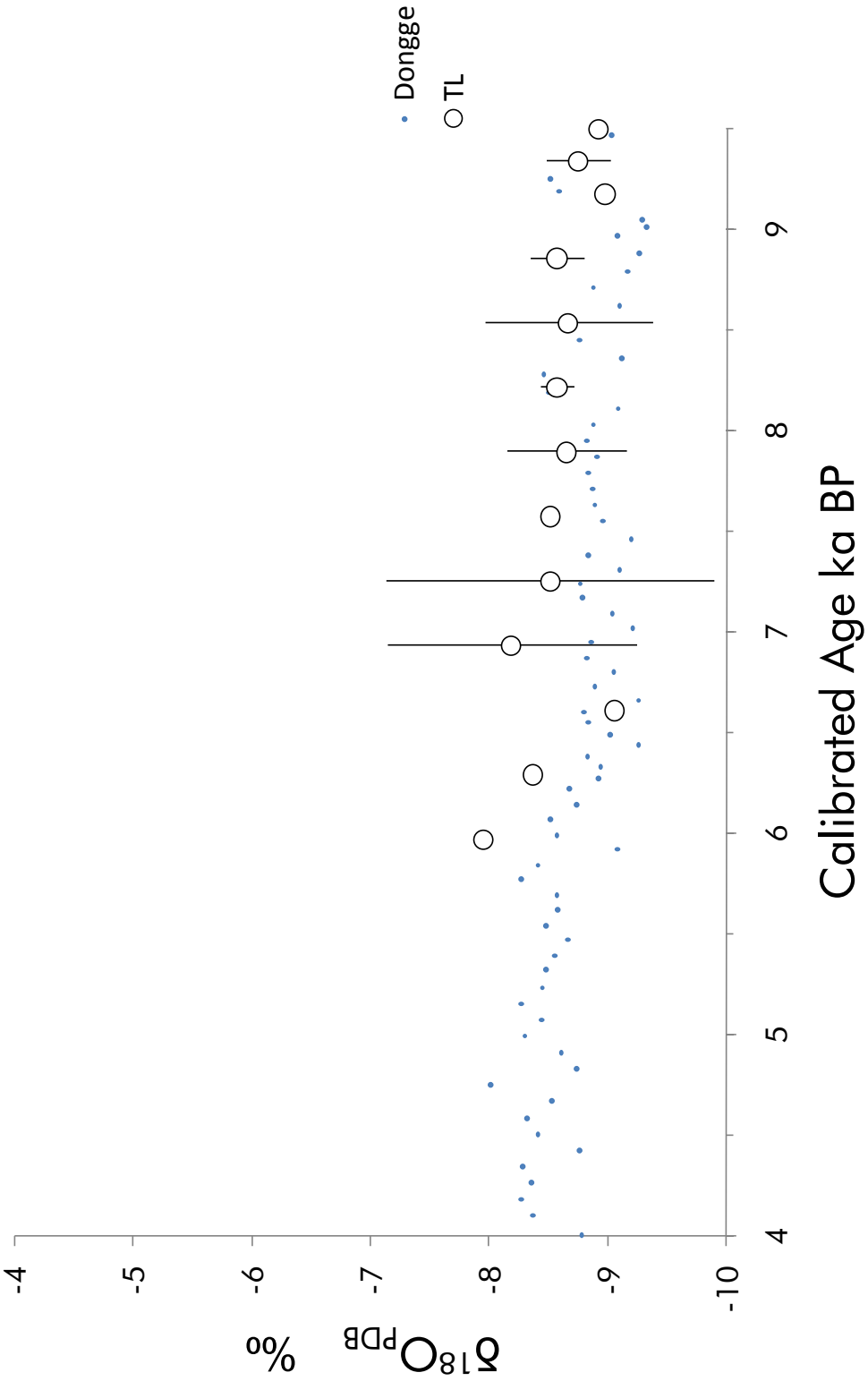
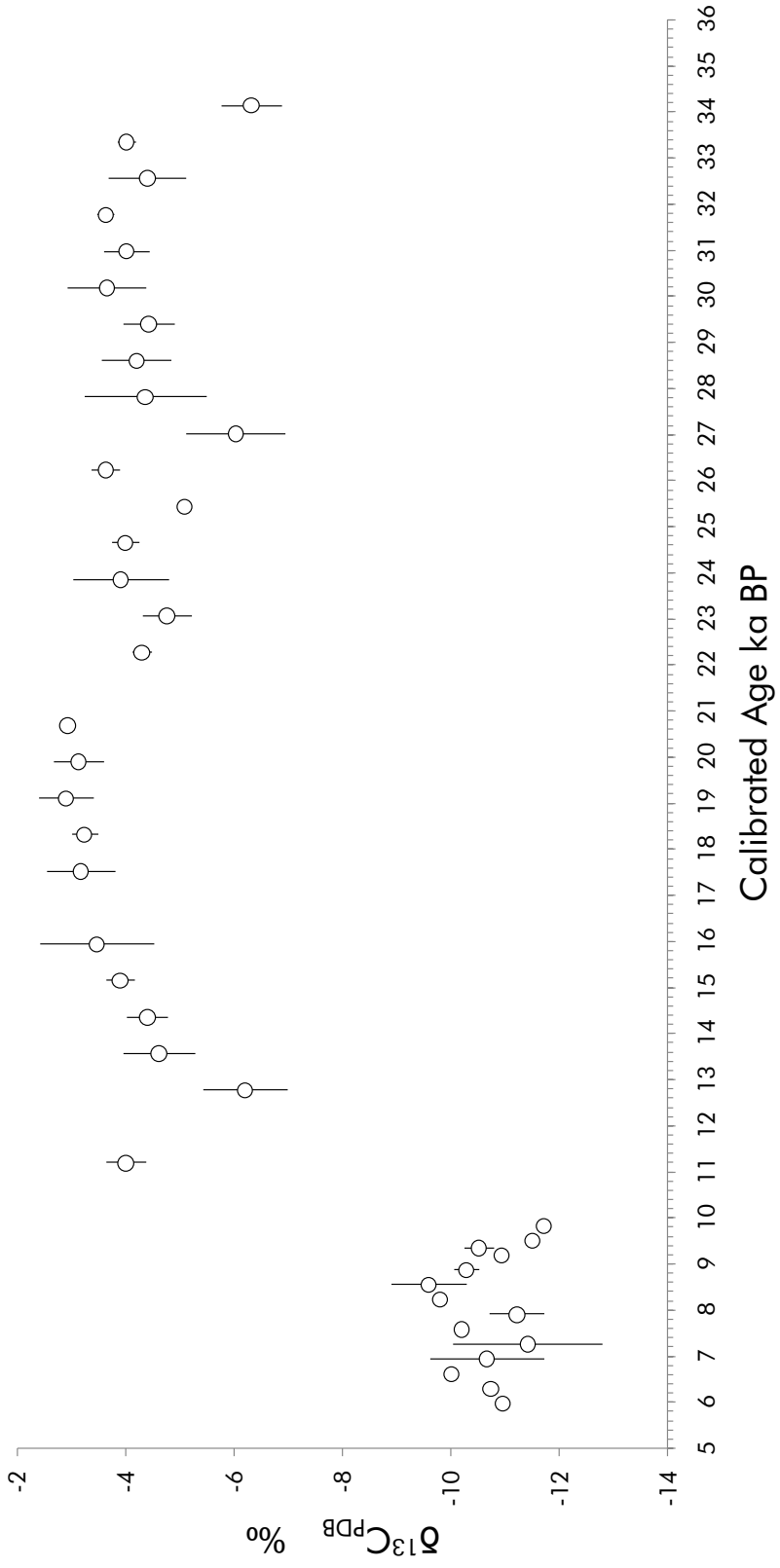


Figure 7.6. Results of carbon isotope analysis of samples from Tham Lod and Ban Rai spanning 30,000 years. Data markers show mean and 95% confidence interval.



8. Testing the hypotheses: Results of the flaked stone artefact assemblage analysis

Introduction

The previous two chapters described some of the key environmental variables that are likely to have had some influence on the strategies that human foragers used to organise their stone technology. The aim of this chapter is to examine the flaked stone artefact record to test predictions developed in the previous two chapters about how sensitive stone artefact technology was to these environmental variables. This chapter presents the results of the analysis of flaked stone artefacts from Tham Lod and Ban Rai. The chapter is organised around testing the hypotheses derived from the three models presented earlier. In many of the results described below correlations are used to provide a summary description of the interaction between changes in climatic conditions measured by $\delta^{18}O$ values and behaviours relating to stone artefact technology. In general, for most influences on human behaviour, correlations range between 0.0 and ±0.5 and rarely exceed ±0.5, unlike the physical sciences where higher correlations are relatively common (such as the depth-age models discussed in chapter six). For example Feingold's (1994) meta-analysis of correlations between gender and assertiveness produced a correlation of 0.25. Similarly, among identical twins raised together, the correlation for most personality traits is 0.50 (Dunn and Plomin 1990, Loehlin et al. 1988). Since this chapter is concerned with human behaviours relating to stone artefact technology, correlations greater than the arbitrary value of ±0.3 are considered to be behaviourally meaningful and requiring explanation. The raw data that this chapter is based on are available by contacting the author via the Department of Archaeology and Natural History, Research School of Pacific and Asian Studies, The Australian National University.

Patch Choice Model

In brief, the predictions derived from this model are that locations and periods of higher patch yields will have evidence of more intensive human occupation as people exploit a reliable and abundant resource. Considering only the contrasting locations of the sites, the synchronic hypothesis predicted that Tham Lod was more intensively

occupied than Ban Rai. However, given the stark difference between Holocene and Pleistocene climates in the study area, the diachronic hypothesis suggests that occupation during the wetter and warmer Holocene should be more intensive, so Ban Rai should be more intensively occupied than Tham Lod. To test these competing predictions, stone artefact discard rates are used here as a proxy of the intensity of human occupation.

A standardised measure of artefact discard is needed for reliable comparison between the two sites. First, the minimum number of artefacts (MNA) was calculated for each excavation unit. This is equivalent to the minimum number of flakes (MNF) plus the total number of cores for each raw material. A simple count of artefacts is unreliable because taphonomic processes can cause fragmentation. Fragmentation of artefacts means that the number of flakes is likely to be less than the number of pieces in the assemblage. The MNF method described in chapter five offers a way to calculate a reliable estimate of artefact abundance. Second, the MNA was standardised as a density measurement by dividing it by the volume of the excavation unit to account for the different excavation strategies at the two sites. This was especially important at Tham Lod where a large intrusive rock significantly altered excavation unit volume as depth increased. Finally, the MNA density measurement is expressed as a density per thousand years to allow comparison between Ban Rai and Tham Lod because their excavation units represent different periods of time. The assumption in using this metric is that the two rockshelters have had relatively continuous deposition of sediments with no substantial loss of sediments to erosion.

Tham Lod

Of all the flakes and flaked pieces recognised from Tham Lod area one (n = 1935), about 30% (n = 573) were broken (Table 8.1). Minimum numbers of flakes in the Tham Lod assemblage were separately calculated for three classes of raw materials: quartzite, sandstone and others. At Tham Lod, 60% (n = 1164) of flakes and flaked pieces were quartzite and 34% (n = 663) were sandstone, together representing 94% (n = 1827) of all flakes and flaked pieces at Tham Lod. These figures only represent flaked stone artefacts from excavation unit seven to unit 32 which is the last excavation unit containing artefacts. The units above unit seven are disturbed so artefacts recovered from those units are excluded from the analysis because of their uncertain provenance. The estimated minimum number of artefacts from Tham Lod in this analysis is 1722,

discarded over about 20,000 years (15,100 – 34,900 BP). Figure 8.1 shows the change in MNA per cubic metre per hundred years over time at Tham Lod. Discard rates range from 3.8 to 29.6 artefacts per cubic metre per hundred years, with an average of 13.8. The main peak in artefact discard is around 30,200-33,300 BP with a secondary peak at about 21,500-23,100 BP. The earlier peak is appears to have been an abrupt increase and decrease in discard while the later peak suggests a more gradual change in discard rate.

Ban Rai

Flakes and flaked pieces from all excavation units at Ban Rai area three are included here (n= 1423), consisting of 77% (n = 1095) complete flakes and 33% (n = 328) flaked pieces (Table 8.2). Amongst flakes and flaked pieces, the main raw material classes at Ban Rai were quartzite (49%, n = 699), andesite (45%, n = 638) and others (6%, n = 86). After calculating minimum artefacts for each excavation unit (Figure 8.2), the range of artefact discard was 2.0 to 466.7 artefacts per cubic metre per hundred years, with an average of 126.4. The main peak in artefact discard occurs at 8700-8500 BP and a smaller peak spread from 7600 to 7100 BP. Both peaks represent relatively abrupt changes in discard rates.

Discussion

The range of discard rates is relatively low overall, suggesting relatively low intensities of site use at both sites. The highest discard rates are 29.6 and 126.4 artefacts per cubic metre per hundred years at Tham Lod and Ban Rai. By comparison, the average number of flakes from a single core in the experimental assemblage discussed in chapter five was 21. This suggests that during the period of maximum discard at these two sites one core was reduced roughly every 25 years. In other words, this degree of activity might reflect small numbers of people visiting the sites for a day or two every few years or for a week every century. The apparent abruptness of the peaks in discard at the two sites is difficult to explain and may be a result of the time-averaging caused by the excavation method. A parsimonious interpretation of the abruptness of the changes might relate to the flexibility of technological change. For example, the changes might suggest that people were capable of substantially altering their artefact discard behaviours within a minimum of 160 years (the average time represented by an excavation unit at Ban Rai).

Stone artefact discard rates are nearly an order of magnitude higher at Ban Rai compared to Tham Lod (Figure 8.3). This large difference supports the diachronic prediction that Holocene occupation will be more intensive because of increased biomass resulting from increased precipitation and warmth. The prediction that Tham Lod would have higher intensities of occupation because of its favourable location in high biomass forests and close proximity to the river is not supported. Examination of higher resolution correlations between artefact discard and climatic conditions offers similar support for the importance of climate influencing occupation intensity. The correlation between artefact discard and $\delta^{18}O$ values at Tham Lod is -0.205 [-0.585, 0.176] and at Ban Rai is 0.099 [-0.384, 0.582]. Although these correlations are weak and probably not statistically significant (since the 95% confidence intervals for both includes 0.0), it is notable that the Tham Lod correlation is slightly negative and is greater in absolute magnitude than the Ban Rai correlation. The negative correlation means that people at Tham Lod may have tended to discard more artefacts when precipitation was higher and discarded fewer artefacts when conditions were drier. The main peak in artefact discard at Tham Lod at about 30,200-33,300 BP is within the warm and wet period identified from the multiple palaeoclimate proxies discussed in the previous chapter. Recalling that the average chronological resolution of the excavation units at Tham Lod was about 791 years, this correlation probably reflects millennium-scale or greater variations in adaptation rather than shorter scale patterns such as the use of the rockshelter during the rainy season versus the dry season. The greater magnitude of the correlation in the Tham Lod sequence compared to Ban Rai sequence suggests that people's decisions about occupation intensity were more sensitive to climatic change during the Pleistocene than during the Holocene. Although variation in stone artefact discard is much higher at Ban Rai compared to Tham Lod, it does not appear to co-vary with $\delta^{18}O$ values.

An important caveat relevant to these findings is that artefact discard rates are only an approximate proxy for occupation intensity. The relationship between artefact discard and occupation intensity is complex and influenced by three factors. First is the nature of the use of the rockshelter. If the loci of activity in the rockshelters shifted over time then the excavated samples may not accurately reflect overall changes in occupation intensity. This possibility is difficult to exclude without excavation of a larger area at each site. The influence of variations in technological strategies on the reliability of artefact discard rates as a proxy for occupation can be evaluated by examining the

correlation between quantities of faunal remains and stone artefacts. An increase in faunal remains would be expected during increased occupation intensity because more people would be expected to be using the rockshelters for processing and consuming food. The correlation between total mass of faunal remains and MNA at Tham Lod is -0.124 [-0.463, 0.214] and at Ban Rai is 0.287 [-0.103, 0.679]. Mass of faunal remains is a problematic measure of faunal abundance because of variations in the allometric ratios between bone mass and carcass mass for individuals in the same taxa of different sex and age of individuals of different taxa. Similarly, larger animals will contribute a larger mass of bone to the assemblage and burning of bone changes bone mass (Casteel 1978, Klein and Cruz-Uribe 1984, Reitz and Wing 1999). Nevertheless, it is the only abundance measure collected by the HAPP for each excavation unit, other measures were calculated on aggregates of excavation units. The problems with mass as an abundance measure make the very weak correlations between mass and MNA difficult to interpret, although they do cast some doubt on the reliability of artefact discard as a proxy for occupation intensity.

A second factor is the possibility of different rates of sediment accumulation and erosion at the two sites that may cause the same intensity of occupation to appear as highly divergent densities of artefacts. The different positions of the sites on the valley sides and different distances to the river may undermine observations about the contrasting densities of artefacts at the two sites. However, in the absence of detailed sediment histories it is not possible to further investigate the influence of different rates of sediment accumulation on artefact densities.

A third factor that influences the relationship between artefact discard and occupation intensity is technological change. Technological change could be a confounding variable if there was substantial change in technological strategies that altered the output of knapping events to produce substantially different numbers of flakes, but without any change in the number of people visiting the site or the duration and frequency of their visits. This will be addressed later in this chapter and the reliability of discard rates as a proxy for occupation intensity will be reassessed.

Table 8.1: Tham Lod: flake breakage by raw material

	Complete	Proximal	Medial	Distal	Longitudinal Right	Longitudinal Left	Estimated MNF	% MNF
Quartzite	760	49	2	1	209	143	1018	59
Sandstone	513	21	0	1	62	66	600	35
Other	89	5	1	0	10	3	104	6
Total	1362	75	3	2	281	212	1722	

Figure 8.1:. Tham Lod: total MNA per cubic metre per 100 years

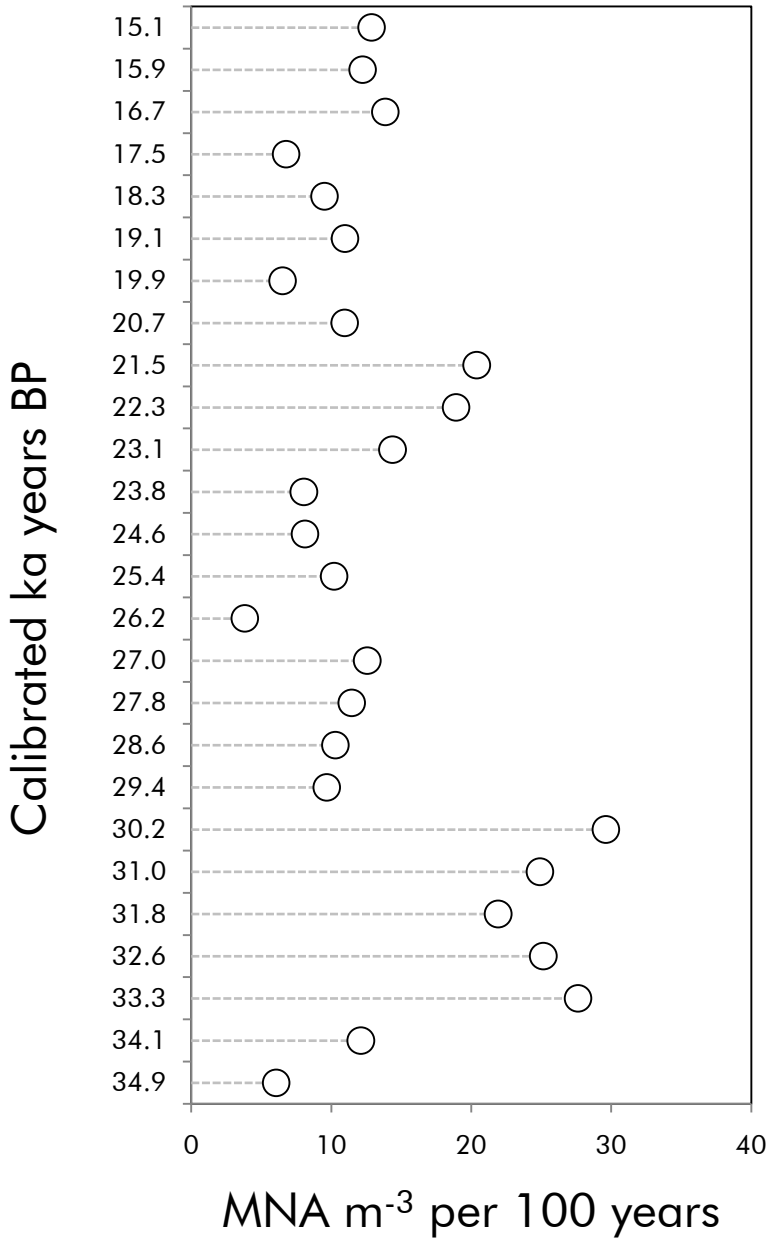


Table 8.2: Ban Rai: flake breakage by raw material

	Complete	Proximal	Medial	Distal	Longitudinal Right	Longitudinal Left	Estimated MNF	% MNF
Quartzite	529	50	0	0	75	46	654	49
Andesite	493	39	0	0	56	53	588	44
Other	73	1	0	0	8	4	82	6
Total	1095	90	0	0	139	103	1324	

Figure 8.2: Ban Rai: total MNA per cubic metre per 100 years

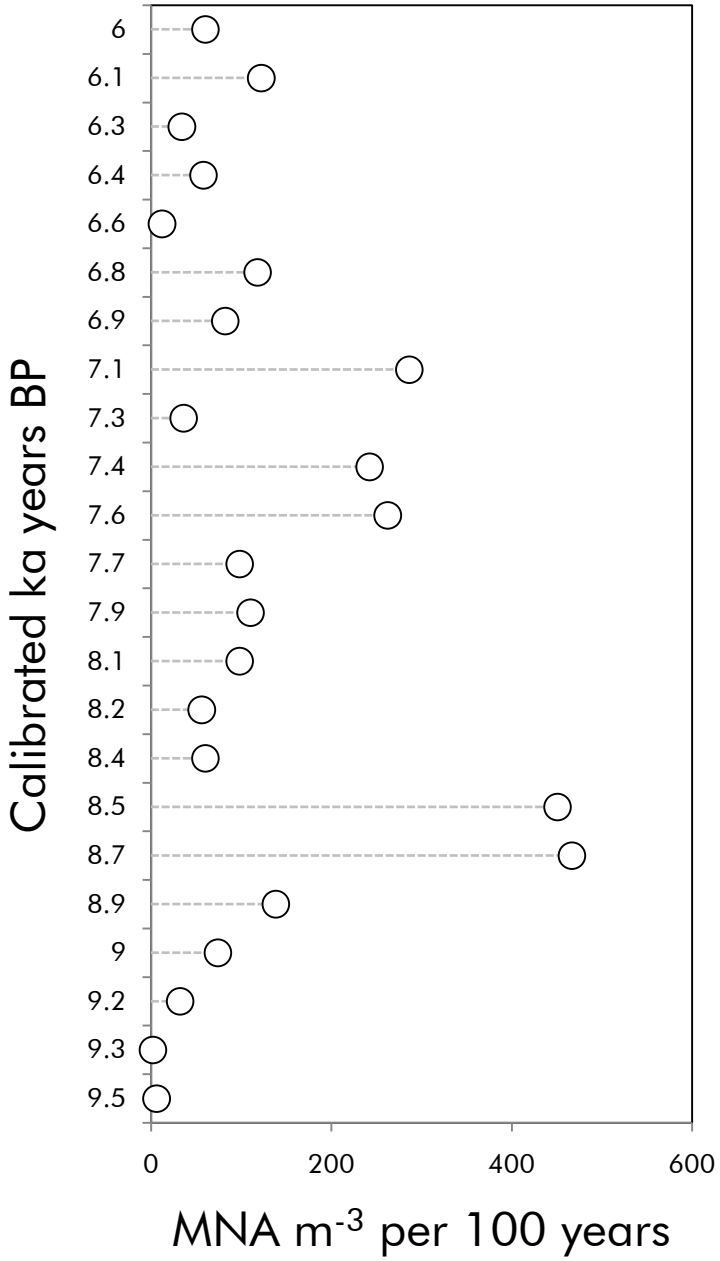
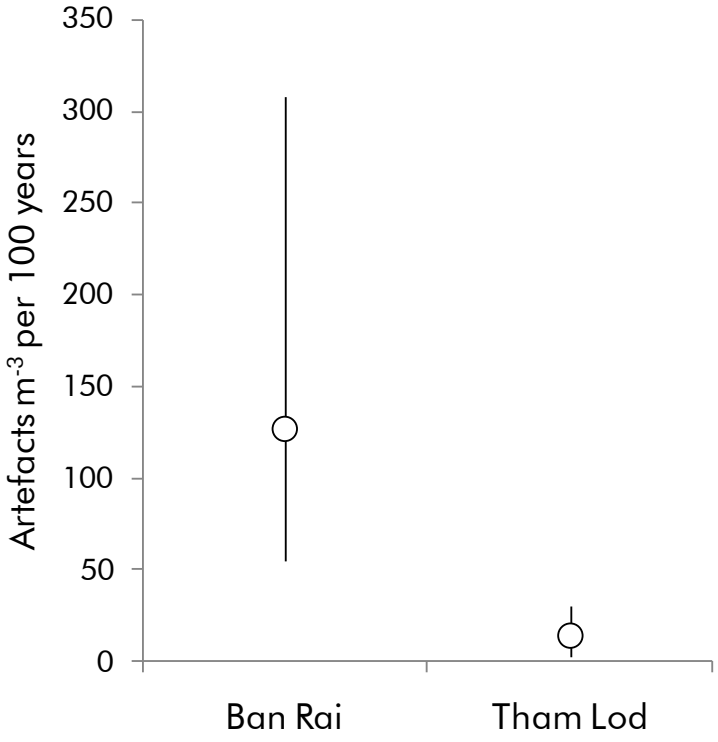


Figure 8.3: Mean and 95% CI for discard rates at Ban Rai and Tham Lod



Central Place Model

The central place model predicts that as travel and transports costs increase then so should the amount of pre-processing of resources to optimize the delivery of useful material at the central place. The term 'pre-processing' is used here only to refer to reduction of an artefact before it arrives at the site of its final use. It does not imply that artefact reduction moves the artefact towards the form of an end product. The attributes of the site locations led to the synchronic hypothesis that predicted Tham Lod would have a lower frequency of pre-processing compared to Ban Rai because of Tham Lod's close proximity to the river as a source of high quality materials for making stone artefacts. On the other hand, consideration of climate history and the timing of site occupation led to the diachronic hypothesis that predicted Tham Lod would have the most extensively pre-processed assemblage because of its Pleistocene occupation, when conditions were drier and travel costs would be amplified.

Measuring the degree of pre-processing in an assemblage was done by analysing core and flake attributes to see how the assemblage differs from what would be expected if the assemblage was produced as part of a closed system without any off-site component. The archetypal closed system is the experimental assemblage described in chapter five. Comparison between the archaeological assemblage and the experimental assemblage is based on the assumption that the lengths of reduction sequences are equivalent. In particular, two methods were employed. First, the ratios of MNF to cores calculated for each site and then for each excavation unit at each site. The expectation is that if stone is processed before it enters the site then the ratio will deviate from the ratio observed in the experimental assemblage which represents a closed system where no introduction or removal occurred. A lower ratio of MNF to cores would be expected in an assemblage where flakes have been removed from the cores off-site during pre-processing to increase the utility of the core as a transported mass of flakable stone.

Second, the size distribution of flake scars on cores was compared to the size distribution of flakes in the assemblage. For this purpose the last five complete flake scars over 5 mm on each core were recorded. This comparison was only undertaken for the whole assemblage from each site because the number of core scars per excavation unit is too low to make reliable comparisons with the distribution of flake lengths. The expectation is that greater difference betweens the distributions of complete flake lengths and core scar lengths will indicate greater degrees of pre-processing. More

specifically, core scar average lengths should be smaller than complete flake average lengths to indicate the presence of some cores that have been introduced to the assemblage with large flakes already removed. A greater difference between average lengths of core scars and complete flakes may indicate a higher proportion of pre-processed cores in the assemblage. Comparison of these metrics with the experimental assemblage may also be useful to calibrate the extent of pre-processing.

Before examining the archaeological data it must be noted that the reliability of the results produced by these methods is compromised by the difficulty of isolating pre-processing from confounding factors. For example, the ratio of MNF to cores not only measures how different an assemblage is from a closed system assemblage where no addition or removal of material has occurred, but is also sensitive to the overall productivity of cores in an assemblage and differential transport of flakes and cores. To extend the example, consider if ten cores were introduced to both assemblages and at Tham Lod each core produced 20 flakes and at Ban Rai each core produced 50 flakes. In this case it would be a mistake to interpret the high MNF to core ratio at Ban Rai as a removal of cores from the assemblage or an increase in flakes being imported into the assemblage. In general it is assumed here that cores are more likely to be imported than flakes because or a core's ability to produce flakes. Other possible measures of pre-processing, such as the amount of cortex on artefacts, are similarly confounded by effects of reduction.

Tham Lod

The ratio of the minimum number of flakes to the total number of cores for all excavation units at Tham Lod is 4.5. The maximum ratio of 107 occurs for sandstone flakes and cores at around 32,600 BP in excavation unit 29 and the minimum ratio of 0.3 occurs for other raw materials at about 27,000 BP in unit 22 (Table 8.3). There is a moderate correlation between the ratio of MNF to cores and MNA (r = 0.317 [-0.181, 0.812] which is mostly explained by the sharp spike in MNF:core values over 30,400-33,600 BP, coinciding with high discard rates over 30,200-33,300 BP.

Figure 8.4 shows the distribution of lengths of all flake scars (n = 1113) recorded on all cores (n = 394) at Tham Lod. Measurements for all five scars were possible for 23% (n = 91) of the cores and more than half of the cores had at least three measurable scars (51%, n = 202). The maximum flake scar length on the cores is 117.9 mm and the minimum is 3.7 mm with a mean of 25.4 [24.7, 26.1] mm. Figure 8.5 shows the

distribution of lengths of all complete flakes (n = 1350) recorded at Tham Lod. The maximum length is 123.3 mm, the minimum is 7.0 mm and the mean is 34.9 [34.2, 35.7] mm.

Ban Rai

The ratio of the minimum number of flakes to the total number of cores for all excavation units at Ban Rai is 11.0. The maximum ratio of 52.5 occurs for quartzite flakes and cores at about 7,100 BP in excavation unit eight and the minimum ratio of 0.7 occurs for andesite at about 6,800 BP in unit six (Table 8.4). As at Tham Lod, there is a moderate correlation at Ban Rai between the ratio of MNF to cores and MNA (r = 0.349 [-0.026, 0.725]. In general at Ban Rai, as the number of artefacts increases, the number of flakes increases also except for the increase in artefact discard at about 8,700-8,500 BP when the ratio of MNF to cores remains relatively low.

Figure 8.6 shows the distribution of lengths of flake scars (n = 389) recorded on all cores (n = 123) at Ban Rai. Core scar data was collected in the same way as for the Tham Lod cores. Measurements for all five scars were possible for 24% (n = 30) of the cores and 63% of cores had at least three measurable scars (n = 77). The maximum flake scar length on the cores is 60.5 mm and the minimum is 7.1 mm with a mean of 20.8 [20.0, 21.7] mm. Figure 8.7 shows the distribution of lengths of all complete flakes (n = 1073) recorded at Ban Rai. The maximum length is 77.9 mm, the minimum is 10.1 mm and the mean is 29.3 [28.61, 29.93] mm.

Discussion

The ratio of MNF to cores when all excavation units are considered together is higher at Ban Rai (11.0) than at Tham Lod (4.5). As an example of a closed system, the experimental assemblage described in chapter five has a range of MNF to core ratios of 1 to 58, with an average of 19.9. The ratio at Ban Rai is closer to the average ratio in the experimental assemblage, suggesting that than the Ban Rai is characterised by less pre-processing of stone than Tham Lod. However, as noted above, the ratio of MNF to cores is a very simple assemblage metric and this direct comparison with the experimental assemblage may be misleading.

