Late Quaternary environmental history from the Kelabit Highlands of Sarawak, Malaysian Borneo: A record of climate, vegetation and land-use

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PhD Thesis

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Abstract

In Borneo people have been influencing the forests for over 50,000 years. A multi-proxy investigation, including pollen, phytolith and sediment analysis, was carried out on six cores from Pa’Dalih, Pa ‘Buda and Bario in the Kelabit Highlands, producing a 50,000 environmental history. The Late Pleistocene record for Bario and Pa’Dalih is marked by fluvial activity (shown by sands, silts and gravels) and frequent burning episodes in Pa’Dalih. These events were probably being influenced by a cooler-arid and possibly more seasonal climate than today, with a higher representation of upper montane taxa, particularly Phyllocladus, Podocarpus and Dacrydium. Some fluctuations in montane taxa, Myrtaceae and Cyperaceae (in Bario) may be associated with changes in precipitation, rather than temperature or fluvial events. Between 29,563 and 12,907 cal BP there is a noticeable rise in aridity in Pa’Dalih, shown by intense burning events and fluvial deposition of gravels and sands. Hiatuses appear in the sediment records ca.30,800-5,600 cal BP at Bario (Ba) and ca.36,000-2,800 cal BP at Pa’Dalih (PDH 212), and could be associated with fluvial down-cutting, during the onset of the Holocene. The late Holocene is characterised by a pronounced human signature on the landscape, particularly within the last 2,800 years, shown by a rise in open ground taxa. Charcoal is recorded at Pa’Buda between 7,000-6,000 cal BP, but there is insufficient evidence to determine whether this is natural or anthropogenic. Both phytolith and pollen evidence indicate the manipulation of Eugeissona for sago and rice cultivation in the last 2300 years, whilst agricultural practices may have intensified within the last 600 years and could signify a change from a nomadic to a more settled way of life.
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CHAPTER ONE: INTRODUCTION
CHAPTER 1
Introduction

1.1 Research context

The island of Borneo is one of the most biologically diverse areas in the world. The tropical forests provide many useful products, which play an important role in people’s livelihoods by providing food (e.g. bamboo shoots, ferns, many different fruits such as Durio and Sapindaceae), medicine and essential building materials (Wong and Kamariah, 1999). Early hunter-gathers on the islands of Southeast Asia probably already had an intricate knowledge of tropical plant use. Evidence for this is suggested by the presence of stone tools, charred nuts and starch grains (consistent with starch from the yam Dioscorea) ca. 49,000-43,000 cal BP, in the Ivane valley, New Guinea (Summerhayes et al., 2010). At the Great Cave of Niah, in the lowlands of Sarawak, evidence of late Pleistocene plant use is further presented by the identification of charred nuts, fruit, plant tissues and starch, ca. 45,000 cal BP, although possibly older (Barker et al., 2002, Barker et al., 2007, Paz, 2005). The identification of palm starch granules at Niah Cave (Barton, 2005) also suggests palm trees were being used for their edible sago pith ca. 40,000 cal BP. Later during the early Holocene, at Loagan Bunut in the lowlands of Borneo, Hunt & Premathilake (2012) have recorded signs of consistently intense forest burning and disturbance, associated with abundant pollen of four genera of sago palms. The palm trees recorded included the lower montane species Eugeissona and Metroxylon, but also Arenga and Caryota. Despite these early sites as well as extensive evidence of plant exploitation from early-mid Holocene sites in the upper Waghi valley, New Guinea (Denham and Harberle, 2008, Denham et al., 2004, 2003, Harberle, 2003) the history of tropical plant exploitation/cultivation in island Southeast Asia remains poorly understood. This thesis will examine evidence for early plant exploitation/cultivation in the highlands of Borneo.

A further query this study will investigate in the importance of rice in the Borneo interior. The timing, importance and the arrival of domesticated rice (Oryza sativa) into island Southeast Asia remains hugely debated. Rice is thought to have expanded into island Southeast Asia via Taiwan and the Philippines (Bellwood et al., 1992), although archaeological evidence remains sparse. In the Philippines evidence is based on one archaeological site at Andarayan, northern Luzon and on one charcoal piece dating between 3900-3000 cal BP (Snow et al., 1986). The site yielded large quantities of earthenware in which rice inclusions were common. On the island of Bali rice may have appeared by 2300-3000 cal BP (Lansing et al., 2004; Bellwood et al., 1992), although the sherd of pottery containing rice husks is from an imported vessel; therefore, some uncertainties of its origin remain. The island of Borneo is the only other Southeast Asian island which has yielded evidence of early rice cultivation/use. The earliest confirmed evidence for rice usage in Borneo is in coastal lowland sites dating to ca. 4300 cal BP at the cave of Gua Sireh (Ipoi and Bellwood, 1991) and ca. 5400-5900 cal
BP at the Great Cave of Niah (Doherty et al., 2000). Close to Niah at Gan Kira, pollen and sedimentary evidence suggest forest disturbance, and that rice may have been utilized as early as 6480 cal BP (Hunt and Rushworth, 2005). This evidence is however, incomplete, but highlights the need for further investigations into the timing and arrival of domesticated rice into the Borneo interior. Rice is today a staple food and culturally important to the Kelabit people (Janowski, 2005); whilst the nomadic hunter-gathering Penan in the region rely substantially on sago palms, particularly *Eugeissona utilis* (Brosius, 1993). Large stands of sago palm can also be found surrounding Kelabit settlements, suggesting that the palms were of central importance to the Kelabit inhabitants and other inland groups in the not so distant past and may have been more important than rice until relatively recently (Barton, 2012).

This PhD thesis is also a key part of the Cultured Rainforest Project, a multi-disciplinary investigation funded by the Arts and Humanities Research Council under their Landscape and Environment strategic research initiative, with the aim of investigating long-term and present-day interactions between people and rainforest in the Kelabit Highlands of central Borneo. ‘The Cultured Rainforest Project’ has three main strands and includes a) anthropologists who have concentrated primarily on oral histories b) archaeologists who have conducted surveys and excavated selected monuments to reconstruct the lives of past forest dwellers and c) The work that has been undertaken for this PhD thesis, which also includes the environmental reconstruction of selected sites in the Kelabit Highlands to 1) present the people of the Kelabit Highlands with an insight into their past, as logging roads have already reached the highlands and therefore future opportunities to do so may not be possible and 2) as part of the ‘Cultured Rainforest Project’ to demonstrate the cultural and archaeological significance of the landscape to its people and to the world.

Some of the sites selected for analysis, in this research project, date back 50,000 years. This has also provided a good opportunity to contribute to global debates on climate and environmental change during the late Quaternary. Today the effects of climate and environmental change are an important subject, particularly in tropical environments, where most of the world’s carbon reserves are. As yet no records of climate and environmental change are available for the highlands of Borneo, whilst the records that are available for the lowlands are not synchronous. For example, Hunt et al. (2007, 2012) describe the area around Niah in coastal Sarawak to have been cyclically dominated by lowland forest, montane forest and open savannah-like vegetation during parts of Oxygen Isotope Stage 3 (58,900-27,600 cal BP), and argue this represents lower temperatures and precipitation. Page et al. (2004) state a positive moisture balance must have occurred in lowland central Kalimantan 27,000-26,000 cal BP, demonstrated by the initiation of peat accumulation at the study site of Sebangau. In west Kalimantan Anshari et al. (2004) suggest a less seasonal climate than today with high rainfall and rapid peat accumulation between 40,000-29,000 cal BP.
This thesis intends to examine primarily the palynological record, but also to undertake some phytolith analysis, to identify patterns of vegetation change caused by both changing environments and by past and present relationships between people and the rainforest in the Kelabit Highlands of Sarawak, Malaysian Borneo. Fieldwork has been undertaken with the permission of the State Planning Unit of Sarawak, under the aegis of Sarawak Museums.

1.2 Research aims:
This project aims to:

1) Construct a vegetational history for the Kelabit Highlands to understand how climate, environmental and land-use change have affected the tropical vegetation in the uplands of interior Borneo over time.

2) To examine the palaeoecological record for evidence of early plant manipulation or cultivation.

3) To integrate these results within the existing framework of understanding environmental change and human-environment interactions in Island Southeast Asia.

To fulfil these aims a number of objectives were met.

1.3 Research objectives

1) Type material: To establish a type collection from plants gathered in the research area. This was supplemented by material from other collections at the Department of Forestry Sarawak Herbarium (SAR).

2) Vegetation-pollen relationships: To establish present palynological signatures of people in the rainforest, so that there is an empirical basis to the search for human activity in the past. This was undertaken through a small programme of surface-sampling in well-defined areas of traditional human activity.

3) Palaeoecology: To produce detailed vegetational histories through stratigraphic investigations of cores and excavated samples. A test programme of different types of samples was carried out to identify the most suitable materials for analysis.

4) Radiocarbon dating: A dating programme was needed to establish the chronological framework of the vegetational history.

In practice, the approach has been to work on all four objectives simultaneously. This thesis therefore describes the outcomes of the research project.

The next chapter will examine the research context in more depth

- Chapter 3 will provide a description of the research area
- Chapter 4 will look at the methodologies employed in the research.
- Chapter 5 will provide an in-depth analysis of the modern surface-samples
- Chapter 6 will provide an in-depth analysis of the Bario core Ba.
- Chapter 7 will provide an in-depth analysis of the Pa’ Dalih core PDH 212
- Chapter 8 will provide an in-depth analysis of the Pa’Dalih core PDH 223
- Chapter 9 will provide an in-depth analysis of the Pa’Dalih core PDH 210
- Chapter 10 will provide an in-depth analysis of the Pa’Dalih core PDH CO1
- Chapter 11 will provide an in-depth analysis of the Pa’Buda core BPG
  (Chapters 6-11 will include details of the location, lithology, radiocarbon results, pollen, palynomorphs, phytoliths, loss on ignition and magnetic susceptibility, an interpretation of results and a conclusion)
- Chapter 12 will compare and discuss the results for of all sites analysed.
- Chapter 13 will finish by concluding the overall results.

The appendices contain information that supports the thesis.
CHAPTER TWO: RESEARCH CONTEXT
Chapter 2
Research Context

2.1 Introduction
Over time both climate change and anthropogenic interactions have played an important role in shaping tropical plant ecosystems. The aim of this chapter is to examine what evidence is available for Southeast Asia and its offshore islands, the island of Borneo in particular. The chapter will show that the Highlands of Borneo warrant investigation. The chapter will begin by describing floral biogeography and vegetational evolution on the Island of Borneo, and the environmental factors that have influenced plant biodiversity in the past and in the present. The effects of climate change on plant biodiversity will be examined over a wider geographical area, to compare regional variations and similarities. The chapter will then go on to describe the anthropogenic history of Southeast Asia and Borneo in particular, including early evidence for hominids, the arrival of modern humans, how people have changed and altered their landscape over time and finally evidence for the beginning of rice agriculture and other forms of plant manipulation.

2.2 Floral Zones of Southeast Asia and the Wallace Line
The plant geography of the Southeast Asian region is highly complex and no single factor can account for the distribution of plants in the region (Morley, 2000). Borneo is a major centre for species endemism, and contains the richest floral biodiversity in western Malesia (the botanical region comprising Malaysia, Indonesia, the Philippines and New Guinea (Whiffin, 2002)).

Over half of all flora species in Borneo are endemic and there may be up to 15,000 species of flowering plants, of which approximately one third are endemic (Whiffin, 2002). The rich biodiversity is attributed to a number of factors associated with plate tectonics, the biological makeup of plant species, seasonal climates associated with monsoonal belts, aseasonal climates linked to the location of Borneo within the Intertropical Convergence Zone (ITCZ), altitudinal factors, as well as past and present climate change (Morley, 2000). The flora of western Malesia consists of aseasonal tropical rainforest, which is centred in Borneo, extending to Sumatra, peninsular Malaysia, western Java and parts of the Philippines. Another zone of aseasonal tropical rainforest is located in the East, centred in New Guinea and extending to northern Australia. Wedged between the two areas of tropical rainforest are regions of monsoonal forests. The northern monsoonal forest extends from mainland Southeast Asia to the western Philippines, whilst the southern monsoonal forest belt is located in northern Australia, through most of Java, the whole of the Lesser Sunda Islands, parts of Sulawesi and most of the Moluccas (Fig 2.1). According to Whiffin (2002) and Bird et al. (2005), during drier periods in the Quaternary these wedges would have joined to form a definite dry corridor, connecting (at least climatically) parts of northern Australia and mainland Southeast Asia.
A major discontinuity separates the biota of Australia and New Guinea from the islands of Southeast Asia. The Wallace Line is named after A. R. Wallace, who documented marked differences in mammals and birds either side of a line that passed between Bali and Lombok, north between Sulawesi and Borneo and then to the east of the Philippines (Fig 2.2). Today however, the line is attributed to the eastern boundary of strictly Asian fauna and flora and coincides with the eastern edge of the Sunda Shelf, whilst Lydekker’s Line marks the western boundary of strictly Australian fauna and is located on the western edge of the Sahul Shelf. Zoologists place Lydekker’s Line west of New Guinea. New Guinea is predominantly a tropical wet zone and, according to Whiffin (2002), botanists would place New Guinea into a separate zone within Southeast Asia, away from the more arid area of Australia.

Weber’s Line marks the transitional zone for some faunal groups, such as the mammals. The area between Wallace’s Line and Lydekker’s Line is often recognised as the area of Wallacea and not only contains a large number of transitional species but also possesses a number of endemic species as well (Whiffin, 2002). Wallacea is related to the monsoonal forest belts described above. The zone is drier than the other two regions and contains extensive areas of monsoonal forest from northern Australia to the Lesser Sunda Islands and southern Sulawesi. According to Whiffin (2002), Wallacea is sometimes taken to include parts of the Philippines, except Palawan, although the western edge of the region is taken as the Huxley Line rather than the Wallace Line.
Fig 2.2: Floral and faunal lines, showing the bio-geographical divisions between the major land areas and the Sahul and Sunda shelves (author, modified after Whiffin, 2002). Colours represent continental shelf depths: Brown colours represent up to -100 m and green represents up to -1000 m

2.3 Origins and Evolution of Southeast Asian Floral Biodiversity

Section 2.3 is split into four sub-sections: Sub-section 2.31 looks at the origins and evolution of Southeast Asian flora with particular reference to Borneo, from the Paleogene until the Quaternary. The Quaternary (covering the Pleistocene, Last Glacial Maximum and the Holocene) is examined in more detail in sub-sections 2.32-2.34. This has been done partly because more records on climate and vegetation change are available for the Quaternary period, but also because the last 50,000 years of the Quaternary are examined in this thesis. An important part of interpreting the fossil pollen record for the Kelabit Highlands is to understand how past climate and environmental change may have influenced the biodiversity within other regions of Southeast Asia and Borneo.

2.31 The Paleogene and Neogene

Floristic richness and endemism in Borneo is thought to have developed between the Neogene and Quaternary; however, diverse mega-thermal vegetation (plants that are supported by a continuous high temperature in combination with high rainfall), demonstrated by a dominance of dicotyledon pollen grains and a good representation of monocot pollen, especially from palms, became established throughout much of the Southeast Asian region during the Middle and Late Eocene epoch (in the Paleogene). This is partly due to dispersal from the Indian subcontinent when the Gondwanan Indian plate collided with Asia, but also because of the hot wet climate at the time (Morley, 2000).
At the end of the Eocene, tectonic restructuring, combined with global climatic deterioration, caused a marked change in flora throughout the region with a major retraction in the range of mega-thermal rainforests and a number of extinctions. Lowland forests were largely replaced during the Oligocene and earliest Miocene by seasonal climate (monsoonal) vegetation types, whilst cooler climates saw an increase in frost tolerant conifers in upland areas (Morley, 2000). Muller (1966) reports an increase in the montane pollen types *Pinus, Picea, Tsuga, Ephedra* and *Alnus* during the Oligocene to early Miocene, which he associates with tectonic uplift during the late Eocene. After the early Miocene, the mountain taxa described above, decline and most are no longer present in the mountains of Borneo today. Muller (1966) attributes the decline and subsequent disappearance of these genera to rapid erosion and states that during the Miocene, the summits of all mountain chains had been levelled down to the 1500 m contour and that it is unlikely any of the Asiatic mountain elements could have survived.

According to Morley (2000), between the Oligocene and Pleistocene there was largely an uninterrupted diversification of flora, during which dipterocarps became an important component. From the Early-Mid Miocene, Morley (2000) describes a return to moist climates and a re-expansion of tropical rainforest related to sea level change, with the greatest expansion taking place at times of higher sea level and when global climates were at their warmest. Lower sea level tended to see an expansion of more seasonal vegetation.

During the Pliocene and the Quaternary, following a regional phase of tectonic adjustment, several montane gymnosperms (e.g. *Podocarpus*) of Australian affinity were able to disperse from New Guinea, via the Philippines, into Borneo (Morley, 2000). Muller (1966) also reports the sudden appearance of *Podocarpus imbricatus* and *Phyllocladus* type from the Pliocene to Pleistocene onwards, which evidently immigrated from New Guinea; however, the late appearance of these pollen types are difficult to reconcile with present day distributions. Van Steenis (1964) reports that *Phyllocladus* must have migrated during a period when former mountain range connections existed from which the species could migrate, as *Phyllocladus* belongs to a stricter thermo-ecological group, which could not have dispersed through the lowland of the tropics.

**2.32 The Quaternary: Pleistocene (2.6 Ma-12 ka BP) climate and vegetation change**

During the Neogene and particularly in the last ca. two and a half million years, known as the Quaternary (Bowen, 1978), there were times when the climate was significantly cooler and drier than it is today. The change in climate would have affected vegetational belts, not only in Borneo but also throughout Southeast Asia. Most records, however, only cover the last 50,000 years, with the earliest record from the northern part of the South China Sea, spanning the last 1.03 million years (Sun et al.,
2003). The rest of Sub-section 2.32 examines the climatic changes and floral responses during this period for Southeast Asia and for Borneo in particular.

Many pollen records for the Pleistocene have generally indicated that the climate was often drier and possibly up to 6-7°C cooler than it was during the Holocene. According to Kershaw et al. (2001) this is demonstrated in ten lowland pollen records from the Southeast Asian region, by a higher percentage of tropical montane forest species recorded during the Pleistocene than recorded in the present tropical evergreen forest, as well as an expansion of grasses at most sites. Hunt and Premathilake (2012) argue that some stadial episodes in lowland Borneo were far more open than suggested by current models, but that other stadials, including the LGM, were characterised by forest vegetation, albeit highly disturbed and rather open. Morley (2000) suggests that evidence from deep sea cores indicates glacial periods during the Quaternary were characterised by dry savannahs and an increase in Poaceae with rainforest refugias probably located in north Borneo, west Sumatra and areas of the Sunda shelf which are now submerged. Cannon et al. (2009) however, suggest tropical lowland forest is supposed to have expanded over the now submerged continental shelf during low sea levels.

Despite a general cooling at times during the Pleistocene, climate was very changeable. Oxygen isotope analysis of five stalagmites from the Hulu caves, carried out to examine Quaternary climate change in the Nansha area of the southern South China Sea, for example, has demonstrated a long sequence of climatic changes took place during the middle Pleistocene, rather than an abrupt event (Wang et al., 2001). Wang et al. (2001) argue that these climate changes correspond with events in the GRIP and NGRIP ice cores, showing that climate events are synchronous across the Northern Hemisphere. There is recent evidence from Whittaker et al. (2011) suggesting that the same events can be picked up from New Zealand.

The high-resolution pollen record from the northern South China Sea carried out by Sun et al. (2003) and dating 1.03 million years at the base, further demonstrates variable climate during the Pleistocene. For example Pinus dominated pollen zones were used to demonstrate interglacials and herb dominated zones, glacialis. Three main periods can also be distinguished in the vegetation history: 1030-908 Ka BP is marked by tropical montane pollen, 908-355 Ka BP is marked by tropical lowland pollen, indicating a climate much more suitable for growth of forests with a tropical nature than in the earlier and latter periods, and 355 Ka BP until present day is marked by trees from the Fagaceae family indicating a change to drier conditions. The pollen record, according to Sun et al. (2003), has also demonstrated a strengthening of the winter monsoon during glacialis. This is demonstrated by an influx of large pollen grains, such as Phyllocladus, but also fern spores, which do not grow in the areas around the northern South China Sea, and are transported chiefly by sea currents driven by the winter monsoon. No similarly long records exist through the rest of the region, but a 300,000 year
pollen, micro-charcoal and oxygen isotope record was taken from the Lombok Ridge by Wang et al. (1999). This shows that interglacials are marked by relatively high percentages of lowland rainforest taxa and glacials by high percentages of Poaceae, Cyperaceae and montane conifers.

From 25 habitat types in Southeast Asia, Louys and Meijaard (2010) have suggested that both the faunal evidence and other palaeoenvironmental studies demonstrate changes of vegetation structure with glacial and interglacial cycles during the late Pleistocene; glacial periods are associated with drier and more mixed habitats and interglacials with more humid environments. This is also reported by Hope et al. (2004), who suggest that marine and terrestrial pollen records from across the region show higher values of boreal/montane conifers with some increase in herbaceous species during glacial periods, whilst interglacials show a high representation of thermophilous elements. Hunt et al. (2012) suggest vegetation during interstadials was rather variable and largely dependent on rainfall, whilst the development of lowland floras similar of recent times, identified during interstadial periods in the lowlands of Sarawak, likely reflect temperatures of above 25 ºC and possibly as much as the present ca. 28 ºC.

Wüst and Bustin (2004) explain that an important factor for climatic changes in Peninsular Malaysia is the movement of air masses across the equator, which causes seasons to depend on wind reversals rather than temperature change, influencing both annual and seasonal precipitation. On the west coast of Peninsular Malaysia, at Pantai Remis, mangrove peat development and the evolution of swamp peat vegetation around ca. 55,000 years ago have been described by Kamaludin and Azmi (1997) as representing a warm climate during an interstadial and also demonstrates a period of relative stability within the late Pleistocene, which may have lasted between 2000 and 4500 years.

In Papua New Guinea, Harberle (1998) identified pollen representing a mixed forest canopy prior to 50,000 yr BP (based on thermoluminescence ages) and interprets the pollen assemblage as belonging to that of an interglacial phase. Brief incursions of cold temperatures are also recorded through pollen based evidence prior to 50,000 yr BP. The period between 50,000 yr BP and 14,500 yr BP (based on age/depth calculations from the thermoluminescence age and ten radiocarbon dates; It is unclear whether or not the radiocarbon dates have been calibrated) is dominated by Nothofagus, which Harberle (1998) explains, are able to expand their altitudinal range during cooler glacial periods. At Sirunki swamp, Flenley (1984) reports a brief change from tropical alpine grassland to lower mountain forest between 28,000-25,000 14C BP, and although not described by Flenley (1984), might be representative of a brief warm incursion before the LGM.

Fluctuating climates during the Pleistocene in Java have also been demonstrated by Van der Kaars and Dam (1997). Palaeosol formation at the Bandung basin, west Java, during the end of the
penultimate glaciation (ca. 135,000 years ago), is described as indicative of a significantly drier and more seasonal climate. Fresh water swamp forest pollen and some typical lowland taxa, present between 126,000-107,000 years ago, are suggested to represent very warm and humid conditions. During this period van der Kaars and Dam (1997) argue temperatures may have been 1-2°C higher with a less pronounced dry season than at present. Between 107,000-81,000 years ago the climate may have been slightly cooler, although temperatures remained warm and humid. Around 81,000 years ago freshwater swamps were replaced by open swamp vegetation with a strong seasonal contrast. Temperatures were probably only slightly cooler than today, but monsoonal precipitation considerably less, affecting montane flora more than lowland flora. Between 74,000-47,000 years ago only subtle climatic changes are recorded in the pollen record, although van der Kaars and Dam (1997) suggest it may have been slightly cooler. Between 16,300 and 11,250 cal BP at Rawa Danau swamp on the north-western tip of west Java, sedimentological, limnological and palynological data infer drier conditions during the Late Glacial period with a more open herbaceous vegetation but found no evidence for cooler conditions and also pointed out that in northern Sumatra, during the most recent glacial period, conditions may have been as wet or possibly wetter than present (Van der Kaars et al., 2001).

Hope (2001) argues for a relatively consistent ecology during the late Pleistocene in Sulawesi, with temperatures 2.5-3.5 ºC cooler than present and a phase up to 50% drier demonstrated by an increase in grass and Casuarina as well as a local dominance of Castanopsis and Lithocarpus 35-15,000 cal BP. Hope (2001) also explains that the relative importance of montane forest elements in the past, compared to the present day, may reflect the presence of higher altitude forest at lower altitudes through the late Pleistocene. Dam et al. (2001) however, describes relatively humid conditions 33,000 cal BP in the lake Torondo area, with rapid rising lake levels and the presence of a humid lowland-submontane forest consisting of Agathis, Daecrycarpus, Dystillion, Lithocarpus and Podocarpus. Between 33,000-30,000 cal BP a colder, drier climate is then described with lower lake levels and a simultaneous decrease in forest pollen.

Borneo

Hunt et al. (2007, 2012) has demonstrated that the area around Niah in coastal Sarawak was cyclically dominated by lowland forest, montane forest and open savannah-like vegetation during parts of Oxygen Isotope Stage 3 (58,900-27,600 cal BP) of the late Pleistocene and argues this represents lower temperatures and precipitation. Page et al. (2004) however, suggest a positive moisture balance must have occurred in lowland central Kalimantan 27,000-26,000 cal BP, demonstrated by the initiation of peat accumulation at the study site of Sebangau. In west Kalimantan Anshari et al. (2004) discuss data from four sediment cores, taken from within and in the vicinity of Lake Pemerak, in which a less seasonal climate than today has been suggested with high rainfall and rapid peat
accumulation, recorded between 40,000-29,000 cal BP. At Lake Sentarum in west Kalimantan Anshari et al. (2001) describes a consistent presence of Ericaceae in addition to *Quercus*, *Podocarpus* and the maintenance of relatively high pteridophyte percentages, as providing a greater confidence in the postulation of temperatures lower than today around 33,647-32,793 cal BP. High fern spores could represent increased precipitation but are described by Anshari et al. (2001) as more likely to be representative of a component of the local vegetation.

The variations in climate during the late Pleistocene records described above reflects how little is known of the late Pleistocene from Borneo, particularly from the interior and that further studies are needed to understand the impacts of climate and local environmental change in Borneo during the late Pleistocene.

2.33 The Quaternary: The Last Glacial Maximum (LGM: 26,000-19,000 cal BP) climate and vegetation change

The Last Glacial Maximum refers to the last glacial period when ice sheets reached their maximum and sea levels were at their lowest. Sub-chapter 2.33 examines the climatic changes and vegetational responses in Southeast Asia and Borneo during this period.

Verstappen (1975) reports that the ITCZ moved further south during the last glacial. This would have resulted in higher pressure over Borneo and continental Asia, increasing the length and intensity of the dry season. Gathorne-Hardy et al. (2002) also suggest higher atmospheric pressure over continental Asia during the last glacial, which led to reduced summer monsoons, while winter monsoons were possibly stronger than they are today and may therefore have caused increased seasonality. Evidence is inferred based on modern bio-geographical data rather than anything giving real information about the past, although this evidence is supported by Bird et al. (2005) who further argue that the East Asian winter monsoon strengthened and the Southeast Asian summer monsoon weakened during the LGM. They also suggest sea water temperatures may have been 2-3°C lower than today and air temperatures may have been reduced by 6-7°C. Urushibara-Yoshino and Yoshino (1997) however, argue that a drop in sea level may have weakened the winter monsoon by preventing it from picking up moisture from the South China Sea.

Sun et al. (2003) noted a considerable increase in cold tolerant boreal conifers (*Picea, Abies* and *Tsuga*) from the northern South China Sea, during the LGM in comparison with those in the Holocene. Boreal conifers are not as high during earlier glacial cycles recorded in the deep-sea pollen record, which covers the last 1.03 million years. Urushibara-Yoshino and Yoshino (1997) discuss a lowering of sea level and the change in monsoon circulations, during the LGM, may have caused temperatures to be 1-2°C and possibly even up to 3-4°C cooler in Java. They also suggest
temperatures in the highland regions of South Asia are likely to be more affected by climate change than in lowland regions. Stuijts et al. (1988) report that the vegetation of Sumatra and west Java, at altitudes between 1300 and 1500 m, were similar to vegetation found now at 1800 m, suggesting a lowering of temperatures between 1.8 and 7°C. For example, at Danau di Atlas, a lake site in Sumatra, the occurrence of Myrsine and Vaccinium pollen between ca. 18,000 and ca. 17,000 14C BP (calibrated ages unknown) could suggest an altitudinal shift of as much as 1200 m, equivalent to a temperature change of ca. 7°C, whilst an inversion in the radiocarbon dates between this period might also suggest a lowering lake level and thus a drier climate; however, a consistent presence of Shima and Atlinia pollen grains implies conditions remained wet and therefore might instead reflect eroding soils (Stuijts et al., 1988). Van der Kaars and Dam (1997) also suggest that during the LGM upper montane forest boundaries may have lowered from 2400-3000 m to 1200 m, whilst Hunt et al. (2012) suggest a decline in temperature between 7-10 °C at Niah in Sarawak.

Cannon et al. (2009) used climatic modelling, incorporating geographical, palaeoclimatic and geological evidence, to examine evergreen rainforest distribution in the Sunda Shelf region at the LGM. Results indicated rainforests covered a substantially larger area than currently present and that, when compared against climate models under maximum glacial conditions, lowland forests were probably reduced from approximately 1.3 to 0.8 x 10⁶ km² while upland forests were probably reduced by half, from approximately 2.0 to 1.0 x 10⁵ km². Cannon et al. (2009) also suggest coastal mangrove and swamp forests may have experienced the most dramatic change during deglaciations, going through a complete and major biogeographic relocation. According to Gathorne-Hardy et al. (2002) rainforests became considerably fragmented and confined to refugia during the last glacial, whilst regions of Thailand, Peninsular Malaysia, western and southern Borneo, eastern and southern Sumatra and Java became covered by savannah vegetation. Bird et al. (2005) also suggest the existence of savannah corridors through the LGM and that there is relatively strong and consistent evidence to support a northward expansion of open vegetation types from southern Sundaland towards the equator during this time. Bird et al. (2005) describes Sundaland as defined to the south and west by the deep waters of the Indian Ocean, and included what are now small island chains west of Sumatra such as the Mentawai Islands. To the east, Sundaland is separated from the biogeographically distinct region of Wallacea by deep-water channels that have ensured that no land bridge has ever existed between the two. This boundary corresponds with Huxley’s Line, running between Bali and Lombok in the south, Borneo and Celebes/Sulu archipelago on the equator and between Palawan and the rest of the Philippines in the north. According to Bird et al. (2005) forests would have been restricted to refugia primarily in Sumatra, north eastern Borneo and the continental shelf beneath the modern South China Sea, although gallery forests could still have occupied valley areas along major river courses throughout the region. Kershaw et al. (2001) further propose fragmentation of forests during the LGM, but argue that this may imply rainfall was reduced by up to 30%. Based on pollen
evidence, Hope (2001) also argues that the climate during the LGM may have been up to 50% drier than it is at present, shown by an increase in dryland grass pollen and Casuarina in southern Sulawesi. Dam et al. (2001) similarly associates a substantial change in pollen taxa in northern Sulawesi, between 30,000-13,000 14C BP (39,442-31,959 to 16,388-14,044 cal BP), dominated by Graminaceae and Cyperaceae, with drier climatic conditions; although the expansion of open herbaceous vegetation is argued to correlate first of all with lake formation rather than uniquely with climate.

Not all pollen records for Southeast Asia provide evidence of reduced rainfall during the LGM. At Nee Soon swamp, Singapore, Taylor et al. (2001) have recorded a larger fraction of pollen, thought to be from montane sources, as well as high levels of Poaceae, during the LGM. These results may indicate a lowering of altitude belts caused by cooler temperatures, but without major reductions in rainfall, although a seasonally drier climate may have existed. Taylor et al. (2001) also suggest cool humid conditions could have resulted in periods of relatively high levels of channel discharge. According to Harberle (1998), during the LGM temperatures may have been 3ºC-11ºC below modern temperatures at the Haepungua site in New Guinea. An expansion of open ground vegetation at the Haepungua site can be seen after 21,000 yr BP (unclear if date is calibrated, if not dates may be between 25,053-24,280), although the presence of the filmy fern Hymenophyllum appears to imply high precipitation for most of the year (Harberle, 1998). At Pea Bullock, north Sumatra, Maloney and Mc Cormac (1996) describe clear signs for cooler conditions and perhaps increased precipitation 24,000 years ago. This is demonstrated by an increase in Dacrydium, Engelhardia and Vaccinium pollen as well as Pteridophyte spores and Cyathaceae tree fern spores in relation to total pollen. The pollen record also indicates a shift in vegetation altitudes of montane species to lower altitudes. After the LGM, through microscopic charcoal analysis of sediments extracted from ten wetland sites in the Indonesian and Papua New Guinea region (Harberle et al., 2001), and later described in Gagan et al. (2004), suggest a prevalence of cool, wet conditions between 20,000-18,000 cal BP. Lentfer et al. (2010), who undertook micro-charcoal and phytolith analysis from Central New Britain, proposes however, that these conditions may have extended as far back as 37,199-32,809 cal BP.

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According to Page et al. (2004) during the LGM and until 12,900 cal BP peat accumulated very slowly at Sebangau, central Kalimantan. The low accumulation rate should, however, be treated with caution since substantial amounts of peat could have been deposited during the LGM that subsequently oxidised as a result of either reduced precipitation, a change in monsoonal strength, increased seasonality or a combination of these factors.

At Niah, the presence of a number of taxa now found only above 1000 m points to low temperatures during the LGM, but also suggests vegetation was highly disrupted, possibly by rapid climate change,
with many indicators of regenerating forest prominent (Hunt et al., 2012). According to Anshari et al. (2001) mountain conifers such as Dacrydium and Dacrycarpus, recorded in the upper Kapuas River Basin in west Kalimantan are best represented during a period which dates less certainly to the Last Glacial Maximum. Anshari et al. (2001) also describe sufficiently wet conditions, at least during part of the LGM, to allow peat development, although precipitation levels may have been lower than those of the other peat forming periods due to the decomposed nature of the peat. Drier conditions might however, also be suggested due to the high representation of Lycopodium spores that are indicative of open-canopied vegetation and increased charcoal levels. Conversely the results of Anshari et al. (2001) are unclear as dates jump from 15,713-3,355 cal BP between 72-67 cm and 32,990-20,058 cal BP between 95-91.5 cm, suggesting a number of gaps in the record.

LGM climate change has also been identified by Partin et al. (2008), who examined the $\delta^{18}$O, $\delta^{13}$C and Mg/Ca values from three absolutely-dated stalagmite oxygen isotopic records at Gunung Buda, northern Borneo, over the last 27,000 years. The $\delta^{18}$O stalagmite values are 1.3 ± 0.3‰ heavier than present and according to Partin (2008) reflect a combination of ice volume, LGM cooling of 2-3.5°C in the western Tropical Pacific, and poorly constrained changes in LGM regional sea water. There is no evidence in the $\delta^{18}$O record for a drier climate; however, both heavier $\delta^{13}$C (1-2 ‰) and higher Mg/Ca values than the Holocene are described by Partin (2008) as consistent with reduced rainfall and/or unknown changes in ecosystem carbon cycling during the LGM.

These results have demonstrated that only limited palaeoecological records are available for the LGM in Borneo and have also highlighted inconsistencies in the role of precipitation. Some authors argue for a much drier climate, other authors have argued that the climate remained humid. Further investigations are needed to understand how climate has changed during this period and how climate change has influenced the tropical vegetation in the interior of Borneo, since no investigations in the interior have yet been done.

2.34 The Quaternary: The Holocene climate and vegetation change (12,000-0 BP)

The onset of the Holocene was a period of climatic amelioration, which, within the Southeast Asian region saw a return to moist conditions, the expansion of tropical forests and the upward migration of montane flora. The rest of Sub-section 2.34 examines the climatic changes and floral responses during this period for Southeast Asia and Borneo.

Pollen and phytolith results from Lake Kumphawapi in north-eastern Thailand show an arid environment existed ca. 14,000 cal BP. The presence, however, of Panicoideae and Oryzoid grasses, and Cyperaceae and Ludwiga pollen, may mark the initial occurrence of standing water in the Kumphawapi basin, reflecting a progressive climatic amelioration after the Last Glacial Maximum
(LGM) (Kealhofer and Penny, 1998). After disturbance episodes during the beginning of the Holocene (ca. 10,000-9,000 cal BP), which may or may not be anthropogenically related, according to Kealhofer and Penny (1998), pollen and phytolith records show a more forested environment with a diversification of arboreal taxa. After ca. 9,000 cal BP, changes in the environmental record represent an increase in water level, which could be associated with a stronger wet season (Kealhofer and Penny, 1998). In Indonesia and northern Australia (the Banda Sea region) the onset of the Holocene is described by Van der Kaars et al. (2000) as experiencing a gradual migration of montane flora to higher altitudes and a return to more humid conditions in the lowlands, with the development of fern rich, closed forest vegetation types. At the Bandung Basin site van der Kaars and Dam (1997) also report “montane vegetation, notably the LMF-II (lower montane forest, restricted to altitudes above 2000 m) retreated to higher altitudes in response to the amelioration of the climate”. The Holocene period at Sikijang Swamp in the uplands of Sumatra show tropical rainforest has persisted with little change for the last 11,000 years (Flenley and Butler, 2001). Morley (1982) has also produced a detailed Holocene pollen record for central Sumatra at Danau Padang swamp and notes “Ten thousand years ago high altitude areas in the close vicinity may have supported forests comparable to montane forest II, characterised by Podocarpus and Engelhardia sp., lower altitude areas bearing oak forest (montane forest I)”. Morley (1982) reports that climate amelioration during the early Holocene saw a reduction in higher montane species such as Podocarpus imbricatus and Symingtonia, whilst trees characteristic of montane forest I and sub-montane forest became more extensive and include taxa such as Aglaia, Baccaria, Celtis, Nauclea and Dipterocarpaceae. Morley (1982) also suggests there may have been a temperature rise of 2°C, but there is no evidence to suggest increases in precipitation.

