

Reconstructing Human Subsistence in the West Mouth (Niah Cave, Sarawak) Burial Series Using Stable Isotopes of Carbon



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THIS PAPER PRESENTS A PALAEODIETARY ANALYSIS using stable carbon isotopes of tooth enamel to explore diachronic patterns of human subsistence in the terminal Pleistocene and Holocene at Niah Cave (Sarawak, Malaysia). Niah's West Mouth has produced an outstanding archaeological assemblage (Barker et al. 2000, 2001, 2002*a*, 2002*b*, 2003; T. Harrison 1957, 1959, 1972; Zuraina 1982) that "contains the longest stratified record of human occupation in Island Southeast Asia" (Bellwood 1997:172). Aside from early human remains of late Pleistocene context, most proper burials recovered from the West Mouth can be considered terminal Pleistocene or Holocene in age (Bellwood 1997; Brooks et al. 1979; B. Harrison 1967; Krigbaum and Manser in prep.). The burial series provides a unique opportunity to address diachronic trends in pre-Neolithic and Neolithic human subsistence patterns in a single locale. Isotopic data presented below provide a fresh perspective for understanding prehistoric lifeways of foraging populations inhabiting tropical lowland settings in Southeast Asia, particularly with respect to how caves serve as a component of complex subsistence and settlement patterns (Anderson 1997).

THE RESEARCH CONTEXT

Surprisingly, little detailed work has been conducted on reconstructing prehistoric human subsistence in the lowland tropics of Southeast Asia. In part this is due to negative evidence in the record and the paucity of sites of appropriate age. Post-glacial changes in topography and climate have greatly affected what evidence might exist for late Pleistocene human presence. Because the Sunda subcontinental shelf is so shallow, sea level transgression dramatically changed the configuration of land and sea, with rising sea levels submerging any habitation sites in coastal lowland settings (Dunn and Dunn 1977; Hanebuth et al. 2000; Sun et al.

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2000; Tjia 1980; Verstappen 1975, 1994). The late Pleistocene archaeological record after the Last Glacial Maximum is therefore biased toward moderately elevated lowland sites (ca. 100–300 m above sea level), inland from the shelf margin. This limits prehistoric subsistence reconstruction to archaeological contexts that are generally more terrestrial than coastal in character. This bias is compounded by the fact that archaeological assemblages in rainforest settings and lowland coastal environments such as peat swamp and mangrove are ephemeral in nature and such environments tend to support low densities of people (Bellwood 1990). Comparable prehistoric situations have been observed in low latitude regions of Sahul (Groube 1989; Pasveer et al. 2002; Pavlides and Gosden 1994), Africa (Brooks and Robertshaw 1990; Eggert 1992; Mercader 2003), and South America (Kipnis 1998; Roosevelt et al. 1996).

A central concern in rainforest prehistory is whether foragers, prior to the invention or adoption of agriculture, inhabited rainforest ecosystems independent of the coast and/or more seasonal monsoon areas (Bailey et al. 1989; Bailey and Headland 1991; Headland 1987; see also this volume: Barker, Barton). As Hutterer (1983) has noted, because of the extensive biomass in perhumid rainforests, humans would have been challenged with regard to mobility and resource procurement. Rainforest is difficult to navigate and foodstuffs are insecure, owing mainly to seasonal flux in fruiting. It is far more likely that foragers capitalized on forest resources via waterways and fringe habitats, accessing interior, terrestrial ecozones where caves such as Niah are found.

Prehistoric foragers inhabiting Southeast Asian rainforest had subsistence regimes often characterized as “broad spectrum” (Gorman 1971; Hutterer 1988; Krigbaum 2003). A wide variety of foodstuffs from hunted game to collected endemic plants and fruits was most certainly consumed (this volume: Barker, Barton, Paz), but the nature of modern human hunter-gatherer subsistence in tropical forest systems prior to and after the origins of agriculture is poorly understood based on current assessments of the archaeological record. Broad spectrum categories, however, do not improve understanding about the nuances of prehistoric human diet, be they cultural or ecological choices made in hunting and collecting food resources. Owing to preservational biases inherent in the archaeological record, diet is more often inferred based on indirect findings such as faunal and floral remains. Analysis of stable isotope ratios of carbon provides a means to infer human subsistence regimes against such important and complementary subsistence data recovered in the record.

