Shorelines, mangroves and human environments in the coastal lowlands of north-eastern Borneo during the Late Quaternary

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Introduction

In this chapter we highlight the importance and value of situating archaeological investigation into a study of its wider geographical and ecological context: putting the people into the landscape. We take the Niah Caves in Sarawak and their environmental setting on the former coastal lowlands and shorelines of north-eastern Borneo as the central subjects of our discussion (Fig. 1; Barker 2005; Barker *et al*. 2002, 2005, 2007, 2013, in press). The paper explores the topographical complexity and biogeography of the ancient coastal terrains over the last 70,000 years. Its two closely-related themes concern: (i) recent hydrographic-, seismic- and borehole evidence for different terrains and habitats in these now-vanished coastal lowlands; and, (ii) palynological evidence of the nature and past locations of mangroves, from the sequence in the West Mouth of the Great Cave of Niah (3°49′09″N; 113°46′42″E: Figs. 1 & 2) and other literature.

Figure 1 about here

Such issues have arisen at other archaeologically-important coastal lowland caves in Southeast Asia. They were emphasized by work that suggested the profound importance of mangrove habitats as sources of food, materials, fuel, resources and medicines for people over the last 50–60,000 years (Pope & Terrell 2008; Rabett 2005). Such studies often demonstrated the limited long-term survival of material from mangroves within the cave sedimentary environment. Nevertheless, from the Late Quaternary sequence in the West Mouth of the Great Cave of Niah (Fig. 1), Rabett identified three bone edge-tools from before *c*.40 ka BP. He associated these with the exploitation of mangroves during a period when eustatic sea level was in the order of 50 m below present (Fig. 2). Subsequently, during the Last Glacial Maximum (LGM, *c*.23–18 cal. BP) sea levels fell to *c*.130 m below present. After this episode, relative sea level rose rapidly (Fig. 2) reaching possibly two to five metres higher than present in the Early Holocene. At that time, mangroves were abundant and close to the Great Cave (Hunt *et al*. 2012). There is abundant evidence at Niah and other sites in the region for coastal human activity from the Terminal Pleistocene to the Mid-Holocene. For example, substantial assemblages of bone tools were designed for use at the shoreline (Rabett 2005). Studies of growth-increment geochemistry of the Early Holocene shells of edible estuarine and mangrove molluscs have demonstrated variations in water-flow caused by fluctuating monsoonal runoff and drought (Stephens et al. 2008).

Figure 2 about here

The modern coast, mangroves and coastal lowlands seawards of the Great Cave

The West Mouth of the Great Cave of Niah opens on a cliff face of a limestone gorge in the limestone massif of the Gunung Subis. Opposite the Hell Trench excavations the entrance is *c*.50 m above current sea level, but it is >10 m lower to the south. The cave is approximately 11 km inland of the sweeping and sandy southern shores of the South China Sea (Admiralty Chart 1988) with their fringing vegetation of she-oaks and palms growing on a linear complex of low sand dunes breached at the Kuala (estuary) Niah by the Sungai (River) Niah (Fig. 1). The dunes are both modern and Pleistocene, the latter with leached podsols and kerangas vegetation (Brunig 1974).

Offshore, the submerged continental shelf mainly comprises a long, gentle seaward-sloping ramp, with a relatively smooth drape of muddy sediment (Hiscott 2001) to depths of *c.*130 m at *c.*80 km from the coast. The slopes are occasionally interrupted by shoals caused by the outcrop of bedrock. At low sea, these would have been hills. There are also many partially-infilled basins (Sathiamurthy and Voris 2006). Beyond ~*c.*80 km from the shore, the gradient increases and the continental slope descends to over 2750 m in the North West Sabah Trough – Palawan Trench.

Between the modern shoreline and the Great Cave, the terrain alongside the Sungai Niah is relatively flat; rising to 5–10 m above mean sea level. The tidal range at the coast is *c.*2–2.5 m. Saline waters extend to immediately south of the town of Batu Niah where they are blocked by bedrock exposures on the river bed. During the highest tides, brackish water extends up the Sungai Tangap and the Sungai Subis, almost to the Great Cave. The river banks close to the sea are lined with inter-tidal mangroves; further inland are back-mangroves. Inland, freshwater streams flow through large lowland swamps with ombrotrophic raised bogs and lithocarp riparian forests above *c.*7.3 m above sea level. Further east, tidal waters extend up the River Baram and its tributary the Tinjar and almost reach Loagun Bunut, the only sizeable freshwater lagoon in Sarawak (6.5 km^2) at *c.*11.5 m above mean sea level (Fig. 1) and over 115 km upstream.

The Gunung Subis is a reef of Miocene age, subsequently modified by karstic processes, now covered in mixed dipterocarp and limestone rainforest. These forest-types grow on the thin humus and pockets of shallow, clay-rich soils. The climate is hot, wet and monsoonal; but prone to intermittent and sometimes prolonged drought (Barker *et al*. 2013, Hazebroek and Morshidi 2001).

The ancient coastal terrain

Assumptions about the now-submerged terrain seawards of the Great Cave tend to be dominated by palaeogeographic reconstructions of the LGM, especially those derived from consideration of bathymetric maps and from seabed coring 600 km WNW of Niah in the delta of the former North Sunda-Molengraaff River, (Fig. 1: Molengraaff 1921; Wang & Li 2009). Especially impressive at the regional scale are the vast coastal plains that bordered the western parts of the much diminished South China Sea during the LGM. Nevertheless, in addition to low hills such as the modern islands such as Natuna Besar (Fig. 1), there was much local geomorphic diversity on these coastal lowlands. The precise nature and distribution of these environments altered through the Pleistocene as sea level and climate changed, and geological, oceanographic, geomorphic and ecological processes had their topographic consequences.

Soils

There was significant development of soils, including laterites, which are characteristic of intensive, protracted weathering in hot wet tropical climates. Elsewhere there is evidence of relative aridity. The narrow coastal lowlands north of the Great Cave were relatively steep during low sea, suggesting relatively good overall drainage.