**Borneo**

At Loagan Bunut in Sarawak, Hunt and Premathilake (2012) have recorded several interacting processes during the Holocene associated with the ITCZ and rainfall patterns, sea level change and vegetation change during the Holocene. Between 11,300-8,200 cal BP the climate was humid and warm with the development of tropical lowland raised bog and kerangas vegetation at Loagan Bunut. Hunt and Premathilake (2012), however, argue that the transition to a warmer-wetter climate was not uniform, with relatively dry periods occurring at 10,370, 9,250-8,890, 7,900 and 7,600-7,545 cal BP. They also suggest rising rainfall during the early Holocene reflects the migration of the mean position of the ITCZ towards central Sarawak, whilst possible early Holocene ENSO-style events may also have taken place.

Page et al. (2004) describe rapid peat accumulation in central Kalimantan during the early Holocene, followed by reduced accumulation between 6,610 and 540 cal BP and explain that the most likely factors responsible are change in sea level, decrease in precipitation and increased seasonality. In west
Kalimantan, Anshari *et al.* (2004), also report the recommencement of peat accumulation within the last few thousand years of the Holocene. Hope *et al.* (2005) explain that the Kutai peat lands began to form during the mid-early Holocene in accordance with the latter stages of global sea level rise with ages ranging from 5,200 cal BP at Lake Melintang to 1,700 cal yrs BP at Lake Siran and Kupang Baru and possibly as young as 700 cal BP in the Sabintulung section.

In the coastal swamp forest of Batulicin, south Kalimantan, the vegetational history, based on pollen analysis, indicates a probable sea level drop and a wetter climate during the mid-Holocene 7,500-5,000 cal BP. Somewhat wetter conditions may have prevailed *ca.* 3,600 cal BP and *ca.* 1,800 cal BP (Yulianto *et al.*, 2005). At Tengah in central Kalimantan, Morley (1981) describes the vegetation on a peat swamp, near to the Sebangau River, as considered to have existed under more seasonal climatic conditions than what is found today. During initial peat development shallow peats may have supported a mixed fresh water swamp forest, whilst deeper peats may have been represented by a transitional community, at first dominated by *Dacrydium* and later by padang (heath forest) species such as *Combretocarpus*. Later successional stages during the Holocene are represented by widespread *Calophyllum retusum* and might be indicative of dipterocarp forests. Morley (1981) also argues that the evidence presented for Tengah suggests local river patterns have changed markedly during the course of the Holocene.

Sabiham (1990), reports that during the early Holocene the coastal plain of the Baram-Belait river Basin in Brunei was influenced by changing sea levels and the dominant vegetation consisted of mangroves such as *Rhizophora, Ceriops, Bruguiera* and *Combretocarpus*. Farther inland rising sea level caused fresh water peat swamps to develop with a dominance of *Castanopsis*. Later Holocene deposits are characterised by mixed dipterocarp forest and are likely to reflect falling sea levels. The development of a Holocene peat near Marudi (Sarawak) was also influenced by rising and falling sea level and as with the Brunei record represents a succession from mangrove swamps to a mixed swamp forest (*Campnosperma, Eugenia, Elaeocarpus, Garcinia* and *Palaquium*) and later high representation of *Shorea* suggests a mixed Dipterocarp forest (Anderson and Muller, 1975).

### 2.4 Anthropogenic Influence

Sections 2.1-2.3 have examined floral biodiversity, evolution and climatic influences affecting plant distribution in Southeast Asia and Borneo; however, people have also been utilising rainforest environments for thousands of years and would also have had a major influence on plant distribution. Understanding past human activities is a key to understanding possible anthropogenic patterns occurring in the palaeoecological record. Section 2.4 is split into three subsections. Sub-section 2.41 begins by looking at early hominid discoveries and human migration into Southeast Asia and Borneo, including a brief historical overview of the formation of Sarawak. Sub-section 2.42 looks at the
beginning of rice agriculture and its introduction into Borneo. Finally sub-section 2.43 looks at early evidence for other forms of agriculture/plant manipulation.

2.41 Early hominid discoveries in Southeast Asia and Borneo, migration, the Neolithic and the Historical period

One of the earliest hominid discoveries in Southeast Asia was revealed during excavations carried out between 1876 and 1890, in which a skull cap, upper jaw molar and later a femur of *Homo erectus* were discovered at Trinil, a site on the bank of the Solo River in central Java (Morwood, 2001). Stone tools found in sediments at the Java man site were later dated to between 1.2-1.6 million years old (Swisher *et al*., 2001, Stone, 2006). A number of stone artefacts argued to be from *Homo erectus* have also been found on the island of Flores and dated to between 900,000 and 730,000 yrs BP, during the early-mid Pleistocene (Morwood, 2001). There is no evidence of *Homo erectus* in Borneo, however.

The first migration of modern humans into Southeast Asia may have taken place around 65,000 years ago. Recent studies on mitochondrial DNA (mtDNA) (Macaulay *et al*., 2005) suggest there was a rapid coastal dispersion around 65,000 years ago around the Indian Ocean littoral and on to Australasia.

The earliest discovery of human remains in Sarawak was the 40,000 year old ‘Deep Skull’ found by Barbara Harrisson in 1958 at Niah Cave. The skull is thought to be a female of about 15-17 years of age (Krigbaum and Datan, 1999) and described in Barker *et al* . (2002) “with similarities to modern Tasmanians. Other workers since have emphasised links more with human fossils from mainland East Asia rather than Australia”. More recent investigations by Barker *et al* . (2002) and Barker *et al*. (2007) have indicated through the radiocarbon dating of two charcoal samples associated with the ‘Deep Skull’ that people first used the cave at least 45,000 cal BP and probably earlier, as charred nut, fruit, plant tissues, starch and bone fragments from a range of both large and small mammals (e.g. birds, bats, fish) were found both above and below the deep skull contexts. Hunt *et al*. (2007, 2012), suggest that the first palynofacies evidence for people in the entrance to Niah Cave, consisting of thermally mature material (often known as micro-charcoal) and spherules, has tentatively been dated to 50,000 cal BP, based on correlation of Hell Trench interstadials with GRIP interstadials, and estimated dates. Macaulay *et al*. (2005) argues that earlier archaeological evidence may have been lost due to sea level rises and, moreover, human populations may have diffused from the coast into the continental interiors more gradually, leaving a greater archaeological signature on the landscape as they grew in size.

Later Pleistocene evidence, for early humans in Borneo, has been recorded by Ipoi and Bellwood (1991). Excavations from the caves of Gua Sireh in inland western Sarawak have produced human deposited shell fish *ca*. 20,000 years ago. In the Tinkayu valley in eastern Sabah some very fine
bifacial tools of chert were excavated and dated to ca. 20,000 years ago by Bellwood (1990); however, some uncertainty remains on the dates (Bellwood, 1990). Cave sites in the Baturong and Maddai massifs have also produced cruder, non biface, stone tools of chert dating between 18,000 and 8,000 $^{14}$C BP (Bellwood, 1988). According to Bellwood (1992) the inner fringes of the Borneo rainforest were certainly exploited by early modern foraging populations by at least 20,000 years ago.

Barker et al. (2002) describe the discovery, by Tom and Barbara Harrisson, of further occupation in the terminal Pleistocene, early Holocene and between about 4,050-2,750 cal BP at Niah, in which the West Mouth was used extensively for burials. Barker et al. (2002) quote that these burials were “of various types including extended, flexed and within pottery jars, of people using Neolithic pottery who were assumed to be agriculturalists”. Barbara Harrisson (Harrisson, 1967) describes the burials at Niah as consisting of many extended burials in log coffins or cigar-shaped caskets of sewn bamboo strips, together with a few secondary burials in large jars. There has also been a number of boat burials discovered in Kain Hitam at Niah, dated to the first century AD (ca. between 1,950-1,850 cal BP) and probably associated with cave paintings found in the cave. Bellwood (1992) suggests by 5,400-2,000 years ago Neolithic Austronesian settlers may have entered Borneo from the Philippines and expanded rapidly around the coasts and up the rivers with little resistance from the existing, but sparse foraging populations, although the latter may have contributed much to subsequent cultures in terms of their environmental knowledge. With their arrival came the introduction of domesticated dogs, chickens, pigs and a range of crops, including rice, millet sugar cane, greater yam and taro. At Kain Hitam at Niah, dramatic cave paintings occur, believed to date between 1,000-2,000 cal BP and include paintings of dancing human figures and curved boats (Pyatt et al., 2005). Analysis indicates that the resin used for the paint was probably from the tree Pindicus and demonstrates that the local people at this time had knowledge of tapping trees. Similar methodologies and practices may be evident in Australia. Pyatt et al. (2005) speculates this is possibly an indication of early “technology transfer” associated with the migration of humans.

Neolithic assemblages dating between 4,500 and 2,000 years ago are also known from sites in Sabah (Bellwood, 1988, 1989, Bellwood and Koon, 1989). In south-eastern Sabah, at a volcanic rock shelter of Bukit Tengkorat, excavations reveal pottery dating 3000 years old of Lapita type, made by the initial Austronesian settlers of Melansia and western Polynesia to as far east as Samoa (Bellwood, 1989 and Bellwood and Koon, 1989). Bellwood (1992) also describes knowledge of iron and bronze metallurgy was introduced into the islands of Southeast Asia from regions such as Vietnam or even India and China by 2000 years ago. Thiessen (2008) suggests early trade took place between Borneo, India and Southeast Asia around 2,240 cal BP and later with Chinese traders around 950 cal BP. After 2,000 cal BP, according to Andaya and Andaya (1982), there is evidence for early trading networks with China, India and the Arab lands. Excavations in northwest Borneo have indicated that during the
seventh century (ca. 1,250-1,150 cal BP) the Sarawak delta was actively involved in the export of smelted iron and gold to other places within the archipelago (Andaya and Andaya, 1982). Blust (2005) describes the smelting and forging of iron ore was a cultural innovation in the ancestral Malayo-Chamic speech community in southwest Borneo during the first few centuries BC (After 2,000 cal BP).

Between 1,550-1,650 cal BP two groups of people existed in Borneo: the indigenous shifting cultivators and hunter gatherers who lived in the interior and the Muslim rice farmers and fishermen, who spoke dialects of Malay, along the coasts and lower riverside regions. Both people also utilised a great variety of forest, mangrove and marine products (Rautner et al., 2005). Particularly during 850-650 cal BP there was explosion of trade between the China and Indo-Malaysian archipelago in forest products, metals, gemstones and spices. By 550-450 cal BP Islamic sultanates had become established in Brunei (Thiessen, 2008) and by 424 cal BP regular trade between Portugal and Brunei is documented (Rautner et al., 2005).

2.42 Evidence for the beginning of rice agriculture in Asia and Island Southeast Asia

Some people (Yasudu, 2002; Wenming, 2002, Liu et al., 2007) argue that the beginning of rice agriculture began in China c.14,000 cal BP, and in India 9000 cal BP, but this is disputed with others arguing much later dates e.g. Fuller et al. (2009), Fuller & Quin (2010); however, limited research has been undertaken in other areas of Asia. Wenning (2002) suggests the beginning of rice agriculture may have begun in the Yangtze Valley China more than 10,000 years ago and was initiated by a change in the subtropical monsoon climate, causing comparatively long winters, which would have resulted in food shortages. He also argues that although wild rice existed in the Yangtze valley it was not abundant enough to meet the daily demands of the inhabitants and that there may have been a need for some kind of food, which could preserve until the following spring, so cultivation was necessary. Yasudu (2002) describes how the earliest farmers collected both wild and cultivated forms of rice and argues that the earliest evidence for rice cultivation is derived from phytolithic evidence at Xianrendong and Diaotonghuan in Jiangxi Province and Yuchanyan in Hunan Province, dating to more than 14,000 cal BP, which was a time of climate amelioration. A warm-wet climate would therefore have been ideal for growing and spreading wild rice and may have played an important role in its domestication. There is, however, a possibility that a cold dry snap during the Younger Dryas may have encouraged the spread of cultivated rice. Yasudu (2002) suggests rice cultivation became established as forest hunter gatherers began to collect the ears of wild rice from the marshy plains and lakes in the middle and lower reaches of the Yangtze River. Sometimes mutations would occur where the wild rice developed mature tough ears, which were not brittle. People may have selected these unconsciously at first, then later by deliberate selection. This was the beginning of domestication. Crawford and Shen (1998) (and discussed in Itzstein-Davey et al., 2007), propose the use of wild rice
during the Pleistocene to Holocene transition. This argument is supported by isotopic evidence from Diaotonghuan and Xianrendong, demonstrating rice consumption during the late Pleistocene to early Holocene transition (MacNeish et al., 1997). Late Pleistocene use of wild rice could also be associated with the origin of pottery in China. The earliest dated pottery dates to 23,000-21,600 cal BP at the Guangxi Zhuang Province (Yasudu et al., 2002). Yasudu et al., (2002) also describe domesticated forms of rice may have become established by 7,500 cal BP. At the Shangsham site at Qu’nancun in Dujiang country, Zhejiang Province, China, rice phytoliths were identified from charred plants found in pottery, dating to 10,000 cal BP and are thought to be from the early stages of domestication. The site appears to have been a sedentary settlement with several dwellings and over twenty ash pits. There are over one hundred stone balls, chipped stone tools, large grinding slabs, a rectangular shaped stone pestle and red pottery with charred plant remains. The site shows the transition from Palaeolithic to Neolithic technologies (Jiang and Liu, 2006). From the results Jiang and Liu (2006) conclude rice was likely to have been domesticated in a broad area including both the lower and middle Yangtze River regions and the site at Shangsham. These sites also appear to be closely associated with the emergence of sedentary villages.

There seems little doubt that rice cultivation started in the Yangtze Valley. The very early sites, ca. 14-11 cal BP, all have phytoliths and grains with wild morphology. Modern cultivated morphologies do not start to appear until ca.8,200-7,200 cal BP but the transition to fully domesticated rice seems to have taken about 2000 years (Liu et al., 2007). By 6,500 cal BP true irrigated paddy agriculture was widely distributed (Ruddiman et al., 2008) and included the construction of paddy fields (Zheng et al., 2009). One of the features of early rice agriculture in China is the maintenance of a pattern of farming both wild and domesticated rice (Liu et al., 2007, Itzstein-Davey et al., 2007). This undoubtedly has led to a dispute between authorities such as Li et al. (2007) who identify early domestication and others, such as Fuller et al. (2009, 2010) who favour a much later date for domestication. At the Neolithic site at Kuahuquio in the lower Yangtze, cultivation began around 7,700 cal BP with highly intensive clearance and management by fire (Jiang, 1995). Rice pollen and phytoliths were identified, as well as disturbed ground weeds, the disappearance of swamp woodland and aquatic fen and the appearance of Tricurus, a parasitic worm hosted by pigs and people. At this time there are also abundant Typha stands, which provide another highly productive plant and therefore may have been encouraged by humans (Jiang, 1995).

Rice cultivation in India is likely to have occurred independently of China and is relevant to this study because it demonstrates the possibility that hunter-gatherers in Borneo could also have been experimenting with wild varieties of rice before the importation of domesticated rice from China (author). In the Ganga Valley of India, the manipulation of wild species began between 11,000-10,000 cal BP and the use of domesticated species between 9,000-7,000 cal BP (Wenming, 2002). Dates as
early as 10,800-11,100 cal BP (actual dates were speculated to be around 9,000 cal BP due to the nature of the deposits) are associated with phytolith evidence for domesticated rice at the site of Lahuradewa (Tewari et al., 2006). This is disputed, however, by Fuller and Qin (2009) who suggest significantly later dates for the appearance of fully domesticated rice. In northern India at Khairadih rice husk-tempered black and red ware have been dated to ca. 4,494 cal BP and according to Bellwood et al. (1992) has produced one of the oldest dates for rice cultivation in India, although a large number of sites from Uttar Pradesh, Bihar and west Bengal have also produced similar dates associated with rice cultivation, whilst more recent investigations described above by Wenming (2002) and Tewari et al. (2006) suggest domesticated rice cultivation took place at least 3000 years earlier.

Despite the likelihood that rice cultivation started and spread from China, other regions of Southeast Asia also show tentative evidence for very early rice cultivation. For example, Maloney (1990) discovered pollen similar to rice pollen at Pea Sim-Sim in the Highlands of north Sumatra around 18,000 years old, although he states other species of grass cannot be ruled out and more evidence such as leaf cuticles, phytoliths, spores and fungal pathogens found in sediments are needed for proof of cultivation. The earliest clear evidence of rice in other parts of Southeast Asia has been identified by Kealhofer and Piperno (1994), in which rice phytoliths have been found at Khok Phanom Di in east central Thailand dating to over 6,000 cal BP, but there is no evidence to suggest whether these are wild or domesticated. Archaeological evidence, however, suggests the site was occupied between 4,000-2,000 cal BP with evidence of rice cultivation throughout this period. At the site of Sembrian in north-eastern Bali rice husk-tempered pottery has been dated to ca. 2,768 cal BP (Bellwood et al., 1992).

At Loagan Bunut National Park, Sarawak, Hunt and Premathilake (pers.comm) identified possible rice cultivation at 8000 yrs BP; however, the data for Loagan Bunut are as yet insubstantial and incomplete and more work is needed in order to confirm this evidence. Close to the Great Cave of Niah in Sarawak, northwest Borneo, Hunt and Rushworth (2005) have suggested widespread fire and forest clearance associated with rice cultivation between 6,500-2,350 cal BP, resulting in large scale soil erosion and rapid overwhelming of mangrove dominated peat swamp. At Niah, rice was certainly being used from as early as 4,990 cal BP, as rice grains are present, incorporated into pottery of this age. This possibly pre-dates Austronesian migrations into Sarawak. These people were generally considered responsible for the introduction of rice into Borneo (Doherty et al., 2000). According to Doherty et al. (2000), rice in pottery was previously only known to exist at the Gua Sireh, but new research has revealed 35 more sites in Sarawak. At the cave site of Gua Sireh 55 km south east of Kuching, excavations carried out by Ipoi Datang in 1989 revealed early pottery. The earliest pottery contained impressed surface patterns made by the use of a carved, basketry-wrapped or cord-wrapped beater. One of these sherds also contained a whole grain of carbonised rice, which was dated to ca.
4,280 cal BP. According to Bellwood, et al. (1992) it is unusual that the site is so far inland for such an early rice date and that this probably suggests that rice cultivation in adjacent coastal regions of Borneo might have begun several centuries earlier. A second pottery sherd containing a rice husk was also identified higher up the site stratigraphy in layers with metal and glass beads dating to ca. 1,350 cal BP (Bellwood et al., 1992).

2.43 Evidence for the beginning of other types of plant manipulation (vegecultures) in Southeast Asia
Past archaeological and environmental investigations in Southeast Asia have demonstrated that during the late Pleistocene, people had intricate knowledge on how to exploit the surrounding vegetation, particularly in Papua New Guinea. According to Maloney (1998) the earliest occupation of New Guinea was around 40,000 cal BP. More recently evidence has been extended back even further at a number of sites, to between 49,000-43,000 cal years BP and coincides with the appearance of stone tools (Summerhayes et al., 2010). Some of these stone tools have yielded starch grains, which seem to be consistent with the yam Dioscorea. Charred Pandanus nuts are also present and have been attributed to human activity because of their association with charcoal, bone fragments and tools 49,000-36,000 cal BP. Starch evidence from Yuku rock shelter in New Guinea shows the processing of yams, which are likely to be from Dioscorea species, 14,200 cal BP (Horrocks et al., 2008).

Other late Pleistocene sites include the Solomon Islands, the island of Borneo and Thailand. Loy et al. (1992) identified starch residues of Colocasia and Alocasia on stone tools at Kilu Cave in the Solomons dated to 28,000 BP (not specified if 14C or cal BP). During the terminal Pleistocene ca.14,000-13,000 BP until the mid-Holocene 7,000-8,000 BP (not specified if 14C or cal BP), botanical remains identified from Spirit Cave in northwest Thailand indicate an early sophisticated use of particular plant species, such as Lagenaria (bottle gourd), Trapa (Chinese water chestnut) and Cucumis a cucumber type, which is still culturally important in Southeast Asia today (Gorman, 1971). The nature of the bone charring, the proximity of charred botanical remains and the dense concentrations of bamboo charcoal also suggest that meat and plants were cooked together in some type of container, possibly constructed out of bamboo (Gorman, 1971).

During the early-mid Holocene there is further evidence of plant manipulation in Southeast Asia. At Kuk Swamp, in the upper Wahgi Valley of Highland Papua New Guinea, taro (Colocasia esculenta) and yam (Dioscorea) were first exploited over 10,000 years ago and could be among those first cultivated by 6,950-6,440 cal BP. There is also evidence from stone artefacts for a range of tool activities with evidence of grinding, pounding and scraping of siliceous, woody and soft, starchy plants (Fullagar et al. 2006). According to Maloney (1998) at Kuk the drainage of swamps is thought to have begun around 9,000 cal BP, possibly for agriculture. Fullagar et al. (2006) also mention the
archaeological evidence at Kuk represents several phases of prehistoric utilisation and drainage of the wetland margin for plant exploitation and cultivation. The earliest use of the wetland margin dates to 10,220-9,910 cal BP, although interpretations vary as to whether this represents agriculture or an undetermined form of plant exploitation. According to Denham *et al.* (2004) several high-caloric and nutritious plants were present in the Kuk vicinity, including *Castanopsis* spp., *Colocasia* taro, *Musa* bananas (including identifiable members of Eumusa section with the onset of grey clay deposition), *Pandanus* spp., cf. *Setaria palmitifolia*, and cf. Zingiberaceae. Denham and Barton (2006) state hunter gatherers were probably able to subsist permanently in the rainforests of highland New Guinea and agriculture is likely to have emerged gradually and was not a revolution from pre-existing subsistence practices. Denham *et al.* (2004) propose from multi-disciplinary investigations at Kuk Swamp that agriculture arose independently at least 6,950-6,440 cal BP. At this time the forests on the floor of the Upper Wahgi had been altered to grassland or secondary regrowth, and mounds were made within cleared plots along the wetland edge and planted with bananas and other inter-cropped plants. Evidence also suggests *Colocasia* taro, cf. Zingiber gingers and other starchy and woody plants were processed, presumably for consumption.

At the Yuku rock shelter In Papua New Guinea the first appearance of banana micro fossils appears 5,200 cal BP and might suggest more intense subsistence practices (Horrocks *et al.*, 2008). The production of hafted multi-purpose obsidian tools and evidence from phytoliths demonstrate arboreal culture at two sites from the west New Britain Province in Papua New Guinea, from 10,000 years ago (Kealhofer *et al.*, 1999). Phytolith evidence includes a wide variety of grasses, mainly from Bambusoideae and Panicoideae; herbs including Compositae, Marantaceae and Cyperaceae; a diverse selection of arboreal taxa such as Palmae, Moraceae, Burseraceae, Annonaceae and Musaceae as well as unknown Dicotyledon types. There also appears to have been three main phases of use. The earliest periods of use have been recorded between 10,000-6,000 BP until 5,900-3,600 BP (based on tephra chronologies) and are characterised by both multi-functional and single purpose tools for processing starch. A more expedient tool use is recorded between 5,900-3,600 until 1,100 BP. Flakes appear to have had informal handles consisting of wrapped plant material and after 1,100 BP there is a trend to expedient tool use and obsidian flakes appear to have been wrapped in bamboo leaves (Kealhofer *et al.*, 1999).

At the Gunung site, Java, Maloney (1985) reports forest disturbance probably dating to 7,000 $^{14}$C BP (calibrated ages unknown), although this disturbance may be volcanic in origin. Maloney (1985), however, argues that there is evidence for definite man-made clearance predating 4,800 $^{14}$C BP (calibrated ages unknown). In Sumatra, Flenley (2001) argues possible slash and burn agriculture in the Sikijang Swamp at 7,000 $^{14}$C BP (8,336-8,044 cal BP). There is however, no evidence for whether this disturbance is anthropogenic or natural. At the Danau di Atas Maloney (1985) explains...
there is strong evidence for human-related forest disturbance around 6,200 $^{14}$C BP (calibrated ages unknown).

In lowland Borneo, archaeological and archaeobotanical findings have demonstrated a wide variety of plants and animals were consumed at Niah during the late Pleistocene between 46-21 cal. ka BP. Animal remains identified from the West Mouth include: primates; pig, monitor lizard and turtles. Botanical remains indicate the exploitation of nearby rainforest habitats for a variety of roots and tubers, fruit, nuts, and the pith of sago palms (Barton, 2005; Barker et al., 2007). The Niah Cave excavations have also demonstrated that late Pleistocene foragers had the requisite knowledge and technology to neutralize successfully several types of plant toxin such as from the yam *Dioscorea hispida* and the nut *Pangium edule*. A series of inter-cutting pits dated to ca. 39-21 cal ka BP might be evidence of the pit method of nut detoxification at Niah, because nut fragments mixed with ash were found in quantity in the pit fills, together with charred nut fragments (Barker et al., 2007). Barton (2005), who carried out starch analysis from the Niah Cave deposits, identified palm starch older than 40,000 cal BP, appearing well below the Deep Skull, with evidence of yams appearing later. Barton (2005) describes the antiquity of palm use by tropical hunter-gatherers as unknown, although its origins must be in the Pleistocene. Barton (2005) also states that it is clear that from the outset of human use of Niah Cave, Pleistocene hunter-gatherers already had the necessary knowledge of plant distribution in the rainforest, as well as the technical knowledge, to extract useful carbohydrates from roots, tubers, and palm pith. Also in lowland Borneo, at Loagan Bunut, Hunt & Premathilake (2012) recorded signs of consistently intense forest burning and disturbance through the early Holocene. This disturbance is associated with abundant pollen of four genera of sago palms, including the lower montane species *Eugeissona* (a native sp.) and *Metroxylon* which originates in Papua New Guinea. These imported taxa, according to Hunt & Premathilake (2012), indicate the propagation of sago by humans and the disturbance indicators suggest the maintenance of suitable habitats for the palms.

Finally, one of the earliest botanists to visit interior Borneo, Lilian Gibbs, describes the forests as containing large areas of ‘well-worked’ secondary vegetation with areas devoted to fruit trees, rotan canes, damar and other produce (Gibbs, 1914: 9). She writes that

‘Certainly the “untrodden jungle” of fiction seems to be as non-existent as the “rain forest” of science. Everywhere the forest is well-worked and has been so for generations... The true home of a jungle people is the jungle, which is to them what our agricultural and pasture land is to us. The Bornean forests have been systematically worked by the inhabitants... (Gibbs 1914: 10).

This is far from the picture of a landscape virtually untouched by its inhabitants, which has been the prevailing wisdom regarding the forests of Borneo.


2.5 Summary

This chapter has examined floral evolution on the island of Borneo and Southeast Asia, and the effects of climate change on vegetation patterns, during the Pleistocene, Last Glacial Maximum and the Holocene period. Previous research has demonstrated that vegetation patterns, associated with warm-cold oscillations have not been monolithic, but instead very changeable, particularly during the Pleistocene. Vegetation patterns during the LGM generally represent a much cooler-drier climate, whilst the Holocene spectra represent a warm-wet climate; however, not all records demonstrate cool-dry and warm-wet associations. There appears to be several inconsistencies, in which some authors argue for increased precipitation and other authors argue for increased aridity. The palaeoecological record for the late Pleistocene, although particularly for the LGM is quite limited for Borneo and there is clearly a need for further palaeoecological investigations, to gain a better understanding of climate variations and the responses of tropical ecosystems to climate change. This thesis will therefore address this issue, to produce the first account of the impact of changing climates on the vegetation of interior Borneo during the late Quaternary.

This chapter has also examined the anthropogenic history of Sarawak from early hominid discoveries in Southeast Asia, 1.2-1.6 million years ago, early human migration into Borneo, the beginning of rice cultivation, as well as other forms of plant manipulation in Borneo and Southeast Asia. Early rice cultivation is likely to have begun in China, particular in the Yangtze Valley ca. 14,000 cal BP and may have been present in Borneo from as early as 4,990 cal BP and perhaps even earlier (8,000 years ago at Loagan Bunut). Before the arrival of rice into Borneo, other plants such as yams, taro and sago were being exploited and had been since the late Pleistocene, but probably much earlier. Early hunter-gathers during the Pleistocene would have had an intricate knowledge of plant distribution in rainforests, as well as the technical knowledge, to extract useful carbohydrates from plants that are considered extremely poisonous. The development of arboreal practices and other types of plant management in tropical regions; however, remain poorly understood. Although some research has been undertaken in lowland Borneo no research has previously been done in the mountainous interior. Nothing is currently known about the beginning of rice cultivation and other types of plant exploitation in the Kelabit Highlands, but today, rice is a staple food and culturally important to the modern day Kelabit (Janowski, 2005), whilst the Penan, who also live in the Kelabit Highlands, rely considerably on sago palms (Rautner et al., 2005). This thesis will therefore investigate the history of rice and other plant use in the interior forests of the Kelabit Highlands.

Most of the papers reviewed in this chapter have also demonstrated a tendency to use single-proxy investigations, but the use of multi-proxy investigations such as pollen, phytoliths and other palynomorphs could provide a more detailed understanding of environmental, climate or land use change in the past.
CHAPTER THREE: THE RESEARCH AREA
3.1 Introduction
This chapter introduces the geographical and ethnographical setting for the research area, which is centred within the vicinity of Bario, Pa’Dalih, and at Pa’Buda in the Kelabit Highlands of Sarawak, Malaysian Borneo. The aim of this chapter is to provide a clearer perspective of the research area with in-depth descriptions of the demographics, climate and geography for the island of Borneo with particular reference to the sites selected for investigation.

3.2 Origin, Size and Climate
The island of Borneo began to develop with the north-westward movement of the Australian continental plate during the Mesozoic following the breakup of the southern mega-continent Gondwanaland at the end of the Palaeozoic. As it moved north-westward, towards the Asian continent, a complex system of micro-continents and areas of oceanic crust were affected, eventually leading to the present configuration of Island Southeast Asia. The island of Borneo is largely a series of fragments of ancient continental crust and accreted terraces, derived from different palaeogeographical areas and therefore of different ages and characteristics. These are partly overlaid and abutted by younger sedimentary rocks. Thus, parts of the present island, now meta-sedimentary rocks in central and southern Sarawak, were laid down in deep-water marine environments during the Late Cretaceous as greywacke sandstones and shales (Hutchinson, 2005). Other deep marine deposits, mostly turbiditic mudstones and sandstones, now known as the Crocker Range of Sabah, probably were laid down adjacent to the South China Sea (Hutchison, 2005), some time before the South China Sea began to open in the Late Cretaceous and before proto-South China Sea oceanic crust started subducting beneath the northwest edge of Borneo. To the southeast of what is currently Borneo, further subduction was occurring on the edge of the Celebes Sea (Hutchinson, 2005). This continued into the early Miocene, where around 17-18 million years ago the south-eastward migrating Luconia subcontinent locked the subduction zone resulting in the uplifting and later deformation of the Crocker Range, running along the north-western Borneo coast (Noad, 2001). To the south and east of the Crocker Range, carbonate sediments of Eocene-Miocene age were deposited as patch-reefs in a shallow sea (Noad 2001). At the same time, delta-front turbidite deposition occurred over much of the current area of Brunei and Sarawak, from rivers draining the uplifted land (Hutchison, 2005). Occasional delta-top coals of Miocene age are known (Anderson & Muller, 1975), suggesting that relative sea-level was variable during this time. In the late Miocene, intrusion of the Mount Kinabalu Granite was initiated. Much of the island was uplifted above sea-level during the Neogene and this uplift is still continuing, with erosion having removed more than 4 km of rock over much of north Borneo (Hutchison 2005).
Today the island of Borneo is the third largest island and one of the most biologically diverse areas in the world, covering an area of 702,000 sq km. In the lowlands the average daily temperature is between 30-32°C with high humidity, with an average rainfall of between 4,000-5,000 mm throughout the year (Pio, 2005). This is partly because in addition to its equatorial position, Borneo lies in the Pacific Warm Pool – one of the warmest areas of sea on Earth (Partin et al., 2007). There are two main seasons: The north-east monsoon, which is predominately the wettest season and runs from October to March, and the south west monsoon, which runs from April to August (Pio, 2005). Despite relatively high rainfall throughout the year, occasionally dry periods occur, which have in the past led to droughts and sometimes forest fires. The El Nino events of 1997-1998 and 1982-1983 are prime examples of dry periods in Borneo, which resulted in the largest uncontrolled forest fires of the 20th century (Wooster et al., 2011). According to Wooster and Strub (2002) the 1982-1983 fire damaged around 50,000 km of Borneo's forest.

3.3 Flora and Fauna
Borneo contains a rich diversity of flora and fauna with species such as the Orang utan, gibbon, sun bear, clouded leopard, pigmy elephant and hornbill. There are more than 210 mammal species in Borneo (44 are endemic) and 15,000 species of flowering plants with 3000 tree species, including 265 dipterocarps, 2000 species of orchid and more than 50 species of carnivorous pitcher plants. A 6.5 ha area of forest may contain over 700 species of tree. Between 1994 and 2004, 361 new animal species were recorded, including 260 insects, 50 plants, 30 freshwater fish, 7 frogs, 6 lizards, 5 crabs, 2 snakes and 1 toad (Pio, 2005).

3.4 Vegetation Zones
This section provides an in-depth account of the typical plants and their groupings found in Borneo and from within the study area today. The purpose of this section is to understand the range of plants which might or are likely to occur during pollen identification in both the surface and core samples. Section 3.4 also provides a detailed account of plants found at certain altitudinal zones within and near to the study site, but also at other sites recorded in Borneo and Southeast Asia, to allow a wider and more local comparison of the types of vegetation which might be affected by climate change. The vegetation types in Borneo can be divided into a number of groups and include: mangroves, peat swamp forests, dipterocarp forests, montane forests and heath or kerangas forest (Rautner et al., 2005).

Mangrove forests
Mangrove forests are usually found around coastlines and river deltas and have evolved a number of mechanisms to tolerate the harsh saline environments in which they live. For example several mangrove species, such as Sonneratia, have evolved roots that protrude above mud and salt water,
absorbing oxygen through tiny pores which they transfer to other roots lying beneath the mud (MacKinnon, 1975). Rautner et al. (2005) also describe adaptations for mechanical fixation in loose soil and specialised mechanisms for dealing with salt concentrations. The mangrove species contain a vast range of sustainable products, including fuel, wood and food; however, in 1985 an estimated 95% of Kalimantans mangroves were allocated for timber. In 2002 just over 1.2 million ha of mangrove forests could be found in Borneo (Rautner et al., 2005).

Swamp forests
Swamp forests can be found close to coastal areas, but they also occur on shores of rivers and lakes. There are two types of swamp forest: fresh water and raised peat swamp forests. Freshwater swamps receive a lot of minerals from river flood waters, whilst raised peat swamps are rain fed, so receive less organic minerals and nutrients. These therefore tend to have lower species diversity than fresh water swamp forests (Rautner et al., 2005). The tops of the highest peat domes are covered with relatively drought-tolerant vegetation (Anderson, 1963).

Dipterocarp forests
Dipterocarp forests are found further inland. They require well drained land and commonly exist up to 1000 m. The dipterocarp forests are the most diverse plant communities in Borneo. In the richest formations, dipterocarps (the family Dipterocarpaceae) can represent 10% of all trees and 80% of all emergents. Dipterocarp forests make up 85% of all forested areas. Trees can exceed 45 m and can sometimes reach as high as 60 m. They are also the most valuable source of timber (Rautner et al., 2005).

Heath or Kerangas forests
These forests can be found in coastal areas and further inland, where they grow predominantly on free draining sandstone and old river gravels. Heath forests are highly acidic and are poor in bases. Trees are generally much smaller with a lower diversity than in mixed rainforests; however, heath forests contain some remarkable plants such as insectivores (the Pitcher plant/Nepenthes, Sundews/Drosera and Bladderworts/Urticaria). These plants obtain nutrients from insects in response to scarcity of availability of nitrogen (Rautner et al., 2005). The Ericaceae family, such Rhododendron and Vaccinium are suggested by Mackinnon et al. (1996) to be found on nutrient poor sands, although Anshari, et al, (2004), Smith (1980) and Kitayama (1992) also describe them as predominantly found at higher altitudes.

