
Chapter 8

Palynology, Phytoliths, Diatoms and Wood in the West Mouth: Stratigraphic and Taphonomic Studies of Late Quaternary Vegetation History

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Introduction

This chapter describes and evaluates the significance of the results of palynological, phytolith and related analyses in the 2000–2004 excavations in the West Mouth of the Great Cave. It also describes palynological work in the alluvial lowlands around the Great Cave that was undertaken to supplement and test the quality of the cave record, and of taphonomic work undertaken to provide a first approximation of the processes involved in the formation of the cave record. From this work, we give an approximation of vegetation change in the lowlands of northern Borneo during the Late Pleistocene and Holocene. Much of the palynological work has been described in a series of earlier publications (Barker *et al.* 2007; Hunt & Rushworth 2005a, 2005b; Hunt *et al.* 2007, 2012), but this is the first synthesis and the first to describe work on the other fossil groups. The vegetation sequence derived from the three fossil groups is integrated with the stratigraphical and geomorphological sequence from the cave and with chronological information from AMS radiocarbon dates to produce a vegetation and environmental history that spans, with some gaps, the period from *c.* 53,000 years ago to the present day. The results of this work enable us to address three key issues: vegetation history and palaeoclimate; human modification of vegetation in the Late Quaternary; and early farming and its impacts. The detailed descriptions of the pollen, palynofacies and phytolith assemblages from the West Mouth are described in the Supplementary Material to the chapter.

Palynological work was done on a reconnaissance scale during the Harrison's excavations at Niah. The eminent Dutch palynologist Jan Muller visited the site and took a sample that yielded pollen of *Avicennia* (Muller 1972; see Volume One, Chapters 2 and 3). Muller's marker was still present in the 'Hell' Trench at the start of the current project, although it is

uncertain whether it was in its original location. His work demonstrated that palynology was possible at Niah. This was confirmed during the scoping work before the start of the project proper when one of the very small sediment samples recovered by DG from the 'Hell' sequence yielded a grain of *Casuarina* and a variety of particulate organic matter. Palynology in the Great Cave was done by CH and GR. Outside the cave, palynology was done by CH, GR, RP and SJ.

Phytoliths (microscopic botanical silica cellular tissue) provide a useful additional line of evidence to other types of botanical remains for several reasons (Piperno 1988, 2006). First, they are very robust and often survive when other types of evidence do not (either macrobotanicals or pollen in oxidizing conditions for example). Second, unlike pollen, they can provide evidence of how plants were used, since they can come from a variety of different parts of a plant (particularly in monocots such as grasses, palms and sedges). Third, pollen and phytoliths often provide complementary lines of information, in that many plants produce species or genus diagnostic phytoliths but not pollen (e.g. grasses), and vice versa (many arboreal taxa). This is particularly critical in interpreting human environments, where combinations of burning and disturbance create patterns of weeds, often grasses, that are difficult to distinguish based on pollen alone ('deforestation' or changes in forest structure). There is virtually no work on phytoliths in Borneo apart from the work of Jones (2012) and Jones *et al.* (2013) on Late Holocene rice phytoliths from the Kelabit Highlands and Barker *et al.* (2011a), which deals with Early Holocene phytoliths in estuarine sediments at Loagan Bunut. Phytoliths in the Great Cave were analysed by LK, and at Loagan Bunut phytoliths were analysed by RP.

Diatoms are planktonic and benthonic algae which secrete characteristic siliceous frustules (shells). Diatoms were present in some pollen samples where

they were examined by Sarah Davis and some phytolith samples, where they were noted by LK. Diatoms require reasonably strong light to flourish and the relatively low light levels in the sampled sites may have precluded this. Some of the diatoms are characteristically brackish-water forms and these certainly would not have lived in the cave. It is therefore reasonable to suggest that they entered the cave in or on animal and/or human vectors.

Starch grains were identified by LK in several phytolith samples. These were not identified to species but were divided into size-classes and recorded. In the context of the cave, it is highly unlikely that the plants in which the starch originated actually grew in the sampling locations, because of desiccation and low light intensity. Their presence is thus likely to reflect human activity in the cave.

Wood was identified by GT. Most of this was derived from artefacts, mostly coffins from the Neolithic cemetery. In the context of the cave, where low light conditions will have prevented tree growth, it is reasonable to suggest that all wood was selected and brought into the cave by people. The identifications are too sparse for any quantitative treatment, but they do provide evidence for the presence of certain taxa in the proximity to the cave. As with phytoliths, wood can provide evidence for the presence of taxa – particularly of the Dipterocarpaceae – which produce rather undiagnostic pollen very sparsely.

The research context

At the start of this project, remarkably little was known about the vegetational history of Borneo, or, indeed, that of Continental and Island Southeast Asia in general. Work had been concentrated in some of the Indonesian islands, such as Java (e.g. Dam 1994; van der Kaars & Dam 1997; Stuijts 1984, 1993) and Sumatra (Flenley 1979, 1984, 1985, 1988, 1996, 1998; Maloney 1980, 1985, 1990, 1992, 1995, 2000; Morley 1982; Newsome & Flenley 1988; Stuijts *et al.* 1988), with some work in peninsular Malaysia (Haseldonckx 1977; Kamaludin & Azmi 1997; Morley 1981), Thailand (Kealhofer & Penny 1998; Maloney 1991, 1998b; Maloney *et al.* 1989) and on deep-sea cores (van der Kaars 1991; van der Kaars & Dam 1995, 1997; Sun *et al.* 2000; Wang *et al.* 1999). Knowledge of vegetational change in Borneo was confined to studies by Anderson and Muller (1975), Morley (1981) and Supiandi (1990) on lowland raised bogs of Holocene age, and the work of Caratini and Tissot (1985) on a long but discontinuous record spanning several glacial/interglacial cycles from the Makhm Delta. The only taphonomic work was by Anderson and Muller (1975) on surface pollen

in a lowland raised bog and Flenley (1973) on surface pollen in upland vegetation on Mount Kinabalu. The history of lowland and alluvial forest such as that present around the Great Cave was completely unknown, and there was no taphonomic work on pollen in tropical caves to enable us to calibrate our work against pollen fallout at the present day.

As late as the 1980s it was commonly held that Quaternary climates in the tropics were virtually stable and that the great tropical forests of the world had been little affected by climatic change, but a different consensus is now emerging: that they have waned in area and changed markedly during the Pleistocene glaciations (e.g. Flenley, 1996; Morley, 2000). Botanical opinion also held that these tropical forests were effectively primeval, largely unaffected by human activity until recent times, though the Harrissons' excavations at Niah and Jack Golson's at Kuk in the New Guinea Highlands (Golson 1985, 1989; Golson & Hughes 1980) had demonstrated that Pleistocene archaeological sites existed in the Pleistocene where the available evidence suggested that there had been rainforest environments contemporary with the human activity. There was at the same time an anthropological debate about how, when and indeed whether foraging peoples had developed the capacity to live in tropical rainforests before the advent of agriculturalists with whom they could exchange (e.g. Bailey *et al.*, 1989; Bailey & Headland 1991; Dentan 1991; Headland 1987; Hutterer 1988; Townsend 1990; and see Volume One, Chapter 1).

At this project's outset there was little hard evidence for early farming in the region. Rice impressions in Neolithic pottery at Gua Sireh (Bellwood *et al.* 1992) and Niah (Doherty *et al.* 2000) seemed consistent with the hypothesis of the spread, around 4500 years ago, of rice-using Austronesian agriculturalists from Taiwan into a region dominated by hunter-gatherers (Bellwood 1997; and see Volume One, Chapter 1). It was possible, however, that indigenous farming in Borneo encompassed forms completely different from grain-based systems: Gibbs (1914), for example, suggested that some indigenous peoples in Borneo had manipulated forest vegetation in a form of arboriculture over considerable timescales, and there were consistent widespread accounts by palynologists of earlier biomass burning and forest disturbance across the region (e.g. Flenley & Butler 2001; Kealhofer & Penny 1998; Maloney 1980), but the limited amount of multi-proxy work meant that the causes of this disturbance had not been firmly identified.

The forests of Borneo

Borneo was almost completely forested until the later 20th century and the lowland forest still exists around

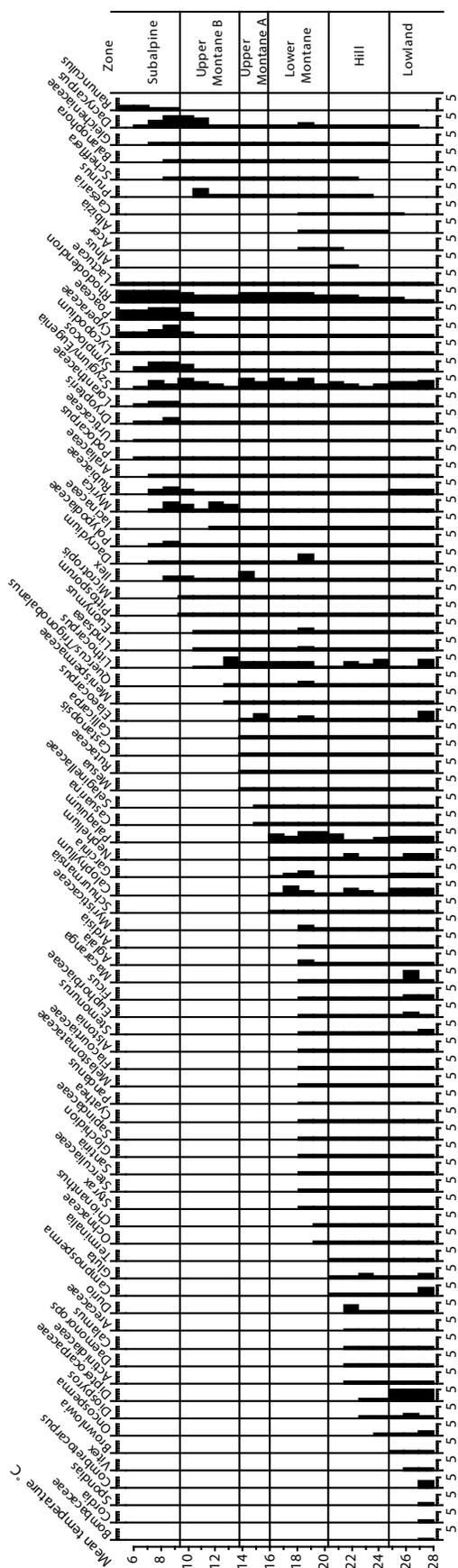


Figure 8.1. Altitudinal zonation of forests in Borneo. Upper boundaries (heights above sea level): Lowland – 400 m; Hill – 1200 m; Lower Montane – 2000 m; Upper Montane A – 2400 m; Upper Montane B – 3200 m; Subalpine – 4000 m.

the Great Cave (Pearce 2004). The prevailing hot wet tropical climate (see this volume, Chapter 2) has caused strong leaching of soils, so most nutrients are held in living biomass. Soils are extremely acid as a result, with pH typically measured between 3.5 and 4.5, and podzolic peats are even known to form on the top of limestone hills. The forests are zoned altitudinally (Fig. 8.1) and as a result of substrate differences (Aiba & Kitayama 1999; Aiba *et al.*, 2002, 2004, 2006; Kitayama, 1992; Pendry & Proctor, 1997; Proctor *et al.*, 1983, 1988).

At the coasts, sand-dunes are colonized by barrier woodlands dominated by *Casuarina* and *Dodonaea*, with Malvaceae and *Ipomoea* colonizing more unstable, open areas. Behind the coastal barriers, mangrove vegetation is controlled by salinity, freshwater flux and substrate (Fig. 8.2) with front-mangroves on the open coast being dominated by *Avicennia*, while alongside saline inlets vegetation is characterized by *Sonneratia alba* and *Rhizophora mucronata*. In more brackish environments, *Kandelia*, *Rhizophora apiculata*, *Bruguiera*, *Ceriops*, *Sonneratia caseolaris*, *Nypa* and *Oncosperma* successively dominate as salinity declines. Riverine vegetation is marked by freshwater mangroves such as *Lumnitzera* and levee species such as *Lithocarpus*, *Elaeocarpus* and Malvaceae (Fig. 8.2).

Inland from the coast, the primary forest below c. 800 m (Fig. 8.1) is dominated by members of the Dipterocarpaceae family, but biodiversity is extremely high with hundreds of tree species per hectare. These forests are characterized by mast-fruiting events, where all the Dipterocarp trees fruit simultaneously, usually after a drought year. Successional development in Dipterocarp forest is well-known (e.g. Brearley *et al.* 2004; Kenzo *et al.* 2010), with early successional taxa such as *Macaranga* and *Trema*, and later successional species such as *Mallotus*, *Cratogeomys* and *Pternandra* (Brearley *et al.* 2004; Slik & Eichorn 2003; Slik *et al.* 2002). The Dipterocarps take significantly more than 50 years to re-establish themselves after forest disruption (Brearley *et al.* 2004). They produce very little pollen, so Dipterocarp forest must be recognized palynologically by prevalence of associated taxa, such as Apocynaceae, Araliaceae, *Artocarpus*, Bombacaceae, *Dacryodes*, *Diospyros*, *Mangifera*, Olacaceae and Oleaceae.

Above c. 800 m the Dipterocarps become rarer and decline in diversity and hill forests are characterized by

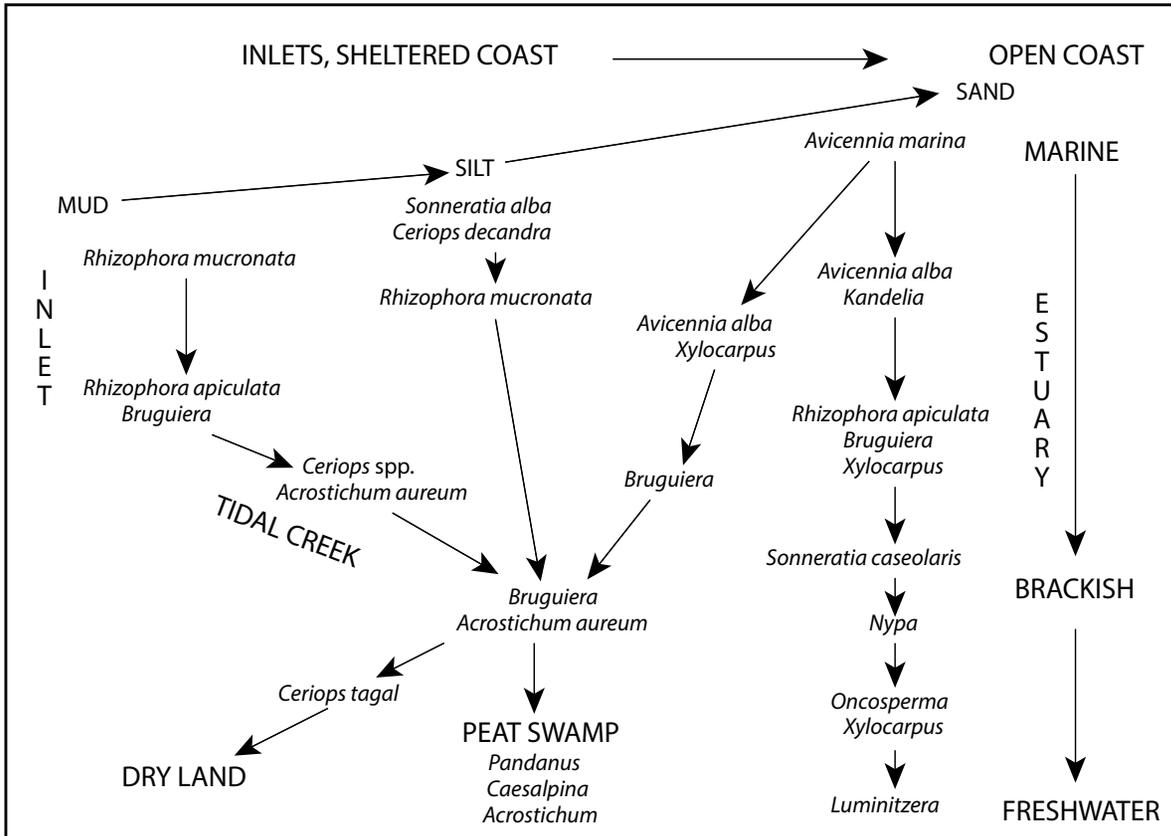


Figure 8.2. Zonation of mangrove forests in Borneo.

relatively high incidences of taxa such as *Palaquium*, *Nephelium*, *Calophyllum* and *Durio* (all of which extend to sea level). In the lower montane forest, from c. 1400 m, the Dipterocarps are no longer present and the hill trees are joined in dominance by the Fagaceae (*Lithocarpus*, *Castanopsis*, *Quercus*), *Elaeocarpus* and the Myrtaceae. Upper montane forest starts c. 2200 m, with the Myrtaceae, *Schima*, *Magnolia*, *Ilex* and gymnosperms such as *Dacrydium*, *Podocarpus* and *Phyllocladus*. High montane forest-scrub is characterized by *Leptospermum* and *Rhododendron* (Kitayama 1992).