Fluvial landforms

The major drainage was the North Sunda River formed of the Molengraaff River and its major tributaries: the nearly 2000 km Chao Phraya drainage from the north, and the Baram, Rajang and Kapuas, all draining from Borneo (Fig. 1). Valleys will have incised during episodes of falling and low sea level. The Baram, and presumably the Sungai Niah, had incised valleys that by-passed abandoned former deltas. A quasi-linear feature offshore from Niah might be a (partially) buried incised river channel of the Sungai Niah. Seismic studies of the sequences beneath the smooth topography of the modern sea bed indicated that generations of incised fluvially-eroded landforms are associated with low sea at the LGM and previous stadials (Fig. 3a). Where large rivers entered the sea there were deltas with complex sedimentary environments. Offshore, there were pro-deltaic and deep-water marine sequences. Coring demonstrates that, the Early Holocene sea extended far inland to Loagun Bunut, which is now a freshwater lake (Fig. 1; Hunt & Premathilake 2012; Hunt *et al*. 2006). At times, the Gunung Subis was part of a headland that extended far into the ocean (Fig. 4a). The rivers of this region discharge the world's highest known sediment loads into the adjacent seas (Hunt & Premathilake 2012; Hunt *et al*. 2006; Sidi *et al*. 2003). Consequently, during the Mid-Late Holocene, tidal waters were infilled and the Niah area was no longer a promontory.

Figure 3a-c about here

Tectonic depressions

Tectonics are likely to have led to significant topography and probably the large basins – some many kilometres wide, sometimes >20 m deep – recently identified beneath the modern sea floor by Sathiamurthy & Voris (2006) from high-precision, satellite-based hydrographic surveys. Compressional tectonics on the Baram delta-front sediments led to synclinal basins which have accumulated 'ponded sediments' (Hutchison 2004). Further north, inversion tectonics has led to mud and shale diapirs and intervening topographic lows off Brunei (Morley *et al*. 2003). On the offshore deltaic sediments, gravity-driven normal faulting is important (Hiscott 2001; Roberts and Sydow 2003). Fig. 3c indicates downthrows of >100 m on Late Holocene faults in the Mahakam Delta sequence. The surface expression of such faults would be linear basins. If sudden and submerged, such faulting could have prompted tsunamis. Rifting has also led to topographic lows off Sabah (Hutchison 2004, 2005). At times of low sea, these landforms would have been variously occupied by freshwater or inlets of the sea (Figs. 4a & b).

Figure 4a and b about here

The nature and connectedness of the many habitats that would have developed within the basin-like landforms are still unknown and there is an almost total absence of published coring or seismic data. As a result, neither their origin(s) nor antiquities are established, but the judgment is that many pre-date the Late Pleistocene. Their margins are likely to have notable 'archaeological potential' (*sensu* Ward & Larcombe 2008): they would have been attractive to people, offered access to a wide range of terrestrial and aquatic habitats, including mangroves, formed route-ways for people and animals, and are likely to have been the places where geoarchaeological processes contributed to the preservation of remains. These margins are, potentially, also readily recognisable in seismic studies.

Coastal reefs.

A notable feature of the ancient coastal lowlands is the presence of distinctive reef terrain. Two types of distinctive landform were present, both of likely significance to people and wildlife. They are (i) bioherms, and; (ii) shelf-edge reefs (Fig. 3). These landforms may be completely or partly buried nowadays beneath a blanket of sediment or are submerged offshore. They are best known from the Quaternary sequences of the Mahakam Delta in the Makassar Strait (Figs. 3b & c, Roberts and Sydow, 2003) and are also reported on the continental shelf west and north of Sabah and Sarawak (Hutchinson 2004, 2005).

Bioherms, formed by the green marine alga *Halimeda*, grew singly or in groups, on slight topographic highs upon gently sloping erosional surfaces. They formed during warm stage marine transgressions in locations unaffected by the influx of muddy riverine sediments. On the East Borneo continental shelf, their last stages of development were during marine transgressions after *c*.30,000 years ago, and the Late Glacial/Holocene transgression. At times of low sea, their distinctive, mound-like topography would have overlooked the exposed coastal plains or emerged from shallow waters. Bioherms might be up to 3 km across and *c*.30 m high, with steep sides. As they are composed of limestone they will have had caves and excellent surface drainage. They are flanked by thick accumulations of limestone detritus (Fig. 3b). Some bioherms are associated with 'moats', the result of the confined topography between adjacent mounds concentrating water scour on the sea-floor (Roberts & Sydow 2003). During low sea, these would have formed linear freshwater lakes at the foot of limestone hills.

More prominent at the coast would have been shelf-edge reefs, found, for instance at the edge of the East Borneo continental shelf (Figs. 1 & 3c) and off Sabah (Hutchison 2005; Roberts & Sydow 2003;). They are located nowadays with their bases at depths of >100 m, in the clear, nutrient-rich up-welling water along the Makassar Strait and North Borneo Trough. Here they form significant coral reefs, *c*.1 km across, and aligned parallel to continental shelf margin. They may have very steep sides, large adjacent fans of coral debris, and adjacent moat-like depressions. These reefs grew at times of Quaternary high sea. During the lowest sea level of the LGM, these ancient reefs would have produced tower karst reaching >100 m above adjacent topography. When partly submerged they were large reefs sheltering coastal lagoons. They are likely to have supported vegetation akin to that on the Gunung Subis and may have been visited by people and animals. Their limestone lithology suggests karstic landforms such as small caves and fissures. Except for those flatter summits which the seismic data suggests were washed by storm waves, their archaeological potential appears good. The complex continental shelf terrain that emerged from reef building and normal faulting is shown in Fig. 3c.

All of this geological and geomorphic research has emphasized the morphological complexity – and perhaps the unexpected character – of the coastal terrain at different times over the last 70,000 years in northwest Borneo. This conclusion is further emphasized if smaller topographic features, invisible to satellite-based surveys (<2 km in diameter), are considered. Ancient coasts were more complicated than the current smoothly curving beaches and dunes aligned (generally) parallel with seafloor isobaths (Fig. 1, Admiralty Chart 1988). At the spatial scales that mattered to most human activity, many of these Pleistocene low sea shorelines were not 'shorter' compared with their modern equivalent, as suggested by Dunn and Dunn (1977), neither were they backed by seemingly infinite areas of flat and uniform terrain. Rather, the shorelines were longer, complex, with many tidal inlets and lagoons, and sometimes overlooked by prominent limestone hills, with freshwater habitats in the hinterland. The only possible, partial, exception is that during the LGM, when eustatic sea level was approximately steady for several thousand years, there may have been some more substantial form of relative stabilisation and coastal 'smoothing'.

A consequence of this initial analysis is that a reliable picture of the past terrain, hydrology, biogeography and human resource-base of these former coastal lowlands, north and east of the Great Cave, is more than can be gained by simply combining hydrographic maps with the course of sea level change. Extrapolation of modern biogeography onto a simple palaeotopography is also likely to be inadequate. These points were emphasised by Voris 2000 (also see Cannon *et al*. 2009; Kershaw *et al*. 2001; Sathiamurthy & Voris 2006). A further conclusion is that over the last 70,000 years, many locations would have been far more favourable for the growth of mangroves than might be anticipated from the adoption of the 'simple, smooth-sweeping, shoreline model': and, sometimes, the sea would have reached close to the Great Cave of Niah (Fig. 4).