Montane forests
Rautner et al. (2005) describes montane forests as beginning between 900-1000 m, ranging up to an altitude of 3300 m and usually having a much lower canopy height, less than 10 m in upper montane
forests. The lowland dipterocarps are replaced by more temperate families, such as the Fagaceae (Beech, Chestnut and Oak). There are also fewer species of plants and animals compared with the lowlands, although according to Rautner et al. (2005), a rich and unique set of species, derived from both Asia and Australasian families, makes them one of the most diverse montane habitats on earth. Between 1000-2500 m Van Steenis (1964) describes montane forest as “not essentially different from mixed tropical lowland forest; its average stature smaller in dimension, with more moss and epiphytes. Many woody families and genera which are, in species and specimens, abundant in the lowland forest, e.g. Anacardiaceae, Annonaceae, Bombacaceae, Burseraceae, Dipterocarpaceae, Ebenaceae, Euphorbiaceae, Leguminaceae, Meliaceae, Moraceae, Palmae, Sapindaceae, Sapotaceae and Verbenaceae lose their predominance and gradually fade away above 1000 m, to disappear almost entirely at the 2000 m contour. They are replaced by genera and species of woody families which are in the lowland distinctly scarcer, e.g. Araliaceae, Celastraceae, Elaeocarpaceae, Ericaceae, Fagaceae, Ilex, Lauraceae, Magnoliaceae, Myrsinaceae, Myrtaceae, Oleaceae, Polygalaceae, Symplocaceae and Theaceae”. The woody genera are also distinctly smaller than in the lowland forests and are usually known as lauro-fagaceous forest types. Van Steenis (1964) also mentions that the number of centric herbaceous plants diminishes upwards: Araceae, Zingiberaceae, Pandanus, and saprophytic herbs disappear at ca. 1500 m and instead are replaced by certain excentric, herbaceaous families and genera, which are scarce or absent in the lowland, e.g. Carex, Hydrocotyle, Hypericum, Impatiens, Lobelia, Sanicula and Viola.

The montane forests of Borneo are in some ways different to montane forests elsewhere in the region. Montane flora from the Highlands of Sumatra has three vegetation zones: A lowland montane forest from 1000-1800 m is usually dominated by the Fagaceae family (Quercus, Lithocarpus and Castanopsis, but do not include Nothofagus). From 1800-2800 m Podocarpus spp dominate the forest, although Podocarpus also occurs at lower altitudes. Above 2800 m dwarf forests, characterised by Ericaceae (e.g. Vaccinium), Leptospermum and Myrica javanica and at 3300 m, on the summit of the granite Gunong Leuser, open Rhododendron scrub is present (Flenley, 1979). In New Guinea today lower montane forests are also dominated by Fagaceae, especially species of Nothofagus, Lithocarpus and Castanopsis, whilst mixed mountain and sub alpine forests tend to be dominated by Gymnosperms such as Papuacedrus, Podocarpus, Phyllocladus and Dacrycarpus (Flenley, 1984). In Sabah, Smith (1980) describes upper montane taxa from Mount Kinabalu up to 3550 m as including the genera: Podocarpus, Phyllocladus, Symlocos, Dacrycarpus, Shima, Vaccinium, Myrica, Leptospermum, Drymis, Eugenia, Ilex and Rhododendron. Flenley (1979) however, also reports Phyllocladus as occurring in lower montane forest today near Sirunki swamp in New Guinea.

In Borneo, most of the work on montane floras has taken place in Sabah. Smith (1980) describes upper montane taxa from Mount Kinabalu up to 3550 m as including the genera: Podocarpus,
Phyllocladus, Symplocos, Dacrycarpus, Shima, Vaccinium, Myrica, Leptospermum, Drymis, Eugenia, Ilex and Rhododendron. More recently Kitayama (1992) carried out an altitudinal transect from 600 m to 3400 m for the flora on Mount Kinabalu and describes five montane zones: lower montane, upper montane, sub alpine, ecotone and alpine. Lower montane as described by Flenley for Sumatra (1979) and Flenley (1984) for New Guinea, is again characterised by Fagaceae, but also Lauraceae, Theaceae, Myrtaceae and Elaeocarpaceae. Fagaceae and Lauraceae however, also have broad altitudinal ranges on Mount Kinabalu, extending to the lowland and subalpine zone. The upper montane zone is characterised by Ascarina philippinensis, Eugenia punctilimba, Olea rubrovenia and Ilex zygophylla. The sub alpine zone is characterised by Ascarina philippinensis, Eugenia punctilimba, Olea rubrovenia, Ilex zygophyllafolia, Syrnolcos buxifolia, Eugenia ampullaria and Rhododendron buxifolium. Kitayama (1992) also describes a higher number of plants with Austral-Antarctic elements with increasing altitude such as Phyllocladus hypophyllus, Dacrycarpus imbricatus, D. kinabaluensis, and Leptospernum recurvum.

More locally at Mount Murud in the Kelabit Highlands, which reaches an altitude of 2424 m, Beaman (1999) describes an oak-laural lower montane forest above 1775 m, which changes into a lower stature dwarfed mossy forest just below the summit ridge at about 2000 m. Some of the plants recorded on Mount Murud include Phyllocladus hypophyllus identified at 2300-2400 m, Dacrycarpus imbuicatus at 1500 m, Dacrydium beccarii at 1200 m, Dacrydium gibbsiae at 2100-2400 m, Dacrydium xanthandrum at 2300-2400 m, and Podocarpus neriifolius at 2300-2400 m. These species do not appear in the botanical collections from Bario at 1150 m, recorded by Latiff et al. (1999) or recorded from my own reference collection of 213 species (see Appendix One and Table 3.1); however, according to Anderson (1988) most of the species described above can also be found between 950-1200 m throughout Sarawak. When compared against all of the botanical studies listed in section 3.41 it appears that although Phyllocladus, Dacrydium and Podocarpus species do occur at lower altitudes, they are more frequent in upper montane forest, above 2000 m. Fagaceae species can also be found at various altitudes but appear to be more frequent within the lower to upper montane boundary, and for the Kelabit Highlands this lies between 1775-2000 m. This argument is further supported by Kershaw et al. (2011) who also describe the pollen taxa of Phyllocladus, Dacrycarpus, Dacrydium and Podocarpus as common montane conifers, and the pollen taxa of Quercus, Lithocarpus and Castanopsis as common lower montane angiosperms. To interpret possible climate fluctuations in the pollen record, the representation of other types of woody taxa found in montane environments, such as Araliaceae, Celastraceae, Elaeocarpaceae, Ericaceae, Ilex, Lauraceae, Magnoliaceae, Myrsinaceae, Myrtaceae, Oleaceae, Polygalaceae, Symplocaceae and Theaceae, described by Van Steenis (1964), should also be taken into consideration. These species however, are also well represented in lower montane forest between 900-1200 m (Latiff et al., 1999). Table 3.1 provides a list of plants collected from different altitudinal belts in Malaysian Borneo, including
plants collected from within the research area. The table provides a modern analogue from which to compare and interpret the fossil pollen record.

3.5 Population and Economy

The population of Borneo in 2005 was 17 million. The island is split into four separate states. The independent state of Brunei (6000 sq km) with a population of 363,000, the Malaysian states of Sabah (72,000 sq km) and Sarawak (124,000 sq km) with a combined population of 4.6 million and the Indonesian state of Kalimantan (500,000 sq km), which is the largest state with a population of 12.3 million. A total of 66 % of the population are Muslim, 29 % non-Muslim (indigenous and other) and 5 % Chinese (who are often Buddhists); however, this depends on location, as in Sarawak 25 % of the population are Chinese and in Kalimantan the indigenous population represent 45 %. There are hundreds of ethnic groups in Borneo, with over 140 languages spoken in Kalimantan, 50 languages and dialects in Sabah and 30 in Sarawak (Rautner et al., 2005).

The 1980s saw a rapid rise in the timber trade. During this period 75 % of Borneo was still covered in forest, but between 1985-2005 Borneo lost an average of 850,000 hectares of forest every year and by 2005 forest cover had been reduced to 50 %. By 2020 forest cover could drop to 25 % (Rautner et al., 2005). Palm oil plantations are the biggest threat to Borneo’s remaining forests. Between 1998 and 2003 the average annual growth rate of oil palm plantations was nearly 8 %, with over 1.8 million hectares in Sabah and Sarawak and 1 million hectares in Kalimantan (Rautner et al., 2005). Today the economy of Borneo is based on palm oil, timber, petroleum and tourism (Thiessen, 2008). The richest state in Borneo is Brunei, which is also the 4th richest country in Asia. Brunei’s main economy is based on the extension of oil and gas fields, which account for over half of the economic activity and consists of 90 % of Brunei’s exports and 40 % GDP. The oil and gas fields are however, not sustainable. The government has therefore established an economic diversification programme targeting international finance, tourism, transport, logistics and ICT as potential growth areas (Thiessen, 2008). In Sabah within the last ten years palm oil has taken over from forestry as the biggest export; although, since the early 2000s tourism has been the fastest growing sector in Sabah’s economy. Petroleum is also important (Thiessen, 2008). In Sarawak the timber industry is the backbone of the economy, in which 40 % of Sarawak’s population are employed. The value of Sarawak’s wood exports increased to 9.1 billion MYR (an increase of 26 %) in 2006. This was an increase from 7.2 billion from the previous year. Sarawak also grows 95 % of Malaysian black peppers. Palm oil is also extremely important, whilst tourism is on the increase (Thiessen, 2008). The main economic sectors for Kalimantan include oil, gas, mining and forestry. Agriculture (Oosternan & Wanababakti, 1999) and palm oil (Rautner et al., 2005) are also very important.
3.6 The Kelabit Highlands

Janowski (2005) describes the Kelabit Highlands as an area covering 90 km in length and 60 km in width, about 1000-3500 m above sea level. It is situated mainly in Sarawak, Malaysia but includes part of Kalimantan and forms the headwaters of a number of rivers including the Baram and Kerayan. Even though this part of Sarawak was under Brooke rule in the nineteenth century, Janowski (2005) explains that few Europeans visited the Kelabit Highlands until after the Second World War and that geographical barriers have isolated the Kelabits from outside cultures. According to Amster (2003), the Brooke government raided the Kelabit Highlands in 1913 to quell headhunting. During these raids thirty villages may have been destroyed and up to two hundred people may have been killed.

![Fig 3.1: Map of Borneo. Sarawak is shaded in grey. The red dots represent Bario, Pa’Dalih and Pa’Buda in the Kelabit Highlands. The upper dot is Bario and the lower dot Pa’Dalih and Pa’Buda](Author)

3.61 Bario

The village of Bario lies about 1064 m above sea level in the Kelabit Highlands, in a broad and flat-floored basin, bounded by steep forested hillslopes in turbiditic shales and sandstones. The Bario basin is a tributary valley of the Pa ‘Dabpur river, itself a tributary of the Baram system (Barker et al., 2008). The climate is warm and wet (although much cooler and less humid than the lowlands) and water drains from the surrounding hills into the valley. Low slopes on nutrient-poor sandstone and clay-rich colluvium, however, prevent runoff, causing water logging and further leaching of nutrients. In some areas shallow peat bogs have developed. Bario is therefore infertile and large areas of land are needed for wet rice cultivation, which is today the main form of agriculture in the Kelabit Highlands. Pineapple cultivation is also common on the surrounding slopes. The main vegetation
growing on the plateau is kerangas. Plants such as *Saurauia*, *Rhododendron*, *Vaccinium* and *Nepenthes* are common. This is similar to the vegetation found today at the Sikijang swamp 1100 m above sea level in Sumatra (Flenley and Butler, 2001).

**Fig 3.2:** A photograph (Author, 2007) of old rice fields on the Bario plateau and pineapples growing on the slope

In the 1960s a regular airstrip opened up in Bario; first to Marudi and later to Miri. Schooling became available both in the highlands and in the towns. The concentration of government services including a primary school, secondary school and clinic led to the in migration of a large number of people from other parts of the highlands. By the 1980s Bario was made up of a number of separate longhouse communities less than an hour’s walking distance from each other. Outside Bario in 1986 there were eight Kelabit longhouse communities within the Kelabit Highlands: Pa’Umo, Pa Ukat, Pa’Derang, Remudu, Pa’Dalih, Pa’Lungan, Long Danu and Batu Patong (Janowski, 2005, and Janowski (2003).

### 3.62 Pa’ Dalih

The village is situated in the southern part of the Kelabit Highlands close to the border of Kalimantan and about twenty miles from Bario. The geology of the Pa’Dalih area is predominantly black shales and sandy turbidites. For much of its course between Pa’Mada and Pa’Dalih, the Kelapang River, a tributary of the Baram, occupies a rock-cut gorge, mostly cut in turbiditic sandstone/shale units. Just below Pa’ Dalih, the valley broadens and its floor contains a series of alluvial terraces. The Pa’Dalih longhouse stands on a low terrace of the Kelapang River. The village is situated in the curve of an ancient river meander. Several palaeochannels ranging from > 50,000 to ca.1000 cal BP have been recorded in and around the vicinity of Pa’Dalih (see Fig 10.1). These old channel systems are extremely fertile and some are currently used for rice cultivation. Due to the fertility of the soils in Pa’Dalih, much smaller fields are required for rice cultivation compared with Bario. Vegetational patterns, with a preponderance of fruit trees, sago palms and second-growth forest on the terraces,
suggest that these relatively flat and fertile locations have been preferred areas for human activity at times in the past. The hillslopes above the river terraces are steep, frequently precipitous and covered in dense montane rainforest, with taxa such as *Agathis*, *Ficus*, *Euphorbiaceae* and *Fagaceae* (Barker *et al.* 2008). The village of Pa’Dalih consists of two longhouse communities, one large longhouse and one smaller with other smaller houses clustered around the evangelical church (Janowski, 2005). Janowski (2003) describes it as situated in the midst of a forest surrounded by an area of buffalo pasture and both dry and wet rice fields.

3.63 Pa’Buda
Pa’Buda lies on a river terrace in the Kelapang Valley south of Pa’Dalih. It lies between two abandoned settlements: Batu Patong to the north, which is a recently abandoned village, although the fields are still cultivated for rice, and Long Kelit, an old ridge site settlement to the south, which is no longer standing and was the site of archaeological excavations.

3.64 The watersheds for Bario, Pa’Dalih and Pa’Buda
Most of the core sites are located on ancient river terraces (see section 4.23). These sites would have been affected by fluvial activity in the past, which would have had some influence on pollen distribution. To understand pollen transport mechanisms during periods of past fluvial deposition it is important to examine present watersheds. The location of present watersheds provides information on distance and altitude of tributaries from the core sites, and therefore an indication of how past tributaries may have affected pollen distribution at the core sites.

Fig 3.3 highlights the main watersheds and catchments surrounding the core sites. Blue represents the River Dabpur and its tributaries, and is the watershed for Bario. Red represents the River Diit and its tributaries, and is the watershed for Pa’Buda and Pa’Dalih in the southern Kelabit Highlands. The River Diit eventually flows into the River Kelapang, which is represented in purple, along with its tributaries; whilst both the Kelapang and the Dabpur are tributaries of the River Baram, represented in pink. The River Dabpur begins near Pa’Lungan and Mount Murud before flowing past Bario. During times of past fluvial activity, these tributaries may have transported pollen from up to 30 km away and from a height of up to 2400 m, to the core site in Bario (1064 m above sea level). The geographical position of the Bario plateau, however, suggests that past fluvial activity was probably influenced predominantly by tributaries running off of the surrounding hills and these would have been within an 8 km radius and no more than 1500 m, rather than from the Pa’Lungan and Mount Murud tributaries. The Pa’Buda core site would have only been influenced by one tributary of the Diit, beginning about 10 km away, and no more than around 1500 m, whilst Pa’ Dalih would have been influenced by two tributaries within a 14-16 km radius but again no more than 1500 m.
3.65 Ethnic communities living in the Kelabit Highlands

The Penan

The Penan are one of the largest indigenous communities of Sarawak with an estimated 15,485 persons. Traditionally mobile hunter-gatherers, the majority of the community have changed to a more settled way of life with only 3% (458 persons in 2006) remaining nomadic. The settled Penan have started to cultivate rice and vegetables on a small scale. A number of the settled communities, however, still forage in the jungle for wild, fruits, vegetables and game, particularly when their small scale farms yield insufficient food supplies. For the Penan the foraging activity would establish ownership and stewardship of the forest with boundaries marked by watersheds, mountains and landmarks. Each group of Penan has their own foraging area, which is passed down from generation to generation. The Penan community in Long Sigu and Long Jaik are considered amongst the poorest groups in Sarawak and live below the poverty line (Suhakam, 2007).

According to Rautner et al. (2005) the Penan depend largely on sago palms, whose trunks contain edible pith. Only one or two stems are cut in a grove, thereby ensuring the plant does not die and will produce food for future generations, the leaf buds, which contain protein and carbohydrate can also be eaten. Rautner et al. (2005) also explains that the movement of a group of Penan in the forest depends on the availability of sago palms. There are also 50 types of fruit that are considered edible, as well as a number of ferns, leaves and flower buds. Wild boar is also considered an important source of food. Both Penan and Kelabit settlements are represented in Fig 3.2, following Janowski (2003). It should however, be noted that this map represents settlement and farming in 1988 and some communities have since moved location. One of the core sites in Bario for example, was close to a Penan settlement, which is not recorded on the map. Janowski (2003) however, does mention that a small number of semi-nomadic Penan hunter gatherers live in the Kelabit Highlands as well as the Kelabit, based in the settlements of Pa’Tik and Pa’Berang.

The Kelabit

The Kelabit people claim to be the original inhabitants of the Kelabit Highlands (Christensen, 2002). The word Kelabit was first used after the 1960s. Previously the people had described themselves by the name of the local river or valley, in which they lived. The name Kelabit was given to them by downriver people and possibly mistakenly used by a government official and with increasing contact from the outside world the name was gradually adopted (Janowski, 2005). The Kelabit have close linguistic and cultural ties with the Lun Bawang people to the north and west and with the Kenya and Kayan people to the South (Christensen, 2002). Janowski (2003) describes the Kelabit as part of a much larger linguistic grouping called the Apo Duat and notes that most people who speak languages belonging to this group live in an interior tableland area, the Kerayan-Kelabit Highland, which includes the Kelabit Highlands, although the main part of this tableland lies in Kalimantan. Hitchner,
et al. (2009) also describes the Kelabit and Kerayan Highlands as home to several closely related ethnic groups including the Kelabit, Lun Dayeh/Lun Bawang, Berian, Lengilu, Saban and Penan, who not only have linguistic and many cross-boundary kinship ties, but also share cultural features including similar wet-rice cultivation techniques and handicrafts (such as bead work and basket weaving), as well as a common history of megalith-making activity.

In 1987 the population of Kelabit was estimated to be 5,059 and constitutes one of the smaller ethnic groups in Sarawak, although today only ca. 2000 Kelabit live in the Kelabit Highlands as more than half of the population have moved to the coastal towns (Christensen, 2002).

The Kelabits are primarily agriculturalists, but until recently practised the frequent shifting of settlements and shifting cultivation (Janowski, 2005). The main crop grown by the Kelabit today is rice, predominantly by wet farming, although dry cultivation is also practised (Janowski, 2005). Before the Second World War Janowski (2005) suggests wet rice cultivation may have been the preferred choice of agriculture rather than dry swidden farming. This is due to limited iron supplies, and thus a limited availability of bush knives. Consequently, flat swampy areas without large trees, which would have been less labour intensive, may have been the preferred choice to cultivate. Fig 3.3 represents the location of wet and dry rice fields in the Kelabit Highlands during the period of 1988 (Janowski, 2003). Janowski (2003) also explains that rice is the staple food for the Kelabit and is a symbol of status, although they still rely heavily on the forest for resources. For the people of Pa’Dalih the rainforest is a rich source of substances necessary to sustain physical life and to enable social life through food and crops. According to Christensen (2002) the Kelabit method of farming rice does not resemble any other method employed in Borneo and may have originated with the irrigated cultivation of *Colocasia esculenta*. Latiff et al. (1999) also describes the local Kelabits as well known for their successful and sustainable cultivation of wet rice.

3.66 Agriculture in the Kelabit Highlands

The exact beginning of early plant use and rice agriculture in the Kelabit Highlands is unknown. Many of the Kelabit and Kerayan say that rice cultivation is ancient. Janowski (2005), explains that it is not known how quickly Austronesian settlers penetrated into the interior of the island of Borneo, but when they did they probably took swamp adapted varieties of rice with them. It is therefore possible that rice cultivation is ancient and that rice has grown there right from the beginning of Austronesian settlement; however, it is also likely that settlement was initially in coastal areas and it may have taken some time until variations of rice were developed, suitable for these altitudes, so that it could be carried inland. Christensen (2002) speculates that early shifting cultivation systems/selective management of wild plants likely existed 5-6,000 years ago and perhaps even longer. These early cultivation systems were probably based on sago (*Eugeissona utilis*), taro
(Colocasia esculenta), yams (Dioscorea) and bananas (Musa spp.). The present Kelabit community of Pa’Dalih, according to Christensen (2002), possess knowledge of at least 650 different species of plant, comprising fungi, lichens, mosses, ferns gymnosperms, monocotyledons and dicotyledons, of which 154 are either cultivated, semi-managed or naturalised species. Christensen (2002) also argues that rice was introduced 1450-950 years ago and became the most important crop, displacing other staple crops. Today only a few indigenous communities still rely on and prefer to eat sago.

3.7 Summary
This chapter has provided a setting for the research area with a detailed account of the climate, geography, vegetation and demographics for the island of Borneo and in particular for the core sites, based in Bario, in the northern Kelabit Highlands and in Pa’Dalih and Pa’Buda in the southern Kelabit Highlands. Apart from the anthropogenic studies carried out by Harrisson (1954, 1959), Janowski (2003, 2005), and Amster (2003) and the ethnobotanical studies carried out by Christensen (2002) the history of the Kelabit Highlands remains fairly unknown. This thesis will address these shortcomings by examining vegetation change in the Kelabit Highlands, providing a more detailed understanding of not only past cultural interactions with the rainforest environment but also environmental and climatic influences. The next chapter, Chapter Four will describe the methodologies employed in the Kelabit Highlands, Kuching and at Queen’s University Belfast (QUB) to fulfil the aims and objectives set out in this PhD thesis.
CHAPTER FOUR: METHODOLOGY
Chapter 4
Methodology

4.1 Introduction
To fulfil the aims and objectives set out in Chapter One a programme of field work and laboratory research was carried out. This included the creation of a modern pollen reference collection to assist identification, the collection of surface samples to provide a modern analogue for comparison with the core results, stratigraphic, sediment, pollen, palynomorph and also phytolith investigations, to produce a multi-proxy record, thus allowing a more rounded interpretation of results. The methods employed to achieve these aims and objectives are described in this chapter: 4.2 to 4.7.

4.2 Fieldwork
Samples were collected during the field seasons of 2007 and 2008 and included the collection of modern pollen, surface samples, core samples and archaeological sediment samples. It should be noted that the choice of localities available to the author to undertake this study was very limited. This is because this project was part of the ‘Cultured Rainforest Project’ and independent field-work away from the bases used by the project could not be done within the limits of time and resources. The base localities chosen for the project were largely decided on anthropological and archaeological grounds and field work was only possible within a day’s walking distance of them.

4.2.1 Pollen reference collection
Despite detailed pollen-morphological research carried out in Taiwan by Huang (1972), the Philippines by Bulalacao (1997), in Borneo by Anderson and Muller (1975) and the availability of a pollen database for Indonesia held at the Australian National University; reference material for island Southeast Asia is still very limited and almost non-existent for the island of Borneo, which has some of the richest biodiversity on earth with c.15000 species of flowering plant and 3000 species of tree (MacKinnon et al. 1998). Before this study began, no pollen reference material was available for the highlands of Borneo; therefore, to aid identification of the fossil pollen record the first step in this investigation was to establish a modern reference collection of pollen from species, from a range of different environments within the Kelabit Highlands, primarily from in and around the villages of Bario and Pa’Dalih, as these were the main sites for core sampling and therefore the local vegetation would have had a strong influence on the pollen record. A range of ecological locations were selected for plant collection and included: secondary forest at various stages after cultivation of hill padi, alluvial forest, wet swamp forest, buffalo pasture, grassland, riverine, roadside, and open ground vegetation. The plant specimens collected, represent various environments within a 3.5 km radius of the Bario and Pa’Dalih core sites. Primary forest specimens have not been included because of the distance away from the research area and core sites to primary forest, and the amount of time that
would have been needed to trek to these sites over difficult terrain. In total 256 plants were collected. During field observations it was noted whether the plant was a shrub, herb or tree. Latitude and longitude have also been recorded and these results are represented in Appendix Two.

The specimens were then identified at SAR, Kuching, by Dr Kit Pearce with the help of literature and the SAR collections, including specimens collected by Christensen (2002). Identification was to species level wherever possible. Species names were checked online at the IPNI (International Plant Names Index) website. Specimens were compared to photographs of type specimens of the relevant species on-line at the National Herbarium Nederland website to resolve their identity further. BRAHMS (Botanical Research and Herbarium Management System) software was used to store identity and collection data and to summarise the data and generate labels for the specimens. The taxa collected from the Kelabit Highlands are listed in Appendix Two. Twenty six pollen specimens were also considered important, but were not collected from the Kelabit Highlands. Instead they were extracted from SAR by the author. The specimens represent genera that may be found in the Kelabit Highlands and species that are considered by the author to be potentially useful for future palynologists. The plant specimens were preserved as herbarium specimens and have been deposited at SAR, while the pollen samples were preserved for further investigation at Queens University Belfast.

Overall 213 species are represented in Appendix One of this thesis (187 from the 256 Highland specimens and 26 from SAR), belonging to 168 identified genera and 82 families. Of these specimens, 41 species could only be identified to genera and 22 could only be identified to family (partly due to lack of a good reference collection and lack of literature). This is unsurprising given the biodiversity of the Borneo forests. A detailed description of the pollen morphology is represented in Appendix One.

4.22 Surface sample collection

Due to a lack of pollen reference material available for the Kelabit Highlands and for Borneo, more time was spent collecting plants from a wide range of habitats than on the collection of modern surface samples. Pollen reference material was prioritised so that a reference collection could be prepared and would be available to aid the identification of pollen from the core sediments. It was not feasible to set up pollen traps as these need to be set up at specific times of the year when plants are flowering, and flights to Sarawak and the Kelabit Highlands were not organised by the author, but were booked as part of the ‘Cultured Rainforest Project’ by the University of Cambridge. It should be noted that for future research moss polsters would perhaps be a better source of modern pollen than surface sediment samples, particularly from disturbed ground, and thus enable a wider range of habitats and vegetation types to be sampled; however, even in disturbed sediments, there should still
be a reasonable representation of modern plants from the surrounding area. It was therefore decided, with the limited time available, to select seven surface samples from around Pa’Dalih (03° 34, 04.1 and 115° 33) (Fig 5.1). This was undertaken in an attempt to provide a modern analogue for the core samples and to examine whether there is spatial patterning of pollen fallout associated with different human activities. The surface samples were then supplemented by analysis of the tops of cores, which provide similar information about local pollen rain. GPS was used to document the exact location of the sample sites. A limitation of using core top samples might be that not all the top core samples represent modern sediments; however, it could also be argued that, although the recent underlying sediments may be missing, the top layer of sediment is likely to be of modern age, particularly if sediments are colonised by vegetation. Despite this argument caution should be applied to the core top sediments and it should be acknowledged that there may be limitations in their use as representative of ‘modern’. For example, the Bario core (see Chapter Six) shows an absence of *Pteridium* spores from the top sample, despite the abundance of the fern at the site today. Surface sample results are described in Chapter Five.

For more information on the types of plants found in Bario and at a higher altitude on Mt. Murud, see Latiff et al. (1999) and Beaman (1999).

4.23 Core sample collection and lithology

To be able to carry out palynological analysis, a number of core samples were obtained using an Eijkelkamp Livingstone-type piston corer, selected because a) it was light and easy to carry and b) because it operates well in both peat and lake sediments. The Russian corer for example, is good at obtaining peat samples but does not work well on clays (Moore et al., 1991). An Eijkelkamp clay-cutting auger was also used in the 2008 season to penetrate desiccated sediments too hard for the piston corer, for instance in core PDH 223. The selection of all sites involved talking to the local people of Pa’Dalih and Bario and then hiring guides to take us to potential locations. These included cultivated/fallow rice and tapioca fields, palaeochannels, kerangas forest and one peat bog. Some of the sites selected in 2007 were impossible to core because tree roots (such as in the kerangas forest) prevented core sampling, whilst other sites (such as the field cores) were not analysed due to poor preservation of pollen and time restraints. The field cores might however, hold potential for future phytolith analysis. During the first season’s fieldwork, core samples were cleaned in the field, the lithology described, sub-sampled and bagged in self-seal polythene bags to allow easier transportation. During the second field season more man-power was available, so core segments were kept intact and wrapped in plastic film and then plastic guttering for storage. This reduced the risk of contamination and allowed other types of analysis to be carried out later. Material retrieved using the clay-cutting auger was carefully cleaned in the field and sub-samples were bagged in self-seal polythene bags. All samples were kept in a cool shady place in the field and refrigerated at 4°C on
return to the laboratory, to minimise pollen degradation and microbial activity. The lithology of the 2008 cores was also described on return to the laboratory. The lithology is an important proxy as it examines the depositional history of the sites studied (for example leached clays might be representative of standing water; sands and gravel of high energetic fluvial deposition; and charcoal of local burning events). A brief summary diagram showing the lithology of the cores investigated is shown in Fig 4.1. See also Appendix Three. A more detailed description of each core is also provided in chapters 6-11.

**Peat bogs**

The aim of the first season’s field work was to locate suitable sites, which would provide a detailed and well preserved pollen record. Acidic and anaerobic conditions produced by peat bogs, provide the most favourable conditions for pollen preservation (Moore et al. 1991) and therefore peat bogs would have been the preferred choice. Peat bogs are known from elsewhere in Borneo, but most are at low altitude (e.g. Anderson & Muller, 1975, Page et al. 1999). Only one peat bog site was located in the Kelabit Highlands. One long core was extracted from a peat bog, adjacent to the new runway in Bario (Ba), in the northern Kelabit Highlands, about 20 km from Pa’Dalih (see Fig 4.1).

**Palaeochannels**

Palaeochannels were selected due to the lack of other available sites for pollen analysis, but also a) their potential in providing an insight into changing environments, such as changing fluvial systems, which may have been influenced by climatic variability or anthropogenic activity b) because at some point in the past the channels may have developed into oxbow lakes, thus providing relatively good preservation and evidence of both environmental and human interactions and c) according to Janowski (2003) and shown in Fig 3.3, wet rice fields appear to be located within the vicinity of village centres and therefore due to the limitation of being unable to core through tree roots to examine the possible timing of dry swidden, the palaeochannels within the vicinity of Pa’Dalih and Pa’Buda offer some potential in understanding the timing of wet rice cultivation after oxbow lake levels declined. Despite the potential in using palaeochannels for pollen and phytolith analysis, it should be noted that there may also be limitations in their use. For example, during past fluvial activity (but also if wet rice cultivation was taking place within the channels at a later period), material may have been washed in from other locations. The Pa’Buda palaeochannel, however, would only have been influenced by in-wash from one tributary within the near vicinity, extending to a distance of no more than 10 km away and 1500 m, whilst the palaeochannels at Pa’Dalih may have been influenced by two tributaries within a 14-16 km radius and 1500 m (See Section 3.64), all within the Kelabit Highlands. Another limitation might be sediment disturbance caused by wet cultivation, which could affect the chronological sequence of events but which should be visible in the sediment characteristics; however, even if some intermixing took place within the palaeochannels it was
expected that a combination of different evidences including charcoal, phytoliths, pollen, changes in lithology, diatoms, other palynomorphs and radiocarbon dating would still provide sufficient evidence to determine environmental change or past anthropogenic signatures on the landscape over different chronological periods, and that by comparing several palaeochannels rather than just analysing one, would further strengthen the palaeoecological evidence.

At the time of coring it was considered that preservation might be quite poor in the older sediments, as fluctuating fluvial activity may have caused erosion or oxidation of the sediments; but it was anticipated that if oxbow lakes developed after the eventual isolation of the palaeochannels then preservation would improve in those sediments. It was also thought that because most of these sites had been used for cultivation in the recent past there would also be a potential for a longer anthropogenic record. The sites (Fig 4.1) selected at Pa’Dalih include 1) a palaeochannel (PDH CO1) only marginally above the modern floodplain level in a palaeo-meander near to the village school and entrance to Pa’Dalih (see Chapter 10); 2) highly organic riverine deposits underlying a river terrace some 10-12 m above the modern floodplain (PDH210), which had been cut by a mechanical excavator on the road that leads into Pa’Dalih, (see Chapter 9); 3) a palaeochannel on a river terrace 15-20 m above the current floodplain (PDH212) by the grass runway adjacent to a fallow rice field (see Chapter 7); and 4) a palaeochannel near to the grass runway adjacent to a fallow rice field 4-6 m above the current floodplain (PDH223), which was currently being used as a fruit grove (see Chapter 8). It was expected that these palaeochannels, because at different levels above the modern river, had been abandoned progressively and would therefore give a longer sequence together than any single one could do on its own. One core was taken from a palaeochannel in Pa’Buda (BPG). This lay on a river terrace fragment some 8 m above the river level at the time of coring, but the river at this point is incised and its altitude could not be compared with nearby floodplains. The coring site at Pa’Buda (see Chapter 11) is south of Pa’Dalih and is currently in use for rice cultivation. Pa’Buda was selected for coring because a) as with Pa’Dalih no peat deposits were available, b) its anthropogenic potential, being adjacent to an old settlement, and c) its proximity to the archaeological excavations at Long Kelit and hence the potential to contribute to the archaeological story.
Fig 4.1: Location of the six cores sites in relation to each other
Archaeological sites
In total 63 samples were also collected from the various contexts of the archaeological sites and placed in sample bags, ready for pollen analysis (see Appendix Four). This was done to compare vegetation change occurring at the sites directly with the archaeological evidence. It was later decided not to use these samples and to focus on the main core samples as a) initial analysis on eight of the selected samples from two of the archaeological sites showed poor preservation, b) the cores had potential in providing both a long environmental and anthropogenic record and c) there was not enough time to analyse both; however, only 15 of the archaeological samples have been analysed and although preservation was relatively poor pollen grains were present in some of the samples. This means the archaeological samples may hold future potential for a small-scale project.

4.3 Laboratory methods
In the laboratory, the second season’s cores were cleaned and sub-sampled for pollen and phytolith analysis. Both season’s core samples then underwent chemical preparation for radiocarbon dating, pollen and phytolith analysis. Magnetic susceptibility determination was carried out on three of the cores (see 4.5) and loss on ignition (see 4.6) was also carried out on three of the cores.

Before initial preparation of the core samples, preliminary investigations were carried out on a selection of six to eight samples from each core, and from 15 of the archaeological samples. This was done to test sample preservation and to understand whether or not it was worth a) continuing with the core and archaeological samples already collected and b) whether further palaeochannel cores should be collected. After the preliminary investigations it was decided to continue with the 2007 Bario (Ba), Pa’Dalih (PDH CO1) and Pa’Buda (BPG) cores and the 2008 (PDH 210, PDH 212 and PDH 223) cores. Despite variation in preservation within the palaeochannel cores, the information that could be extracted was sufficient to warrant further and continued investigations. Cores were selected on the basis of those providing the best preservation and the longest record.

4.3.1 Radiocarbon dating
Radiocarbon dating is widely used as a way of determining the age of material containing organic carbon, and less than 50,000 years old. Alternative methods such as optically stimulated luminescence were not available to the author. Optically stimulated luminescence on cores also requires larger diameter cores than were available to the author (Walker, 2005). Tephrochronology is today often used to date peats in Ireland (e.g. Pilcher et al., 1996), but this is still very much in the initial stages for Southeast Asia, with very few tephra chronologies available, despite the presence of numerous active volcanoes during the Quaternary. The tephra studies that have been conducted generally tend to be older than the chronology for this project, which begins ca. 50,000 years BP. For example, Alloway et al. (2004) records a date of 52±3 ka from the Maninjau Caldera in west central Sumatra,
Chesner et al. (1991) describes the Toba chronology from Papua New Guinea as ranging from 501 to 74 ka and Pubellier et al. (1991) records Pliocene to Eocene tephra in the Celebes and Sulu Sea basins. Tephra layers ranging from the Pleistocene until present day are also recorded in the Celebes and Sulu basins, but according to Pubellier et al. (1991) the source of these tephras is difficult to establish. Some tephra chronologies do however, fall between 50,000 yrs BP and present day and include tephra from the Ambra crater in New Guinea: 2,700 to 560 BP (Coulter et al., 2009), the Tabar Lihir Tanga Feni volcanic chain: 213.6 ka to 1.9 ka (Horz et al., 2004), Merapi in central Java, Bromo, Kelu and Ijen in east Java: between 783±44 and 1112±73 yrs BP (Andreastuti et al., 2000) and the Tangkuban Perahu volcano in west Java: 40,750±270 to 9,445±50 BP (Kartadinata et al., 2002), although no geochemical analysis is described in this paper. From the western Philippine Sea 21 tephra layers range between 2.65 ma and 0.5-0.3 ka (Wei et al., 1998) and in the Sibuyan Sea, a mid-Holocene c.6000 year tephra layer has been identified, originating from the Taal and Mayon volcanoes (Lit et al., 2010). In Japan further Holocene tephra deposits have been recorded by Lim et al. (2008). Tephra sherd s can provide a good age marker for sediments, but only if a detailed tephra chronology exists. It was decided not to undertake tephra analysis because of insufficient tephra identified in cores and no guarantee of a chronology due to limited availability of geochemical data on tephra sherd s. It was therefore decided that radiocarbon dating would be the best option.