In addition to altitude, factors such as substrate, drainage and nutrient status are important controls on vegetation. On lowland raised bogs successive assemblages of vegetation colonize and modify the habitat by laying down great thicknesses of nutrient-poor peat (Anderson 1963; Anderson & Muller 1975; Dommain *et al.* 2011; Morley 1981; Page *et al.* 1999, 2004). Raised bogs on Borneo can reach a great size and are visible on satellite imagery because of their strong zonation. Anderson (1963) and Anderson and Muller (1975) recognized a series of zones on the raised bogs, with marginal wetlands (Phase I) characterized by *Gonystylus*, *Dactylocladus* and *Nesocortechinia*, the slopes of the

peat dome characterized by *Shorea albida* (Phases II-IV) and the higher slopes with *Tristania*, *Parastemon* and *Palaquium* (V). The summits of the larger domes have stunted vegetation dominated by *Combretocarpus* and *Dactylocladus*, but also drought-tolerant taxa such as Ericaceae, *Myrica* and *Casuarina* (Phase VI) because the extremely high acidity causes water-stress (Anderson 1963). This bog-summit vegetation is very similar to the acid- and drought-tolerant forest known as *kerangas* which develops on well-drained and nutrient-poor substrates including old river gravels and ancient beach ridges (Miyamoto *et al.* 2003).

Methodologies

Samples for palynology of approximately 50 ml were used wherever possible. These were decalcified in dilute hydrochloric acid, then deflocculated in sodium pyrophosphate and sieved to remove fine particles and solutes on nominal 6 µm nylon mesh using a filtered water supply. Remaining silicates were removed using cold hydrofluoric acid. The samples were neutralized by dilution and stained with basic fuchsin and safranin, then mounted in Gurr Aquamount for microscopic

examination. All pollen grains in each sample were counted, together with all algal microfossils. In each stratigraphic sample, an aliquot of about 200 organic particulates was also counted for palynofacies analysis (Hunt & Coles 1988). In the palynofacies analysis, the term 'thermally mature' is used to denote materials showing the dark brown colours typical of burning, but also typical of palynomorphs recycled from very lightly (*c.* 300–400°C) metamorphosed bedrock. In most cases this will be the result of charring but it is possible that this term will also include pollen, woody tissue and amorphous matter derived from bedrock either locally or at a distance and therefore the non-genetic term is preferred.

The samples were counted under transmitted light using $\times 1000$ magnification and oil immersion. Pollen identification used the type collection made by Bernard Maloney which is stored at Queen's University Belfast, supplemented by reference to the published literature. Taxa were initially calculated as percentages of total pollen and spores. In the stratigraphic samples, further calculations were made excluding *Justicia* (Acanthaceae), because it was present in extremely large numbers in many samples and thus prevented all other pollen signals from being apparent. Diagrams were calculated and drawn using TILIA (Grimm 1993). Ecological groupings were derived from the published literature, largely following Hunt *et al.* (2007, 2012).

Some 25 samples were processed for phytoliths, 9 from archaeologically defined contexts and 16 from the monoliths removed for pollen analysis. The archaeological samples were processed at the University of Leicester according to Piperno's (1988) protocol with minor modifications. The monolith samples were processed at Santa Clara University using the same protocol, with minor modifications (e.g. sodium metatungstate for heavy liquid). The monolith samples were extremely small (< 5 g) for bulk sediment analysis (particularly in non-cultural deposits). This undoubtedly limited phytolith recovery. All samples were analysed under a light microscope at $\times 400$ magnification, with diagnostic forms photographed and counted. Identification was based on a reference collection compiled by Kealhofer for research in South-east Asia (Kealhofer 2002; Kealhofer & Piperno 1994, 1998). Other types of microfossils were counted but not identified. Samples with significant starch counts were forwarded to Huw Barton for further analysis.

Wood analysis used conventional thin sectioning techniques and was carried out by Andrew Tukai Selang and GT using type material at the Forest Research Institute, Kuching. A total of eighteen samples were well enough preserved to be analysed, all from the Holocene part of the sequence.

Pollen taphonomy

It was apparent from the start of the project that a taphonomic study would be essential to understand how pollen arrived in the cave and how it was laid down. Most pollen-analytical work has been done in bogs and lakes, where taphonomic processes are relatively well-understood (Moore *et al.* 1992) and at the time this project started (and in fact, even today), our understanding of pollen taphonomy in rainforest environments was extremely limited (e.g. Anderson & Muller 1975; Flenley 1973; Morley 1976, 1981; Newsome & Flenley 1988).

Pollen taphonomic processes in caves are rather poorly understood, even in the temperate zone (e.g. Coles *et al.* 1989; Coles & Gilbertson 1994; Diot 1991; Genty *et al.* 2001) and prior to this project there were no taphonomic studies of pollen in tropical caves. Because of the wide range of cave geomorphology and sedimentation patterns, it is becoming apparent that each cave should be approached as a separate system requiring its own taphonomic study. The geomorphology of any particular cave system is a major determinant of pollen taphonomy, since it will govern air, water and sediment flows and patterns of sedimentation (Coles & Gilbertson 1994; Weinstein-Evron, 1981). In most caves, palynomorphs arrive by a variety of routes, including air currents, running water, mudflows and other mass-transport processes, and on and inside animals and people. Plants and other organisms living within the cave will also produce palynomorphs (Coles *et al.* 1989). It is likely from the stratigraphic record described in Volume One, Chapter 3 that all of these vectors have operated at times in the past.

In biologically rich caves such as at Niah, the behaviour pattern of animal vectors is a critical determinant of sedimentation and pollen taphonomy. Raptors such as owls bring pollen into many caves in their pellets (Coles & Gilbertson 1994), but there is no evidence of raptors nesting in the Great Cave at present. Hawks have, however, been seen in the cave entrance and often take bats and swiftlets as they leave the cave (see this volume, Chapter 26). Hyaenas, rats and other terrestrial predators and scavengers may also be also significant vectors of pollen (e.g. Djamali *et al.* 2011; Gale *et al.* 1993). There is, however, no equivalent to the hyaena in Borneo, and smaller predators or scavengers are rarely seen in the Great Cave, apart from a wild cat (*Felis pengulensis*) and rats including *Rattus exulans*, a recently arrived exotic. Insect vectors include bees, which bring pollen into their nests (Bottema 1975). Bats and swiftlets are clearly the important sources of guano and therefore likely to be important vectors of pollen. The bats are very territorial within the cave

system: the fruit bats nest in small colonies deep in the cave and one, the naked bat, has roosted in the same place for at least the last 50 years (Earl of Cranbrook & Philip Piper, *pers. comm.*), while small *Hipposiderus* (insectivores) roost from near the front of the cave roof (above the rear part of the excavation site) to well back in the cave. White-winged tomb bats used to nest in crevices above the site but they have now left the cave. Of the swiftlets, only *Aerodramus esculenta* has preferred nesting areas, close to the front of the cave. The other species nest over wide areas, and far into the dark zone, using their echo-location apparatus to navigate.

People should not be neglected as potential vectors of pollen. It is apparent from forensic studies that people transport pollen and other microfossils on their apparel and footwear and amongst materials that they are carrying. These may include (amongst others) flowers and fructifications, muddy objects with pollen and other microfossils contained in the mud, and animals in which pollen will be carried in the gut contents and on fur. Humans will also carry pollen and other microfossils within their gut contents and the use of caves for latrines is documented (Hunt *et al.* 2011). Digging pits and graves will disturb the deposits and can potentially lead to stratigraphically mixed pollen assemblages. (For this reason, palynological work was not pursued in Area B, the area of Late Pleistocene pits, nor in Area C, the cemetery zone.)

Different vectors are likely to bring different pollen assemblages into the cave. Thus air-dispersed pollen will be preferentially brought into the cave by air currents, sinking streams entering a cave will bring pollen of riverine plants, animal vectors will bring in pollen of plants they have eaten or brushed against, or pollen eaten by the insects or animals they have eaten, and so on.

The strategy adopted was to sample accreting sediment, in order to quantify modern depositional patterns in the West Mouth. One of the limitations of this taphonomic study is that not all of the processes occurring in the past may still be operating at the present day. Observation of events in the cave and examination of the ground surface and the most recent layers of the stratigraphy in the West Mouth suggest that, at present, airfall is the predominant depositional process, as was observed by the Harrissons. The airfall material has a variety of sources, including material such as dead leaves and pollen grains that have blown into the cave, rock fragments from the cave roof and guano and organic debris from the colonies of bats and birds on the cave roof. It is not uniformly distributed. From observation, freshly fallen rock fragments appear to be fairly randomly distributed across the cave floor, but windblown leaf-litter is mostly found adjacent to

the cave mouth and guano is concentrated under bat and bird roosting areas.

To quantify these observations, an experiment was designed to measure the flux of airfall material. Experience suggests that Tauber Traps and similar pollen-collection apparatus are usually vandalized if people are about (e.g. Coles & Gilbertson 1993; Coles *et al.* 1989; Simpson & Hunt 2009). Surface collection of sediment would likely have been problematical because of the intense archaeological and other human activity in the cave and the possibility of bioturbation, for instance by the burrowing wasp *Sphex diabolicus* (Harrisson 1966a). A transect of collection sites was therefore extemporized from the plastic roofs which had been put in place by Sarawak Museums to protect the excavated areas (Volume One: Fig. 1.10). These were rigorously cleaned at the end of the 2001 excavation season (late March) and then left undisturbed for material to accumulate until March 2002. This is acknowledged as a highly imperfect method, since it is likely that draughts and spray from severe rainfall would remove light material, potentially including airfall pollen, from the collection points. The material that had accumulated by March 2002 did, however, resemble the material accumulating nearby on the cave floor. On the 22nd March 2002, at the beginning of the next excavation season and before digging started, the collection areas on the plastic roofs were carefully scraped, using cleaned trowels, into self-seal polythene bags. In addition, droppings were collected below the roosts of identified bat species and from under the nest of a swiftlet (probably *Aerodramus maximus*). A burrow of a large burrowing wasp, likely *Sphex diabolicus*, was carefully excavated, together with a sample of the material into which the animal had burrowed. These animals bring insects such as large crickets into the cave to provide food for their developing larvae and could potentially introduce pollen with their prey and in the mud used for burrow lining. Harrisson (1966a) noted that the wasps did not burrow into fresh guano.

In all cases, the samples were frozen until they could be returned to the UK. In the laboratory, the samples were weighed and the nature of the material in each was evaluated. Sub-samples were taken for the determination of water content, organic carbon by low-temperature loss on ignition (Gale & Hoare 1991), calcium carbonate determination by calcimetry (Gale & Hoare 1991) and palynological analysis (Hunt 1985). Total pollen counts were carried out on selected aliquots of the sediment, prepared using the methods described earlier.

The distribution and composition of material deposited on the sample sites are shown in Table 8.1

Table 8.1. Sediment flux in gm^2a^{-1} (grams per year) in the West Mouth of Niah Great Cave.

| Sample no. | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 |
|------------------------------|-------|-------|-------|-------|-------|--------|---------|--------|
| Distance from cave mouth (m) | 7 | 13 | 20 | 30 | 34 | 45 | 47 | 49 |
| Dry weight | 12.92 | 14.62 | 4.8 | 6.45 | 10.35 | 29.5 | 122.48 | 65.88 |
| % Water | 12.83 | 9.87 | 11.11 | 17.13 | 15.7 | 37.39 | 25.88 | 31.75 |
| % Carbon | 42.26 | 76.12 | 51.52 | 59.67 | 75.67 | 82.93 | 71.33 | 78.58 |
| % Calcium carbonate | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Leaves | 5.168 | 5.848 | 0.240 | 0 | 0 | 0 | 0 | 0 |
| Moss | 0 | 2.924 | 0.720 | 0.064 | 0 | 0.590 | 0 | 36.234 |
| Bird urine pellets | 0.646 | 0.710 | 0 | 0 | 0 | 0 | 12.248 | 0 |
| Bird droppings | 0.26 | 0.721 | 1.004 | 3.865 | 6.652 | 21.650 | 103.984 | 19.176 |
| Feathers | 0.256 | 0.041 | 0.024 | 0 | 0.100 | 0.475 | 0.124 | 0.584 |
| Eggshell | 0 | 0 | T | 0 | 0 | T | T | T |
| Insect fragments | 0 | 1.316 | 1.780 | 0.005 | 0.414 | T | T | 3.294 |
| Bone | 0 | 0 | 0.048 | 0 | 0.108 | 0 | 0 | 0 |
| Fine dust | 6.460 | 4.386 | 0.960 | 2.516 | 3.105 | 3.835 | 6.124 | 6.592 |

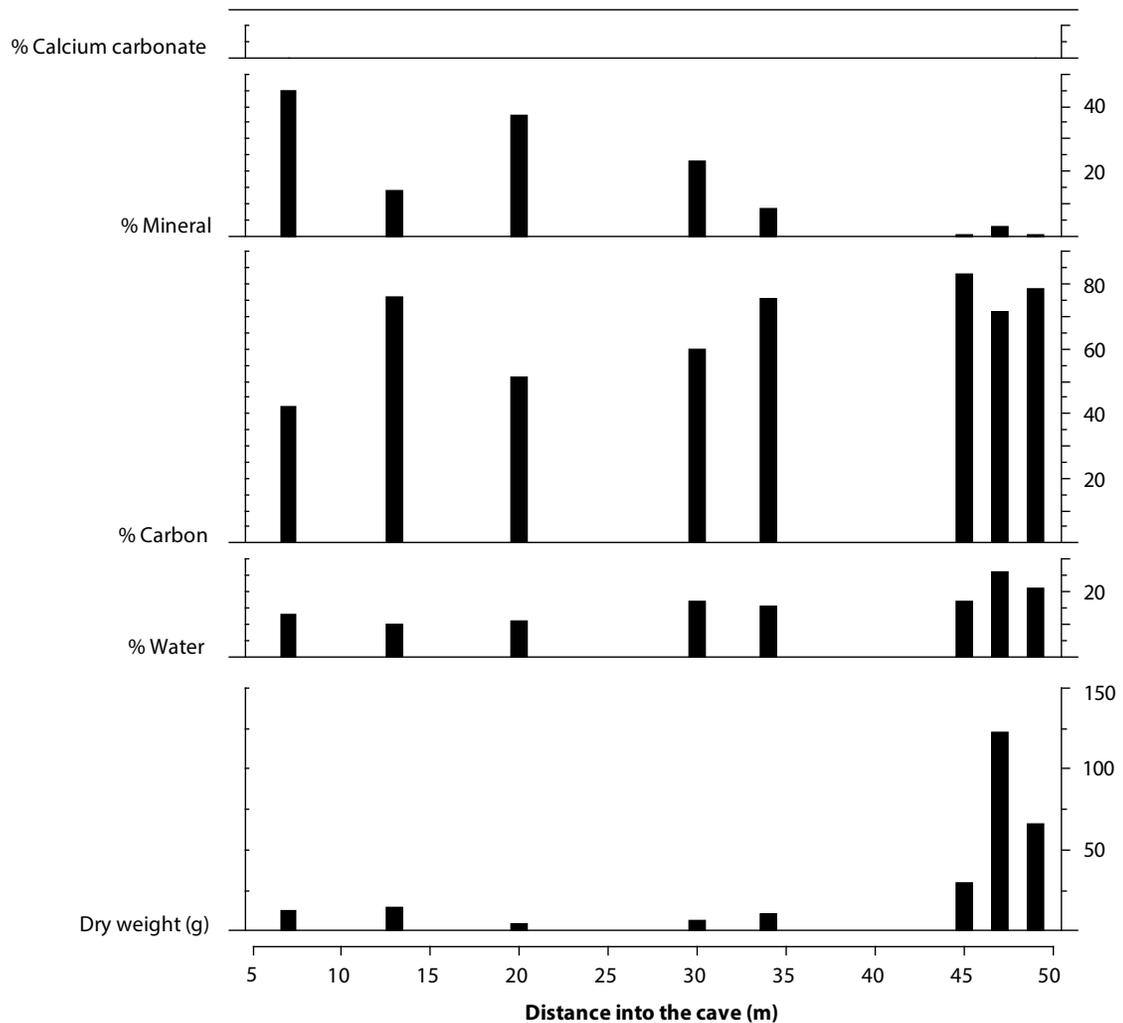


Figure 8.3. Bulk characteristics of sediments accreting at the sample sites. (Data from Hunt & Rushworth 2005a.)