Mangroves – past and present

The presence of mangroves is empirical evidence for the former position of shorelines and sea levels. Nowadays, tidal inlets and embayments – of the types hypothesised above to have existed in this region – support substantial mangrove vegetation. Taphonomic study within mangrove habitats shows that modern pollen assemblages can reflect spatial variations in species composition (Mao *et al*. 2006). Such evidence led mangroves to be described as a 'perfect indicator of coastline changes' by Wang *et al*. (2008, 2070). Studies of modern mangroves suggest that they can probably accommodate the current rate of rising sea levels, as long as natural adjustment is not impeded by 'permanent' barriers such as modern human settlements and hard-engineering structures (Blasco *et al*. 1996; Chan & Ong 2008; Ellison 2008; Wang *et al*. 2008). Such capacity to adjust indicates that mangroves would have coped with past rapid rates of sea level rise and geographical change (Fig. 2 and 4).

Reconnaissance boat survey in 1999-2001 showed that away from modern centres of human activity, the (estuary) Kuala Niah and its main entrant river, the Sungai (River) Niah, are fringed by dense mangroves including *Avicennia*, *Sonneratia*, *Rhizophor*a, *Bruguiera* (respectively in Malay – Api-api; Pedada; Bakua minyak / Bakau kurap; Berus). In optimal growing conditions in Peninsular Malaya, mangroves can be 45 m high, but reach only 4–5 m in the Kuala Niah. The mangroves are distinctly zoned with an outer sandy *Avicennia-Sonneratia* zone, and an inner *Brugiera-Rhizophora* zone on slightly higher and muddier tidal-flats (Fig. 5). The less-frequently inundated back-mangrove habitats have shrubs and trees of *Kandelia* and *Oncosperma* (Nibong palm-tree) with *Acrostichum aureum* (the mangrove fern: Piai Raya Laut), which tolerates brackish water, requires freshwater to become established, but does not tolerate sustained freshwater flooding. Brackish-water palms of the genus *Nypa* (Nipah) form dense stands along the Sungai Niah, immediately downstream of Batu Niah, where there is significant freshwater influence (Fig. 1). *Nypa, Bruguiera* and the freshwater mangrove *Luminitzera* extend a few kilometres upstream of Batu Niah to where bedrock outcrops on the river bed prevent major saline intrusion. All these modern mangrove habitats occur within 11 km of the Great Cave.

The taxonomic and habitat zonation of mangroves along the Kuala Niah correspond with those in the estuaries in northern Borneo and adjacent areas (summarised in Fig. 5: see also Blasco *et al*. 1996; Brunig 1974; Chai 1975a, b; Chan & Ong 2008; Dahdoubh-Guebas & Koedam 2008; Hazebroek & Morshidi 2001; Ramsar n.d; Satayanarayana *et al*. 2010; Sidi *et al*. 2003; Spalding *et al*. 1997; Sun *et al*. 1999, 2000; Tomascik *et al*. 1997; Tomlinson 1986; Whitmore 1990; Woodroffe 1990, 2000, 2005; Woodroffe & Grindrod 1991). This provides a model of the composition of Late Pleistocene mangroves in this area.

Figure 5 about here

Mangrove pollen in and adjacent to the Great Cave

Whilst the earlier excavations of Tom Harrisson in the West Mouth focussed upon artefacts, vertebrates and molluscs (Harrisson 1965, 1970), the eminent palynologist Professor Jan Müller visited the excavations in the 1950s and found significant mangrove pollen in the exposed sediments, including characteristic mangrove taxa such as *Avicennia*, *Sonneratia*, *Rhizophor*a, *Brugeria*, and *Nypa*: all genera found by the modern tidal river. Müller was an expert on the mangroves of Borneo, and on their modern and fossil pollen. His identifications are not likely to have been in error (see Anderson & Müller 1975; Müller 1964, 1969, 1978; Müller & Caratini 1977; Müller & Hui-Lui 1966). Nor is it likely that he permitted any form of contamination. He marked one stratum in which he discovered mangrove pollen with a labelled and sealed plastic container containing a further sealed description of his finds and their stratigraphic location. This was found in 1999 and subsequently interpreted to be within the body of sediments designated 'Lithofacies 2 – the Red Brown Silts and Sands' (Gilbertson *et al*. 2005).

Subsequently, Hunt *et al*. (2007, 2012, in press) identified mangrove pollen at this point and elsewhere in the West Mouth sequence. The mangrove pollen had at times the same range of taxa and thus habitats as found in the area today (Figs. 5 & 6). But Hunt *et al*. (in press) also found marine dinocysts and estuarine diatoms, also probably associated with mangroves. This palynological work was based on close interval sampling of well-cleaned exposures of known stratigraphic significance, where the sediments studied had not been affected by episodes of local erosion, bioturbation and mass-movements evident elsewhere, or by contamination. It located the same habitat types that were inferred from the animal remains from Harrisson's excavations (Cranbrook 2000). In addition to mangroves, however, the palynological work also found layers containing pollen from intermittent drier episodes. There was also good evidence for the occasional impact of fire (Barker *et al*. 2002; 2007; Gilbertson *et al*. 2005; Hunt *et al*. 2007; 2012).

The stratigraphic distribution of mangrove pollen and marine microfossils, in relation to estimated ages and the global palaeoclimatic record are summarised in Fig. 6. This chronology is underpinned by lithostratigraphic studies supported by radiocarbon and Th/U dates (Gilbertson *et al*. 2005). Comparisons between Figs. 2, 4 & 6 are informative. The percentages of mangrove pollen are greatest in the early Holocene when there is much local evidence for the immediate proximity of mangroves, including mangrove peats and clays close to eastern entrances to the Great Cave (Hunt & Rushworth 2005b).

Figure 6 about here

There were sustained, if lesser influxes of *Acrostichum* between 17 and 13 cal. KBP. This was a time of global warming, and the local re-establishment of the monsoon (Partin *et al*. 2007) with very rapid eustatic sea level rise and marine transgression, with the result that mangrove habitats may well have come within *c*. 10–15 km of the Great Cave (see Fig. 4). A distinctive peak in mangrove pollen (notably *Avicennia* which favours sandy substrates and exposed habitats) is indicated at about 38 cal. KBP, with a further lesser peak in concentrations around *c*.42 cal. KBP – both periods marked by a rise in sea level (Fig. 2). The presence of the widest suite of mangrove taxa, between *c*.46–54 uncal. kbp, likewise matches other periods of relatively high sea levels. A distinctive feature is the abundance of *Avicennia* before 35 cal. KBP. This genus favours the (more energetic) open and sandy substrates and was notable in the well-studied ancient mouth of the North Sunda River during the LGM (Fig. 1). Mangrove taxa that favour more muddy and sheltered habitats dominated in the Niah pollen sequence after 17 cal. KBP.