To identify the earliest signs of anthropogenic activity and to date the vegetational history in the Kelabit Highlands a number of samples were selected from each site for radiocarbon dating. In total 18 charcoal samples, 10 wood samples and one peat sample have been radiocarbon dated (See chapters 6-11). Treatment for radiocarbon dating was carried out by the author on charcoal at 89 cm from Pa’Buda and on all of the CO1 charcoal samples. This was done to save some money on radiocarbon dates. Laboratory personnel from the radiocarbon unit at Queen’s University Belfast completed treatment on all other samples. Treatment was carried out according to De Vries and Barendsen (1954). Samples were placed in 50 ml 4% HCl and left on a hot plate at 80 ºC for three hours. After three hours the samples were filtered through a fine sieve and neutralised with deionised water. The temperature of the hotplate was then reduced and the samples were placed in 50 ml of 0.5% sodium hydroxide (NaOH) for two hours. It was advised by laboratory personnel not to soak small charcoal samples in NaOH, as this will cause them to disintegrate. It was therefore decided not to use the NaOH treatment on the 324-326 cm sample from core CO1. After two hours the samples were again sieved and neutralised and the HCL treatment was repeated at the original hotplate setting of 80 ºC for two hours. Finally the samples were sieved, neutralised and placed in a drying oven. Laboratory personnel then completed combustion, graphite synthesis and AMS dating.

At Belfast, the 14CHRONO Centre uses Accelerator Mass Spectrometry (AMS) with a NEC compact model 0.5MV AMS machine. AMS requires much smaller amounts of material compared with
conventional spectrometry dating (Bayliss et al., 2004). Normal spectrometers cannot discriminate between $^{14}$C and other elements of similar weight (e.g. $^{14}$N); however with AMS, particles are subjected to large voltage differences so that they travel at very high speeds and even the smallest number of $^{14}$C atoms in a sample can be detected (the proportion of $^{14}$C atoms relative to $^{13}$C or $^{12}$C) (Lowe and Walker, 1997). This technique also differs from conventional radiocarbon dating as the decay products are not counted (Lowe and Walker, 1997, Walker, 2005).

Ages were calibrated primarily by using the CALIB Radiocarbon calibration program (Stuiver and Reimer, 1993) with the IntCal09 calibration curve (Reimer et al., 2009). These include UBA-9312 and UBA-10003 from core Ba, Bario. Calibrated radiocarbon ages are reported as cal BP rather than AD/BC. The main reason for this was for easier comparison with other published research, as almost all environmental records for Southeast Asia are given as cal BP ages. Another reason is that because this is a multicultural project, using BP avoids the whole philosophical debate about whether it is better to use AD and BC, which are explicit references to Christianity.

4.32 Age/Depth model
Age/depth models were produced for cores Ba, PDH 212 and PDH 223 in order to estimate the calendar ages of depths analysed. This was not done for cores BPG, PDH 210 and PDH CO1 because of insufficient numbers of radiocarbon dates and the presence of some age reversals. To produce age/depth models the statistical modelling program clam (Blaauw, 2010) was used. Clam produces age/depth models run in ‘R’ statistical software. The software reads, interprets and plots radiocarbon curves. According to Blaauw (2010), generally, the age/depth models produced by clam seem to provide reasonable approximations of the true (simulated) accumulation history, although occasionally the true curve lies outside the calculated confidence intervals, but these deviations tend to occur at sections of low dating density.

4.33 Magnetic Susceptibility
Magnetic susceptibility reflects the magnetic mineralogy in a sample and is primarily used to identify erosional in-wash (Hilton and Lishman, 1985); however, volcanic ash, precipitation of iron from ground water and the heating of some iron minerals will also affect the magnetism (Hilton and Lishman, 1985). It was thought that differences in the magnitude of erosional in-wash might provide an indication of forest disturbance and support other proxy data in determining if this is natural or anthropogenic disturbance. Whole core segments are needed for an accurate magnetic susceptibility reading using a core scanner. Magnetic susceptibility was carried out by the author on cores PDH 212, PDH 223 and PDH 210 using a Bartington MS2 meter and core scanner. Magnetic susceptibility scanning was not carried out on any of the 2007 cores as these had already been subsampled.
Magnetic susceptibility was not carried out between 131.5-14 cm in core PDH 223 as these samples had to be placed in bags, whilst in the field due to the highly consolidated nature of the sediments which prevented piston coring.

4.34 Loss on Ignition
Loss on Ignition (LOI) is done to obtain the percentage of carbon content in the samples and in some situations can indicate variations in plant productivity (Lowe and Walker, 1997). Changes in plant productivity might be an indication of environmental or land-use change. Samples extracted for LOI correspond with all sample depths taken for pollen analysis in each core. One gram of sediment per sample was placed in crucibles and left over night in a drying cupboard at 30ºC. The dry weight minus crucible weight was then measured and samples were placed in an oven heated to 550 ºC for 4 hours. After 4 hours the burnt weight minus crucible weight was recorded. The equation for calculating LOI is dry weight-burnt weight/dry weight *100 (Heiri et al. 2001) Loss on Ignition was carried out on the main cores: Ba (carried out by John Davidson, Queen’s University Belfast), PDH 212 and PDH 223 (carried out by the author).

4.35 Pollen and palynomorphs
Palynomorphs are microscopic carbon-based fossils, such as pollen, spores, algal spores, dinoflagellate cysts, acritarchs and scolocodonts and their study is known as palynology (Hyde and Williams, 1944). Amongst the palynomorph groups, the study of pollen (derived from the flowers of angiosperms and the male organs of gymnosperms) and spores (from the sporangia of lower plant groups, such as ferns and club-mosses), known as pollen analysis, is the most powerful. Other parts of the palynological assemblage are, however, very useful for palaeoenvironmental reconstruction. Algal spores are informative about the environment of water-bodies in which they lived (e.g. Van Geel, 1976). Palynofacies analysis, which is the study of the whole assemblage of organic matter in a sample, is an increasingly powerful way of reconstructing ancient environments and patterns of human activity (Hunt and Coles, 1988).

The palynology of tropical environments is known to be particularly problematical, because of the very low and erratic pollen productivity of major components of the vegetation, such as the Dipterocarpaceae, and the fragility of the pollen of others such as the Lauraceae; however, a pioneering study of pollen-vegetation relationships in Borneo by Anderson and Muller (1975) suggests that palynology provides a reliable indicator of local vegetation. Moreover, the sites in this study lie above the main zone of dipterocarp vegetation, so this issue would not be as problematical as a study carried out at lower altitude. Pollen analysis has been chosen as the main proxy for this research because it enables the reconstruction of vegetation, and because plants are environmentally-
limited, from this can be deduced ancient climate and environments (Moore et al., 1991; Lowe and Walker, 1997). This section outlines the methods employed (mainly derived from Moore et al. 1991, Hunt, 1985 and Hunt and Coles, 1988) for pollen and palynomorph preparation and identification. All laboratory preparation and identification was conducted by the author at Queen’s University Belfast. Table 4.11 provides a brief account of cores selected and sample numbers analysed. Seven surface samples (5 g) were also prepared for pollen and palynomorph identification.

Modern pollen preparation

The anthers of all specimens collected were extracted for pollen preparation at Queen’s University Belfast by the author, where they were treated with acetolysis mixture to remove fine cellulose material and sieved through a 120 µm and 6 µm mesh to remove larger and finer organic material following Moore et al. (1991). After preparation, samples were mounted in silica gel and secured using candle wax.

Core and Surface sample pollen preparation

For samples showing lithologies likely to lead to good preservation, such as peats (i.e. Bario Ba), 2 g of sediment was processed. For samples showing lithologies likely to have low pollen representation, such as clays and sands, 4 g of sediment was processed where available (PDH 212, 223 and 210). All core and surface samples collected were boiled in 10% KOH to break down organic content. Acetolysis was not used on the core or surface samples as it tends to destroy fragile pollen and spores (Coles, 1989). Samples were then sieved through a 120 µm nylon mesh to remove large particles, and swirled in a clock glass to remove sand and silt according to the technique used by Hunt (1985). Samples were then washed on a 6 µm nylon mesh to remove solutes and fines. After checking samples to see if any further chemical treatments were required it was decided that sodium pyrophosphate was needed to break down and disperse clay aggregates in some samples. This method has been derived from Bates et al. (1978). Each sample was placed in a beaker with 75ml of distilled water with 5 g of sodium pyrophosphate and left to boil for 15 minutes, then samples were again sieved on a 6 µm nylon mesh. PDH 212 also required HF treatment to remove minerals. HF treatment (described in Moore and Web, 1978) was carried out by Lisa Coyle, a PhD student at Queen’s University Belfast, who had received full safety training. After HF treatment the PDH 212 samples were boiled in 100 % HCl to remove calcium fluoride produced in the HF treatment. The samples were then sieved again through a 6 µm mesh and mounted onto slides. Silicone gel, which was the preferred medium for pollen preservation at QUB (Moore et al., 1991), was used as a mounting agent for Ba, CO1 and Pa’Buda. Due to low pollen representation in PDH 212 the mounting agent was later changed to Aquamount (used in Hunt et al., 2007) as this method, when tested, allowed a better concentration of material on the slide and was also a lot quicker to use than silicone gel.
4.36 Phytolith Samples

Phytoliths form when soluble silica is absorbed by plant roots and carried up via the water conducting tissue of the xylem. Some of the absorbed silica is eventually laid down as a solid in the cell walls, cell interiors and intercellular spaces of the plant forming specific shapes that can be used for identification (Piperno, 2006). Many plant families, but not all, produce phytoliths. The Graminaceae family in particular produce abundant, diverse and distinctive phytoliths (Lu et al., 2002). *Oryza* produces at least three different types of phytolith, which include bilobates (Fig. 4.3) produced in the leaf cells (Piperno, 2006, Harvey and Fuller, 2005), double peaked glume phytoliths (Fig. 4.4) produced in the epidermis of the rice glume (Piperno, 2006) and bulliform phytoliths (Fig 4.2) produced in the leaf cells (Lu et al., 2002). Bilobate phytoliths can only be identified to the Ehrhartoideae family, which contains the genera *Ehrharta, Oryza* and *Leersia* (Piperno, 2006). Double peaked and bulliform phytoliths can be identified to species level and by carrying out specific measurements it is possible to determine domesticated rice from wild varieties (Piperno, 2006, Lu et al., 2002). Phytoliths were examined from cores: CO1, BPG, PDH 212 and PDH 223 (Table 4.2), as all of these sites or their immediate surroundings were formerly used for rice cultivation and it was therefore inferred that the cores could produce evidence for earlier cultivation. Only preliminary investigations were carried out on the BPG core due to time limitations.

Phytoliths were used to support the pollen results, but also to fill in gaps occurring in the pollen record, and vice versa. For example, pollen does not survive well in oxidised soils, but silica does; the presence of large scabrate Poaceae pollen suggests wild or domesticated rice (although some other Poaceae types also produce scabrate pollen), whilst phytoliths can confirm whether *Oryza sativa* or wild taxa were present; and palm phytoliths suggest the presence of palm trees, whilst the pollen can determine which genera of palm (e.g. the sago palm *Eugeissona*).

Phytolith slides were prepared using methods derived by Piperno (2006), in which 25 ml of hydrogen peroxide was added to 2 grams of sediment in 100 ml pyrex beakers and boiled for 2 hours at 100° C until the samples became oxidised. Water was then added to the 80 ml mark, mixed well and left for 2 hours before being pipetted off. Water was added again for 1 hour and pipetted off. Water was added to the 80 ml mark for 4 seconds, the supernatant was added to a clean beaker and left for 4 minutes and the supernatant was then pipetted off leaving the heavier phytoliths at the bottom of the beaker. This was repeated three times. After preparation naphrax was selected for mounting the samples because this medium has a high index of refraction allowing better identification of clear silica phytoliths and diatoms.
4.4 Microscopy and analytical techniques

Modern pollen collection

The modern pollen grains for each species were photographed and morphologically described using an Olympus BX 51 high powered microscope. Pollen specimens have been described using terminology in Punt et al. (2007) and Huang (1972). Economical uses have been assigned to a number of specimens found in the Kelabit Highlands, mainly using Christensen (2002), and ecological descriptions have been assigned to Family, Genus and Species where possible. An attempt has been made to use only published literature, but due to a lack of published literature for a number of specimens it has been necessary to rely on the internet to provide some ecological descriptions. Only authentic Internet sites have been used in this study (i.e. herbarium sites, university botanical sites, government sites and sites university botanical sites, government sites and sites which have published versions of botanical literature i.e.: Flora of China).

Core, surface sample pollen and other palynomorphs

According to Moore and Web (1978) pollen counts should be sufficient to give a good approximation of the relative abundance of pollen types, which are of greatest interest to the study. Harberle (1998) for example attempted to count a minimum of 250 pollen grains from the Tari Basin, Papua New Guinea, although actual counts range from 202 to 915 pollen and spores. Dam et al. (2001) used a minimum pollen count of 200 pollen grains for Lake Tondano in Sulawesi, and Behling et al. (2001) counted a minimum of 300 pollen grains, although in a few cases only 200 grains were counted. In this investigation it was decided to count a minimum of 300 grains, excluding spores, although as with Harberle (1998) and Behling et al. (2001) this was not always possible. The peat core (Ba) provided good preservation with high pollen concentrations compared to the other sites and therefore minimum counts were achieved for this particular site. In the other sites, palynomorphs were counted until the prepared material was all counted or until 300 grains were reached. Preservation and dilution caused fluctuations in the pollen counts in all of the palaeochannel cores, but coupled with phytoliths, other palynomorphs, lithology, loss on ignition and magnetic susceptibility an environmental reconstruction has been possible.

An Olympus BX 51 high powered microscope was used for identification. Any grain that could not be identified was photographed and a brief description made (see Appendix Five). Pollen has been identified using a number of resources including the authors own reference material, Huang (1972), Roubik and Moreno (1991), Davis (2001), APSA (2006-2007) and Stevenson (2005). Palynomorphs were identified using Van Geel (1978) and Limaye et al. (2007). Pollen and palynomorphs counts were entered directly into a pollen and palynomorph counting programme, created in Excel by Dr. Maarten Blaauw from Queen’s University Belfast. Once the Excel sheets were complete pollen and palynomorph data were edited using Tilia and TG View (Grimm, 1991-1993). Experiments were
carried out to see what effect adding and subtracting spore counts to/from the pollen sum would have on vegetation representation. The results led to the decision not to add the spore counts to the pollen sum. The reason for this decision is that sometimes large fluctuations in the spore count would occur, causing an under representation of actual pollen grains and thus concealing subtle changes taking place in the vegetation record, indicated by the pollen. Hunt (1994) notes that samples deposited in riverine environments often show a taphonomic imprint caused by the fluvial processes, which winnow out and remove the relatively light pollen grains, while leaving behind the relatively denser spores, so this was to be expected in the samples from the palaeochannels. Spore counts were calculated separately as a percentage of total pollen, palynomorphs and spores. Other palynomorphs, which were counted on the same pollen slides, were calculated as a percentage of total palynomorphs and included everything other than charcoal. Diatoms and testate amoebae occasionally appeared during the pollen counts and were also included in the palynomorph sum. As with the spore counts, there were often large fluctuations in charcoal particles appearing on the pollen slides, at different sites and at different depths; therefore, charcoal particles with a diameter >5μm have been calculated separately, as a percentage of total charcoal pieces. Both the charcoal counted on the pollen slides and the charcoal identified in the lithology, are discussed in the results and discussion sections. All palynomorphs were counted until maximum pollen counts had been reached (Chapters 6-12).

Pollen taxa have been divided into various ecological groups, which include kerangas, montane taxa, general forest, lianes, small tree-shrubs, open ground, wetland and catholic (all other pollen taxa). Groups were allocated based on various botanical descriptions, which include: Anderson (1980), Ashton (1988), Adema et al. (1996), botanical literature on the web i.e. Flora of China, AAU Herbarium database (2009) and APSA (2006-2007). It should however be noted, that some taxa may belong to more than one group, but have been assigned into a specific group, where the author considers they occur most frequently. The decision has been based on the work carried out by Pearce (2004), Pearce (2006), Flenley (1979), Flenley (1984), Smith (1980), Beaman (1999), Van Steenis (1964) and Kitayama (1992). Results for the ecological groups will be discussed in more detail in Chapters 6-12.

Zonation of the pollen diagrams is based on Constrained Incremental Sum of Squares (CONISS) cluster analysis (Grimm, 1987), of pollen percentages with a minimum value of 0.3 %. The value of 0.3 % was selected because the pollen data sets showed a wide diversity of taxa, with lower percentage representation than would be found in European pollen data sets with a smaller diversity of taxa. CONISS results are displayed as a dendrogram on the Tilia diagrams.

**Phytoliths**

Phytoliths were counted using an Olympus BX 51 high powered microscope and identified using modern reference material held at Queen’s University Belfast, Piperno (2006), Lu et al. (2002).
Mercader et al. (2000) and the University of Missouri (MU) Phytolith Database (1998-2008). All phytolith bulliforms with *Oryza* characteristics have been photographed and measured. Diatoms often appeared frequently on the phytolith slides and it was therefore decided to count both phytoliths and diatoms as percentage of total phytoliths and diatoms. Counts were entered into the Excel counting program, derived by Dr. Maarten Blaauw and edited using Tilia and TGView (Grimm, 1991-1993).

The best way of determining domesticated rice from wild varieties is by using discriminant function analysis on double-peaked glume phytoliths (Zhao et al., 1998), described by Itzstein-Davey et al. (2007). Only four double peaked glume phytoliths were recorded from the core samples, one a wild variety from a Pleistocene deposit in Bario, two likely wild varieties from core PDH 212 near Pa’Dalih and another, recorded from core PDH 223 near Pa’Dalih. The glume phytolith recorded from PDH 223 has been determined as belonging to domesticated rice, using the discriminant function analysis. All other phytoliths used to distinguish domesticated rice from wild varieties are bulliform phytoliths. If the glumes of *Oryza* were being harvested with the rice, as would be expected, this might explain the low representation of double peaked phytoliths in the core samples.

Only if *Oryza* bulliforms met all of the measurement criteria listed below were they classified as *Oryza sativa*. If measurements were less than those stated below the bulliforms were classified as wild *Oryza* and if bulliforms represented a combination of measurements (i.e. both fitting and less than the measurements listed below) they were classified as *Oryza* undifferentiated. L1, L2, TH and W measurements have been modified from measurements determined by Dr. R. Premathilake (pers.comm) from the University of Colombo.

Domesticated rice bulliform measurements (See Fig 4.2 for a key to the symbols used below):

- **L1**: >20 μm, **L2**: >20 μm, **TH**: >15 μm, **W**: >35 μm and **PL**: >3 rows >20 plates

Plate measurements (PL) were adapted from measurements carried out by Lu et al. (2002).

According to Pearsall et al. (2005) the lengths, thickness and width measurements of some Oryzeae and Bambusina tribes overlap and therefore these measurements alone should not be used to determine *Oryza sativa*. Lu et al. (2002) describe bulliform phytoliths in *Oryza* as generally characterised by numerous small shallow scale like decorations on the half round side. Other grass phytoliths do not have such specific decoration. His study identified a larger on average number of scale/plate like decorations (8-14) on domesticated rice compared with wild varieties (<9). Therefore a combination of width, length and thickness measurements with row and plate counts should be used when determining domesticated from wild varieties of rice. Confirmed domesticated bulliforms identified from the Kelabit Highlands cores tended to have on average >30 plates.
**Fig 4.2.** An example of a rice bulliform. Symbols represent the different sections of the phytolith, which need to be measured, when distinguishing between domesticated and wild rice. (Author, not drawn to scale)

**Key**
- L1: Length 1
- L2: Length 2
- W: Width
- TH: Thickness
- PL: Plates

25 μm

**Fig 4.3:** Ehrhartoideae bilobates (Author)

**Fig 4.4** Double peaked *Oryza* glume by Dr.R. Premathilake University of Colombo
Other *Oryza* bulliforms with 8-14 scales, which would fall into the domesticated category, determined by Lu *et al.* (2002), were also present; however, these tended to fall outside of the measurements used to identify *Oryza sativa*, determined by Dr. R. Premathilake (pers.comm). Therefore only bulliforms with over 20 plates with the appropriate measurements were considered to belong to domesticated rice. A further complication is likely to be preservation. Zhao (1988) has also noted that relatively high pH can affect phytolith preservation over a long period of time, in which phytoliths can be dissolved and it is possible that preservational differences may account for some of the variation in phytoliths in this study.

*Oryza* bulliforms, very similar to *Oryza sativa*, but with noticeable size differences have also been recorded in some of the Pa’Dalih core samples. These bulliforms are very thick, with 40-50 plates, are of the right shape for *Oryza sativa*, but the lengths and widths are too small to belong to domesticated varieties. It is possible, that some *Oryza sativa* plants did not fully mature, resulting in the production of smaller phytoliths or that the environment had in some way affected the size of phytolith production. For example, in Dong-Mei *et al.* (2010), a study on the characteristics of phytoliths in *Leymus chinensis* leaves from five different pH-value habitats, from the Songnen Plain in China, demonstrated increased size with increasing pH, and also with changes in biochemical indices, such as proline (an α-amino acid) content. A detailed investigation into the morphological characteristics and size of rice phytoliths in relation to changes in the local environment in the highlands of Borneo may help to clarify the appearance of these smaller thick plated bulliform phytoliths. Zhao (1988) has also noted that relatively high pH can affect phytolith preservation over a long period of time, in which phytoliths can be dissolved.

Only cores PDH 223 (Chapter Eight), PDH 212 (Chapter Seven) and PDH CO1 (Chapter Ten) from Pa’Dalih produced rice phytoliths. Echinate palm-type phytoliths were also identified from the Bario, Ba core (Chapter Six). Due to low numbers of phytoliths comparable with *Oryza sativa* in core PDH 223 and the difficulty of referring bulliforms to species, the measurements described above were also compared with large numbers of unpublished precise bulliform measurements from type material from Sri Lanka, India, Sarawak, New Guinea and other localities (Dr R. Premathilake, pers. comm.. 2010, Table 4.1).

Table 4.1 was used to try to determine whether the low numbers of *Oryza* bulliforms appearing with very similar but not complete characteristics of *Oryza sativa*, were indeed from domesticated varieties or whether they originated from wild types. Photographs of undifferentiated bulliforms were also sent to the University of Colombo for a second opinion. These results are discussed in more detail in Chapter Eight.
<table>
<thead>
<tr>
<th>Species</th>
<th>Width</th>
<th>L1</th>
<th>L2</th>
<th>L2/W</th>
<th>L1/W</th>
<th>L1/L2</th>
<th>Thickness</th>
<th>Locality</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>O. sativa</em> (Domesticated)</td>
<td>36.0</td>
<td>29</td>
<td>49</td>
<td>17.80</td>
<td>7.26</td>
<td>9.29</td>
<td>0.62</td>
<td>0.35-1.0</td>
</tr>
<tr>
<td><em>O. nivara</em> (Semi wild)</td>
<td>40.20</td>
<td>33</td>
<td>54</td>
<td>21.50</td>
<td>14-23</td>
<td>26.05</td>
<td>0.65</td>
<td>0.44-0.81</td>
</tr>
<tr>
<td><em>O. rhizomatis</em> (Wild)</td>
<td>25.80</td>
<td>20</td>
<td>34</td>
<td>11.30</td>
<td>8.16</td>
<td>22.80</td>
<td>0.90</td>
<td>0.66-1.3</td>
</tr>
<tr>
<td><em>O. eichingeri</em> (Wild)</td>
<td>29.80</td>
<td>24</td>
<td>32</td>
<td>11.20</td>
<td>9.14</td>
<td>17.20</td>
<td>0.59</td>
<td>0.5-0.75</td>
</tr>
<tr>
<td><em>O. rufipogon</em> (Wild)</td>
<td>33.00</td>
<td>24</td>
<td>48</td>
<td>13.00</td>
<td>10-18</td>
<td>22.20</td>
<td>0.70</td>
<td>0.5-0.71</td>
</tr>
<tr>
<td><em>O. minuta</em> (Wild)</td>
<td>25.45</td>
<td>20</td>
<td>29</td>
<td>10.55</td>
<td>7-15</td>
<td>22.45</td>
<td>0.90</td>
<td>0.53-1.0</td>
</tr>
<tr>
<td><em>O. meyeriana</em> (Wild, bamboo habit)</td>
<td>37.60</td>
<td>50</td>
<td>31</td>
<td>11.40</td>
<td>7-17</td>
<td>29.00</td>
<td>0.80</td>
<td>0.56-1.1</td>
</tr>
<tr>
<td><em>O. longiglumis</em> (Wild)</td>
<td>32.16</td>
<td>19</td>
<td>41</td>
<td>16.00</td>
<td>10-17</td>
<td>18.84</td>
<td>0.60</td>
<td>0.84-0.38</td>
</tr>
<tr>
<td><em>O. ridleyi</em> (Wild)</td>
<td>34.15</td>
<td>28</td>
<td>39</td>
<td>15.92</td>
<td>10-23</td>
<td>31.61</td>
<td>0.93</td>
<td>0.71-1.3</td>
</tr>
<tr>
<td><em>O. schlechteri</em> (Wild)</td>
<td>NO</td>
<td>NO</td>
<td>NO</td>
<td>NO</td>
<td>NO</td>
<td>NO</td>
<td>NO</td>
<td>NO</td>
</tr>
<tr>
<td><em>O. latifolia</em> (Wild)</td>
<td>29.84</td>
<td>15</td>
<td>39</td>
<td>9.76</td>
<td>6-16</td>
<td>26.93</td>
<td>0.96</td>
<td>0.56-1.8</td>
</tr>
<tr>
<td><em>O. longistaminata</em> (Wild)</td>
<td>28.66</td>
<td>24</td>
<td>32</td>
<td>9.00</td>
<td>8-10</td>
<td>19.00</td>
<td>0.66</td>
<td>0.46-0.93</td>
</tr>
<tr>
<td><em>O. punctata</em> (Wild)</td>
<td>29.00</td>
<td>28</td>
<td>30</td>
<td>11.00</td>
<td>9-13</td>
<td>22.50</td>
<td>0.77</td>
<td>0.64-0.9</td>
</tr>
</tbody>
</table>

Table 4.1: Summary of the measurement of fan shape phytolith produced from wild and domesticated rice species. Mean values of a, b, ratios (c/a, b/a and b/c) and thickness are included. Numbers in red indicate full range of variation. Table from Dr. R. Premathilake, University of Colombo, Sri Lanka.

4.5 Conclusion

This chapter has outlined the methodologies applied during fieldwork and in the laboratory. Results obtained are described and interpreted in Chapters 5-12 and these are further discussed in Chapter 13.
CHAPTER FIVE: RESULTS
SURFACE SAMPLE AND MODERN PLANT COLLECTIONS
5.1 Introduction
Chapter Five has two main objectives a) to examine the modern composition of plants from various different habitats in the Kelabit Highlands and b) to examine the results obtained from the surface sample collections, to determine whether there is spatial patterning of pollen fallout associated with different human activities and to provide a modern analogue with which to compare the core results.

5.2 Modern plant collection
Detailed palynological work in Southeast Asia has been carried out by a number of researchers such as Polak (1933), Muller, (1964, 1963, 1966), Huang (1972), Anderson and Muller (1975), and more recently Bulalacao (1997). A large pollen database is also held at the Australian National University; however, published reference material in Southeast Asia is still limited. This particularly applies to Borneo. No palynological work has ever been carried out in the Kelabit Highlands of Sarawak, Malaysian Borneo. It quickly became apparent, during laboratory work after the 2007 field season, that a type collection of species local to the Kelabit Highlands was needed before pollen analysis could be effective. The type collection not only provides a modern reference guide for the fossil pollen, but also provides a modern analogue of some of the typical vegetation found in the Kelabit Highlands and in particular the types of plants, found from various different habitats, within the vicinity of the core sites. In total 256 plants were collected from within a 3.5 km radius of the Bario and Pa’Dalih core sites, from a wide range of habitats (see Chapter Four). A list of all plants collected, the latitude, longitude, whether the plant was collected from Bario or from the southern Kelabit Highlands and the type of plant (herb, shrub, tree, epiphyte or climber) has been listed in Appendix Two. The pollen images shown in Fig 5.1 provide an example of some of the plants collected from the northern and southern Kelabit Highlands, the genera of which have also been recorded in the fossil pollen record. A more detailed pollen morphological account of all 213 pollen grains is provided in Appendix One.
| 1) Palmae: **Eugeissona utilis** | A sago palm collected in *Eugeissona* dominated woodland at Long Kelit and from a burnt flower in cleared *Eugeissona* forest at Perupun Paya Palipa, close to Pa’Dalih. |
| 2) Nepenthaceae: **Nepenthes stenophylla** | A pitcher plant found in open vegetation near the new runway in Bario. MacKinnon *et al.* (1998) describes this species as an upper mountain forest species. |
| 3) Myrtaceae: **Syzygium subcrenatum** | A small tree recorded in Bario. One specimen has previously been recorded from Borneo (GBIFF, 2009). |
| 4) Melastomataceae: **Dissochaeta monticola** | A scrambling shrub or woody climber. Found near to Pa’Dalih. Renner *et al.* (2001), describes it as found in evergreen forest or in disturbed places, at low altitudes up to 600 m. |
| 5) Euphorbiaceae **Glochidion sp.** | A small tree found in secondary forest close to the new runway in Bario. |
| 6) Euphorbiaceae **Macaranga costulata** | A small tree found in secondary forest close to the new runway in Bario and in secondary forest near to the runway in Pa’Dalih. Small trees, endemic throughout Borneo and found in both primary and secondary forest up to 1700 m (Pax and Hoffman, 2009). |
| 7) Ericaceae: **Rhododendron durionifolium** | Shrubs and small trees found at the edge of secondary forest near to the runway in Bario. This species is described as common in the Highlands of Sarawak, especially in areas bordering Kalimantan (Latiff *et al.*, 1999). |
| 8) Ericaceae: **Vaccinium laurifolium** | Shrubs and small trees found at the edge of secondary forest near to the runway in Bario. |
| 9) Fagaceae: **Lithocarpus ewyckii** | Found near to Pa’Dalih in the Southern Kelabit Highlands. Occasionally and widely distributed in mixed dipterocarp forest and submontane forest up to 5500 ft/1650 m. Found throughout Sarawak (Anderson, 1980). |

**Fig 5.1** Pollen images for some of the plants collected in the Kelabit Highlands (see Appendix One)
By comparing the 256 plant species collected from the Kelabit Highlands with other plant specimens collected at different altitudinal ranges in Borneo (See Appendix Six), most of the Kelabit Highland species appear to fall within an altitudinal range of 2350-950 m. Table 5.1 highlights the plant genera most frequently identified at different altitudinal ranges. Some of the species recorded from the Kelabit Highlands also appear to fall within a higher altitudinal range (2350-2800 m), including Schefflera, Ilex, Vaccinium, Syzygium, Symlocos and Rhododendron. The Fagaceae family, of which Lithocarpus, Quercus and Castanopsis were collected in the Kelabit Highlands, appear more frequently in the lower montane boundary between 2350-1200 m. Podocarpus, Phyllocladus and Dacrydium are not recorded in the modern plant collections, although these genera with the exception of Phyllocladus have been recorded by several authors between 950-2800 m. The absence of Podocarpus and Dacrydium from the modern plant collection could be due to an absence of primary kerangas forest in the vicinity of Bario and Pa’Dalih. It is also possible that these trees were not in flower during the 2008 field season or the flowers were out of reach for pollen collection, as only flowering plants were collected. One other plausible explanation, suggested in Chapter Three, is that these species are found more frequently above 2000 m.

<table>
<thead>
<tr>
<th>Altitude Range</th>
<th>Plant Genera</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Upper montane</strong> <em>2350-2800 m</em></td>
<td>Calamus, Rhododendron, Podocarpus, Phyllocladus, Dacrydium, Schefflera, Ilex, Vaccinium, Syzygium, Symlocos</td>
</tr>
<tr>
<td><strong>Lower montane</strong> <em>1200-2350 m</em></td>
<td>Dacrydium, Podocarpus, Ilex, Rhododendrons, Nepenthes, Garcinia, Syzygium, Symlocos, Ficus, Calamus, Melicope, Sonerila, Medinilla, Schefflera, Saurauia, Elaeocarpus, Lithocarpus, Quercus, Castanopsis, Listea.</td>
</tr>
<tr>
<td><strong>Lower montane</strong> <em>1200-950 m</em></td>
<td>Rhododendron, Lithocarpus, Listea, Elaeocarpus, Macaranga, Saurauia, Ardisia, Ficus, Smilax, Glochidion, Castanopsis, Dacrydium and Podocarpus.</td>
</tr>
<tr>
<td><strong>Lowland</strong> <em>&lt;1200 m</em></td>
<td>Shorea, Eugenia, Ficus, Piper, Cyrtandra, Pandanus, Ficus, Castanopsis, Begonia, Antidesma.</td>
</tr>
</tbody>
</table>

*Table 5.1 Altitudinal variations of the most frequent appearing plant genera, based on collections by Kitayama (1992), Anderson (1980), Pearce (2004), Beaman (1999), Pearce (2006) and Latiff et al. (1999) in Borneo; see Appendix Six.*

**5.3 Surface samples**

Seven surface samples (listed below) were taken from various different sites around the village of Pa’Dalih to examine the modern composition of pollen grains and other palynomorphs appearing in the pollen record, from anthropogenic habitats. Surface samples from five of the cores (Chapters 6-11) have also been examined. Below is a list of the surface (Fig 5.2) and core top samples collected from Pa’Dalih, Pa’Buda and Bario. Figs 5.3 to 5.8 are photographs showing the locations of six of the surface and core sample sites.
The main limitation of the surface sample study has been an absence of quadrats or transects to identify the composition of modern vegetation in relation to the composition of pollen grains, appearing in the surface and core-top sample results. An ideal situation would have been to identify the plants in the field, however, in tropical environments there is a wide species diversity and this was not possible for the author. All of the plants collected for the modern reference collection had to be identified at SAR. There was insufficient funding to carry out both identification of plants along transects/quadrats and for reference material. The reference collection does provide a general composition of the modern vegetation, but does not provide information on proportional representation. For future studies, the collection of a more diverse-range of either surface samples or moss polsters would also provide a tighter and more in-depth understanding of modern pollen deposition. Spider webs might also hold potential for modern pollen collection. Despite the lack of modern vegetation sampling, the surface samples that have been taken do appear to be in general agreement with the different environments in which these samples were taken. For example, spatial patterning of pollen fallout associated with different human activities has been demonstrated in surface sample 4, with poor pollen content caused by anthropogenic use of the ditch; surface sample 2, with a dominance of Poaceae and Cyperaceae pollen, as well as high spore counts, associated with the playing field; surface sample 8, by high representation of Sapindaceae (fruit trees), associated with the orchard; and the core top sample of PDH 223, by the presence of Sapindaceae, Sapotaceae, Moraceae and open ground taxa, indicating the presence of fruit groves and open pasture which were visible at the time of collection. Table 5.2 provides a summary of the results obtained from the surface samples.
Fig 5.2: Photo (Tellian, 2003) showing the location of surface samples collected from various sites around Pa’Dalih
**Fig 5.3:** Location of surface sample 2 on the grass playing field, facing the village school in Pa’Dalih

**Fig 5.4:** Location of surface sample 3 on the NW side of the longhouse and small vegetable plots (photo taken by Borbála Nyíri)

**Fig 5.5:** Location of surface sample 4 on the SE side of the longhouse (photo taken by Borbála Nyíri)

**Fig 5.6:** Location of surface sample Ba on a peat bog in Bario

**Fig 5.7:** A photo of water buffalos on the grass runway in Pa’Dalih (Site 212 and 223 are located nearby). The area is surrounded by secondary forest and fruit groves.

**Fig 5.8:** Location of core BPG at Pa’Buda from an abandoned field, but surrounded by rice fields currently in use.
The main vegetation is grass, but secondary forest, vegetable plots and fruit groves surround the site. Grass is the dominant pollen, with high percentages of Cyathaceae spores. Single grains of Podocarpus, Aquifoliaceae, Rosaceae and Rutaceae are also present. Fungal hyphae represent 31.2% among the palynofacies. Zoospores are present. These results tie in well with the grass dominating vegetation on the playing field. In an open field, some amount of outside material getting into the local record would be expected. The high percentages of Cyathaceae may have been blown onto the site from ferns located in nearby secondary forest; however, the spore probably also survives well in oxidized soils (Hunt, 1994) where pollen grains would be less resistant to degradation. The fungal hyphae count is higher than in all other surface samples, suggesting they are particularly suited to open-grassy environments. Other types, including zoospores, are frequently reported from soils.

Ditch: Bare of vegetation, but facing towards the grass playing field. Poaceae and Cyperaceae are the dominant pollen taxa. Poaceae is lower than in surface sample 2, probably because this sample was taken slightly further away from the grass field. There is also a more diverse range of trees, shrubs and herbs, especially disturbed and cultivated ground taxa, such as Compositae, Cucurbitaceae, Impatiens and Solanum. The trees and shrub pollen have likely been blown or washed in from adjacent vegetation surrounding the longhouse, whilst the pollen of herbs, vegetables and open-disturbed ground taxa possibly originate from the vegetable plots located next to the ditch. Some algae were also recorded: this would be expected in a ditch.

Ditch: Bare of vegetation but facing towards coconut palms and fruit trees. Only contained two pollen grains (Poaceae and Solanaceae) as well as seven spores. Surface sample 4 did however, contain other palynomorphs including cellulose, plants cells, asceptate hyphae, soil symbiotes, VAMs (Vesicular arbuscular mycorrhiza) and seeds. Waste-water from cooking, cleaning and washing flows into this side of the ditch, therefore pollen may have been washed away - a process known as 'winnowing'. The hyphae, soil symbiotes and VAMs may be a sign of disturbance, from eroded soil on the side of the ditch, whilst other organic material demonstrates plants growing close to the ditch.