THE WEST MOUTH BURIAL SERIES

Although other archaeologically significant cave mouths in the Niah massif were explored by Tom Harrisson and his Sarawak Museum colleagues during the 1950s and 1960s, excavation focused on the West Mouth deposits. The West Mouth stands ca. 20 m above lowland swamp and mixed dipterocarp forest. Archaeological “habitation” deposits up to 4 m in depth are mainly situated close to the mouth, in areas with ample afternoon sun and good shelter from the rain. Shallower “cemetery” deposits lie in the darker interior along the northern wall (Fig. 1; and this volume: Barker, Fig. 3). Over 370 trenches were excavated to varying

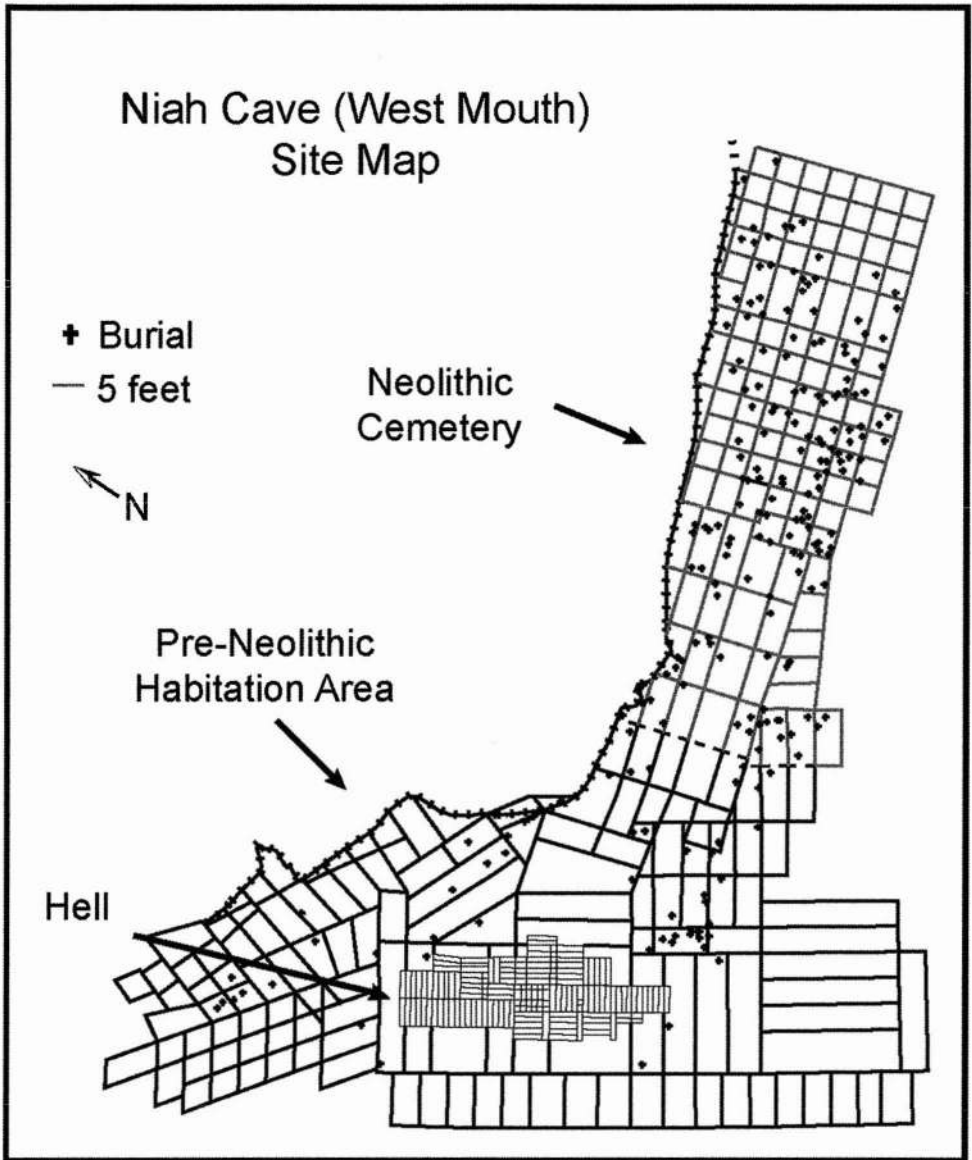


Fig. 1. Niah Cave (West Mouth): the original trench layout, showing the three areas of concentrated archaeological excavation: the pre-Neolithic "habitation" area; the "Hell" deep sounding; and the Neolithic "cemetery."

depths by Tom Harrisson and Zuraina Majid, with the smaller units of the Hell deep sounding underlying the larger units in the habitation area, beginning at 96 in. below the original ground surface (Harrison 1967; Zuraina 1982).

Remains of human activity, including faunal remains and pre-Neolithic burials, were found in the habitation area of the site, with some Neolithic burials associated with ceramics near the ground surface. The cemetery area produced an

abundance of more superficial Neolithic-associated burial remains. The sheer size and temporal depth of this burial series, despite its fragmentary condition, make it the largest diachronic skeletal population in Island Southeast Asia.

In 1967 Barbara Harrisson outlined a classification system for the more than 170 burials that had been recovered at that time. These types correlate with pre-ceramic and ceramic-associated modes of burial. The pre-Neolithic assemblage included primary flexed, seated, and secondary so-called "mutilation" burials. This latter classification term, as defined by Harrisson (1967:140), refers specifically to incomplete burial features rather than isolated elements. The ceramic-associated Neolithic remains consist mostly of primary "extended" burials (often in coffins), together with less frequent secondary burnt burials (often in ceramic vessels) and cremation burials. The only assigned human burial recovered in Hell Trench was the Deep Skull and associated postcranial remains, probably dating to ca. 43,000 B.P. (Barker et al. 2002a; Krigbaum et al. 2003; and see this volume: Barker; Gilbertson et al.).