Conversely, the long period of the sustained lowest eustatic sea levels during and before the LGM (Fig. 2) was not associated with the deposition of mangrove pollen and marine microfossils in the Great Cave. In general, mangrove pollen and marine microfossils are missing from the cave sequence whenever the eustatic sea level was lower than *c*.50 m below present. Breaks in the sequence correspond with the minor sea level peak at *c*.28–30 cal. KBP.

The taphonomy of modern mangrove pollen in the West Mouth of the Great Cave

At present, there is no sedimentary evidence that mangrove habitats were immediately adjacent to the entrance to the Great Cave except during the Holocene. Whilst the palaeotopographic work described above indicates that suitable habitats may well have occurred locally at particular sea level stages (Fig. 4), the mangrove pollen and the marine microfossils found in the West Mouth appear most likely to have been introduced into this cave by taphonomic processes that reflected local topography, habitat structure and form, prevailing winds, animal vectors including different species of bats and birds. It is also impossible to rule out roles for other animals or people (see Coles *et al*. 1989; Maher 2006).

The processes that transport and deposit pollen in the West Mouth are comparatively well-known and documented (Hunt & Rushworth 2005a). Mangrove taxa comprised 5 to 45 per cent of the modern pollen input to the West Mouth and their composition corresponds to those of modern mangrove communities nearby, described above. The myriad bats that roost in the Great Cave provide a constant the drizzle of faeces which, with some input from birds, creates the cave's most characteristic infill deposit – guano. Guano can be rich in mangrove pollen (Hall *et al*. 2002; Harrisson 1966; Hunt & Rushworth 2005a; Leh 1993; Leh & Hall 1996; Leh & Kheng 2001; Maher 2006). The cave nectar bat, *Eonycteris spelaea* (Dobson) inhabits the cave (Hazebroek & Morshidi 2001) and is known from the Late Quaternary deposits (Aldridge & Medway 1963; Cranbrook 2010; Medway 1966). This species is important as a gatherer of pollen - it will fly long distances to feed upon flowers of the mangrove *Sonneratia*. It has been observed to range as far as *c*.80 km into lowland rainforests to the north east of the Great Cave (Start 1974; Yumoto 2000) and a sample of its faeces from the cave contained over 60% *Sonneratia* (Hunt *et al*. in press). Further, the wrinkle-lipped bat (*Chaerephon plicatus*) which forages over coastlands is common in the Late Quaternary deposits of the Great Cave. It became extinct at Niah in the 17th Century AD (Stimpson 2012). Any screening of the cave entrance by trees and hanging vegetation is likely to have enhanced the proportions of pollen of bat-pollinated mangroves accumulating on the cave floor, relative to anemophilous taxa. Other mangroves are pollinated by variety of animals including flies, wasps, birds, butterflies, moths and especially bats (Tomlinson 1986) but *Rhizophora* and *Avicennia* are wind-pollinated. Their pollen is most common in the cave entrance sequence before *c*.37 cal. KBP. Outside the cave, within adjacent dense dipterocarp and swamp forests the mangrove pollen from surface leaf-litter samples comprised only 0 to 0.5% of the total pollen (Hunt & Rushworth 2005a). A sample of surface mud laid down by a small stream flowing through closed riverine woodland close to the National Park HQ also contained a very small percentage of mangrove pollen, pointing to the secondary dispersal of this pollen upstream of the 'visible' saline limit by tidal flows (Hunt & Rushworth 2005a).

In summary, a combination of meteorological, habitat and animal vectors similar to those observed in the present day would have been capable of introducing mangrove pollen into the Great Cave, over the distances and different coastal geographies suggested by Fig. 4, with wind-transported mangrove pollen being more important in those pollen assemblages that pre-date *c.*37 cal. KBP. The marine microfossils might have been introduced into the cave by animal or human vectors after contact with exposed tidal muds.

Mangrove pollen in Late Quaternary marine and inshore sequences in Southeast Asia

Mangrove pollen is carried seawards by river discharges and ebb tides, sometimes travelling hundreds of kilometres to be deposited on the sea floor, exceeding 20 per cent of assemblages from 50–300 km offshore from Sarawak (Fig. 1; Sun *et al*. 1999, 222). Upstream dispersal of marine microfossils probably occurs in the tidal waters of the Sungai Niah, as described in other tidal estuaries by Trigueros and Orive (1999).

Mangrove pollen is widely reported regionally from many Late Quaternary sites ranging from deep-water offshore to terrestrial (Fig. 1: see Anderson & Müller 1975; Ellison 2008; Grindrod *et al*. 1999; 2002; Gremmen 1990; Hunt *et al*., 2007, 2012; Hunt & Premathilake 2012; Hunt & Rushworth 2005b; Ijiri *et al*. 2005; Kamaludin & Azmi 1997; Mao *et al*. 2006; Sun & Li 1999; Sun *et al*. 1999, 2000; Supiandi 1990; Tanabe *et al*. 2003a, b; Van der Kaars 1991; 2001; Wang & Li 2009; Wang *et al*. 2008;

2009; Wong 2005; Wong *et al*. 2003; Woodroffe & Grindrod 1991; Zheng & Li 2000). It was most abundant during times rapid marine incursion, in offshore cores and the Great Cave (Figs. 2 & 4). Between *c*.30 to *c*.24 cal. KBP, (Fig. 2) the mangrove communities declined on across the region, as they 'followed' the rapidly regressing sea (Grindrod *et al*. 2002; Wang *et al*. 2008). The interstadials between *c*.30 and *c*.50 cal. KBP are also associated with mangroves in the Malacca Straits and South China (Kamaludin & Azmi 1997; Zheng & Li 2000). The taxonomic composition of mangroves from the region appears to have been stable, except for the local extinction of *Sonneratia* in South China during the Late Pleistocene (Zheng & Li 2000). Thus the changing abundance and location of mangroves in the wider region over the Late Quaternary appears to correspond closely with the palynological record in the Great Cave (Fig. 6).

Conclusions

The modern shoreline and coastal lowlands north and east of the Great Cave of Niah are relatively simple in form. Reconstructions of past coastal topographies and of environmental processes suggest that inter-tidal habitats and mangroves were found far closer to the Great Cave on several occasions during the Late Pleistocene than might once have been anticipated.