Vegetable plot containing a wide variety of different vegetables, adjacent to the grass playing field. Poaceae and Cyperaceae are the dominant taxa. There is also a wide variety of cultivated and disturbed ground taxa, such as Cucurbitaceae, Leguminosae, Urticaceae/Moraceae (although, Moraceae can also be a tree), Solanaceae, Umbelliferae and Compositae. Tree and shrub representation is low and is probably because the site is relatively sheltered from outside pollen. The dominance of grass and sedge pollen is caused by the close proximity of the playing field to this sample site. The presence of charcoal in the microfossil record (Fig 5.8 and Fig 5.15) represents clearance and burning to promote nutrients for the vegetable garden and the highest overall representation of VAMs (8.4%) reflects fungal content of the soil.

Table 5.2: A summary of pollen and palynomorph results for the surface soil and core top samples

<table>
<thead>
<tr>
<th>Sample</th>
<th>Vegetation</th>
<th>Pollen</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>The main vegetation is grass, but secondary forest, vegetable plots and fruit groves surround the site.</td>
<td>Grass is the dominant pollen, with high percentages of Cyathaceae spores. Single grains of Podocarpus, Aquifoliaceae, Rosaceae and Rutaceae are also present. Fungal hyphae represent 31.2% among the palynofacies. Zoospores are present.</td>
<td>These results tie in well with the grass dominating vegetation on the playing field. In an open field, some amount of outside material getting into the local record would be expected. The high percentages of Cyathaceae may have been blown onto the site from ferns located in nearby secondary forest; however, the spore probably also survives well in oxidized soils (Hunt, 1994) where pollen grains would be less resistant to degradation. The fungal hyphae count is higher than in all other surface samples, suggesting they are particularly suited to open-grassy environments. Other types, including zoospores, are frequently reported from soils.</td>
</tr>
<tr>
<td>3</td>
<td>Ditch: Bare of vegetation, but facing towards the grass playing field and vegetable plots.</td>
<td>Poaceae and Cyperaceae are the dominant pollen taxa. Poaceae is lower than in surface sample 2, probably because this sample was taken slightly further away from the grass field. There is also a more diverse range of trees, shrubs and herbs, especially disturbed and cultivated ground taxa, such as Compositae, Cucurbitaceae, Impatiens and Solanum.</td>
<td>The trees and shrub pollen have likely been blown or washed in from adjacent vegetation surrounding the longhouse, whilst the pollen of herbs, vegetables and open-disturbed ground taxa possibly originate from the vegetable plots located next to the ditch. Some algae were also recorded: this would be expected in a ditch.</td>
</tr>
<tr>
<td>4</td>
<td>Ditch: Bare of vegetation but facing towards coconut palms and fruit trees</td>
<td>Only contained two pollen grains (Poaceae and Solanaceae) as well as seven spores. Surface sample 4 did however, contain other palynomorphs including cellulose, plants cells, aseptate hyphae, soil symbiotes, VAMs (Vesicular arbuscular mycorrhiza) and seeds.</td>
<td>Waste-water from cooking, cleaning and washing flows into this side of the ditch, therefore pollen may have been washed away- a process known as 'winnowing'. The hyphae, soil symbiotes and VAMs may be a sign of disturbance, from eroded soil on the side of the ditch, whilst other organic material demonstrates plants growing close to the ditch.</td>
</tr>
<tr>
<td>5</td>
<td>Vegetable plot containing a wide variety of different vegetables, adjacent to the grass playing field.</td>
<td>Poaceae and Cyperaceae are the dominant taxa. There is also a wide variety of cultivated and disturbed ground taxa, such as Cucurbitaceae, Leguminosae, Urticaceae/Moraceae (although, Moraceae can also be a tree), Solanaceae, Umbelliferae and Compositae. Tree and shrub representation is low and is probably because the site is relatively sheltered from outside pollen.</td>
<td>The dominance of grass and sedge pollen is caused by the close proximity of the playing field to this sample site. The presence of charcoal in the microfossil record (Fig 5.8 and Fig 5.15) represents clearance and burning to promote nutrients for the vegetable garden and the highest overall representation of VAMs (8.4%) reflects fungal content of the soil.</td>
</tr>
</tbody>
</table>
The main vegetation around the sample site consists of open ground scrub taxa, secondary forest, vegetable plots and fruit trees. Poaceae, Cyperaceae and Cyperus are the dominant taxa, plus: Plantago, Compositeae, Chenopodium, and Trianthema. The aquatic plant Nuphar and Cyperus is also present. Tree pollen taxa include: Elaeocarpus, Dacrydium and Podocarpus as well as the fruit trees/shrubs Passiflora and Ananas. In the palynomorph record the highest overall representation of freshwater algae for surface samples was recorded. These results generally correspond well with the present taxa found at the site, although Dacrydium and Podocarpus have likely been blown in from outside. The presence of pollen from weed, vegetable and fruit taxa as well as a high representation of charcoal/burnt wood fragments from the microfossil record (Fig 5.8, Fig 5.15) indicate anthropogenic clearance at the site, whilst the presence of aquatics (Fig 5.4) demonstrates wet ground and flooding of the river.

Riverbank: A grassy area with secondary scrub, close to gardens and facing secondary forest on the opposite side of the river. Jackfruit was nearby. Mainly dominated by grass, although some shrubs were present. High values of edible plants were also recorded and include Coffea, Ananas, Impatiens, Sapotaceae and Solanum, as well as the trees Carpinus and Elaeocarpus, Ericaceae was also present. These results show a good correlation with the general vegetation types found today around the river. The assemblage suggests the adjacent vegetation is a mixture of trees and cultivated plants. The presence of Ericaceae suggests nearby soil is poorly drained and possibly slightly acidic. There is also some evidence of burning with burnt wood and spheroidal carbon particles, usually formed after intense burning (although these may have blown onto the site).

Orchard dominated by fruit trees belonging to the Sapindaceae family. Shrubs and ferns were also present. Sapindaceae is the dominant taxon. Shrub taxa show a wide diversity (eg: Acanthaceae, Aquifoliaceae, Celastraceae, Meliaceae and Vitaceae). Open ground taxa are high and the aquatic Nuphar is present as well as some freshwater dinoflagellate cysts. Fern spore counts are high compared with the other surface samples. The most frequent occurring spore is from Pteridaceae. The high representation of Sapindaceae suggests that they were either growing directly where the surface sample was taken or that the majority of fruit trees in the orchard are of Sapindaceae species. Overall the results indicate wet soils, occasional flooding and relatively open forest. The high spore representation further suggests relatively open forest, allowing the growth of bracken; however, fern spores are often over-represented in water-lain deposits and soils (Hunt, 1994).

The main vegetation on the peat bog is bracken (Pteridium), whilst the peat bog is surrounded by secondary kerangas forest. Pollen results suggest general forest is dominant, although open ground taxa are also high. Pollen percentages do not include fern spores. Pteropsida ferns represent 19.5 % total pollen and spores, whilst Pteridium is not represented. Testate amoebae and the aquatic algae Spirogyra are also present. No transect was taken around the core site (see methodology); however, previous botanical work (Latiff et al., 1999) and modern plant collections from within a 3.5 km radius of the core-site suggest apart from the absence of Pteridium, the general aspect of the vegetation is similar to the assemblage. Intra-specific differences in spore production and dispersal may explain the absence of Pteridium in the spore record (see Behling et al., 1997) or that the surface at this site has been eroded. The age-depth curve, described in Chapter 6 (Fig 6.5) suggests that erosion most likely took place.
**5.4 Discussion**

Core top samples were used to extend the surface sample results, although it should be noted that not all of the top core samples might be representative of modern sediments (described in Chapter Four e.g. the under-representation of *Pteridium* in Bario Ba) and therefore caution should be applied when interpreting such data. When identifying fossil pollen it should also be taken into account that not all plant taxa growing at a particular site will be represented in the pollen record and that different pollen dispersal rates occur between different taxa. Some taxa may be common but have low pollen production; other taxa can blow and wash in from outside. Preservation can also be an issue. For

<table>
<thead>
<tr>
<th>PDH CO1</th>
<th>Used previously for rice cultivation and today fruit trees grow around the palaeochannel, whilst the channel itself is covered by grass.</th>
<th>The pollen demonstrates a primarily open environment with Poaceae and Cyperaceae the dominant taxa. Plant palynofacies are well represented, particularly organic matter and soil fungi; burnt plant tissue and freshwater algae-diatoms.</th>
<th>Poaceae and Cyperaceae results represent anthropogenic use of the palaeochannel in the recent past, although there is also a wide diversity of trees, including fruit trees such as Sapindaceae, <em>Coffea</em> and <em>Citrus</em>.</th>
</tr>
</thead>
<tbody>
<tr>
<td>PDH 212</td>
<td>The site is grassy buffalo pasture. Secondary forest and fruit groves surround the site and a rice field is adjacent.</td>
<td>Open ground taxa dominate, predominantly large scabrate Poaceae and other Poaceae. Cyperaceae are also present, as are general forest and shrubs/small tree taxa. Spore counts are high with Cyathaceae, Polypodiaceae and <em>Lygodium</em> (a disturbance indicator).</td>
<td>The open aspect of the vegetation is well-represented. Cyathaceae (tree ferns) and the Polypodiaceae have likely been blown in from nearby forest. Their high representation could be used as a further indication of open canopy. Under closed canopy spore transportation may be limited by tree cover, resulting in lower spore counts. Fern spores may also be over-represented in soils, as spores tend to be more resistant than pollen grains to oxidation (Hunt, 1994).</td>
</tr>
<tr>
<td>PDH 223</td>
<td>A young fruit grove with an understory of semi-wild aroids and ferns, not far from to the river and close to rice fields and buffalo pasture.</td>
<td>Open ground taxa are dominant, including Poaceae, Compositae and Brassicaceae. Montane taxa are present and include: <em>Podocarpus</em>, <em>Dacrydium</em>, Fagaceae, and <em>Phyllocladus</em>. Small trees/shrubs and aquatics are also present. Fruit trees are likely represented by Sapindaceae, Sapotaceae, Moraceae and <em>Eugeissona</em> pollen (sago).</td>
<td>The trees on the site are young and may not be producing much pollen. A number of fig trees were noted growing by the air field, as well as certain Sapindaceae and Euphorbiaceae fruit species. Sago is found close by in secondary forest. Montane taxa appear higher than general forest taxa.</td>
</tr>
<tr>
<td>BPG</td>
<td>The site was bare of vegetation, except small patches of grass and moss, but was surrounded by rice fields, a grass bank, scrub, bamboo forest and secondary forest</td>
<td>High Poaceae pollen, although other open ground taxa such as Malvaceae and Compositae, aquatic pollen and shrubs/small trees, particularly <em>Sarcococca</em>, are also present.</td>
<td>The presence of aquatic pollen demonstrates the palaeochannel is still wet and is indeed still being used for wet rice cultivation. The pollen results correspond well with the local vegetation.</td>
</tr>
</tbody>
</table>

Table 5.2: Surface and core-top sample results
example, the pollen of the Zingiberaceae and Musaceae families do not preserve well (poor preservation has been demonstrated during preparation of these pollen grains for the modern reference collection). Another issue is that it is rarely possible to identify pollen to species level, particularly in tropical environments where there is a wide species diversity of plant taxa and limited reference material. The primary aim of this PhD thesis is not to produce a precise reconstruction of the vegetation in the past (at present, given the limitations of knowledge of modern pollen morphology an unrealistic ambition), but to look for specific indicators of climate, environmental and land use change. Therefore identification of pollen to genera and sometimes even to family is realistic and should be sufficient. Where possible, gaps in the pollen record will be filled by other environmental proxies, such as phytoliths, lithology and other palynomorphs (e.g. domesticated rice cannot be identified from the pollen record but they can from the phytolith record).

5.5 Summary
Despite the absence of modern vegetation sampling and the limitations associated with variations in pollen dispersal and transportation, overall the surface pollen, top soil pollen and palynomorph results for the Kelabit Highlands are in general accordance with the immediate environment at each site, with the exception of Bario Ba, which may be associated with erosion of the surface sediments. The modern plant collection for the pollen reference collection provides further information on the types of plants found within the locality of the core sites in Bario and Pa’Dalih. As long as the limitations described above are taken into consideration, the study of modern sediment samples demonstrates that pollen analysis is a viable and important tool for examining past environments and for determining anthropogenic signatures on the landscape. The use of a multi-proxy record will also add to strengthen the pollen results, particularly where gaps occur in the record. Chapters 6-11 will now examine the core results in more detail.
CHAPTER SIX
CORE BA, BARIO
Chapter 6 Bario-Core Ba

6.1 Site Description

The village of Bario is situated 1,064 m above sea level in a broad basin on low angle terrain, on a plateau in the northern part of the Kelabit Highlands (Figs 6.1, 6.2). The climate is warm and wet. A 344 cm core was taken from a peat bog situated a few meters from the runway in Bario, constructed in the 1980s. The River Dabpur, a tributary of the Baram River is situated just over 1 km away to the east of the new runway. Some rice fields are located adjacent to the peat bog. The peat bog is surrounded by kerangas forest and plants such as *Saurauia*, *Rhododendron*, *Vaccinium* and *Nepenthes* are common, whilst the main vegetation on the bog itself is bracken following a fire during the clearance of the runway (Fig 6.3).
The Bario plateau is relatively infertile, as nutrient-poor, clayey sandstone in the basin prevents infiltration of the runoff from the surrounding hills, causing soils to become waterlogged and leached. Despite nutrient poor soils, the plateau is used extensively for rice cultivation, and pineapple groves can be found on the surrounding hills. In comparison with the village of Pa’Dalih, c.14 km to the south of Bario, larger areas of land are needed for rice cultivation. The stratigraphy of the cores obtained at Bario shows that the village lies on highly-eroded peats. These rest on several metres of clayey grey colluviums, which down-slope inter-fringes with fluvial sands, of a low terrace of the Dabpur River, into which is incised the peat-filled palaeochannel, sampled in this study. The site was selected for its potential to provide a well preserved and detailed palaeoecological record.
6.2 Radiocarbon results

The radiocarbon ages for core Ba are shown below in Table 6.1. Wood (not identified to species) was used for most of the radiocarbon ages, as other macrofossils occurred less frequently. A hiatus (from 30,756-30,219 cal BP to 5,645-5,483 cal BP) and two age reversals (from 31,066-30,517 cal BP at 160 cm to 34,939-34,497 cal BP at 118 cm, and from 1,699-1,558 cal BP at 49 cm to 2,703-2,351 cal BP at 32 cm) have also been identified. These are discussed in more detail in section 6.7.

<table>
<thead>
<tr>
<th>UBA No</th>
<th>Depth (cm)</th>
<th>$^{14}$C Age BP</th>
<th>AMS $\delta^{13}$C</th>
<th>Calibrated Age (2 $\sigma$) AD/BC</th>
<th>Calibrated Age (2 $\sigma$) BP</th>
<th>Material</th>
</tr>
</thead>
<tbody>
<tr>
<td>UBA-15637</td>
<td>29-31 cm</td>
<td>1433±23</td>
<td>-28.6</td>
<td>584-653 AD</td>
<td>1366-1297</td>
<td>Peat</td>
</tr>
<tr>
<td>UBA-9995</td>
<td>32.5-33</td>
<td>2428±42</td>
<td>-28.3</td>
<td>753-401 BC</td>
<td>2703-2351</td>
<td>Charcoal</td>
</tr>
<tr>
<td>UBA-10000</td>
<td>47-49 cm</td>
<td>1719±25</td>
<td>-25.5</td>
<td>251-392 AD</td>
<td>1699-1558</td>
<td>Wood</td>
</tr>
<tr>
<td>UBA-10001</td>
<td>59-65 cm</td>
<td>4841±29</td>
<td>-25.2</td>
<td>3695-3533 BC</td>
<td>5645-5483</td>
<td>Wood</td>
</tr>
<tr>
<td>UBA-10002</td>
<td>78-80 cm</td>
<td>25598±104</td>
<td>-25.4</td>
<td>28806-28269 BC</td>
<td>30756-30219</td>
<td>Wood</td>
</tr>
<tr>
<td>UBA-9310</td>
<td>114-118 cm</td>
<td>29981±109</td>
<td>-24.6</td>
<td>32989-32547 BC</td>
<td>34939-34497</td>
<td>Wood</td>
</tr>
<tr>
<td>UBA-9311</td>
<td>160-162 cm</td>
<td>26040±90</td>
<td>-25.6</td>
<td>29116-28567 BC</td>
<td>31066-30517</td>
<td>Wood</td>
</tr>
<tr>
<td>UBA-10003</td>
<td>258-260 cm</td>
<td>40397±436</td>
<td>-26.1</td>
<td>43067-41503 BC</td>
<td>45017-43453</td>
<td>Wood</td>
</tr>
<tr>
<td>UBA-9312</td>
<td>286-292 cm</td>
<td>44583±345</td>
<td>-23.9</td>
<td>42967-41647 BC</td>
<td>49006-46479</td>
<td>Wood</td>
</tr>
</tbody>
</table>

Table 6.1: Radiocarbon dates and calibrated age ranges for core Ba

For future work, further radiocarbon dates before and after potential age reversals, and hiatuses, might produce a tighter chronology for the Bario core. Despite the age reversals and the hiatus described above, the age-depth graph (Fig 6.4) shows a relatively linear relationship between 50,000-30,000 cal BP, in four out of five dates, which appear to fit the stratigraphy with relative constant sedimentation. This is with the exception of UBA-9311 (31,066-30,517 cal BP). The Holocene sequence (Fig 6.4) shows a non-linear relationship, representing much slower sediment accumulation between 5,645-1,558 cal BP, than between 1,558-0 cal BP, whilst UBA-9995 (2428 cal BP) falls outside of the line of best fit and is probably associated with the fluvial recycling of charcoal (see section 6.7).
6.3 Age/Depth model

Fig 6.4 was calculated using the statistical modelling program *clam* (Blaauw, 2010), to produce a potential age/depth relationship over the last 50,000 years. A smooth spline model was chosen from the *clam* program, as this type of model produced the most reasonable approximation for the calibrated age sequence. The model has also taken into account a hiatus occurring between 30,756-30,219 cal BP and 5,645-5,483 cal BP. Ages discussed in sections 6.7 and 6.8 have been extrapolated using the age-depth model. Minus values represented in the age/depth model may be an indication that the top sediments are missing.

![Smooth spline age/depth model for Bario (Ba) calculated in *clam* (Blaauw, 2010). Grey bands represent 95% uncertainty in the age estimates. Average sediment accumulation rates (cm/yr) have also been included.](image)

Sediment accumulation rates were calculated using the ages of best fit produced by the age/depth model, shown in Fig 6.4. A more detailed account is provided in Appendix Three. Based on the age/depth relationship, sediment accumulation shows a relatively linear relationship between 47,200-37,300 cal BP; although a slightly higher accumulation rate is represented between 44,700-40,100 cal BP. The slowest rate of sediment accumulation appears between 33,800 cal BP
and 2,300 cal BP, and may reflect a second hiatus between 5,500-2,300 cal BP. Highest accumulation rates occur in the last 400 years.

6.4 Lithology and Loss on Ignition

The lithology and loss on ignition of core Ba, is represented as a summary diagram below, in Fig 6.5. The stratigraphy consists of sand, slit, clay and peat. Sand disappears by 229.5 cm and is gradually replaced by organic silty clay. A lot of wood is present between 196-90 cm, whilst very wet unconsolidated peat is recorded between 86-65 cm. See Appendix Three for a more detailed account of the lithology and loss on ignition results.

Fig 6.5: A summary diagram representing the lithology and loss on ignition results for Ba
6.5 Pollen, spores and Palynomorph results

Appendix Seven provides a detailed account of all pollen and palynomorph percentages identified in core Ba. Total counts are also described in Appendix Seven. These results are summarised in Figs 6.6-6.11 below. Pollen percentages are expressed as percentages of total pollen, excluding spores; spores are expressed as percentages of total pollen and spores; whilst other organics are expressed as percentages of total organics and include other palynomorphs, phytoliths and charcoal. Only charcoal sherds >5µm have been recorded. Ages are by extrapolation from the age-depth model. Due to time limitations phytolith analysis was not undertaken on the Bario core; however, phytoliths did appear on the pollen slides. They have not been included in the pollen sum, but were included as part of all other organics. Fig 6.11 summarises the phytolith results.
Fig 6.6: A summary of montane and general taxa for Ba
Fig 6.7: A summary of kerangas, lianes, shrubs/small trees and aquatic taxa for Ba
Fig 6.8: A summary of open ground, catholic and unknown taxa for Ba
Fig 6.9: A summary of all pollen and spore taxa recorded in Ba. Montane forest include all montane sp. Upper montane forest consist of *Podocarpus, Dacrydium, Dacrycarpus and Phyllocladus*. Lower montane forest consists of all Fagaceae sp. The summary diagram also includes interpolated dates, calculated in *clam* (Blaauw, 2010). See Appendix Three for more detail.
Fig 6.10: A summary of other organics for Ba. + represents presence, whilst multiple +’s represent a higher percentage representation
6.7 Zone description

For a more detailed zone description see Appendix Seven

**Zone Ba-1: 344-265 cm** \( (ca. > 49,000-45,000 \text{ cal BP}) \)

This zone is defined by Fagaceae \((15.9-43.5 \%)\), Asplenium \((1.1-10.9 \%)\), Ophioglossaceae \((3.1-6 \%)\), all Ericaceae \(sp. \) \((4.5-7.9 \%)\), *Exallage* \((0-1 \%)\) and *Lygodium* \((0-0.8 \%)\). Other pronounced taxa for this zone include Cyathaceae \((4.1-6.9 \%)\), Sapotaceae \((0-2.2 \%)\), *Juniperus* \((0.6-1.8 \%)\), Myrsinaceae \((0.9-3.2 \%)\) and Cyperaceae \((0-4.1 \%)\). Cyperaceae however, fluctuates.

Upper montane forest generally shows a lower representation \((6.5-28 \%)\) than the Fagaceae \(sp.\). For example, *Dacrydium* representation is generally below \(9 \)\%, although some fluctuations occur \((e.g. 25 \% \text{ at } 307 \text{ cm and } 12.8 \% \text{ at } 287 \text{ cm})\). Lianes represent 0-0.6 \% total pollen and indicate the presence of trees. Open-ground taxa represent 9.5-14.8 \% \((\text{including: Capparidaceae, *Rumex* and Cruciferae. Shrub/small trees represent 8.6-15.4 \%, kerangas represent 5.3-8.9 \% and aquatics represent 3.4-5.4 \%, of which *Myriophyllum* represents 1.3-4.5 \%. *Equisetum, Isoetes, Urticularia, Nymphaceae and Typha* are also present. Large scabrate Poaceae are present at 269 cm and at 234 cm. and *Drosera* appears for the first time above 295 cm. *Concentricystes* is also present throughout this zone, whilst testate amoebae are present at 295 cm, but are not present after 295 cm. Fungal spores are present at 287 cm.

**Zone Ba-2: 265-184 cm** \( (ca. 45,000-39,500 \text{ cal BP}) \)

Species composition is significantly different from zone Ba-1 and is characterised by a) a decline in Fagaceae \(sp.\) to 10.6-25.3 \%; b) the appearance of taxa that were not present in zone Ba-1: *Pteris, Davalliaceae, Nepenthes, Selaginella, Pteropsida, Sapindaceae, Macaranga, Glochidion, Oleaceae, Buxaceae, Apocynaceae, Lycopodium, Primulaceae, Vitaceae, Cocculus*, and an unknown 2 sulcate grain, possibly belonging to the Arecaceae family; c) by taxa, that become more established in zone Ba-2: *Syzygium, Myrtaceae, Loranthaceae, Lithocarpus, Ligustrum* type, Araceae, Rutaceae and Poaceae. The aquatic *Equisetum* is present \((0.3-0.9 \%)\) at 217 cm and at 159 cm and fungal spores are present between 257-227 cm and at 189 cm; d) by the disappearance of taxa: *Angiopteris, Asplenium, Drosera, Annonaceae, Geranium* type and *Exallage* type and e) by a number of fluctuations in the pollen record, between 42,015 and 40,111 cal BP. For example:

1) At 217 cm, Fagaceae \(sp.\) increase from 12.5-18.8 \%, upper montane forest decline from 22.4 \% to 12.5 \%, and open ground taxa from 21.5 \% to 9.9-9.2 \%. There is also a rise in
the aquatic *Myriophyllum* from 1.16 % to 13.07 % by 207 cm, and kerangas taxa from 9.03 % to 11.4 %.

2) At 197 cm, *Dacrydium* increases to 11.8 %, *Podocarpus* increases to 9.2 % and *Ilex* to 3.2 %. There is also a spike in Cyperaceae (from 1.9 % to 12.72 %) and open ground taxa increase from 9.2 % to 21.5 %. Kerangas taxa decline to 5.9 %, Fagaceae *sp.* from 13.6-13 % and there is a sharp decline in *Myriophyllum* to 1.4 %.

3) At 189 cm *Isoetes* (0.3 %) appear. No other aquatics are present. Kerangas taxa rise to 8.4 %, mainly demonstrated by a rise in *Syzygium* from 0.3 % to 5.7 %; *Macaranga* (0.4 %) and Sapindaceae (0.4 %) are present; and Fagaceae increase from 11.8 % to 22.7 %. *Dacrydium* percentages decline from 11.8 % to 8.7 %. At 187 cm fern spores show a noticeable rise from 10.7 % to 31.1 % and include Cyathaceae (from 3.3 % to 10.24 %) and Davalliaceae (from 0.6 % to 5.22 %).

**Zone Ba-3: 184-99 cm** (ca. 39,500-32, 600 cal BP)

This zone is represented by upper and lower montane forest *sp.* including *Podocarpus*, *Dacrydium*, *Dacrycarpus* and Fagaceae (although Fagaceae percentages remain lower than in zone Ba-1), the absence of fungal spores and *Concentricystes*, the representation of the liana Menispermaceae (0-2.8 %), Myrtaceae species (0.6-5.04 %), including: *Syzygium* (0.3-7.97 %), *Decaspermum* (0-2.31 %), *Leptospermum* (0-2.6 %), *Psidium* (0-2.8%) and also by the presence of large scabrate Poaceae (0.31-1.3 %).

As with zone Ba-2 some fluctuations in the pollen record have also been recorded: Between 159-157 cm upper montane forest taxa briefly decline from 20.2-12.5 %, whilst Fagaceae species also decrease from 22.1 % to 17.9 %. *Lithocarpus* however, shows an increase (from 0.3 % to 3.8 %), as do general forest taxa, from 2.5 % to 4.3 %; small shrubs/trees, which represent 17.6-13.9 %; and open ground (10.98 %), including large scabrate Poaceae (from 0 to 0.86 %), Cyperaceae (from 1.2 % to 2.6 %), Liliaceae type (from 0 to 0.28 %) and Ranunculaceae (from 0.96 % to 4.04 %). Similar fluctuations also take place between 117-107 cm. Aquatics range from 0.94-6.6 % with the highest representation occurring at 137 cm. This is chiefly associated with an increase in *Myriophyllum* (6.32 %). *Equisetum*, *Potamogeton* and Nymphaceae also appear at 157 cm. Other aquatics including *Isoetes*, *Urticularia*, Nymphaceae and *Potamogeton* are present at 117 cm. *Spirogyra* and testate amoebae are also present in this zone.
**Zone Ba-4: 99-72 cm** (ca. 32,600-30,300 cal yrs BP)

Zone Ba-4 represents a rise in the upper montane taxa *Phyllocladus* from 4.71 % at 101 cm to 8.04 % by 83 cm, *Podocarpus* from 2.5 % at 101 cm to 9.53 % by 93 cm, *Dacrydium* from 6.0 % at 97 cm to 16.5 % by 87 cm and *Juniperus* from 0 to 1.6 %.

Above 83 cm a general decline in upper montane forest pollen takes place. This can be seen by a decline in *Dacrydium* (to 8.7 % by 75 cm), *Phyllocladus* (to 4.2 %) and *Podocarpus* (to 2.2 %). Fagaceae also declines above 79 cm (from 13.5 % to 11.8 % by 75 cm). Kerangas taxa show a noticeable decline above 97 cm (from 7.6 % at 97 cm to 2.9 % at 93 cm), particularly the Myrtaceae family (from 2.4 % to 0), including *Syzygium* (from 0.9 % to 0.3 %) and *Leptospermum* (from 0.6 % to 0), and the liana Menispermaceae (0.31 % to 0). Small trees and shrubs such as Sapindaceae, *Macaranga*, Myrsinaceae, *Acacia/Albizzia* type, *Saurauia* and *Theaceae* also briefly disappear after 97-93 cm until 83 cm, as does the general forest taxa Elaeocarpaceae and the moss *Selaginella*. The Myrtaceae family, Menispermaceae and small tree/shrubs, which had previously disappeared between 97-93 cm, reappear by 79 cm. After 93 cm open ground taxa, rise from 12.7 % to 22.6 % by 83 cm, but by 75 cm open-ground taxa decline to 15.47 %. Large scabrate Poaceae disappear after 97 cm. Between 83 cm and 79 cm Cyperaceae increases from 4.4 % to 8.97 %. The aquatic *Myriophyllum* represents 0.31-3.1 % by 87 cm, but percentages then fluctuate. No significant change takes place in other aquatic taxa, although *Typha* disappears until the mid-Holocene. *Spirogyra* and *Concentricystes* are present at 83 cm.

**Zone Ba-5: 72-47 cm** (ca.30,300 to 7,600-2,300 cal years BP)

Zone Ba-5 represents the highest percentage values for upper montane forest (14.9-42.1 %) and includes a rise in *Dacrydium* (from 8.7 % to 33.6 %); this is also the highest percentage for *Dacrydium* recorded for core Ba. Other montane forest taxa also increase and include Aquifoliaceae (from 1.9 % to 7.9 %, which is higher than zones Ba-1 to Ba-4), *Podocarpus* (from 2.2 % to 5.2 %), *Dacrycarpus* (from 0 to 1.4 %) and Fagaceae (from 11.8 % to 14. 8 %, with the exception of *Lithocarpus*). Between 62 cm and 58 cm, all montane forest decline to 48.8 %.

Kerangas taxa percentages range from 10-17.7 %. Myrtaceae values appear to decline throughout this zone, particularly *Syzygium* (4.43 % at 75 cm to 0.3 % by 72 cm), whilst all of the Ericaceae recorded (Ericaceae: 4.9-6.4 %, *Vaccinium* type: 1.6-6.7 % and *Rhododendron* type: 0.95-2.46 %) are highest in zone Ba-5 compared with all other zones.
Open-ground taxa show a general decline, from 15.5 % to 5.7 % between 75-62 cm (except 13.5 % at 52 cm). Cyperaceae for example, shows a noticeable decline from 7 to 1 % and Liliaceae, which had been relatively consistent in zones Ba-1 to Ba-4, disappears in zone Ba-5 (except for 0.27 % at 62 cm). Malvaceae, however, shows a more consistent presence (0.3-1.47 %) compared to zones Ba-1 to Ba-4. Aquatics also show a low representation at 62 cm (0.8 %), but at 52 cm represent 8.8 %. These percentages are mainly influenced by *Myriophyllum*, which is 0.27 % at 62 cm and 8.8 % at 52 cm. Fern spores increase from 4.2 % to 16.8 % between 75-58 cm, particularly Cyathaceae, Davalliaceae and Polypodiaceae.

**Zone Ba-6 47-0 cm (ca. 2,300 cal BP-0 BP)**

Zone Ba-6 shows the lowest overall representation of upper montane forest (13.3-1.3 %), an increase in Fagaceae. (19.5-40.5 %), a sharp rise in *cf. Campanulaceae* at 34 cm (from 2.7 % to 22.5 %), the appearance of *Eugeissona* (1.6 to 0.34 %) and the highest overall representation of spore counts (9.6-55.38 %), with a sharp rise in Cyathaceae from 10.6 % to 35.3 % between 46-43 cm. Pteropsida in particular increases within the top 3 cm (from 2.4 % at 13 cm to 19.51 % by 3 cm). Polypodiaceae are also strongly represented and *Lycopodium* is present, although *Lycopodium* briefly disappears between 38-34 cm. *Stenochlaena* (0.14-0.66 %) is only present between 28-3 cm. *Trema* is also present, although appears more consistent within the last 18 cm. Other Arecaceae species also appear more consistently in the top 22 cm (0.5-1.9 %).

Kerangas taxa generally represent 2.35-9.79 %, although at 38 cm there is a rise to 12.41 %. *Syzygium* generally ranges from 0.8-3.9 %, although represents 8.27 % at 38 cm. *Psidium* is only present at 38 cm and at 3 cm. Ericaceae species show a lower percentage representation than in zone Ba-2 (generally lower than 2.5 %). Small trees/shrubs represent 7.9-22.5 %, with the highest representation found within the top 18 cm, particularly at 3 cm, where percentages increase to 22.5 %. *Sapindaceae* appears consistent between 28-8 cm (0.32-0.95 %), although is not present at 3 cm. *Saurauia* is also consistent within the top 28 cm (0.32-1.71 %). Open-ground taxa represent 14.5-36.7 % and include *Artemisia* Scrophulariaceae Malvaceae Capparidaceae Caprifoliaceae and Asteraceae. *Cyperaceae* is only present at 46 cm, 34 cm and at 3 cm. Aquatic pollen varies between 1.6-7.6 %. *Myriophyllum* is not present at 34 cm but represents 5.41 % at 28 cm and 5.29 % at 18 cm. Other aquatic plants such as *Urticularia*, *Potamogeton* and *Typha* are also present. *Typha* shows an increase in the top 7 cm (from 0.5 % to 1.36 %). Between 46-43 cm *Concentricystes* and the green algae *Spirogyra* is present. *Concentricystes* and Zygnemataceae
briefly disappear at 34 cm (ca. 1515 cal BP). Charcoal increases from 0 at 12 cm to 6.28% (10 sherds > 5 µm) by 3 cm.

6.6 Phytoliths

Section 6.6 starts by examining the phytolith evidence. As explained in Chapter Four, a thorough phytolith investigation could not be carried out on core Ba, but despite this, phytoliths appearing on the pollen slides were counted as part of all other organics and have provided an important contribution to understanding the anthropogenic use of certain plants within the vicinity of the core site. The distribution of phytoliths in the Bario core is shown in Fig 6.11.

**Fig 6.11**: A summary of phytoliths appearing in the Bario core.
Fig. 6.12 represents one *Oryza* double peaked phytolith, derived from rice husk, identified within the Bario Ba record, at 116 cm (*ca.* 34,600 cal BP, according to the age/depth model). The phytolith was measured and photographed, and sent to Dr. Premathilake at the Post Graduate Institute of Archaeology at the University of Colombo, who confirmed it as being wild *Oryza*. Fig 6.13 is a photograph of a potential *Oryza* bulliform, again from 116 cm.

![Fig 6.12: Double peaked *Oryza* phytolith](image1)

![Fig 6.13: Poaceae bulliforms, possibly *Oryza* type](image2)

Fig 6.14 shows a Poaceae pollen grain, also identified at 116 cm. This grain has a similar scabrate pattern to *Oryza* sp., identified from type material, held at Queen’s University Belfast. Scabrate micro-spinulate patterns appear to be common in *Oryza*, although some species of grass also have scabrate morphology. For precise identification, careful attention would be needed on a strong morphological approach. Fig 6.15 shows photographs of two Poaceae grains that were collected from a giant water reed, during the 2007 field trip, in the village of Bario. The photo demonstrates similar morphological features to *Oryza* grains, although the water reed appears to have a smaller annulus. Both the pollen evidence combined with evidence from the double peaked phytolith; however, are likely to indicate wild rice was present in the Bario area around 34,000 years ago.

![Fig 6.14: Scabrate Poaceae possibly *Oryza*](image3)

![Fig 6.15: Poaceae from a water reed in Bario](image4)
Besides the _Oryza_ phytolith identified in Ba-3, round-echinate phytoliths were also common within the top 28 cm of the pollen record, _ca._ 1298 cal BP (see Fig 6.11). At least three different families produce round-echinate phytoliths. These include Bromeliaceae, Marantaceae and Arecaceae (Piperno, 2006). As pineapples (Bromeliaceae) are known to contain phytoliths, and today pineapple (an introduced species from South America, which probably arrived in Borneo within the last 200 years) cultivation is common on the hills around Bario, the possibility of these being pineapple phytoliths had to be tested. To test this possibility, phytoliths (shown in Fig 6.16) from the top 12 cm of core Ba were compared with phytoliths extracted from the leaves of modern pineapples (Fig 6.17). The pineapple phytoliths however, appear smoother and are on average between 6.8-9 µm in diameter, whilst those from Bario have a more echinate appearance and are on average between 10 and 13 µm in diameter. The phytoliths identified in the Pleistocene sediments also appear to have the same morphological features as the phytoliths occurring in the top sediments. There are also no native Bromeliaceae in Borneo, as it originates from South America. This therefore suggests the Bario phytoliths do not belong to the Bromeliaceae family.