Radiocarbon dating has been an important aspect to interpreting the Niah Cave record since the initial stages of excavation. Absolute ^{14}C dating on human bone was attempted by the Harrissons on several burial features (e.g., B. Harrisson 1967; T. Harrisson 1972, 1975) and by Brooks et al. (1979) on a subset of 30 burials. Given the complexities involved in securing accurate bone dates (Taylor 1992), all Niah Cave bone dates generated to date are deemed erroneous. Recent attempts to retrieve bone collagen from 28 burials sampled by Brooks et al. (1979) yielded negative results (Krigbaum 2001). For present purposes, cultural attribution of burials is simply based on burial context following Barbara Harrisson's classification. Different types may discriminate different prehistoric groups using the cave in prehistory, although this remains supposition. It is certain, however, that those burial types associated with ceramics are of Neolithic age.

The extraordinary amount of vertebrate and invertebrate remains recovered throughout the West Mouth sequence is testimony to the importance of broad spectrum subsistence hunting and collection typical of present-day hunter-gatherers in the region (Brosius 1991; Hutterer 1988). Animals such as the bearded pig (*Sus barbatus*), porcupine (*Hystrix* or *Thecurus* spp.), and various monkeys (*Macaca fascicularis* and *Presbytis* spp.) dominate the assemblage, along with freshwater snails. These remains span the Holocene transition from predominantly seasonal subtropical forest to more closed forest. Cranbrook's work on the Harrison fauna identified 59 mammal species present in various levels of the habitation zone (Cranbrook 2000; Medway 1979). Plant food remains are considerably less abundant in the deposits, but certainly wild tubers, vegetables, fruits, and nuts factored into the overall subsistence regime (Barker et al. 2002a; this volume: Barker; Barton; Paz).

At times of low sea level, Niah Cave may have been quite distant (ca. 100 km) from the South China Sea (see this volume: Gilbertson et al.), whereas by mid-Holocene times (ca. 6000 B.P.), the site was much closer to the coast. Subsistence trends therefore track environmental changes and local ecology in a fundamental way. Recovered invertebrate shell remains do show a slight increase in the number and abundance of marine and estuarine species in later Holocene levels, indicative of Niah Cave's close proximity to the coast at that time (Zuraina 1982; and this volume: Barker).

STABLE ISOTOPE RATIO ANALYSIS

Major advances in bone chemistry have rapidly expanded the scope of palaeodiet research in the past decade. Stable isotope ratio analysis, in particular, is now well established in bioarchaeology (e.g., Ambrose and Katzenberg 2000; Krigbaum and Ambrose 2003). Such biogeochemical methods provide data with which to characterize diet in a particular sample or population. The old adage “you are what you eat” is true to the extent that dietary signals sequestered in most biological tissues (e.g., teeth, bone, hair, fingernails) and by-products (e.g., breath CO₂) can be measured and quantified. Differences in stable carbon isotope ratios of plants and their consumer’s tissues, such as bone or tooth enamel, thereby provide a dietary signature of the individual sampled that directly correlates with its diet (Ambrose 1993; Katzenberg 2000; Pate 1994; Schoeninger 1995; van der Merwe 1982).

The stable carbon isotope ratio (¹³C/¹²C) is determined for a given organic sample and compared to a standard of known abundance. With carbon, that standard is typically PDB, which refers to the Cretaceous belemnite from the Pee Dee Formation in South Carolina (Craig 1953), or its equivalent (since PDB has been exhausted). Oxygen’s standard can be PDB or V-SMOW (or simply SMOW), referring to Vienna-Standard Mean Ocean Water (Gonfiantini 1978). Using delta notation (δ), δ¹³C values are expressed in parts per thousand (‰) or “per mil.” For a given sample *A*, its δ¹³C value is determined by comparing its ratio (where *R* is ¹³C/¹²C or ¹⁸O/¹⁶O) to that of a known standard, calculated as:

$$\delta A(\text{‰}) = (R_{\text{sample}} - R_{\text{sample}}/R_{\text{std}}) \times 1000 \quad \text{or} \quad (R_{\text{sample}}/R_{\text{std}} - 1) \times 1000$$

Lighter isotopes (e.g., ¹²C) react more quickly in chemical and physiological reactions than do their heavier counterparts (e.g., ¹³C). It is these differences in mass and their interplay during biochemical and metabolic processes that permit subtle differences to be measured by means of mass spectroscopy (Hoefs 1997). For example, ¹²C is more mobile and reacts more quickly than ¹³C as plants apply their carbon reserves to fix atmospheric CO₂ during photosynthesis. Thus plants use more ¹²C than ¹³C during photosynthesis and are isotopically lighter (more negative in δ¹³C value) than atmospheric CO₂, which has a modern δ¹³C value of -7.8‰ (-6.5‰ in preindustrial times). Fractionation refers to the process whereby differences in isotopic abundance occur because of physiological and/or environmental processes. Such differences can be measured across various tissues within the same individual or across species, depending upon the types of research questions being raised.