and Figure 8.3 gives a summary of the bulk characteristics. The samples were all completely lacking in calcium carbonate. The dry weight of accreting material varied between 4.8 and 122.48 gm^2a^{-1} (grams per year). The distribution of blown-in material such as leaves is a function of distance into the cave (Fig. 8.4). Other materials – bird urine pellets and faeces, bat droppings, insect fragments, feathers and eggshell – are controlled by the location of the bird and bat population, and particularly by the presence of a colony of approximately 40 swiftlet nests within an aven (fissure) above site 13. The dust component changes markedly in visual

characteristics and composition. Near the front of the cave in sites 7 and 8, the dust is light brown in colour and predominantly silty. This seems to be carried in spray from water washing down the cliff outside the cave during heavy rainfall. This material is not calcareous so cannot be derived from the silty and sandy calcareous sediment exposed in the nearby ‘Hell Trench’ excavation. Further back in the cave, the dust is highly organic and is likely to be the result of the breakdown of other organic materials, probably mostly guano. This pattern is reflected, to some extent, by the pattern of % organic carbon which rises generally towards the

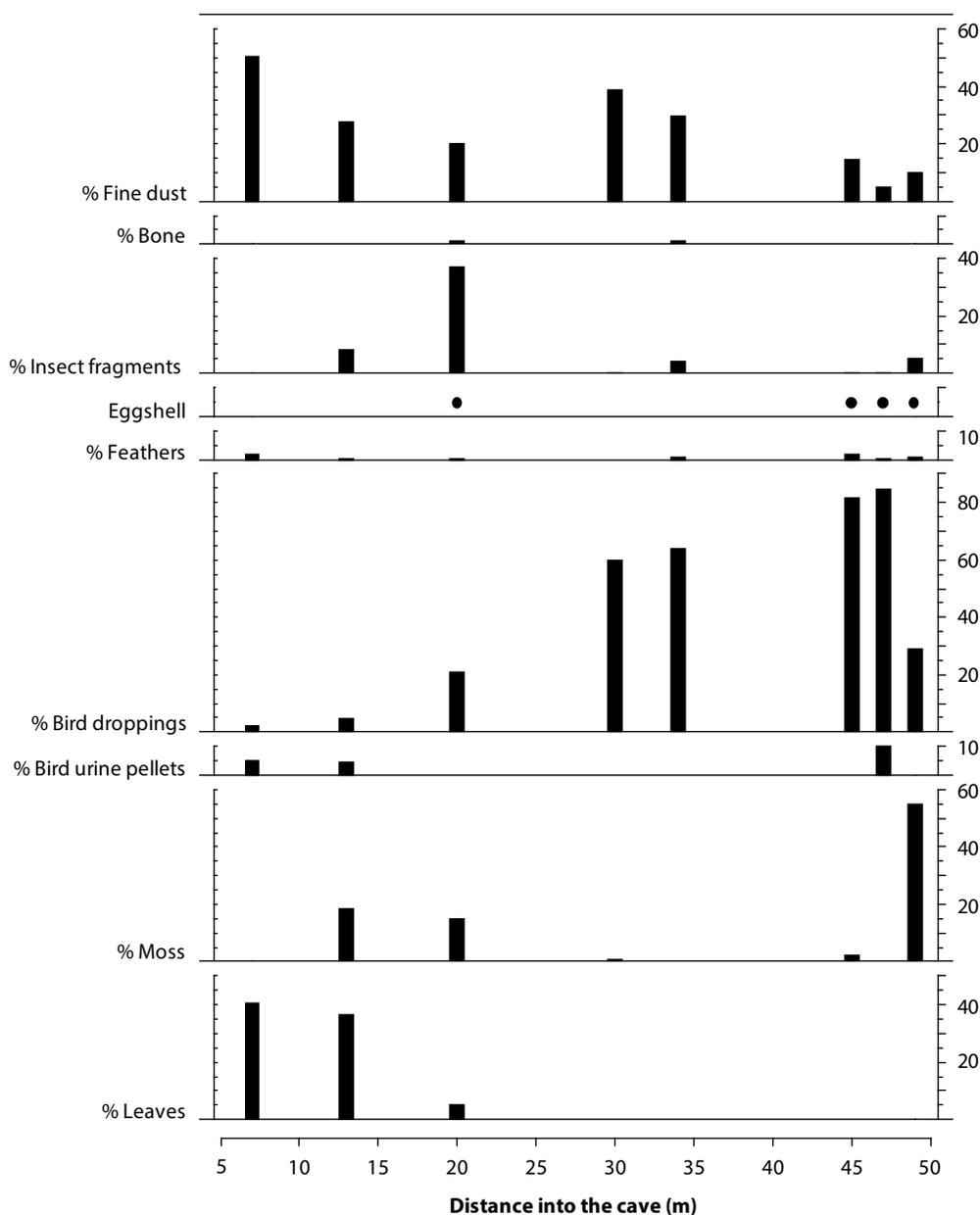


Figure 8.4. Distribution of airfall material at the sample sites. (Data from Hunt & Rushworth 2005a.)

Table 8.2. *The sedimentation zones in the West Mouth of Niah Great Cave.*

| Zone | 1 | 2 | 3 | 4 |
|-----------------------------|--------------|----------------|--------------------------------|--------------------------|
| Geomorphology | Entrance | Rear entrance | Interior | Below nest concentration |
| Total sediment flux | Moderate | Low | High | Extremely high |
| Main components of sediment | Leaves, silt | Bird droppings | Bird droppings, nest materials | Bird droppings |
| Sample sites | 7, 8 | 9, 10, 11 | 12, 14 | 13 |

interior of the cave (Fig. 8.3). Several distinct zones of deposition can be distinguished in the West Mouth (Table 8.2). The silty entrance facies is particularly distinctive, compared with the more organic facies present further into the cave.

Estimated pollen influx rates range between 618,596 and 14,266,620 pollen grains m^2a^{-1} (Fig. 8.5). Pollen deposition rises into the cave, and thus differs markedly from the usual pattern of attenuation with depth into the cave that is typical of airfall deposition (e.g. Coles & Gilbertson 1994). The greatest level of pollen deposition is under the swiftlet colony in the aven (site 13) and the lowest is at site 9, in the rear entrance zone. The taxonomic distribution of pollen in the West Mouth is also markedly patterned: near

the front of the cave, the proportions of the various groups broadly reflect the vegetation outside the cave and, in the case of some of the ferns, the flora of the cave entrance (Fig. 8.6). The pollen rain in samples 7 and 8 in the cave entrance is broadly comparable with spectra in surface scrapes on the forest floor (Table 8.3). In general, ferns, rainforest/swamp taxa and weeds/cultivars decline over the first 30 m into the cave. Mangrove and riverine taxa, typified by *Sonneratia alba* and *Elaeocarpus*, respectively, become increasingly important beyond this point in the cave.

It can be concluded that rainforest, swamp, weed and cultivar pollen is mostly brought into the cave by air currents, whereas pollen of mangrove and riverine taxa is mostly carried into the cave by the swiftlets and

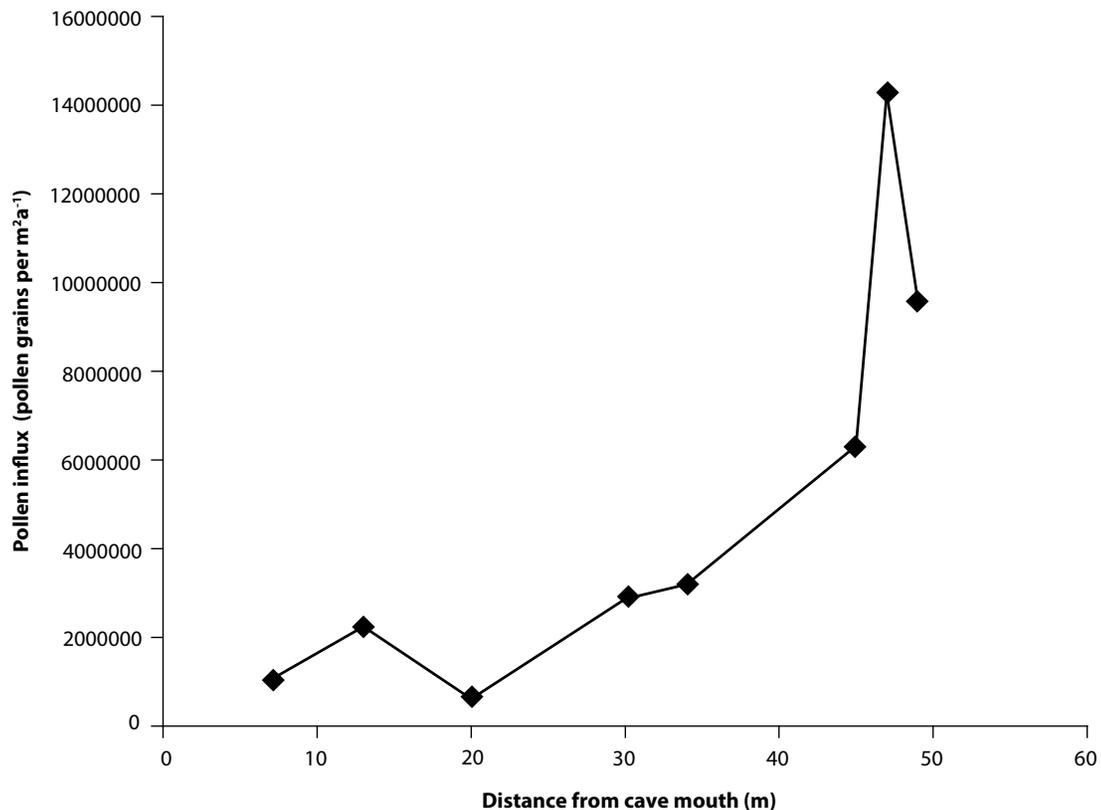


Figure 8.5. *Pollen influx rates in the West Mouth. (Data from Hunt & Rushworth 2005a.)*

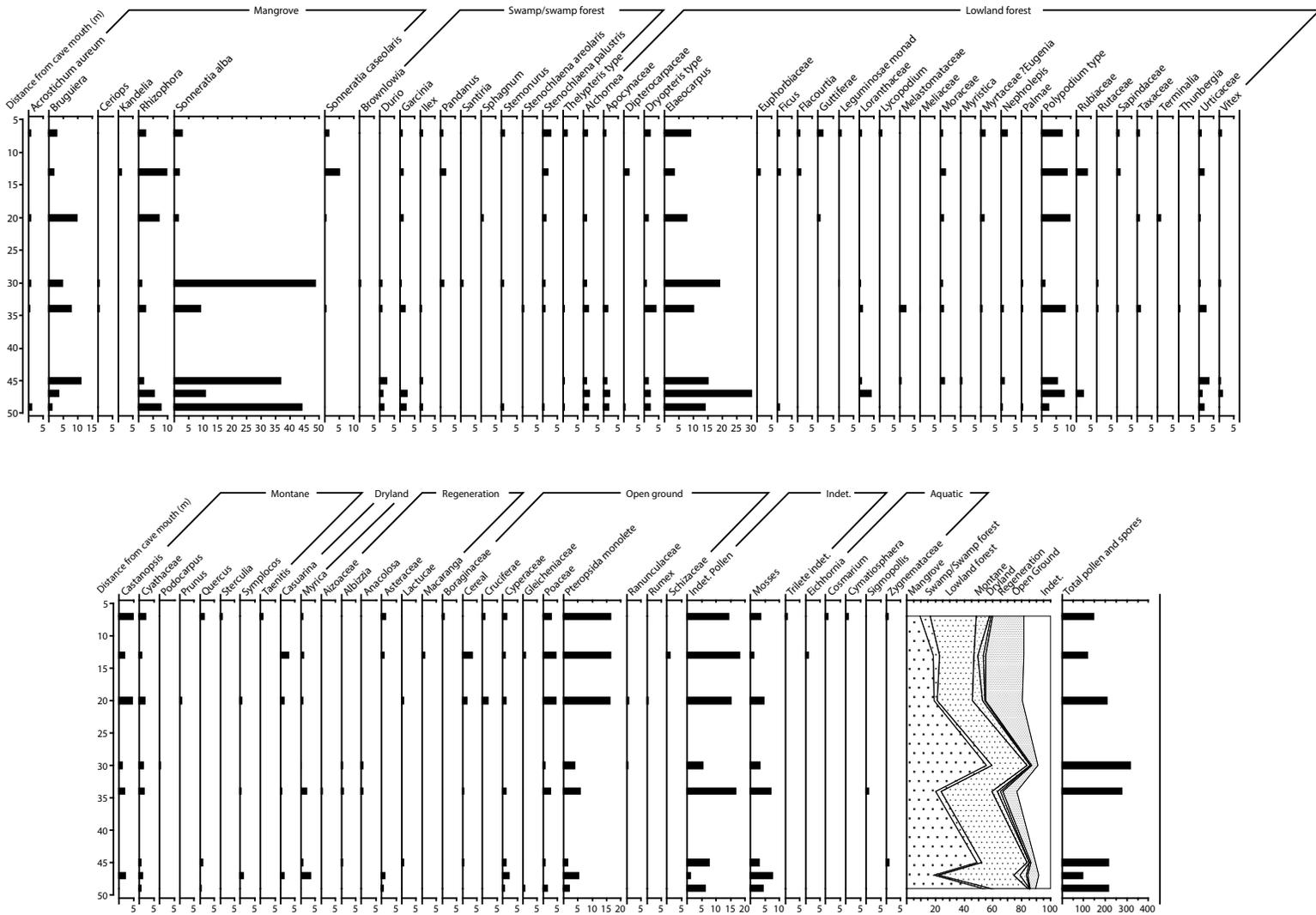


Figure 8.6. Distribution of pollen rain in the West Mouth, calculated as percentages. (Partly after Hunt & Rushworth 2005a.)

bats whose droppings dominate the inner part of the transect. This inference can be tested by comparing the airfall assemblages with the pollen from the droppings of swiftlets and bats (Table 8.4). *Sonneratia* (mangrove) and *Ficus* (fig) pollen heavily dominate the assemblage from *Eonycteris spelaea*, the dawn bat, which grazes flowers and fruit (Start & Marshall 1976), but although *Sonneratia* pollen is common in the airfall deposits, *Ficus* is extremely rare. On the other hand, there is a reasonable correspondence between the assemblage from the swiftlet droppings (Table 8.4) and the pollen assemblage at site 13 (Table 8.3, Fig. 8.6), to be expected given the number of swiftlet nests in the aven above.

The differing pollen assemblages shown in Table 8.4 are consistent with each vector having a very different foraging territory. The predominance

of *Sonneratia* and *Elaeocarpus* in the swiftlet and dawn bat (*Eonycteris spelaea*) droppings is consistent with them feeding and drinking some distance away from the caves, and predominantly over back-mangroves and riverine vegetation, respectively. The Sungai Niah is 2 km distant, providing the nearest stands of *Elaeocarpus*, and the mangrove zone starts some 7–8 km away, towards the coast. The dawn bat grazes on *Sonneratia* flowers (Start & Marshall 1976) and this may explain the very high figures for the pollen of this species in the dawn bat droppings. On the other hand, the insectivorous *Hipposiderus diadema* seems to have foraged mostly in the local rainforests. Both the swiftlet and *Hipposiderus* had collected pollen from a wide selection of species, most probably because they were taking insects which had been harvesting pollen

Table 8.3. Comparison of pollen deposition patterns on the forest floor (External 1 and External 2) with those in the cave – summary of percentage data. Ext – External. Numbers refer to distances (m) from the cave mouth.

| | Ext 1 | Ext 2 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 |
|-------------------|-------|-------|------|------|------|------|------|------|------|------|
| Mangrove/riverine | 0 | 16.3 | 17.6 | 24.6 | 27.2 | 73.9 | 29.8 | 63.8 | 49.9 | 20.8 |
| Rainforest/swamp | 34.8 | 53.6 | 21.8 | 18.6 | 12.1 | 8.6 | 20.7 | 13.6 | 22.3 | 12.4 |
| Weeds/cultivars | 13 | 5.3 | 6.8 | 9.3 | 10.2 | 1 | 4 | 2.3 | 3.2 | 2.5 |
| Ferns etc. | 52.2 | 25.2 | 36.1 | 54.2 | 31.1 | 8 | 21.8 | 9.9 | 15.9 | 9.9 |
| Mosses | 0 | 0 | 3.4 | 0.8 | 4.3 | 3.2 | 6.9 | 2.8 | 7.4 | 4.5 |
| Algae | 11.2 | 6.5 | 0 | 2.5 | 0 | 0 | 0.7 | 0.9 | 0 | 0 |

Table 8.4. Summary of pollen content in droppings of the flower/fruit-eating bat (*Eonycteris spelaea*), insectivorous bat (*Hipposiderus diadema*) and swiftlet (*Aerodramus maximus*).

| | Flower/fruit-eater | Insectivore | Swiftlet |
|-------------------|--------------------|-------------|----------|
| Mangrove/riverine | 70.4 | 1.3 | 34.1 |
| Rainforest/swamp | 5 | 62.4 | 21.5 |
| Weeds/cultivars | 0.2 | 2.5 | 3.2 |
| Ferns etc. | 0.8 | 33.8 | 15.8 |

from a variety of species. In contrast, the vegetarian dawn bat seems to have been exceedingly selective in its diet of *Sonneratia* flowers, supplemented only by figs.