![Fig 6.16: Echinate phytoliths](image1)

![Fig 6.17: Modern pineapples phytoliths](image2)

The phytolith results were later compared with pollen of economical importance. Echinate phytoliths represent 1-16 % of other organics (counts of 1-5) at 28-23 cm, and 34-48.9 % (counts of 16-73 %) between 13-3 cm. An increase in phytoliths within the top 30 cm, although particularly within the top 12 cm, _ca._ 600 cal BP, seemed to coincide with the appearance and then consistent presence of _Eugeissona_ (Arecaceae/Palmae) pollen grains, beginning _ca._ 1298 cal BP (Fig 6.18) until present day. There is therefore a strong probability that the phytoliths are from the Arecaceae family and particularly within the top 30 cm, belong primarily to _Eugeissona_. It should be noted that all species of Arecaceae produce echinate phytoliths and other species may be occurring in the record as well. For example small amounts of _Calamus, Areca_ type and unknown Arecaceae pollen grains have also been recorded throughout the Bario record.
6.8 Interpretation of results

Section 6.8 provides an interpretation of all of the results described in this chapter (sections 6.2-6.7) and includes lithology, $^{14}$C dates, loss on ignition, pollen, phytoliths and other palynomorphs. The interpretation has been divided into late Pleistocene (50,000-30,200 cal BP), late Pleistocene-mid Holocene (30,760-5480 cal BP) and mid Holocene-late Holocene (5640-0 cal BP). For the Pleistocene – mid Holocene interpretation depth (cm) has been used rather than age. This has been done because due to a hiatus occurring in the sediment sequence between 80-59 cm, the exact timing of the Pleistocene-Holocene boundary is unknown.
Late Pleistocene (50,000-30,300 cal BP)

Between ca. >49,000-45,000 cal BP (Zone Ba-1) Fagaceae are the dominant taxa with two peaks at ca. 49,000 and 45,000 cal BP. Representation of Fagaceae is higher than upper montane species and is similar to levels in the Holocene period. Beaman (1999) describes present-day oak at lower altitudes (1700 m) in the Kelabit Highlands near Mount Murud. Oak representation here could be an indication of wetter and possibly warmer conditions than after 47,188 cal BP. Hunt and Premathilake (2012) report interstadials at ca. 49,000 and 45,000 cal. BP in lowland Borneo, which they provisionally correlate with NGRIP interstadials 13 and 12. An alternative theory for the dominance of Fagaceae could be fluvial transport, from up to 20 miles away and from up to a 700 m higher altitude (see Chapter Three). The presence of sands, very low loss on ignition (demonstrating poor organic accumulation) and aquatic plant taxa >49,000-45,000 cal BP, suggests that the Bario plateau was being influenced by fluvial deposition at the same time as the Fagaceae rise. One argument against the fluvial deposition of Fagaceae however, is that other montane taxa do not show a similar increase, instead upper montane taxa only increase as Fagaceae sp. decrease.

An indicator of wet soils associated with either fluvial deposition or increased rates of precipitation, is shown by the presence of Concentricystes. Concentricystes is described by Marett (2009) as freshwater algae, by Qin et al., (2007) as an indicator of freshwater deposits and by Hunt and Rushworth (2005) as common in wet soils. Another indicator of fluvial activity seems to be the fern spore Asplenium. The consistency of Asplenium, followed by its subsequent disappearance after 42,533 cal BP until present day, and the fact that its disappearance coincides with that of fluvial sands, rise in loss on ignition and appearance of organic clays suggests an association with fluvial deposition. According to Hunt (1994), high spore contents are often found in fluvial deposits and this may explain why spores are strongly represented, although Behling et al. (1997) describe fern spores as showing a higher representation after disturbance. Disturbance may have allowed only the most resistant pollen and spores to have preserved. For example, Birks and Birks (1980) describe some spores as having a higher sporopollenin content than pollen grains and therefore resist corrosion. Oxidation and corrosion of pollen grains could have occurred if fluvial disturbance was taking place. Evidence of a previous river course can be seen just beyond the edge of the peat bog in a terrace deposit, now completely covered by Kerangas forest. Jaman et al. (1999) recorded six modern species of Asplenium in Bario, all of which are lower montane to montane species, but two can also be found in Kerangas: Asplenium nidus and the epiphyte Asplenium pellucidum. Cyathaceae is relatively consistent between >49,000-42,500
cal BP. Jaman et al. (1999) also recorded four species of Cyathaceae, which includes two kerangas species: *Cyathea recommutata* and *Cyathea contaminans*. The *Asplenium* and Cyathaceae could have lived in kerangas, although Cyathaceae can occur within both montane and general forest habitats, whilst *Asplenium* can be found in other habitats too. Fungal spores also appear during this period and these are probably associated with fluvial disturbance. Evidence of disturbance is further presented by either dominance or a consistent presence of certain open ground taxa, including Capparidaceae, *Rumex*, Cyperaceae, Cruciferae, and *Lygodium*. High energy fluvial deposition during the Late Pleistocene has also been reported by Thomas et al. (2007) from NE Queensland (2007), who describe coarse deposits of alluvial gravels and sands mainly found during OIS3 (between 64,000-28,000 cal BP), with finer grained fans appearing to have accumulated mainly during OIS2 until at least 15,000-14,000 cal BP. Thomas et al. (2007) also report similar observations at other fan sites, dating to ca. 30,000 cal BP, which are again coarser than later deposits. They propose that although OIS3 climates were cool they are also believed to have been considerably wetter than OIS2 (glacial climates) throughout much of the tropics. As a result this would have led to the appearance of high energy fluvial systems during OIS3, whilst a decline in rainfall during the Last Glacial Maximum should have produced much lower energy systems, with finer sediments. It is quite possible that increased but more seasonal precipitation provided not only optimal conditions for oak forests but was also responsible for high energy fluvial deposition at Bario.

Upper montane forest taxa *Phyllocladus*, *Dacrydium* and *Podocarpus*, show a much higher representation throughout the Late Pleistocene compared to the Holocene, although percentage representation is lower than the Fagaceae between >49,000-45,000 cal BP (Zone Ba-1). Wong et al. (1987) describe the species *Dacrydium beccarii* as able to adapt to thin and nutrient deficient soils such as on sandstone plateaus, in coastal areas, mountain forests and in kerangas. Mackinnon et al., (1998) also describe *Dacrydium* as a padang species. Some fluctuations in *Dacrydium* may be representative of local environmental changes associated with the braid plain. The upper montane taxa *Phyllocladus*, *Podocarpus* and *Darycarpus*, however, do not show any significant increases until after 45,000 cal BP and all upper montane taxa show a significantly higher representation than during the Holocene. This therefore suggests that these taxa were being influenced predominantly by cooler temperatures during the Late Pleistocene. Beaman (1999) describes *Phyllocladus, Dacrydium and Podocarpus* as recorded on the summit of Mount Murud in the Kelabit Highlands, above Fagaceae dominated woodland forest.
The general vegetation between >49,000-45,000 cal BP has the aspect of upland kerangas-padang. Whitten et al., (2000) describe padang as shrubby vegetation in which the average trees usually only reach about 5 m, but trees reaching 25 m are not uncommon. Within this group Ericaceae, cf. *Rhododendron*, cf. *Vaccinium* and *Casuarina* appear most common. Ericaceae, *Rhododendron* and *Vaccinium* are predominantly higher altitude plants (Anshari, et al., 2004) and form much of the summit flora on Mt. Kinabalu (Smith, 1980). Ericaceae and cf. *Rhododendron* show on average a higher representation in Bario >49,000-45,000 cal BP, compared with the Holocene record. This therefore may be a further indication of cooler temperatures than during the Holocene, although Mackinnon et al. (1996) also describe Kerangas vegetation as open-scrub vegetation found on nutrient poor sands. Ericaceae species have a symbiotic relationship with fungal mycorrhizae, providing the plants with nutrients, and therefore conditions on the braid plain would have provided optimal environmental conditions for Ericaceae growth. Given that Ericaceae representation is pronounced throughout the period of oak dominance, suggests Ericaceae were indeed thriving on the nutrient poor sands of the braid-plain, particularly between >49,000-45,000 cal BP; however, lower representation during the Holocene period is also likely to reflect a climatic influence.

By ca. 42,700 cal BP (Zone Ba-2) a combination of change in the lithology to more organic sands-clays, increase in loss on ignition and changes in sediment accumulation rate suggest energetic fluvial activity gradually weakened. Increases in the aquatic *Myriophyllum* might further reflect periods of reduced fluvial activity, with the development of swampy conditions or pool deposits. Fluctuations in high energetic fluvial deposition, however, still continued and are demonstrated by alternating sands-clays and a 94 % reduction in loss on ignition (LOI) at 275 cm. Large spinulate Poaceae are also present, presumably originating from wild *Oryza*, although other Poaceae species should not be ruled out. Quiet pools in the braid-plain would however, have been ideal environments for wild *Oryza* to grow.

*Drosera*, which can be found in wet, shaded and open environments in lowland and highland areas (Lianli and Kondo, 2001), is a carnivorous species, which uses insects to supplement poor nutrient uptake (Lianli and Kondo, 2001). Its presence after ca.47,000 cal BP demonstrates that soils locally were still relatively nutrient poor. The fact that *Drosera* only occurs after 47,000 cal BP and only in the more organic sediments suggests conditions on the sandy braid plain, before 47,000 cal BP, to have been too harsh for its survival, and that it may well have survived better within a more stable environment, consisting of semi-open kerangas-shrub vegetation. Myrtaceae
and *Syzygium* become permanently established between 47,700-42,700 cal BP. Myrtaceae (Chen and Craven, 2007) do not have the ability to fix nitrogen from other sources, like Ericaceae and *Drosera*, so may not have been able to survive on the nutrient deficient sands deposited on the braid-plain, and are therefore a further indication of reduced fluvial activity and erosional deposition on the Bario plateau. *Nepenthes* also appear for the first time after fluvial deposition declines. Cyperaceae appears to be more frequent after 47,700 cal BP, and is likely to represent a reduction in fluvial activity and increased soil wetness. The appearance, increase and decline of specific taxa between 45,000-39,500 cal BP (described in zone Ba-2), as well as increased sediment accumulation and the deposition of more organic silty clays, represent a decline in fluvial energy, thus allowing for higher organic matter deposition. Despite a reduction in fluvial activity, very slow flow or pool deposits probably still continued. Between 42,000 and 40,100 cal BP a number of fluctuations took place in forest, shrub and herbaceous taxa; for example, increases in *Myriophyllum*, Fagaceae and Myrtaceae coincide with decreases in upper montane forest (*Dacrydium*, *Podocarpus* and *Phyllocladus*) and open-ground taxa, and vice versa. There are no significant changes in the lithology to suggest any flood events, as sediments gradually become more organic. The rise in the aquatic *Myriophyllum* reflects the presence of standing water/pool deposits on the plateau. At ca. 40,500 cal BP a fall in loss on ignition to 85.5 % coincides with a rise in upper montane taxa and decline in aquatics. These results may reflect fluctuations in precipitation rather than fluvial activity with periods of aridity and periods of increased precipitation. Following the recent publication by Hunt *et al.* (2012), suggesting that a reflection of NGRIP events are recorded in this area, an alternative explanation of the 45,000-39,000 changes in terms of temperature could be developed. At this stage, however, the Bario evidence does not seem to justify such a global interpretation. Perhaps for future work a tighter sampling resolution may answer this question. Between 39,600-32,800 cal BP (Zone Ba-3) relatively stable conditions are likely to have prevailed on the Bario plateau. The comparatively coarse sampling in this interval may, however, have missed short-lived events as several fluctuations in global climate are known at this time. High loss on ignition and very organic peaty clays with wood fragments may reflect an increase in woodland taxa, particularly upper and lower montane forest *Podocarpus*, *Dacrydium*, *Dacrycarpus* and Fagaceae. *Dacrycarpus* becomes relatively consistent in this period and may signify either a further reduction in temperature, or that temperatures were already low and that a reduction in fluvial activity allowed these trees to become more established locally. Open ground representation however, remains similar to ca. >49,000-45,000 cal years BP. This might be suggestive of a relatively open/semi-open environment around the channel. The presence of large scabrate Poaceae throughout most of
this zone may represent wild *Oryza*, as one double peaked *Oryza* glume is also present at ca.34,600 cal BP (Fig 6.12). These results are probably reflective of pool deposits/swampy conditions, which would have provided an ideal environment for wild *Oryza* species to thrive. Gilliland (1971) describes four species of wild rice found in Borneo: *Oryza rufipogon*, *Oryza granulata*, *Oryza ridleyi* and *Oryza minuta*. *Oryza rufipogon* is a shallow water rice found growing as a weed on rice fields with more than one form in Malaezia. *Oryza granulata* is found in wet areas and on river banks. *Oryza ridleyi* is found in the lowlands, and is unlikely to occur in the Kelabit Highlands, whilst *Oryza minuta* is found in swamps, ditches, rice fields and in the lowlands. *Spirogyra* and testate amoebae are also present in this zone and may be reflective of pool deposits or damp soils. *Myriophyllum* generally declines in this period, although small fluctuations occur, which may be representative of a small flood event or brief increases in the water table as no change in the lithology or organic content has been recorded.

At ca. 38,100 cal BP, montane taxa (*Dacrydium*, *Phyllocladus* and *Podocarpus*, Fagaceae spp. with the exception of *Lithocarpus*) all briefly decline. General forest, small trees/shrubs increase, but so do open ground taxa. The increase in open ground taxa mainly consist of large scabrate Poaceae, *(cf. Oryza sp.)*, Cyperaceae, Liliaceae and Ranunculaceae. Most of these taxa are likely to be associated with increased soil wetness. *Spirogyra* is also present, as are the aquatics *Potamogeton* and Nymphaceae. Similar fluctuations also take place between ca.33,800-35,000 cal BP, although there are no notable changes in scabrate Poaceae (a double peaked *Oryza* glume ca. 34,600 cal BP), Ranunculaceae and Liliaceae. Increases in precipitation may have caused a decline in montane forest, but may also have resulted in an increase in swamp conditions on the plateau. Relatively small flood events could also have taken place, which might explain the presence of aquatics and an age reversal occurring between 160-118 cm, although there are no obvious changes in the lithology to suggest a flood event. An alternative explanation for the age-reversal could be tree roots, other plant roots or bioturbation. Howard *et al.* (2009) report macrofossils may produce younger ages as a result of root penetration, whilst Bateman *et al.* (2007) discuss how bioturbation from fauna and flora can rejuvenate sediments. This is considered less likely to have taken place in the Bario core because of the well-stratified pollen record.

Between 32,600-31,700 cal BP (Zone Ba-4), montane and open ground vegetation increase, particularly the upper montane forest *Phyllocladus*, *Podocarpus* and *Dacrydium*. Kerangas taxa show a noticeably decline, particularly the Myrtaceae family, including *Syzygium*, *Leptospermum*
and Decaspermum, but also the Ericaceae family. As described earlier Leptospermum and many Ericaceae including Rhododendron and Vaccinium are predominantly higher altitudinal plants (Anshari, et al., 2004, Smith, 1980), and therefore if temperatures had declined then these taxa should have increased. Other taxa that show a notable reduction include the liana Menispermaceae, whilst certain small trees/shrubs such as Sapindaceae, Macaranga, Myrsinaceae, Acacia/Albizzia type, Saurauia and Theaceae briefly disappear. From these results it can be inferred that the canopy cover probably reduced significantly during this period. There is no evidence in the lithology, loss on ignition or other palynomorph record to suggest that the decline in canopy cover was related to a fluvial event. Myriophyllum is present, but percentages fluctuate. There is no other evidence of increased wetness in the aquatic record. Instead Typha disappears completely until the mid-Holocene. Another plausible explanation is a significant rise in aridity. This argument is further supported by a decline in sediment accumulation (see Fig 6.4 & Appendix Three) and the brief disappearance of Elaeocarpaceae. The species Elaeocarpus griffithii, collected from the Kelabit Highlands in 2008 (see Appendix One), is described as mostly found in swamps and along rivers on ultrabasic or poor sandy soils (Hovencamp, 2009).

More local indicators of increased aridity include a brief disappearance of Selaginella and the disappearance of large spinulate Poaceae.

Between ca.31,700-30,340 cal BP (Zone Ba-4), sediments become wet and unconsolidated. A return to wetter conditions on the plateau and an increase in canopy cover is suggested by the reappearance of the Myrtaceae family, Menispermaceae and small tree/shrubs, but also by a sharp decline in the upper montane forest, Dacrydium, Phyllocladus and Podocarpus. A more local indication of increased wetness is suggested by a rise in Cyperaceae, presence of Spirogyra and Concentricystes, and decline in open-ground taxa. There is no evidence of alluvial deposition in the lithology, whilst loss on ignition remains high.

**Late Pleistocene – mid Holocene (30,300-2,300 cal BP)**

A hiatus is suggested between 30,760-30,219 to 5,645-5,483 cal BP (Zone Ba-5), which means the record for the Last Glacial Maximum is missing. One theory to explain the hiatus is a stillstand in sedimentation or even erosion during or after the LGM. It is unlikely that the hiatus was caused by anthropogenic activity as there is no evidence of burning and open ground taxa decline. Large scabrate Poaceae, which might be representative of rice, also disappear in this zone and there are no other anthropogenic indicators in the record at this depth. Hope _et al._ (2004) report chronological problems in many tropical regions during the Pleistocene – Holocene transition.
This is seen in Borneo, at Lake Sentarum where a hiatus starts ca. 30,000 BP (Anshari et al. 2001). Thomas et al. (2007) report an absence of riverine sediments during the Last Glacial Maximum, with a gap of 3,000 years and no direct evidence of deposition, and attribute this to a reduction in fluvial activity. This may have happened at Bario. Despite wet and unconsolidated sediments the environment appears to have become drier, demonstrated by a much lower representation of Cyperaceae than previously recorded and by the disappearance of Liliaceae, which had been relatively consistent throughout the late Pleistocene; except at 62 cm. An increase in aridity is also represented by a general decline in the Myrtaceae family. The Ericaceae family however; including Vaccinium and Rhododendron types, but also Casuarina show the highest overall representation for the Pleistocene and Holocene record. Hunt and Premathilake (2012) regard Casuarina as tolerant of relatively xeric conditions, whilst the Ericaceae family tend to be more common at higher altitudes (Van Steenis, 1964, Anshari, et al, 2004, Smith, 1980, Kitayama, 1992; and demonstrated in Appendix Six). The Ericaceae values are also similar to values between ca. >49,000-42,530 cal BP, which as discussed earlier may have been influenced by alluvial deposition. Alluvial deposition of sands is not present during this period. Instead sediments remain very organic and therefore, as with the upper montane forest, the increase in Ericaceae may be further evidence of a much cooler-drier climate. The aquatic Myriophyllum also shows a low representation, until after 5483 cal BP. Aquifoliaceae, Podocarpus, Dacrycarpus and Fagaceae (except Lithocarpus) also rise at 62 cm. Ilex could be representative of upper montane forest. Both Smith (1980) and Kitayama (1992) describe Ilex as found in upper montane habitats on Mount Kinabalu, although Suzuki et al. (1996) describes an Ilex hydroglauc- Cephalomappa paudicola community as the major taxa of a mixed peat swamp forest at Naman, in the lowlands of Sarawak, and this therefore demonstrates a wide temperature distribution. Aquifoliaceae types continue to increase after 62 cm and therefore might be reflective of environmental conditions after the hiatus. Wood identified between 59-65 cm has been dated to 5,650-5,480 cal BP; although, the rise in most montane forest, particularly Dacrydium, (which has the highest representation compared to all other periods during the late Pleistocene and Holocene record), is probably reflective of much cooler-drier conditions during the Last Glacial period, just before the date. For future research, further radiocarbon dates between 55 cm and 75 cm might help to clarify these results.

An alternative theory for the hiatus is fluvial down cutting, caused by precipitation during the early to mid-Holocene. Holocene fluvial down cutting may have removed the drier LGM sediments, which might also explain why low sediment accumulation occurs, and why no change
is recorded in loss on ignition or the lithology. Certain spores increase by 58 cm, particularly Cyathaceae, Davalliaceae and Polypodiaceae, which could be a further indication of fluvial activity (Hunt, 1994).

Above 62 cm montane forest species decline and the aquatic *Myriophyllum* increases. These results could be reflective of warmer to wetter conditions, between 5,500-2,300 cal BP. Sedimentation rates, however, do not recover until after 2,300 cal BP and could possibly reflect another hiatus during this period. An increase in open ground taxa after 62 cm might also be representative of disturbance, caused by erosion from intense precipitation, during the Holocene to Pleistocene transition, although other forms of disturbance, such as anthropogenic disturbance is also a possibility.

**Late Holocene (2,300-0 cal BP)**

The montane forest *Dacrydium, Podocarpus* and *Phyllocladus* show the lowest overall representation between 2,280-0 BP (Zone Ba-6) and as with the increased sediment accumulation rates for this period, and a rise in the lower montane taxa Fagaceae, probably reflect present climatic conditions during the warmer-wetter Holocene, particularly within the last 2300 years.

Between *ca.* 2,300-1,400 cal BP a flood event takes place. This is demonstrated by a drop in loss on ignition to 83.7 %, and by a change in sediments to brown, and then greys clays. *Concentricystes* and the green algae *Spirogyra* are present and may represent either standing water or the presence of pool deposits. Other aquatic plants, such as *Urticularia, Potamogeton* and *Typha* are also present in this zone, although percentages are below 2 % and tend to vary. *Myriophyllum* declines by *ca.*1500 cal BP. A small flood event may have prevented the growth of *Myriophyllum*, but allowed fresh water algae to survive. The highest representation of open ground taxa takes place at 2,300 cal BP and includes taxa such as *Artemisia*, Scrophulariaceae and Malvaceae. These taxa may be associated with fluvial erosion. The lack of heavier sands in the lithology during this likely flood event, compared with alluvial deposition during the late Pleistocene, can almost certainly be explained by increased canopy cover during the Holocene and stabilization of the surrounding slopes and plateau by vegetation. A rise in Fagaceae at 2,300 cal BP might also be associated with the flood event.

A sharp rise in Cyathaceae, at the same time, is probably further associated with the flood event. There is a possibility that a lack of vegetation as a result of human disturbance, caused the Bario
plateau to become more susceptible to flood waters 2,300-1,400 years ago; however, only one piece of dated charcoal was present at ca. 1,500 cal BP (according to the age-depth model, although the actual age of the charcoal piece is between 2703-2351 cal BP) and no micro-charcoal was identified until ca. 1,000 cal BP. There is no other evidence in the pollen or palynomorph record to suggest anthropogenic disturbance, at this particular point in time, although flood waters may have washed the evidence away. The dated charcoal piece is bracketed by younger dates (see section 6.2). It is quite likely that this age reversal was caused by fluvial recycling of charcoal, as charcoal is more resistant to decay than peat or wood, and therefore susceptible to erosion and deposition (Gavin, 2001). An alternative explanation for the flood event and rise in pioneer taxa may be related to an opening of the canopy by disease or a major storm or event. The charcoal piece also coincides with a sharp rise in cf. Campanulaceae; the spike in cf. Campanulaceae is likely to date between 1,700-1,400 cal BP, according to the age-depth model, and occurs after the spike in Cyathaceae. The cf. Campanulaceae may have been a pioneer species, establishing itself after the fluvial disturbance. A peak in Asteraceae and the presence of Caprifoliaceae, during the same period, are again likely to be associated with the fluvial disturbance. Spore representation is much higher throughout the late Holocene (during and after the flood event) compared to the late Pleistocene and is probably an indicator of increased levels of disturbance (Behling et al., 1997). These results might be representative of both anthropogenic and fluvial disturbance.

The sago palm *Eugeissona* appears for the first time in the pollen record at ca. 1,300 cal BP (Fig 6.17); therefore the appearance of Campanulaceae could also have some association with anthropogenic clearance prior to the cultivation of sago palms, although more evidence would be needed to confirm this. When compared with the phytolith record (Section 6.6 and Fig 6.18) echinate phytoliths also begin to increase at the same time as *Eugeissona* pollen appears. As described earlier these are unlikely to belong to the Bromeliaceae family, which also produce echinate phytoliths, but probably represent the Arecaceae family and correlate well chronologically with the *Eugeissona* pollen. Other Arecaceae species however, cannot be ruled out and are likely to be present throughout the record, although the increase in phytoliths towards the top of the core, combined with the pollen results probably reflect manipulation of *Eugeissona* for sago. The rise in echinate phytoliths in the top sediments could represent increased sago production within the last 600 years. Charcoal also increases in the top 8 cm, although *Eugeissona* pollen grains decline. If land was being cleared, this may have included the burning
of sago trees, resulting in increased concentrations of palm phytoliths in the soil and reduced pollen grains. Erosional inwash from adjacent hill-slope cultivation is also a possibility.

Fig 6.19 demonstrates that other plants of economic value are also present in this zone and include some varieties of fruit trees, such as Myrtaceae species, Sapindaceae and *Ficus*. The Myrtaceae family includes many fruit trees, especially *Syzygium* (Christensen, 2002). Myrtaceae and *Syzygium* occur frequently within the last 1,300 years, but also occur frequently throughout the late Pleistocene from 45,100 cal BP. Sapindaceae species also appear during the Pleistocene, but are more consistent within the last 1,300 years and could be the result of deliberate manipulation. *Stenochlaena*, an edible fern (Christensen, 2002), only occurs within the last 1,300 years, except for one early occurrence in the Pleistocene record. It is unlikely to have been cultivated, but is probably a disturbance indicator and there is a strong possibility that its presence along with the presence of *Trema*, also a disturbance indicator (Liguo *et al.*, 2003) is associated with anthropogenic clearance. According to Horton *et al.* (2005) *Stenochlaena palustris* is common on disturbed freshwater swamps with sudden and severe disruption of the vegetation. Bombacaceae and *Durio* are also present but these could be natural occurrences as *Durio* was also found at ca. 30,800 cal BP. Although durian trees have been planted close to Bario by the ancestors of the present inhabitants, it is uncertain how far back this practice extends.

Between 900-0 cal BP loss on ignition drops to 85 %. The surface of the deposit has probably been eroded during forest fires, indicated by an increase in charcoal within the last 8 cm, and may not represent present day. The forest fires are likely to be associated with relatively recent anthropogenic clearance episodes, supported by an increase in certain open ground taxa such as *Lygodium*, Scrophulariaceae, Malvaceae Capparidaceae and a steep rise in Pteropsida. This period of disturbance may have been caused by clearance of the kerangas forest to make way for the new runway, now located next to the peat bog next, although other disturbances associated with cultivation are also possible. After the forest fires the site would have been exposed to intense precipitation and soils would have become saturated, which might explain a rise in the aquatic *Typha* and the presence of other aquatics. The site is now above water-level because of ditching and drainage. Today kerangas forest exists around the edge of the peat bog.
Fig 6.19: Plants of economic value from Ba
6.9 Summary

Late Pleistocene

These results show a dynamic landscape during the late Pleistocene, governed by both environmental forces and by climatic variability. The general vegetation during the late Pleistocene consisted of upland shrub-kerangas vegetation, particularly the Ericaceae family, but lower and upper montane forest such as Fagaceae, *Dacrydium*, *Podocarpus* and *Phyllocladus* may also have established themselves on the plateau. Between 49,500-45,000 cal BP, although the climate was likely to have been cooler than during the Holocene, the climate may have been wetter and possibly warmer than after 45,000 cal BP. This has been demonstrated by a significant representation of oak dominated woodland. Some uncertainty exists, however, on whether oak forest representation has been influenced to some extent, by fluvial deposition; as the presence of sands before 49,000 cal BP represents high energetic fluvial activity during the same period. A sandy braid-plain may have existed during this time under a more seasonal climate than during OIS2 with a pronounced dry season, but also intense precipitation during the wet season.

Around 45,000 cal BP a reduction in fluvial activity took place. This has been demonstrated by an increase in carbon content and the replacement of alluvial sands with finer silts. There is also a notable shift in vegetation, in which certain plants that had previously been able to survive under the harsh environmental conditions of the braid plain disappear and other plants become established, such as *Drosera* and the Myrtaceae family. Increases in the aquatic *Myriophyllum* might further reflect swampy conditions or pools. A reduction in fluvial activity may also have allowed the higher altitude plants *Dacrydium*, *Podocarpus* and *Phyllocladus* to become established locally. When compared to the Holocene pollen record the Ericaceae family, *Phyllocladus*, *Podocarpus* and *Dacrydium* are also generally higher during the late Pleistocene and therefore suggest cooler temperatures during this part of the late Pleistocene. The Ericaceae family may also have been influenced by conditions on the braid plain. Fluctuations in montane forest, shrub, herbaceous and aquatic taxa during the late Pleistocene, may be related to fluctuations in precipitation, as no significant change takes place in the lithology to suggest flood events, although very small flood events could have taken place, which might explain an age reversal occurring between 30,500-35,000 cal BP.

A period of increased aridity may have taken place between 32,600-31,700 cal BP, with a significant decline in canopy cover, rise in upper montane and a brief disappearance of certain wet soil taxa, including Elaeocarpaceae and wild *Oryza*. This is followed by a return in forest cover and possible increased precipitation 31,700-30,340 cal BP with a rise in Myrtaceae, Cyperaceae, decline in upper montane forest and the appearance of wet unconsolidated organic sediments.
Late Pleistocene-mid Holocene transition

One or more hiatuses occur somewhere between 72-47 cm, with sediments mostly missing from 30,756-30,219 cal BP to 5,645-5,483 cal BP. The highest overall representation of upper montane forest, just below 62 cm, suggests that some sedimentation occurred associated with drier-cooler temperatures during or close to the Last Glacial Maximum. The lack of charcoal or disturbance indicators may suggest that the hiatus/es may be related to down-cutting caused by fluvial incision during the onset of the warmer-wetter Holocene rather than anthropogenic disturbance. This is followed again by pool development. After 5,650-5,480 cal BP a decline in upper montane forest took place, as well as a rise in *Myriophyllum*, suggesting pool development and a warmer-wetter mid Holocene. An increase in Fagaceae during the Holocene period may also be reflective of a warmer-wetter environment, whilst an increase in open ground taxa could represent disturbance, caused by erosion from intense precipitation during the Holocene to Pleistocene transition. Other forms of disturbance, such as anthropogenic clearance, are also a possibility. No evidence of potential anthropogenic activity has, however, been recorded between 5,650-5,480 cal BP.

Late Holocene

At the beginning of the late Holocene record a low intensity flood event is recorded *ca.* 2,300-1,400 cal BP, which could have been initiated by disturbance, through lack of vegetation. A sharp rise in Cyathaceae occurs at the same time, possibly representing fluvial sediments. This is subsequently followed by a sharp rise in *cf.* Campanulaceae, possibly a pioneer species, occurring after the flood or disturbance event. The rise in *cf.* Campanulaceae occurs at the same depth as an age reversal, dated from a charcoal piece (2,703-2,351 cal BP, although the true age is probably between 1,700-1,400 cal BP). Other disturbance indicators are also present and may be related to natural openings in the canopy; however, anthropogenic clearance is also quite probable. The spike in *cf.* Campanulaceae is followed immediately by the appearance of *Eugeissona* pollen (*ca.* 1,300 cal BP), and Palmae phytoliths. Both the pollen and phytoliths suggest *Eugeissona* was being cultivated or manipulated for its edible sago pith. The presence of *Eugeissona* seems to be associated with the appearance of *Stenochlaena*, the disturbance indicator *Trema*, and an increase in spores, thus further suggesting anthropogenic activity. The fruit trees *Durio*, Myrtaceae, Sapindaceae and Sapotaceae are also present, but these species also exist during the late Pleistocene and therefore it is less certain that they are associated with anthropogenic activity. Particularly within the last 600 years there is a sharp rise in Palmae phytoliths. This may have been caused by erosional inwash from adjacent hill-slopes, the result of increased hill-slope clearance although the deposition or eroded slope sediments have not been recorded in the lithology. An alternative explanation could be intensification in the use of sago within the last 600 years until relatively recently. Finally in more recent times the site has been cleared of kerangas forest (although kerangas forest still surrounds its perimeter) and bracken has become the dominant vegetation.
CHAPTER SEVEN
PDH 212-PA’DALIH
Chapter 7-PDH 212

7.1 Site description

A series of ancient river terraces lie to the east of the River Diit, south of Pa’Dalih. One very large terrace landform has been levelled by the people of Pa’Dalih for use as an airfield. This terrace surface lies over 10 m above the current river level (it is difficult to be more accurate than this because the terrace is separated from the river by several hundred metres of sometimes steep, densely forested terrain). Away from the runway the terrace surface shows subdued relief, with a series of sinuous palaeochannels, now often excavated for rice fields.

Fig 7.1: Location of core PDH 212 at Pa’Dalih (Produced by Athanson, 2010, as part of the Cultured Rainforest Project and edited by the author)

The area was selected because it was the former location of the Pa’Dalih longhouse before the construction of the runway in the 1970s, and therefore had potential in providing a long ethno-palynological record. The site was also selected for its potential in providing evidence of early rice cultivation, as rice was being grown recently in a palaeochannel nearby. The surrounding area consists of fruit groves, rice fields and secondary forest, whilst the grassed air strip is now used as buffalo pasture. A 4.61 m core was taken in a grassy depression, adjacent to a fallow rice field, located in a small palaeochannel (Fig 7.1). The site was situated between the air strip and the Diit tributary on the southern edge of Pa’Dalih.
7.2 Radiocarbon results

Seven samples from wood and charcoal were radiocarbon aged; shown in Table 7.1 (also illustrated in Figs: 7.3-7.11). The three bottom ages are measured as ca. 47,000 to 50,000 radiocarbon years old, but were too old for both the IntCal09 and Fairbanks calibration curves. All samples are in chronological order, except for the bottom two ages. This could be due to sediment mixing caused by fluvial disturbance or it may simply be because these ages are infinite with very minor contamination. What the bottom two or three ages suggest is that the base of the core is very likely to be older than 50,000 cal BP. A major discontinuity is evident between UB 13654 and UB 10585.

<table>
<thead>
<tr>
<th>Depth (cm)</th>
<th>UBA-number</th>
<th>Sample_ID</th>
<th>¹⁴C Age BP</th>
<th>Calibrated Age (2 σ) AD/BC</th>
<th>Calibrated Age (2 σ) BP</th>
<th>Sample_type</th>
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<tr>
<td>31 cm</td>
<td>10584</td>
<td>PDH212 31</td>
<td>43±17</td>
<td>1708-1955 AD</td>
<td>242-0</td>
<td>Charcoal</td>
</tr>
<tr>
<td>95-97 cm</td>
<td>12735</td>
<td>PDH212 95-97</td>
<td>329±23</td>
<td>1486-1641 AD</td>
<td>464-309</td>
<td>Wood</td>
</tr>
<tr>
<td>193-194 cm</td>
<td>10585</td>
<td>PDH212 193-194</td>
<td>2655±23</td>
<td>888-794 BC</td>
<td>2838-2744</td>
<td>Charcoal</td>
</tr>
<tr>
<td>255-257 cm</td>
<td>13654</td>
<td>PDH212 255-257</td>
<td>32,670±177</td>
<td>35,986-34,662 BC</td>
<td>37,936-36,612</td>
<td>Wood</td>
</tr>
<tr>
<td>345-347 cm</td>
<td>12738</td>
<td>PDH212 345-347</td>
<td>47,501±514</td>
<td>Age too old for calibration</td>
<td>Age too old for calibration</td>
<td>Charcoal</td>
</tr>
<tr>
<td>425-427 cm</td>
<td>12741</td>
<td>PDH212 425-427</td>
<td>50,321±552</td>
<td>Age too old for calibration</td>
<td>Age too old for calibration</td>
<td>Wood</td>
</tr>
<tr>
<td>449.5-451 cm</td>
<td>10586</td>
<td>PDH212 449.5-451</td>
<td>47,468±611</td>
<td>Age too old for calibration</td>
<td>Age too old for calibration</td>
<td>Charcoal</td>
</tr>
</tbody>
</table>

Table 7.1: Radiocarbon and calibration results for core PDH-212

7.3 Age/Depth model

Fig 7.2 was calculated using the statistical modeling program clam (Blaauw, 2010), to produce a potential age/depth relationship over the last 50,000 years. Both the interpolated and smooth spline models from the clam program produced similar interpretations. The smooth spline model was chosen as this model also suggests potential error margins. The model has taken into account the hiatus occurring at 37,936-36,612 cal BP (shown in Fig 7.2). Older dates have also been incorporated into the age/depth model, although it should be noted that calibrated ages are unknown. It was hoped that by including these dates, information would be provided on other potential hiatuses occurring in the record. No obvious hiatuses however, appear in the model (Fig 7.2), except for the hiatus at ca. 37,000 cal BP. There might have been additional shorter hiatuses.
but the current low resolution of dates cannot resolve this. Appendix Three provides a table showing all age/depth calculations for PDH 212.

**Fig 7.2:** Smooth spline age/depth model for PDH 212, calculated in *clam* (Blaauw 2010). Average sediment accumulation rates (cm/yr) have also been included. The dotted line represents the hiatus. The dotted line represents a hiatus at 250 cm. It should be noted that this depth is only an estimation and that the hiatus could occur anywhere between 257-193 cm.

Minus values represented in the age/depth model (see Appendix Three) may be an indication that the top sediments are missing. Sediment accumulation rates, summarised in Fig 7.2, were calculated using the ages of best fit from the age/depth model. Lowest accumulation rates occur between 4,400-500 cal years BP. Sedimentation rates increase particularly after 500 cal BP, although the highest accumulation rates occur in the last 100 years. See Appendix Three for a more detailed account of sediment accumulation rates.
7.4 Lithology, Loss on Ignition and Magnetic susceptibility

The lithology, loss on ignition and magnetic susceptibility (measured in Si units) are represented as a summary diagram in Fig 7.3. The stratigraphy consists of alternating silts, sands and clays below 249 cm, blue-grey clay is present between 249 and 202 cm, followed by very iron mottled silty clay with bands of charcoal-rich grey clay, with sand appearing between 117-104.5 cm. Some iron mottling has also been recorded in the Pleistocene sediments. One of the most noticeable features of the lithology is frequent burning, particularly during the late Pleistocene. This is represented by the appearance of burnt organic matter and charcoal pieces. Two further burning events also took place between 196-192 cm (2838-2744 cal BP) and between 97-94 cm (464-309 cal BP). The 97-94 cm event coincides with a major spike in magnetic susceptibility. It is quite likely that burning of the surrounding vegetation caused a large influx of erosional material to wash into the channel, with heavier sands settling first, followed by the lighter charcoal. No major changes in magnetic susceptibility occur during the late Pleistocene despite the frequency in burning events. This may mean that although frequent, forest fires during the Pleistocene were less intense than the 464-309 cal BP event. See Appendix Three for a more detailed account of the lithology, magnetic susceptibility and loss on ignition results.