Plants that fix atmospheric CO₂ using a three-carbon molecule (phosphoglycerate) follow the C₃ (Calvin) photosynthetic pathway (all rainforest flora) and show a wide range of δ¹³C values, between -20‰ and -35‰, averaging -27‰ (O’Leary 1981, 1988). In contrast, most arid-adapted grasses and some sedges use a four-carbon molecule (dicarboxylic acid) and follow the C₄ (Hatch-Slack) photosynthetic pathway. C₄ plants show less fractionation with atmospheric CO₂ and exhibit a narrower range of δ¹³C values, between -16‰ and -7‰, averaging -12.5‰ (O’Leary 1981, 1988). C₃ plants include most trees, herbs, shrubs, and shady grasses. Common Southeast Asian C₃ cultivars include rice, all tubers (e.g.,

yams), fruits, nuts, and most vegetables. C_4 plants reflect adaptation to warm, water-stressed environments. East and Southeast Asian C_4 cultigens include some millets, sorghum, Job's tears, and sugarcane.

Significant fractionation offset occurs between plants (primary producers) and the consumers (primary, secondary, etc.) that eat them. These consistent differences, or offsets, can be traced in biological tissues, resulting in a positive shift in $\delta^{13}\text{C}$ value in the consumer tissue being analyzed: "you are what you eat" plus the offset value for the tissue being analyzed (Ambrose 1993). Whereas bone collagen has an offset value of 5‰, for tooth enamel it is 9‰ for carnivores and 14‰ for herbivores (Cerling and Harris 1999; Schwarcz 2000). Based on these figures, tooth enamel values would be expected to fall anywhere between -17‰ and -13‰ for a pure C_3 vegetarian diet.

In most palaeodiet studies using stable isotopes derived from human bone, C_3 vs. C_4 dietary intake has been explored in contexts where C_4 plants are involved in the adoption and diffusion of agricultural cereal crops (Schoeninger and Moore 1992). In the lowland rainforests of Southeast Asia, however, C_3 plants (and cultivars) are virtually ubiquitous, while C_4 cereals are less likely to be adopted on account of the ever-wet conditions characteristic of the lower latitudes. The lack of a clear C_3 vs. C_4 scenario has dissuaded workers from applying isotopic techniques to areas dominated by C_3 plants, such as Southeast Asia, where rice is assumed to be the principal domesticate. As Heaton (1999) and others (e.g., Ambrose 1993; Tieszen 1991) have noted, C_3 plant variation is underutilized in palaeodiet studies. $\delta^{13}\text{C}$ plant variation is significant for C_3 plants depending upon aspects of microhabitat (Heaton 1999). Plants grown in more open conditions are enriched in ^{13}C and have less negative $\delta^{13}\text{C}$ values, in contrast with plants grown in more closed conditions, where there is extensive canopy cover (Krigbaum 2001). This is referred to as the "canopy effect" phenomenon. Average $\delta^{13}\text{C}$ values of -27‰ are present at canopy level, but ground-level plants and browse are considerably more negative, in the order of -30‰ to -35‰ (Jackson et al. 1993; Krigbaum 2001, 2003; van der Merwe and Medina 1989, 1991; Vogel 1978). A vertical $\delta^{13}\text{C}$ gradient exists (leaves, air, and so on) on account of decreased light levels (Broadmeadow and Griffiths 1993; Ehleringer et al. 1986) and recycled CO_2 from the soil (Vogel 1978).

With respect to consumer tissues of interest (i.e., bone and teeth), two biological fractions are of interest: an organic, collagen fraction and an inorganic, mineral fraction referred to as hydroxyapatite or simply apatite. Both retain biological signals that isotopically correlate to overall diet. Mature bone tends to reflect a greater averaging effect due to the continuous nature of bone turnover and bone maintenance processes throughout adulthood. However, bone collagen is often degraded and difficult—if not impossible—to extract from remains recovered from hot and humid tropical contexts (Ambrose 1990; Ambrose and Norr 1992; Krigbaum 2001; Pate 1997). Under such conditions, bone mineral too is susceptible to postmortem diagenesis (Lee-Thorp 2000; Schoeninger et al. 1989). Tooth enamel, on the other hand, consists mainly of an inorganic fraction and is very resistant to postmortem alteration. It is the biological material of choice in palaeontological isotope studies because of its intrinsic physical properties and the structure of its hydroxyapatite crystal lattice (Wang and Cerling 1994). The biological signal in tooth enamel provides an accurate dietary signature during the

time of enamel formation for the individual sampled. Third molars, being the last to form in the human dentition, tend to be highly variable in terms of development. Enamel formation may commence anywhere between 7 and 13 years of age, with crown completion occurring typically in the mid to late teens (Hillson 1996). Thus, although biased toward what might be considered a subadult diet, tooth enamel provides the best material in the lowland tropics to predict overall adult diet for individual remains. Data derived from such materials may then be interpreted against isotopic data derived both from modern plants and animals and from fauna from the archaeological record.