For example, the difference in MNF to core ratios between Tham Lod and Ban Rai can be explained by a number of possibilities: cores have been removed from Ban Rai; flakes have been introduced to Ban Rai independent of the cores they were struck

from; flakes have been removed from Tham Lod; or previously worked cores have been introduced to Tham Lod without any further flake production at the site. The only two of these that are relevant to the question of pre-processing are the possibilities of flakes being introduced to Ban Rai without their parent cores (assuming that the flakes are the end point of pre-processing and the cores have been discarded off-site as waste) and previously worked cores being introduced to Tham Lod with no further flake production (assuming that the core is the optimum load). Unfortunately the available evidence does not discern between these two possibilities since the assumptions about the intended utility of the transported material cannot be tested. The safest conclusion here is that these results hint at more pre-processing at Tham Lod, but the method does not permit a high level of confidence in this finding. Correlations between the ratios of MNF to cores and $\delta^{18}O$ values are low for both sites, suggesting no influence of climate on this measure of pre-processing (Tham Lod: r = -0.181 [-0.557, 0.194], Ban Rai: r = -0.007 [-0.598, 0.582].

Like the MNF:core data, the flake metrics data require careful consideration before they can be used for hypothesis testing. The greater maximum and mean values of the flake lengths compared to the core scars at both sites is not relevant to testing pre-processing hypotheses. The difference in these means is expected because the larger flake scars on the cores corresponding to the large flakes are absent due to the removal of these scars from the core during early stages of core reduction. After the early stages of flake reduction these flake scars are now dorsal flake scars on large flakes. Differences between the average core scar length and average complete flake length are almost non-existent between the two assemblages. Figure 8.8 shows the average and 95% confidence intervals for core scar lengths and complete flake lengths for the two sites. For Ban Rai the difference is 8.5 mm and for Tham Lod the difference in 9.5 mm. With only 1 mm between the two assemblages, these differences in point values do not immediately suggest much difference in pre-processing. On the other hand differences in the shape of the distributions of values between the mean and maximum suggest that some complicated differences do exist.

Figure 8.9, Figure 8.10 and Figure 8.11 show the probability density functions for the lengths of flakes and flake scars on cores at Tham Lod, Ban Rai and the experimental assemblage from chapter five. These probability density function plots are smoothed versions of the histograms that are more suitable for visual comparison. Of particular

relevance to the central place model is the shape of the curves in the region between the mean and maximum values for the three assemblages. This region is relatively symmetrical for the Tham Lod assemblage but the Ban Rai and experimental assemblages shows an unusual asymmetry. This asymmetry reflects the complex distributions of larger flake scar lengths as the core geometry shifts during reduction. Similarly, the asymmetry in the distribution of complete flake lengths for Ban Rai and the experimental assemblage probably reflects complex relationships in changing core geometry. Given that the experimental assemblage is the control data for a closed assemblage, the similarity between Ban Rai and the experimental assemblages indicates that Ban Rai was more of a closed assemblage than Tham Lod. More formal support for this conclusion is provided by Two-Sample Kolmogorov-Smirnov tests that show no significant differences between the distribution of flake scar lengths on cores from Ban and the experimental assemblage (ks = 0.126, $p = 0.095$). For all of the other pairs of distributions the Kolmogorov-Smirnov tests show that each pair of observations could not reasonably have come from the same distribution. This supports the results of the MNF:core data that pre-processing was more frequent at Tham Lod.

The difference between the minimum values of core scar lengths and flake lengths, where minimum flake lengths are consistently greater than minimum core scar lengths, may be in part due to recovery biases that neglected to collect smaller flakes from the sieves during excavation because they are less distinctive than larger flakes. To test this possibility I sieved two cubic metres of excavated sediments from spoil heaps at Tham Lod through a 1 mm sieve. A small number of additional flakes and flake pieces were recovered, but they were all within the size range of the assemblage recovered by the HAPP. It is also possible that the seasonal rains wash smaller pieces off the surface of the rockshelter before they can be incorporated into the matrix. If recovery and taphonomic biases can be assumed to have a small effect on the distribution of flakes smaller than the average length, then differences between the two assemblages might be relevant to differences in pre-processing. However, inspection of the probability density functions suggests that there is little difference between the two sites in the region between the mean and the minimum values. So if these data in this region of the distribution are relevant to the question of pre-processing then they do not support substantial differences between the two sites.

A more general limitation of this analysis is that pre-processing is difficult to reliably measure independently of general artefact reduction. It was noted earlier that the ratio of MNF to cores measures not only how different an assemblage is from a closed system assemblage where no addition or removal of material has occurred, but is also sensitive to the overall productivity of cores in an assemblage. The problem is that pre-processing is a special kind of stone artefact reduction – one that only occurs in transit - and is difficult to unambiguously measure. This is a unique problem for stone artefacts because it is unlike other types of resources that have relatively distinctive low-utility or no-utility components. For example, resources that have been productively modelled using central place foraging theory typically have components that are readily recognisable as waste suitable for removal during pre-processing prior to consumption. Acorns and mussels have shells and mammals have bony sinewy parts such as phalanges, metatarsi and caudal vertebrae (Bettinger et al. 1997, Bird and Bliege Bird 1997, Nagaoka 2005).

With stone, especially when the assemblage is dominated by informal and unretouched pieces, it is less clear about what can be considered low-utility or no-utility components. Only in special cases when the final stone product can be identified with some certainty, such as in the study by Beck et al. (2002) of Palaeoarchaic bifaces from the Great Basin, are more reliable statements about pre-processing of stone possible. But even with bifaces, Beck et al. (2002) claim that the point of maximum utility is difficult to measure because both the biface and the flakes removed from it have degrees of utility that vary depending on the intent of the manufacturer; the biface might have been a finished tool, a blank or a core. As argued in chapter four, intentionality in mainland Southeast Asian flaked stone artefact manufacture is an unquantifiable variable, so if intention is important for understanding pre-processing, as Beck et al. claim, then the role of the manufacturer's intent in determining stone utility is another substantial confounding influence for the quantification of utility.

In the relatively simple stone artefact assemblages analysed here, obtaining reliable measurements of utility or intentionality is beyond the ability of current methods. However, it is possible to assess the influence of one possible confounding variable with data produced for testing the predictions of the optimal dispersion model. If there is a high correlation between the MNF:core values and the key reduction variables at the two sites then it is possible that increases in MNF:core values are determined by the

increased numbers of flakes produced when assemblage reduction intensity increases. This would imply that the reliability of MNF:core as a measure of pre-processing is low. At Ban Rai the correlations between the eight key reduction variables described in chapter five (overhang removal, interior platform angle, amount of dorsal flake scar, percentage of dorsal cortex and the four categories of dorsal cortex location) and MNF:core values are all between 0.0 and ±0.3 and at Tham Lod the correlations are similarly low, between 0.0 and ±0.26, except for flakes with 100% cortex (r = -0.392 [-0.645, -0.139]). The correlation between flakes with 100% cortex and MNF:core values suggests that as the number of flakes relative to cores increases, the proportion of flakes with 100% cortex decreases, a relationship that might be expected as core reduction is extended and increasing numbers of flakes are removed after the cortex-bearing flakes are all detached. However, the overall low correlations between the other five variables measuring assemblage reduction and MNF:core values suggest that assemblage reduction intensity in general is not a major confounding factor and that the MNF:core measure may be useful as an indicator of pre-processing.

To summarise the results of testing the predictions of the central place model, Ban Rai appears to be closer to the paradigmatic closed assemblage represented by the experimental assemblage, so pre-processing appears to have been more important at Tham Lod. This supports the prediction that Tham Lod would have the most extensively pre-processed assemblage because of its Pleistocene occupation, when conditions were drier and travel costs were greater than during the Holocene. These results support the importance of climate over location and proximity to resources in human forager adaptation. The possibility of the reliability of these results being compromised by confounding factors related to assemblage reduction was explored and found to be minor, but limiting the degree of confidence that can be placed in the intpretations.

Table 8.3: Tham Lod: Ratios of MNF to cores, maximum and minimum values highlighted, empty cells indicate no cores.

Calibrated years BP	Sandstone	Quartzite	Others	All materials combined
14,100	21.0	4.0	1.0	5.2
14,900	1.8	10.6		6.4
15,700	3.0	14.3	2.3	7.3
16,500	1.0	3.0	3.0	2.1
17,300	19.0	11.5	3.3	8.7
18,200	0.9	7.0	4.0	2.9
19,000	1.9	2.7		2.4
19,800	4.3	4.5		4.4
20,600	2.6	3.8	1.3	2.8
21,400	2.6	1.7	0.5	2.2
22,200	11.5	3.6	1.0	5.2
23,000	2.8	7.0	1.0	3.3
23,900	4.7	6.5		4.6
24,700	2.4	2.4		2.5
25,500	5.5	0.6		1.5
26,300	7.8	1.5	0.3	2.5
27,100	1.5	1.4	4.0	1.5
27,900	2.8	1.6	3.0	2.2
28,700	1.2	0.9		1.1
29,500	11.2	3.4	1.5	6.3
30,400	48.5	5.6		19.3
31,200	30.7	5.7	14.0	17.6
32,000	107.0	15.0		47.3
32,800	11.3	7.2	4.0	9.3
33,600	37.0	16.0	3.0	18.7
34,400		2.0		29.0

Figure 8.4: Tham Lod: Distribution of flake scar lengths on all cores.

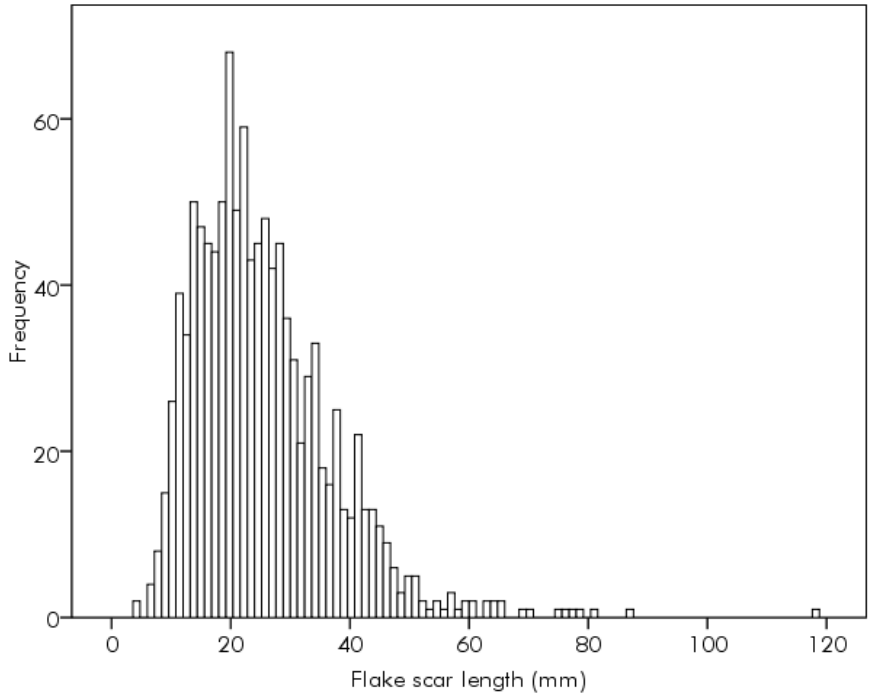


Figure 8.5: Tham Lod: Distribution of flake lengths for all complete flakes.

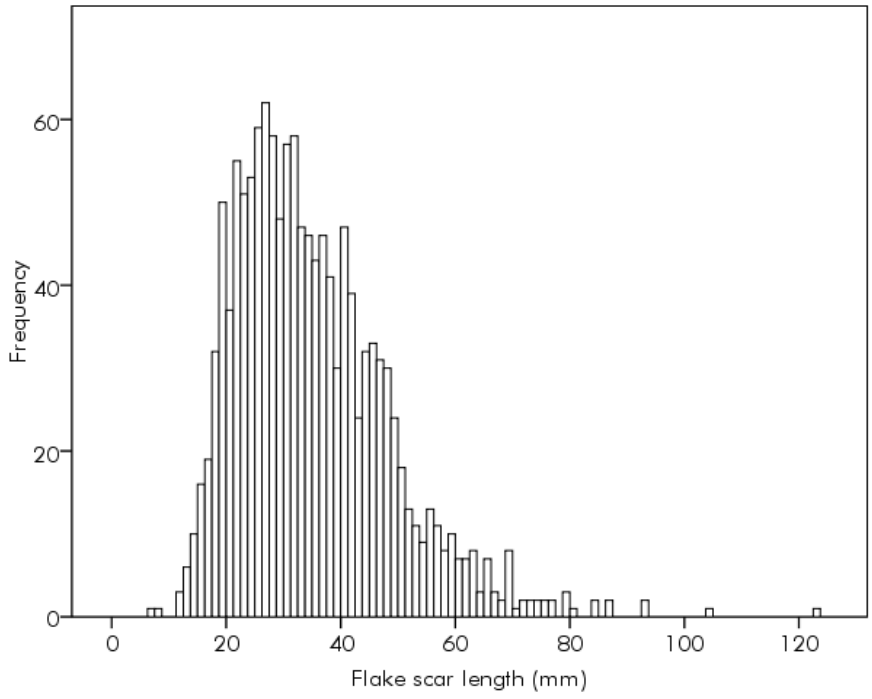


Table 8.4: Ban Rai: Ratios of MNF to cores, maximum and minimum values highlighted, empty cells indicate no cores.

Calibrated years BP	Andesite	Quartzite	Others	All materials combined
6400		12.0	1.0	9.0
6500		7.2		9.2
6600		16.0		16.0
6800	2.0	6.0		4.2
6900				5.0
7000	0.7		3.0	13.8
7100	4.5			10.0
7300		52.5		70.5
7400	7.0			8.5
7500	7.0		12.0	29.3
7600	13.7	25.7	3.5	15.6
7800		28.0		48.0
7900	7.3	13.5		10.2
8000	7.5	15.5		11.5
8100	3.5	7.0		4.6
8200	5.0	5.0		5.2
8400	20.6	17.5		21.7
8500	7.7	9.2		8.7
8600	2.5	4.0		3.3
8700	1.9	5.5		2.7
8900	13.0			15.0

Figure 8.6: Ban Rai: Distribution of flake scar lengths on all cores.

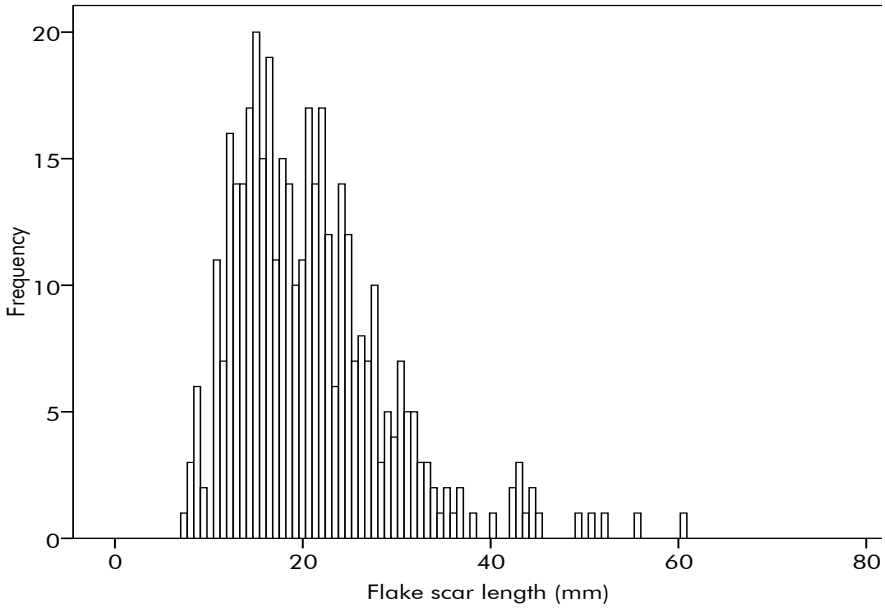


Figure 8.7: Ban Rai: Distribution of flake lengths for all complete flakes.

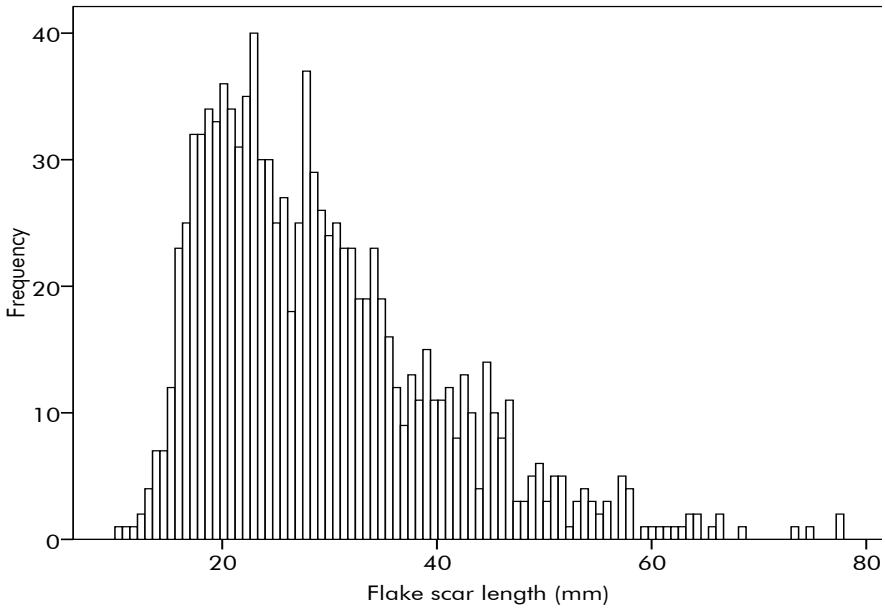


Figure 8.8: Average values and 95% confidence intervals for core scar lengths (hollow circles) and complete flake lengths (solid circles) at Tham Lod and Ban Rai

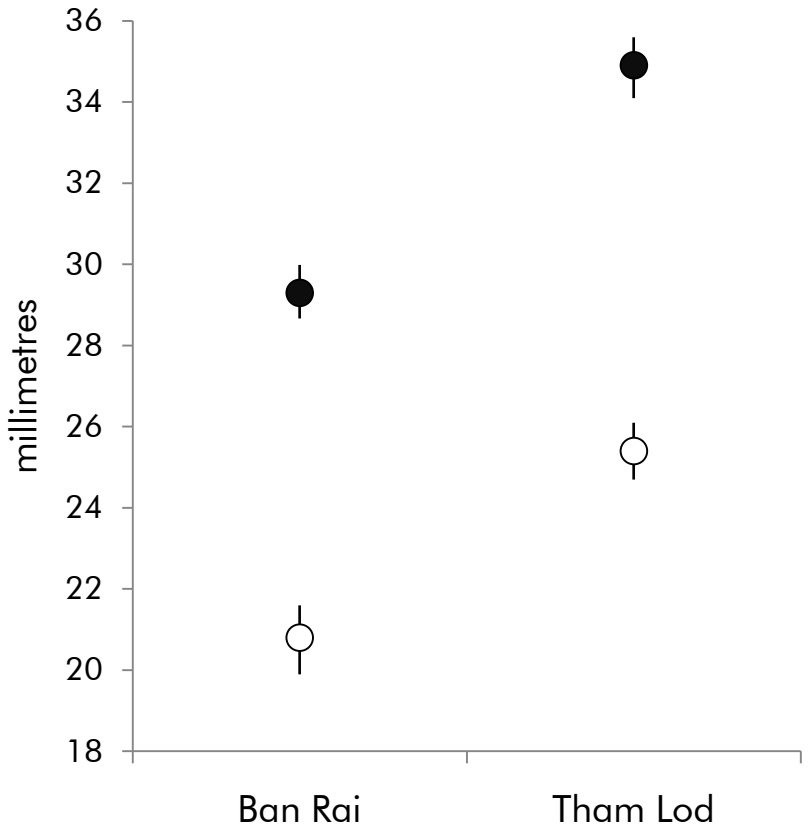


Figure 8.9: Tham Lod: Probability density functions for the lengths of complete flakes and flake scars on cores

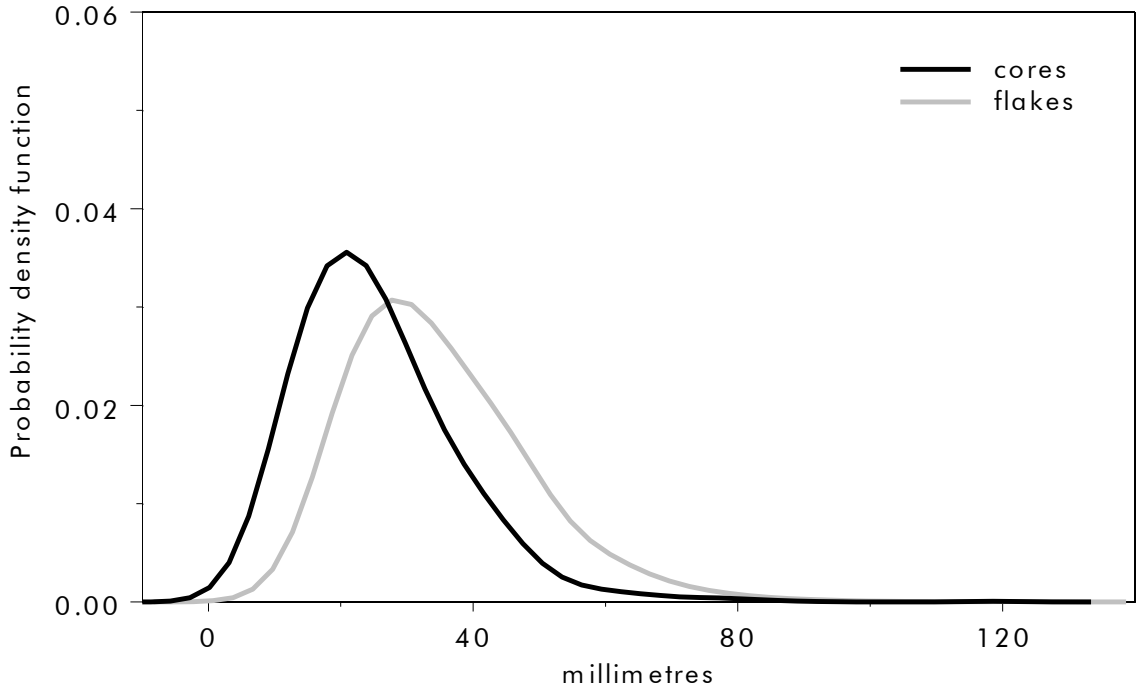


Figure 8.10: Ban Rai: Probability density functions for the lengths of complete flakes and flake scars on cores

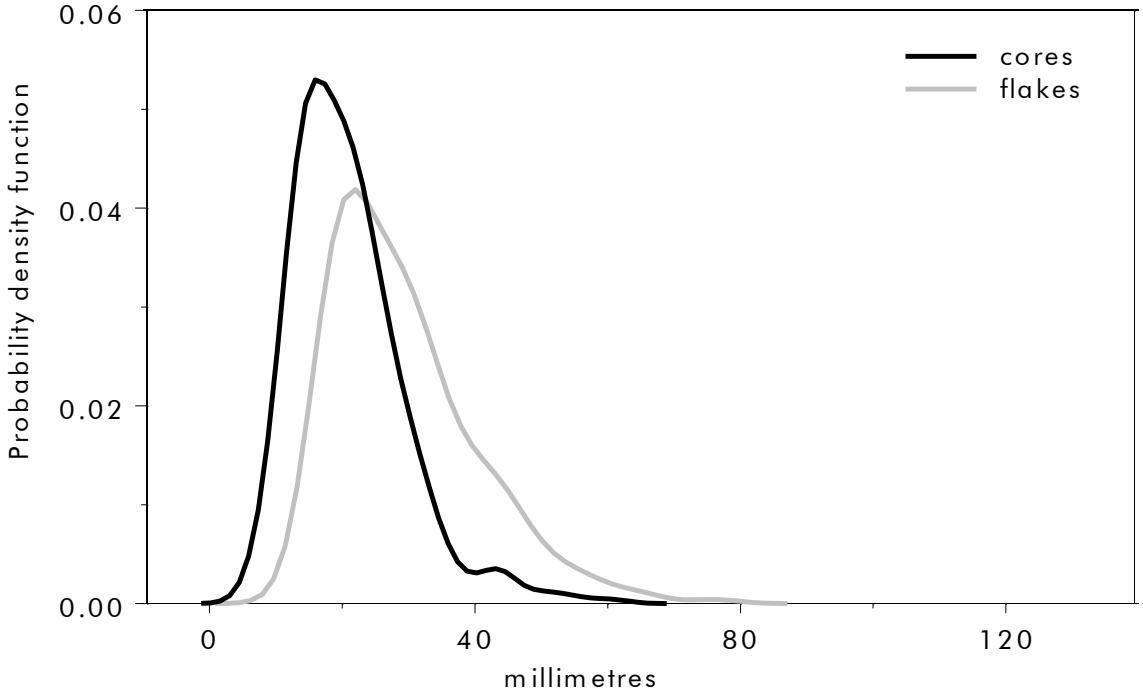
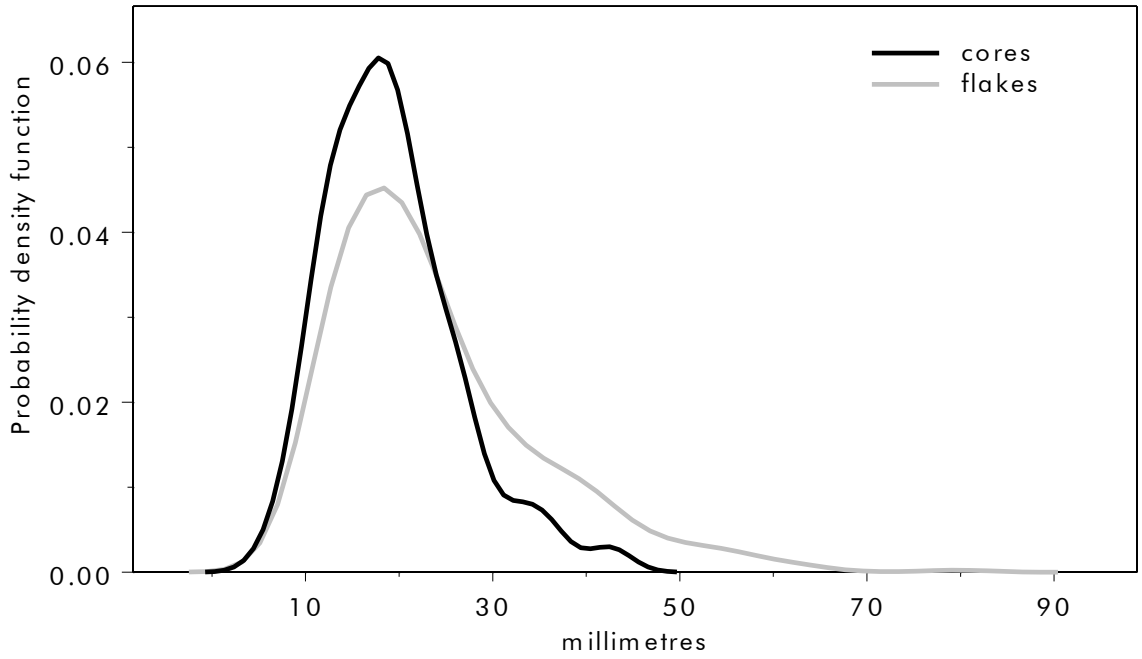


Figure 8.11: Probability density functions for the lengths of complete flakes and flake scars on cores from the experimental assemblage



Optimal Dispersion Model

A model of optimal dispersion predicts optimum forager settlement patterns under different environmental conditions, assuming they are minimizing round-trip travel costs from resource to settlement location. The assumptions are the same as the central place model, but the predictions are more generally about forager mobility rather than specifically about one kind of resource processing. This increased generality suggests that predictions of the optimal dispersion model can be more reliably tested than the central place model. The optimal dispersion model evaluated here predicts that as resources become more mobile and clumped, foragers will increasingly aggregate into larger groups practicing logistical foraging but when resources are more stable and evenly distributed, foragers will increasingly disperse into smaller groups using a residential settlement pattern. The synchronic hypothesis, derived from the proximity of major resources to the two sites, predicts that occupation at Ban Rai was dominated by logistical strategies compared to Tham Lod which is predicted to have been dominated by residential strategies. These differing levels of dominance are not meant to imply that the two sites had opposing strategies. Instead the implication is that there were different combinations or balances of the two strategies at the two sites. The archaeological correlate of this prediction is that assemblage reduction will be more extensive at Ban Rai compared to Tham Lod. On the other hand, the diachronic hypothesis, informed by the climate history revealed by the $\delta^{18}O$ sequences, predicts that reduction will be lower at Ban Rai because it was occupied during the Holocene when climatic conditions favoured more stable and evenly distributed environments.

The methods for measuring assemblage reduction were presented in detail in chapter five where analysis of the experimental assemblage revealed a small number of flake attributes that are particularly well suited to measuring reduction in assemblages similar to Tham Lod and Ban Rai. As a first step in the analysis of the archaeological assemblages, the reliability of these attributes as suitable reduction measures for the archaeological assemblages was verified by analysing correlations between a sample of these variables to confirm their usefulness as reduction indicators. The second step was summarising the two assemblages in terms of these variables for a detailed comparison of differences in reduction at the two sites. These summary statistics were compared to the equivalent statistics from the experimental assemblage described in chapter five to calibrate the intensity of reduction for the two archaeological assemblages. Finally,

changes in the reduction variables over time at each site were considered and correlations with $\delta^{18}O$ values were evaluated.

Tham Lod

Figure 8.12 is a scatter plot matrix showing correlations for four of the key flake reduction variables for all complete flakes at Tham Lod (n = 1093). The correlations are similar in magnitude to the experimental assemblage and reveal no unusual multicollinearities. As expected, there are negative correlations between dorsal cortex and the other variables indicating that the proportion of dorsal cortex decreases as numbers of dorsal scars, flakes with overhang removal and interior platform angle size increases. Positive correlations between numbers of dorsal scars, flakes with overhang removal and interior platform angle size were also predicted by the reduction model because each of these variables increase with increasing reduction. None of the 95% confidence intervals include 0.0, so these correlations are unlikely to be due to chance. These results indicate that the reduction model presented in chapter five is probably a reliable framework for interpreting the Tham Lod assemblage.

Given the suitability of the reduction model to this assemblage, it is possible to summarise the assemblage in terms of the key reduction variables identified by the model. Table 8.5 presents a summary of the key flake variables for Tham Lod. It should be noted that the mean and median values for the interval variables, such as dorsal cortex percentage, dorsal scar number and interior platform angle were calculated from the entire assemblage as a single sample. Mean and medians of the nominal variables, such as overhang removal and the four dorsal cortex categories, were calculated using the excavation units as sub-samples. The divergence between the mean and median values for dorsal cortex percentage reflects the skewed distribution of this variable, indicating that the mean is probably a poor indictor of central tendency in this case. Similarly, the absence of overlap in the 95% confidence intervals for mean and median values of interior platform angle reflects the unusual shape of the distribution of this variable and that the median should be used as a more robust measure of central tendency.

The position of these summary statistics along the one to ten scale of assemblage reduction intensity used for the experimental assemblage (where one is very light reduction and ten is very intensive reduction) gives a rough measure to calibrate assemblage reduction at Tham Lod. Interpolation of Figure 5.5 in chapter five indicates

that the median dorsal cortex value at Tham Lod is equivalent to about five to six on the scale of reduction intensity derived from the experimental assemblage. Similarly, the values in the Tham Lod assemblage for mean dorsal flake scars is about six on the reduction intensity scale. Median interior platform angle at Tham Lod is 100° which is beyond the upper limits of the 95% confidence interval at eight on the reduction scale. This value is beyond the range of the experimental assemblage and is ambiguous because if the average at Tham Lod was lower it could correspond either to levels 6-7 or levels 9-10. Values for overhang removal at Tham Lod are also at the upper extremes of the range recorded in the experimental assemblage and are difficult to calibrate reliably because of the large 95% confidence intervals for the experimental data. This large variation may be because it is a proportion and not an average like the other variables. The process of averaging removes extremes of variation from the other variables. The safest interpretation of the interior platform angle and overhang removal data from Tham Lod is that they probably indicate relatively intensive reduction somewhere in the six to ten region of the scale. The ratios of the four categories of cortex distribution at Tham Lod correspond to a reduction intensity level of three to four. Overall, calibration of the key reduction variables measured for the Tham Lod assemblage suggests a moderate level of assemblage reduction of about five to six on the scale of one to ten.