During interstadial high sea episodes, sandy exposed habitats dominated by *Avicennia* appeared close to the cave, with sheltered back-mangroves also nearby. This presents a very different shoreline configuration to what is there currently, with the Gunung Subis massif standing adjacent to an exposed coast.

Rapid mangrove retreat took place occurred during times of rapid regression and at low sea level stands. The frequent Late Pleistocene fluctuations between *c*.70 m and *c*.30 m below modern sea level will have repeatedly produced significant coastal change. Incised channels and tectonic depressions were inundated and then abandoned by the sea; limestone reefs partially or completely emerged to form islands enclosing lagoons, or karst towers on the mainland. The habitats of the coastal lowlands were topographically-controlled and formed a complex of wetlands and dryland. After the LGM, the diversity of shoreline and coastal plain habitats remained high into the Early Holocene, when mangrove pollen is found in the largest quantities in the Great Cave. The emergence of modern coastal geography and biogeography appears to be a product of the more recent Holocene. Overall, the types of mangrove dominant in the Holocene at the Great Cave correspond to those commonest in the area today. These taxa favour muddy sheltered locations, and some are bat-pollinated. This is at least in part the response of modern mangrove communities to enormous sediment flux resulting from erosion caused by rapid down-cutting of the tectonically-rising interior of the island (Dykes & Thornes 2000) plus clearance and agricultural development (Douglas 1996) and may indicate that similar levels of erosion are not new in the Holocene of Borneo.

Long sweeping shorelines, like the present, could have started to develop during the very low sea levels of the LGM when the open sea was *c*.80 km north of the Cave, with tidal waters extending a limited distance inland along former inlets such as the proto-Niah. Mangrove pollen at low sea was not recorded in the West Mouth: suggesting that the shorelines of the time were beyond aerial or animal-vector dispersal to the Great Cave. The exposed continental shelf during low sea was not smooth and uniform. It was topographically and most probably ecologically diverse – with many resources for the people of the time.

There is a consistent relationship over the Late Quaternary between the presence of mangrove pollen in the Great Cave and sea level trends, but there is no simple linear relationship. There is a surprisingly good relationship between the frequency of mangrove pollen from the Great Cave and sea levels above -55 m below datum, and fluctuations in sea level between *c*.35 and *c*.55 uncal. kbp correspond with fluctuations in the abundance of mangrove pollen in the cave. This pattern broadly corresponds to those noted elsewhere in the region. The actual distances from the Great Cave to mangrove habitats at the modern day and the Mid-Holocene have been established by taphonomic and coring studies. The modern long-distance pollen-taphonomic mechanisms for mangrove pollen are evident in ecological research.

This study is essentially a reconnaïssance of the changing palaeo-economic and biogeographical potentials of the ancient coastal landscape. In future, if opportunity arises through coring and seismic studies offshore, it will be important to identify potentially-suitable mangrove and wetland habitats, and the biogeography of the people who lived in the former coastal lowlands of northeast Borneo.

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Graeme Barker has always viewed archaeological investigations in their wider geographical and ecological contexts. His work in economic archaeology takes account of the changing degrees to which human behaviour related distinctly to key resources such as water, wood, shelter, plants and animals. As ancient geography changed, so these resources and their use will also have changed. This chapter enlarges on these themes with relation to the findings of the Niah Caves Project, which he directed. We thank the members of the AHRC-funded Niah Cave and the British Academy-funded Loagan Bunut Project, especially Graeme Barker, Garry Rushworth, Rasnathiri Premathilake for help in field and lab and for discussion. We thank the Chief Minister's Department of Sarawak for permission to undertake the fieldwork at Niah, and the staff of Sarawak Museum, especially its Directors Sanib Said and Ipoi Datan, for their support and encouragement. DDG acknowledges the support of (i) a "Distinguished Visiting Scholarship" research grant from the Faculty of Humanities and Social Sciences of the University of Adelaide, and (ii) a grant from the British Institute for Research in South East Asia, that enabled him to visit the former excavations in West Mouth of Great Cave and the mangroves of the Niah region in 1999. We thank Libby Mulqueeny for cartography

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Figures:

Figure 1, The geography of Sundaland and the South China Sea at the Last Glacial Maximum (c.23–18 cal. KBP) when eustatic sea level was at the *c*.120–130 m isobath. (after Voris 2000; Hanebuth & Stattegger 2003; 2005; Hiscott 2001, 2003; Molengraaff 1921; Sathiamurthy & Voris 2006; Staub & Esterle 1993, 1994).

Figure 2, The general course of eustatic ocean level change in the South China Sea over the last 70,000 years, from geomorphological evidence in this region: the pattern of change is broadly similar that reconstructed from more distant sources (after Sathiamurthy & Voris 2006, Aharon & Chappell 1986; Bird *et al*. 2004, 2007; Chappell *et al*. 1996; Chappell and Polach 1991; Hanebuth *et al*. 2000; Rimbamann 1992; Tamura *et al*. 2009; Thommeret and Thommeret 1978; Tija 1980, 1996; Tija *et al*. 1983, 1984, Woodroffe 2005: Woodroffe & Horton 2005; Siddall *et al*. 2003).