MATERIALS AND METHODS

Fifty human molars from different adult individuals buried at Niah were analyzed for stable isotopes, 43 from burial features with good context information (Table 1). Of these, 15 are from pre-Neolithic contexts, while 28 have Neolithic associations/features. Most of the Neolithic remains sampled are from the interior cemetery, while all pre-Neolithic remains are from the habitation portion of the site (Fig. 1). All disturbed/random remains sampled were recovered from the habitation area.

The external surfaces of teeth were cleaned with a Dremel tool. The cleaned enamel was ground and the enamel powder was oxidized in a 2 percent bleach solution (NaOHCl). Oxidation of the sample was followed by pretreatment with 0.1 M acetic acid. About 50–70 mg of pretreated enamel powder was then hydrolyzed with 100 percent phosphoric acid (H₃PO₄) in sealed reaction vessels for two hours at 90°C. Evolved CO₂ was passed through a silver phosphate trap (AgPO₄) to remove evolved H₂S or SO₂, and the resultant CO₂ gas was collected by cryogenic distillation. Stable isotope ratios for carbon and oxygen were then measured on a Finnigan MAT 251 isotope ratio mass spectrometer at Yale University's Department of Geology and Geophysics. The precision of these analyses is less than 0.05‰ for carbon and about 0.2‰ for oxygen.

TABLE 1. NIAH CAVE (WEST MOUTH): BURIALS SAMPLED FOR ISOTOPIC ANALYSIS BY TYPE,^a SEX, AND LOCATION.

	BURIAL TYPE	N	SEX			WEST MOUTH	
			M/M?	F/F?	?	HABITATION	CEMETERY
Pre-Neolithic burials	Seated	3	2	1	0	3	0
	Flexed	7	2	3	2	7	0
	Mutilation	5	1	3	1	4	1
	Subtotal	15	5	7	3	14	1
Neolithic burials	Burnt	4	2	1	1	0	4
	Cremated	2	0	1	1	0	2
	Extended (incl. multiple)	22	7	12	3	1	21
	Subtotal	28	9	14	5	1	27
Disturbed/random		7	0	0	7	7	0
Total		50	14	21	15	22	28

^aTypes are as classified by B. Harrison (1967); see text for explanation.

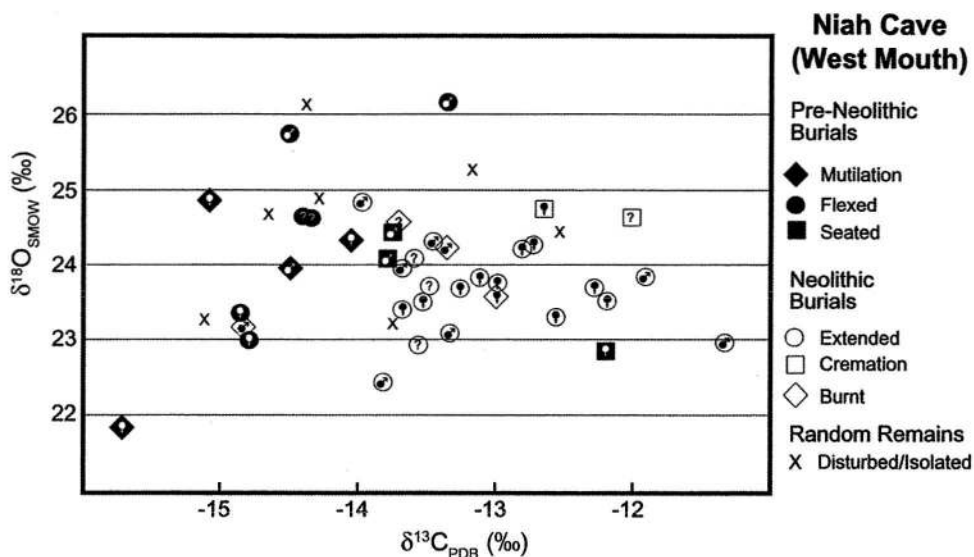


Fig. 2. Niah Cave (West Mouth): $\delta^{13}\text{C}_{\text{PDB}}$ and $\delta^{18}\text{O}_{\text{SMOW}}$ values (tooth enamel apatite) for pre-Neolithic and Neolithic human burials and disturbed/isolated remains. See text for explanation of burial terms.

RESULTS

$\delta^{13}\text{C}$ and $\delta^{18}\text{O}$ results for human remains sampled from the West Mouth are presented in Figure 2 for the six burial types and the disturbed/random burials. Table 2 presents the descriptive statistics for the burials sampled, and Figure 3 graphs the mean $\delta^{13}\text{C}$ and $\delta^{18}\text{O}$ values and standard deviation (2σ) by burial type.