Examination of values of the key flake variables for each excavation unit showing the distribution of the sample in more detail than the summary statistics described above. In Figure 8.13 the variables are shown as Z-scores with Lowess regression lines showing the change in four variables over time. The Lowess curves were generated in S-Plus with symmetric locally-fitted quadratic polynomials with a span of 0.3. Figure 8.14 shows similar graphs for the four categories of cortex distribution. In this case, the signs on the Z-score values for percentages of dorsal cortex were reversed (from negative to positive and vice versa) so that higher Z-scores for all four variables indicate more intensive assemblage reduction. Lowess regression lines were generated by S-PLUS. Lowess is a locally weighted polynomial regression technique for smoothing non-parametric data (Cleveland 1981, Cleveland and Devlin 1988). The Lowess technique reduces noise by generating a predicted value for each point. The predicted value is derived by fitting a weighted linear regression where the weights decrease with distance from that point (Insightful Corporation 2007: 359). The main advantage of Lowess regression is that it does not require a function to describe the

regression model so it is ideal for modelling complex processes where theory is weak or non-existent. In this case, the division of assemblage into excavation units is arbitrary and not based on any theory of change in forager use of the sites over time. Given this atheoretical sampling strategy, Lowess is an especially suitable technique to visualise trends across the excavation units.

These graphs reveal three interesting details about change over time in the stone artefact assemblage at Tham Lod. First, there is a broad trend towards more intensive assemblage reduction over time. The lowess lines, although showing considerable variation, tend to trend upwards for for all variables. This trend is most pronounced for overhang removal and least apparent for dorsal cortex especially between 30,200-34,900 BP (units 26-32) when Z-scores for dorsal cortex trend upwards. This suggests that there is synchrony in these indicators of reduction intensity at broad chronological scales. Second, proportions of flakes with overhang removal shows much greater range of variation than the other variables. Overhang removal Z-scores range ±1.5 standard deviations from the mean while the others do not exceed ±0.3 standard deviations. This may indicate that overhang removal was more sensitive to changes in assemblage reduction than the other variables. On the other hand, it may result from the greater range of variation due to the analysis of overhang removal as a proportion rather than an average like the other variables, as noted for the experimental assemblage. Third, aside from the overall upward trend, directions of change amongst these four variables are not closely synchronised. This suggests that at finer scales the variables appear to be responding to different influences or to the same influences in different ways that are difficult to reliably interpret.

Graphs of the four categories of dorsal cortex on complete flakes support this interpretation of broad-scale increasing reduction (Figure 8.14). Despite poor synchrony at the level of the excavation unit, Figure 8.14 shows relatively high reduction in the later periods of site occupation, with high proportions of flakes with no cortex and distal cortex and low proportions of flakes with crescent cortex. Similarly, in the earlier periods of occupation the proportion of flakes with no cortex and distal cortex are relatively low and the proportion of flakes with crescent cortex is relatively high, suggesting relatively low reduction. Proportions of flakes with 100% dorsal cortex do not clearly follow the trend evident in the other three categories.

Ban Rai

The results from Ban Rai are similar to Tham Lod, with correlations similar in magnitude and direction to the experimental assemblage and no problematic multicollinearities. Figure 8.15 is a scatter plot matrix showing correlations for four of the key flake reduction variables for all complete flakes at Ban Rai (n = 707). None of the 95% confidence intervals include 0.0, so these correlations are unlikely to be due to chance. As for the Tham Lod assemblage, these results indicate that the reduction model presented in chapter five is probably a reliable framework for interpreting the Ban Rai assemblage.

Table 8.6 shows the summary statistics for the key flake variables at Ban Rai, calculated in the same way as for Tham Lod. Major divergences between mean and median values (indicated by no overlap between 95% confidence intervals) are apparent for dorsal cortex percentage, dorsal scars and interior platform angle. Inspection of the distributions of these variables confirms that the median is a more robust measure of central tendency for these variables because of skewed distributions, especially large numbers of zero values for dorsal cortex. These values were then calibrated by reference to the experimental assemblage in the same way that the Tham Lod values were calibrated. The dorsal cortex value at Ban Rai calibrates to the maximum reduction intensity level of ten. The median dorsal flake scar value calibrates to about level six. As for Tham Lod, the median interior platform angle at Ban Rai is towards the upper limit of the range observed experimentally, so the calibrated level is ambiguous. Similarly, the high value for overhang removal at Ban Rai makes calibration unreliable except to note that it calibrates to the higher end of the reduction intensity scale. The ratios of the four categories of cortex distribution at Tham Lod correspond to a reduction intensity level of six to seven. Considered together after calibration, the key reduction variables measured for the Ban Rai assemblage suggests a moderate to high level of assemblage reduction of about seven to eight on the scale of one to ten.

Analysis of changes in these variables over time confirms the observation about the greater sensitivity of overhang removal that was noted for Tham Lod assemblage. At Ban Rai the higher range of variation in the proportion of flakes with overhang removal relative to the other variables is very similar to Tham Lod, with overhang removal varying more than ±2.0 standard deviations and the others not exceeding ±1.0

standard deviation (Figure 8.16). As noted above, this may be partially explained because it is a proportion rather than an average. Like Tham Lod, a broad trend in these four variables towards more intensive reduction is also apparent at Ban Rai. Unlike Tham Lod, there appears to be some synchrony at a finer scale at Ban Rai, with fairly close changes in direction and magnitude of Z-scores for overhang removal, dorsal cortex and dorsal scars. Interior platform angle does not show the same degree of co-ordinated change (Figure 8.16). This synchrony suggests that changes in these variables were tuned to relatively fine chronological scales rather than the broad scales observed at Tham Lod.

Changes in the four categories of dorsal cortex similarly show a degree of co-ordinated variation (Figure 8.17). In particular, the proportions of flakes with no cortex, flakes with crescent-shaped cortex and flakes with distally located cortex co-vary closely. The general pattern of change is similar to that observed in the other variables, of higher reduction in the later period of occupation. As at Tham Lod, proportions of flakes with 100% dorsal cortex do not follow the trends evident in the other three categories.

Discussion

Comparing the summary statistics and the overall calibrated intensity reduction levels for the two assemblages suggests that the Ban Rai assemblage was probably reduced more intensively than the Tham Lod assemblage. The calibrated values for the two assemblages indicate a moderate level of reduction for Tham Lod compared to a moderate-high level for Ban Rai. However this calibration is only a rough guide to the difference between the sites because of overlapping error ranges for each of the ten reduction levels in the experimental data as well as the problem of archaeological data that could not be calibrated because it fell outside the range of the experimental data. Another perspective on the differences between the two sites is presented in Figure 8.18 which summarises the differences between the key variables at the two sites. Overall, these graphs support the results of the calibration and show that reduction was more intensive at Ban Rai than Tham Lod. In particular, values for median dorsal cortex percentage were lower at Ban Rai and values for mean overhang removal and mean dorsal scars were lower at Tham Lod, all indicating more intensive reduction at Ban Rai. Values for median interior platform angle were equivalent at the two sites, indicating that these variables have limited power to discriminate. Figure 8.18 also shows that three of the four categories of cortex distribution (the exception is distal

cortex) indicate substantially higher assemblage reduction at Ban Rai compared to Tham Lod. Crescent and 100% cortex flakes were higher at Tham Lod, indicating less intensive reduction while the proportion of flakes with no cortex was higher at Ban Rai, indicating more intensive reduction.

Returning to the predictions derived from the optimal foraging model, the higher degree of reduction intensity at Ban Rai supports the synchronic hypothesis. Higher assemblage reduction was predicted for Ban Rai compared to Tham Lod when the proximity of major resources to the two sites was the main influence on technological organization, rather than climatic conditions. These data suggest that foragers occupying Ban Rai tended to organize their technology around logistical strategies more than the occupants of Tham Lod who employed more residential strategies.

Examination of changes in these variables with the sequence at each site shows that although local resource distribution appears to have been the dominant influence on patterns of optimal dispersion, the stone artefact assemblages were also responsive to changes in climate. At Tham Lod the highest correlation between $\delta^{18}O$ values and technological attributes is a moderate positive correlation with overhang removal (r = 0.435 [0.124, 0.746]). This correlation suggests that as conditions become drier and cooler people tended to produce flakes with higher proportions of overhang removal, probably reflecting an increase in reduction intensity during these times. The other variables have very weak correlations with $\delta^{18}O$ values (dorsal flake scars: r = 0.186 [-0.101, 0.473], dorsal cortex: r = -0.046 [-0.441, 0.348], interior platform angle: r = 0.122 [-0.274, 0.517], no cortex: r = -0.222 [-0.599, 0.155], distal cortex: r = 0.184 [-0.275, 0.643], crescent cortex: r = -0.289 [-0.204, 0.782] and all cortex: r = -0.074 [-0.460, 0.312]). The moderate positive correlation between $\delta^{18}O$ values and overhang removal, combined with higher variation in overhang removal values compared to the others, suggests that stone artefact technology of the occupants of Tham Lod was probably sensitive to climatic variation.

This sensitivity of technology to climatic variation is not evident in the Ban Rai assemblage. Correlations between technological attributes and $\delta^{18}O$ values are generally very low or inconsistent with models of technological sensitivity to climatic conditions employed here. For example, the correlation between $\delta^{18}O$ values and interior platform angle is 0.320 [-0.241, 0.881], suggesting that as climate varies towards more difficult conditions then reduction intensity increases. Conversely, the correlation

between $\delta^{18}O$ values and numbers of dorsal flake scars is -0.343 [-0.888, 0.201], a result that is inconsistent with theory that predicts more intensive assemblage reduction during drier and cooler conditions. These correlations between $\delta^{18}O$ values and interior platform angle and numbers of dorsal flake scars are the highest correlations for the Ban Rai assemblage. The other variables have very weak correlations with $\delta^{18}O$ values, some of which are also inconsistent with the models (dorsal cortex: r = 0.104 [-0.665, 0.874], overhang removal: r = -0.124 [-0.884, 0.635], no cortex: r = -0.081 [-0.687, 0.526], distal cortex: r = -0.218 [-0.972, 0.536], crescent cortex: r = -0.137 [-0.682, 0.407] and all cortex: r = 0.152 [-0.614, 0.919]). These results suggest that the technological strategies employed by the occupants of Ban Rai were relatively insensitive to climatic variation, a result also noted in the analysis of the patch choice model.

Figure 8.12: Scatter plot matrix of key reduction variables for all complete flakes at Tham Lod. Each point represents a single complete flake. The values have been jittered to separate overlapping points.

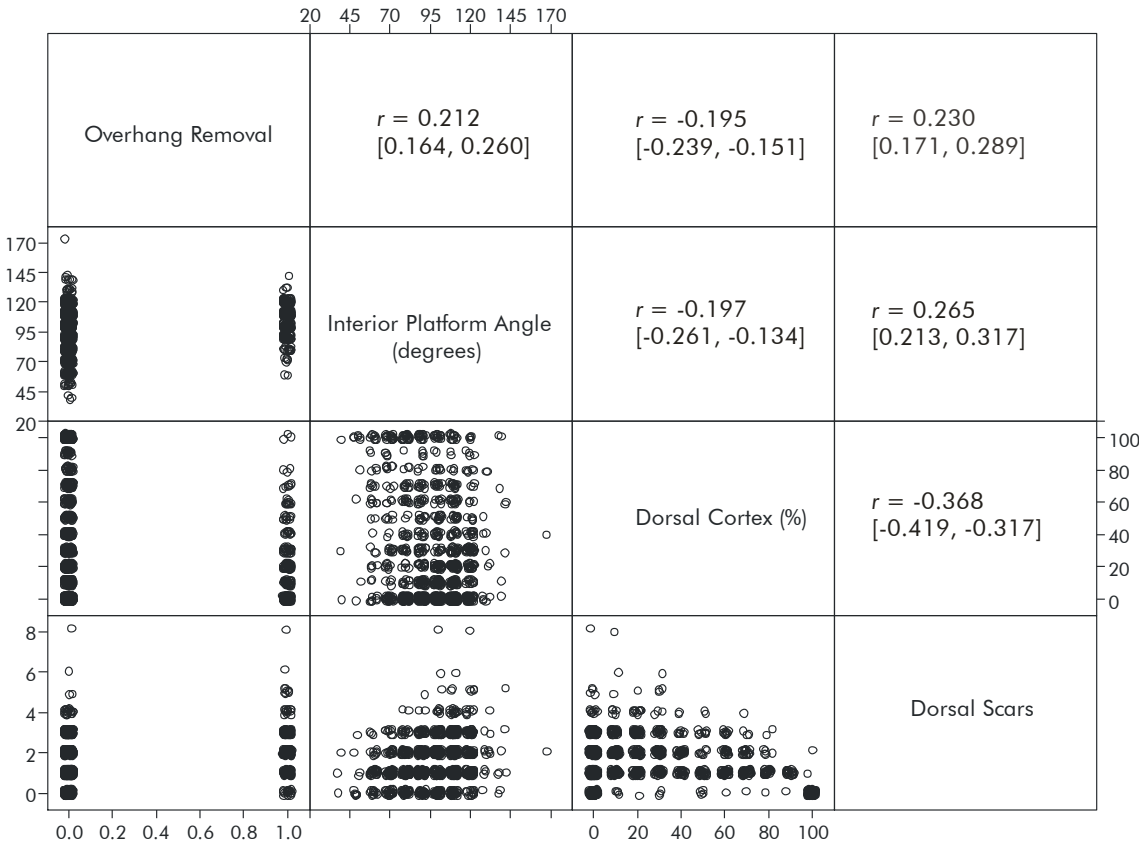


Table 8.5: Tham Lod: Mean, median values and 95% confidence intervals for dorsal cortex, dorsal flakes scars, overhang removal, interior platform angle and dorsal cortex distribution. See text for further explanation.

Key flake variables	Mean	Confidence Interval minimum	Confidence Interval maximum
Dorsal cortex (%)	29.7	27.7	31.6
Dorsal flake scars (#)	1.61	1.54	1.67
Overhang removal (proportion)	0.21	0.17	0.25
Interior platform angle (degrees)	97.1	96.0	98.2

	Median	Confidence Interval minimum	Confidence Interval maximum
Dorsal cortex (%)	20.0	16.2	23.8
Dorsal flake scars (#)	2.00	1.02	2.97
Overhang removal (proportion)	0.21	0.16	0.27
Interior platform angle (degrees)	100.0	100.0	100.0

Dorsal cortex distribution	Mean	Confidence Interval minimum	Confidence Interval maximum
No cortex	0.36	0.32	0.39
Distal cortex	0.20	0.17	0.24
Lateral cortex	0.23	0.21	0.26
100% cortex	0.08	0.06	0.10

	Median	Confidence Interval minimum	Confidence Interval maximum
No cortex	0.34	0.29	0.40
Distal cortex	0.21	0.16	0.27
Lateral cortex	0.22	0.17	0.27
100% cortex	0.08	0.05	0.11

Figure 8.13: Tham Lod: Z-score plots and Lowess curves for (a) average percentages of dorsal cortex on complete flakes per excavation unit, (b) average numbers of dorsal flake scars on complete flakes per excavation unit, (c) proportion of flakes with overhang removal per excavation unit and (d) average interior platform angle per excavation unit.

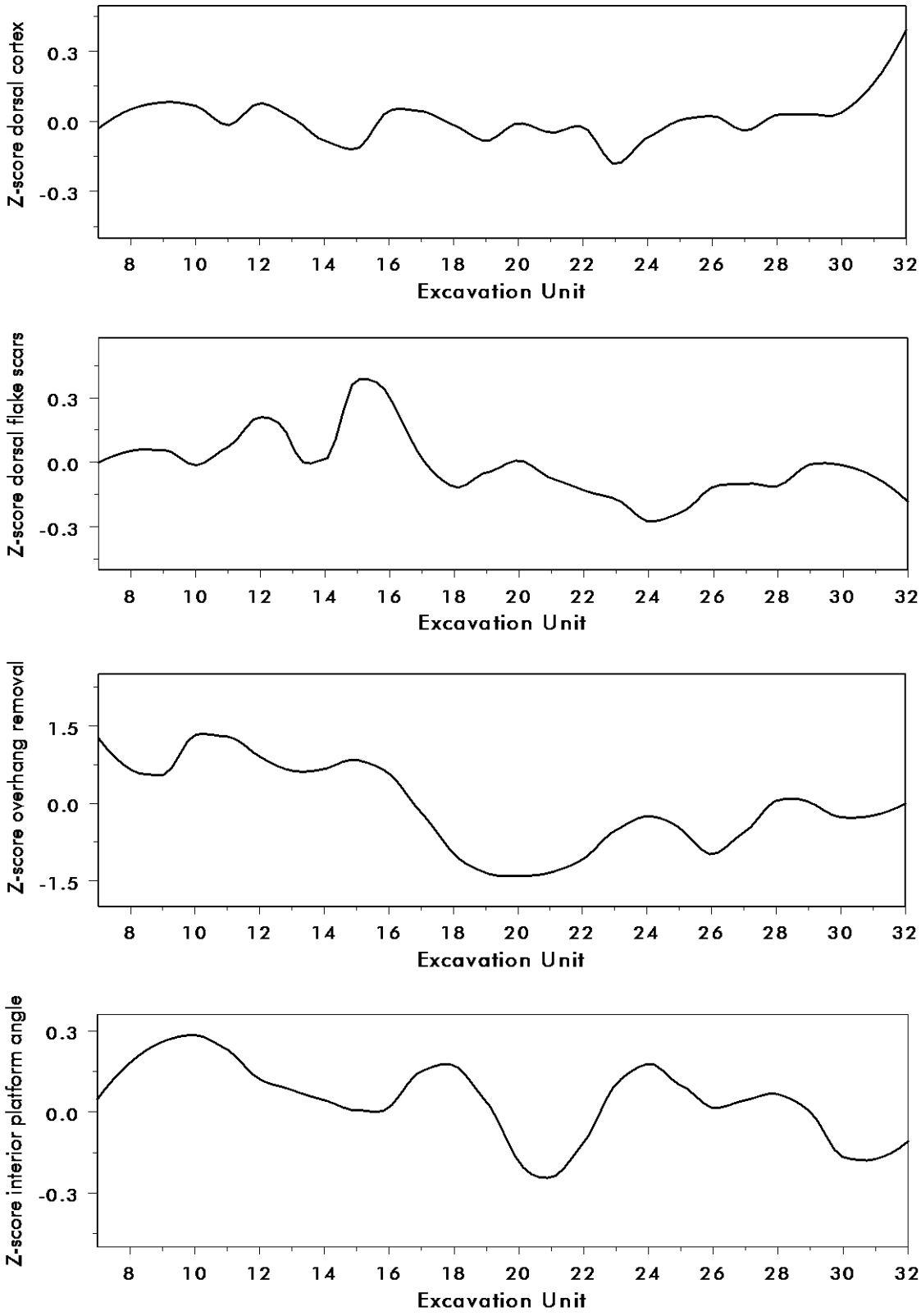


Figure 8.14: Tham Lod: Z-score plots and Lowess curves for proportions of flakes with (a) no cortex, (b) distal cortex, (c) lateral cortex, (d) all cortex

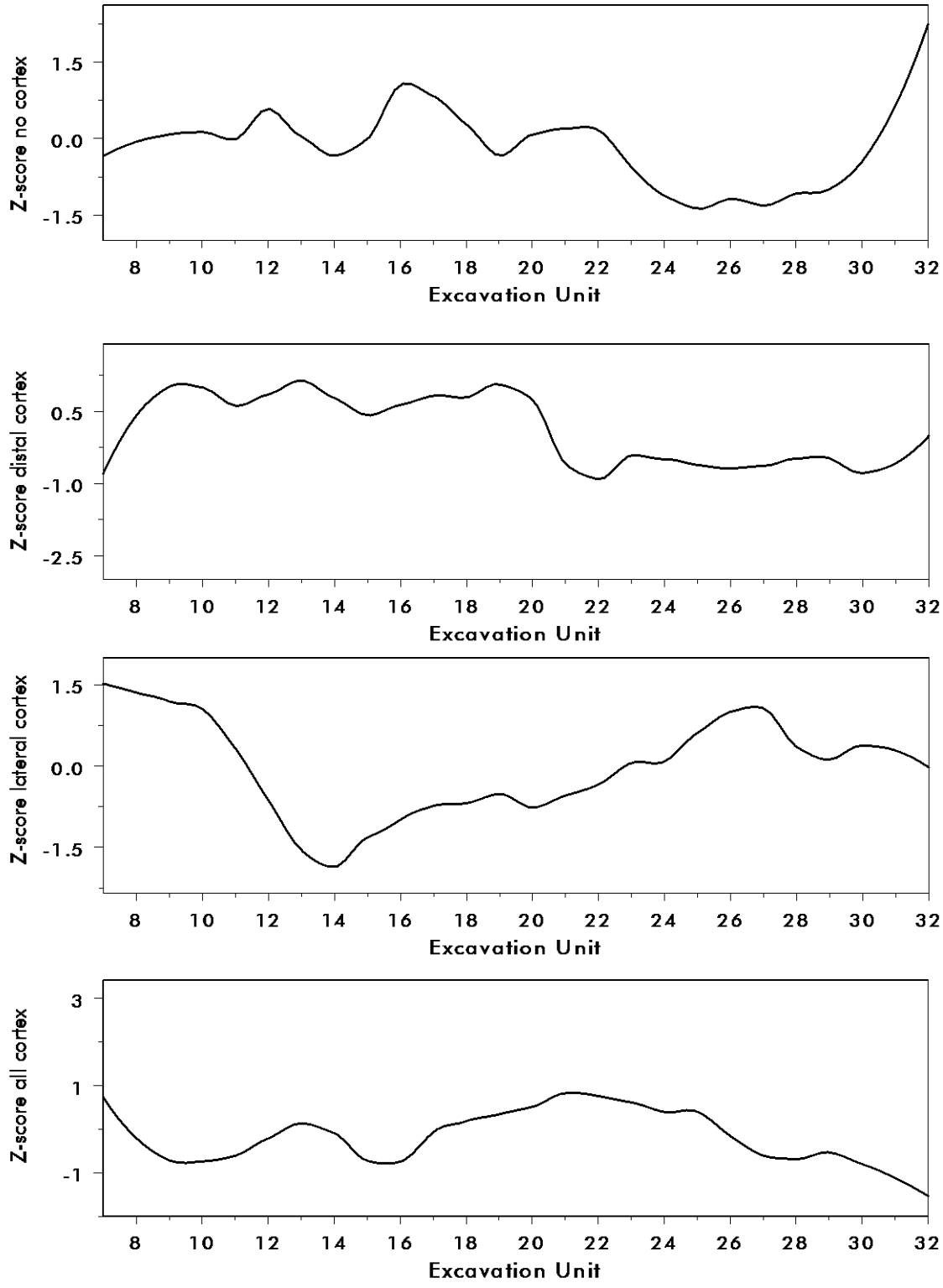


Figure 8.15: Scatter plot matrix of key reduction variables for all complete flakes at Ban Rai. Each point represents a single complete flake. The values have been jittered to separate overlapping points.

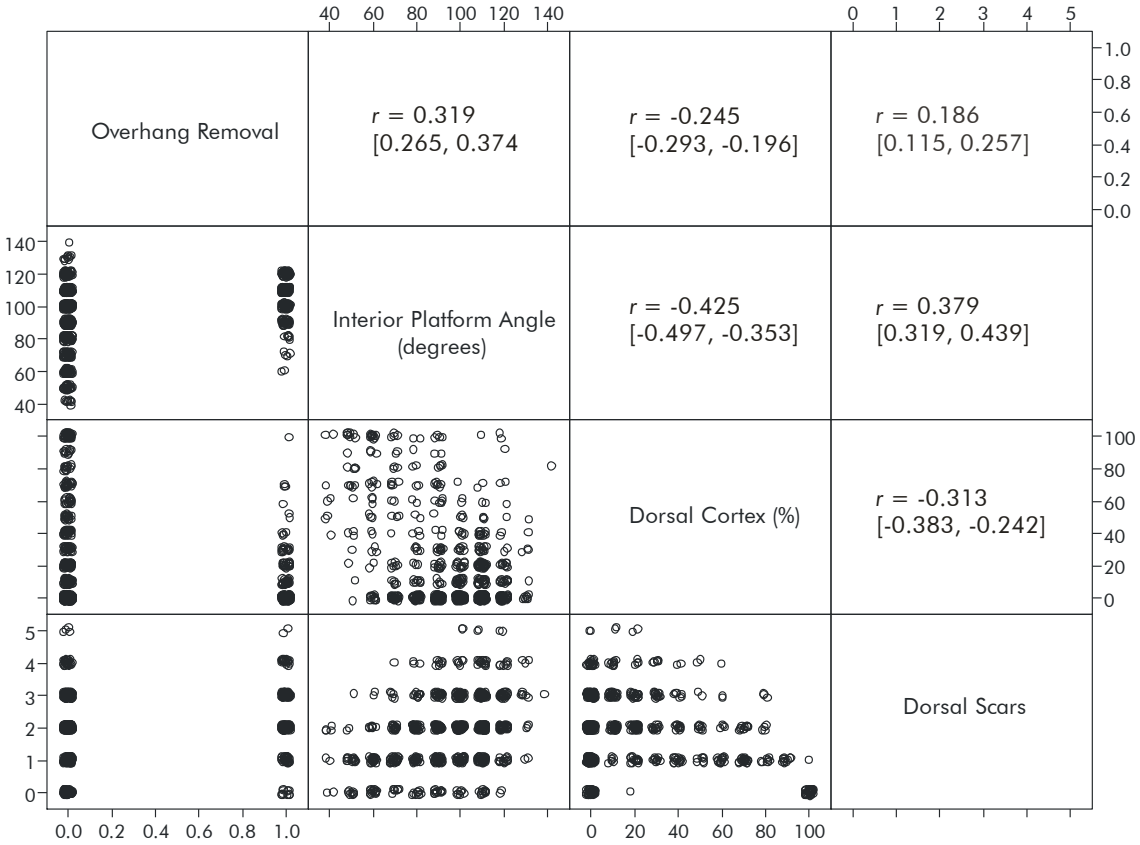


Table 8.6: Ban Rai: Mean, median values and 95% confidence intervals for dorsal cortex, dorsal flakes scars, overhang removal, interior platform angle and dorsal cortex distribution. See text for further explanation.

Key flake variables	Mean	Confidence Interval minimum	Confidence Interval maximum
Dorsal cortex (%)	20.1	17.9	22.3
Dorsal flake scars (#)	1.88	1.81	1.96
Overhang removal (proportion)	0.26	0.21	0.31
Interior platform angle (degrees)	94.5	93.0	96.0

	Median	Confidence Interval minimum	Confidence Interval maximum
Dorsal cortex (%)	0.0	0.0	0.0
Dorsal flake scars (#)	2.00	2.00	2.00
Overhang removal (proportion)	0.27	0.22	0.31
Interior platform angle (degrees)	100.0	98.9	101.0

Dorsal cortex distribution	Mean	Confidence Interval minimum	Confidence Interval maximum
No cortex	0.55	0.48	0.61
Distal cortex	0.15	0.11	0.18
Lateral cortex	0.20	0.16	0.24
100% cortex	0.04	0.02	0.06

	Median	Confidence Interval minimum	Confidence Interval maximum
No cortex	0.55	0.44	0.61
Distal cortex	0.16	0.11	0.22
Lateral cortex	0.22	0.16	0.27
100% cortex	0.04	0.01	0.07

Figure 8.16: Ban Rai: Z-score plots and Lowess curves for (a) average percentages of dorsal cortex on complete flakes per excavation unit, (b) average numbers of dorsal flake scars on complete flakes per excavation unit, (c) proportion of flakes with overhang removal per excavation unit and (d) average interior platform angle.