The burrowing wasp, identified by Harrison (1966a) as *Sphex diabolicus*, had a marked impact on pollen assemblages. There is an order of magnitude of more pollen in the nest material ('Burrow' on Fig. 8.7) than in the mid-Holocene sediment into which it was inserted ('Matrix'). There are strong taxonomic differences between the Mid-Holocene sediment and the lining contents, though the small count from the Mid-Holocene sediment makes statistical analysis unreliable. The Mid-Holocene sediment apparently reflects a landscape with considerable agricultural activity, shown by high grasses, weeds and cereal pollen, while the nest material contains relatively more rainforest taxa, more similar to pollen rain

in the environs of the cave today. For this reason, stratigraphic sampling avoided burrowed horizons, wherever practicable.

The pollen taphonomic pathways identified in this research are broadly similar to those identified in the temperate zone (e.g. Coles & Gilbertson 1994; Coles *et al.* 1989; Genty *et al.* 2001) but differ markedly in rate and extent. The importance of animal vectors in the West Mouth is much greater than in caves in the temperate zone. There are no direct parallels in the temperate zone for the tropical zone swiftlets and vegetarian bats and the range of potential vectors is much greater. The roosts of bats and swiftlets are in places characterized by pollen assemblages completely unlike those accumulating by airfall. The locations of the colonies have been broadly stable over the last 40 or so years (Earl of Cranbrook, *pers. comm.*) and it is possible that this stability extends

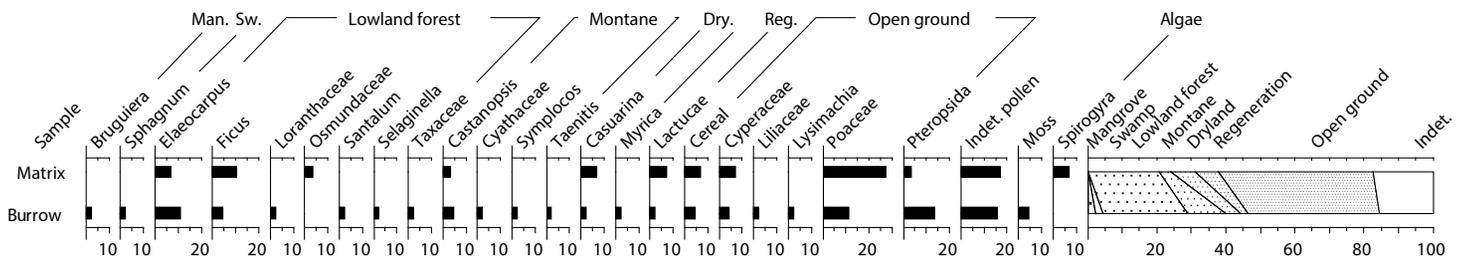


Figure 8.7. Comparison of pollen from the burrow lining ('Burrow') of a burrowing wasp, *Sphex diabolicus*, with that of the Mid Holocene sediment ('Matrix') in which it was embedded. Man. sw. – mangrove swamp; Dry. – Dryland; Reg. – Regeneration. (Partly after Hunt & Rushworth 2005a.)

further into the past, but it should be noted that shifts in the spatial patterning of the animal communities in the cave might lead to major changes in the pollen assemblages accumulating beneath them, with little reference to environmental changes outside the cave. It is clear from the present study that different vectors produce markedly different and distinctive assemblages and that these are likely to be recognizable in the fossil record.

In the absence of major geomorphological changes in the West Mouth, the ecological, sedimentary and thus palynological patterning described above is likely to have been broadly stable in the past. The Hell Trench deposits accumulated in a part of the cave where pollen influx rates were relatively low and sedimentation is today dominated by wind-blown silt, together with leaves and pollen originating in the plant communities outside the cave. This is consistent with the surviving 'Hell Trench' sediments, and suggests that these should not have been subjected to extreme taphonomic bias. The much more organic Lithofacies 4 sediments ('Brown Silts and Anthropogenic Deposits') overlying them may be the result of changing spatial patterning of animal activity in the cave roof or of the almost complete cessation of clastic sedimentation. Further into the cave, organic sedimentation from guano and nest-building activity becomes predominant, and there is likely to have been continuing spatial patterning, as indicated for sites 12, 13 and 14. It is probable that these two sedimentary facies interfinger *c.* 15–30 m into the cave entrance.

Phytolith taphonomy

The taphonomy of phytoliths in caves can be quite different from the taphonomy of palynomorphs. Phytolith deposition usually follows one of four modes: *in situ* plant decay leading to phytolith deposition on surfaces; wind dispersion of phytoliths (common in arid to semi-arid environments, rare in humid tropical environments); alluvial or colluvial redeposition of phytoliths along with their associated sediments; and cultural deposition of phytoliths through food or material cultural remains. Animals do not normally serve as vectors of phytoliths, except for animals that consume grasses.

In the case of the Great Cave, the distribution of phytoliths in the sediments provides some indication of the nature of depositional processes. The lack of phytoliths in many samples confirms that wind dispersion of phytoliths in this environment was rare. The presence of phytoliths in some of the Hell Trench samples suggests that alluvial or colluvial processes may have played a limited role in some of the phytolith

redeposition, which is consistent with our understanding of the patterns of sedimentation (Volume One, Chapter 3). The lack of living vegetation in the cave rules out *in situ* deposition of phytoliths. In the main, therefore, phytolith deposition in the cave is most likely to have been through human or animal vectors. While animals are possible vectors for pollen deposition in the cave, none of the animals (bats, swiftlets) associated with this environment are grass eaters, and therefore it is unlikely that animals played a role in phytolith deposition. The strong variability in phytolith deposition in the cave sediments supports this supposition. If other vectors were part of the phytolith depositional process we would expect a more uniform distribution of phytoliths through the sediments.

Given that humans are the likely agents for phytolith deposition in the cave, the plants brought into the cave are most likely to be those to be found near the cave entrance (within a few kilometres at most) collected for food, as medicines, or other purposes such as craft work. The phytolith assemblage therefore represents a very different, and smaller, scale of environment than the pollen assemblage, which may be coming from zones much further away through both wind and animal vectors.

Stratigraphic studies

In the light of the taphonomic study, the pollen stratigraphic study was limited to the area dominated by aeolian deposition close to the cave entrance. Beyond the entrance dripline, the cave floor is too dry for the growth of plants, so taphonomic bias caused by the growth of a specialized cave mouth flora is largely absent. It can be inferred that taphonomic biases caused by natural depositional processes are unlikely to be marked, since very skewed assemblages typical of taphonomic bias were not found in the area close to the cave mouth. One thing that cannot be quantified, however, is the contribution of people, who will have contributed pollen carried on their bodies, materials (including inflorescences) that they carried and in their excrement. It is likely that, if taphonomic biases are present, they are the result of human agency.

It was clear from the evaluation of the samples taken by DG in 1999 that, as is often the case in cave sediments, pollen concentrations were likely to be very low and therefore that relatively large pollen samples would be needed to provide counts suitable for statistical analysis. To sample the archaeologically significant stratigraphic units, monoliths with dimensions 15 cm × 10 cm × 50 cm were taken and wrapped tightly in aluminium foil, cling film and

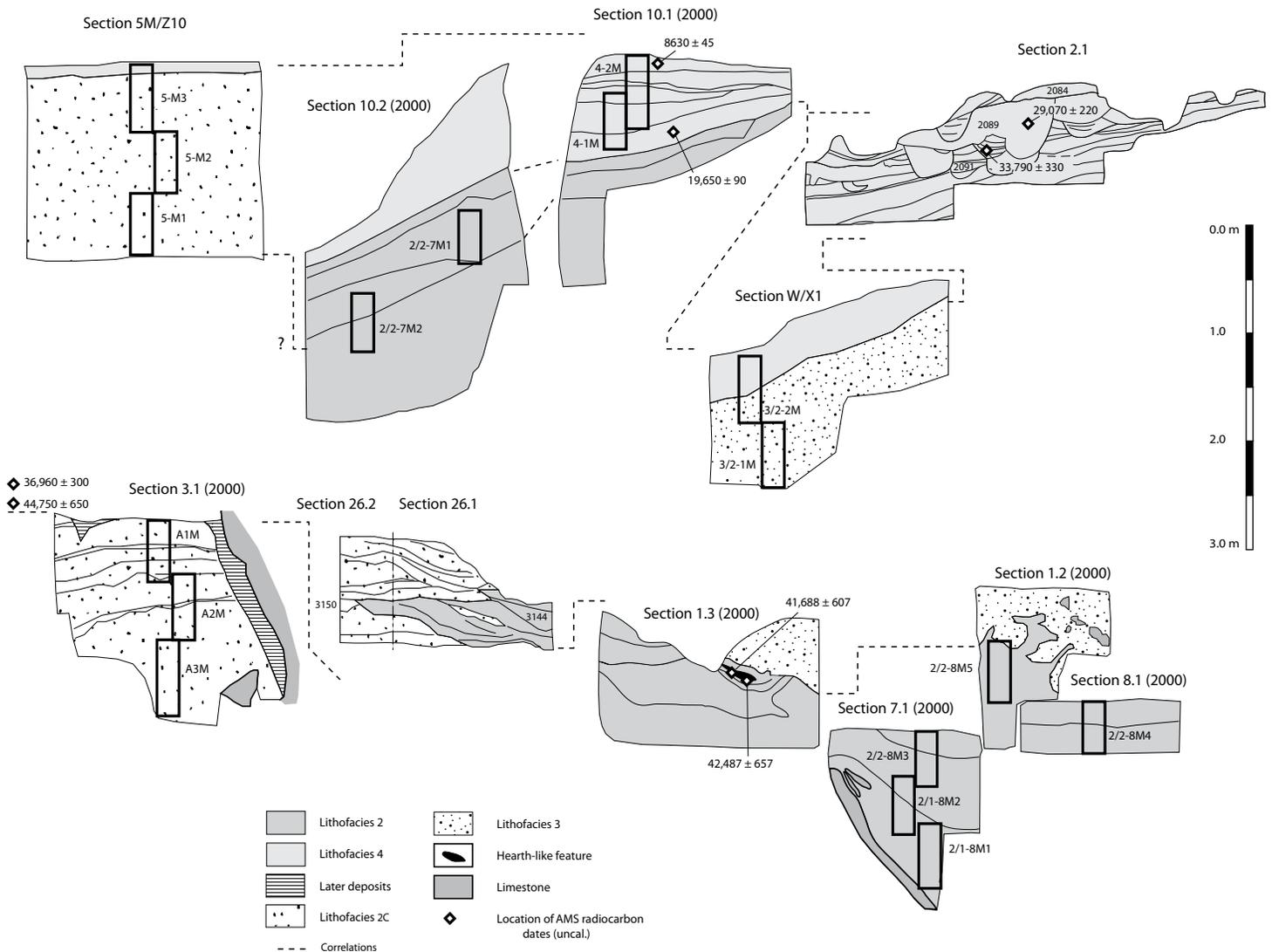


Figure 8.8. The principal sampled sections showing the location of the monoliths. ^{14}C dates are shown as ‘uncalibrated bp’ (see Appendix for full details). (Partly after Hunt et al. 2012.)

adhesive tape (Volume One: Fig. 2.40; Fig. 8.8). These monoliths were also used in the geochemical study (this volume, Chapter 5). The monoliths could not sample the full extent of all stratigraphic units, and some of the monoliths did not survive transport back to the UK, so the sequence described here is not the full sequence exposed in the cave. The monoliths were stored in an air-conditioned room at the Niah National Park HQ, then in the UK in a cold-room at 4°C . Sub-sampling was at 5 cm intervals, unless this crossed obvious lithological boundaries. In addition, two samples associated with the Deep Skull were analysed: a subsample from the British Museum of the sediments cleaned from the cranial cavity by Don Brothwell in 1959; and a subsample from Harrison’s

archived sample labelled “Soil from around Skull at H/6 107” Niah 15-2-58” from close to the find spot of the skull. It should be noted that this sample is from a different square in Harrison’s grid system than the charcoal (H/19, 106”) suggested by Harrison to be from the same context.

Dating of the sequences was derived firstly from interpolation between radiocarbon dates calibrated using Calib 6.01 (Reimer et al. 2009). The thermophile (lowland forest plus swamp forest) curve was tuned, within the constraints of the radiocarbon dates, against the NGRIP 50-year record (NGRIP members 2004a, 2004b) to provide more refined dating (Fig. 8.9). Temperature estimates were derived from a database of the altitudinal ranges of plants in Borneo derived from

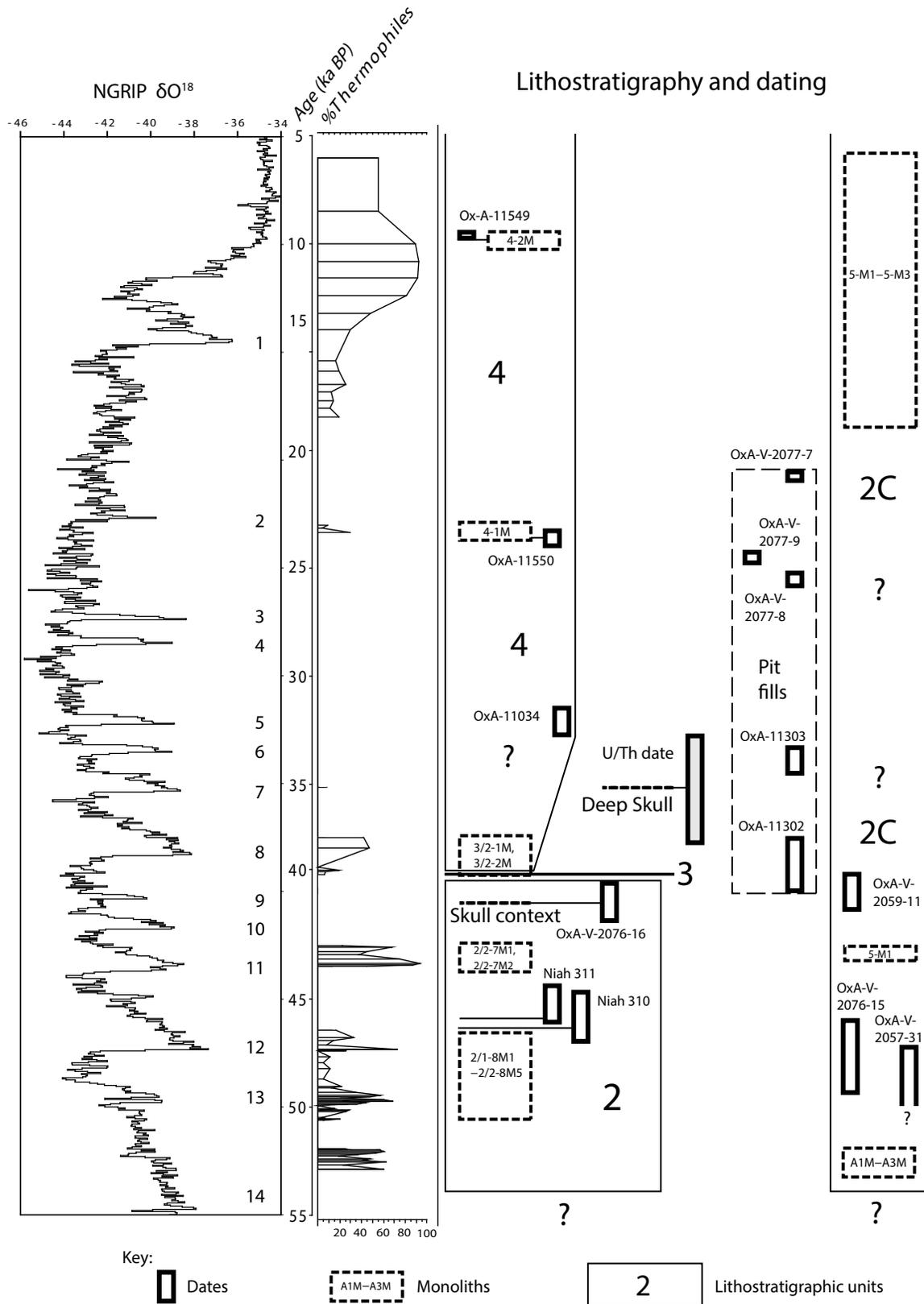


Figure 8.9. The stratigraphic units in the West Mouth, the monoliths, key calibrated radiocarbon dates and the summary of thermophilous pollen, tuned against the NGRIP 50-year record. (After Hunt et al. 2012.)

the published literature (Fig. 8.1), calibrated against the lapse rate of Kitayama (1992).