Although this study focuses on the $\delta^{13}\text{C}$ values as the primary data of interest in subsistence reconstruction, the $\delta^{18}\text{O}$ values assist in examining $\delta^{13}\text{C}$ variability

TABLE 2. DESCRIPTIVE STATISTICS FOR HUMAN $\delta^{13}\text{C}$ AND $\delta^{18}\text{O}$ RESULTS (TOOTH ENAMEL CARBONATE) FROM NIAH CAVE (WEST MOUTH) BY BURIAL TYPE^a

	PRE-NEOLITHIC			NEOLITHIC		
	MUTILATION	FLEXED	SEATED	EXTENDED	CREMATION	BURNT
$\delta^{13}\text{C}$						
N	5	7	3	22	2	4
Mean	-14.9	-14.4	-13.3	-13.2	-12.3	-13.7
SD	0.63	0.52	0.91	0.82	0.46	0.79
Range	-15.7 to -14.1	-14.9 to -13.4	-13.8 to -12.2	-14.7 to -11.3	-12.7 to -12.0	-14.8 to -13.0
$\delta^{18}\text{O}$						
N	5	7	3	22	2	4
Mean	24.0	24.6	23.8	23.7	24.7	23.9
SD	1.28	1.13	0.83	0.53	0.12	0.59
Range	21.9 to 25.0	23.0 to 26.2	22.9 to 24.5	22.5 to 24.8	24.6 to 24.8	23.2 to 24.6

^a See text for explanation.

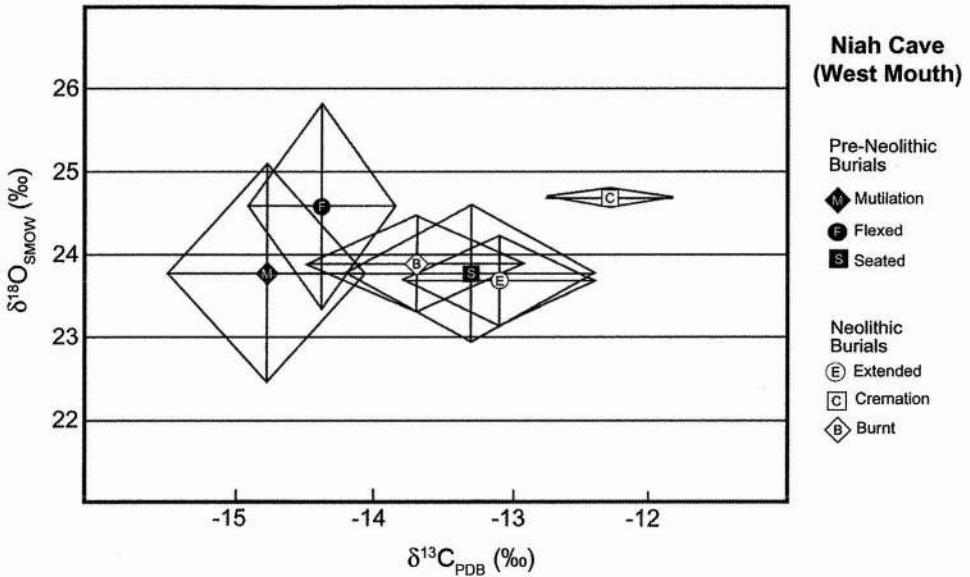


Fig. 3. Niah Cave (West Mouth): mean and standard deviation (2σ) for $\delta^{13}\text{C}_{\text{PDB}}$ and $\delta^{18}\text{O}_{\text{SMOW}}$ values (tooth enamel apatite) for pre-Neolithic and Neolithic human burials. See text for explanation of burial terms.

(Figs. 2 and 3). For $\delta^{13}\text{C}$, the pre-Neolithic remains ($X = -14.5\text{‰}$) are on average 1.3‰ more negative than the Neolithic remains ($X = -13.2\text{‰}$). This difference is statistically significant by Student's t -test at the 0.01 level. Although the average difference may appear small, $\delta^{13}\text{C}$ results demonstrate diachronic change in subsistence between these two time periods at Niah Cave. The $\delta^{13}\text{C}$ range is -15.7‰ to -12.2‰ for pre-Neolithic remains and -14.8‰ to -11.3‰ for the Neolithic sample. Absolute difference in $\delta^{13}\text{C}$ values for all human remains assayed is 4.4‰ . Such a wide range of $\delta^{13}\text{C}$ values is not only interesting for Niah, but encouraging for this and future studies assessing subsistence patterns using human tooth enamel apatite in C_3 -dominated ecosystems. $\delta^{18}\text{O}$ values for pre-Neolithic remains are slightly more positive (24.2‰) compared with the Neolithic remains (23.8‰), although there is no statistical difference between the two groups.

Regarding specific burial types, the mutilation and flexed burial remains are more negative on average than the Neolithic sample, as presented above. Mutilation burials are fairly tightly clustered at the low end of $\delta^{13}\text{C}$, while flexed burials are more varied in $\delta^{13}\text{C}$, with some (Burial 172, -13.4‰) approaching the extended/total Neolithic average. Taken together, the data suggest that pre-Neolithic subsistence at Niah was based on foraging in a variety of terrestrial habitats within closed forest. These findings are in reasonable accord with the emerging information from the geomorphology, palynology, archaeobotany, and archaeozoology for mosaic environments around Niah at the time of its occupation in the Pleistocene (this volume: Barker; Gilbertson et al.).