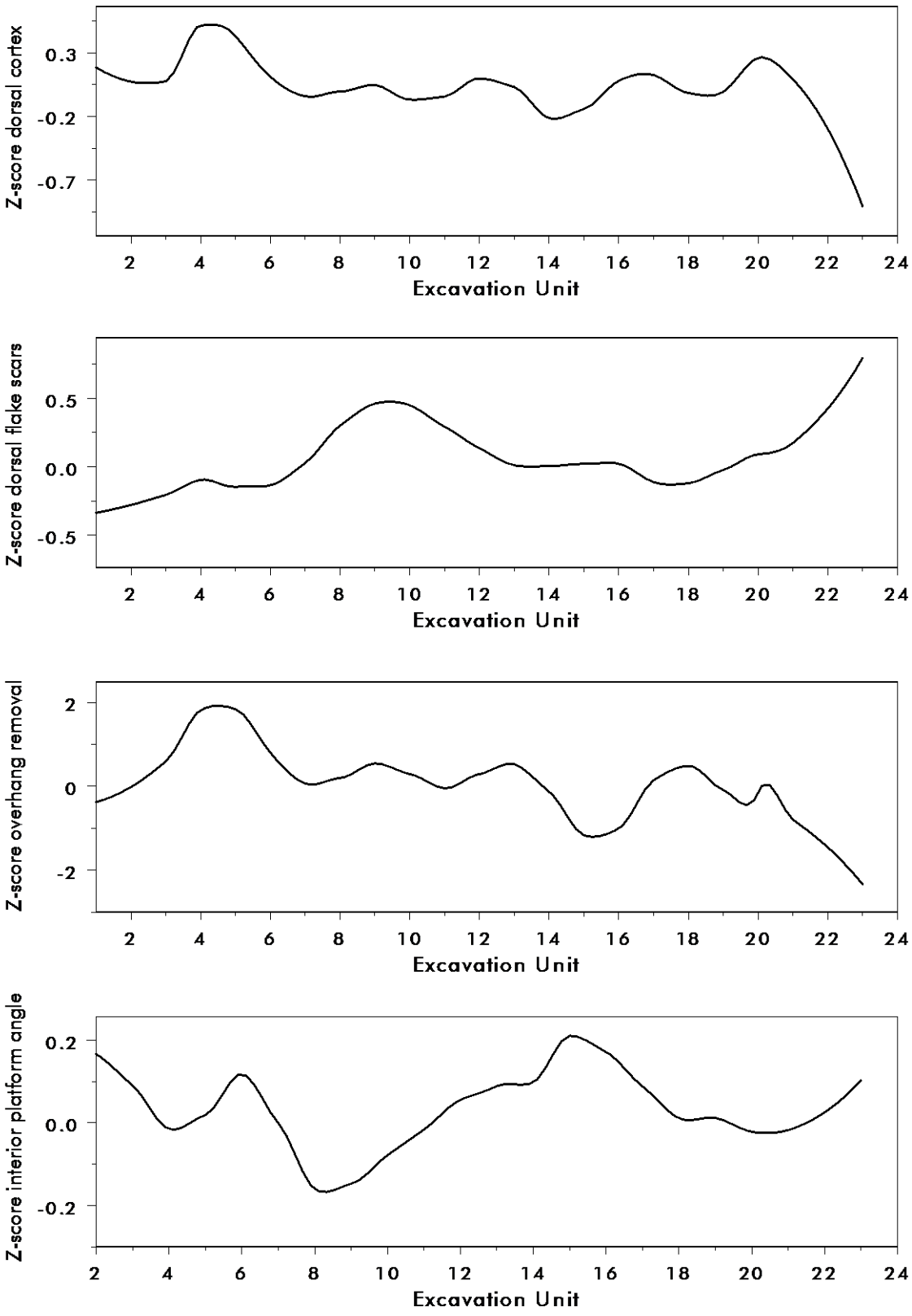


Figure 8.17: Ban Rai: Z-score plots and Lowess curves for proportions of flakes with (a) no cortex, (b) distal cortex, (c) lateral cortex, (d) all cortex

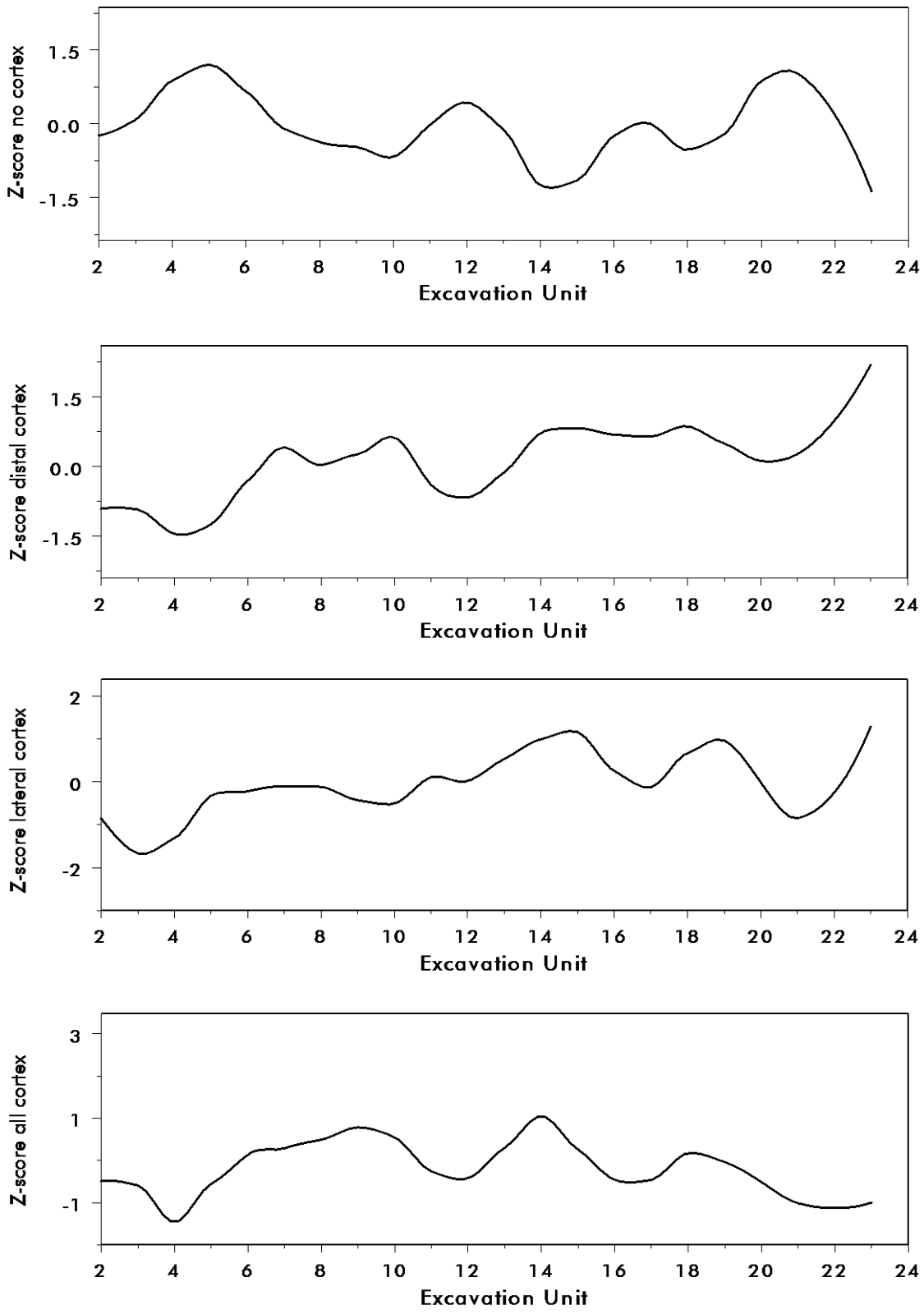
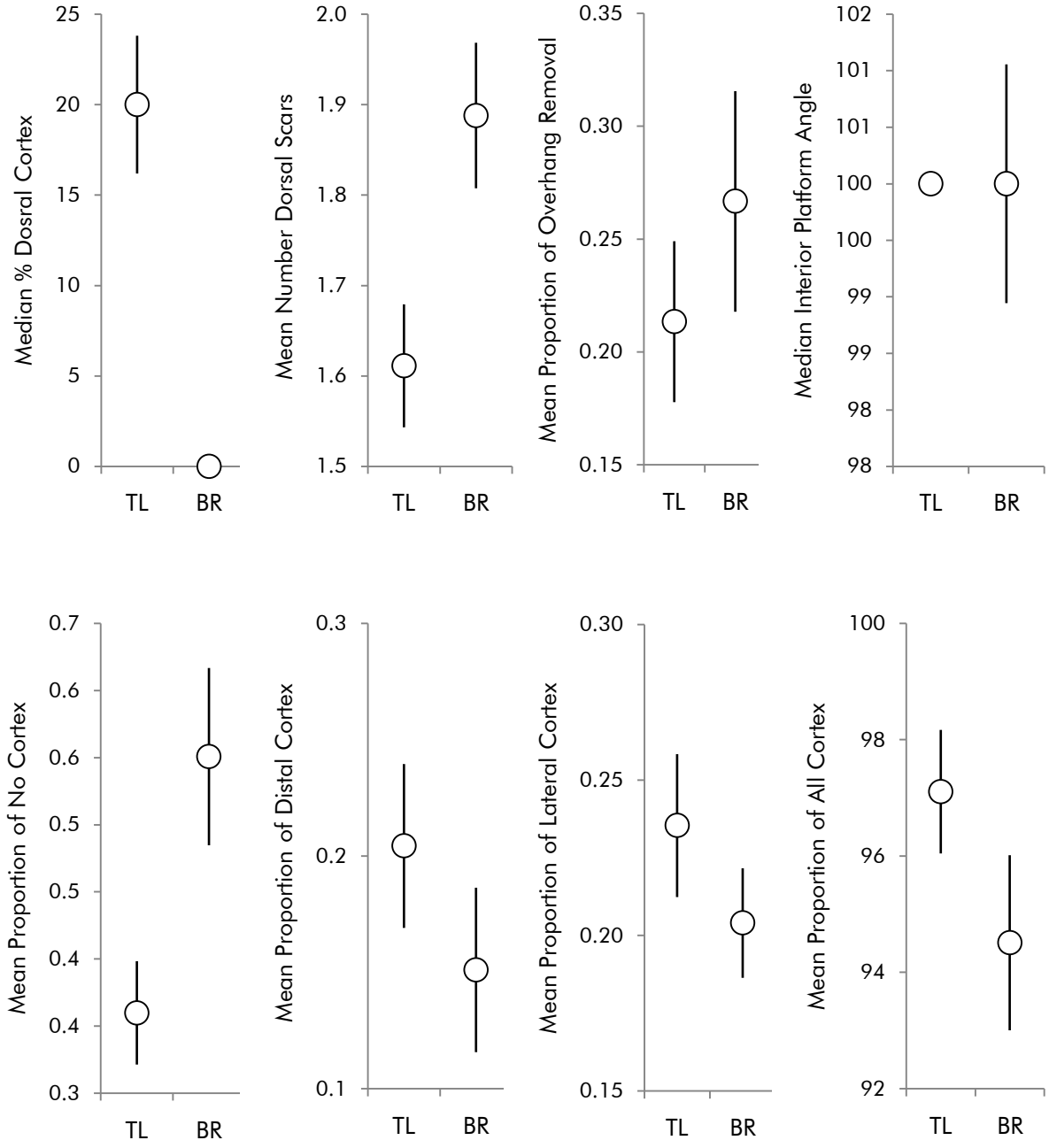


Figure 8.18: Central tendencies and 95% confidence intervals for or dorsal cortex, dorsal flakes scars, overhang removal, interior platform angle and dorsal cortex distribution at Tham Lod and Ban Rai.



Conclusion

This chapter has described the results of testing predictions derived from three optimal foraging models with the flaked stone artefact data from Tham Lod and Ban Rai. To summarise the results briefly, the data supported the patch choice model's prediction that occupation intensity was influenced more by climatic conditions than proximity of the site to resources. Similarly, the data supported the central processing model's prediction that pre-processing was influenced more by climatic conditions than resource proximity although this support is only equivocal because of confounding factors. Finally, in contrast to the previous two models, the data supported the optimal dispersion model's prediction that assemblage reduction was more influenced by proximity of the site to resources than climatic conditions.

Some of the results are less straightforward than predicted by the models. In part, this is because the models are simplifications of very complex systems with stochastic components that are difficult to measure reliably. However, some of this complexity also highlights unexpected interactions between the technological and climatic variables. One notable pattern is the apparent close climatic tracking evident in the Tham Lod assemblage. Artefact discard rates and assemblage reduction intensity at Tham Lod are more closely correlated with $\delta^{18}O$ values than at Ban Rai. This suggests that the technological strategies of Pleistocene foragers more closely tracked environmental fluctuations than Holocene foragers. One explanation for this might be the greater magnitude of fluctuation in environmental conditions during the Pleistocene compared to the Holocene. This might have resulted in environmental conditions that fluctuated close to the limits of tolerance of the stone artefact technology, necessitating relatively frequent technological adjustment to maintain efficiency during rapid and high magnitude changes in climate. This tracking behaviour may be analogous to habitat tracking and appears to have been less important during the Holocene when Ban Rai was occupied, perhaps because environmental parameters during that time were less variable overall and well within the range of tolerance of the technology. An alternative interpretation of the assemblage reduction data is that the overall higher degree of reduction at Ban Rai meant that foragers were already buffered against exposure to environmental fluctuations. With the available evidence it is difficult to rule out this alternative interpretation, but modification of current theory might offer a way to discern between the two interpretations. This will be pursued further in the next chapter.

A second unexpected pattern is the different scales of synchrony observed in the technological variables at each site, independent of correlations with $\delta^{18}O$ values. At Tham Lod a broad-scale trend of increasing assemblage reduction was observed, but only weak synchrony of variables at the level of the excavation unit. Conversely, at Ban Rai there appears to be a close co-ordination of changes in most of the technological variables at the level of the excavation unit. This suggests that although technology may have been more sensitive to relatively high-frequency environmental changes at Tham Lod, it appears to have been a relatively subtle response that did not require major technological adjustments. On the other hand, although technology at Ban Rai is relatively insensitive to environmental change, changes in technological organisation at Ban Rai appears to have been more coherent and tuned to a higher frequency of variation than at Tham Lod. The available evidence does not shed any light on possible causes of this high frequency variation.

Finally, the analysis in this chapter has encountered an important limitation in using flaked stone artefact assemblages to test predictions derived from optimal foraging models. The question of whether artefact discard rates are a problematic proxy for occupation intensity remains unresolved. Faunal correlations did little to strengthen the relationship between artefact discard and occupation intensity. The second possible confounding factor is technological change that alters the numbers of artefacts without any change in the amount of people or the frequency and duration of their occupation of the site. The data presented for testing the predictions of the optimal dispersion model are relevant to this problem because, all things being equal, more intensive assemblage reduction could result in higher MNA values without implying more intensive occupation. Low correlations between the key assemblage reduction variables and MNA would suggest that MNA is not confounded by variation in technological strategies and that occupation intensity is decoupled from technological organisation.

At Ban Rai all correlations between technological variables and MNA are between 0 and ±0.3. At Tham Lod all of the technological variables have similarly low correlations with MNA of between 0 and ±0.08 except for the four categories of dorsal cortex distribution. Although correlations between MNA and four categories of dorsal cortex distribution are slightly higher, they suggest that reduction was less intensive when MNA was high. For example, the correlations suggest that flakes with no cortex (r = -

0.462 [-0.779, -0.145]) and flakes with distal cortex (r = -0.251 [-0.621, 0.119]) tend to become relatively less numerous as the MNA increases, while flakes with crescent cortex (r = 0.354 [0.016, 0.692]) become more numerous, indicating that reduction becomes less intense when MNA increases. Flakes with 100% cortex do not follow this pattern (r = -0.328 [-0.557, -0.079]), becoming more abundant when MNA is low, rather than less abundant as expected given the other correlations, indicating more intensive reduction during periods of high MNA. Despite this inconsistency, these results are interesting because they mostly suggest that people actually invested less effort in optimising core productivity during times when high numbers of artefacts were discarded. This is the opposite of what would be expected if technological variation was a confounding variable for MNA as a measure of occupation intensity. That said, the absence of similar correlations between MNA and the other key flake variables at Tham Lod, and the absence of correlations for any variables at Ban Rai, suggest that any links between MNA and technological change are weak. The safest conclusion here is that MNA is probably a reliable measure of occupation intensity because it is not confounded by technological changes that would otherwise explain variation in MNA.

To conclude, this chapter has tested the hypotheses derived from the three models presented earlier and discussed some of the complexities and limitations revealed by the tests. The next chapter will address the implications of these results, especially the apparent paradox of the patch choice and central place models appearing to give primacy to climatic conditions as the dominant variable influencing technological organisation while the optimal dispersion model conversely suggests resource proximity was more important.

9. Discussion and Conclusion

Introduction

This chapter draws out the implications of the results presented in the previous chapter and describes how they contribute to the problems raised by previous work discussed in chapter two. A revision of the foraging models is presented to better accommodate the results. Some general future directions for research are proposed and the four questions posed in chapter one are answered.

Modelling technology, climate and resource proximity at the two sites

The outcomes of testing the three optimal foraging models present an apparent paradox. The unique differences in the environmental contexts and history of occupation of the two sites provided an unusual opportunity to test the importance of small-scale differences in local resource availability and environment change. On one hand, Ban Rai is located relatively distant from important resources such as stone and water and occupied only during the Holocene. On the other hand, Tham Lod is located very close to running water and abundant stone supplies and was only occupied during the Pleistocene. From the simple difference in the timing of occupation at the two sites it could be suggested that during the Pleistocene people tended to tether themselves to locations with close and reliable resources, which during the Holocene their residential patterns were less constrained because increased precipitation removed some of the limits to settlement in more distant and patchy areas. The paradox is that instead of a consistent and direct relationship between human behaviour and environmental change or local resource distribution, the results show a mosaic of relationships. For example, for the patch choice model and the central place model it was found that behaviour was influenced more by climatic conditions than proximity of the site to resources, but the optimal dispersion model suggested that people were more influenced by proximity of the site to resources than climatic conditions.

More specifically, the paradox is that Ban Rai has a higher intensity of site occupation than Tham Lod as well as a higher degree of assemblage reduction intensity than Tham Lod. This suggests that people are simultaneously optimising their response to climatic

conditions and local resource availability, but in a way that was not predicted by the existing models. The models predict that a low degree of site occupation intensity should accompany high assemblage reduction intensity. Employing the Marginal Value Theorem (MVT) here as a generalised analytical tool for optimising benefit to cost ratios helps to demonstrate the problem. Although originally conceived by Charnov (1976) to model how long a forager resides in patches of food to maximise their net rate of energy intake, MVT has been used to model diverse ecological phenomena such as optimising the trade-off between egg size and egg number (Smith and Fretwell 1974), optimal courtship persistence and mate guarding (Parker 1974, Parker and Stuart 1976).

Figure 9.1 shows how this model can be similarly adapted for stone artefact technological strategies that optimise risk reduction. The vertical axis corresponds to the currency involved in this model: risk reduction. On the right side of the risk reduction axis is the time invested in stone artefact reduction, increasing to the right. The curved line is a proposed relationship between time invested in technology and risk reduction. This line suggests that a small investment in technology will produce a rapid increase in risk reduction, but then after further investments in technology the returns in risk reduction will eventually taper off. This can be conceived as reflecting the physical limits in artefact reduction; artefacts below a certain size are difficult to productively reduce by further knapping, and difficult to use for processing resources. On the left side of the risk reduction axis is the time spent by foragers being mobile. The straight line that connects time spent being mobile to the curve of the relationship between time invested in technology and risk reduction indicates the optimum configuration under certain conditions. For example, when forager mobility is relatively high (point B), perhaps because of low biomass and patchy food distribution, then this model predicts that the optimum investment in assemblage reduction will also be relatively high, compared to conditions when mobility is less (point A).

To reprise the discussion in chapters three and four, the logical justification of this model is based on the contribution that artefact reduction makes to risk reduction. In chapter four a number of categories of risk were surveyed and the kind most relevant the assemblages under investigation here was found to be technological or venture risk (Elston and Raven 1992: 33-34). Technological risk refers to the risk of running out of usable tools or raw material and being unable to perform key activities. This risk

increases during a toolstone foray in proportion to the time, energy, and opportunity costs involved in searching for, handling and processing stone. As the costs of acquiring stone increase, for example through increased travel times to the source, it would be expected that the use extracted per unit of stone acquired will increase. In practical terms, the more difficult it is to get a nodule of rock, the more useful that rock has to be inorder to justify the investment in acquiring it. One way to measure how much use has been extracted in an assemblage is to see how extensive nodule reduction has been, or how much time and effort was put into extracting flakes from cores to perform tasks. Figure 9.1 assumes that the costs of acquiring stone increase as the time spent being mobile increases because increased mobility constrains the scheduling of stone tool procurement and reduction through a decrease in the predictability of encountering stone sources.

The modelin Figure 9.1 is well suited to the evidence from Tham Lod, where assemblage reduction intensity appeared to have been tuned to environmental changes indicated by the $\delta^{18}O$ values. In terms of the schematic in Figure 9.1, foragers at Tham Lod probably occupied the spectrum between point A and point B, depending on the degree of mobility that suited the environmental conditions. A similar model explains the pattern of occupation intensity at Tham Lod, if the 'time invested in technology' axis is relabelled 'inverse of occupation intensity', since occupation appeared to become less intensive during times when higher mobility is predicted because of reduced precipitation.

The model is less well suited to describing the differences between Tham Lod and Ban Rai, which includes a major reorganisation of mobility strategies as people shift their habitation from a low site close to the river and stone sources to an elevated site away from these resources. If occupation at Tham Lod can be modelled as occupying the region between points A and B on Figure 9.1, how can Ban Rai be modelled? The higher values for assemblage reduction intensity suggest that the optimum level of mobility at Ban Rai should be to the left of point B, but the higher occupation intensity and lower degree of pre-processing at Ban Rai suggest that forager mobility at Ban Rai was not higher than Tham Lod, or at least not substantially higher. As it is, the model in Figure 9.1 can not resolve these differences between the two sites.

One clue towards resolving these differences into a unified model is the timing of occupation at the two sites. In light of the local environmental conditions, the absence

of overlap in the histories of occupation of the two sites is probably not accidental. Drier and more variable conditions during the Pleistocene may have made locations like Ban Rai impossible to occupy except fleetingly en route to more habitable locations. Similarly, increased wetness during the Holocene may have made Tham Lod uninhabitable because of the high density of vegetation, high humidity and inhospitable fauna such as snakes and mosquitoes. In the case of Tham Lod, this suggests that the correlation between wetness and site habitability is not a simple linear function, but has a turning point where increasing wetness ceases to increase a site's habitability and instead makes it less habitable. In the case of Ban Rai, it may have only become habitable after a certain threshold of wetness was passed, increasing the reliability availability of surface water and altering the vegetation structure so that semi-evergreen forests were more accessible from the site.

One approach to modelling the idea of a turning point is to consider a less complex model relating only assemblage reduction and wetness or amount of precipitation. Figure 9.2 shows how wetness could be related to assemblage reduction for the two sites. At maximum dryness there is only one option for optimum reduction, but as wetness increases there are two increasingly divergent optimal levels of reduction. On the left side of the curve the optimal level of reduction decreases as wetness increases, to the point where the curve intersects the vertical axis where no further decreases in reduction are possible (there are obvious limits on the amount useful work that can be done with unmodified cobbles). This is equivalent to the predictions of the optimal dispersion model where increasing wetness corresponds to increasing evenness and predictability of resources, increasing residential mobility and assemblages biased towards place provisioning.

On the right side of the curve the optimal level of reduction increases as wetness increases. This means that for a limited range of wetness there are two optimal levels of reduction. For example, Figure 9.2 shows that a certain range of wetness can have two different levels of assemblage reduction as optimal solutions (A-B or A'-B'). The possibility of two optimal states for assemblage reduction in a given range of wetness means that other factors must have played a substantial role in determining which of the two solutions was the overall optimum state of technological organisation for a given time and location. In this case, proximity of resources can be considered as an

important factor for deciding between the two possible optimal solutions because of the substantial difference in the local settings of the two sites.

The assemblage from Tham Lod occupies the region between points A and B on Figure 9.3, with relatively low levels of wetness corresponding to moderate levels of reduction. The assemblage from Ban Rai occupies the region of the curve between points C and D on Figure 9.3. The shorter distance between C and D compared to A and B reflects difference in magnitude of variation in assemblage reduction intensity between the two sites. This intersection of the curve with the vertical axis on Figure 9.3 is important because it indicates the point where the degree of wetness is sufficiently high that further decreases in assemblage reduction are not a practical response to increasing wetness and a major reorganisation of settlement patterns are necessary.

This may have been the case with Tham Lod and Ban Rai, where the commencement of occupation at Ban Rai signalled a major shift in settlement patterns and increase in assemblage reduction was an optimal strategy for foragers during the increased wetness of the Holocene. This settlement shift is probably an outcome of innovative behaviour compelled by conditions of greater risk sensitivity. Fitzhugh (2001) proposes that as risk sensitive populations begin to experience mean yields below minimum requirements, they should switch from a risk-averse to a risk prone attitude to innovation. A risk prone attitude involves testing new technologies or strategies that might give higher payoffs than existing ones in the new conditions. In this case, the shift from Pleistocene to Holocene conditions was probably what caused foragers to experience mean yields below minimum requirements and trigger a brief change in risk management until the new strategy – one including Ban Rai as part of the settlement system and abandoning Tham Lod – became established.

Integration of this simple turning-point model of wetness and assemblage reduction into the MVT results in Figure 9.4. The key difference between this model and the unmodified MVT is in the relationship between assemblage reduction and risk reduction. In this modified model the relationship states that instead of ending in a horizontal asymptote, the function reaches a point of inflection where increased investment in assemblage reduction leads to continuing increases in risk reduction, resembling a cubic function. In this example, the point of inflection represents the shift in settlement from the low location of Tham Lod near the river to the elevated and distant location at Ban Rai. For simplicity and realism, this function is defined as a

partial function that is not defined for values beyond certain minimum and maximum points on the horizontal axis, reflecting limitations encountered by human foragers. Since the intention here is only semi-quantitative modelling, it is not necessary to specify an equation to describe this model. Similar to the unmodified MVT, the Tham Lod assemblage occupies the region between points A and B. The Ban Rai assemblage occupies the region between points B and C on the horizontal axis, a much smaller range than Tham Lod, reflecting the much smaller range of variation in assemblage reduction intensity at Ban Rai compared to Tham Lod. The introduction of a point of inflection means that although the degree of mobility was not very different between the two sites, it is possible for the more reduced assemblage at Ban Rai to have been an alternative optimal solution. The point of most extensive reduction at Ban Rai is represented on Figure 9.4 by C'.

The implications of this revised model are that conventional models do not generalise well when constraints result in more than one optimum strategy. This is a problem that has been noted by animal ecologists, for example Kacelnik and Bateson (1996) note that risk-sensitive foraging theory makes different predictions about how animals should respond depending on the precise biological scenario, with the energy budget rule failing as a universal predictor for risk-sensitive foraging models. The poor fit of models based on energy as a currency has led Bateson (2002) to suggest that 'we may have to abandon the idea that animals evaluate alternative options using any absolute currency, but instead evaluate options comparatively'. Although psychological factors are undoubtedly relevant, they are unfortunately out of reach of an analysis of flaked stone artefacts. Furthermore, the abandonment of an absolute currency might be an overly extreme suggestion, since the identification of multiple optima here means that risk reduction can still be employed as a single currency that is maximised despite switches in habitat preference.

Figure 9.1. Standard Marginal Value Theorem model

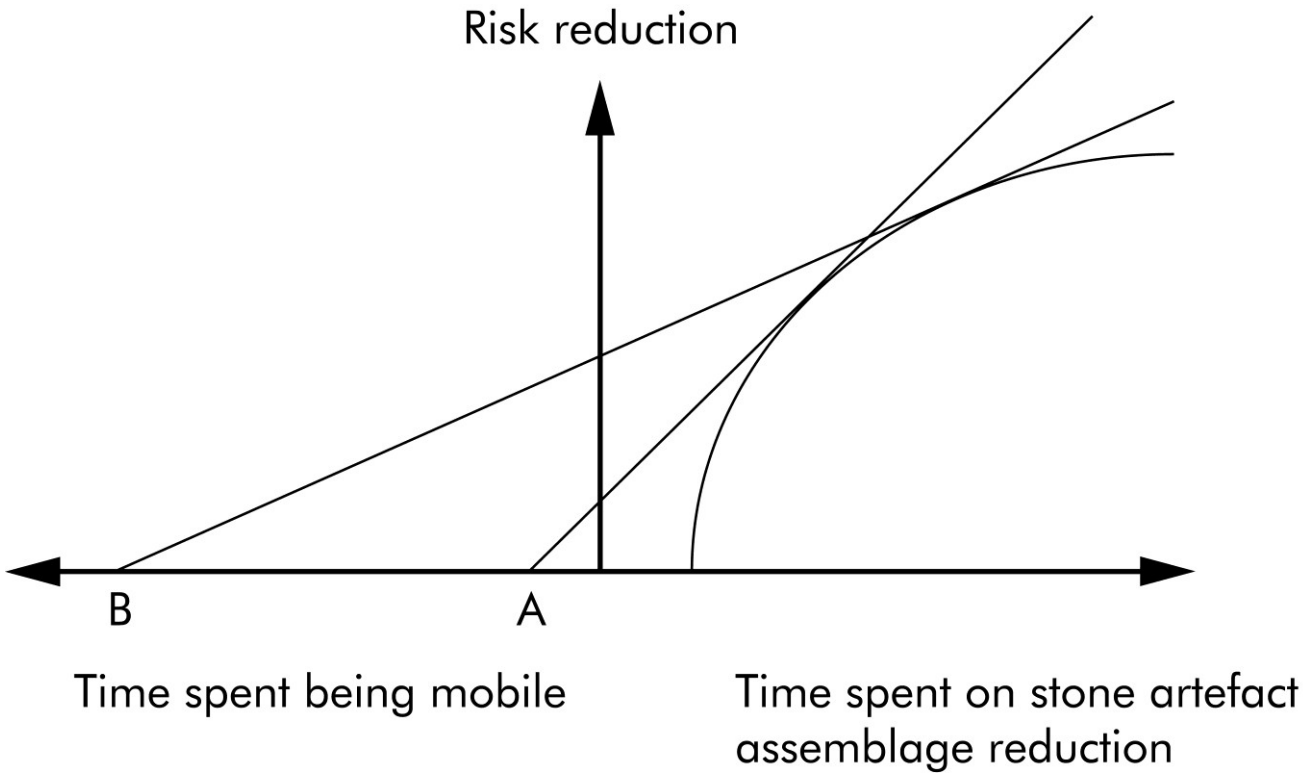


Figure 9.2. Schematic of a derivative function for the modified Marginal Value Theorem of Figure 9.1 above.

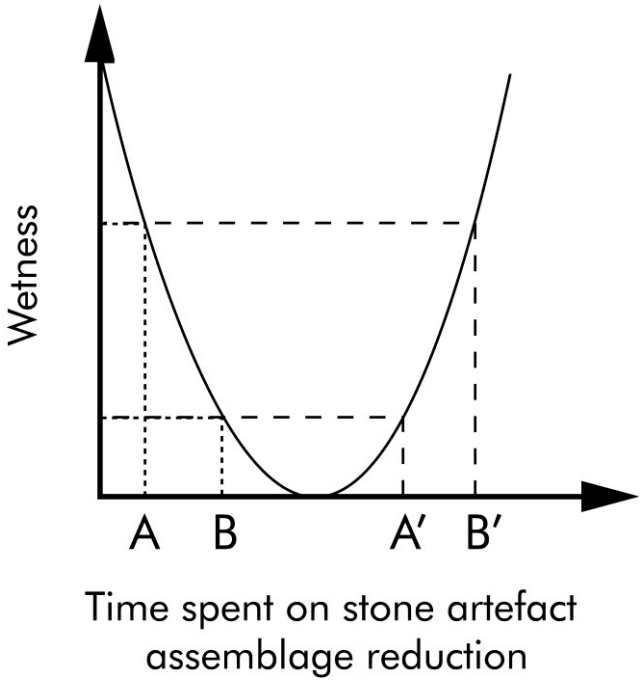


Figure 9.3. Derivative function for modified Marginal Value Theorem showing probable positions of Tham Lod (A-B) and Ban Rai (C-D).

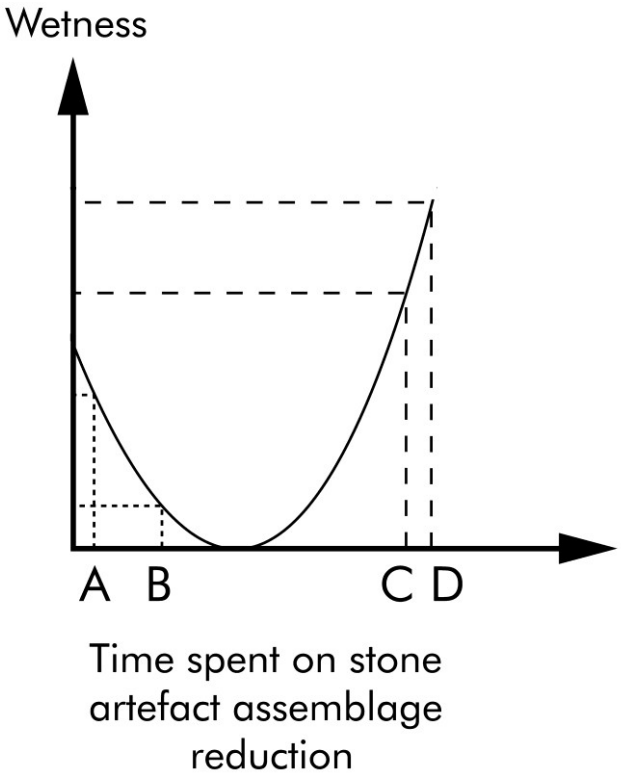
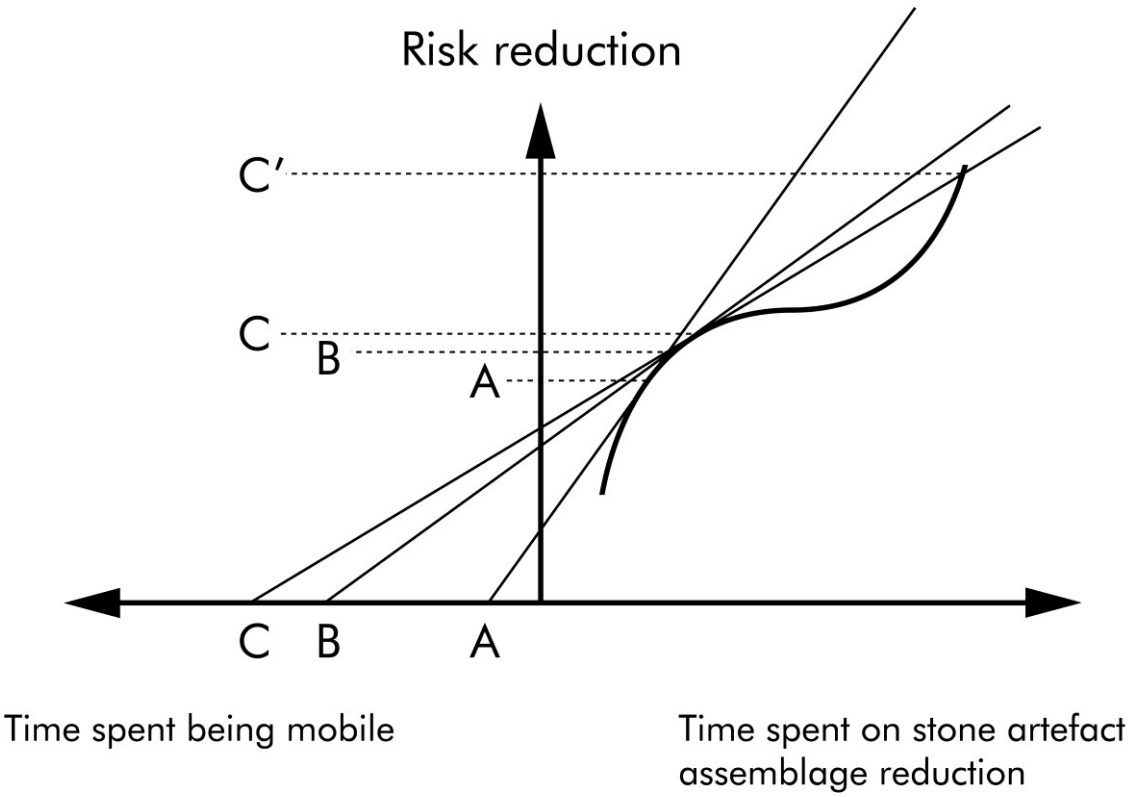


Figure 9.4. Marginal Value Theorem modified to include inflection and multiple optima



A history of human foragers in the northwest Thai uplands

In the context of previous archaeological work discussed in chapter two, this modelling of technology and settlement has three substantial implications for current understandings of cultural history in mainland Southeast Asia. The first implication is a contribution to regional culture history. The first occupation of Tham Lod at about 35,000 BP is within the timing of first modern human activity in mainland Southeast Asia proposed by other sites, such as about 38,000 BP at Lang Rongrien. The river cobbles in the lowest levels of Tham Lod suggest that it was not a suitable location for human habitation prior to about 35,000 BP. If Tham Lod had a substantial depth of sterile deposit below the lowest artefacts then it might suggest that people were not in the area at all until 35,000 BP. As it is, the geoarchaeology of Tham Lod only suggests that this particular site was unsuitable for habitation during earlier periods and does not rule out earlier human occupation of the study area. Earlier evidence is currently very sparse, with small numbers of hominin teeth recovered from caves in northeast Thailand (Tougard et al. 1998) and Vietnam (Demeter et al. 2005) dated to before 100,000 BP. There are also claims of hominid skeletal remains at 500,000 BP from Lampang Province, Northwest Thailand (Pramankij and Subhavan 2001). The contribution of Tham Lod to questions surrounding the earliest colonisation is that sites in low open contexts such as Tham Lod are likely to be poor archives of human or hominin occupation throughout varying hydrological regimes. More productive sites are likely to be found in more elevated contexts.