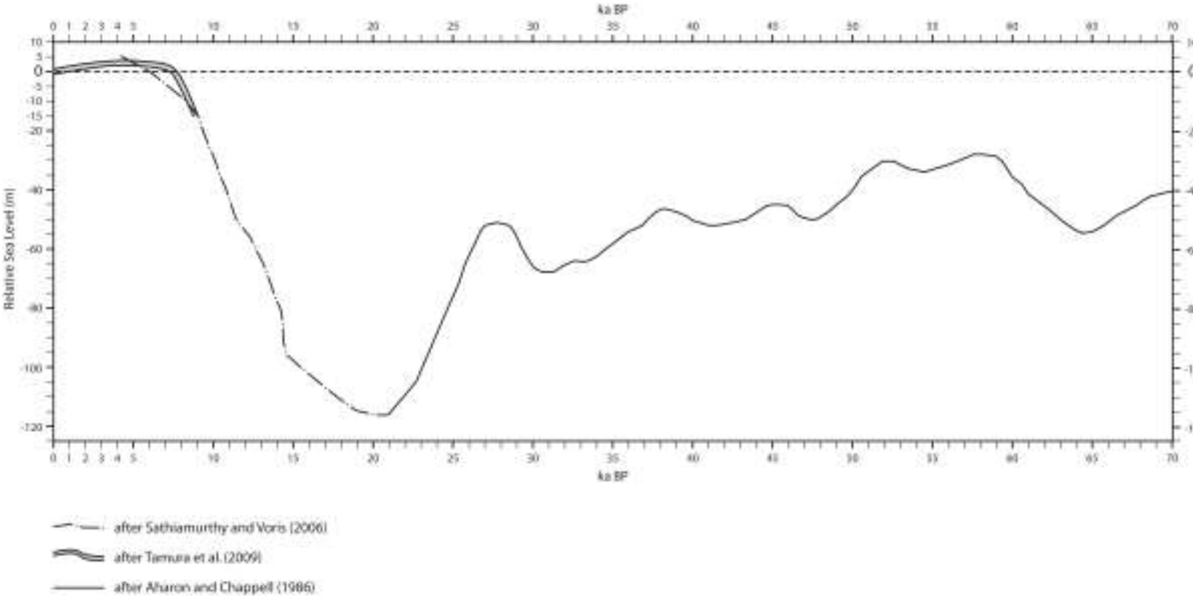
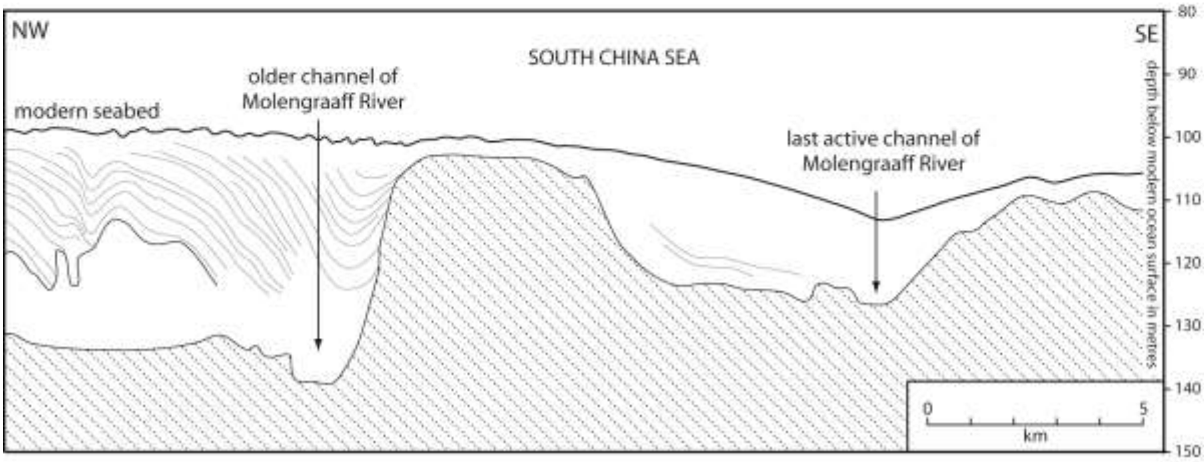
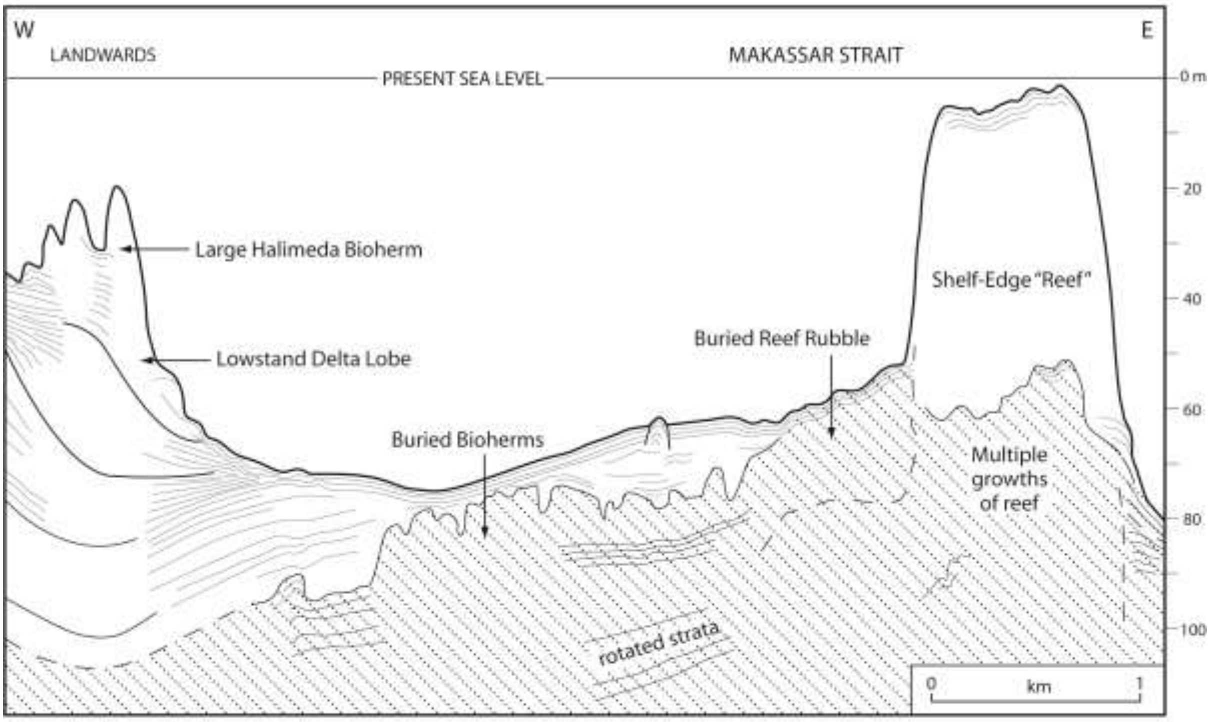


Figure 3a (upper), A NW to SE seismic profile across the former mouth of the Molengraaff River, *c*.18–21 cal. KBP: showing that at this time it flowed as a meandering river in a channel 7 km wide. This channel had floodplain relief of 1–6 m, was bounded by relatively steep slopes *c*.20–28 m high, with flatter terrain inland. The river-mouth was relatively mud-free. Approximately 10–15 km to the north of this estuary, there was a partially infilled steep-sided riverine *older* channel *c*.5 km wide with complex dipping fluvial infill sediments. This older channel also has complex relief, the tops of the former river-cliffs were least 20 m below the later sea level at 18–21 cal. KBP. The undulating lines show there are other seismic reflectors (after Hanebuth & Stattegger 2003).

Figure 3b (middle), A detailed seismic profile from west to east on the continental shelf off the mouth of the Mahakam River in eastern Borneo. It indicates the dimensions of reefs and the complexity of the submerged topography that was exposed by falling sea level. The now buried bioherms would have been significant hills. They were often the sites of re-growth of coral reefs, including during the Holocene. The *rotated strata* indicate a block of limestone affected by older collapse. The undulating lines are other seismic reflectors.