The seated burials, the final burial type assigned to the pre-Neolithic, have anomalous $\delta^{13}\text{C}$ values for their supposed time period. They have a mean

($X = -13.3\text{‰}$) very similar to the mean for all Neolithic extended burials ($X = -13.2\text{‰}$). This probably represents a cultural distinction from mutilation and flexed burials that are near contemporaneous, although it may be that the single seated burial (Burial 141, -12.2‰) is anomalous and the other two are simply slightly less negative than the others. More information regarding burial context is needed before such questions can be addressed with certainty. It appears, however, that the people of the seated burials had a diet routine that was different from that of the people in the other pre-Neolithic burials at Niah.

The largest Neolithic sample, the extended series, shows a wide range of $\delta^{13}\text{C}$, with a relatively small error margin ($SD = 0.53$). Burnt and cremation burials also exhibit small ranges of deviation. However, one burnt and two or three extended burials are fairly negative and similar in $\delta^{13}\text{C}$ values to many of the flexed and mutilation burials. Again, deciphering explanations for random burials is not possible at this stage, but it is likely that cultural factors and/or personal dietary preference are reflected in the $\delta^{13}\text{C}$ differences. The two cremation burials have on average less negative $\delta^{13}\text{C}$ values than other Neolithic remains, although several extended burials approach them. Burnt burials are temporally late in context at Niah, with one quite negative burial (Burial 103B, -14.8‰) and three typical for the Neolithic sample.

DISCUSSION AND CONCLUSION

Broad-spectrum foraging at Niah for much of the late Pleistocene and Holocene is inferred by the wide variety of fauna recovered from the West Mouth deposits. Excavated remains demonstrate that virtually all represented vertebrate groups (except ubiquitous swiftlet and bat species) and shellfish remains were brought to the West Mouth by human agency (Cranbrook 2000; Medway 1959, 1960, 1979), thus directly associated with the human occupation of and/or visitation to the site (e.g., T. Harrison 1957, 1959, 1972; Medway 1979). Conclusions about variation and pattern of human subsistence trends over the course of pre-Neolithic and Neolithic occupation at West Mouth have therefore been minimal to date. Poor preservation of organic remains coupled with poor excavation methods in the initial stages of excavation (when most of the site was removed) leave provenience and feature context as well as temporal context in question. This does not make all excavated faunal remains useless; rather, novel approaches to their study remain to be implemented.

The stable carbon isotope data presented here are necessarily semi-quantitative and subject to interpretation, but represent the first diachronic investigation of prehistoric human subsistence in the rainforests of tropical Southeast Asia. Figure 4 summarizes the data presented above and allows new insights into pre-Neolithic broad-spectrum foraging patterns and Neolithic subsistence. The Neolithic period, of course, potentially reflects new subsistence regimes including some forms of food production and/or systematic collection (Bellwood 1992; Bellwood et al. 1992). A number of variables must be considered when interpreting these isotopic data, but without question the $\delta^{13}\text{C}$ values reported directly reflect subsistence patterns of individuals tested, during the time of enamel formation—mostly in their older childhood, subadult years.

Neolithic presence in the mid-late Holocene (after ca. 3500 B.P.) is indicated

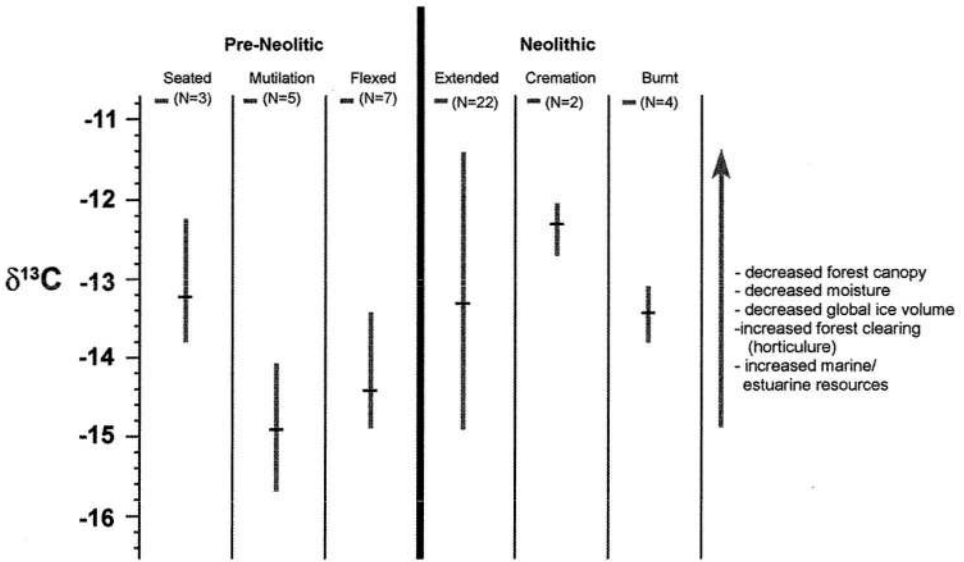


Fig. 4. Niah Cave (West Mouth): trends in $\delta^{13}C_{PDB}$ values for Pre-Neolithic and Neolithic human burials. See text for explanation of burial terms.