Pollen was generally well-preserved, but concentrations were very variable, with zero to 4328 grains per sample. Pollen zones for each section were established (Table 8.5). Palynofacies assemblages were also very variable. Phytoliths were rare to uncommon in all but two samples and diatoms were sometimes present. Based on the types and character of the assemblages present even in low abundance samples, preservation does not seem to play a role in the lack of abundance in some samples. Starch grains and thinly silicified forms seem to be preserved even in samples with relatively few other microfossils. The lack of phytoliths or low abundance of phytoliths in these samples seem most likely to be related to an actual paucity of botanical remains in the sediments.

Relating pollen stratigraphy to lithostratigraphy and chronology

As discussed earlier, the pollen assemblages are likely to have accumulated in the cave by a combination of airfall, animal transport and anthropogenic activity. Given that the pollen is preserved in fluvial, colluvial and mudflow sediments, there is therefore the probability of mixing and recycling, to some degree, resulting from biogenic and sedimentary processes. Nevertheless, the pollen analysis shows a well-stratified record which can be interpreted as evidence of past climate change.

It is possible that the climatic phases suggested above have no relationship to Northern Hemisphere trends, or that they are in phase with Antarctic climatic events. The available dating evidence, however, and the fact that temperature fluctuations in Borneo and elsewhere in Southeast Asia and Australasia (Hunt & Premathilake 2012; Lewis *et al.* 2011) and even as far to the south as New Zealand (Whittaker *et al.* 2011) are synchronous with events in China (Dykoski *et al.* 2005; Wang *et al.* 2001) and Greenland, may be taken to suggest that forest phases probably mostly correspond to NGRIP interstadials (NGRIP members 2004a) (Fig. 8.9). It is also possible that some open vegetation resulted from natural fires (Goldammer & Seibert 1989) or from biomass-burning by humans. While this possibility cannot be discounted, climatic change and temperature decline in the phases interpreted here as stadials are suggested by the loss of lowland, temperature-limited taxa, the increases in taxa whose modern centre of distribution is in hill or montane forest, increases of open-ground species and the appearance of species whose present distribution does not reach sea level such as *Albizzia*, *Alnus*,

Prunus and *Balanophora*. On the other hand *Justicia*, a 'fireweed' which today follows fire in lowland rainforest and mangroves in Borneo (Hunt *et al.* 2007), is abundant during some phases where lowland forest, swamp forest and mangrove pollen dominates. This can plausibly be linked with biomass burning, as discussed below.

The earliest part of the sequence, zones A-1 to A-6 and H-1 to H-10, evidenced in Section 3.1(2000) under the rock overhang (Fig. 3.6) and in Sections 1.2(2000), 1.3(2000), 7.1(2000) and 8.1(2000) in the Hell Trench (Fig. 3.7), lies within the fine-grained well-stratified fluvial and colluvial sediments of Lithofacies 2 and 2C (Fig. 8.8). The available radiocarbon dates suggest that the A1M to A3M monoliths predate *c.* 48,000 BP and the Hell Trench monoliths predate *c.* 45,000 BP. Tuning these records with the NGRIP ice core interstadials (NGRIP Members 2004a, 2004b) suggests that the interstadial in zones A-1 to A-5 may correlate with the latter part of NGRIP Interstadial 14, the interstadial in zones H-5 and H-6 may correlate with NGRIP Interstadial 13, and the interstadial in zones H-9 and H-10 may correlate with NGRIP Interstadial 12. It is, of course, entirely possible that one or more significant erosion surfaces are present within the Niah Cave record and that these correlations should be with older NGRIP interstadials.

A probably later part of Lithofacies 2 was sampled in Section 10.2(2000) (zones RS-1 to RS-4). This section is only dated within the overlying and much later sediments of Lithofacies 4 (Fig. S8.7), so correlation of the interstadial in RS-1 and RS-2 could be with any of NGRIP interstadials 11 to 9 given the dissimilarity of the assemblages with the interstadials in Section 3.1 and the Hell Trench. There is considerable similarity with assemblages in zone EA-1 (Section 5M/Z10), which may be of the same age, or from a later interstadial of similar facies.

Deposition of fluvial sediments of Lithofacies 2 seems to have slowed or ceased sometime shortly after 35,510 ± 350 bp or 39,676–41,503 cal. BP (OxA-V-2076-16) and the deposition of the sediments associated with the Deep Skull context (H6/107"). These deposits most probably relate to a stadial. Shortly after, a major mudflow (Lithofacies 3) impacted on and partially truncated the existing deposits. The mudflow is likely to have been derived from superficial materials in the cave (Dykes 2007), so pollen within the mudflow deposits (Section W/X1, pollen zone M-1) probably partly reflect the vegetation immediately prior to the mudflow, which is of stadial facies.

The pollen of the basal part of Lithofacies 4, which overlies Lithofacies 3 in Section W/X1 (Fig. 8.8), is consistent with a major interstadial with closed

Chapter 8

Table 8.5. Pollen zones in the sediments of the West Mouth of Niah Great Cave, in approximate chronological order from oldest (top) to youngest (bottom).

| Lithofacies | Depth (cm) | Zone code | Defining taxa | Other important taxa | Interpretation |
|--|------------------------|-----------|--|--|--|
| 2C | 120–105 | A-1 | <i>Bruguiera</i> , <i>Euonanthus</i> | <i>Lithocarpus</i> , <i>Symplocos</i> , <i>Camptosperma</i> , <i>Hopea</i> , <i>Justicia</i> | Mangroves, swamp and lowland forest: hot wet but cooling climate with high sea. <i>Justicia</i> suggests fire |
| 2C | 105–80 | A-2 | <i>Dodonaea</i> , <i>Lithocarpus</i> , <i>Bruguiera</i> | <i>Eugenia</i> , <i>Elaeocarpus</i> , <i>Nephelium</i> , <i>Symplocos</i> , Palmae, Liliaceae, Cyperaceae, <i>Justicia</i> | Mangroves, swamp, lowland and montane forest with some scrub and open patches: fairly hot fairly wet climate with high sea. <i>Justicia</i> suggests fire. |
| 2C | 80–68 | A-3 | <i>Dodonaea</i> , <i>Gluta-Arenga</i> | <i>Hydrocotyle</i> , <i>Santiria</i> , <i>Elaeocarpus</i> , <i>Kleinhovia</i> , Pteropsida monolete, <i>Justicia</i> | Swamp, lowland and dry forest, some scrub and open patches: hot but not very wet climate. <i>Justicia</i> suggests fire |
| 2C | 68–47 | A-4 | <i>Dodonaea</i> , <i>Elaeocarpus</i> | <i>Eugenia</i> , small Palmae, small smooth trilete, <i>Symplocos</i> , Poaceae, Pteropsida monolete, <i>Justicia</i> | Lowland, montane and dry forest and a little scrub: moderately hot dry climate. <i>Justicia</i> suggests fire |
| 2C | 47–27 | A-5 | <i>Elaeocarpus</i> , <i>Myrica</i> | <i>Rhododendron</i> , <i>Dodonaea</i> , <i>Diospyros</i> , <i>Justicia</i> | Dry montane and dry forest: warm dry climate. <i>Justicia</i> suggests fire |
| 2C | 27–0 | A-6 | <i>Myrica</i> , <i>Casuarina</i> , <i>Podocarpus</i> | <i>Sphagnum</i> , Cyathaceae, Cyperaceae, Poaceae, Pteropsida monolete, <i>Justicia</i> | Dry and montane forest with open patches: cool, dry climate. <i>Justicia</i> suggests fire |
| OxA-V-2076-15: 44,750±650 bp or 46,321–49,593 cal. BP | | | | | |
| Gap of unknown duration | | | | | |
| 2 | 215–204 | H-1 | <i>Podocarpus</i> , Cyperaceae, Poaceae | <i>Quercus</i> , <i>Myrica</i> , <i>Casuarina</i> , <i>Sphagnum</i> | Montane podocarp forest becoming more open: cool, wet but drying climate |
| 2 | 204–190 | H-2 | Poaceae, Cyperaceae | Bombacaceae, Rubiaceae, <i>Alnus</i> , <i>Lithocarpus</i> , <i>Podocarpus</i> , Ericaceae, <i>Myrica</i> | Savannah with dry forest patches: cold, dry climate. <i>Justicia</i> suggests fire |
| 2 | 190–180 | H-3 | Poaceae, Cyperaceae, <i>Podocarpus</i> , <i>Sphagnum</i> , <i>Quercus</i> | <i>Myrica</i> , <i>Brownlowia</i> , <i>Alnus</i> , <i>Elaeocarpus</i> , <i>Artemisia</i> , Pteropsida monolete, Palmae, Rosaceae, small smooth trilete spores. <i>Justicia</i> is very abundant (50–150%) | Savannah with some lowland/montane forest: cool, moderately dry climate. <i>Justicia</i> suggests fire though numbers might suggest import of inflorescences into cave |
| 2 | 180–165 | H-4 | Poaceae, <i>Quercus</i> | Rubiaceae, <i>Podocarpus</i> , Cyperaceae, Pteropsida, <i>Justicia</i> | Savannah with increasing montane forest patches: cold, moderately dry climate. <i>Justicia</i> suggests fire |
| 2 | 165–145 | H-5 | <i>Lithocarpus</i> , <i>Dodonaea</i> , Cyperaceae | <i>Combretocarpus</i> , <i>Casuarina</i> , <i>Elaeocarpus</i> , <i>Gluta</i> , Palmae indet., <i>Areca</i> , Rubiaceae, Rutaceae, <i>Castanopsis</i> , <i>Chionanthus</i> , <i>Quercus</i> , <i>Sterculia</i> , Poaceae, Pteropsida monolete, <i>Justicia</i> | Montane 'oak' forest, some lowland species and some open places: cool, moderately dry climate. <i>Justicia</i> suggests fire |
| 2 | 145–117 | H-6 | <i>Lithocarpus</i> , <i>Dodonaea</i> , <i>Iguanura</i> | <i>Myrica</i> , <i>Avicennia</i> , Aizoaceae, <i>Elaeocarpus</i> , <i>Iguanura</i> , Rubiaceae, Rutaceae, <i>Castanopsis</i> , <i>Quercus</i> , <i>Sterculia</i> , Cyperaceae, Poaceae Pteropsida monolete. <i>Justicia</i> and juvenile Palmae extremely abundant | Lowland/montane forest, some mangroves: warm climate and fairly high sea. <i>Justicia</i> suggests fire, though high numbers of this species and juvenile Palmae might point to import of inflorescences into the cave |
| 2 | 117–84 | H-7 | Poaceae, Cyperaceae, Pteropsida monolete, <i>Podocarpus</i> | <i>Myrica</i> , Urticaceae, Chenopodiaceae. <i>Justicia</i> is sometimes present | Savannah with montane forest patches: cool dry climate. <i>Justicia</i> suggests fire in early part of zone. Possibility of several small hiatuses |
| 2 | 84–51 | H-8 | Pteropsida, <i>Podocarpus</i> , Poaceae | Cyathaceae, <i>Symplocos</i> , <i>Lithocarpus</i> | Very sparse, variable assemblages: montane forest with open patches becoming open savannah |
| 2 | 51–31 | H-9 | <i>Avicennia</i> , <i>Symplocos</i> | Poaceae, <i>Chionanthus</i> , <i>Brownlowia</i> , <i>Lithocarpus</i> , <i>Callicarpa</i> | Rapid transition from montane forest to lowland forest, swamp forest and mangroves, then disrupted vegetation: hot, briefly wet climate and high sea levels |
| Gap of unknown duration | | | | | |
| 2 | 31–0 | H-10 | <i>Symplocos</i> , <i>Podocarpus</i> | <i>Casuarina</i> , Convolvulaceae, <i>Avicennia</i> , <i>Elaeocarpus</i> , <i>Areca</i> , <i>Quercus</i> , Lactucaae, Poaceae, Pteropsida monolete | Montane forest spreads, some dry forest, lowland forest and mangroves decline: warm and cooling moderately dry climate and high but falling sea levels |
| Niah-310: 42,487±657 bp or 44,654–46,820 cal. BP | | | | | |
| Niah-311: 41,688±607 bp or 44,297–46,044 cal. BP | | | | | |
| Gap of unknown duration | | | | | |
| Estimated context of Deep Skull H/6 107" Niah 15-2-58 and OxA-V-2076-16: 35,510±350 bp or 39,676–41,503 cal. BP | | | | | |
| 2 | Soil from around Skull | SK-1 | <i>Podocarpus</i> , Ericaceae | <i>Alnus</i> , <i>Casuarina</i> , <i>Albizzia</i> , Cyperaceae, Poaceae, Pteropsida monolete | N.B. very sparse assemblage: possibly montane forest: cool damp climate |

Table 8.5. (cont.)

| Lithofacies | Depth (cm) | Zone code | Defining taxa | Other important taxa | Interpretation |
|--|----------------|---------------------|--|--|--|
| Gap of unknown duration – little stratigraphic control | | | | | |
| Niah Deep Skull: 35200±260 BP (U-series date in calendar years) | | | | | |
| 2 | Skull contents | SK-2 | Poaceae, Ericaceae, Pteropsida monolete | Labiatae, Cyperaceae, Cyathaceae, <i>Myrica</i> , <i>Casuarina</i> | Mixed assemblage: savannah with dry forest patches = cool, dry climate; plus lowland, swamp and mangrove forest = wet tropical climate |
| Gap of unknown duration – little stratigraphic control | | | | | |
| 2 | 155–128 | RS-1 = ?=EA-1 | <i>Santiria</i> , <i>Elaeocarpus</i> | <i>Palaquium</i> , <i>Stemonurus</i> , <i>Eugenia</i> , <i>Myrica</i> , Poaceae, <i>Justicia</i> | Lowland and swamp forest: warm, moist climate. <i>Justicia</i> suggests fire |
| 2 | 128–108 | RS-2 | <i>Elaeocarpus</i> , <i>Myrica</i> , <i>Santiria</i> | <i>Casuarina</i> , Urticaceae, Pteropsida monolete, Poaceae, <i>Justicia</i> | Lowland forest and swamp forest with open patches: warm, moderately dry climate. <i>Justicia</i> suggests fire |
| Gap of unknown duration | | | | | |
| 3 | 100–25 | M-1 | <i>Callicarpa</i> , Ericaceae | Poaceae, <i>Sphagnum</i> , Rubiaceae, <i>Alnus</i> , <i>Casuarina</i> , Cyperaceae | Mudflow recycling regenerating montane forest assemblage with much far-travelled material: cool, wet climate |
| Gap of unknown duration | | | | | |
| 4 | 25–0 | M-2 | <i>Elaeocarpus</i> , <i>Callicarpa</i> , <i>Avicennia</i> | <i>Quercus</i> , <i>Symplocos</i> , Ericaceae, Poaceae | Lowland forest with mangroves at the end of the zone: warm, moist climate. Recycling of material from Lithofacies 3 at base of zone |
| Gap of unknown duration – little stratigraphic control | | | | | |
| OxA-11302: 33,790±330 bp or 37,431–39,550 cal. BP | | | | | |
| OxA-11303: 29,070±220 bp or 33,121–34,518 cal. BP | | | | | |
| Gap of unknown duration – little stratigraphic control | | | | | |
| 2C | 147–137 | EA-1 = ?=RS-1 | <i>Santiria</i> , <i>Elaeocarpus</i> , Myrtaceae | <i>Palaquium</i> , <i>Dodonaea</i> , <i>Myrica</i> , Ericaceae, <i>Symplocos</i> , <i>Lithocarpus</i> , Sterculiaceae, Asteraceae, Poaceae, Pteropsida monolete, <i>Justicia</i> | Swamp and lowland forest: warm, moist climate. <i>Justicia</i> suggests fire |
| Gap of unknown duration | | | | | |
| 2C | 137–97 | EA-2 = in part RS-5 | Poaceae, Pteropsida monolete | <i>Casuarina</i> , <i>Myrica</i> , Cyperaceae, Lactuceae, <i>Callicarpa</i> | Savannah with dry forest patches: cool dry climate, episode of disrupted vegetation indicated by high <i>Callicarpa</i> = RS-5 |
| Gap of unknown duration | | | | | |
| OxA-11550: 19,650±90 bp or 23,086–23,859 cal. BP | | | | | |
| 4 | 85–45 | RS-5 = part of EA-2 | <i>Callicarpa</i> , herbaceous taxa | <i>Casuarina</i> , <i>Myrica</i> , <i>Palaquium</i> , <i>Podocarpus</i> , <i>Artemisia</i> , Ericaceae | Dry regenerating montane forest: cool, dryish climate |
| 2C | 97–67 | EA-3 | Poaceae, <i>Casuarina</i> , <i>Quercus</i> , Pteropsida monolete | <i>Polypodium</i> , <i>Myrica</i> , Ericaceae, <i>Sphagnum</i> , <i>Podocarpus</i> | Dry forest with savannah patches: cool, moderately dry climate |
| Gap of unknown duration | | | | | |
| 4 | 35–17 | RS-7 | Pteropsida monolete, <i>Polypodium</i> , <i>Stenochlaena</i> | Lactuceae, <i>Podocarpus</i> , <i>Sphagnum</i> , <i>Ilex</i> , <i>Lygodium</i> | Poorly-preserved assemblages dominated by taphonomically-robust fern spores. Indications of drought-tolerant <i>kerangas</i> vegetation, some disrupted, open vegetation, cool but warming climate |
| 4 | 17–0 | RS-8 = EA-4 | Pteropsida monolete, <i>Casuarina</i> , <i>Myrica</i> | Ericaceae, <i>Acrostichum aureum</i> , <i>Lepisorus</i> , Dipterocarpaceae, <i>Polypodium</i> , <i>Pteris</i> , <i>Rhododendron</i> , Poaceae, Lactuceae | RS-6 has poorly preserved assemblages, dominated by monolete Pteropsida spores which are taphonomically robust. Dry forest expanding, open areas contracting: warm, dryish climate |
| 2Ca | 67–47 | | | | |
| Gap of unknown duration | | | | | |
| OxA-11549: 8630±45 bp or 9530–9688 cal. BP | | | | | |
| 2Cb | 47–9 | EA-5 | <i>Elaeocarpus</i> , <i>Lepisorus</i> | Pteropsida monolete <i>Polypodium</i> , <i>Stemonurus</i> , <i>Santiria</i> , <i>Campnosperma</i> , <i>Stenochlaena</i> , <i>Dictyophyllum</i> , <i>Pteris</i> , Cyathaceae | Poorly preserved assemblages, dominated by monolete Pteropsida spores which are taphonomically robust. Lowland forest and swamp forest, occasional indications of disturbance: hot, wet climate |
| 4 | 9–0 | EA-6 | <i>Sonneratia</i> | Pteropsida monolete, <i>Rhizophora</i> , <i>Alchornea</i> , <i>Capparis</i> , Cyathaceae, <i>Casuarina</i> , Poaceae | Mangrove vegetation and lowland forest with some regeneration – strong signs in high count of juvenile <i>Sonneratia</i> pollen of taphonomy involving fruit-bats |