In light of previous work, Tham Lod is unique as a site with continuous occupation from about 35,000 BP to about 10,000 BP. Sequences at sites of similar antiquity, such as Lang Rongrien and Lang Kamnan were interrupted by roof fall, creating discontinuities and limiting analytical options. The sequence from Tham Lod has allowed a longitudinal analysis of technological variation that has not been possible at other sites. This has resulted in a number of new insights into Pleistocene occupation that may reflect general trends in mainland Southeast Asia. For example, at Tham Lod there is a peak in occupation intensity between about 30,200 BP and 33,300 BP, when $\delta^{18}O$ values are at their lowest, indicating relatively warm and wet conditions. This has not been observed previously and might reflect a small increase in population as conditions became less risky. A second insight is the observation that the Pleistocene occupants of Tham Lod appear to have adapted their stone artefact technology to closely track environmental change. This is an important point because previous work

has tended to characterise Pleistocene assemblages as homogenous and unchanging throughout the entire period. The results presented here suggest that this is not the case, and instead that Pleistocene assemblages were flexible and their variation was a key instrument of forager adaptation to the highly variable Pleistocene climate.

The second implication relates to one of the major themes in previous work on the archaeological of foragers in mainland Southeast Asia; the apparent dominance of flakes in Pleistocene assemblages, interpreted by Anderson (1990) and Van Tan (1997) as the toolkit of highly mobile hunters. Although the discussion in chapter two was limited to sites in Thailand, Van Tan (1997) argues that the prominence of flakes in Pleistocene assemblages is also found in sites in northern Vietnam and southern China. He labels the phenomena the Ngoumian and, like Anderson, argues that the change from flake to pebble artefacts resulted from a change from cool climates to warmer and more humid climates from the Pleistocene to the Holocene.

The approach taken here with the evidence from Tham Lod and Ban Rai suggests that the Ngoumian as a distinctive cultural tradition is probably illusory. In chapter three it was argued that unretouched flaked stone artefact assemblages, such as those typical of mainland Southeast Asian sites, are poorly suited to the identification of cultural traditions. This is because of the difficultly in reliably identifying and measuring variation in artefact form that can be attributed to transmission biases that are distinctive to a cultural tradition. Similarly, it was argued that invoking an explanation for artefact form based on social transmission is problematic because of the difficulty of reliably separating the effects of intentionality from the constraints of raw material mechanics. The same arguments apply to other industries proposed from flaked stone artefact assemblages in mainland Southeast Asia, such as the Hoabinhian and Sonvian.

Further, the evidence from Tham Lod and Ban Rai, like Lang Kamnan, offers little support for the ubiquity of the Ngoumian in mainland Southeast Asia. While there are a few excavation units with high MNF to core ratios in the Pleistocene, spanning a few thousand years in total, there is no evidence for a sustained high ratio of MNF throughout the Pleistocene compared to the Holocene assemblage at Ban Rai. In fact the MNF to core ratios are generally lower during the Holocene. The pattern of a change from flake tools to cobble tools does not seem to be present at Tham Lod and Ban Rai, casting doubt on the universality claimed for the Ngoumian. That said, the identification of the Ngoumian as a variation in stone artefact assemblages related to

ecological conditions is strongly supported by the results presented in the previous chapters. The previous chapter pointed out a number of stark differences between Pleistocene and Holocene stone artefact technologies that were argued to be a result of environmental factors. The key implication of this analysis for the Ngoumian is that the characterisation of foragers as Pleistocene hunters and Holocene tree choppers is a caricature. The differences are substantially more subtle and complicated than a change from dominance of flakes to dominance of cobbles, but research instruments employed in previous studies have not been designed to identify these subtleties.

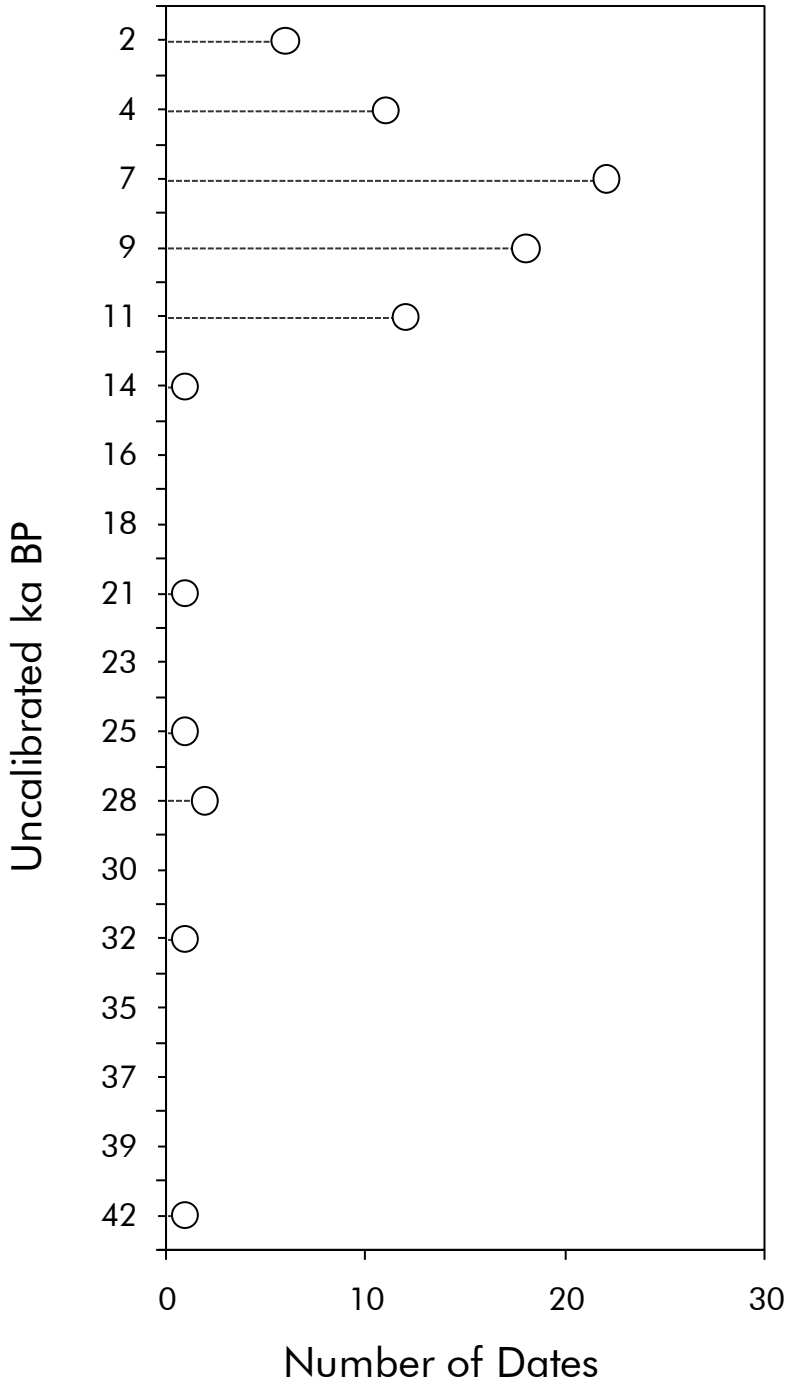
The human behavioural ecological theory discussed in chapters three and four offers a sound conceptual framework to pursue themes such as the Ngoumian. These concepts, coupled with the robust methods discussed in chapter five, will contribute towards a more objective and reliable understanding of variation in stone artefact assemblages and more systematic monitoring technological adjustments to ecological variation. For example, Anderson (1990) proposes that different regional typological variants of the Hoabinhian probably reflect adaptations to different environmental settings. However, available typological descriptions of these Hoabinhian variants are not based on ecological theory and do not permit productive comparison to test Anderson's proposal. One of the key contributions of the work presented here is that a method has been presented that will produce a theoretically informed and objective assemblage analysis suitable for comparing with other assemblages analysed in the same way. The method presented here avoids the problems of previous essentialist methods that ignored large numbers of artefacts because they did not fit into type categories. These previous methods also ignored continuous morphometric variation at the assemblage level in favour of ideal specimens despite the empirical reality that these ideal types are not representative of the assemblage.

The third implication of the work presented here that is relevant to previous archaeological research is the apparent increase in numbers of sites during the early to late Holocene. In chapter two it was noted that all nine sites described were occupied over the period 10,000-5,000 BP with five sites that were only occupied during this period. Reynolds' (1990b) collection of dates from of a large number of Hoabinhian sites throughout mainland Southeast Asia similarly suggests that this period was one that resulted in a peak in the archaeological record (Figure 9.5). This middle Holocene peak in human activity does not appear to have been previously described or

explained. One possible explanation can be suggested from the discussion of palaeoclimate data in chapter seven. It was noted that pollen sequences in China record a Middle Holocene Optimum, a warm-moist event caused by changes in the Earth's orbit that spanned 8,200–5,700 BP. The trend of increasing dryness in the sequence of $\delta^{18}O$ values from Ban Rai was argued to reflect the end of this Middle Holocene Optimum. This correlation of chronology of occupation and climatic conditions, like all the correlations discussed here, does not prove the cause, but it gives a strong hint. It is possible that the increased rainfall and reduced variability of the Middle Holocene Optimum increased the abundance of resources and forager population sizes increased as a result. The relatively high MNA at Ban Rai compared to Tham Lod is suggestive of a higher population during the middle Holocene, but a longer and more detailed Holocene sequence is needed to determine if this is localised to the Middle Holocene Optimum or typical of the entire Holocene, or even due to altered settlement patterns unrelated to population changes

If the Middle Holocene Optimum is related to the peak in forager activity then it is noteworthy that there were no apparent changes in technological trajectories. For example at Ban Rai there is no correlation between any of the stone artefact variables and $\delta^{18}O$ values as the effect of the Middle Holocene Optimum declines, although the short span of the occupation sequence at Ban Rai means that the full effect of the Middle Holocene Optimum is difficult to reliably measure. One possible explanation for the apparent absence of technological reorganisation at this time is that the change in climatic conditions resulted in an increase in population, which then posed new problems for resource procurement and mobility organisation. The optimum solution to these problems may have been a major reorganisation of subsistence strategies, perhaps including more extensive manipulation of the availability of plant resources in a way that came to resemble horticulture.

Figure 9.5. Distribution of radiocarbon dates in mainland Southeast Asian archaeological sites dominated by flaked stone artefact assemblages (n = 76). Data from Reynolds (Feynman 1965, 1985)



Some future directions

Comparison of the results presented in the previous chapters with the archaeological research described in chapter two, such as in the previous section, is relatively straightforward. On the other hand, comparison of the processes of obtaining results used by this project and by previous workers reveals some stark differences and raises broader implications about the nature of scientific progress in archaeology. A review of the approach adopted for this project illustrates some of the philosophical departures from previous work. This project was undertaken from the position that archaeology is a science, a process of learning – in this case about people in the past – where competing ideas are measured against observations (Feynman 1965, 1985). This is generally also the case with previous work but it is helpful to identify alternative views of the scientific method to understand the differences between this project and previous work.

Although the body of relevant previous work is relatively small, it can be described as the output of a 'republic of science' consisting of independent thinkers whose work has been judged by three main criteria: plausibility; scientific value (including accuracy, intrinsic interest and importance) and originality (Polanyi 1962). In this case, the main criterion of scientific merit is adherence to research traditions and the deference to the authority of communal beliefs and values (Ziman 2000a). Explicit discussion of hypotheses and theories has not been prominent in previous work and there is limited evidence of critical engagement. In the context of stone artefact archaeology in mainland Southeast Asia, one of the key research traditions has been the typological method of assemblage classification, based on the idea that discrete stone artefact types are identifiable and have meaning relevant to human behaviour. This tradition has been challenged twice, by Matthews (1964) and White and Gorman (2004), but with limited effect probably because of the relatively delayed and obscure delivery of these challenges and the firmness of typology as an established method.

The research project described here has attempted to work outside of the established research traditions and extend the challenge posed by Matthews (1964) and White and Gorman (2004). For example, the frothy debates about the definition, distribution and timing of the Hoabinhian have been side-stepped here. Chapter four was devoted to the problems and inadequacies of typological approaches to flaked stone artefact assemblages in mainland Southeast Asia. As a result of that investigation, typological

approaches were completely rejected for the analysis undertaken here. The innovations presented in this thesis are well below the order required for a Kuhnian (1962) shift in the focus of investigation where a large body of contradictory data has accumulated or an alternative focus has been presented that explains the discrepancies between the previous work and their observations. Instead, a possible future direction that this work hints at is a shift from the adherence to tradition typical of the republic of science model to the establishment of a broad scientific research program that is working on the 'hard core' of prehistoric human ecology in mainland Southeast Asia (cf. Lakatos 1980).

In this context, the hypotheses of previous work are still valid and useful because of their relevance to the hard core, despite the poor fit between the methods employed to test these hypotheses. This project has offered some more effective methods and progressive theory to continue the advancement of this scientific research program. However, the proposal to establish a scientific research program does not necessarily require the use of the theory and method presented here. It simply requires the confrontation of multiple hypotheses with data as the arbitrator (Hilborn and Mangel 1997: 14). The formulation of hypotheses should encourage more explicit links between method and theory, which has been the most serious weakness of the typological approach. The constant testing and rejection of hypotheses is more likely to lead to innovation and breakthroughs than the republic of science approach which has given more weight to conformism than originality.

The 'hard core' of the research program that most of the previous work has revolved around has been largely implicit. Anderson (1990) and Shoocongdej (2000) have been the most explicit with their claims for links between climate and forager mobility and technology. This project has evaluated these links in the context of one region and attempted to more explicitly define the core of the research program. This has been done by the identification of a theory, or a systematic statement of principles and relationships, suitable for understanding flaked stone artefact assemblages typical of mainland Southeast Asia. In this case, human behavioural ecology was identified as the most productive conceptual framework.

An important consequence of the choice of theory in this project was that the theory came with a number of well-developed models, or stylised representations used in explaining phenomena. The explicit use of models is an important distinction between

this project and previous work. Models are tools used to simplify a complex system or process and direct attention to specific problems, communicate ideas and devise testable predictions (Winterhalder 2002). Models are a bridge between raw intuitions and abstractions and observable consequences and measureable qualities. They are valuable for the discipline they impose on the selection of method and the logical links they provide between theory and measurement. The use of models in archaeology is not new (Clarke 1972), and this project has shown that models do not need to be highly mathematical or sophisticated in order to reliably test predictions and generate new knowledge about flaked stone artefact archaeology in mainland Southeast Asia.

Conclusion

To determine if the aim of this project was achieved, the four questions posed in the introduction are reviewed here. The first question asked what the most productive conceptual framework is for the analysis of technological organisation in mainland Southeast Asia. This question was answered in chapter three which argued in general that evolutionary theory was the most productive. Technological change was argued to be analogous to Darwinian selection, where technological variants compete for selection as the most successful instrument or action under the pressures of specific tasks. More specifically, human behavioural ecology was identified as the style of evolutionary explanation that was best suited to the constraints of the evidence from the two sites. Selectionist approaches were dismissed because of their failure to address questions about human behaviour and the problem of unstated and undemonstrated assumptions about how technological change affects human reproductive fitness. Dual Inheritance Theory (DIT) was similarly inappropriate because of the difficulty in distinguishing between morphometric variation that is related to bias in the cultural transmission of artefact-manufacturing instructions or simply related to variation in the amount of reduction that the artefact or assemblage has undergone. A further problem for both the selectionist and DIT approaches is that they have only been employed on assemblages containing artefacts with very distinctive forms such as Palaeoindian points. An important constraint of mainland Southeast Asian assemblages is that they lack visually distinctive artefact forms, making it difficult to employ selectionist and DIT approaches. Human behavioural ecology is more suitable because it is focussed on adaptation rather than transmission, and how stone artefacts form part of a general behavioural strategy to optimize risk reduction under specific environmental conditions.

The second question posed in the introduction asked how variation in technological organisation in mainland Southeast Asia assemblages should be measured most reliably and validly. Chapter three concluded with three models to generate predictions to test with the stone artefact assemblages. In chapter four it was established that the link between the predictions of the models and measurement of the assemblages was the quality of risk reduction. Risk is a general quality that strongly influences the way people organise their stone artefact technology. Kuhn's (1995) spectrum of place and individual provisioning was adapted as an instrument to measure risk reduction. Individual provisioning is a strategy expected when the risk of failing to obtain stone when it is needed is high, resulting in high investments of time and energy in extending the useful lives of artefacts. On the other hand, place provisioning is a strategy expected when risks of failure are low and relatively less time and energy is invested in artefact production and maintenance. Through the production and analysis of an experimental stone artefact assemblage, it was demonstrated in chapter five that there are five attributes of complete flakes that are indicators of the time and energy invested in stone artefact assemblages. These variables are the presence of overhang removal, the percentage of dorsal cortex, the number of dorsal flake scars, the interior platform angle and the distribution of dorsal cortex. The identification of these variables completed the link from human behavioural ecological theory to the three foraging models and their predictions to the measurement of the assemblages for testing of the predictions.

The third question posed in the introduction was about the climatic history that formed the backdrop of human forager activity in the northern Thai uplands. Chapter six described the current climate and environmental setting of the two sites, identifying the environmental parameters that were most likely to vary as a result of changes in climate. Chapter seven reviewed previous work on climate history in Thailand and presented a new proxy in the form of oxygen isotope sequences derived from freshwater bivalves excavated from Tham Lod and Ban Rai. The reliability of the oxygen isotope sequences was demonstrated by comparison to similar records from speleothems in China. In general, the oxygen isotope sequences showed that Pleistocene climates were substantially drier and more variable than Holocene climates. More importantly, the isotope sequence established a climate history well-suited for comparison with the stone artefact record because it came from the same

location and at the equivalent chronological resolution of the stone artefact sequences at Tham Lod and Ban Rai.

The fourth question asked to what extent climatic conditions were related to technological organisation over time and space in the northern Thai uplands. This question was answered in detail in chapter eight and earlier in this chapter. Three key findings are worth repeating here: first, the results of the stone artefact analysis demonstrated that Pleistocene technology was more sensitive to climate change than Holocene technology, second that the change in climate from the Pleistocene to the Holocene was accompanied by a shift in forager settlement patterns rather than a substantial change in their stone artefact technology, and third that during the Holocene technological change was more coherent and tuned to a higher frequency of variation than during the Pleistocene, but no longer strongly coupled to environmental variation.

Answering these four questions has made a modest but novel contribution to the research problems resulting from incomplete knowledge and flawed understandings of the organisation of flaked stone artefact technology under varying climatic conditions in mainland Southeast Asia. Substantial future potential has been revealed for reduction-based stone artefact assemblage analysis in mainland Southeast Asia and computer-intensive statistical methods based on resampling for stone artefact analysis in general. These kinds of analysis should now be employed to establish corroborating evidence from a greater number of sites in Thailand. The evidence that the patterns described here are based is very limited and future work should investigate the presence of these patterns at other sites with evidence of Holocene and late Pleistocene behavioural systems. Beyond the research problem, the practical significance of this contribution is that two general human systems have been affirmed as successful strategies for dealing with climate change: shifts in technological organisation and shifts in settlement patterns. This project has demonstrated the resilience and vulnerability of human groups to environmental variability. There is always a risk of sounding trite when attempting to express the contemporary relevance of archaeological research, especially research into chronologically remote and exotic forms of human social organisation such as foragers. However, human cultures gauge their ability to adapt to future climate variations on the basis of what is known from past records and experience. Efforts to understand past cultural responses to large and

persistent climate changes may prove instructive for assessing modern preparedness for a changing and uncertain future (deMenocal 2001, Weiss and Bradley 2001). The research described here implies that changes in human technological organisation and settlement patterns are likely to be important strategies for managing climate change in some contexts, including the present and future. Similarly, this research also implies that in other contexts human behaviour and technology has sufficient pliancy and latitude to manage climate change without any discernable modifications.

References

ABDI, H. (2006) Z-scores. IN SALKIND, N. J. (Ed.) *Encyclopedia of Measurement and Statistics.* Sage Publications, Thousand Oaks.

AHLER, S. A. (1986) *The Knife River Flint Quarries: Excavations at Site 32DU508,* Bismarck, State Historical Society of North Dakota.

ALDENDERFER, M. (1998) Quantitative methods in archaeology: A review of recent trends and developments. *Journal of Archaeological Research,* 6**,** 91-120.

AMICK, D. S., MAULDIN, R. P. & BINFORD, L. R. (1989) The potential of experiments in lithic technology. IN AMICK, D. S. & MAULDIN, R. P. (Eds.) *Experiments in Lithic Technology.* Oxford, BAR International Series 528.

AMICK, D. S., MAULDIN, R. P. & TOMKA, S. A. (1988) An evaluation of debitage produced by experimental bifacial core reduction of a Georgetown chert nodule. *Lithic Technology,* 17**,** 26-36.

AN, Z. S., PORTER, S. C., KUTZBACH, J. E., WU, X. H., WANG, S. M., LIU, X. D., LI, X. Q. & ZHOU, W. J. (2000) Asynchronous Holocene optimum of the East Asian monsoon. *Quaternary Science Reviews,* 19**,** 743-762.

ANDERSON, D. D. (1987) A Pleistocene - Early Holocene rockshelter in Peninsular Thailand. *National Geographic Research,* 3**,** 184-198.

ANDERSON, D. D. (1988) Excavations of a Pleistocene rockshelter in Krabi and the prehistory of Southern Thailand. IN BRONSON, B. & CHAROENWONGSA, P. (Eds.) *Prehistoric Studies: The Stone and Metal Ages in Thailand.* Bangkok, Thai Antiquity Working Group.

ANDERSON, D. D. (1990) *Lang Rongrien rockshelter: a Pleistocene-early Holocene archaeological site from Krabi, Southwestern Thailand,* Philadelphia, University Museum, University of Pennsylvania.

ANDERSON, D. D. (1997) Cave archaeology in Southeast Asia. *Geoarchaeology,* 12**,** 607-638.

ANDERSON, D. R., BURNHAM, K. P. & THOMPSON, W. L. (2000) Null Hypothesis Testing: Problems, Prevalence, and an Alternative. *The Journal of Wildlife Management,* 64**,** 912-923.

ANDREFSKY, W. (1998) *Lithics: A macroscopic approach,* Cambridge, Cambridge University Press.

AUCLAIR, A.-C., LECUYER, C., BUCHER, H. & SHEPPARD, S. M. F. (2004) Carbon and oxygen isotope composition of *Nautilus macromphalus*: a record of thermocline waters off New Caledonia. *Chemical Geology,* 207**,** 91.

AUETRAKULVIT, P. (1995) การวิเคราะห์เทคนิคการกระเทาะเครื่องมือหิน : กรณีศึกษาตัวอย่าง เครื่องมือหินที่พบในหลุมขุดค้นแหล่งโบราณคดีถ้ำหมอเขียว 2 อำเภอเมือง จังหวัดกระบี่ *Department of Archaeology.* Bangkok, Silpakorn University.

AYLING, B. F., MCCULLOCH, M. T., GAGAN, M. K., STIRLING, C. H., ANDERSEN, M. B. & BLAKE, S. G. (2006) Sr/Ca and [delta]18O seasonality in a Porites coral from the MIS 9 (339-303 ka) interglacial. *Earth and Planetary Science Letters,* 248**,** 462-475.

BAKER, A., ITO, E., SMART, P. L. & MCEWAN, R. F. (1997) Elevated and variable values of 13C in speleothems in a British cave system. *Chemical Geology,* 136**,** 263-270.

BAMFORTH, D. B. (1986) Technological Efficiency and Tool Curation. *American Antiquity,* 51**,** 38-50.

BAMFORTH, D. B. (2002) Evidence and metaphor in evolutionary archaeology. *American Antiquity,* 68**,** 573-580.

BAMFORTH, D. B. & BLEED, P. (1997) Technology, Flaked Stone Technology, and Risk. IN BARTON, C. M. & CLARK, G. A. (Eds.) *Rediscovering Darwin: Evolutionary Theory in Archeological Explanation.* Archeological Papers of the American Anthropological Association Number 7

BANNANURAG, R. (1988) Evidence for ancient woodworking: A microwear study of Hoabinhian tools. IN BRONSON, B. & CHAROENWONGSA, P. (Eds.) *Prehistoric Studies: The Stone and Metal Ages in Thailand.* Bangkok, Thai Antiquity Working Group.

BAR-YOSEF, O. (1991) Raw material exploitation in the Levantine Epi-Paleolithic. IN MONTET-WHITE, A. & HOLEN, S. R. (Eds.) *Raw Material Economies Among Prehistoric Hunter-Gatherers.* Lawrence, University of Kansas Publications in Anthropology.

BAR-YOSEF, O. (2002) The role of the Younger Dryas in the origin of agriculture in west Asia. IN YASUDA, Y. (Ed.) *The Origins of Pottery and Agriculture.* New Delhi, Roli Books.

BARLOW, K. R. & METCALFE, D. (1996) Plant utility indices: Two Great Basin examples. *Journal of Archaeological Science,* 23**,** 351-371.

BARTON, C. M. (1988) *Lithic Variability and Middle Paleolithic Behaviour: New evidence from the Iberian Peninsula,* Oxford, British Archaeological Reports.

BASALLA, G. (1988) *The Evolution of Technology,* Cambridge, Cambridge University Press.

BATESON, M. (2002) Recent advances in our understanding of risk-sensitive foraging. *Proceedings of the Nutrition Society,* 61**,** 509-519.

BAUMLER, M. F. & DOWNUM, C. E. (1989) Between micro and macro: A study in the interpretation of small-sized lithic debitage. IN AMICK, D. S. & MAULDIN, R. P. (Eds.) *Experiments in Lithic Technology, British Archaeological Reports International Series.*

BAXTER, M. J. (1994) *Exploratory multivariate analysis in archaeology,* Edinburgh, Edinburgh University Press.

BECK, C., TAYLOR, A. K., JONES, G. T., FADEM, C. M., COOK, C. R. & MILLWARD, S. A. (2002) Rocks are heavy: transport costs and Paleoarchaic quarry behavior in the Great Basin. *Journal of Anthropological Archaeology,* 21**,** 481-507.

BELSLEY, D. A., KUH, E. & WELSCH, R. E. (2004) *Regression Diagnostics: Identifying Influential Data and Sources of Collinearity,* New York, Wiley-IEEE.

BENTLEY, R. A. & SHENNAN, S. J. (2003) Cultural transmission and stochastic network growth. *American Antiquity,* 68**,** 459-485.

BERKSON, J. (1938) Some Difficulties of Interpretation Encountered in the Application of the Chi-Square Test. *Journal of the American Statistical Association,* 33**,** 526-536.

BETTINGER, R. L. & EERKENS, J. (1997) Evolutionary implications of metrical variation in Great Basin projectile points. IN BARTON, C. M. & CLARK, G. A. (Eds.) *Rediscovering Darwin: Evolutionary Theory and Archaeological Explanation.* Arlington, Virginia, American Anthropological Association.

BETTINGER, R. L. & EERKENS, J. (1999) Point Typologies, Cultural Transmission, and the Spread of Bow-and-Arrow Technology in the Prehistoric Great Basin. *American Antiquity,* 64**,** 231-242.

BETTINGER, R. L., MALHI, R. & MCCARTHY, H. (1997) Central Place Models of Acorn and Mussel Processing. *Journal of Archaeological Science,* 24**,** 887-899.

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**,** 4-20.

BINFORD, L. R. & BINFORD, S. R. (1966) A Preliminary Analysis of Functional Variability in the Mousterian of Levallois Facies. *American Anthropologist,* 68**,** 238-295.

BIRD, D. & O'CONNELL, J. (2006) Behavioral Ecology and Archaeology. *Journal of Archaeological Research,* 14**,** 143-188.

BIRD, D. W. & BLIEGE BIRD, R. L. (1997) Contemporary Shellfish Gathering Strategies among the Meriam of the Torres Strait Islands, Australia: Testing Predictions of a Central Place Foraging Model. *Journal of Archaeological Science,* 24**,** 39-63.

BLAND, J. M. & ALTMAN, D. G. (1996) Statistics notes: Transformations, means, and confidence intervals. *British Medical Journal,* 312**,** 1079.

BLEED, P. (1986) The optimal design of hunting weapons: maintainability or reliability. *American Antiquity,* 51**,** 737-747.

BLEED, P. (1997) Content as variability, result as selection: toward a behavioural definition of technology. IN CLARK, G. A. & BARTON, C. M. (Eds.) *Rediscovering Darwin: Evolutionary Theory in Archaeology.* Washington, American Anthropological Association.

BLEED, P. (2001) Trees or chains, links or branches: conceptual alternatives for consideration of stone tool production and other sequential activities. *Journal of Archaeological Method and Theory,* 8**,** 101-127.

BLIEGE BIRD, R., SMITH, E. & BIRD, D. (2001) The hunting handicap: costly signaling in human foraging strategies. *Behavioral Ecology and Sociobiology,* 50**,** 9-19.

BOONE, J. L. & SMITH, E. A. (1998) Is it evolution yet? A critique of evolutionary archaeology. *Current Anthropology,* 39**,** 141-157.

BOOS, D. D. (2003) Introduction to the Bootstrap World. *Statistical Science,* 18**,** 168-174.

BOOS, D. D. & HUGHES-OLIVER, J. M. (2000) How Large Does n Have to be for Z and t Intervals? *The American Statistician,* 54**,** 121-128.

BOOTH, J. G. & HALL, P. (1994) Monte Carlo approximation and the iterated bootstrap. *Biometrika,* 81**,** 331-340.

BORDES, F. & DE SONNEVILLE-BORDES, D. (1970) The Significance of Variability in Palaeolithic Assemblages. *World Archaeology,* 2**,** 61-73.

BORISKOVSKY, P. I. (1971) *Ancient Stone Age of South-Eastern Asia,* Leningrad, Nauka.

BORODICH, F. M. (1997) Some fractal models of fracture. *Journal of the Mechanics and Physics of Solids,* 45**,** 239-259.

BOUSMAN, C. B. (1993) Hunter-gatherer adaptations, economic risk and tool design. *Lithic Technology,* 18**,** 59-85.

BOUSMAN, C. B. (2005) Coping with risk: Later stone age technological strategies at Blydefontein Rock Shelter, South Africa. *Journal of Anthropological Archaeology,* 24**,** 193–226.