Figure 3c (lower), Schematic representation of the stratigraphy of the interbedded terrestrial, fluvial, deltaic, shelf, and shelf edge sequences determined by seismic and MISEDOR coring in the Mahakam Delta and the continental shelf in the Makassar Strait, eastern Borneo. Several surfaces of widespread erosion - termed Ravinement – are shown. Some were disrupted by gravity-driven normal faulting in the Holocene (after Carbonel & Moyes 1987; Carbonel *et al*. 1987; Roberts and Sydow 2003).


NW
SE
SOUTH CHINA SEA
modern seabed
older channel of Molengraaff River
last active channel of Molengraaff River
depth below modern ocean surface in metres
80
90
100
110
120
130
140
150
0
5
km


W
E
LANDWARDS
MAKASSAR STRAIT
PRESENT SEA LEVEL
0 m
20
40
60
80
100
Large Halimeda Bioherm
Lowstand Delta Lobe
Shelf-Edge "Reef"
Buried Reef Rubble
Buried Bioherms
Multiple growths of reef
rotated strata
0
km
1

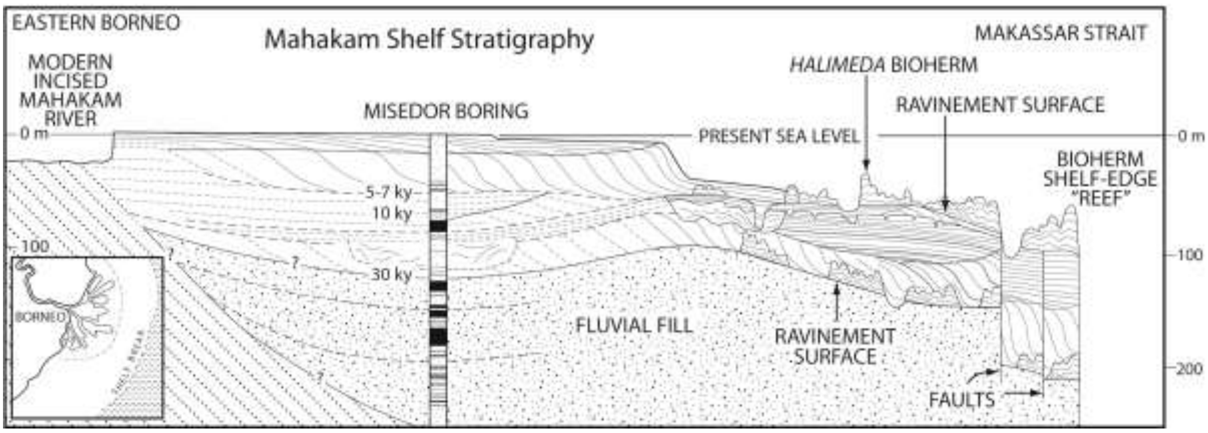

EASTERN BORNEO
Mahakam Shelf Stratigraphy
MAKASSAR STRAIT
MODERN INCISED MAHAKAM RIVER
MISEDOR BORING
HALIMEDA BIOHERM
RAVINEMENT SURFACE
PRESENT SEA LEVEL
0 m
BIOHERM SHELF-EDGE "REEF"
5-7 ky
10 ky
30 ky
100
200
FLUVIAL FILL
RAVINEMENT SURFACE
FAULTS
BORNEO

Figure 4 (a and b), Reconstruction of the coastal geography of north-eastern Borneo during (4a) ~13 cal. KBP, and between *c*.30–70 uncal. kbp; and at the eustatic low sea level of the LGM *c*.18 to 21 cal. KBP; (4b) 11–10 cal. KBP and 7–6 cal. KBP: following Sathiamurthy & Voris (2006). Their primary hydrographic data source was ETOPO2 GLOBAL 2′ Resolution Digital bathymetric survey of the modern seafloor, modified here to include the results of seismic surveys in the Baram Delta (Hiscott 2001, 2003) and coring in the buried valleys of the Rivers Baram and Tinjar (Caline & Huong 1992; Hunt & Premathilake 2012; Hunt *et al*. 2006). At *c*.14 cal. KBP, and extrapolated from the course of eustatic sea level change to the period between 30 to 70 uncal. kbp, the bathymetric data suggest there was greater topographic complexity than during the LGM or in the Holocene, with numerous offshore islands, sheltered inlets of the sea, and very large basins, some of which may have been open to the sea, favouring mangroves; others would have constituted enclosed freshwater and wetland habitats. At times a large marine inlet was just offshore from modern Bintulu, west of Niah. The large S-N orientated channel of the proto-Niah is suggested, this at times may have been a long, sheltered inlet bringing the sea almost to the Great Cave. At the end of the Pleistocene, there was a long (>120 km) inlet at the mouth of the Baram and the Great Cave was at the base of a large coastal headland. Topographic features < 2 km in size were not detected by these surveys, so these reconstructions underestimate the likely degree of topographic complexity.