by extended, cremated, and burnt (jar) burials associated with elaborate pottery and polished stone tools. Whether these people reflect a new population of occupants (Austronesians) or simply a continuation of earlier representatives at the West Mouth remains an open question. A 4000-year gap in accepted ^{14}C dates suggests a hiatus in cave use at the West Mouth, when sea levels may have been higher than present day and Niah Cave may have been more or less an isolated massif (though occupation may have continued in the Lobang Angus occupation; see this volume: Barker). This may well impact the understanding of biological and/or cultural influences reflected in Niah's Neolithic record (Krigbaum 2003).

The less negative $\delta^{13}C$ values observed in Neolithic individuals compared with the pre-Neolithic sample are statistically significant. Ecological factors are unlikely to account for the shift, as the opposite trend would be expected in the improving climate of the Holocene: individuals subsisting on C_3 foodstuffs in the more open and seasonal woodlands of the late Pleistocene would be expected to exhibit less negative values compared with foragers inhabiting the closed canopy forests of the Holocene. The lack of an ecological effect influencing $\delta^{13}C$ values therefore suggests that anthropogenic factors are accountable for this shift, and that purposeful changes to the local environment influenced Neolithic diet. The trend could be influenced by several causal factors, all potentially interrelated.

The $\delta^{13}C$ shift may reflect increased access to marine and estuarine resources, as noted in their increased frequency in more superficial levels of the site (Zuraina 1982), though further research is required to tease apart preservational and depositional constraints on these invertebrate materials. Also, it is unlikely that these would affect $\delta^{13}C$ values to any marked degree, as coastal invertebrate species have been demonstrated to get their source carbon from terrestrial sources (Rodelli et al. 1984). Increased access to foods grown in more open settings

("gaps") and/or the purposeful felling of tree stands would be consistent with a shift in $\delta^{13}\text{C}$ values. This could have been coupled with the more systematic collection of plants and invertebrates from a greater diversity of ecozones.

However, the heterogeneity reflected in the Neolithic sample, especially among the extended burials, requires further analysis. The wide range of $\delta^{13}\text{C}$ values suggests that the people who shared mortuary space and practice at Niah's West Mouth were characterized by a number of different dietary regimes. As Sather (1995) and others (e.g., Bellwood 1997; Harris 1989; Hutterer 1983) have proposed, foraging modes of subsistence probably remained in vogue among certain groups, while others may have been involved in food production to a greater degree. Further research on these data and continued analysis of the West Mouth burial series, as well as continued isotopic research on prehistoric and modern materials, will no doubt clarify the diverse roles that people played in northern Borneo during this period of increased complexity and interaction.

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ABSTRACT

The human burial series from the West Mouth of Niah Cave (Sarawak) offers a unique opportunity to explore prehistoric subsistence patterns in lowland tropical rainforest. Over 200 primary and secondary burials, classified as pre-Neolithic

and Neolithic, have been recovered since preliminary excavations began there a half-century ago. Stable isotope ratios of carbon ($^{13}\text{C}/^{12}\text{C}$, reported as $\delta^{13}\text{C}$ values) derived from human tooth enamel provide a quantitative measure of individual food consumption during the time of enamel formation. Such data provide a robust and independent assessment of total diet that complements other subsistence information recovered from the archaeological record. West Mouth human tooth enamel examined shows a broad range of $\delta^{13}\text{C}$ values (-15.7‰ to -11.3‰), consistent with a C_3 -based subsistence regime as would be expected in rainforest habitats dominated by C_3 vegetation. Pre-Neolithic individuals have more negative $\delta^{13}\text{C}$ values on average ($N = 15$, $X = -14.3\text{‰}$) than Neolithic individuals sampled ($N = 28$, $X = -13.1\text{‰}$). This isotopic shift is statistically significant and suggests a fundamental change in human subsistence between the late Pleistocene/early Holocene and later Holocene inhabitants at Niah. Pre-Neolithic $\delta^{13}\text{C}$ values suggest broad spectrum rainforest foraging, whereas less negative Neolithic $\delta^{13}\text{C}$ values, on average, suggest a more coordinated regime of food production and/or collection. Studies of $\delta^{13}\text{C}$ variation in rainforest habitats contribute to this interpretation, particularly with respect to the "canopy effect," whereby closed-canopy foraging predicts more negative $\delta^{13}\text{C}$ values, while food resources consumed by exploiting more open settings (such as fields, gaps, and swamps) predict less negative $\delta^{13}\text{C}$ values. These data have important implications for interpreting the nature of human subsistence in a rainforest setting prior to and after the potential adoption of agriculture by the inhabitants represented in the West Mouth burial series. **KEYWORDS:** Niah Cave, Southeast Asia, Borneo, prehistory, late Pleistocene, Holocene, Neolithic, bioarchaeology, palaeodiet, subsistence, carbon isotopes.