warm lowland forest with a high percentage of the front-mangrove *Avicennia*, suggesting a major marine incursion into the nearby Sungai Niah (zone M-2). This pollen zone postdates the mudflow deposit of Lithofacies 3, which lies above a radiocarbon date of $36,510 \pm 350$ bp or 39,676–41,503 cal. BP (OxA-V-2076-16) but predates a radiocarbon date of $33,790 \pm 330$ bp or 37,431–39,550 cal. BP (Ox-A-11302) from charcoal in pit fills cut in the lower levels of Lithofacies 4. This pollen zone is thus likely to correlate with NGRIP Interstadial 8.

There is then a major break, caused by the loss by excavation of suitable sediments, before sampling could resume. Following this break, the nature of the palynological record is rather different. In Section 10.1(2000) in Area A, Block B (Fig. 8.8), following a likely non-sequence or discontinuity the local base of Lithofacies 4, dated to $19,650 \pm 90$ bp or 23,086–23,859 cal. BP (OxA-11550) around the LGM, contains assemblages (RS-5) characterized by very high *Callicarpa* and an assortment of upland, dryland and herbaceous taxa, including the obligate hill/mountain taxa *Acer*, *Alnus*, *Prunus* and *Albizzia*. This suggests depressed temperatures relative to modern, possibly as low as

21°C (Fig. 8.10) and forest regeneration. It is likely that the regenerating vegetation followed climatic disruption of the forest in a cool dry environment immediately after the NGRIP H2 event (cf. Wang *et al.* 2001). In Section 5M/Z10, following a probable non-sequence, very sparse pollen assemblages in zones EA-2 and EA-3 are characterized by open ground, upland, dryland and regeneration taxa. These are consistent with relatively low temperatures, and an environment that was relatively open and dry. It is possible that the peak in *Callicarpa* at 122 cm in zone EA-2 correlates with the peak of this species in zone RS-5 in Section 10.1(2000). If so, this vegetation regeneration event, possibly to be equated with early in NGRIP Interstadial 2, is preceded and followed by generally cool, dry, open vegetation.

The expansion of lowland forest in zones EA-3 and EA-4 marks the rise of temperature in the Late Glacial and Holocene, but it would appear that the current wet tropical climatic pattern took some time to become established, since dryland taxa remain common in EA-4 and swamp forest species only become established in EA-5. This unfortunately undated record seems to be consistent with the climatic predictions

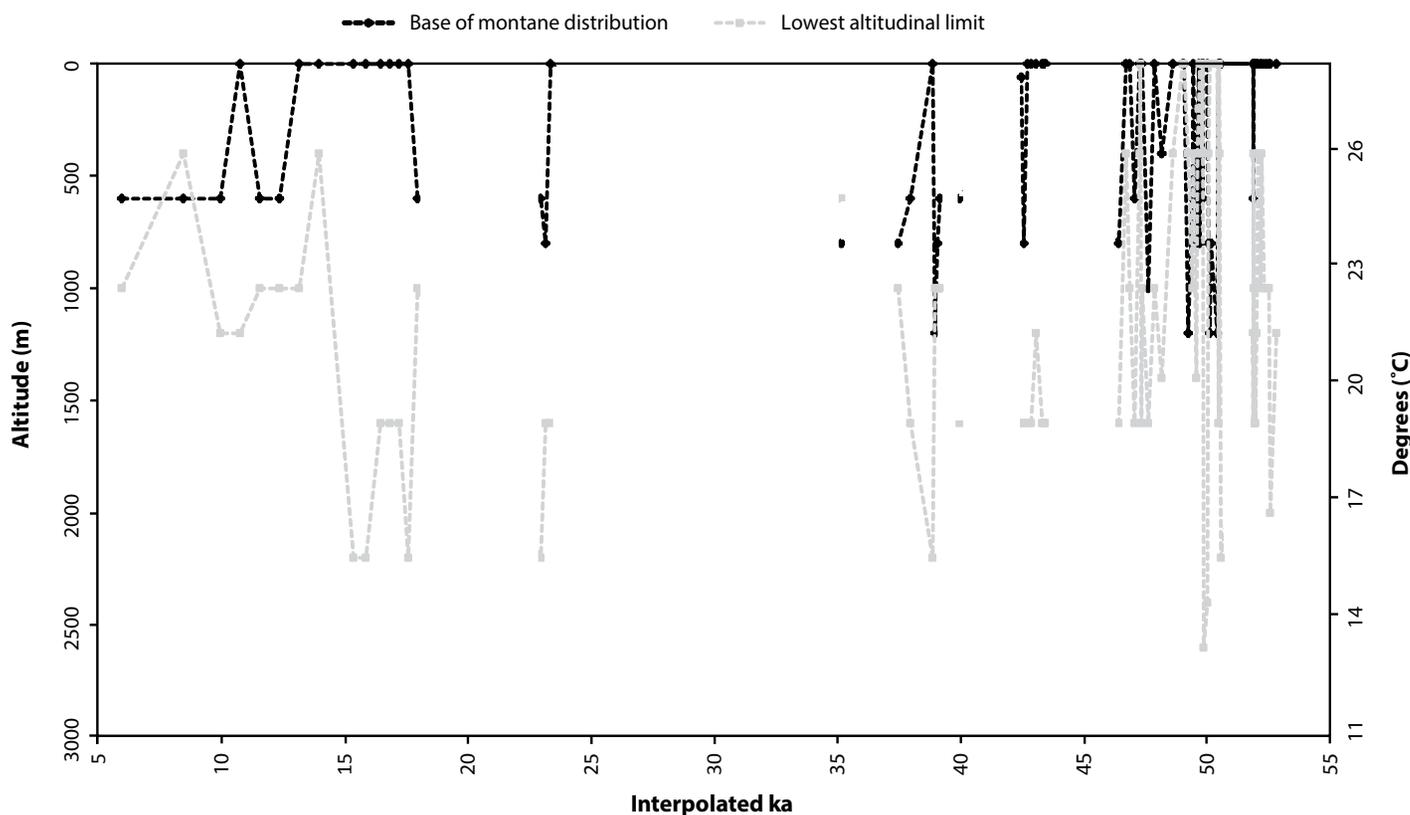


Figure 8.10. Possible temperature ranges indicated by the pollen assemblages from Niah Great Cave. (After Hunt *et al.* 2012.)

of Partin *et al.* (2007), who suggested a gradual rise in precipitation from the LGM into the Early Holocene.

Pleistocene vegetation and climate

Through the Pleistocene sequence, there is an alternation of phases where pollen of lowland forest taxa dominate and phases where pollen of regeneration/open-ground and montane taxa are very common. It is very likely that the alternating phases are the result of climate change (Fig. 8.11).

Interstadial phases

Zones early in temperate phases, such as H1, H4-H5, H-8, EA-4 (Figs S8.3, S8.4), are characterized by taxa typical of modern montane forest, such as *Quercus* and *Podocarpus*. In some cases during the thermal maxima (e.g. pollen zones H-9 to H-10, RS-1: Figs S8.3, S8.7), pollen of lowland and swamp forest species is very common, suggesting wet tropical forest similar in aspect to the Holocene and modern forests of the lowlands around the Great Cave (Hunt & Premathilake 2012; Hunt & Rushworth 2005a, 2005b; Figs 8.1, 8.12). The phytolith assemblages recovered from the Great Cave all relate to interstadial phases, and they are mostly characterized by abundant forest taxa, thus confirming and amplifying the pollen record. If the phytolith assemblage signature represents some mix of environmental and cultural materials (see below), the extremely low frequency of Poaceae phytoliths would strongly suggest that during interstadials during OIS 3 the local environment was dominated by mainly closed tropical forest.

During what appear to be minor interstadials, such as pollen zones A-3 and H-3 (Figs S8.1, S8.3), and after thermal maxima including pollen zones A-4 to A-6, H-10, RS-2, RS-3 (Figs S8.1, S8.3, S8.7), pollen of dry scrub, dry lowland mixed forest and montane forest are an important part of assemblages. These characteristics make them unlike assemblages from Holocene and modern regional wet tropical forest (e.g. Hunt & Premathilake 2012; Hunt & Rushworth 2005a, 2005b). This could be because water tables were lower, responding to low sea level, since this would have limited the growth of swamp and raised bog forest dependant on the water table, but it is more likely to be because of rather lower rainfall than today. At times, such as pollen zones A-1 to A-5 (Fig. S8.1), it is likely that the forest was rather open and dry, characterized by dryland scrub and open-ground species.

The mangrove pollen assemblages suggest further variation in interstadial environments. Back-mangroves are common in A-1 and A-2 (Fig. S8.1), and front-mangroves are abundant in H-9 and M-2

(Figs S8.3, S8.10). In the other interstadials, mangrove pollen is rare or absent. It is probable that high pollen of front-mangrove taxa at Niah reflects relatively high sea during major interstadials and thus nearby front-mangrove vegetation in the valley of the Sungai Niah. During lesser interstadials, back-mangroves occupied the valley of the Sungai Niah, or the coast was so far away that mangrove pollen was only a minor component of the pollen rain in the Great Cave. The diatom assemblages also provide evidence for nearby saline waters during some interstadials, since estuarine taxa are often present.

The phytolith data come from layers mostly regarded on pollen evidence as interstadial facies. We can therefore regard the pollen and phytoliths as indicating broadly the same type of interstadial environments, despite the marked differences in their catchment scales and taphonomy.

Episodes of desiccation

As remarked above, several phases are characterized by drought-resistant species today typical of *kerangas* and coastal dunes such as *Myrica*, *Casuarina* and *Dodonaea* (Fig. 8.11). This is particularly the case with A-2 to A-5, H-5 to H-6, RS-2 to RS-5, EA-2 to EA-4 (Figs S8.1, S8.3, S8.7, S8.15). Many of these are characterized by low incidences of lowland forest pollen and are thus likely to have stadial affinities, but some, such as A-2 to A-5 and EA-5, contain significant lowland forest pollen and are thus likely to be of interstadial facies. This observation adds a further degree of complexity to the climatic history, since it suggests that two different circulation modes were present during interstadials, one likely characterized by dry winds, most probably coming from a northerly or northwesterly direction and the Asian landmass, and the other by more oceanic winds.

Stadial phases

During phases H-2, H-4, H-7, RS-5, M-1, EA-2, EA-3 (Figs S8.3, S8.7, S8.10, S8.15), the pollen assemblages are dominated by open ground, regeneration and upland taxa (Fig. 8.11). Temperature decline and/or aridity would have killed many rainforest trees, thus opening forest canopies. Further canopy-opening by fire is also highly likely. Canopy-opening would have favoured plants able to colonize open environments such as grasses, sedges and Pteropsida, followed by regeneration with Compositae, bamboos, *Macaranga*, *Callicarpa* and *Mallotus*. During these episodes taxa were present which are now confined to hill or lower montane forest, including *Schefflera*, *Balanophora spicata*, *Prunus*, *Caeseria*, *Albizzia*, *Acer* and *Alnus*. Pollen of taxa which today are prevalent in hill or lower montane forest are also frequent, including *Quercus*,

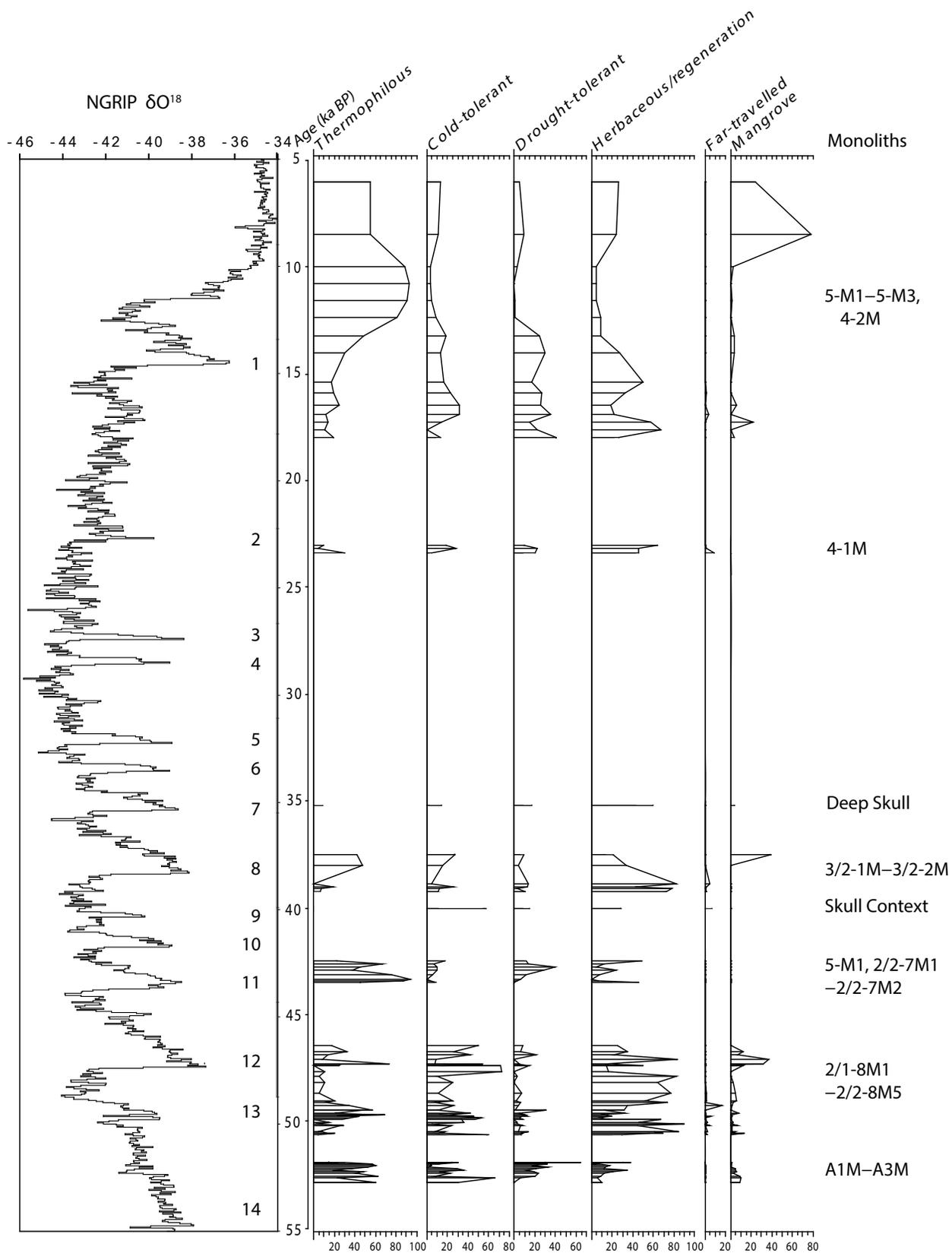


Figure 8.11. Summary pollen diagram for Niah Great Cave. (After Hunt et al. 2012.)