BOWLER, P. J. (2003) *Evolution: The History of an Idea,* Berkeley, CA, University of California Press.

BOYD, R. & RICHERSON, P. J. (1985) *Culture and the Evolutionary Process,* Chicago, University of Chicago Press.

BOYD, R. & RICHERSON, P. J. (1992) Cultural inheritance and evolutionary ecology. IN WINTERHALDER, B. (Ed.) *Evolutionary Ecology and Human Behavior.* New York, Aldine de Gruyer.

BRANTINGHAM, P. J. & KUHN, S. L. (2001) Constraints on Levallois Core Technology: A Mathematical Model. *Journal of Archaeological Science,* 28**,** 747-761.

BRANTINGHAM, P. J., OLSEN, J. W., RECH, J. A. & KRIVOSHAPKIN, A. I. (2000) Raw Material Quality and Prepared Core Technologies in Northeast Asia. *Journal of Archaeological Science,* 27**,** 255-271.

BRAUN, D. R., TACTIKOS, J. C., FERRARO, J. V. & HARRIS, J. W. K. (2005) Flake recovery rates and inferences of Oldowan hominin behavior: a response to Kimura 1999, 2002. *Journal of Human Evolution,* 48**,** 525-531.

BRIGHTON, H., SMITH, K. & KIRBY, S. (2005) Language as an evolutionary system. *Physics of Life Reviews,* 2**,** 177-226.

BROUGHTON, J. M. (1994) Late Holocene Resource Intensification in the Sacramento Valley, California: The Vertebrate Evidence. *Journal of Archaeological Science,* 21**,** 501-514.

BROWN, C. T. (2001) The Fractal Dimensions of Lithic Reduction. *Journal of Archaeological Science,* 28**,** 619-631.

BROWN, C. T., WITSCHEY, W. R. T. & LIEBOVITCH, L. S. (2005) The Broken Past: Fractals in Archaeology. *Journal of Archaeological Method and Theory,* 12**,** 37-78.

BUCK, C. E., CAVANAGH, W. G. & LITTON, C. D. (1996) *Bayesian approach to interpreting archaeological data,* England, Wiley Chichester

BUCK, C. E. & SAHU, S. K. (2000) Bayesian models for relative archaeological chronology building. *Applied Statistics,* 49**,** 423-440.

BULBECK, F. D. (2003) Hunter-gatherer occupation of the Malay Peninsula from the Ice Age to the Iron Age. IN MERCADER, J. (Ed.) *Under the Canopy: The Archaeology of Tropical Rainforests.* Piscataway, NJ :, Rutgers University Press,.

BURNHAM, K. P. & ANDERSON, D. R. (2002) *Model selection and multimodel inference: a practical information-theoretic approach,* New York, Springer-Verlag.

CANTY, A. J., DAVISON, A. C. & HINKLEY, D. V. (1996) Contribution to the discussion of 'Bootstrap confidence intervals' by T. J. DiCiccio and B. Efron, . *Statistical Science,* 11**,** 214-219.

CARACO, T. (1981) Risk-Sensitivity and Foraging Groups. *Ecology,* 62**,** 527-531.

CARMINES, E. G. & ZELLER, R. A. (1979) *Reliability and validity assessment: Quantitative applications in the social sciences,* Beverly Hills, Sage.

CARRE, M., BENTALEB, I., BLAMART, D., OGLE, N., CARDENAS, F., ZEVALLOS, S., KALIN, R. M., ORTLIEB, L. & FONTUGNE, M. (2005) Stable isotopes and sclerochronology of the bivalve *Mesodesma donacium*: Potential application to

Peruvian paleoceanographic reconstructions. *Palaeogeography, Palaeoclimatology, Palaeoecology,* 228**,** 4-25.

CARVER, R. P. (1993) The Case Against Statistical Significance Testing, Revisited. *Journal of Experimental Education,* 61**,** 287-292.

CASTEEL, R. W. (1978) Faunal Assemblages and the" Wiegemethode" or Weight Method. *Journal of Field Archaeology,* 5**,** 71-77.

CHARNOV, E. L. (1976) Optimal foraging: the marginal value theorem. *Theoretical Population Biology,* 9**,** 129-136.

CHERNICK, M. R. (1999) *Bootstrap methods: A practitioner's guide,* New York Wiley.

CHIBNIK, M. (1985) The Use of Statistics in Sociocultural Anthropology. *Annual Review of Anthropology,* 14**,** 135-157.

CHRISTEN, J. A. & LITTON, C. D. (1995) A bayesian approach to wiggle-matching. *Journal of Archaeological Science,* 22**,** 719-725.

CHRISTENSON, A. L. (1979) On the Virtues of Simplicity: Some Comments on Statistical Analysis in Anthropology. *Plains Anthropologist,* 24**,** 35-38.

CHRISTIE, D. (2004) Resampling with Excel. *Teaching Statistics,* 26**,** 9-14.

CHUNG, T. N. (1994) Technological and typological characteristics of the chipped tools in the Hoa Binh culture. *Vietnam Social Sciences,* 5**,** 46-55.

CLARK, G. A. & STAFFORD, C. R. (1982) Quantification in American Archaeology: A Historical Perspective. *World Archaeology,* 14**,** 98-119.

CLARKE, D. L. (1968) *Analytical archaeology,* London, Methuen

CLARKE, D. L. (1972) *Models in archaeology,* London, Methuen.

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. *School of Archaeology and Anthropology.* Canberra, Australian National University.

CLARKSON, C. (2006) Interpreting Surface Assemblage Variation in Wardaman Country, Northern Territory: An Ecological Approach. IN ULM, S. & LILLEY, I. (Eds.) *An Archæological Life: Papers in Honour of Jay Hall.* Brisbane, Aboriginal and Torres Strait Islander Studies Unit, The University of Queensland.

CLARKSON, C. (2007) *Lithics in the land of the lightening brothers. The archaeology of Wardaman Country, Northern Territory,* Canberra, ANU E Press.

CLARKSON, C. & LAMB, L. (2005) Introduction: Casting New Light on Old Stones. IN CLARKSON, C. & LAMB, L. (Eds.) *Rocking the Boat: Recent Australian Approaches to Lithic Reduction, Use and Classification.* Oxford, Archaeopress.

CLARKSON, C. & O'CONNOR, S. (2005) An Introduction to Stone Artefact Analysis. IN BALME, J. & PATERSON, A. (Eds.) *Archaeology in Practice: A Student Guide to Archaeological Analysis.* Blackwell Publishing.

CLEVELAND, W. S. (1981) LOWESS: A Program for Smoothing Scatterplots by Robust Locally Weighted Regression. *The American Statistician,* 35**,** 54-54.

CLEVELAND, W. S. (1984a) Graphical Methods for Data Presentation: Full Scale Breaks, Dot Charts, and Multibased Logging. *The American Statistician,* 38**,** 270-280.

CLEVELAND, W. S. (1984b) Graphs in Scientific Publications. *The American Statistician,* 38**,** 261-269.

CLEVELAND, W. S. & DEVLIN, S. J. (1988) Locally Weighted Regression: An Approach to Regression Analysis by Local Fitting. *Journal of the American Statistical Association,* 83**,** 596-610.

CLEVELAND, W. S. & MCGILL, R. (1985) Graphical Perception and Graphical Methods for Analyzing Scientific Data. *Science,* 229**,** 828-833.

CLEVELAND, W. S. & MCGILL, R. (1987) Graphical Perception: The Visual Decoding of Quantitative Information on Graphical Displays of Data. *Journal of the Royal Statistical Society. Series A (General),* 150**,** 192-229.

COLANI, M. (1927) L'âge de la pierre dans la province de Hoa Binh. *Mémoires du Service Géologique de l'Indochine,* 13.

COLLARD, M., KEMERY, M. & BANKS, S. (2005) Causes of Toolkit Variation Among Hunter-Gatherers: A Test of Four Competing Hypotheses. *Canadian Journal of Archaeology,* 29**,** 1-19.

COLLARD, M. & SHENNAN, S. (2000) Processes of Culture Change in Prehistory: A Case Study from the European Neolithic. IN RENFREW, C. & BOYLE, K. (Eds.) *Archaeogenetics: DNA and the Population Prehistory of Europe.* Cambridge, McDonald Institute for Archaeological Research.

COLLARD, M. & TEHRANI, J. J. (2005) Cladistic analysis of Turkmen textiles sheds light on cultural evolution. IN MACE, R., HOLDEN, C. J. & SHENNAN, S. (Eds.) *The Evolution of Cultural Diversity: a Phylogenetic Approach.* London, UCL Press.

COLLINS, M. C. (1975) Lithic technology as a means of processual inference. IN SWANSON, E. (Ed.) *Lithic Technology: Making and Using Stone Tools.* The Hague, Mouton.

COTTERELL, B. & KAMMINGA, J. (1987) The Formation of Flakes. *American Antiquity,* 52**,** 675-708.

COWAN, F. L. (1999) Making Sense of Flake Scatters: Lithic Technological Strategies and Mobility. *American Antiquity,* 64**,** 593-607.

COWGILL, G. L. (1977) The Trouble with Significance Tests and What We can do about It. *American Antiquity,* 42**,** 350-368.

CRABTREE, D. E. (1972) *An introduction to flintworking*, Occasional Papers of the Idaho State University Museum, N.28.

CRISS, R. E. (1999) *Principals of Stable Isotope Distribution,* New York, Oxford University Press.

CRONK, L. (1991) Human Behavioral Ecology. *Annual Review of Anthropology,* 20**,** 25-53.

CUMMING, G. & FINCH, S. (2001) A Primer on the Understanding, Use, and Calculation of Confidence Intervals that are Based on Central and Noncentral Distributions. *Educational and Psychological Measurement,* 61**,** 532-574.

CUMMING, G. & FINCH, S. (2005) Inference by Eye: Confidence Intervals and How to Read Pictures of Data. *American Psychologist,* 60**,** 170-180.

DANSGAARD, W. (1964) Stable isotopes in precipitation. *Tellus* 16 438-468.

DAVIDSON, I. (2002) The 'Finished Artefact Fallacy': Acheulean Handaxes and Language Origins. . IN WRAY, A. (Ed.) *The Transition to Language.* Oxford, Oxford University Press.

DAVIDSON, I. & NOBLE, I. R. (1993) Tools and Language in Human Evolution. IN GIBSON, K. & INGOLD, T. (Eds.) *Tools, Language and Cognition in Human Evolution.* Cambridge, Cambridge University Press.

DAVISON, A. C. & HINKLEY, D. V. (1997) *Bootstrap methods and their application,* Cambridge, Cambridge University Press

DAWKINS, R. (1982) *The Extended Phenotype: The Long Reach of the Gene,* Oxford, Oxford University Press.

DE TERRA, H. & MOVIUS, H. L. (1943) Research on Early Man in Burma. *Transactions of the American Philosophical Society,* 32**,** 271-393.

DEAL, M. & HAGSTRUM, M. (1995) Ceramic Reuse Behavior among the Maya and Wanka: Implications for Archaeology. IN SKIBO, M., WALKER, W. H. & NIELSEN, A. E. (Eds.) *Expanding Archaeology.* Salt Lake City, University of Utah Press.

DELLAPORTAS, P. (1998) Bayesian Classification of Neolithic Tools. *Applied Statistics,* 47**,** 279-297.

DEMENOCAL, P. B. (2001) Cultural Responses to Climate Change During the Late Holocene. *Science,* 292**,** 667-673.

DEMETER, F., BACON, A.-M., NGUYEN, K. T., LONG, V. T., DURINGER, P., ROUSSE, S., COPPENS, Y., MATSUMURA, H., DODO, Y., NGUYEN, M. H. & TOMOKO, A. (2005) Discovery of a second human molar and cranium fragment in the late Middle to Late Pleistocene cave of Ma U'Oi (Northern Vietnam). *Journal of Human Evolution,* 48**,** 393-402.

DENNETT, D. C. (1994) *Darwin's Dangerous Idea: Evolution and the Meanings of Life,* London, Simon & Schuster.

DENNIS, B. (1996) Discussion: Should Ecologists Become Bayesians? *Ecological Applications,* 6**,** 1095-1103.

DETTMAN, D. L. & LOHMANN, K. C. (1993) Seasonal change in Paleogene surface water δ18O: Fresh-water bivalves of western North America. *Climate change in continental isotopic records, Geophysical Monograph 78.* American Geophysical Union.

DETTMAN, D. L., REISCHE, A. K. & LOHMANN, K. C. (1999) Controls on the stable isotope composition of seasonal growth bands in aragonitic fresh-water bivalves (Unionidae). *Geochimica et Cosmochimica Acta,* 63**,** 1049-1057.

DI STEFANO, J., FIDLER, F. & CUMMING, G. (2005) Effect size estimates and confidence intervals: An alternative focus for the presentation and interpretation of ecological data. IN BURK, A. R. (Ed.) *New Trends in Ecology Research.* Hauppauge, NY, Nova Science Publishing.

DIACONIS, P. & EFRON, B. (1983) Computer Intensive Methods in Statistics. *Scientific American,* 248 116-130.

DIBBLE, H. (1995) Middle Paleolithic scraper reduction: background, clarification, and review of evidence to date. *Journal of Archaeological Method and Theory* 2**,** 299-368.

DIBBLE, H., L. , SCHURMANS, U., A. , IOVITA, R., P. & MCLAUGHLIN, M., V. (2005) The measurement and interpretation of cortex in lithic assemblages. *American Antiquity,* 70**,** 545-560.

DIBBLE, H., ROTH, B. & LENOIR, M. (1995) The use of raw materials at Combe-Capelle Bas. IN DIBBLE, H., ROTH, B. & LENOIR, M. (Eds.) *The Middle Paleolithic Site of Combe-Capelle Bas (France).* Philadelphia, University Museum Press.

DIBBLE, H. L. (1987) The Interpretation of Middle Paleolithic Scraper Morphology. *American Antiquity,* 52**,** 109-117.

DIBBLE, H. L. & BERNARD, M. C. (1980) A Comparative Study of Basic Edge Angle Measurement Techniques. *American Antiquity,* 45**,** 857-865.

DIBBLE, H. L. & PELCIN, A. (1995) The Effect of Hammer Mass and Velocity on Flake Mass. *Journal of Archaeological Science,* 22**,** 429.

DIBBLE, H. L. & WHITTAKER, J. C. (1981) New experimental evidence on the relation between percussion flaking and flake variation. *Journal of Archaeological Science,* 8**,** 283.

DICICCIO, T. J. & EFRON, B. (1996) Bootstrap Confidence Intervals. *Statistical Science,* 11**,** 189-212.

DICICCIO, T. J. & ROMANO, J. P. (1988) A Review of Bootstrap Confidence Intervals. *Journal of the Royal Statistical Society. Series B (Methodological),* 50**,** 338-354.

DORALE, J. A., EDWARDS, R. L., ITO, E. & GONZALEZ, L. A. (1998) Climate and Vegetation History of the Midcontinent from 75 to 25 ka: A Speleothem Record from Crevice Cave, Missouri, USA. *Science,* 282**,** 1871-1874.

DRENNAN, R. D. (1996) *Statistics for Archaeologists: A Commonsense Approach,* New York, Plenum Press.

DUNKLEY, J. R. (1985) Karst and Caves of the Nam Lang - Nam Khong region, North Thailand. *Helictite,* 23**,** 3-22.

DUNKLEY, J. R. & BRUSH, J. B. (Eds.) (1986) *Caves of Northwest Thailand: Report of the Australian Speleological Expedition 1983-1986,* Sydney, Speological Research Council.

DUNN, J. & PLOMIN, R. (1990) *Separate Lives: Why Siblings are So Different,* New York, John Wiley.

DUNNELL, R. C. (1971) *Systematics in Prehistory,* New York, The Free Press.

DUNNELL, R. C. (1978) Style and function: A fundamental dichotomy. *American Antiquity,* 43**,** 192-202.

DUNNELL, R. C. (1980) Evolutionary theory and archaeology. IN SCHIFFER, M. B. (Ed.) *Advances in Method and Theory.* New York, Academic Press.

DUNNELL, R. C. (1982) Science, social science, and common sense: the agonizing dilemma of modern archaeology. *Journal of Anthropological Research,* 38**,** 1-25.

DUNNELL, R. C. (1986) Methodological issues in Americanist artifact classification. IN SCHIFFER, M. B. (Ed.) *Advances in Archaeological Method and Theory.* New York, Academic Press.

DUNNELL, R. C. (1989) Aspects of the application of evolutionary theory. IN LAMBERG-KARLOVSKY, C. C. (Ed.) *Archaeological thought in America.* Cambridge, Cambridge University Press.

DUNNELL, R. C. (1992) Archaeology and evolutionary science. IN WANDSNIDER, L. (Ed.) *Quandaries and quests: Visions of archaeology's future.* Center for Archaeological Investigations Occasional Paper 20.

DUPRÉ, J. (1993) *The Disorder of Things: Metaphysical Foundations of the Disunity of Science,* Cambridge, Harvard University Press.

DURHAM, W. H. (1981) Overview: Optimal Foraging Analysis in Human Ecology. IN WINTERHALDER, B. & SMITH, E. A. (Eds.) *Hunter-Gatherer Foraging Strategies: Ethnographic and Archaeological Analyses.* Chicago, The University of Chicago Press.

EBERT, J. I. (1979) An ethnoarchaeological approach to reassessing the meaning of variability in stone tool assemblages. IN KRAMER, C. (Ed.) *Ethnoarchaeology:*

Implications of Ethnography for Archaeology. New York, Columbia University Press.

EERKENS, J. W. & BETTINGER, R. L. (2001) Techniques for Assessing Standardization in Artifact Assemblages: Can We Scale Material Variability? *American Antiquity,* 66**,** 493-504.

EFRON, B. (1979) Computers and the Theory of Statistics: Thinking the Unthinkable. *SIAM Review,* 21**,** 460-480.

EFRON, B. (1987) Better Bootstrap Confidence Intervals. *Journal of the American Statistical Association,* 82**,** 171-185.

EFRON, B. & TIBSHIRANI, R. (1991) Statistical Data Analysis in the Computer Age. *Science,* 253**,** 390-395.

EFRON, B. & TIBSHIRANI, R. J. (1993) *An introduction to the bootstrap,* New York, Chapman & Hall.

ELSTON, R. & RAVEN, C. (Eds.) (1992) *ArchaeologicaI lnvestigations at Tosawihi, A Great Basin Quarry,* Silver City, Intermountian Research.

ELSTON, R. G. & BRANTINGHAM, P. J. (2002) Microlithic Technology in Northern Asia: A Risk-Minimizing Strategy of the Late Paleolithic and Early Holocene. *Archeological Papers of the American Anthropological Association,* 12**,** 103-116.

ELY, M. (2001) The importance of estimates and confidence intervals rather than *p* values. *Sociology,* 33**,** 185-190.

EREN, M. I., DOMINGUEZ-RODRIGO, M., KUHN, S. L., ADLER, D. S., LE, I. & BAR-YOSEF, O. (2005) Defining and measuring reduction in unifacial stone tools. *Journal of Archaeological Science,* 32**,** 1190-1201.

EVANS, D., POTTIER, C., FLETCHER, R., HENSLEY, S., TAPLEY, I., MILNE, A. & BARBETTI, M. (2007) A comprehensive archaeological map of the world's largest preindustrial settlement complex at Angkor, Cambodia. *Proceedings of the National Academy of Sciences,* 104**,** 14277-14282.

FALINI, G., ALBECK, S., WEINER, S. & ADDADI, L. (1996) Control of Aragonite or Calcite Polymorphism by Mollusk Shell Macromolecules. *Science,* 271**,** 67-69.

FEINGOLD, A. (1994) Gender differences in personality: a meta-analysis. *Psychological Bulletin,* 116**,** 429-56.

FEYNMAN, R. P. (1965) *The Character of Physical Law,* Cambridge, MIT Press.

FEYNMAN, R. P. (1985) *Surely You're Joking Mr Feynman,* New York, W. W. Norton and Sons.

FIDLER, F., BURGMAN, M. A., CUMMING, G., BUTTROSE, R. & THOMASON, N. (2006) Impact of Criticism of Null-Hypothesis Significance Testing on Statistical Reporting Practices in Conservation Biology. *Conservation Biology,* 20**,** 1539-1544.

FIDLER, F., CUMMING, G., BURGMAN, M. & THOMASON, N. (2004a) Statistical reform in medicine, psychology and ecology. *Journal of Socio-Economics,* 33**,** 615-630.

FIDLER, F., THOMASON, N., CUMMING, G., FINCH, S. & LEEMAN, J. (2004b) Editors can lead researchers to confidence intervals, but can't make them think: statistical reform lessons from medicine. *Psychological Science,* 15**,** 119-26.

FIELLER, N., GILBERTSON, D., GRIFFIN, C., BRIGGS, D. & JENKINSON, R. (1992a) The statistical modeling of the grain size distributions of cave sediments using log skew Laplace distributions: Creswell Crags, near Sheffield, England. *Journal of Archaeological Science,* 19**,** 129-150.

FIELLER, N. R. J., FLENLEY, E. C. & OLBRICHT, W. (1992b) Statistics of Particle Size Data. *Applied Statistics,* 41**,** 127-146.

FISH, P. R. (1978) Consistency in archaeological measurement and classification: a pilot study. *American Antiquity,* 43**,** 86–89.

FITZHUGH, B. (2001) Risk and invention in human technological evolution. *Journal of Anthropological Archaeology,* 20**,** 125-167.

FLANNERY, K. V. (1999) Process and agency in early state formation. *Cambridge Archaeological Journal,* 9**,** 3–21.

FLECK, J. (1992) Selectionism Dominant: An Essay Review. *Science, Technology, & Human Values,* 17**,** 237-248.

FLENLEY, J. R. (1979) *The equatorial rain forest: A geological history,* London, Butterworths.

FLENLEY, J. R. (1998) Tropical Forests Under the Climates of the Last 30,000 Years. *Climatic Change,* 39**,** 177-197.

FLENNIKEN, J. J. (1984) The Past, Present, and Future of Flintknapping: An Anthropological Perspective. *Annual Review of Anthropology,* 13**,** 187-203.

FORESTIER, H. (2000) De quelques chaînes opératoires lithiques en Asie du Sud-Est au pléistocène supérieur final et au début de l'holocène *L'Anthropologie,* 104**,** 531-548.

FORESTIER, H., ZEITOUN, V., SEVEAU, A., DRIWANTOR, D. & WINAYALAI, C. (2005) Prospections paléolithicques et perspectives technologiques pour redéfinir le hoabinhien du Nord de la Thaïlande (campagnes 2002-2005). *Aséanie,* 15**,** 33-60.

FRIEDMAN, G. F. (1959) Identification of carbonate minerals by staining methods. *Journal of Sedimentary Petrology,* 29**,** 87-97.

GALLAGHER, J. (1977) Contemporary stone tools in Ethiopia: Implications for archaeology. *Journal of Field Archaeology,* 4**,** 407-414.

GAMBLE, C. (2004) *Archaeology: The Basics,* London, Routledge.

GARDNER, M. J. & ALTMAN, D. G. (1986) Confidence intervals rather than P values: estimation rather than hypothesis testing. *British Medical Journal,* 292**,** 746-50.

GEIST, J., AUERSWALD, K. & BOOM, A. (2005) Stable carbon isotopes in freshwater mussel shells: Environmental record or marker for metabolic activity? *Geochimica et Cosmochimica Acta,* 69**,** 3545.

GELL, A. (1998) *Art and Agency. An Anthropological Theory,* Oxford, Clarendon Press.

GILL, J. (1999) The Insignificance of Null Hypothesis Significance Testing. *Political Research Quarterly,* 52**,** 647-674.

GILLAN, D. J. & RICHMAN, E. H. (1994) Minimalism and the Syntax of Graphs. *Human Factors: The Journal of the Human Factors and Ergonomics Society,* 36**,** 619-644.

GLINER, J., A., LEECH, N., L. & MORGAN, G., A. (2002) Problems with Null Hypothesis Significance Testing (NHST): What do the textbooks say? *The Journal of Experimental Education,* 71**,** 83.

GLOVER, I. (1993) Other people's pasts: Western archaeologists and Thai prehistory. *Journal of the Siam Society,* 81**,** 45-53.

GLOVER, I. C. (2001) Archaeology, Nationalism and Politics in Southeast Asia. *Hukay: Bulletin of the University of the Philippines Archaeological Studies Program,* 3**,** 37-65.

GOEDE, A. (1994) Continuous early last glacial palaeoenvironmental record from a tasmanian speleothem based on stable isotope and minor element variations. *Quaternary Science Reviews,* 13**,** 283-291.

GOLDBERG, P. & MACPHAIL, R. I. (2006) *Practical And Theoretical Geoarchaeology,* Cornwall, Blackwell Publishing.

GOOD, P. (2005) *Introduction to statistics through resampling methods and Microsoft Office Excel,* Chichester, Wiley.

GOODYEAR, A. C. (1989) A hypothesis for the use of crypto-crystalline raw materials among Paleoindian groups of North America. IN ELLIS, C. G. & LOTHROP, J. C. (Eds.) *Eastern Paleoindian Lithic Resource Use.* Boulder (Co), Westview Press.

GORMAN, C. (1969a) Hoabinhian: A pebble tool complex with early plant associations in Southeast Asia. *Science,* 163**,** 671-673.

GORMAN, C. (1969b) Review of 'Archaeological Excavations in Thailand, Volume 1: Sai Yok: Stone Age Settlements in the Kanchanaburi Province. Dr H. R. van Heekeren and Count Eigil Knuth. Copenhagen: Munksgaard, 1967. *Asian Perspectives,* 11**,** 124-127.

GORMAN, C. (1971a) The Hoabinhian and After: Subsistence Patterns in Southeast Asia during the Late Pleistocene and Early Recent Periods. *World Archaeology,* 2**,** 300-320.

GORMAN, C. (1971b) Prehistoric Research in North Thailand: A Culture-Chronographic Sequence from the Late Pleistocene to the Early Recent Period. PhD Thesis. Honolulu, University of Hawaii.

GORMAN, C. (1972) Excavations at Spirit Cave, North Thailand: Some interim interpretations. *Asian Perspectives,* 13**,** 79-107.

GOSDEN, C. (2005) What Do Objects Want? *Journal of Archaeological Method and Theory,* 12**,** 193-211.

GOULD, R. A., KOSTER, D. A. & SONTZ, A. H. L. (1971) The Lithic Assemblage of the Western Desert Aborigines of Australia. *American Antiquity,* 36**,** 149-169.

GRAYSON, D. K. & DELPECH, F. (1998) Changing diet breadth in the Early Upper Palaeolithic of Southwestern France. *Journal of Archaeological Science,* 25**,** 1119-1130.

GREMILLION, K. J. (2002) Foraging Theory and Hypothesis Testing in Archaeology: An Exploration of Methodological Problems and Solutions. *Journal of Anthropological Archaeology,* 21**,** 142-164.

GROSSMAN, E. L. & KU, T. (1986) Oxygen and carbon isotope fractionation in biogenic aragonite: temperature effects. *Chemical Geology,* 59**,** 59-74.

GUTHERY, F. S., BRENNAN, L. A., PETERSON, M. J. & LUSK, J. J. (2005) Information Theory in wildlife science: Critique and viewpoint. *Journal of Wildlife Management,* 69**,** 457-465.

HALEKOH, U. & VACH, W. (2004) A Bayesian approach to seriation problems in archaeology. *Computational Statistics and Data Analysis,* 45**,** 651-673.

HALL, P. (1986) On the Number of Bootstrap Simulations Required to Construct a Confidence Interval. *The Annals of Statistics,* 14**,** 1453-1462.

HALL, P. (1988) Theoretical Comparison of Bootstrap Confidence Intervals. *The Annals of Statistics,* 16**,** 927-953.

HALL, P. (1989) Unusual properties of bootstrap confidence intervals in regression problems. *Probability Theory and Related Fields,* 81**,** 247-273.

HARPENDING, H. C. & DAVIS, H. (1977) Some implications for hunter-gatherer ecology derived from the spatial structure of resources. *World Archaeology,* 8**,** 275-286.

HASTINGS, P. & LIENGSAKUL, M. (1983) Chronology of the Late Quaternary climatic changes in Thailand. IN THIRAMONGKOL, N. & PISUTHA-ARNOND, V. (Eds.) *Proceedings of the First Symposium on Geomorphology and Quaternary Geology of Thailand.* Bangkok, Chulalongkorn University Department of Geology.

HAWKES, K., HILL, K. & O'CONNELL, J. F. (1982) Why hunters gather: Optimal foraging and the Ache of Eastern Paraguay. *American Ethnologist,* 9**,** 379-398.

HAWKES, K., ROGERS, A. R. & CHARNOV, E. L. (1995) The male's dilemma: Increased offspring production is more paternity to steal. *Evolutionary Ecology,* 9**,** 662-677.

HAYDEN, B. (1977) Stone tool functions in the Western Desert. IN WRIGHT, R. V. S. (Ed.) *Stone Tools as Cultural Markers, Change, Evolution and Complexity.* Canberra, Australian Institute of Aboriginal Studies.

HAYDEN, B. (1979) *Palaeolithic Reflections: Lithic Technology and Ethnographic Excavations Among Australian Aborigines* Canberra, Australian Institute of Aboriginal Studies.

HEFFLEY, S. (1981) The Relationship between Northern Athapaskan Settlement Patterns and Resource Distribution: An Application of Horn's Model. IN WINTERHALDER, B. & SMITH, E. A. (Eds.) *Hunter-Gatherer Foraging Strategies: Ethnographic and Archaeological Analyses.* Chicago, The University of Chicago Press.

HEIDER, K. G. (1958) A pebble-tool complex in Thailand. *Asian Perspectives,* 2**,** 64-67.

HEMMING, S. R. (2004) Heinrich events: massive late Pleistocene detritus layers of the North Atlantic and their global climate imprint. *Review of Geophysics,* 42**,** 1-43.

HENRY, D. (1989) Correlations between reduction strategies and settlement patterns. IN HENRY, D. O. & ODELL, G. H. (Eds.) *Alternative Approaches to Lithic Analysis.* Washington, American Anthropological Association.

HIGHAM, C. F. W. (2002) *Early Cultures of Mainland Southeast Asia,* Bangkok, River Books.

HILBORN, R. & MANGEL, M. (1997) *The Ecological Detective: Confronting Models with Data,* Princeton Princeton University Press.

HISCOCK, P. (1994) Technological responses to risk in Holocene Australia. *Journal of World Prehistory,* 8**,** 267-292.

HISCOCK, P. (2002a) Pattern and Context in the Holocene Proliferation of Backed Artifacts in Australia. *Archaeological Papers of the American Anthropological Association,* 12**,** 163-177.

HISCOCK, P. (2002b) Quantifying the Size of Artefact Assemblages. *Journal of Archaeological Science,* 29**,** 251-258.

HISCOCK, P. (2006) Blunt and to the Point: Changing technological strategies in Holocene Australia. IN LILLEY, I. (Ed.) *Archaeology in Oceania: Australia and the Pacific Islands.* Blackwell.

HISCOCK, P. (2007) Looking the other way: a materialist/technological approach to classifying tools and implements, cores and retouched flakes, with examples from Australia. IN MCPHERRON, S. & LINDLEY, J. (Eds.) *Tools or Cores? The*

Identification and Study of Alternative Core Technology in Lithic Assemblages. Pennsylvania, University of Pennsylvania Museum.

HISCOCK, P. & ATTENBROW, V. (2003) Early Australian implement variation: a reduction model. *Journal of Archaeological Science,* 30**,** 239–249.

HISCOCK, P. & ATTENBROW, V. (2005) *Australian's Eastern Regional Sequence Revisited. Technology and change at Capertee 3*, Oxford, Archaeopress.

HISCOCK, P. & CLARKSON, C. (2005a) Experimental evaluation of Kuhn's geometric index of reduction and the flat-flake problem. *Journal of Archaeological Science,* 32**,** 1015-1022.

HISCOCK, P. & CLARKSON, C. (2005b) Measuring Artefact Reduction - An Examination of Kuhn's Geometric Index of Reduction. IN CLARKSON, C. & LAMB, L. (Eds.) *Lithics 'Down Under': Australian Perspectives on Lithic Reduction, Use and Classification.* Oxford, Archaeopress.

HOEFS, J. (2004) *Stable Isotope Geochemistry,* Berlin, Springer.