Fig 7.3: Lithology, loss on ignition and magnetic susceptibility (measured in Si units) for core PDH 212
7.5 PDH 212 Pollen and Palynomorph Results

Pollen and palynomorph results are summarised in Figs 7.4-7.10. Pollen percentages are expressed as percentages of total pollen, excluding spores; spores are expressed as percentages of total pollen and spores, whilst other palynomorphs are expressed as percentages of total palynomorphs, excluding pollen and spores.

7.6 Phytolith and diatom results

Phytolith and diatom results are summarised in Fig 7.11, whilst *Oryza* measurements and photographs are provided in Appendix Eight. Appendix Nine provides photographs of diatoms, testate amoebae and other phytoliths. Phytoliths, diatoms and testate amoebae are recorded as percentages of total phytoliths, diatoms and testate amoebae.

Appendix Seven provides a complete percentage representation and raw counts of pollen, other palynomorphs, phytoliths and diatoms identified in core PDH 212.
Fig 7.4: A summary of montane taxa for PDH 212. + represents low pollen counts
Fig 7.5: A summary of general forest taxa for PDH 212. + represents low pollen counts
Fig 7.6: A summary of lianes and shrub/small tree taxa for PDH 212. + represents low pollen counts
Fig 7.7: A summary of kerangas, aquatic and catholic taxa for PDH 212. + represents low pollen counts
Fig 7.8: A summary of open-ground taxa for PDH 212. + represents low pollen counts
Fig 7.9: A summary of all taxon groups
Fig 7.10: A summary of other palynomorphs for PDH 212
Fig 7.11: A summary of phytoliths, diatoms and testate amoebae for PDH 212.
7.7: Zone descriptions

PDH 212-1: 461-266 cm (>50,000 cal BP->37,900 cal BP)
212-1 has been divided into six subzones 212-1a to 212-1f based on analysis calculated using CONISS. The zone is defined on the high average percentage representation of montane pollen, which varies between 40.95 and 62.45 %.

PDH 212-1a: 461-445 cm (>50,000 cal BP)
Pollen and other Palynomorphs
This sub-zone represents low pollen and spore counts: 5 pollen grains and 8 spores were recorded. Charcoal represents 97.7-98 % total organics (counts of 86 to 168 charcoal pieces above 5 µm).

PDH 212-1b: 445-415 cm (>50,000 cal BP to <50,000 cal BP)
Pollen and other Palynomorphs
Pollen counts are generally above 300 pollen grains, except one count of 263. This sub-zone is characterised by upper montane taxa: Dacrydium (11.9-23.4 %), Phyllocladus (7.6-24.8 %) and Podocarpus (6.8-10.2 %), as well as Fagaceae (0.8-4.7 %) and Ericaceae (2.8-4.95 %). Open-ground taxa (12.6-14.8 %), which appear much lower than in zone 212-3, are more extensive in sub-zone 212-b and include large scabrate Poaceae, other Poaceae, Cyperaceae, Chenopodium, Polygonaceae, Ranunculaceae, Galium and Gleicheniaceae). Small trees-shrubs are also present (4.0-9.2 %), particularly Meliaceae (1.5-3.9 %) and Myrsinaceae (0.3-2.7 %); as are Concentricystes and Zygnemataceae. This sub-zone is also represented by a general decline in charcoal counts (3.6-26.4 %).

Diatoms and Phytoliths
At 426 cm centric diatoms represent 52 % and pennate diatoms 13.8 % of total phytoliths and diatoms, whilst grass phytoliths: 43.75 % and forest phytoliths: 43.75 %.

PDH 212-1c: 416-374 cm (<5,000 cal BP)
Pollen and other Palynomorphs
This sub-zone is represented by a sudden drop in pollen and spores to only 4-39 pollen grains and 15-32 spores. Taxa present include Poaceae, Commeliaceae and Ilex, and the liana Vitaceae at 416 cm, whilst spores include Demmstaedtia, Polypodiaceae, Selaginella, Lygodium and Cythaceae. At 416 cm there is a sharp rise in charcoal counts 85.4 % (1820 counts). After 416 cm charcoal counts range from 37.9-97.4 % total palynomorphs (counts of 72-183).
Diatoms and Phytoliths
Centric diatoms represent 32 % at 386 cm and pennate diatoms 24.0 %, whilst testate-amoebe are also present.

PDH 212-1d: 374-336 cm (<50,000 cal BP)
Pollen and other Palynomorphs
Pollen counts generally remain above 300 except at 346 cm, where counts decline to 159 grains. This zone is mainly characterised by all montane taxa (40.95-49.3 %), as well as the Ericaceae family (2.2-9.3 %), a wide distribution of shrubs (7-13.96 %) such as: Aralia (0.3-3.2 %), Meliaceae (0-5.6 %), Myrica (1-3.1 %), Verbenaceae (0.3-2 %) and Oleaceae (0-1.6 %). Open-ground taxa also represent 18.23-30 % and include large scabrate Poaceae, other Poaceae, Cyperaceae, Malvaceae, Compositae and Rumex. At 346 cm there is an increase in aquatic pollen Urticularia (0.62 %), Nymphaceae (1.3 %) and Equisetum (0.62 %). Other aquatic palynomorphs Concentricystes,Spirogyra and Zygnemataceae are also present between 356-346 cm. Charcoal counts are between 17.7-83 % (72-849 counts). Charcoal counts reach 849 at 346 cm.

Diatoms and Phytoliths
Centric diatoms represent 5.7-16.39 % and pennate diatoms 51.42-55.7 %, between 374-335 cm. Poaceae phytoliths increase from 33.3 % at 386 cm to 71.4 % at 366 cm. Forest phytoliths decrease from 66.7 % at 386 cm to 28.57 % at 366 cm.

PDH 212-1e: 336-315 cm (< >50,000 cal BP)
Pollen and other Palynomorphs
Pollen (6-22 grains) and spore (20-30) counts are low and include the spores: Cyathaceae, Davalliaceae, Polyopodiaceae and Lygodium; the mountain taxa: Phyllocladus, Podocarpus and Juglandaceae; and the open-ground indicators Scrophulariaceae and Celastraceae. This zone is also characterised by a rise in fungal gemmate spheres (0-2.9 %), Concentricystes (0-2.9 %) and testate amoebae (2.8-5.4 %). Charcoal represents 65.97 % (636 counts) total palynomorphs at 336 cm but rises to 87.8 % (158 counts) by 315 cm.

Diatoms and Phytoliths
Forest phytoliths represent 33.3-35.7 %. Poaceae phytoliths represent 50-66.6 %. Poaceae bilobates rise from 21.4 % at 336 cm to 50 % by 315 cm. Centric diatoms also increase from 51.4 % to 67.6 %, whilst pennate diatoms increase from 5.7 % to 10.8 % by 315 cm.
PDH 212-1f: 315-240 cm (50,000 cal BP to 37,900-36,600 cal BP)

Pollen and other Palynomorphs

Pollen counts generally remain above 300, except 181 counts at 256 cm. The sub-zone is characterised by upper and lower montane forest species (mainly between 43.42-62.5 %). At 256 cm all montane taxa decline to 39.2 %, except *Lithocarpus*, which increases from 0.7-14.4 % to 25.96 %. *Dacrydium*, for example, declines from 11.2-26.6 %, to 2.76 %, *Phyllocladus* from 3.6-18.4 % to 1.1 % and *Podocarpus* from 6.6-17.1 % to 2.2 %; however, the results at 256 cm might have been influenced by lower pollen counts. This sub-zone is also characterised by kerangas forest (6.25-21.1 %), particularly *Syzygium* (18.1 % at 276 cm). The liana Vitaceae is present and there is a peak in the shrub *Aralia* at 257 cm to 32.6 %. Open-ground taxa show a strong representation between 315-266 cm (11.9-29.6 %) and include Pteropsida, large scabrate Poaceae, Scrophulariaceae and *Lygodium*. Large scabrate Poaceae increase from 5.8 % at 286 cm to 14.14 % at 276 cm but are not present at 256 cm. Aquatics are also present and include *Urticularia* and *Potamogeton*. At 296 cm charcoal counts increase from 172 counts at 306 cm to 660 counts (34.7 % to 67.7 %).

Diatoms and Phytoliths

Diatoms decline (centric diatoms to 19.04 % and pennate diatoms to 7.1 %) by 276 cm. Forest facetate phytoliths rise to 74.2 % by 276 cm and Poaceae phytoliths fall to 6.45 %, whilst testate amoebae increase to 23.8 % at 298 cm, but are absent at 276 cm.

PDH 212-2: 247-208 cm (37,900-36,600 to 3122 cal BP)

This zone represents poor pollen preservation, a rise in grass phytoliths and diatoms.

Pollen and other Palynomorphs

Pollen preservation is poor with counts 0-5 grains (except 95 grains at 236 cm). Spores also show a low representation (1-20 spores, except 241 at 236 cm). *Dacrydium* is present between 246-236 cm, as is Fagaceae and *Symlocos* at 236 cm. At 236 cm open-ground taxa represent 48.42 % and include Cyperaceae, Caryophyllaceae, *Sedum*, *Galium*, Ranunculaceae, Polygonaceae, *Lygodium*, Malvaceae and Poaceae. Large scabrate Poaceae pollen are also present at 236 cm.

Diatoms and Phytoliths

At 236 cm Poaceae phytoliths represent 81.8 %; particularly Poaceae bulliforms (45.45 %), but also long clear elongated (18.18 %) and wavy types (18.18 %). Forest types decline to 13.6 %. At 236 cm a double peaked *Oryza* glume phytolith was also recorded. This was considered too small
to belong to domesticated varieties. Diatoms also increase to 77.4 % (centric 58.1 % and pennate 20.3 %) at 236 cm.

**PDH 212-3: 208-0 cm (3122 to 0 cal BP)**

This zone represents a significant decline in montane taxa, an increase in disturbance indicators and the presence of *Oryza sativa* phytoliths. On average percentage representation (of pollen counts above 300 grains) of montane pollen during the Holocene period is 5.9-22.29 %. Kerangas taxa also show a considerably lower representation than the late Pleistocene (0-1.6 %). PDH 212-3 has been divided into two subzones 212-3a and 212-3b.

**PDH 212-3a: 208-40 cm (3122 to 84 cal BP)**

Pollen and other Palynomorphs

Pollen recovery in 212-3a is very variable and often low. The terrestrial vegetation is dominated by open-ground (for pollen counts above 200 grains: 63.6-95.2 % compared to 11.9-30 % throughout the Pleistocene) and scrub taxa (for pollen counts above 200 grains: 0.86-9.3 %, although 21.5 % at 66 cm), notably *Artemisia* (0.9-3.8 %), Boraginaceae (0-67.9 %), Caryophyllaceae (0-8.76 %), Cyperaceae (0.3-2.17 %), Malvaceae (0-3.6 %) and Poaceae (2.4-4.8 %, although 91.3 % at 196 cm). Spore representation is also high (92.5-98.6 % total pollen and spores, for pollen counts above 200 grains), compared to late Pleistocene representation (45.8-84.1 %). Spores include Cyathaceae, Polypodiaceae, Gleicheniaceae, *Lygodium* and *Lycopodium*. Where pollen counts are above 200 grains, other forest ferns show a dramatic reduction and include Hymenophyllaceae (0-0.58 %), *Aspidium* (absent) and *Dennstaedtia* (0-0.3 %). Fungal gemmate spheres become more pronounced after 106 cm.

Some general forest taxa show a decline including Sterculiaceae (0.4 %), *Reevesia* type (absent) and *Hopea* type (absent); small tree/shrub taxa including *Aralia* (0-0.47 %), *Meliaceae* (0-0.47 %) and Verbenaceae (0-0.47 %). *Eugeissona* pollen appears after 166 cm (ca. 1988 cal BP). *Concentricystes* and Zygnemataceae are present, although Zygnemataceae is less consistent in this sub-zone. At 136 cm (ca.1253 cal BP) 495 charcoal sherds were counted and at 96 cm 2130 sherds were recorded in the palynomorph record.

**Diatoms and Phytoliths**

Poaceae bulliforms, bilobates and elongated type phytoliths represent 59-72.2 % in this sub-zone. Wild *Oryza* and undetermined *Oryza* bulliforms appear for the first time between 196-127 cm (ca.
2,795-1,058 cal BP). Some of the undifferentiated types of rice bulliform recorded could perhaps belong to *Oryza sativa*, as morphological features including the correct thickness and an elaborate network of scales were present; however, either the length and width of these phytoliths were too small for domesticated varieties or the phytoliths wouldn’t turn so complete measurements could not be carried out. Domesticated *Oryza* bulliforms appear for the first time at 96 cm.

Forest phytoliths represent 0.75-11.4 % throughout zone 212-3 and are significantly lower when compared to the Pleistocene results. Echinate phytoliths also appear for the first time at 196 cm and continue to be present for the rest of the record, although the highest representation occurs between 196-127 cm (4.8-2.4 %). A decline in echinate phytoliths takes place between 96-66 cm (0.67-0.41 % total phytoliths).

Diatom representation fluctuates in 212-3a: At 196 cm centric diatoms are absent but increase to 34.2 % at 126 cm and pennate diatoms are also absent at 196 cm but increase to 9.7 % at 126 cm, whilst between 96-66 cm centric diatoms decline to 6.9-7.9 % and pennate diatoms decline to 2.9-2.7 %.

**PDH 212-3b: 40-0 cm (84 to 0 cal BP)**

**Pollen and other Palynomorphs**

Pollen counts are generally above 300 grains (except at 6 cm with only 21 counts and at 36 cm with 48 counts). This sub-zone is mainly characterised by open-ground taxa (44-55.9 %, the highest representation is 55.9 % at 3 cm). Large scabrate Poaceae, particularly in the top 15 cm, increase to 23.3-26.7 %. This is the highest percentage representation of these pollen grains for counts above 300, throughout the PDH 212 record. A rise in smaller Poaceae grains (12.82 %) takes place at 3 cm. Other taxa represented in this sub-zone include general forest (6.9-13.4 %), shrubs (7.9-13.4 %, increasing to 13.4 % in the top 3 cm) and aquatic pollen (generally below 1 %, although 4.26 % at 15 cm). Montane taxa increase from 11.47 % at 26 cm to 22.3 % at 15 cm. *Podocarpus* in particular rises to 11.08 % at 15 %, similar to percentage representation during the Pleistocene. Charcoal counts remain low in the palynomorph record (36 sherds >5 µm).

**Diatoms and Phytoliths**

In the phytolith record *Oryza sativa* continues to be present (0.06-0.86 %) until 16 cm and then disappears from the record. At 16 cm there is a sharp rise in Ehrhartioideae bilobates (92.3 %), as well as rise in elongated clear (14.6 %) and wavy Poaceae phytoliths (10.9 %) at 1 cm. At 3 cm
Poaceae represent 44.23% Ehrhartoideae bilobates represent 47.97% and forest types represent 5.29%.

Diatoms show a lower percentage representation in comparison to the rest of the PDH 212 record. For example, centric diatoms decline from 7.9% at 66 cm to 0.24-2.98% between 23-1 cm, whilst penniset diatoms decline from 2.74% to 0.59-0.99%.

7.8: Interpretation of results
Section 7.8 provides an interpretation of all of the results described in this chapter (sections 7.2-7.7) and includes lithology, ¹⁴C dates, loss on ignition, magnetic susceptibility, pollen, phytoliths and other palynomorphs. The interpretation has been divided into late Pleistocene (older than 50,000-30,200 cal BP), late Pleistocene–mid Holocene (38,000 to 3,100 cal BP) and mid Holocene-late Holocene (3,100-0 cal BP). The interpretation is expressed through time; however, because of uncertainties in age, cm has also been used.

Late Pleistocene (older than 50,000-30,200 cal BP)
Sub-zones PDH 212-1a-1c (< > 50,000 cal BP)
Prior to and just after ca.50,000 cal BP (the precise age is unknown as radiocarbon ages were too old for calibration) the site at PDH 212 was under the influence of energetic, but oscillating fluvial deposition. This is represented by the presence of alternating grey sands, silty sands and organic-woody bands, the result of erosion and deposition caused by flowing water; low loss on ignition; Concentricystes, found in both fresh water deposits (Marett, 2009) and wet soils (Hunt and Rushworth, 2005); Zygnemataceae (green algae); and later by the presence of centric diatoms and penniset diatoms. Organic bands could indicate that at times the river was slow enough to allow the deposition of organic matter, whilst trees falling into the channel, caused by forest fires surrounding the channel, could have caused the appearance of woody bands. Forest fires within the vicinity of the site are represented both in the lithology and in the charcoal record. Periods of poor pollen and spore preservation appear to be linked to increased charcoal counts, and are probably representative of oxidation, caused by intense burning and subsequent weathering of the soils. There is a strong possibility that major burning episodes also influenced fluvial intensity, in which an opening of the canopy would have increased the exposure of soils to erosion, thus increasing fluvial in-wash. Reduced erosion may have resulted in less intense fluvial deposition (ie. slower moving water and the deposition of clays rather than sands). An alternative theory for the poor
pollen counts is an increase in fluvial activity caused the washing away of light pollen and the accumulation only of heavy charcoal, sands and heavy fern spores in the channel.

Montane and kerangas forest are the dominant taxa throughout the late Pleistocene and include *Dacrydium*, *Fagaceae*, *Lithocarpus*, *Phyllocladus*, *Podocarpus* and *Ericaceae*. Representation is higher than during the Holocene, particularly *Dacrydium*, *Podocarpus* and *Phyllocladus*, which survive well at high altitudes on Mt. Kinabalu (Kitayama, 1992, Smith, 1980), and therefore might be representative of lower temperatures. Certain montane taxa also survive well in kerangas or on nutrient-deficient sediments, such as sands deposited during fluvial activity (Wong et al., 1987, Mackinnon et al., 1998); however, as described in Chapter 3.41, although *Phyllocladus*, *Dacrydium* and *Podocarpus* species do occur in kerangas and on nutrient-deficient sediments at lower altitudes, they are more frequent in upper montane forest, above 2,000 m (Beaman, 1999, Flenley, 1984, Smith, 1980). A combination of a cooler climate and fluvial deposition of nutrient-poor sands may have provided optimal conditions for montane-kerangas growth. Thomas et al. (2007) also describe the likelihood of unstable and fluctuating climates during OIS3, although they argue that this period remained relatively humid.

A high representation of shrub and open-ground taxa might reflect an opening of the canopy caused by cooler, more seasonal climates or reflect the frequency in burning episodes on the surrounding vegetation. A wider diversity of open-ground taxa compared with the Holocene, as well as the presence of small trees-shrubs suggest regular disturbance of the forest canopy with the development of open-ground and regeneration flora between. A semi-open forested area is likely to have existed around the channel and this is further supported by the presence of both grass and forest phytoliths. Fluctuations between Poaceae and forest phytoliths are likely to be associated with burning episodes. For example at 364 cm a charcoal band occurs in the lithology, whilst Poaceae phytoliths increase and forest phytoliths decrease. The presence of the liana Vitaceae further indicates the presence of some woodland around the channel.

**Sub-zone PDH 212-1d (<50,000 cal BP)**

The period before and after 47,501 $^{14}$C years BP experienced frequent burning episodes, represented by thick charcoal pieces, burnt material and very low pollen and spore counts. The spores Cyathaceae, Davalliaceae, Polypodiaceae and *Lygodium* (a disturbance indicator) are also present and are possibly associated with the burning episodes. According to Hunt (1994), high spores are often found in fluvial deposits, whilst Behling et al. (1997) describes high spore counts
as often associated with disturbance. The appearance of them here suggests they are associated with disturbed environments and fluvial sediment, whilst the presence of open-ground taxa and fungal gemmate spheres may be a further indication of disturbance. The presence of Concentricystes and testate amoebae likely reflect wet soils. Forest phytoliths indicate the continued presence of forest taxa surrounding the channel; however, Poaceae phytoliths also demonstrate a relatively open environment. The pollen record also demonstrates a continued dominance of montane forest.

A major burning episode is likely to have taken place at 346 cm, shown by an increase in charcoal (849 sherds) in the palynomorph record; by charcoal flecks in the lithology; by a decline in loss on ignition to 0, signifying an absence in organic accumulation; a change in the lithology to dark grey clay, followed by heavier sands; and by a decline in pollen counts. The pollen counts appear to be associated with the presence of aquatic taxa Urticularia, Nymphaeaceae and Equisetum. There is no significant change in magnetic susceptibility to suggest increased erosional deposition; however, the deposition of sands may have been caused by increased runoff into the channel through lack of vegetation. The presence of the aquatics and clay layers could be an indication of standing water/pool development, although may also be related to forest disturbance and less intense runoff into the channel. Other aquatic palynomorphs Concentricystes, Spirogyra, Zygnemataceae and diatoms are also present and might again be suggestive of periods of quieter or slower moving water within the channel.

At 336 cm Poaceae bilobates rise, suggesting the surrounding vegetation may have become more open at this particular period. This is probably associated with further burning events recorded in the lithology. Centric and pennate diatoms increase by 315 cm and could again be linked to a lack of vegetation cover and increased runoff into the channel or to slower moving water, although burning events and the subsequent lack of vegetation probably influenced flood events.

Sub-zone PDH 212 1e (<50,000 cal BP to 37,900-36,600 cal BP)

The pollen results show montane forest remains the dominant vegetation group between 47,501 $^{14}$C years to 37,900-36,600 cal BP, although at 256 cm all montane taxa except Lithocarpus decline. These results are likely to have been influenced by a drop in pollen counts (to 181 pollen grains), caused by oxidisation processes within the channel (wetting and drying). Kerangas forest is also present during this period, particularly at 276 cm with a rise in Syzygium. An increase in wooded taxa is also represented by the liana Vitaceae.
Most of the open-ground taxa represented in this sub-zone may belong to regeneration flora after small scale forest fires, as a number of charcoal bands have been recorded in the lithology. A major burning episode took place around 296 cm, as 660 sherds (> 5 µm) have been recorded in the palynomorph record. The lowest open-ground pollen representation occurs around 37,900-36,600 cal BP and appears to correlate well with the phytolith results. The phytolith results demonstrate a rise in forest facetate phytoliths and a fall in Poaceae phytoliths at 276 cm, suggesting an increase in canopy cover. This is presumably associated with a longer discontinuity in fluvial activity than previously recorded, with lower water levels, represented by iron mottled sediments and a decline in diatoms. A rise in testate amoebae and the presence of *Urticularia* and *Potamogeton* pollen at 266 cm might be further representative of slower moving water or pools within the channel. These results might also be related to a decline in forest fires at this particular period. This is with the exception of large scabrate Poaceae, which increase at 276 cm. Poaceae, which may belong to wild rice varieties, were probably thriving under optimal conditions within the channel, and could therefore be a further indicator of a longer discontinuity in fluvial activity with lower water levels. Large scabrate Poaceae are no longer present at 256 cm. Further forest fires are represented at 259-253 cm by a number of charcoal bands appearing in the lithology. A peak in *Aralia* may also be associated with the forest fires; however, no charcoal was recorded in the palynomorph record.

**Late Pleistocene – mid Holocene (38,000 to 3,100 cal BP)**

**Zone PDH 212-2**

The change in lithology to blue-grey clays and the presence of iron mottling at *ca.*38,000 cal BP, suggests a gradual increase in the water table with longer periods of standing water. This could be representative of an oxbow lake. An increase in diatoms further supports this theory.

Pollen and spore preservation is extremely poor in this zone, except at 236 cm. The fact that clays appear after a charcoal band, recorded at 253 cm, and not sands, suggest that intense fluvial activity could not have been responsible for the removal of lighter pollen grains, but more likely that oxidation of sediments took place, caused by the later weathering of sediments in the channel. The river may have been located further away from the palaeochannel, so a low energy flood event might be responsible for the deposition of clays, instead of silts and sands, which would have been expected during more energetic fluvial events. A lack of vegetation cover on the surrounding slopes, followed by increased precipitation and runoff after the dry/burning episode, may have influenced the flood event.
Despite poor pollen counts, the pollen that has been recorded at 236 cm demonstrates a relatively open environment, shown by a dominance in open-ground taxa, although the montane taxa Dacrydium, Fagaceae and Symlocos are also present. An increase in open-ground taxa is also represented in the phytolith record, shown by a decline in forest phytoliths and a rise in Poaceae types; particularly Poaceae bulliforms, but also long clear elongated and wavy types. Wild rice, demonstrated by the presence of large scabrate Poaceae pollen and a double peaked Oryza glume phytolith, probably flourished in the swampy conditions of the palaeo-channel.

As with the Bario core Ba, a hiatus in the sediment record is present. Dates jump from 37,936-36,612 cal BP to 3,122 cal BP and could be related to fluvial down-cutting. One quite plausible theory is intense rainfall during the Holocene, resulting in fluvial incision. Incision of fans following postglacial warming of climate, during the Pleistocene-Holocene transition is also reported by Thomas et al. (2007) in NE Queensland.

**Mid-late Holocene (3,100-0 cal BP)**

Sub-zones PDH 212-3a-3b

The general climate during the mid-late Holocene was probably much warmer than the late Pleistocene. This is suggested through a significantly lower representation of montane taxa than identified during the late Pleistocene (from pollen counts above 200 grains). In more recent times montane taxa show a slight increase, particularly Podocarpus. This could be associated with a change in climate, such as a decline in temperature. If this is true then a similar pattern should have been observed in the other cores investigated, but no such pattern has been recorded and also Dacrydium and Phyllocladus remain much lower than during the late Pleistocene. A more plausible theory is an opening of the environment, possibly attributed to the construction of the grass runway, allowed an accumulation of pollen grains from higher altitudes.

From 3,100 cal BP until relatively recently, episodic drying and oxidation of the channel sediments was taking place and is likely to have been responsible for periods of low pollen preservation. Episodic drying is indicated by the presence of iron mottled sediments throughout most of the mid-late Holocene record. The process of iron mottling is described by Hanso and Whittig (1980) ‘When iron in previously aerated soils becomes saturated it is insoluble and with the presence of organic material, lack of oxygen, occurrence of anaerobic microorganisms ferric iron is reduced to ferrous iron resulting in a mottled appearance’. Episodic drying is also represented by fluctuations in the diatom record and by fluctuations in Concentricystes and the algae Zygnemataceae.
The terrestrial vegetation from 3,100 cal BP was dominated by open-ground and scrub taxa such as *Artemisia*, Boraginaceae, Caryophyllaceae, Cyperaceae, Malvaceae and Poaceae, as well as the spores Cyathaceae, Polypodiaceae, Gleicheniaceae, *Lygodium* and *Lycopodium*. High fern representation may be linked to the episodic drying, described above, as fern spores tend to be more resistant than pollen grains to oxidation (Hunt, 1994). Another explanation for high fern representation could be that certain types of fern spore increase after disturbance. For example, in Chapter Five the surface sample results show a strong representation of Cyathaceae (described by Jaman (1999) as a forest fern), associated with the grass playing field in Pa’Dalih, again arguably because these spores are tough and survive better than pollen grains. An increase in Cyathaceae, as well as a rise in other fern species could therefore be related to an increase in open-ground. An open environment is further presented in the phytolith record with Poaceae bulliforms, bilobates and elongated types. When compared with the late Pleistocene results, open-ground representation is much higher during the mid-late Holocene. These results combined with the decline in general forest taxa: Sterculiaceae, *Reevesia* type and *Hopea* type; general forest ferns: Hymenophyllaceae, *Aspidium* and *Dennstaedtia*; small trees/shrubs: *Aralia*, Meliaceae, Sapindaceae and Verbenaceae; and all kerangas taxa; as well as the presence of a charcoal band ca.2,700 cal BP in the lithology and charcoal pieces recorded throughout the mid-late Holocene record in the palynomorph record at ca.1,250 cal BP, infer anthropogenic clearance rather than climate or environmental change.

Anthropogenic manipulation of *Eugeissona* palms for sago, could have been taking place ca.2,000 cal BP, represented by the presence of *Eugeissona* pollen; although *Eugeissona* pollen also appears during the late Pleistocene, whilst pollen representation is sporadic and therefore is insufficient evidence to be an indication of nearby cultivation/manipulation. The sporadic occurrence may however, be associated with poor preservation. Echinuate phytoliths also appear for the first time at ca.2,800 cal BP and continue to be present for the rest of the record. The highest representation occurs between ca.2,800-1,030 cal BP. These could well represent *Eugeissona* cultivation/manipulation, although echinate phytoliths could also belong to a number of genera in the Arecaceae family or the Euphorbiaceae family. It is however, interesting to note that echinate phytoliths only appear after ca.2,800 cal BP and that when compared with *Eugeissona* pollen and echinate phytoliths occurring in cores Ba and PDH 223, there is evidence to suggest cultivation/manipulation of sago palms was taking place 2,700-1,300 years ago in Bario and Pa’Dalih (see Chapters Six and Eight).
Wild *Oryza* and undetermined *Oryza* bulliforms also appear for the first time between *ca.* 2,800-1,030 cal BP, although there is no evidence to suggest rice was being cultivated or domesticated at this time. Episodic wetting and drying of the palaeochannel, which could have been influenced by the burning event, may simply have provided an optimal environment for wild *Oryza* to grow. Some of the undifferentiated types of rice bulliform recorded could also belong to *Oryza sativa*, as morphological features including the correct thickness and an elaborate network of scales were present; however, either the length and width of these phytoliths were too small for domesticated varieties or the phytoliths wouldn’t turn so complete measurements could not be carried out. Forest phytoliths are significantly lower when compared to the Pleistocene results and further signify a predominantly more open-environment during the Holocene, which is again likely to be linked to anthropogenic clearance. The beginning of managed cultivation at site PDH-212 was likely to have been taking place by *ca.* 530-490 cal BP, represented by a thick charcoal layer in the lithology, with 2130 shards recorded in the palynomorph record, a sharp increase in magnetic susceptibility, suggesting intense burning and erosion, and most importantly domesticated rice bulliforms appear for the first time. *Concentricystes* is also present and could when combined with all the results, be an indication of wet rice cultivation; however, diatom representation is only 9.8%. The shade cast by the rice crops might have limited diatom production, but it is more likely that the decline in diatoms is associated with generally shallower and less persistent flooding of the palaeochannel. An alternative explanation for the presence of *Concentricystes* could be that clearance of the surrounding vegetation and subsequent saturation of the unprotected soils from rain water caused an increase in freshwater algae. The presence of fungal gemmate spheres may represent a number of disturbance episodes and in-wash of eroded soil into the channel, whilst the high magnetic susceptibility and a decline in diatoms might instead be representative of dry cultivation of rice around the channel, rather than within the channel. This would also explain the decline in diatoms. Janowski (2003) and Seavoy (1973) propose dry rice may have been more favourable than wet cultivation, particularly in the Southern Kelabit Highlands, although Janowski (2005) suggests that before the Second World War flat swampy areas may have been used for wet rice cultivation, due to a limited availability of bush knives. These areas would have been without large trees and subsequently less labour intensive. Today the Kelabit are well known for their wet rice cultivation (Latiff et al., 1999). A decline in echinate phytoliths *ca.* 530-490 cal may be associated with the burning event, although the results could equally be representative of a decline in sago use, as rice became important.
By 100 cal BP (sub-zone PDH 212-3b) the channel had dried up completely, shown by the lowest overall representation of diatoms, increase in loss on ignition (organic accumulation), increased pollen preservation and by a general rise in kerangas, shrub and general forest. Another possibility for the increase in shrub and general forest taxa is that according to the people of Pa’Dalih; about sixty years ago the former longhouse near to the site of PDH 212 was abandoned and moved to its present location. Therefore an increase in shrubs and general forest taxa recorded above could also be representative of regeneration flora after the abandonment of the longhouse. The presence of *Oryza sativa* until 16 cm suggests rice cultivation continued near or at the site until relatively recently.

A rise in large scabrate Poaceae between 15-1 cm, which is likely to be representative of relatively modern sediments, is the highest percentage representation of these pollen grains, for counts above 300, throughout the 212 record, and although likely *Oryza sativa* bulliforms are not recorded in the phytolith record after 15 cm, the high representation of these pollen grains could signify increased rice cultivation at other locations away from site PDH-212, but within the local vicinity. This might also explain a sharp rise in Ehrhartoideae bilobates, although a component of the grass runway is also plausible. A rise in smaller Poaceae grains at 3 cm, as well as elongated and wavy Poaceae phytoliths at 1 cm, is likely to be associated with the recent construction of the grass runway.

7.9: Summary

The late Pleistocene

The environmental records from PDH 212 provide evidence of oscillating fluvial activity from 47,468 ± 611 ¹⁴C BP (effectively an infinite date before 50,000 BP) until after 37,936-36,612 cal BP. Major breaks in the sedimentary record may have also occurred during the late Pleistocene, but they are difficult to recognise with certainty. The appearance of organic bands, could either be related to burning episodes on the surrounding slopes, or might suggest that at times during the Pleistocene the river was slow enough for deposition of organic matter to take place. The presence of woody bands suggests that trees may have fallen into the channel. No iron mottling is recorded during the deposition of these bands, which would have provided an indication of wet-dry phases on the channel. There is however, strong evidence of weathering from the pollen assemblages, which may be associated with intense burning of the surrounding vegetation. An increase in fluvial activity, causing the washing away of light pollen and the accumulation only of heavy charcoal, sands and heavy fern spores in the channel, is another suggestion.
A high diversity in open-ground taxa, despite lower overall representation when compared to the Holocene record, as well as fluctuations in grass-forest phytoliths suggests an association partly with fluvial deposition and partly with burning episodes. Charcoal bands appear more frequently throughout the late Pleistocene period with some particularly intense phases of burning occurring. Anthropogenic influence is possible, but there is no evidence of this in the pollen record. Another highly plausible suggestion is that burning episodes are associated with periods of relative aridity, linked to climatic changes. Burning episodes may also have played a role in fluvial activity by increasing sediment supply and causing aggradation.

The dominant vegetation during the late Pleistocene consisted of montane forest taxa, particularly Dacrydium, Podocarpus and Phyllocladus. These taxa generally show a much higher representation in comparison to the Holocene record and are today found more frequently at higher altitudes, on Mount Murud and Mount Kinabalu, which therefore suggests lower temperatures. The pollen record shows limited evidence of climate fluctuations during the late Pleistocene, where pollen is abundant, and instead portrays relative stability in forest dynamics. Changes in climate may have been masked by periods of non-deposition and weathering.

An increase in forest species, diatoms, other aquatic taxa and presence of clays around 37,900-36,600 cal BP may reflect a longer discontinuity in fluvial activity than previously recorded. Iron mottling between 301-249 cm further supports this theory as this indicates intermittent weathering of the deposits and that water levels were low enough for wetting and drying to take place. It is quite possible that water levels may have been influenced to some extent by increased canopy cover, which might signify a reduction in the frequency of forest fires, although burning events still continued. Wild Oryza was probably growing within the swampy conditions of the channel and may be a further indication of lower water levels.

The Pleistocene-Holocene junction
A hiatus in sedimentation took place from sometime after 36,936-36,612 cal BP to sometime before 3,122 cal BP. Increased aridity during the LGM (causing an opening of the canopy and soil desiccation) may have meant sediments were more susceptible to weathering and erosion, particularly during the Holocene where intense precipitation could have initiated severe downcutting, as there is no direct evidence of wet cultivation/domestication during this period. Intense precipitation may also have resulted in the formation of pool sediments/an oxbow lake, demonstrated by the appearance of blue-grey sediments and a steep rise in diatoms.
The Holocene

From 3,100 cal BP until present day, montane forest was considerably lower in abundance than during the late Pleistocene and is likely reflective of much warmer temperatures. Open-ground taxa were also considerably higher in abundance than during the Pleistocene and this is likely to be attributed to anthropogenic clearance episodes. Between 2,800-1,200 cal BP *Eugeissona* was present, but evidence is insufficient to suggest cultivation/manipulation. The appearance of echinate phytoliths, although not sufficient evidence alone, could when compared with evidence from cores PDH 223 and Ba, be an indication of cultivation/manipulation of sago palms before 2,700 cal BP, whilst after 460 cal BP, a decline in echinate phytoliths may be representative of a decline in sago use. More evidence would however, be needed to confirm this. The presence of *Oryza* bulliforms 2,800-1,200 cal BP are likely to be associated with wild rice varieties, surviving on the saturated soils of the palaeochannel; although some of the undifferentiated bulliforms could represent potential cultivation or experimental forms of cultivation during this period. This site therefore holds potential for future more in-depth phytolith investigations. Between 530-490 cal BP there was a sharp rise in the deposition of eroded material, caused by intense burning and this is likely to be associated with rice cultivation. These results are supported by the first appearance of rice phytoliths of domesticated types. Rice cultivation continued until relatively recently and may have taken place within the channel; however, dry cultivation is also a strong possibility, particularly between 530-490 cal BP.