Lithocarpus, *Podocarpus*, *Dacrydium*, *Lindsaea*, *Euonymus* and *Rhododendron* (Flenley 1973; Kitayama 1992). Thus *Podocarpus* comprises over 50 per cent in the pollen counts in H-1 and H6/107" (the assumed context of the Deep Skull) and *Lithocarpus* and *Quercus* are together over 40 per cent in H-5 and H-6. Vegetation zones at these times may, therefore, have been depressed by as much as 1400 m relative to their positions today (Figs 8.1, 8.10), suggesting temperature decline by *c.* 7–9°C using the lapse rate of Kitayama (1992). Unfortunately phytoliths were not recovered from levels suggested on pollen evidence to be of stadial facies.

High *Callicarpa* and montane taxa characterize a particular stadial facies in M-1 and RS-5 (Figs S8.7, S8.10). In Borneo, *Callicarpa* is typical of regenerating woodland (Bramley, 2009). Elsewhere in the Niah sequence, what appears to have been fire-disruption is followed by regeneration involving *Justicia* and herbaceous taxa such as Cyperaceae and Pteropsida, then a group of species including *Macaranga* and *Kleinhovia*. The *Callicarpa*-dominated assemblages may reflect vegetation disrupted by rapid climate change rather than by fire. In these assemblages, the presence of the altitudinally restricted *Acer* and *Albizzia*, and relatively high *Quercus*, is comparable with modern vegetation between 1000 and 1600 m (e.g. Flenley 1973; Kitayama 1992), thus suggesting temperatures of *c.* 19–22°C (Figs 8.1, 8.10). High *kerangas* species including *Casuarina*, *Myrica* and Ericaceae may suggest relatively low rainfall as well as low temperatures.

Vegetation at the Last Glacial Maximum

The assumption of Cannon *et al.* (2009) that forest canopies would be unbroken in lowland Borneo at the LGM is not fully substantiated by the evidence presented and discussed above. Forest vegetation may have persisted during the Late Pleistocene stadials, but it was highly disrupted and the canopy was broken enough to allow taxa typical of regenerating and open-ground environments to flourish (Fig. 8.11). The poorly resolved mammalian evidence from the Great Cave (Cranbrook & Piper 2007; and see this volume, Chapters 25 and 26) most probably reflects the continued presence of forest of some kind, perhaps in sheltered localities close to groundwater sources around the Gunung Subis, but the migration of mammals, as with the migration of the forest trees, was unlikely to have kept pace with the rapid and substantial changes in climate. The pollen record from the Great Cave is consistent in character with Late Pleistocene sequences elsewhere in Sundaland and Sahul, suggesting lowered vegetation zones with more open vegetation, lowered rainfall and temperature declines of *c.* 5–10°C during northern hemisphere stadials (Anshari *et al.*, 2001,

2004; Dam *et al.* 2001; Flenley 1996; Haberle 2005; Hope 1976, 1998, 2001 2009; van der Kaars & Dam 1995, 1997; van der Kaars *et al.* 2000, 2001; Dam *et al.* 2001a, 2001b; Kealhofer 2003; Maloney 1980, 1998b; Walker & Flenley 1979; Wang *et al.* 2009; White *et al.* 2003). In some cases, an additional factor in the destabilization of vegetation was anthropogenic activity in the form of biomass burning.

Holocene vegetation and climate

The earliest Holocene assemblages in the West Mouth (pollen zones EA-5, EA-6, RS-7, and RS-8; Figs S8.7, S8.14) are marked by very high percentages of lowland forest and swamp forest species, suggesting temperatures and rainfall comparable with modern levels. Small numbers of regeneration and open-ground taxa are present. These may be following natural tree-fall, but it is also possible that anthropogenic activity was modifying forest vegetation (see next section). Later spectra in the cave are marked by high percentages of mangrove species, particularly *Sonneratia caseolaris*, following sea-level rise and the invasion of the now-buried valley of the Sungai Niah by back-mangroves.

The alluvial lowlands and areas of low relief developed on Miocene siltstones around the Subis massif provided an opportunity for us to sample extended Holocene sequences (Hunt & Rushworth 2005b), and we sampled further Holocene sequences at Loagan Bunut, a lake in the floodplain of the Sungai Tinjar, some 60 km inland from Niah (Hunt *et al.* 2006; this volume: Fig. 7.5). Augering close to the Great Cave used a modified Livingstone corer of Aberystwyth pattern (Volume One: Figs 6.5, 6.6). One borehole was near the Penan settlement mapped as Rumah Chang but known to its inhabitants as Kampong Irang and more recently Rumah Patrick Libau. The second, the Gan Kira site, is located in the floor of the gorge-like feature which separates the karst tower containing Gan Kira (the 'Painted Cave') from the larger karst tower containing the Great Cave of Niah. Both boreholes showed sequences of dark grey laminated silty-clays overlain by thin peats with abundant charcoal at the top and then pale grey-brown mottled strong brown crudely layered dense clays with occasional charcoal. Both sequences are capped by a thin litter layer (this volume: Fig. 7.4). Hand augering reached a depth of *c.* 5 m in these sites.

At Loagan Bunut, initial coring to 15 m in the lake and the surrounding peatlands used a modified Livingstone corer but was followed by percussion coring to a depth of 40 m (Volume One: Fig. 6.2). The deep sequence (Fig. 8.13) comprised 30.5 m of slightly organic muds, brownish-grey to yellow-brown in colour, laminated and containing occasional wood, overlain

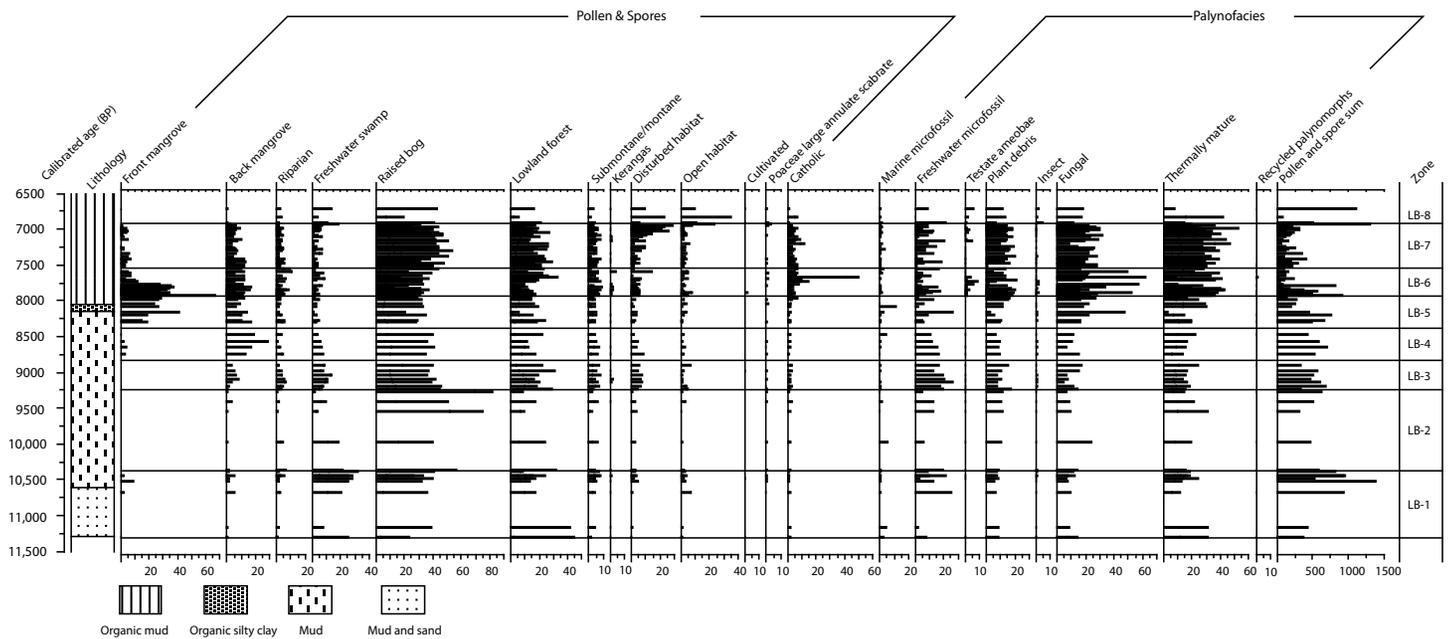


Figure 8.13. Summary pollen diagram from the deep borehole at Loagan Bunut. (Data from Hunt & Premathilake 2012.)

by 6.5 m of organic mud, then 1.75 m of greyish-brown to black organic silty clay and finally 1.25 m of dense yellow-brown mud. Up to 9 m of peat was present in the raised peatlands around the lake. Radiocarbon dates suggest that the deposits below 1.25 m accumulated more or less continuously between *c.* 11,200 BP and *c.* 6500 BP (Hunt & Premathilake 2012). The Pleistocene floras evidenced in the West Mouth had already retreated at Loagan Bunut by *c.* 11,200 BP. Abundant pollen of mangrove taxa including *Rhizophora*, *Bruguiera* and *Sonneratia* plus cysts of marine dinoflagellates and acritarchs suggest a major inlet of the sea (see this volume, Chapter 7). Riparian species suggest the input of a major river. Swamp taxa are replaced by raised bog species, indicating that marshes followed seral development to raised bogs at the freshwater margins of the inlet. The high percentages of lowland taxa and of swamp and raised bog species, compared with the Pleistocene sequences in the West Mouth, imply generally significantly higher temperatures and rainfall.

Apart from fluctuations in *kerangas* species which point to short periods of lower rainfall at *c.* 9200 BP, *c.* 8000–7600 BP, and *c.* 7000 BP (approximately contemporary with episodes of lowered temperatures in the Northern Hemisphere), there is no evidence for climate change during the period represented by this core. Lowland forest species are less common than disturbed habitat species, and open-ground species are consistently present. The pollen of a number of sago palms, including the hill sago *Eugeissona* and *Metroxylon sagu*,

is present, the former from the base of the sequence at 11,200 BP and the latter from just after 10,500 BP. The consensus of evidence from biogeographical and genetic studies is that *Metroxylon* originated in New Guinea and the islands of eastern Indonesia, and is a recent arrival in Borneo. Thermally mature (charred) material is present throughout. Phytoliths (Fig. 8.14) include common (mostly over 20 per cent) *Oryza* types, abundant phytoliths assignable to the Poaceae (*sensu lato*) including mostly grasses but also some bamboo types, some forms attributable to swamp taxa such as Arundinoideae and Cyperaceae and some dicotyledonous types. *Oryza*, of course, is also typical of swamps. Many of the *Oryza* types are burnt and *Oryza* bulliforms are very rare in the core after *c.* 7500 BP but husk phytoliths remain common. Unpublished morphological work by RP suggests that it may not be possible to separate different *Oryza* species reliably using phytoliths.

Raised peatlands grew during the later Holocene at Loagan Bunut (Jones 2006). In a 9 m borehole through one raised bog sequence starting *c.* 6500 BP, there is no evidence for climate change (Fig. 8.15). In spite of this being a raised bog, the seral species reported by Anderson and Muller (1975) as dominating pollen assemblages from the larger peatland at Maraudi were relatively inconspicuous. Assemblages were instead generally dominated by fern spores and mangrove pollen. The core showed consistent but declining marine influence with pollen of back mangroves and marine microfossils common until

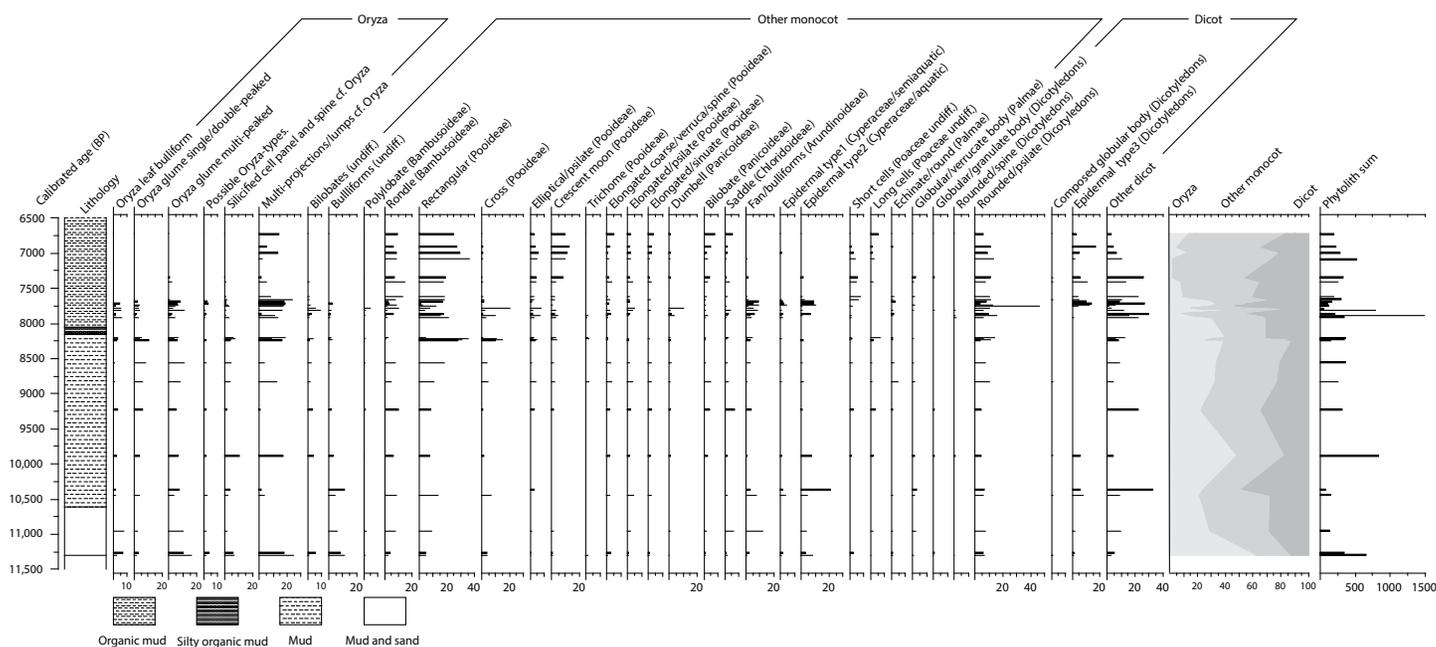


Figure 8.14. Phytolith diagram from the deep borehole at Loagan Bunut.