HORN, H. S. (1968) The adaptive significance of colonial nesting in the Brewer's Blackbird (*Euphagus cyanocephalus*). *Ecology,* 49**,** 682-694.

HOYLE, S. D. & CAMERON, D. S. (2003) Confidence intervals on catch estimates from a recreational fishing survey: a comparison of bootstrap methods. *Fisheries Management and Ecology,* 10**,** 97-108.

HULL, D. L. (1965a) The Effect of Essentialism on Taxonomy--Two Thousand Years of Stasis (I). *British Journal for the Philosophy of Science,* 15**,** 314-326.

HULL, D. L. (1965b) The Effect of Essentialism on Taxonomy--Two Thousand Years of Stasis (II). *British Journal for the Philosophy of Science,* 16**,** 1-18.

HULL, D. L., LANGMAN, R. E. & GLENN, S. S. (2001) A general account of selection: Biology, immunology, and behavior. *Behavioral and Brain Sciences,* 24**,** 511–573.

HUTTERER, K. L. (1977) Reinterpreting the Southeast Asian Palaeolithic. IN ALLEN, J., GOLSON, J. & JONES, R. (Eds.) *Sunda and Sahul.* London, Academic Press.

HUTTERER, K. L. (1985) The Pleistocene archaeology of Southeast Asia in regional context. *Modern Quaternary Research in Southeast Asia,* 9**,** 1-23.

HUU NGA, H. (1994) The Hoa Bin and Bac Son cultures in Vietnam. *Vietnam Social Sciences,* 5**,** 31-34.

III, J. E. P., WIENER, J. G. & SMITH, M. H. (1978) The Weibull Distribution: A New Method of Summarizing Survivorship Data. *Ecology,* 59**,** 175-179.

INSIGHTFUL CORPORATION (2002) *S-PLUS Resample Library User's Manual,* Seattle, Insightful Corporation.

INSIGHTFUL CORPORATION (2007) *S-PLUS 8 for Windows User's Guide,* Seattle, Insightful Corporation.

JEFFARES, B. (2002) The Scope and Limits of Biological Explanations in Archaeology. MA Thesis. Wellington, Victoria University of Wellington.

JEFFARES, B. (2005) Regaining Archaeology's Nerve: Culture and Biology in Archaeological Theory. *Biology and Philosophy,* 20**,** 545-556.

JEREMIE, S. & VACHER, S. (1992) Le Hoabinhien en Thailande: un exemple d'approche experimentale. *Bulletin de l'Ecole Francaise d'Extreme-Orient,* 79**,** 173-209.

JOCHIM, M. (1983) Optimization models in context. IN MOORE, J. A. & KEENE, A. S. (Eds.) *Archaeological Hammers and Theories.* London, Academic Press.

JOCHIM, M. A. (1989) Optimization and stone tool studies: Problems and potential. IN TORRENCE, R. (Ed.) *Time, Energy and Stone Tools.* Cambridge, Cambridge University Press.

JOHNSON, D. H. (1999) The Insignificance of Statistical Significance Testing. *The Journal of Wildlife Management,* 63**,** 763-772.

JOHNSON, D. H. (2005) What hypothesis tests are not: a response to Colegrave and Ruxton. *Behavioural Ecology,* 16**,** 323-324.

JOHNSON, J. B. & OMLAND, K. S. (2004) Model selection in ecology and evolution. *Trends in Ecology & Evolution,* 19**,** 101-108.

JONES, D. S., QUITMYER, I. R. & ANDRUS, C. F. T. (2005) Oxygen isotopic evidence for greater seasonality in Holocene shells of *Donax variabilis* from Florida. *Palaeogeography, Palaeoclimatology, Palaeoecology,* 228**,** 96-108.

JORDAN, P. & SHENNAN, S. (2003) Cultural transmission, language, and basketry traditions amongst the California Indians. *Journal of Anthropological Archaeology,* 22**,** 42-74.

JUSTESON, J. S. (1973) Limitations of Archaeological Inference: An Information-Theoretic Approach with Applications in Methodology. *American Antiquity,* 38**,** 131-149.

KAANDORP, R. J. G., VONHOF, H. B., DEL BUSTO, C., WESSELINGH, F. P., GANSSEN, G. M., MARMOL, A. E., ROMERO PITTMAN, L. & VAN HINTE, J. E. (2003) Seasonal stable isotope variations of the modern Amazonian freshwater bivalve *Anodontites trapesialis*. *Palaeogeography, Palaeoclimatology, Palaeoecology,* 194**,** 339.

KACELNIK, A. & BATESON, M. (1996) Risky Theories--The Effects of Variance on Foraging Decisions. *American Zoologist,* 36**,** 402-434.

KACELNIK, A. & BATESON, M. (1997) Risk sensitivity: cross-roads for theories of decision-making. *Trends in Cognitive Science,* 1**,** 304-309.

KAPLAN, H. & HILL, K. (1992) The evolutionary ecology of food acquisition. IN SMITH, E. A. & WINTERHALDER, B. (Eds.) *Evolutionary Ecology and Human Behaviour.* New York, Aldine De Gruyter.

KASS, R. E. & RAFTERY, A. E. (1995) Bayes Factors. *Journal of the American Statistical Association,* 90**,** 773-795.

KEALHOFER, L. (1996) The human environment during the terminal Pleistocene and Holocene in Northeastern Thailand: Phytolith evidence from Lake Kumphawapi. *Asian Perspectives,* 35**,** 229-254.

KEALHOFER, L. (2002) Changing Perceptions of Risk: The Development of Agro-Ecosystems in Southeast Asia. *American Anthropologist,* 104**,** 178-194.

KEALHOFER, L. & PENNY, D. (1998) A combined pollen and phytolith record for fourteen thousand years of vegetation change in northeastern Thailand. *Review of Palaeobotany and Palynology,* 103**,** 83-93.

KELLEY, K. (2005) The Effects of Nonnormal Distributions on Confidence Intervals Around the Standardized Mean Difference: Bootstrap and Parametric Confidence Intervals. *Educational and Psychological Measurement,* 65**,** 51-69.

KELLY, R. L. (1988) The Three Sides of a Biface. *American Antiquity,* 53**,** 717-734.

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

KELLY, R. L. (1995) *The Foraging Spectrum: Diversity in Hunter-Gatherer Lifeways,* Washington, D.C, Smithsonian Institution Press.

KENT, S. (1992) Studying Variability in the Archaeological Record: An Ethnoarchaeological Model for Distinguishing Mobility Patterns. *American Antiquity,* 57**,** 635-660.

KERNMEL-TORRÈS, D. (Ed.) (2004) *Atlas of Thailand: Spatial Structures and Development,* Chiang Mai, IRD Editions, Paris.

KHAC SU, N. (1994) The Sonvian and the problem of the proto-Hoabinhian in Vietnam. *Vietnam Social Sciences,* 5**,** 22-30.

KHAOKIEW, C. (2004) Geoarchaeology of Tham Lod rockshelter, Mae Hong Son. MA Thesis. *Department of Geology.* Bangkok, Chulalongkorn University.

KHEDARI, J., SANGPRAJAK, A. & HIRUNLABH, J. (2002) Thailand climatic zones. *Renewable Energy,* 25**,** 267-280.

KIERNAN, K. (1987) Soil erosion from the hilltribe opium swiddens in the Golden Triange, and the use of Karren as an erosion yardstick. *Endins: Publicació d'Espeleologia,* 13**,** 59-63.

KIERNAN, K. (1991a) Geomorphological Evidence for Quaternary Climatic Change in the Low Sino-Burman Ranges. *Singapore Journal of Tropical Geography,* 12**,** 112-123.

KIERNAN, K. (1991b) Tropical Mountain Geomorphology and Landscape Evolution in Northwest Thailand. *Zeitschrift für Geomorphologie NF,* 53**,** 187-206.

KILIAN, L. (1999) Finite-Sample Properties of Percentile and Percentile-t Bootstrap Confidence Intervals for Impulse Responses. *The Review of Economics and Statistics,* 81**,** 652-660.

KILLICK, D. (2004) Social constructionist approaches to the study of technology. *World Archaeology,* 36**,** 571-578.

KIM DZUNG, N. (1994) The study of using traces on the stone tools of Xom Trai Cave (Hoa Binh culture). *Vietnam Social Sciences,* 5**,** 56-63.

KINTIGH, K. W. (1984) Measuring Archaeological Diversity by Comparison with Simulated Assemblages. *American Antiquity,* 49**,** 44-54.

KLEIN, R. G. & CRUZ-URIBE, K. (1984) *The Analysis of Animal Bones from Archeological Sites,* Chicago, University Of Chicago Press.

KUHN, S., L. (2004a) Evolutionary perspectives on technology and technological change. *World Archaeology,* 36**,** 561-570.

KUHN, S. L. (1990) A geometric index of reduction for unifacial stone tools. *Journal of Archaeological Science,* 17**,** 581-593.

KUHN, S. L. (1992a) Blank Form and Reduction as Determinants of Mousterian Scraper Morphology. *American Antiquity,* 57**,** 115-128.

KUHN, S. L. (1992b) On planning and curated technologies in the Middle Paleolithic. *Journal of Anthropological Research,* 48**,** 185-207.

KUHN, S. L. (1994) A Formal Approach to the Design and Assembly of Mobile Toolkits. *American Antiquity,* 59**,** 426-442.

KUHN, S. L. (1995) *Mousterian Lithic Technology,* Princeton, Princeton University Press.

KUHN, S. L. (2004b) Upper Paleolithic raw material economies at UcagIzlI cave, Turkey. *Journal of Anthropological Archaeology,* 23**,** 431-448.

KUHN, T. (1962) *The Structure of Scientific Revolutions,* Chicago University of Chicago Press.

LAKATOS, I. (1980) *The Methodology of Scientific Research Programmes,* New York, Cambridge University Press.

LAO YI PA, S. & TACUMMA, T. (2000) Forests in the Kong River and Lang River Basins. IN DILOKWANICH, S., KULPARADIT, K., SIRIPORNPIBUL, C., SHOOCONGDEJ, R., SPIES, J., CHAREONTHONG, K. & LAOYIPA, S. (Eds.) *An Exploration and Database of the Caves of Mae Hong Son Province.* Unpublished Report to the Thailand Research Fund.

LEWIS, D. W. & MCCONCHIE, D. (1994) *Analytical sedimentology,* New York, Chapman & Hall.

LIEW, P. M., LEE, C. Y. & KUO, C. M. (2006) Holocene thermal optimal and climate variability of East Asian monsoon inferred from forest reconstruction of a subalpine pollen sequence, Taiwan. *Earth and Planetary Science Letters,* 250**,** 596-605.

LOEHLIN, J. C., WILLERMAN, L. & HORN, J. M. (1988) Human Behavior Genetics. *Annual Review of Anthropology,* 39**,** 101-133.

LÖFFLER, E., THOMPSON, W. P. & LIENGSAKUL, M. (1983) Geomorphological development of the Tung Kula Ronghai. IN THIRAMONGKOL, N. & PISUTHA-ARNOND, V. (Eds.) *Proceedings of the First Symposium on Geomorphology and Quaternary Geology of Thailand.* Bangkok, Chulalongkorn University Department of Geology.

LUNNEBORG, C. E. (2000) *Data Analysis by Resampling: Concepts and Applications,* California, Duxbury.

LYMAN, R. & O'BRIEN, M. (2006) Evolutionary archaeology is unlikely to go extinct: response to Gabora. *World Archaeology,* 38**,** 697-703.

LYMAN, R. L. & O'BRIEN, M., J. (1998) The goals of evolutionary archaeology: History and explanation. *Current Anthropology,* 39**,** 615.

LYMAN, R. L. & O'BRIEN, M. J. (1997) The Concept of Evolution in Early Twentieth-Century Americanist Archaeology. *Archeological Papers of the American Anthropological Association,* 7**,** 21-48.

LYMAN, R. L. & O'BRIEN, M. J. (2000) Measuring and Explaining Change in Artifact Variation with Clade-Diversity Diagrams. *Journal of Anthropological Archaeology,* 19**,** 39-74.

LYMAN, R. L. & O'BRIEN, M. J. (2002) Classification. IN TERRELL, J. E. (Ed.) *Darwin and Archaeology: A Handbook of Key Concepts.* Westport, Connecticut, Bergin and Garvey.

LYMAN, R. L., O'BRIEN, M. J. & DUNNELL, R. C. (1997) *The Rise and Fall of Culture History,* New York, Plenum Press.

MACARTHUR, R. H. & PIANKA, E. R. (1966) On optimal use of a patchy environment. *American Naturalist,* 100**,** 603-609.

MACE, R., HOLDEN, C. J. & SHENNAN, S. J. (Eds.) (2005) *The evolution of cultural diversity. A Phylogenetic Approach,* London, UCL Press.

MACGREGOR, O. (2005) Abrupt Terminations and stone artefact reduction potential. IN CLARKSON, C. & LAMB, L. (Eds.) *Rocking the Boat: Recent Australian Approaches to Lithic Reduction, Use and Classification.* Oxford, Archaeopress.

MACKAY, A. (2005) Informal Movements: Changing Mobility Patterns at Ngarrabullgan, Cape York Australia. IN CLARKSON, C. & LAMB, L. (Eds.) *Rocking the Boat: Recent Australian Approaches to Lithic Reduction, Use and Classification.* Oxford, Archaeopress.

MADSEN, D. B., LI, J., BRANTINGHAM, P. J., GAO, X., ELSTON, R. G. & BETTINGER, R. L. (2001) Dating Shuidonggou and the Upper Paleolithic blade industry in North China. *Antiquity,* 75**,** 706-716.

MAGNE, M. P. & POKOTYLO, D. (1981) A pilot study in bifacial lithic reduction sequences. *Lithic Technology,* 10**,** 34-47.

MALONEY, B. K. (1992) Late Holocene Climatic Change in Southeast Asia: The Palynological Evidence and Its Implications for Archaeology. *World Archaeology,* 24**,** 25-34.

MALONEY, B. K. (1999) A 10,600-year pollen record from Nong Thale Song Hong, Trang Province, South Thailand. *Bulletin of the Indo-Pacific Prehistory Association (Melaka Papers, Volume 2),* 18**,** 129-137.

MANISAN, V. (1995) *Geography and climatology in every season of various parts in Thailand, Technical document of Meteorological Department, Thailand,* Bangkok.

MANLY, B. F. J. (1997) *Randomization, Bootstrap and Monte Carlo Methods in Biology,* London, Chapman and Hall.

MANNINO, M. A., SPIRO, B. F. & THOMAS, K. D. (2003) Sampling shells for seasonality: oxygen isotope analysis on shell carbonates of the inter-tidal gastropod Monodonta lineata (da Costa) from populations across its modern range and from a Mesolithic site in southern Britain. *Journal of Archaeological Science,* 30**,** 667.

MARKS, A. (1988) The curation of stone tools during the upper Pleistocene: a view from the central Negev, Israel. IN DIBBLE, H. & MONTET-WHITE, A. (Eds.) *Upper Pleistocene Prehistory of Western Eurasia.* Philadelphia, University Museum Press.

MARKS, A., SHOKLER, J. & ZILHAO, J. (1991) Raw material usage in the Paleolithic. The effects of local availability on selection and economy. IN MONTET-WHITE, A. & HOLEN, S. R. (Eds.) *Raw Material Economies Among Prehistoric Hunter-Gatherers.* Lawrence, University of Kansas Publications in Anthropology.

MARWICK, B. (2006) What can archaeology do with Boyd and Richerson's cultural evolutionary program? *The Review of Archaeology* 26**,** 30-40.

MARWICK, B. (2007a) Approaches to Stone Artefact Archaeology in Thailand: A Historical Review. *Silpakorn University International Journal,* 7**,** 49-88.

MARWICK, B. (2007b) 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,* doi:10.1016/j.jas.2007.08.007.

MATTHEWS, J. M. (1964) The Hoabinhian in Southeast Asia and elsewhere. PhD Thesis. Canberra, Australian National University.

MATTHEWS, J. M. (1966) A Review of the 'Hoabinhian' in Indo-China. *Asian Perspectives,* 9**,** 86-95.

MAULDIN, R. P. & AMICK, D. S. (1989) Investigating patterning in debitage from experimental biface core reduction. IN AMICK, D. S. & MAULDIN, R. P. (Eds.) *Experiments in Lithic Technology.* Oxford, BAR International Series 528.

MAXWELL, A. L. (2001) Holocene Monsoon Changes Inferred from Lake Sediment Pollen and Carbonate Records, Northeastern Cambodia. *Quaternary Research,* 56**,** 390-400.

MAXWELL, A. L. & LIU, K. B. (2002) Late Quaternary pollen and associated records from the monsoonal areas of continental South and SE Asia. IN KERSHAW, P., DAVID, B., TAPPER, N., PENNY, D. & BROWN, J. (Eds.) *Bridging Wallace's Line: The Environmental and Cultural History and Dynamics of the SE-Asian-Australian Region, Advances in GeoEcology 34.* Reiskirchen, Catena Verlag.

MAXWELL, S. E., CAMP, C. J. & ARVEY, R. D. (1981) Measures of strength of association: A comparative examination. *Journal of Applied Psychology,* 66**,** 525-534.

MAXWELL, S. E. & DELANEY, H. D. (1990) *Designing Experiments and Analyzing Data: A Model Comparison Perspective,* Belmont, CA, Wadsworth.

MAYR, E. (1959) Darwin and the evolutionary theory in biology. IN MEGGERS, J. (Ed.) *Evolution and anthropology: A centennial appraisal.* Washington, DC, Anthropological Society of Washington.

MAYR, E. (1982) *The Growth of Biological Thought: Diversity, Evolution and Inheritance,* Cambridge, Harvard University Press.

MCCALL, G. S. (2006) Multivariate perspectives on change and continuity in the Middle Stone Age lithics from Klasies River Mouth, South Africa. *Journal of Human Evolution,* 51**,** 429-439.

MCCALL, G. S. (2007) Behavioral ecological models of lithic technological change during the later Middle Stone Age of South Africa. *Journal of Archaeological Science,* In Press, Corrected Proof.

MCCULLOUGH, B. D. & WILSON, B. (2005) On the accuracy of statistical procedures in Microsoft Excel 2003. *Computational Statistics & Data Analysis,* 49**,** 1244-1252.

MCDERMOTT, F. (2004) Palaeo-climate reconstruction from stable isotope variations in speleothems: a review. *Quaternary Science Reviews,* 23**,** 901-918.

MEESE, D. A., GOW, A. J., ALLEY, R. B., ZIELINSKI, G. A., GROOTES, P. M., RAM, M., TAYLOR, K. C., MAYEWSKI, P. A. & BOLZAN, J. F. (1997) The Greenland Ice Sheet Project 2 depth-age scale: Methods and results. *Journal of Geophysical Research,* 102**,** 26411-26424.

MEINEKE, I. (2000) An add-in implementation of the resampling syntax under Microsoft Excel. *Computer Methods and Programs in Biomedicine,* 63**,** 99-104.

MESOUDI, A. (2005) The transmission and evolution of human culture. PhD Thesis. St. Andrews, United Kingdom, University of St. Andrews.

MESOUDI, A., WHITEN, A. & LALAND, K. N. (2004) Is Human Cultural Evolution Darwinian? Evidence Reviewed from the Perspective of *The Origin of Species*. *Evolution,* 58**,** 1-11.

MESOUDI, A., WHITEN, A. & LALAND, K. N. (2006) Towards a unified science of cultural evolution. *Behavioral and Brain Sciences,* 29**,** 329-347.

METCALFE, D. & BARLOW, K. R. (1992) A model for exploring the optimal trade-off between field processing and transport. *American Anthropologist,* 94**,** 340-356.

MINC, L. & SMITH, K. (1989) The spirit of survival: Cultural responses to resource variability in north Alaska. IN HALSTEAD, P. & O'SHEA, J. (Eds.) *Bad Year Economics.* Cambridge, Cambridge University Press.

MITHEN, S. (1988) Modeling hunter-gatherer decision making: complementing optimal foraging theory. *Human Ecology,* 17**,** 59-83.

MONTET-WHITE, A. (1991) Lithic acquisition, settlements, and territory in the Epigravettian of central Europe. IN MONTET-WHITE, A. & HOLEN, S. R.

(Eds.) *Raw Material Economies Among Prehistoric Hunter-Gatherers.* Lawrence, University of Kansas Publications in Anthropology.

MOONEY, D. C. Z. & DUVAL, R. D. (1993) *Bootstrapping: A Nonparametric Approach to Statistical Inference,* London, Sage Publications Inc.

MOORE, A. M. T. & HILLMAN, G. C. (1992) The Pleistocene to Holocene Transition and Human Economy in Southwest Asia: The Impact of the Younger Dryas. *American Antiqtuity,* 57**,** 482-494.

MOORE, M. W. & BRUMM, A. (2007) Stone artifacts and hominins in island Southeast Asia: New insights from Flores, eastern Indonesia. *Journal of Human Evolution,* 52**,** 85-102.

MORRIS, J. C. (2004) "Agency" theory applied - a study of later prehistoric lithic assemblages from northwest Pakistan. IN GARDNER, A. (Ed.) *Agency Uncovered: Defining and Demystifying Agents in Archaeology.* London, UCL Press.

MORROW, C. A. (1984) A biface production model for gravel-based chipped stone industries. *Lithic Technology,* 13**,** 28-32.

MORROW, T. (1995) Bigger is better: Comments on Kuhn's Formal approach to mobile Toolkits. *American Antiquity,* 61**,** 581-590.

MOSER, J. (2001) *Hoabinhian: Geographie und Chronologie eines steinzeitlichen Technocomplexes in Südostasien,* Köln, Lindensoft.

MOURER, R. (1977) Laang Spean and the prehistory of Cambodia. *Modern Quaternary Research in Southeast Asia,* 3**,** 29-56.

MOVIUS, H. L. (1944) *Early man and Pleistocene stratigraphy in southern and eastern Asia,* New York, Kraus Reprint.

MOVIUS, H. L. (1949) The Lower Paleolithic Cultures of Southern and Eastern Asia. *Transactions of the American Philosophical Society, New series,* 38**,** 329-420.

MYERS, A. (1989) Reliable and maintainable technological strategies in the Mesolithic of mainland Britain. IN TORRENCE, R. (Ed.) *Time, Energy and Stone Tools.* Cambridge, Cambridge University Press.

NAGAOKA, L. (2005) Declining foraging efficiency and moa carcass exploitation in southern New Zealand. *Journal of Archaeological Science,* 32**,** 1328-1338.

NEELEY, M. P. & BARTON, C. M. (1994) A new approach to interpreting late Pleistocene microlith industries in southwest Asia. *Antiquity,* 68**,** 275-288.

NEIMAN, F. D. (1995) Stylistic variation in evolutionary perspective: implications for decorative diversity and inter-assemblage distance in Illinois Woodland ceramic assemblages. *American Antiquity,* 60**,** 7-36.

NELSON, M. C. (1991) The study of technological organization. *Archaeological Method and Theory,* 3**,** 57-100.

NETER, J. & WASSERMAN, W. (1996) *Applied linear statistical models,* Chicago, Irwin Homewood.

NEWCOMER, M. (1971) Some quantitative experiments in handaxe manufacture. *World Archaeology,* 3**,** 85–94.

NICKERSON, R. S. (2000) Null hypothesis significance testing: A review of an old and continuing controversy. *Psychological Methods,* 5**,** 241-301.

NISHIMURA, M. (2005) Attribute analysis of the Hoabinhian industry: implications from a comparative study of Bung Cave and Xom Trai Cave, northern Vietnam. *Journal of Southeast Asian Archaeology,* 25**,** 81-104.

NIX, T. W. & BARNETTE, J. J. (1998) The data analysis dilemma: Ban or abandon. A review of null hypothesis significance testing. *Research in the Schools,* 5**,** 3-14.

O'BRIEN, M. J., DARWENT, J. & LYMAN, R. L. (2001) Cladistics Is Useful for Reconstructing Archaeological Phylogenies: Palaeoindian Points from the Southeastern United States. *Journal of Archaeological Science,* 28**,** 1115-1136.

O'BRIEN, M. J. & HOLLAND, T. D. (1990) Variation, selection, and the archaeological record. IN SCHIFFER, M. B. (Ed.) *Archaeological Method and Theory.* Tuscon, University of Arizona Press.

O'BRIEN, M. J. & HOLLAND, T. D. (1992) The Role of Adaptation in Archaeological Explanation. *American Antiquity,* 57**,** 3-59.

O'BRIEN, M. J. & LYMAN, R. L. (2000) *Applying Evolutionary Archaeology: A Systematic Approach,* New York, Kluwer Academic/Plenum.

O'BRIEN, M. J. & LYMAN, R. L. (2002) Evolutionary Archeology: Current Status and Future Prospects. *Evolutionary Anthropology,* 11**,** 26-36.

O'CONNELL, J. F. & HAWKES, K. (1981) Alyawarra plant use and optimal foraging theory. IN SMITH, B. & WINTERHALDER, B. (Eds.) *Hunter-Gatherer Foraging Strategies.* Chicago, Chicago University Press.

ODELL, G. H. (1989) Experiments in lithic reduction. IN AMICK, D. S. & MAULDIN, R. P. (Eds.) *Experiments in Lithic Technology.* Oxford, British Archaeological Reports.

ODELL, G. H. S. (2001) Stone Tool Research at the End of the Millennium: Classification, Function, and Behavior. *Journal of Archaeological Research,* 9**,** 45-100.

ORIANS, G. H. & PEARSON, N. E. (1979) On the theory of central place foraging. IN HORN, D. J., MITCHELL, R. D. & STAIRS, G. R. (Eds.) *Analysis of Ecological Systems.* Columbus, Ohia State University.

OSBORNE, J. (2002) Notes on the use of data transformations. *Practical Assessment, Research & Evaluation,* 8**,** 1-7.

OSWALT, W. H. (1976) *An Anthropological Analysis of Food-getting Technology,* New York, Wiley.

PAPPU, S. (2001) Middle Palaeolithic stone tool technology in the Kortallayar Basin, South India. *Antiquity,* 75**,** 107-117.

PARKER, G. A. (1974) Courtship persistence and female-guarding as male time investment strategies. *Behavior* 48**,** 157-184.

PARKER, G. A. & STUART, R. A. (1976) Animal behavior as a strategy optimizer: evolution of resource assessment strategies and optimal emigration thresholds. *American Naturalist* 110**,** 1055-1076.

PARRY, W. J. & KELLY, R. L. (1987) Expedient core technology and sedentism. IN JOHNSON, J. K. & MORROW, C. A. (Eds.) *The Organization of Core Technology.* Boulder, Westview Press.

PATTERSON, L. W. (1990) Characteristics of Bifacial-Reduction Flake-Size Distribution. *American Antiquity,* 55**,** 550-558.

PATTERSON, L. W. & SOLLBERGER, J. B. (1978) Replication and Classification of Small Size Lithic Debitage. *Plains Anthropologist,* 23**,** 103-112.

PELLANT, C. (1992) *Rocks and Minerals,* New York, Dorling Kindersley.

PENNY, D. (1999) Palaeoenvironmental analysis of the Sakon Nakhon Basin, Northeast Thailand: Palynological perspectives on climate change and human occupation. *Bulletin of the Indo-Pacific Prehistory Association (Melaka Papers, Volume 2),* 18**,** 139-149.

PENNY, D. (2001) A 40,000 year palynological record from north-east Thailand; implications for biogeography and palaeo-environmental reconstruction. *Palaeogeography, Palaeoclimatology, Palaeoecology,* 171**,** 97-128.

PERFECT, E. (1997) Fractal models for the fragmentation of rocks and soils: a review. *Engineering Geology,* 48**,** 185-198.

PHAGAN, C. J. (1985) Lithic technology: flake analysis. IN VIERRA, R. (Ed.) *Prehistory of the Ayacucho Basin, Peru.* Michigan, The University of Michigan Press.

POLANYI, M. (1962) The Republic of Science: Its Political and Economic Theory. *Minerva,* 1**,** 54-73.

POOKAJORN, S. (1984) *The Hoabinhian of mainland southeast Asia : new data from the recent Thai excavation in the Ban Kao area,* Bangkok :, Thai Khadi Research Institute, Thammasat University.

POOKAJORN, S. (1985) Ethnoarchaeology with the Phi Tong Luang (Mlabrai): Forest Hunters of Northern Thailand. *World Archaeology,* 17**,** 206-221.

POOKAJORN, S. (1988) *Archaeological research of the Hoabinhian culture or technocomplex and its comparison with ethnoarchaeology of the Phi Tong Luang, a hunter-gatherer group of Thailand,* Tubingen, Verlag Archaeologica Venatoria : Institut fur Urgeschichte der Universitat Tubingen.

POOKAJORN, S. (1990) Hoabinhian cave excavations in Ban Kao District, West Thailand. IN GLOVER, I. & GLOVER, E. (Eds.) *Southeast Asian Archaeology 1986. Proceedings of the First Conference of the Association of Southeast Asian Archaeologists in Western Europe.* London, BAR.

POOKAJORN, S. (1992) *The Phi Tong Luang (Mlabri): A hunter-gather group in Thailand,* Bangkok, Odeon Store.

POOKAJORN, S. (1996) Human activities and environmental changes during the Late Pleistocene to Middle Holocene in Southern Thailand and Southeast Asia. IN STRAUS, L. G., ERIKSEN, B. V., ERLANDSON, J. M. & YESNER, D. R. (Eds.) *Humans at the End of the Ice Age: The Archaeology of the Pleistocene-Holocene Transition.* New York, Plenum Press.

POPE, G. G. (1989) Bamboo and Human Evolution. *Natural History***,** 48-56.

POPPER, K. R. (2003) *The Open Society and its Enemies,* London, Routledge & Kegan Paul.

POUSSART, P. F. & SCHRAG, D. P. (2005) Seasonally resolved stable isotope chronologies from northern Thailand deciduous trees. *Earth and Planetary Science Letters,* 235**,** 752-765.

PRAMANKIJ, S. & SUBHAVAN, V. (2001) Preliminary Report on the Discovery of Evidence of the oldest Hominids (2 Million to 200,000 years old) in Thailand. *Silpa Wattanatham,* 23**,** 38-47 (in Thai).

PRAMOJANEE, P. & HASTINGS, P. J. (1983) Geomorphological and palynological investigation of sea level changes in Chantaburi, SE Thailand. IN THIRAMONGKOL, N. & PISUTHA-ARNOND, V. (Eds.) *Proceedings of the First Symposium on Geomorphology and Quaternary Geology of Thailand.* Bangkok, Chulalongkorn Univeristy Department of Geology.

PREUCEL, R. W. (1999) Review of O'Brien, Michael J. (editor) 1996. "Evolutionary archaeology: Theory and application" Foundations of Archaeological Inquiry Series. Salt Lake City: University of Utah Press. *Journal of Field Archaeology,* 26**,** 93-99.

PUMIJUMNON, N. & TRIKANCHANAWATTANA, C. (2006) Pollen over time: The search for Holocene environments. IN SHOOCONGDEJ, R. (Ed.) *Social, Cultural and Environmental Dynamics in the Highlands of Pangmapha, Mae Hong Son Province: Integrated Archaeological Research into the Region.* Bangkok, Highland Archaeology Project in Pangmapha (In Thai).

RADLINSKI, A. P., RADLINSKA, E. Z., AGAMALIAN, M., WIGNALL, G. D., LINDNER, P. & RANDL, O. G. (1999) Fractal Geometry of Rocks. *Physical Review Letters,* 82**,** 3078-3081.

RAMSEY, C. B., BUCK, C., E., MANNING, S., W. , REIMER, P. & PLICHT, H. V. D. (2006) Developments in radiocarbon calibration for archaeology. *Antiquity,* 80**,** 783.

REAL, L. & CARACO, T. (1986) Risk and Foraging in Stochastic Environments. *Annual Review of Ecology and Systematics,* 17**,** 371-390.

REECE, R. (1994) Are Bayesian statistics useful to archaeological reasoning? *Antiquity,* 68**,** 848-850.

REITZ, E. J. & WING, E. S. (1999) *Zooarchaeology,* Cambridge, Cambridge University Press.

REYNOLDS, T. E. G. (1989) Techno-typology in Thailand: A case study of Tham Khao Khi Chan. *Bulletin of the Indo-Pacific Prehistory Association,* 9**,** 33-43.