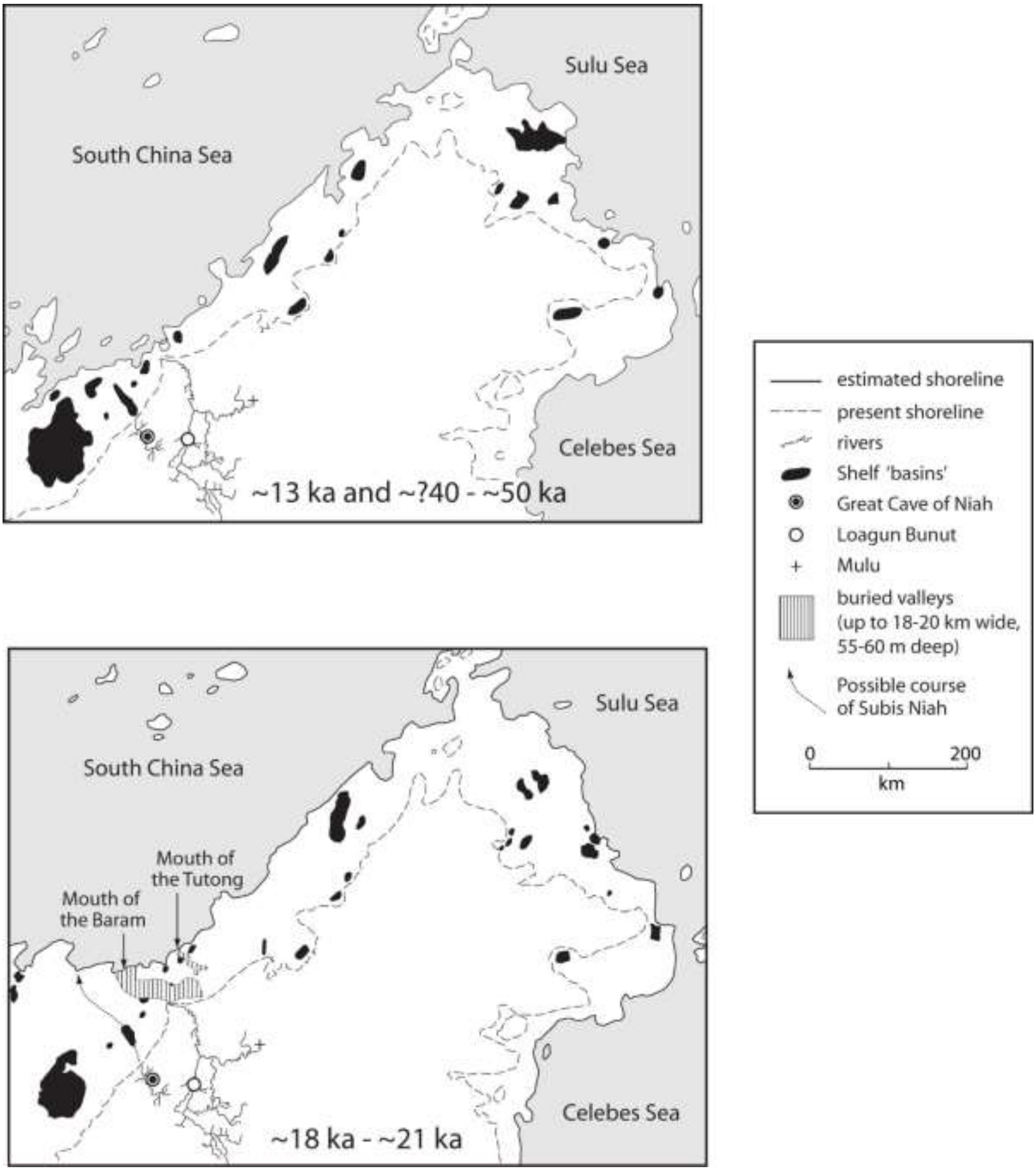

Sulu Sea
South China Sea
Celebes Sea
~13 ka and ~?40 - ~50 ka
estimated shoreline
present shoreline
rivers
Shelf 'basins'
Great Cave of Niah
Loagun Bunut
Mulu
buried valleys
(up to 18-20 km wide,
55-60 m deep)
Possible course
of Subis Niah
0
200
km
Sulu Sea
South China Sea
Mouth of
the Tutong
Mouth of
the Baram
Celebes Sea
~18 ka - ~21 ka

Figure 5, The topographic and substrate relationships of the main mangrove taxa within the modern study area (after Hunt *et al*. 2012).

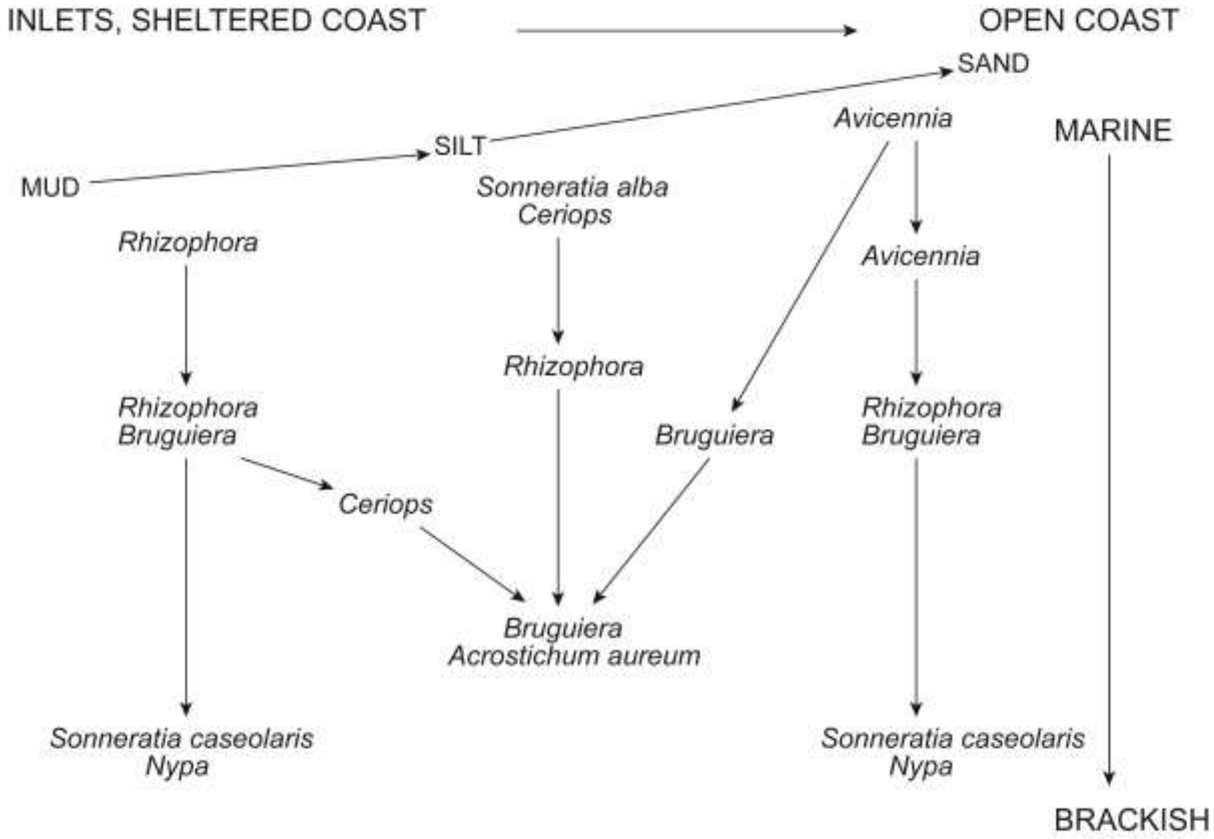


Figure 6, The stratigraphic distribution of the mangrove pollen and marine cysts in the Late Quaternary infill-sequence in the West Mouth of the Great Cave of Niah: indicating climatic associations (NGRIPδ^{18}O: [broadly] values to the left indicate increasing cold global climate), marine oxygen isotope stages, and estimated age in years cal. B.P. The chronology and lithostratigraphy of this sequence are in Gilbertson *et al*. (2005) and Hunt *et al* (2007, 2012).