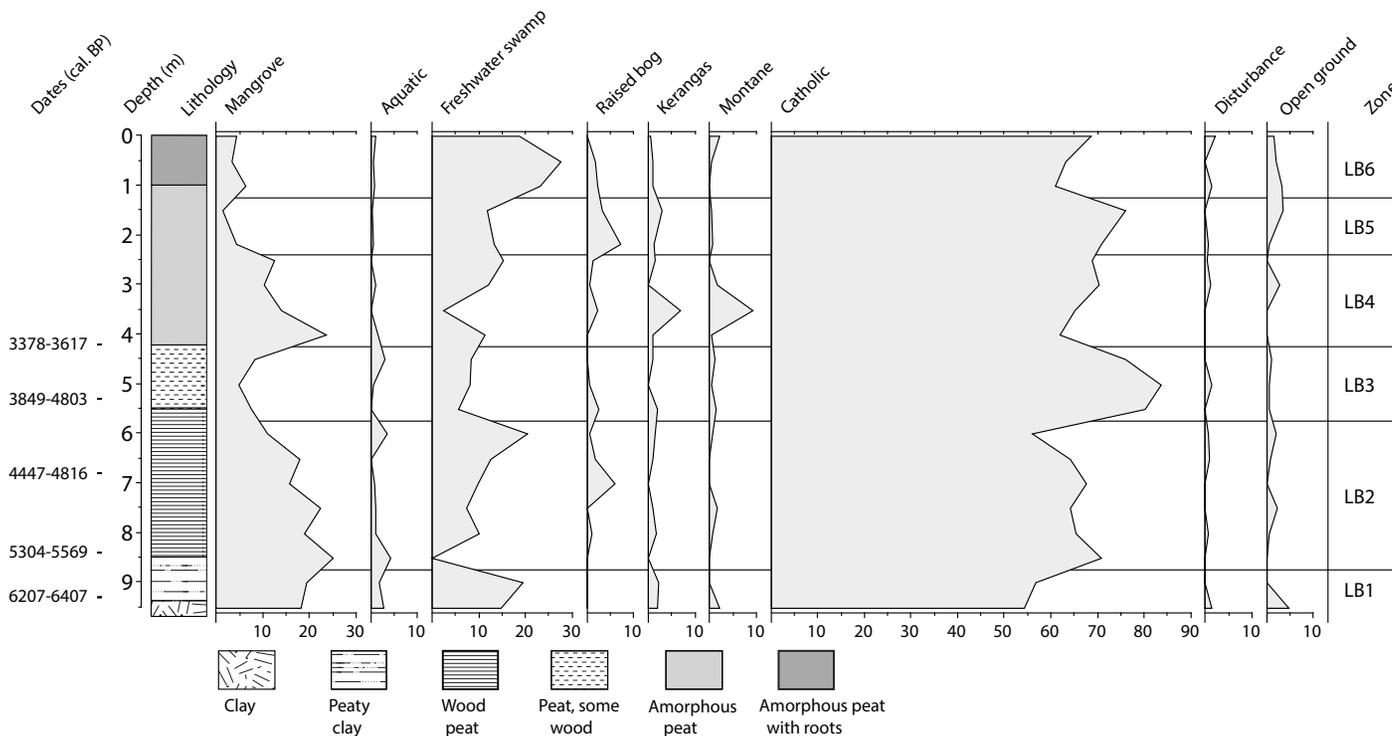


Figure 8.15. Pollen diagram from a raised peatland at Loagan Bunut. (Data from Jones 2006.)

c. 3000 years ago, when brackish-water taxa rise. The brackish phase seems to have persisted until c. 1000 years ago, when freshwater algae become dominant and raised bog and swamp species become common. Pollen of disturbance indicators and of herbaceous taxa is rare but present throughout. It would appear from the Loagan Bunut and Maraudi cores (Anderson & Muller 1975) that the nutrient-depleted raised mire vegetation was unattractive to humans and avoided for settlement and cultivation.

At the Gan Kira and Kampong Irang sites the basal laminated clays are likely to be older than 6450 BP (Hunt & Rushworth 2005b; Volume One: Figs 6.7 and 6.8 and accompanying discussion). The clays and overlying peats are characterized by abundant pollen of back-mangroves including abundant *Bru-guiera*, and some *Ceriops*. These sequences provide evidence for mangrove vegetation and thus seawater a long way inland from the position of the current

coastline during the Early Holocene. At Gan Kira, pollen of Poaceae (some of it comparable with *Oryza*, but not attributable to species) and Cyperaceae is present in the peats. At Kampong Irang, pollen of *Oryza* type is present in the basal part of the overlying clays. The overlying dense clays are characterized by the presence of very abundant spores of Pteropsida and a variety of algae, principally *Spirogyra*. It is extremely likely that the pollen assemblages in the dense clays have been highly altered by taphonomic processes, but the presence of algae and especially *Spirogyra* is significant because the green algae require sunlight for spore formation. It is highly likely that the dense clays accumulated in an open environment. We hypothesize that the dense clays accumulated in fields in which rice was grown (see Hunt & Rushworth 2005b).

Wood identifications from the Great Cave all relate to the Holocene (Table 8.6). All taxa are either

Table 8.6. Wood identifications from the West Mouth, in approximate chronological order. Tr.– Trench. Indet. – indeterminate. Identifications by Andrew Tukau Selang and Gill Thompson, phasing by Lindsay Lloyd-Smith.

| Context | Area | Taxon | Notes | Date BP |
|---------|---------|---|--|--|
| 3029 | D Tr.1 | <i>Durio</i> sp. (Bombacaceae) | Lower flow channel fill – but ‘cut’ into by ‘animal’ disturbance, thus possibly contaminated with Metal Age material | c. 11,500–6500 |
| 2401 | D. Tr.1 | <i>Dryobalanops lanceolata</i> (Dipterocarpaceae) | Sub-surface deposit, cut through by bird-nesters’ posts; deposit likely contains later material | c. 6500 (as subsurface deposit in Area D), or Metal Age (2000–0) |
| 3276 | C Tr.2 | <i>Eusideroxylon zwageri</i> (Lauraceae) | Fill of Burial B212 (NCP B12). | c. 3300–1900 |
| 3280 | C. Tr.3 | <i>Dipterocarpus</i> sp. (Dipterocarpaceae) | Sub-surface deposit over Neolithic grave, with Double Spout vessel | c. 3300–2200 |
| 2316 | C. Tr.1 | Indet. root/stem | Loose fill on surface of exposed <i>in situ</i> jar Burial B190; C14 date on sample of charred wood from B190 | OxA-11548, 2308+/-35 bp or 2159–2362 cal. BP |
| 3287 | C. Tr.3 | <i>Palaquium</i> sp. (Sapotaceae) | Post in square (40 × 40 cm) four-post ‘structure’ in Neolithic cemetery; possible grave-side offering platform | c. 3300–2200 |
| 3001 | C. Tr.2 | Indet. | Section cleaning. Probably derives from Neolithic coffin exposed in section | |
| 3083 | C. Tr.2 | Indet. | Post-cemetery trampled guano layer, building up during Metal Age, but likely to include Neolithic remains too | c. 3300–2200, or c. 2000–500, or later |
| 3089 | C. Tr.2 | <i>Sterculia macrophylla</i> (Sterculiaceae) | | |
| 3176 | C. Tr.2 | <i>Eusideroxylon zwageri</i> (Lauraceae) | | |
| 3181 | C. Tr.2 | <i>Dryobalanops lanceolata</i> (Dipterocarpaceae) | | |
| 3186 | C. Tr.2 | Indet. | | |
| 3189 | C. Tr.2 | <i>Cotylobium</i> sp. (Dipterocarpaceae) | | |
| 3259 | C. Tr.3 | <i>Cotylobium</i> sp. (Dipterocarpaceae) | | |
| 3224 | D. Tr.1 | <i>Phoebe opaca</i> (Lauraceae) | Bird-nesters’ post | c. 500–0 |

from swamp forest (*Palaquium* sp., *Durio* sp., *Sterculia macrophylla*) or lowland forest (all Dipterocarpaceae, *Eusideroxylon zwageri*). There is no discernable trend in the data, but the wood identifications suggest that lowland and swamp forest were probably available locally to people at Niah throughout the Holocene.

Humans and plants

The studies described above provide a number of clues to possible human behaviour at Niah and the region around it over the last *c.* 50,000 years. These include a number of strands: the gathering of plants for food and other necessities; the management of vegetation by fire; and a later group of activities which might be called transitional to farming.

Import of plants into the Great Cave

Starch grains were found during the phytolith study in Lithofacies 2 and 2C sediments in monoliths A2M and A3M (Lithofacies 2C), 2/2-8M4 and 2/2-8M5 (Lithofacies 2), 3/2-1M and from four samples of Lithofacies 4 in Section 2.1. The starches were not identified to species, but include those of aroids (Huw Barton, *pers. comm.*). The phytoliths from the Lithofacies 2 and 2A monoliths provide evidence for wood (the arboreal dicots), bamboo, palms (including the starch producing *Caryota*), *Dioscorea*, Urticaceae (used for greens and fibre), and fruit (Annonaceae and Moraceae). The Lithofacies 4 samples contained phytoliths derived from a wide variety of wood, *Dioscorea*, fruit (Moraceae), Urticaceae, Burseraceae (resin producers), Zingiberaceae (gingers), palms, bamboo, grasses and herbs. The Lithofacies 2/2C and Lithofacies 4 assemblages are broadly similar in aspect, although they contained highly variable amounts of tissue, phytoliths, and starch. The absence of palm phytoliths from the Lithofacies 4 samples may reflect a different set of subsistence strategies at this time, possibly more use of tubers, which would be consistent with the contemporary ecology of a drier more seasonal forest. The variability of assemblages supports the general interpretation of the human use of the cave entrance as intermittent, with potentially a quite variable set of activities. The phytoliths suggest a range of material culture potentially including mats, rope/cord, and bamboo tools in addition to food consumption.

Sizeable aggregates of immature pollen, mostly of palms, in Late Pleistocene contexts (zones A-2 to A-4, H-3, H-5, H-6 and RS-2) provide evidence that people were bringing palm tops including inflorescences into the cave. Many uses for palms in Borneo are suggested by ethnobotanical research (e.g.

Christiansen 2002, 284–9) and their use as a green vegetable in Late Pleistocene Niah is possible. Clumps and tetrads of *Justicia* pollen in many horizons in H-5 and H-6 are consistent with the import of flowers to the cave. Ethnobotanical sources describe the use of *Justicia gendarussa* to treat wounds and toothache and in religious ceremonies (Christiansen 2002) and the Muruts in Sabah use it in infusions for stomach ache (Kulip 2003). It is possible that humans were the vectors of the *Justicia* pollen in the West Mouth, either for medicinal or possibly for ceremonial reasons or because they had walked through stands of the plant as it regenerated following fire. In combination, the starch grains, phytoliths and pollen aggregates provide clear evidence for the human import and use through much of the Late Pleistocene of starchy plants, fruits and other edible plants, as well as plants with other uses such as for poisons and basketry, evidence supported by the other studies of plant residues including on tools (Volume One, Chapters 4 and 6; this volume, Chapters 17 and 27).

Biomass burning in the Late Pleistocene

The use of fire in the cave is shown by numerous hearth-like features in the Hell Trench (Lithofacies 2 and 2A), and by the presence of thermally mature amorphous matter, which is formed within soil and sediment profiles by heating beneath fires. In the context of a cave this is extremely likely to be the result of fires of anthropogenic origin (Hunt *et al.*, 2007; Figs S8.2, S8.4, S8.8, S8.9, S8.14). This evidence is supported by the frequent presence of burned phytoliths.

Forest-edge habitats are important for many of the key tuberous and leafy species gathered for food by local people today, as well as attracting game such as pigs, and were probably widely available in the Late Pleistocene around the Gunung Subis during phases with relatively open environments. These habitats would not have been available during the heavily forested warmer and wetter episodes. Preliminary palynological evidence from the Great Cave suggested that humans in the Late Pleistocene had burnt vegetation near the cave to maintain forest-edge and open habitats (Hunt *et al.* 2007), and the results reported here substantiate this observation: from the lowest samples studied, dating to *c.* 53,000 BP, upwards through the Late Pleistocene sediment sequence, virtually every phase of afforestation identified in the palynological record is accompanied by numerous pollen grains of *Justicia* (Acanthaceae), which today follows fire, especially in wet forest and mangroves. Interpretation is complicated because of the extremely high concentrations and sometimes tetrads and clumps of *Justicia* pollen

in some assemblages, which suggest that a vector of some sort was bringing flowers of this species into the cave, as discussed above. Regeneration and herbaceous taxa are regularly observed during forest phases, substantiating the idea that disruption of vegetation was occurring. Regeneration taxa such as bamboos, *Macaranga* and at times grasses and other herbaceous plants are visible at times in the phytolith assemblages, which all relate to interstadials. It is thus very likely that at these times people burnt back the forest to create forest-edge and regenerating habitats. Secondary forest was maintained by many tribes in the early 20th century (Gibbs 1914) and is still significant in the economy of people such as the Kelabit (Janowski 2003).

The findings at Niah chime with evidence for Late Pleistocene anthropogenic biomass burning in New Guinea and Australia (Haberle 1998, 2005; Haberle *et al.* 2001; Hope 1998, 2009; van der Kaars *et al.* 2000; Kershaw *et al.* 2001, 2002; Summerhayes *et al.* 2010; Wang *et al.* 1999). Modification of forest appears to have been a very ancient practice amongst modern humans in Southeast Asia and Australasia.

Arboriculture and agriculture

The presence in Early Holocene sediments at Loagan Bunut of *Metroxylon*, a sago palm derived from New Guinea, points to translocation of this species over some 3000 km of sea – definite evidence for human agency. Its regular association with other sago species – *Eugeissona*, *Arenga* and *Caryota* – is highly suggestive that a form of arboriculture was being practised, though whether this was ‘plant-and-leave’ or part of a more intensive system is impossible to determine at present. The appearance of *Metroxylon* in Borneo is assumed to have followed the start of its use in New Guinea, although there is currently no other evidence for this. It is very likely that the intense burning visible in the high counts for thermally mature material in the Loagan Bunut core relates to human agency, presumably to a continuing regime of vegetation control through fire. The field sediments at the two Niah pollen cores and the high incidence of often-burned rice phytoliths at Loagan Bunut (Hunt & Premathilake 2012; Hunt & Rushworth 2005b) all point to a form or forms of rice cultivation being practised over virtually the whole Holocene, although whether this involved morphologically cultivated or wild species is at present extremely unclear, as is the nature of the cultivation practices (Barker *et al.* 2011a). Traditional agricultural forms in Borneo include forest-gardens or *simpukng* (e.g. Latinis 2000; Mulyoutami *et al.* 2009; Sellato 2001; Wiersum 1997) and it is likely that these practices

have had a long prehistory despite being virtually invisible to palaeoecological research. Evidence for forest modification by fire during the Early Holocene is known from upland Borneo (Jones 2012; Jones *et al.* 2013), Sumatra (Flenley & Butler 2001; Maloney 1980, 1999a, 1999b), Cambodia (Maxwell 2004), and Thailand (Kealhofer 2003; Kealhofer & Penny 1998), but the lack of extensive multi-proxy work in these regions means that the causes of these disturbances have not been firmly identified. They do, however, point to very widespread patterns, and a deep history, of human engagement with and management of rainforest (Hunt & Rabett 2014). As noted by Lilian Gibbs as long ago as 1914, the composition of enormous areas of the region’s rainforests is the result of millennia of management practices.

Conclusion

This account of the palynological and phytolith work of the Niah Caves Project makes it very apparent that research efforts here are far from complete: there are many sampling ‘gaps’. Numerous limitations have also been made apparent, most notably that sampling for the various proxies did not always coincide. Even so, this research has transformed our understanding of the Late Pleistocene and Holocene environments and patterns of human activity in lowland Borneo.

The palynological work in the cave has allowed the refinement of dating by tuning pollen-based climate changes against global records and has thereby pushed the dating of the initiation of human activity in the cave to before c. 53,000 years ago. It has also enabled a climatic sequence to be identified. It seems that temperatures during interstadials permitted the development of lowland floras fairly similar to those of recent times, although often lacking the modern raised bog vegetation. It is thus probable that temperatures of 25°C, possibly as much as the present day 28°C, were achieved. Vegetation during interstadials was rather variable, largely dependent on relative humidity, with some phases being significantly drier than present. Vegetation during some stadial episodes in lowland Borneo was far more open than suggested by current models, with open environments widespread, but other stadials, including the LGM, were characterized by forest vegetation, although highly disturbed and rather open. In the lowlands around Niah, during some stadials the vegetation included species now present 1000–1600 m above sea level in Borneo, suggesting that mean temperature had fallen to 19–22°C (compared with the modern mean of 28°C). It is likely that temperature change was at times so rapid that trees were killed and the forest canopy

disrupted, allowing a foothold for regeneration taxa. The absence of altitudinally restricted taxa during some probable stadials could indicate that there was a lag in the migration of many species during episodes of rapid temperature change, but many taxa seem to have been able to migrate extremely rapidly.

There is a range of evidence that people actively managed vegetation using fire to create forest-edge habitats during interstadials, from the beginning of the known sequence *c.* 53,000 years ago, and that this pattern persisted in the Holocene until at least 6500 years ago at Loagan Bunut, and probably into sub-recent times at Niah. This provides a partial explanation of how people could colonize and use tropical forest environments during the Late Pleistocene. During the Holocene, the management of vegetation seems to have been transformed into a system involving

sago palms and rice, contemporary with if not earlier than the precocious agriculture based on bananas and tuberous plants known from New Guinea (Denham 2011; Denham *et al.* 2003, 2004; Haberle *et al.* 2012), ancient practices that were still present in Borneo until the recorded past and that may survive in some form today.

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The authors would like to acknowledge the seminal contribution of Bernard Maloney to Southeast Asian palynology. It was originally intended that he would analyse the landscape cores taken at Niah and he worked with the team in 2000 (Volume One, Fig. 2.44), but he tragically died suddenly and prematurely a few weeks later.