REYNOLDS, T. E. G. (1990a) Problems in the Stone Age of Thailand. *Journal of the Siam Society,* 78**,** 109-114.

REYNOLDS, T. E. G. (1990b) Review of Hoabinhian. IN BARNES, G. (Ed.) *Hoabinhian. Jomon, Yayoi. Early Korean States: Bibliographic Reviews of Far Eastern Archaeology.* Oxford, Oxbow Books.

REYNOLDS, T. E. G. (1992) Excavations at Banyan Valley Cave, Northern Thailand: A report on the 1972 season. *Asian Perspectives,* 31**,** 77-97.

RICHARDS, S. A. (2005) TESTING ECOLOGICAL THEORY USING THE INFORMATION-THEORETIC APPROACH: EXAMPLES AND CAUTIONARY RESULTS. *Ecology,* 86**,** 2805-2814.

RICHARDSON, E. (2003) A geographical analysis of prehistoric sites in Pang Mapha. *Conference on People, Culture, and Paleoenvironment in Highland Pang Mapha, Mae Hong Son Province.* Silpakorn Unversity, Bangkok.

RICHERSON, P. J. & BOYD, R. (1992) Cultural inheritance and evolutionary ecology. IN SMITH, E. A. & WINTERHALDER, B. (Eds.) *Evolutionary Ecology and Human Behavior.* Hawthorne, NY, Aldine de Gruyter.

RICHERSON, P. J. & BOYD, R. (2000) Built for speed: Pleistocene climate variation and the origin of human culture. IN THOMPSON, N. & TONNEAU, F. (Eds.) *Perspectives in Ethology Vol. 13.* New York, Kluwer Academic/Plenum.

RICHERSON, P. J., BOYD, R. & BETTINGER, R. L. (2001) Was Agriculture Impossible during the Pleistocene but Mandatory during the Holocene? A Climate Change Hypothesis. *American Antiquity,* 66**,** 387-411.

ROLLAND, N. (1981) The Interpretation of Middle Palaeolithic Variability. *Man,* 16**,** 15-42.

ROTH, B. J. & DIBBLE, H. L. (1998) Production and Transport of Blanks and Tools at the French Middle Paleolithic Site of Combe-Capelle Bas. *American Antiquity,* 63**,** 47-62.

ROYALL, R. M. (1986) The Effect of Sample Size on the Meaning of Significance Tests. *The American Statistician,* 40**,** 313-315.

RUNDEL, P. W. & BOONPRAGOB, K. (1995) Dry forest ecosystems of Thailand. IN BULLOCK, S. H., MOONEY, H. A. & MEDINA, E. (Eds.) *Seasonally Dry Tropical Forests. .* Cambridge, UK., Cambridge University Press.

SANTISUK, T. (1988) *An account of the vegetation of Northern Thailand,* Stuttgart, Franz Steiner Verlag.

SANTONI, M., PAUTREAU, J.-P. & PRISHANCHIT, S. (1990) Excavations at Obluang, Province of Chiang Mai, Thailand. IN GLOVER, I. & GLOVER, E. (Eds.) *Southeast Asian Archaeology 1986. Proceedings of the First Conference of the Association of Southeast Asian Archaeologists in Western Europe.* London, BAR.

SANTROCK, J., STUDLEY, S. A. & HAYES, J. M. (1985) Isotopic analyses based on the mass spectra of carbon dioxide. *Analytical Chemistry,* 57**,** 1444-1448.

SARASIN, F. (1933) Prehistoric Researches in Siam. *Journal of the Siam Society,* 26**,** 171-202.

SCHEPS, S. (1982) Statistical Blight. *American Antiquity,* 47**,** 836-851.

SCHIFFER, M. B. (2002) Studying Technological Differentiation: The Case of 18th-Century Electrical Technology. *American Anthropologist,* 104**,** 1148-1161.

SCHIFFER, M. B. & SKIBO, J. M. (1987) Theory and experiment in the study of technological change. *Current Anthropology,* 28**,** 595-622.

SCHIFFER, M. B. & SKIBO, J. M. (1997) The explanation of artefact variability. *American Antiquity,* 62**,** 27-50.

SCHWARCZ, H. P. (1986) Geochronology and isotopic geochemistry of speleothems. IN FRITZ, P. & FONTES, J. C. (Eds.) *Handbook of Environmental Isotope Geochemistry.* Amsterdam, Elsevier.

SELLET, F. (1993) Chaîne opératoire; the concept and its applications. *Lithic Technology,* 18**,** 106-12.

SHANAHAN, T. M., PIGATI, J. S., DETTMAN, D. L. & QUADE, J. (2005) Isotopic variability in the aragonite shells of freshwater gastropods living in springs with nearly constant temperature and isotopic composition. *Geochimica et Cosmochimica Acta,* 69**,** 3949.

SHAO, J. & TU, D. (1995) *The Jackknife and Bootstrap,* New York, Springer.

SHAOMENG, L., YULOU, Q. & WALKER, D. (1986) Late Pleistocene and Holocene Vegetation History at Xi Hu, Er Yuan, Yunnan Province, Southwest China. *Journal of Biogeography,* 13**,** 419-440.

SHAVER, J. P. (1993) What Statistical Significance Testing Is, and What It Is Not. *Journal of Experimental Education,* 61**,** 293-316.

SHEA, J. J. (1991) Review of 'Time, Energy and Stone Tools'. *American Anthropologist,* 93**,** 250.

SHENNAN, S. (1988) *Quantifying archaeology,* Edinburgh Edinburgh University Press.

SHENNAN, S. (2001) Demography and Cultural Innovation: a Model and its Implications for the Emergence of Modern Human Culture. *Cambridge Archaeological Journal,* 11**,** 5-16.

SHENNAN, S. (2002a) Archaeology and evolutionary ecology. *World Archaeology,* 34**,** 1-5.

SHENNAN, S. (2002b) *Genes, Memes and Human History,* London, Thames and Hudson.

SHENNAN, S. & STEELE, J. (1999) Cultural learning in hominids: a behavioural ecological approach. IN BOX, H. & GIBSON, K. (Eds.) *Mammalian Social Learning: Comparative and Ecological Perspectives.* Cambridge, Cambridge University Press.

SHENNAN, S. & WILKINSON, J. (2001) Ceramic style change and neutral evolution: A case study from Neolithic Europe. *American Antiquity,* 66**,** 577-594.

SHOOCONGDEJ, R. (1996a) Forager mobility organisation in seasonal tropical environments: A view from Lang Kamnan Cave, western Thailand. PhD Thesis. Ann Arbor, The University of Michigan.

SHOOCONGDEJ, R. (1996b) Working towards an anthropological perspective on Thai prehistory: Current research on the Post-Pleistocene. *Bulletin of the Indo-Pacific Prehistory Association (Chiang Mai Papers, Volume 1),* 14**,** 119-132.

SHOOCONGDEJ, R. (2000) Forager Mobility Organization in Seasonal Tropical Environments of Western Thailand. *World Archaeology,* 32**,** 14-40.

SHOOCONGDEJ, R. (2004) Preliminary report on the archaeological investigations of the highland archaeology project in Pang Mapha (HAPP), Mae Hong Son Province, between 1998-2004. *Southeast Asian Archaeology International Newsletter,* January 2004**,** 6-8.

SHOOCONGDEJ, R. (2005) โบราณคดีบนพื้นที่สูงในอำเภอปางมะผ้า จังหวัดแม่ฮ่องสอน, Nakhorn Patom, Silpakorn University Press.

SHOOCONGDEJ, R. (2006a) Late Pleistocene activities at the Tham Lod Rockshelter in Highland Pang Mapha, Mae Hong Son Province, Northwestern Thailand. IN BACUS, E. A., GLOVER, I. C. & PIGGOTT, V. (Eds.) *Uncovering Southeast Asia's Past: Selected Papers from the 10th Annual Conference of the European Association of Southeast Asian Archaeologists.* Singapore, NUS Press.

SHOOCONGDEJ, R. (Ed.) (2006b) พลวัตทางสังคม วัฒนธรรม และสิ่งแวดล้อมบนพื้นที่สูง ในอำเภอปางมะผ้า จังหวัดแม่ฮ่องสอน: งานวิจัยบูรณาการโบราณคดีเชิงพื้นที่แบบครบวงจร [*Social, Cultural and Environmental Dynamics in the Highlands of Pangmapha, Mae Hong Son Province: Integrated Archaeological Research into the Region],* กรุงเทพ [Bangkok], โครงการโบราณคดีพื้นที่สูงในอำเภอปางมาะผ้า จังหวัดแม่ฮ่องสอน [Highland Archaeological Project in Pangmapha, Mae Hong Son].

SHOOCONGDEJ, R. & STAFF (2003a) รายงานวิจัยฉบับสมบูรณ์ โครงการโบราณคดีบนพื้นที่สูงในเขตอำเภอปางมะผ้า, จังหวัดแม่ฮ่องสอน ระยะที่สอง, (เล่มที่ 4: การขุดค้นแหล่งโบราณคดีเพิงผาบ้านไร่). เสนอต่อ สำนักงานกองทุนสนับสนุนการวิจัย (สกว.) ฝ่ายที่ *3* ฝ่ายสวัสดิภาพสาธารณะ. Bangkok, Highland Archaeology Project in Pang Mapha District, Mae Hong Son Province.

SHOOCONGDEJ, R. & STAFF (2003b) รายงานวิจัยฉบับสมบูรณ์ โครงการโบราณคดีบนพื้นที่สูงในเขตอำเภอปางมะผ้า, จังหวัดแม่ฮ่องสอน ระยะที่สอง, (เล่มที่ 5: การขุดค้นแหล่งโบราณคดีเพิงผาถ้ำลอด). เสนอต่อ สำนักงานกองทุนสนับสนุนการวิจัย (สกว.) ฝ่ายที่ *3* ฝ่ายสวัสดิภาพสาธารณะ. Bangkok, Highland Archaeology Project in Pang Mapha District, Mae Hong Son Province.

SHOTT, M. J. (1986) Technological organization and settlement mobility: An ethnographic examination. *Journal of Anthropological Research,* 42**,** 15-51.

SHOTT, M. J. (1989a) On Tool-Class Use Lives and the Formation of Archaeological Assemblages. *American Antiquity,* 54**,** 9-30.

SHOTT, M. J. (1989b) Technological organization in Great Lakes Paleoindian assemblages. IN ELLIS, C. J. & LOTHROP, J. C. (Eds.) *Eastern Paleoindian lithic resource use.* Boulder Westview Press.

SHOTT, M. J. (1994) Size and form in the analysis of flake debris: Review and recent approaches. *Journal of Archaeological Method and Theory,* 1**,** 69-110.

SHOTT, M. J. (1995) How much is a scraper? Curation , use rates and the formation of scraper assemblages. *Lithic Technology,* 20**,** 53-72.

SHOTT, M. J. (1996) Stage versus continuum in the debris assemblage from production of a fluted biface. *Lithic Technology,* 21**,** 6–22.

SHOTT, M. J. (1997) Transmission theory in the study of stone tools: A midwestern north American example. *Rediscovering Darwin: Evolutionary Theory and Archaeological Explanation.* Arlington, Virginia, American Anthropological Association.

SHOTT, M. J. (2005) The reduction thesis and its discontents: Review of Australian approaches. IN CLARKSON, C. & LAMB, L. (Eds.) *Rocking the Boat: Recent Australian Approaches to Lithic Reduction, Use and Classification.* Oxford, Archaeopress.

SHOTT, M. J. & SILLITOE, P. (2004) Modeling Use-Life Distributions in Archaeology Using New Guinea Wola Ethnographic Data. *American Antiquity,* 69**,** 339-356.

SHOTT, M. J. & SILLITOE, P. (2005) Use life and curation in New Guinea experimental used flakes. *Journal of Archaeological Science,* 32**,** 653-663.

SHRADER-FRECHETTE, K. S. & MCCOY, E. D. (1992) Statistics, costs and rationality in ecological inference. *Trends in Ecology & Evolution,* 7**,** 96-99.

SIH, A. & CHRISTENSEN, B. (2001) Optimal diet theory: when does it work, and when and why does it fail? *Animal Behaviour,* 61**,** 379-390.

SIMMS, S. (1983) Comment on "Anthropological applications of optimal foraging theory: a critical review" by E.A. Smith. *Current Anthropology,* 24**,** 646.

SIMMS, S. (1987) *Behavioral Ecology and Hunter. Gatherer Foraging: An Example from the Great Basin,* Oxford, British Archaeological Reports.

SMITH, C. C. & FRETWELL, S. D. (1974) The optimal balance between size and number of offspring. *American Naturalist,* 108**,** 499-506.

SMITH, E. A. (1983) Anthropological Applications of Optimal Foraging Theory: A Critical Review. *Current Anthropology,* 24**,** 625-651.

SMITH, E. A. (1991) *Inujjuamiut Foraging Strategies: Evolutionary Ecology of an Arctic Hunting Economy,* New York, Aldine.

SOBEL, E. & BETTLES, G. (2000) Winter hunger, winter myths: subsistence risk and mythology among the Klamath and Modoc. *Journal of Anthropological Archaeology,* 19**,** 276-316.

SOBER, E. (1980) Evolution, population thinking, and essentialism. *Philosophy of Science,* 47**,** 350–383.

SPAULDING, A. C. (1953) Statistical techniques for the discovery of artifact types. *American Antiquity* 18**,** 305-313.

SPETH, J. D. (1972) Mechanical Basis of Percussion Flaking. *American Antiquity,* 37**,** 34-60.

SPÖTL, C. & MATTEY, D. (2006) Stable isotope microsampling of speleothems for palaeoenvironmental studies: A comparison of microdrill, micromill and laser ablation techniques. *Chemical Geology,* 235**,** 48-58.

SRIKOSAMART, S., NOASAWASD, S., LAO YI PA, S. & SUTEETHORN, V. (1999) *The status of salt earth and wildlife in Mae Hong Son province and the potential for supporting eco-tourism,* Bangkok, Thai Forestry Department.

STAHLE, D. & DUNN, J. (1982) An analysis and application of the size distribution of waste flakes from the manufacture of bifacial stone tools. *World Archaeology,* 14**,** 84–97.

STEFFEN, A., SKINNER, E. J. & AINSWORTH, P. W. (1998) A view to the core: Technological units and debitage analysis. IN WANDSNIDER, A., RAMENOFSKY, F. & STEFFEN, A. (Eds.) *Unit Issues in Archaeology.* Salt Lake City, University of Utah Press.

STEPHENS, D. W. (1990) Risk and incomplete information in behavioural ecology. IN CASHDAN, E. (Ed.) *Risk and Uncertainty in Tribal and Peasant Economies.* Boulder, Colorado., Westview Press.

STEPHENS, D. W. & KREBS, J. R. (1986) *Foraging Theory*, Princeton University Press.

STEPHENS, P. A., BUSKIRK, S. W. & DEL RIO, C. M. (2007a) Inference in ecology and evolution. *Trends in Ecology & Evolution,* In Press, Corrected Proof.

STEPHENS, P. A., BUSKIRK, S. W., HAYWARD, G. D. & DEL RIO, C. M. (2007b) A call for statistical pluralism answered. *Journal of Applied Ecology,* 44**,** 461-463.

STEPHENS, P. A., BUSKIRK, S. W., HAYWARD, G. D. & MARTINEZ DEL RIO, C. (2005) Information theory and hypothesis testing: a call for pluralism. *Journal of Applied Ecology,* 42**,** 4-12.

STERELNY, K. (2004) Review of Genes, Memes and Human History. *Mind & Language,* 19**,** 249-257.

STEWART-OATEN, A. (1995) Rules and Judgments in Statistics: Three Examples. *Ecology,* 76**,** 2001-2009.

STUIJTS, I., NEWSOME, J. C. & FLENLEY, J. R. (1988) Evidence for Late Quaternary vegetational change in the Sumatran and Javan highlands. *Review of Palaeobotany and Palynology,* 55**,** 207-216.

SULLIVAN, A. P., III & ROZEN, K. C. (1985) Debitage Analysis and Archaeological Interpretation. *American Antiquity,* 50**,** 755-779.

SUROVELL, T. A. (2003) The Behavioural Ecology of Folsom Lithic Technology. PhD Thesis. *Department of Anthropology.* Tucson, The University of Arizona.

TEHRANI, J. & COLLARD, M. (2002) Investigating cultural evolution through biological phylogenetic analyses of Turkmen textiles. *Journal of Anthropological Archaeology,* 21**,** 443-463.

TËMKIN, I. (2004) The evolution of the Baltic psaltery: A case for phyloorganology. *The Galpin Society Journal,* 57**,** 219-30.

TËMKIN, I. & ELDREDGE, N. (2007) Phylogenetics and Material Cultural Evolution. *Current Anthropology,* 48**,** 146-153.

THOMAS, A. D. (2001) Statistical significance, effect size, and replication: What do the journals say? *The Journal of Experimental Education,* 69**,** 310-20.

THOMAS, D. H. (1978) The Awful Truth about Statistics in Archaeology. *American Antiquity,* 43**,** 231-244.

THOMPSON, B. (1999) If Statistical Significance Tests are Broken/Misused, What Practices Should Supplement or Replace Them? *Theory Psychology,* 9**,** 165-181.

THOMPSON, B. (2002) What Future Quantitative Social Science Research Could Look Like: Confidence Intervals for Effect Sizes. *Educational Researcher,* 31**,** 25-32.

THOMPSON, B. (2004) The" significance" crisis in psychology and education. *Journal of Socio-Economics,* 33**,** 607-613.

THOMPSON, J. B., PALOCZI, G. T., KINDT, J. H., MICHENFELDER, M., SMITH, B. L., STUCKY, G., MORSE, D. E. & HANSMA, P. K. (2000) Direct Observation of

the Transition from Calcite to Aragonite Growth as Induced by Abalone Shell Proteins. *Biophysical Journal,* 79**,** 3307-3312.

TOMKA, S. A. (1989) Differentiating lithic reduction techniques: An experimental approach. IN AMICK, D. S. & MAULDIN, R. P. (Eds.) *Experiments in Lithic Technology.* Oxford, BAR International Series 528.

TORRENCE, R. (1983) Time budgeting and hunter-gatherer technology. IN BAILEY, G. (Ed.) *Hunter-Gatherer Economy in Prehistory.* Cambridge, Cambridge University Press.

TORRENCE, R. (1989) Re-tooling: towards a behavioral theory of stone tools. IN TORRENCE, R. (Ed.) *Time, Energy and Stone Tools.* Cambridge, University of Cambridge.

TORRENCE, R. (2001) Hunter-Gatherer Technology: Macro- and Microscale Approaches. IN PANTER-BRICK, C., LAYTON, R. & ROWLY-CONWY (Eds.) *Hunter-Gatherers: An Interdisciplinary Perspective.* Cambridge, Cambridge University Press.

TOUGARD, C., JAEGER, J. J., CHAIMANEE, Y., SUTEETHORN, V. & TRIAMWICHANON, S. (1998) Discovery of *Homo* sp. tooth associated with a mammalian cave fauna of Late Middle Pleistocene age, northern Thailand. *Journal of Human Evolution,* 35**,** 47-54.

TREERAYAPIWAT, C. (2005) Patterns of Habitation and Burial Activity in the Ban Rai Rock Shelter, Northwestern Thailand. *Asian Perspectives,* 44**,** 231-245.

TRIGGER, B. G. (1989) *A History of Archaeological Thought,* Cambridge, Cambridge University Press.

TRIKANCHANAWATTANA, C. (2005) Palynological study at Ban Tham Lod and Ban Rai in Pang Mapha district, Mae Hong Son province, northern Thailand. MA Thesis. Bangkok, Mahidol University.

TUFTE, E. R. (1986) *The visual display of quantitative information*, Graphics Press Cheshire, CT, USA.

TURCOTTE, D. L. (1997) *Fractals and Chaos in Geology and Geophysics,* Cambridge, Cambridge University Press.

UGAN, A., BRIGHT, J. & ROGERS, A. (2003) When is technology worth the trouble? *Journal of Archaeological Science,* 30**,** 1315-1329.

UKOUMUNNE, O. C., DAVISON, A. C., GULLIFORD, M. C. & CHINN, S. (2003) Non-parametric bootstrap confidence intervals for the intraclass correlation coefficient. *Statistics in Medicine,* 22**,** 3805-3821.

VACHA-HAASE, T. (2001) Statistical Significance should not be Considered one of Life's Guarantees: Effect Sizes are Needed. *Educational and Psychological Measurement,* 61**,** 219-224.

VAN HEEKEREN, H. R. & KNUTH, E. (1967) *Archaeological Excavations in Thailand. Volume 1. Sai Yok. Stone Age Settlements in the Kanchanaburi Province,* Copenhagen, Munksgaard.

VAN TAN, H. (1994) The Hoabinhian in Southeast Asia: Culture, cultures or technocomplex? *Vietnam Social Sciences,* 5**,** 3-8.

VAN TAN, H. (1997) The Hoabinhian and before. *Bulletin of the Indo-Pacific Prehistory Association (Chiang Mai Papers, Volume 3),* 16**,** 35-41.

VANPOOL, C. S. & VANPOOL, T. L. (1999) The Scientific Nature of Postprocessualism. *American Antiquity,* 64**,** 33-53.

VELLEMAN, P. F. & WELSCH, R. E. (1981) Efficient Computing of Regression Diagnostics. *The American Statistician,* 35**,** 234-242.

WANG, L., SARNTHEIN, M., ERLENKEUSER, H., GRIMALT, J., GROOTES, P., HEILIG, S., IVANOVA, E., KIENAST, M., PELEJERO, C. & PFLAUMANN, U. (1999) East Asian monsoon climate during the Late Pleistocene: high-resolution sediment records from the South China Sea. *Marine Geology,* 156**,** 245-284.

WANG, S., LÜ, H., LIU, J. & NEGENDANK, J. (2007) The early Holocene optimum inferred from a high-resolution pollen record of Huguangyan Maar Lake in southern China. *Chinese Science Bulletin,* 52**,** 2829-2836.

WANG, Y. J., CHENG, H., EDWARDS, R. L., AN, Z. S., WU, J. Y., SHEN, C. C. & DORALE, J. A. (2001) A High-Resolution Absolute-Dated Late Pleistocene Monsoon Record from Hulu Cave, China. *Science,* 294**,** 2345-2348.

WANGWACHARAKUL, V., RATANASEAMPONG, S., NABHITABRATA, J., JINTANAYON, S. & TRISURAT, Y. (2000) *Biological resource values in Mae Hong Son province Bangkok,* Bangkok, Office of Environmental Policy and Planning.

WARD, D. (1992) Role of satisficing in foraging theory. *Oikos,* 62**,** 312-317.

WATTANAPITUKSAKUL, S. (2006a) Late Pleistocene mammal teeth from Tham Lod rockshelter, Amphoe Pang Mapha, Changwat Mae Hong Son. MA Thesis. *Department of Geology.* Bangkok, Chulalongkorn University.

WATTANAPITUKSAKUL, S. (2006b) Why is that size important? Perspectives from an analysis of mammalian teeth from the Late Pleistocene. IN SHOOCONGDEJ, R. (Ed.) *Social, Cultural and Environmental Dynamics in the Highlands of Pangmapha, Mae Hong Son Province: Integrated Archaeological Research into the Region.* Bangkok, Highland Archaeology Project in Pangmapha (In Thai).

WEAVER, A. J., SAENKO, O. A., CLARK, P. U. & MITROVICA, J. X. (2003) Meltwater Pulse 1A from Antarctica as a Trigger of the Bolling-Allerod Warm Interval. *Science,* 299**,** 1709-1713.

WEISS, H. & BRADLEY, R. S. (2001) ARCHAEOLOGY: What Drives Societal Collapse? *Science,* 291**,** 609-610.

WENINGER, B., JÖRIS, O. & DANZEGLOCKE, U. (2007) CalPal-2007. Cologne Radiocarbon Calibration & Palaeoclimate Research Package. http://www.calpal.de/, accessed 2007-11-08.

WHITE, J. C. & BOUASISENGPASEUTH, B. (2007) Archaeology of the Middle Mekong: Introduction to the Luang Prabang Exploratory Survey. IN GOUDINEAY, Y. & LORRILLARD, M. (Eds.) *Research Nouvelles sur le Laos* Paris, l'École Française d'Extrême Orient.

WHITE, J. C. & GORMAN, C. F. (2004) Patterns in "amorphous" industries: the Hoabinhian viewed through a lithic reduction sequence. IN PAZ, V. (Ed.) *Southeast Asian archaeology: Wilhelm G. Solheim II Festschrift.* Quezon City, University of the Phillipines Press.

WHITE, J. C., PENNY, D., KEALHOFER, L. & MALONEY, B. (2004) Vegetation changes from the late Pleistocene through the Holocene from three areas of archaeological significance in Thailand. *Quaternary International,* 113**,** 111-132.

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

WHITE, J. P. (1977) Crude, colourless and unenterprising? Prehistorians and their views on the Stone Age of Sunda and Sahul. IN ALLEN, J., GOLSON, J. &

JONES, R. (Eds.) *Sunda and Sahul: Prehistoric studies in Southeast Asia, Melanesia and Australia.* London, Academic Press.

WHITTAKER, J. (1994) *Flintknapping: Making and Understanding Stone Tools,* Austin, University of Texas Press.

WIESSNER, P. (1982) Beyond Willow Smoke and Dogs' Tails: A Comment on Binford's Analysis of Hunter-Gatherer Settlement Systems. *American Antiquity,* 47**,** 171-178.

WILLCOX, G., FORNITE, S. & HERVEUX, L. (2007) Early Holocene cultivation before domestication in northern Syria. *Vegetation History and Archaeobotany***,** DOI: 10.1007/s00334-007-0121-y.

WINTERHALDER, B. (1980) Environmental analysis in human evolution and adaptation research. *Human Ecology,* 8**,** 135-170.

WINTERHALDER, B. (1981) Optimal foraging strategies and hunter-gatherer research in anthropology: theory and models. IN WINTERHALDER, B. & SMITH, E. A. (Eds.) *Hunter-Gatherer Foraging Strategies: Ethnographic and Archaeological Analyses.* Chicago, The University of Chicago Press.

WINTERHALDER, B. (1990) Open field, common pot: The behavioral ecology of nonmarket, intergroup exchange. IN CASHDAN, E. (Ed.) *Risk and uncertainty in tribal and peasant economies.* Boulder, Colorado, Westview Press.

WINTERHALDER, B. (2002) Models. IN HART, D. M. & TERRELL, J. E. (Eds.) *Darwin and Archaeology: A Handbook of Key Concepts.* Westport, Conneticut, Bergin and Garvey.

WINTERHALDER, B. & GOLAND, C. (1997) An evolutionary ecology perspective on diet choice, risk, and plant domestication. IN GREMILLION, K. J. (Ed.) *People, Plants and Landscapes: Studies in Paleoethnobotany.* Tuscaloosa, AL, University of Alabama Press.

WINTERHALDER, B., LU, F. & TUCKER, B. (1999) Risk-sensitive adaptive tactics: Models and evidence from subsistence studies in biology and anthropology. *Journal of Anthropological Research,* 7**,** 301-348.

WINTERHALDER, B. & SMITH, E. A. (1992) Natural selection and decision-making: Some fundamental principles. IN SMITH, E. A. & WINTERHALDER, B. (Eds.) *Evolutionary Ecology and Human Behavior.* Hawthorne, NY, Aldine de Grutyer.

WINTERHALDER, B. & SMITH, E. A. (2000) Analyzing adaptive strategies: human behavioural ecology at twenty-five. *Evolutionary Anthropology,* 9**,** 51-72.

WONNACOTT, T. (1987) Confidence intervals or hypothesis tests? *Journal of Applied Statistics,* 14**,** 195-201.

WOOD, M. (2004) Statistical inference using bootstrap confidence intervals. *Significance,* 1**,** 180-182.

WOOD, M. (2005) Bootstrapped Confidence Intervals as an Approach to Statistical Inference. *Organizational Research Methods,* 8**,** 454-470.

WYLIE, A. (1989) Archaeological cables and tacking: the implications of practice for Bernstein's 'Options beyond objectivism and relativism'. *Philosophy of the Social Sciences,* 19**,** 1-18.

WYLIE, A. (1995) An Expanded Behavioral Archaeology: Transformation and Redefinition. IN SKIBO, J. M., WALKER, W. H. & NIELSEN, A. E. (Eds.) *Expanding Archaeology.* Salt Lake City, University of Utah Press.

WYLIE, A. (2000) Questions of Evidence, Legitimacy, and the (Dis)Unity of Science. *American Antiquity,* 65**,** 227-237.

XIANGJUN, S., YUSHU, W., YULOU, Q. & WALKER, D. (1986) Late Pleistocene and Holocene Vegetation History at Kunming, Yunnan Province, Southwest China. *Journal of Biogeography,* 13**,** 441-476.

YESNER, D. R. (1981) Archaeological Applications of Optimal Foraging Theory: Harvest Strategies of Aluet Hunter-Gatherers. IN WINTERHALDER, B. & SMITH, E. A. (Eds.) *Hunter-Gatherer Foraging Strategies.* Chicago, The University of Chicago Press.

YI, S. & CLARK, G. A. (1983) Observations on the Lower Palaeolithic of Northeast Asia. *Current Anthropology,* 24**,** 181-202.

YOCCOZ, N. G. (1991) Use, overuse, and misuse of significance tests in evolutionary biology and ecology. *Bulletin of the Ecological Society of America,* 72**,** 106-111.

YUAN, D., CHENG, H., EDWARDS, R. L., DYKOSKI, C. A., KELLY, M. J., ZHANG, M., QING, J., LIN, Y., WANG, Y., WU, J., DORALE, J. A., AN, Z. & CAI, Y. (2004) Timing, Duration, and Transitions of the Last Interglacial Asian Monsoon. *Science,* 304**,** 575-578.

ZEITOUN, V., SEVEAU, A., FORESTIER, H., THOMAS, H., LENOBLE, A., LAUDET, F., ANTOINE, P.-O., DEBRUYNE, R., GINSBURG, L. & MEIN, P. (2005) Decouverte d'un assemblage faunique a Stegodon-Ailuropoda dans une grotte du Nord de la Thailande (Ban Fa Suai, Chiang Dao). *Comptes Rendus Palevol,* 4**,** 255.

ZELEZNIK, W. S. & IAN, M. B. (1991) Assumption validity in human optimal foraging: The BarÃ- hunters of Venezuela as a test case. *Human Ecology,* V19**,** 499-508.

ZHAO, J.-X., WANG, Y.-J., COLLERSON, K. D. & GAGAN, M. K. (2003) Speleothem U-series dating of semi-synchronous climate oscillations during the last deglaciation. *Earth and Planetary Science Letters,* 216**,** 155-161.

ZHENG, S., HOU, F. & NI, B. (1983) CO isotope study of precipitations in China. *Chinese Science Bulletin,* 13**,** 801–806.

ZHISHENG, A., PORTER, S. C., WEIJIAN, Z., YANCHOU, L., DONAHUE, D. J., HEAD, M. J., XIHUO, W., JIANZHANG, R. & HONGBO, Z. (1993) Episode of Strengthened Summer Monsoon Climate of Younger Dryas Age on the Loess Plateau of Central China. *Quaternary Research,* 39**,** 45-54.

ZHOU, W., HEAD, M. J. & DENG, L. (2001) Climate changes in northern China since the late Pleistocene and its response to global change. *Quaternary International,* 83-85**,** 285-292.

ZHOU, X. H. & DINH, P. (2005) Nonparametric confidence intervals for the one- and two-sample problems. *Biostatistics,* 6**,** 187-200.

ZHOU, X. H., GAO, S. & HUI, S. L. (1997) Methods for Comparing the Means of Two Independent Log-Normal Samples. *Biometrics,* 53**,** 1129-1135.

ZHUO, Z., BAOYIN, Y. & PETIT-MAIRE, N. (1998) Paleoenvironments in China during the Last Glacial Maximum and the Holocene optimum. *Episodes,* 21**,** 152–158.

ZIMAN, J. (2000a) Commentary on The Republic of Science: Its Political and Economic Theory. *Minerva,* 38**,** 21-25.

ZIMAN, J. M. (Ed.) (2000b) *Technological innovation as an evolutionary process,* Cambridge, U.K. :, Cambridge University Press.