By *ca.* 100 cal BP the channel had completely dried up allowing organic accumulation and an increase in plant diversity, although an increase, particularly in shrub and general forest taxa may also have had some association with the abandonment of the former Pa’Dalih longhouse around sixty years ago. Domesticated rice phytoliths are no longer present after 15 cm. This may signify the abandonment or relocation of the previous cultivation site. An increase in scabrate Poaceae in more recent times might be representative of increased rice cultivation at other sites within the vicinity. Finally a rise in montane forest in more recent times could be associated with a brief cooling event, although the increase is most likely to be associated with clearance and a more open environment, allowing the transportation of montane pollen grains from higher altitudes. Clearance could be related to the construction of the grass runway, which would also explain the rise in grass pollen and phytoliths in the last 10 cm.
CHAPTER EIGHT
PDH 223-PA’DALIH
Chapter 8: PDH 223

8.1 Site description

A 2.7 m core was taken at in a palaeo-channel on a low terrace, with a surface 4-5 m above the Kelapang, a tributary of the River Diit. This had not been utilised recently for rice cultivation, but was instead the location of a fruit tree grove. Besides the fruit grove, the local environment surrounding PDH 223 consists of rice fields, secondary forest and the grassy air strip, directly north of core 212, on a higher terrace of the Kelapang. Rice fields are today usually constructed via excavation of sediments, whilst the planting and harvesting of wet rice lead to bioturbation within the field sediments. This core was therefore drilled in a site less prone to disruption, so that a continuous record might be obtained. Fig 8.1 shows the location of core PDH 223 and its relation to PDH 212. It was hoped that detailed analysis of core PDH 223, which is also close to the site of a previous Pa’Dalih longhouse, would yield evidence of human activity that could be associated with the earliest archaeological dates.

![Fig 8.1: Location of core PDH 223 at Pa’Dalih (Produced by Athanson, 2010, as part of the Cultured Rainforest Project and edited by the author)](image-url)
8.2 Radiocarbon results

The radiocarbon ages for PDH 223 are shown below in Table 8.1. Three charcoal samples were radiocarbon dated and all samples are in chronological order. No dating material was available for the uppermost sediments. The age of the base of core PDH 223 dates to 2,352-2,322 cal BP, whilst organic rich sediments are no longer present by 1,715-1,604 cal BP.

<table>
<thead>
<tr>
<th>Depth (cm)</th>
<th>UBA-number</th>
<th>(^{14})C Age BP</th>
<th>Calibrated Age (2 (\sigma)) AD/BC</th>
<th>Calibrated Age (2 (\sigma)) BP</th>
<th>Sample_type</th>
</tr>
</thead>
<tbody>
<tr>
<td>144-146 cm</td>
<td>UBA-10593</td>
<td>1751±19</td>
<td>cal AD 235- 346</td>
<td>1,715-1,604 BP</td>
<td>Charcoal</td>
</tr>
<tr>
<td>178-182 cm</td>
<td>UBA-10594</td>
<td>1867±18</td>
<td>cal AD 82- 216</td>
<td>1,868-1,734 BP</td>
<td>Charcoal</td>
</tr>
<tr>
<td>275-278 cm</td>
<td>UBA-10595</td>
<td>2308±18</td>
<td>cal BC 402- 372</td>
<td>2,352-2,322 BP</td>
<td>Charcoal</td>
</tr>
</tbody>
</table>

Table 8.1: PDH 223 radiocarbon ages and calibrated age ranges.

8.3 Age/Depth model

Fig 8.2 was calculated using the statistical modelling program *clam* (Blaauw, 2010) to produce a potential age/depth relationship over the last 2,300 years. A smooth spline model was chosen from the *clam* program, as this type of model produced the most reasonable approximation for the calibrated age sequence. Appendix Three provides a table showing all age/depth calculations for PDH 223, as well as a more detailed account of sediment accumulation rates.
Sediment accumulation rates were calculated using the ages of best fit produced by the age/depth model. Based on the age/depth relationship, sediment accumulation appears to be highest between 2,343-1,340 cal BP and in the recent sediments *ca.* 30 cal BP. A decline in sedimentation takes place between 1,340-160 cal BP.

### 8.4 Lithology, Loss on ignition and Magnetic susceptibility

The lithology, loss on ignition and magnetic susceptibility (measured in Si units) are summarised below in Fig 8.3. The stratigraphy consists of alternating sands and clays from the core base to 219 cm, alternating iron mottled clays, silty clays and sandy clays between 219 and 124 cm, grey very stiff iron mottled clay from 124 to 14 cm and silty clays in the top 14 cm. Several organic bands, woody bands and charcoal layers also appear in the lithology. A more detailed interpretation is provided in Appendix Three. Sediments between 131.5-14 cm were taken using a gauge augur- thus no magnetic susceptibility could be determined by core scanning.
**Fig 8.3:** Lithology, Loss on Ignition and Magnetic susceptibility for PDH 223

### 8.5 Pollen, Palynomorph and Phytolith Results

Appendix Seven provides detailed descriptions of pollen and palynomorphs identified in core PDH 223. These results are summarised in Figs 8.4-8.8. Pollen percentages are expressed as percentages of total pollen, excluding spores; spores are expressed as percentages of total pollen and spores, whilst other palynomorphs are expressed as percentages of total palynomorphs.

Appendix Seven also provides detailed descriptions of phytoliths and diatoms identified in core PDH 223. These results are summarised in Fig 8.9, whilst *Oryza* measurements and photographs are provided in Appendix Eight. Phytolith and diatoms are recorded as percentages of total phytoliths and diatoms.
Fig 8.4: A summary of montane and general forest taxa for PDH 223.
Fig 8.5: A summary of lianes, small trees/shrubs, kerangas and aquatic taxa for PDH 223.
Fig 8.6: A summary of catholic and open-ground taxa for PDH 223.
<table>
<thead>
<tr>
<th>Dates cal BP</th>
<th>Montane forest</th>
<th>General forest</th>
<th>Lianes</th>
<th>Small tree/shrubs</th>
<th>Catholic</th>
<th>Open ground</th>
<th>Kerangas</th>
<th>Aquatics</th>
<th>Pollen sum</th>
<th>Spores</th>
</tr>
</thead>
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<tr>
<td>2352-2322</td>
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</tbody>
</table>

**Lithology**
- Organic
- Iron mottle
- Clay
- Sand
- Charcoal
- Silt
- Gravel

**CONISS**

**Total sum of squares**

**Fig 8.7:** A Pollen and spore summary for PDH 223
Fig 8.8: A palynomorph summary for PDH 223, + represents low percentages.
Fig 8.9: A Phytolith summary for PDH 223, + represents low percentages.
8.6 Zone description
Zones have been divided into 223-1 to 223-5 and calibrated ages are based on the age/depth model.

PDH 223-1: 280-241 cm (ca.2,350-2,180 cal BP)
Pollen and other Palynomorphs
Pollen representation is low (17-86 grains). This zone is characterised by the sago palm tree *Eugeissona*, appearing at 261 cm (ca.2,300 cal BP). *Eugeissona* represents 10.6-32.6 % total pollen (10.6 % at 241 cm), which is a much higher percentage representation in comparison to most other plant species recorded. This is with the exception of Cyperaceae, which is 29.95 % at 241 cm.

PDH 223-1 is also represented by open ground taxa (40.7-77.1 %) and shrubs (0-2.99 %) including Meliaceae (0-5.8 %) and Oleaceae (0-5.8 %), some kerangas (0-5.9 %), montane (6.5-17.64 %) and general forest (0-33.72 %) taxa have also been observed. There is also a high representation of the forest spores Cyathaceae (24.34-71.7 %), Pteridaceae (1.5-31.2 %) and Polypodiaceae (21.71-33.23 %). Large scabrate Poaceae occur throughout this zone (4.37-35.29 %) and Zyggnemataceae is also present. Burnt organic material represents 80.7-33.7 % total palynomorphs.

Diatoms and Phytoliths
In the phytolith record, one *cf. Oryza sativa* bulliform is present between 251-253 cm, which fits all size criteria for domesticated rice (see Appendix Eight). The shape of the identified *Oryza* bulliform is however; slightly different to that of modern *Oryza sativa* and the number of plates could not be counted.

PDH 223-2: 241-167 cm (2,180-1,760 cal BP)
Pollen and other Palynomorphs
Pollen counts reach a maximum of over 300 grains in this zone, although 109 grains were recorded at 183-181 cm (ca. 1,860-1,850 cal BP). This zone is represented by *Eugeissona*, (0.3-11.3 %), Cyathaceae (8-60.4 %), Polypodiaceae (10.2-47.1 %) and by the montane taxa (particularly at 231 cm, ca.2,150 cal. BP) *Dacrydium* (0.7-4.7 %) and *Podocarpus* (1.4-5.9 %).

Kerangas taxa are present between 241-221 cm with the appearance of *Casuarina, Rhododendron* type and Ericaceae. Catholic taxa (1.2-20.6 %) and small trees to shrubs (2.9-6.8 %) increase and
include Sapindaceae (0-1.4 %); open ground taxa also increase (from 43.24 % to 90.5 %) and include large scabrate Poaceae (particularly between 211-183 cm), general Poaceae and Cyperaceae. There also seems to be high species diversity of shrubs/small trees, shown by the appearance of Myrsinaceae, *Macaranga*, Meliaceae, Sapotaceae and Theaceae. The aquatic taxa *Myriophyllum* and *Urticularia* are also present between 203-193 cm. The spore *Lygodium* is present but representation fluctuates. At 201-203 cm (*ca*. 1,970-1,980 cal BP) hyphae (from 0.1 % to 5.6 %), xylem (from 0 to 1.6 %) and cells (0.12 % to 7.8 %) all increase. Burnt organic material represents 33.9-85.5 %. The lowest representation of burnt organic material coincides with an increase in hyphae, xylems and plant cells.

Above 183 cm, percentages drop for both scabrate Poaceae (from 9.8-2 %) and general Poaceae (from 14.3-5.2 %), although Cyperaceae percentages rise (from 20.3-2.8 %). The spore *Lygodium*, which is frequently present in zones 223-1 and 223-2, disappears completely above 173 cm and the spore Cyathaceae also shows a sharp decline (from 60.4-8 %) after 183 cm.

**Diatoms and Phytoliths**

Pennate diatoms show a presence (0-6 %) between 223 cm and 173cm, whilst in the phytolith record one identified domesticated rice bulliform was recorded at 201-203 cm (*ca*. 1,970-1,980 cal BP). A further *cf.* *Oryza sativa* bulliform was identified at 171-173 cm (*ca*.1,790-1,800 cal BP), along with one likely domesticated *Oryza* glume phytolith. A wild *Oryza* bulliform was also identified at 183-181 cm (*ca*. 1,860-1,850 cal BP) and a *cf.* wild *Oryza* bulliform at 211-213 cm (*ca*. 2,020-2,040 cal BP), although the *cf.* wild bulliform has an elaborate network of scales similar to domesticated rice. Ehrhartioideae bilobates are present at 193 cm.

**PDH 223-3: 167-132 cm (1,760-1,490 cal BP)**

**Pollen and other Palynomorphs**

This zone is characterised by a significant decline in *Eugeissona* (0.17-0.47 %, absent at 143 cm), Cyathaceae (4.7-8.7 %) and Polypodiaceae (7.1-14.5 %). Open ground taxa remain the dominant group (71.4-96.96 % total pollen) and particularly at 147 cm (*ca*.1,600 cal BP) include large scabrate Poaceae, general Poaceae and Scrophulariaceae. Cyperaceae rises at 173 cm, but then declines. This zone is also characterised by the presence of shrubs/small trees: *Macaranga*, *Trema*, Meliaceae, Myrsinaceae Myrica; the montane taxa Fagaceae and *Podocarpus*; and the aquatics *Potamogeton*, *Urticularia* and *Equisetum*. Microscopic burned material shows the lowest overall representation in this zone (5.88 % at 163 cm, although rises to 37.43 % by 133 cm).
There is also a higher representation of plant cells (6.55-14.24 %) than in zones PDH 223-1 and PDH 223-2.

Diatoms and Phytoliths
Pennate diatoms are present, but only at 133 cm. No *Oryza* phytoliths occur in this zone.

**PDH 223-4: 132-61 cm** (1,490-730 cal BP)

Pollen and other Palynomorphs
This zone is represented by very low pollen counts of between 0-6 grains per sample depth. Individual pollen grains of Fagaceae (at 84 cm), Loranthaceae (at 62 cm), *Eugeissona* (at 84 cm) and Araliaceae (103-84 cm) are present in the pollen record, as are the spores Pteridaceae (between 103-83 cm), Polypodiaceae (between 103-78 cm), Glicheniaceae (between 103-84 cm), as well as Cyathaceae and Davalliaceae (between 103-78 cm). Large scabrate Poaceae are also present at 103 cm and at 78 cm. There is a rise in VAMs (11.9-45.2 %, except 1.9 % at 103 cm). Burned organic material represents 43.5-65 %.

Diatoms and Phytoliths
Cyperaceae type phytoliths increase to 25 % at 62 cm and at 103 cm. No domesticated *Oryza* types occur in the phytolith record, whilst wild *Oryza* bulliforms are present and appear more consistently (0-3 %) than in zones 223-3 to 223-1. Ehrhartioideae bilobates appear at 78 cm (2 %).

**PDH 223-5: 61-0 cm** (730-0 cal BP)

Pollen and other Palynomorphs
Pollen counts remain low in this zone (0-2 grains) until 10 cm and then recover slightly (42 to 59 grains). The montane taxa *Dacrydium* (0-8.47 %), *Lithocarpus* (0-3.38 %), Fagaceae (0 to 7.14%), *Phyllocladus* (0 to 5.69 %) and *Podocarpus* (0 to 10.16 %) generally increase within the top 10 cm, but particularly in the top 2 cm. These results may however, have been influenced by the very low pollen counts. Open-ground taxa fluctuates, but in the top 10 cm represents 45.8-54.8 % and includes large scabrate Poaceae, Compositae, Solanaceae, Cyperaceae and Caryophyllaceae. Small trees/shrubs such as *Mallo* tus, Meliaceae, *Myrica*, Myrsinaceae, Sapotaceae and Sapindaceae also appear to increase in the top 10 cm, as well as the spores Cyathaceae, Pteridaceae, Polypodiaceae and Davalliaceae. The aquatic spore *Equisetum* increases to 7.1-3.4 %. Burned organic material represents 46.6-26.1 % with lowest percentages occurring
in the top 15cm. An increase in plant cells (from 2.9 % to 17.9 %) and appearance of testate amoebae also take place in the top 10 cm.

Diatoms and Phytoliths
At 10 cm *Oryza* bulliforms appear, which display some characteristics to *Oryza sativa*; however, measurements are closer to that of wild *Oryza sp*, whilst achene phytoliths, possibly sedge type increase in the top 2 cm from 0.44-13.5 %.

8.7: Interpretation of results
Section 8.7 provides an interpretation of all of the results described in this chapter (sections 8.2-8.6) and includes lithology, $^{14}$C dates, loss on ignition, magnetic susceptibility, pollen, phytoliths and other palynomorphs. The interpretation represents the mid-Holocene just before 2,350-2,320 cal BP until present day.

2,350-2,180 cal BP (PDH 223-1)
Between 2,350-2,180 cal BP a low energy fluvial channel probably existed at the site of PDH 223. This channel appears to have been influenced by forest fires taking place within the catchment area, demonstrated by alternating sands and clays, organic bands, charcoal in the lithology and in the palynomorph record, low loss on ignition and generally low pollen representation, as well as a peak in magnetic susceptibility to 71.5 SI units, which reflects erosional in-wash, transported to the site by fluvial processes.

The general vegetation during this period was dominated by open ground taxa, although some shrubs/small trees, general forest and montane forest types also existed in the pollen catchment. High representation of forest spores, such as Cyathaceae, Pteridaceae and Polypodiaceae might also reflect a predominantly open environment. This theory originally arose from the results of surface sample two (see Chapter Five), which demonstrated a higher proportion of the tree fern Cyathaceae on the grass playing field in Pa’Dalih, when compared to more closed and forested surface sample sites. Behling et al. (1997) also describe fern spores as showing a higher representation after disturbance. An alternative explanation for the appearance of high fern spores could be the normal taphonomic processes in rivers, which lead to enrichment of fern spores (Hunt, 1987, 1994). The presence of Zygnemataceae is consistent with semi-permanent water, at least in the channel. These filamentous algae require sun-warmed, shallow, usually fairly
still water (Van Geel, 1976), so the low numbers may reflect either continued current activity or a shaded channel.

Around 2,290 cal BP, representation of the sago palm tree *Eugeissona* appears much higher in comparison to most other plant species growing near the channel, with the exception of Cyperaceae, whilst charcoal flecks and pieces are present throughout this period. These results provide the earliest indication of sago cultivation/management in the Kelabit Highlands. According to Christensen (1997) and Barton (2012), sago may have been an important crop before rice (also mentioned in Chapter Six); however, one *cf. Oryza sativa* bulliform, which fits almost all criteria for domesticated rice was identified at 2,230-2,240 cal BP. It is possible some form of experimental rice cultivation was also taking place during the same period; perhaps some form of dry rice as the palaeo-channel would have been a low-energy fluvial channel at the time. Conversely, the shape of the identified *Oryza* bulliform is slightly different to that of modern *Oryza sativa* and the number of plates could not be counted, therefore the presence of wild rice cannot be ruled out either. Large scabrate Poaceae occur throughout and these could either belong to domesticated or wild rice (although a few grasses are also known to produce large scabrate grains).

**2,180-1,760 cal BP (PDH 223-2)**

The presence of *Eugeissona* between 2,180-1,760 cal BP is likely to be representative of continued sago use. A brief decline in *Eugeissona* at 221 cm is probably linked to a major burning episode, which took place between 2,150-2,130 cal BP, whilst a later increase might represent an increase in cultivation/management. The burning episode between 2,150-2,130 cal BP is demonstrated by a thick charcoal band, a small increase in magnetic susceptibility and also by the appearance of gravely sand. The lack of tree cover caused by the burning event is likely to have resulted in strong run-off into the channel, increasing erosion and subsequently causing more intense fluvial activity, shown by the deposition of gravels. After this event regeneration flora became established, demonstrated by a rise in open-ground taxa. The presence of the palm tree *Eugeissona* in zone 223-1 has demonstrated people were managing the landscape, so the burning episode could well have been anthropogenically induced, although natural burning cannot be ruled out either.

Around *ca.* 2,150 cal BP montane forest taxa increase and include *Dacrydium* and *Podocarpus*. These results are unlikely to be associated with climate change, but rather with the burning and
high intensity fluvial event described above. Upper montane pollen grains could have been washed into the channel during the high energetic fluvial event. Alternatively a more open environment, caused by the burning of vegetation, could have allowed the accumulation and higher representation of wind dispersed pollen from further distances. Catholic taxa and small trees/shrubs also increase, which as with the open ground taxa probably reflect a rise in regeneration flora after the burning event. There also appears to be a wider species diversity, which again is likely to be reflective of a more open environment (a more open environment would mean less competition for light and space). This is shown by the appearance of Myrsinaceae, Macaranga, Meliaceae, Sapotaceae, Sapindaceae and Theaceae. Certain species of Sapotaceae, Sapindaceae and Euphorbiaceae are fruit trees. A comparison of modern surface samples taken from an orchard located in Pa’Dalih (Surface sample 8, Chapter Five) show an elevated representation of Sapindaceae (34.2 %) and is likely to reflect cultivation of certain Sapindaceae species within the orchard; however, proportions of Sapindaceae are low between 2,180-1,760 cal BP (0-1.4 %), which means cultivation/manipulation cannot be confirmed and the pollen could just as easily represent wild species. Macaranga is also frequently present between 2,180-1,760 cal BP. According to Slik et al. (2003), who carried out a study examining the distribution of Macaranga and Mallotus species in relation to disturbance in East Kalimantan, Macaranga is a common indicator of disturbed forest. They also showed burned forest types were mainly characterised by Macaranga species, which were absent or rare in primary forest. Slik et al. (2003) suggest only a low count of Macaranga is sufficient to indicate disturbance and secondary forest. Kerangas taxa are also present during this period, with the appearance of Casuarina, Rhododendron type and Ericaceae. The Ericales are bee pollinated plants and therefore are typified by low pollen representation, but increased diversity of these taxa means that they could constitute a large proportion of the surrounding vegetation. Apart from occasional flood events and the major flood event at ca 2,150-2,130 cal BP, an increase in plant diversity may also be associated with a general reduction in the energy of fluvial deposition, described above, as well as an opening of the local forest canopy, during a period where the forest was further cleared and open-ground areas increased.

The aquatic taxon Myriophyllum is only found between 2,150-2,000 cal BP. According to Osmond (2009), Myriophyllum prefers lakes, ponds, shallow reservoirs and slow moving water and may suggest generally slower moving water than previously. The presence of Urticularia at ca. 2,000 cal BP suggests pond or swampy conditions, whilst pennate diatoms further represent the presence of an aquatic environment between 2,100-1,800 cal BP. The appearance of these
shallow water plants and diatoms coincide with one identified domesticated rice bulliform at ca. 1,970-1,980 cal BP, a cf. Oryza sativa bulliform at ca. 1,790-1,800 cal BP and one likely domesticated Oryza glume also at ca. 1,790-1,800 cal BP. These results might be representative of wet rice cultivation within the channel during this period. A wild Oryza bulliform was also identified at ca. 1,860-1,850 cal BP and a cf. wild Oryza bulliform at ca. 2,020-2,040 cal BP, although the cf. wild bulliform has an elaborate network of scales, similar to domesticated rice. Ehrhartioideae bilobates are present at ca. 1,940 cal BP (193 cm). These could belong to domesticated rice, but are also representative of wild varieties and grasses within the Ehrhartioideae family (Piperno, 2006). Large scabrate Poaceae also rise between ca. 2,050-1,880 cal BP (211-183 cm), whilst loss on ignition drops to 2.3 % by ca. 1,940 cal BP (193 cm) and might be a further indication of rice cultivation within the channel. The major burning episode described between 2,150-2,130 cal BP, could be related to clearance of the surrounding vegetation in preparation for rice cultivation (Seavoy, 1973); however, sedimentation associated with rice fields (leached clays, iron mottling) are not present. Increased magnetic susceptibility and the appearance of gravels demonstrates intense erosional in-wash, probably caused by slope clearance and may instead be linked again to dry rice cultivation with increased levels of slope erosion, resulting in the deposition of rice phytoliths within the channel.

By ca. 1,960 cal BP, the sediments changed from grey to brown sandy clays. Pollen counts also reach a maximum of over 300 counts and these results may signify a reduction in fluvial activity and the stabilisation of sediments to allow sedimentation of organic particles; although, flood events still continued, shown by alternating sands, silts and clays. Between 1,940-1,830 cal BP several organic layers intermittent with burnt layers are observed in the lithology and these might be related to clearance and burning for rice cultivation or even for other forms of plant use such as for fruit groves or Eugeissona. General Poaceae show a relatively high representation until ca. 1,880 cal BP (183 cm). At 1,880 cal BP pollen percentages drop and a woody band appears in the lithology. This is subsequently followed by a percentages drop in both scabrate Poaceae and general Poaceae, although Cyperaceae increases. These results may represent a decline in anthropogenic activity or possibly a change in environmental conditions within the channel, such as increased wetness of sediments, suitable for sedge and woody taxa, but not for grass types. The disappearance of Lygodium and sharp decline in Cyathaceae could either represent a decline in anthropogenic disturbance within the immediate vicinity or a reduction in fluvial disturbance.
1,760-1,490 cal BP (PDH 223-3)

By 1,730 cal BP, diminishing fluvial activity is further suggested by an increase in loss on ignition to 6.9 %, and by a higher representation of plant cells than previously recorded. Between 1,720-1,700 cal BP vegetation was being burnt within the vicinity of the channel. This is demonstrated by a charcoal band, a rise in magnetic susceptibility (2-203.5 SI units), indicating a large influx of erosional material after the burning event, and by the subsequent appearance of sandy clays. A rise in Cyperaceae (173 cm) might also be representative of increased wetness, caused by a lack of vegetation cover, linked to the burning event. Several charcoal bands appear between 1,760-1,490 cal BP (Zone 223-3). The frequency of burning episodes is likely to be associated with increased anthropogenic activity in the landscape rather than climate change (see Chapter Twelve for a more detailed comparison of burning episodes, identified from all of the core samples). Trema also appears consistently during this period. According to Liguo, *et al.* (2003), *Trema* is often found in disturbed and degraded habitats. Cyathaceae shows a significant decline and again this may be due to forest fires. The presence of *Macaranga* and rise in montane taxa Fagaceae and *Podocarpus* may also signify disturbance, whilst the presence of aquatic pollen and spores such as *Potamogeton*, adapted to deeper water (Lida *et al.*, 2009), *Urticularia* and *Equisetum*, as well as pennate diatoms might be representative of pool development near to the site. Despite the frequency in forest fires and erosional deposition, loss on ignition continues to increase and reaches 14.1 % by 1,490 cal BP. These results could either signify burning episodes taking place further away from the channel, or that fluvial deposition was continuing to decline and therefore organic content was able to increase.

The sago palm *Eugeissona* is present (except at 143 cm) until 1,490 cal BP and may be representative of continued *Eugeissona* use. Percentages are however, significantly lower than previously recorded, and might instead be indicative of a reduction in use, although a higher frequency in burning episodes would also cause a sharp decline in the surrounding forest taxa, including *Eugeissona*. Open-ground taxa remain the dominant taxon group. Cyperaceae declines after 173 cm, and may be related to drier soils caused by the burning. Poaceae and large scabrate Poaceae increase by 1,600 cal BP, as do Scrophulariaceae, and might be reflective of an open landscape around the channel with the presence of wild rice rather than domesticated varieties, as no domesticated rice phytoliths occur in this zone. The lack of domesticated phytoliths may signify an end to rice cultivation, or it may simply be that the area cultivated was moved and no longer yielded phytoliths to the deposition site. It should however be noted, that the percentage of rice phytoliths, identified as likely *Oryza sativa* in the PDH 223 record is low and therefore
domesticated rice may have been present within the vicinity of the site, but not recorded in the phytolith record.

1,490-730 cal BP (PDH 223-4)

After 1,490 cal BP, water levels in the channel had fallen significantly to cause frequent wetting and drying of the channel sediments. This is represented by very iron mottled sediments, very low pollen counts and decline in loss on ignition. The appearance of very sandy iron-mottled clay ca 1,490-1,450 cal BP may reflect erosion into the channel caused by the increased levels of burning described earlier. An increase in fungal VAMs might also be associated with eroded soil entering the channel. After ca. 1,450 cal BP iron mottled grey clays appear and could represent wetting and drying associated with a more intense form of rice cultivation than previously seen in the sequence; but this should have been recorded in the phytolith record and is not. Instead only wild Oryza bulliforms are present. These appear more consistently than earlier in the record. Ehrhartoideae bilobates also appear at 78 cm and despite the poor pollen representation large scabrate Poaceae also show a presence at 103 cm (ca. 1207 cal. BP) and 78 cm (ca. 931 cal. BP). The pollen grains and Ehrhartoideae bilobates could be associated with rice cultivation, although wild species of Oryza may just as easily be growing amongst other grasses (depending on the species), as Poaceae bulliforms have been recorded throughout. A more detailed phytolith study would be necessary to answer this question. Another theory is that the wetting and drying is caused by seasonal rainfall. This suggests that the local water table had fallen, further suggesting that the river had cut down below the level of the channel, effectively forming the current river terrace by around 1,490 cal BP.

Individual pollen grains of Fagaceae, Loranthaceae, Eugeissona and Araliaceae indicate some forest-open forest and shrubs surrounded the channel. The presence of Pteridaceae, Polypodiaceae, Gleicheniaceae, as well as Cyathaceae and Davalliaceae spores demonstrate the surrounding area is likely to have remained relatively open between 1,490-730 cal BP. The presence of Eugeissona might signify continued Eugeissona use; however, evidence is limited to just one pollen grain due to poor pollen preservation, and therefore this grain could equally represent Eugeissona growing naturally near to the channel.

730-0 cal BP (PDH 223-5)

Continued wetting and drying in the channel is likely to have taken place between ca. 730 cal BP until ca. 150 cal BP, followed by the eventual drying up of the channel. This is demonstrated by:
a) continued iron mottling until 15 cm, b) the fact that organic content does not increase until after 15 cm c) pollen counts remain low until 10 cm and then recover slightly from 42 to 59 grains and d) the replacement of iron mottled sediments by organic silty clays after 15 cm.

The absence of domesticated rice phytoliths within the last 730 years may signify an end to rice cultivation within the vicinity of the site. Large scabrate Poaceae are present within more recent sediments (the last 10 cm), as are *Oryza* bulliforms, which display some characteristics to *Oryza sativa*; however, measurements are closer to that of wild *Oryza* sp. An increase in plant cells probably represents soil formation and stabilisation by plants. Despite stabilisation by plants, a relatively open-semi open environment probably existed on and within the vicinity of the site. This can be demonstrated by the presence of small trees/shrubs such as *Mallotus*, Meliaceae, *Myrica*, Myrsinaceae, Sapotaceae and Sapindaceae, as well as open ground pollen taxa, Poaceae phytoliths and presence of the spores Cyathaceae, Pteridaceae, Polypodiaceae and Davalliaceae. Testate amoebae also appear only in the last 10 cm as does the aquatic *Equisetum* and may be representative of waterlogged soils.

The montane taxa *Dacrydium*, *Lithocarpus*, Fagaceae, *Phyllocladus* and *Podocarpus* generally increase as well within the top 10 cm, but particularly in the top 2 cm. This might reflect part of the surrounding woody vegetation. Another suggestion is that modern temperatures may be slightly cooler than during the mid-Holocene, although a more open environment, caused by anthropogenic disturbance within the vicinity of the site, would also allow an increase in pollen blown in from higher altitudes. It should be noted however, that pollen counts were extremely low and therefore although this information can provide a general account of the surrounding vegetation, the counts are too low to provide an accurate percentage representation of the different proportions of plants growing within the area.

Today a fruit grove exists on the site and contains species of fruit trees belonging to Sapindaceae, Sapotaceae and Moraceae (*Ficus*), all of which are represented in the pollen record. It is likely that grass and wild rice varieties, as well as a number of other herbs and shrubs (see Fig 8.5 and Fig 8.6) such as Oleaceae, Cyperaceae, Compositae and Scrophulariaceae were growing amongst the semi open fruit grove as it became established.
8.8 Summary

Overall palaeoecological results have demonstrated the presence of a riverine channel ca.2,350 cal BP. The general vegetation surrounding the channel consisted of open-ground and semi-open scrub and woodland. Experimental forms of rice cultivation may have been taking place nearby, although evidence is limited and the presence of wild varieties is also a possibility. Away from the channel, the surrounding forest was very likely being used by the local inhabitants for the manipulation of *Eugeissona*, in order to extract the edible carbohydrate *ca.* 2,290 cal BP. A large area was deforested *ca.* 2,150-2,130 cal BP, the result of a major burning episode, followed by a steep rise in open-ground cover. With no protection of forest cover the amount of run-off must have been intense, causing a major flood event and the deposition of gravels. Although natural burning cannot be ruled out, anthropogenic burning seems more likely, as continued *Eugeissona* use and the presence of domesticated rice between *ca.* 1,980-1790 cal BP demonstrates that people were managing the landscape. The increase in erosion and the subsequent appearance of domesticated varieties of rice could indicate dry rice farming rather than wet.

By *ca.* 1,940-1,830 cal. BP a decline in fluvial deposition took place, with the development of organic sediments during slow flow, although occasional energetic fluvial activity still continued. Fluvial activity may have been influenced by anthropogenic clearance episodes, resulting in increased runoff into the channel. Around 1,760-1,490 cal BP there was a marked increase in levels of burning, which may represent a phase of intensified anthropogenic clearance; however, *Eugeissona* pollen percentages between 1,760-1,490 cal BP are significantly lower than between 2,290-1,760 cal BP. The reduction in *Eugeissona* could be associated with a decline in sago use, although the frequency in burning episodes could also have caused the reduction. After 1,760 cal BP domesticated rice is no longer present in the phytolith record. Rice cultivation may have ended within the vicinity of the site, or the area cultivated was moved and no longer yielded phytoliths to the deposition site. Due to the low representation of domesticated rice phytoliths that have been recorded in the phytolith record, there is a strong possibility that after 1,760 cal BP domesticated rice was still being grown within the vicinity of the site, but the phytoliths were not recorded. Further phytolith work may help to determine this answer.

Between 1,490-150 cal BP, iron mottled clays appear indicating wetting and drying in the channel. No evidence of domesticated rice has been identified, except perhaps for the large scabrate Poaceae grains, which may be a further indication of continued rice cultivation at other locations within the vicinity of the core site. Wetting and drying of the channel sediments is likely
to be associated with the gradual lowering of the water table in the channel, whilst open-scrub forest with montane elements continued to surround the site. *Eugeissona* is present, but due to poor preservation there is not enough evidence to suggest anthropogenic use. A rise in organic sediments, disappearance of iron mottling and rise in pollen counts represents the drying up of the channel after *ca.*150 cal BP. More recently this is followed by the appearance of a semi closed fruit grove with *Ficus*, species of Sapindaceae and Sapotaceae.
CHAPTER NINE
PDH 210-PA’DALIH
Chapter 9-PDH 210

9.1 Site Description

PDH 210 is a 94 cm core, taken from sediments exposed in a deep cut, made by a mechanical excavator in the roadside that leads into the village of Pa’Dalih, where this cuts through a substantial terrace landform (Fig 9.1). The cut has exposed a thick layer of grey trough-cross-bedded gravelly sands and clays filled with bedded leaves, wood, and a large fallen timber, all overlain by over 3 m of yellow inorganic overbank silts of the terrace deposits. The geomorphological position suggested that this deposit represents a Pleistocene riverine deposit. Radiocarbon dates later confirmed the Pleistocene age. This core provides a unique record for the period close to the Last Glacial Maximum in Borneo.

The hillslopes above the river terraces are steep and covered in dense montane rainforest, with taxa such as Agathis, Ficus, Euphorbiaceae and Fagaceae. Dykes (2002) contends that steep montane landscapes of this type in Borneo evolve by shallow land-sliding, following riverine undercutting of the slope foot.

Fig 9.1: Location of core PDH 210 in relation to core CO1 (Chapter 10).
9.2 Radiocarbon results

The radiocarbon ages for PDH 210 are shown below in Table 9.1. One wood and two charcoal samples were radiocarbon aged; this was dependent on the availability of dating material. The oldest sample age is 26,886-29,563 cal BP. At 24 cm wood has been aged to between 13,105-12,907 cal BP. An age reversal is observed at the top of the core (16,872-16,379 cal BP), which suggests that the charcoal of UBA-13655 is recycled. Charcoal is much more likely to recycle than wood (Gavin, 2001). This raises the possibility that the basal date may be recycled too. More radiocarbon dates may contribute to a better understanding the chronology of the site.

![Table 9.1: PDH 210 Radiocarbon dates and calibrated age ranges.](image)

9.3 Lithology and Magnetic susceptibility

The lithology and magnetic susceptibility (measured in SI units) are represented as a summary diagram in Fig 9.2. The stratigraphy consists of alternating sands, silts, clays gravel and thick charcoal bands (up to 12 cm in thickness). Some iron mottling is also present. The charcoal bands appear to coincide with peaks in magnetic susceptibility, suggesting forest fires were responsible for intense erosional in-wash into the channel. See Appendix Three for a more detailed account of the lithology.
9.4 Pollen and Palynomorph Results

Appendix Seven provides detailed descriptions of pollen, spores, phytoliths and palynomorphs identified in the PDH 210 core. Pollen counts for PDH 210 were poor, with only two samples containing counts of over 100 grains and no sample reached 200 grains, although spores were abundant. Despite poor pollen counts the pollen results have been presented in Figs 9.3-9.7, as it was thought that the limited counts may still provide some useful information. Pollen percentages are expressed as percentages of total pollen, excluding spores; spores are expressed as percentages of total pollen and spores; other palynomorphs are expressed as percentages of total palynomorphs. Palynomorphs are represented in Fig 9.7.
Fig 9.3: A summary of montane, general forest and liana taxa for PDH 210. Pollen represents a percentage of total pollen taxa excluding spores, whilst spores represent a percentage of total pollen and spores.
Fig 9.4: A summary of small tree/shrubs and open ground taxa for PDH 210. Pollen represents a percentage of total pollen taxa excluding spores, whilst spores represent a percentage of total pollen and spores.
Fig 9.5: A summary of catholic, kerangas and aquatic taxa for PDH 210. Pollen represents a percentage of total pollen taxa excluding spores, whilst spores represent a percentage of total pollen and spores.
Fig 9.6: A pollen and spore summary for PDH 210. Spores have not been included in the main pollen sum.
Fig 9.7: A summary of other palynomorphs for PDH 210. Palynomorphs represent a percentage of total palynomorphs.
9.5 Zone description

Zone-210-93-65 cm (29,560-26,890 and younger cal BP)

The main groups represented in this zone are montane taxa, Small trees/shrubs and open-ground taxa. Montane taxa represent 42-50 % (where pollen counts are between 133-181 grains), although 25 % at 84 cm (total pollen counts: 94). Dacrydium: 16.1-8.8 %, Podocarpus: 6.5-15.8 % and Lithocarpus: 6.1-1.1 %, Fagaceae: 1-2 % and Phyllocladus: 1-8 %.

Small trees/shrubs represent 9.7-21.8 %, especially Macaranga 1.7-7.5 %, Myrsinaceae 0-3.7 % and Sterculiaceae 2.2-8.3 %, whilst kerangas taxa represent 1-28 % and include Ericaceae: 1.1-6.8 % and Syzygium: 0-9.9 %. There is also a wide range of open ground taxa (12-38 %, between 94-74 cm). These include: Amaranthaceae, Compositae, Scirpus, Rumex, Scrophulariaceae, and Gleicheniaceae.

Zone 210-2: 64-25 cm (Younger than 29,560-26,890 to 13,110-12,910 cal years BP)

This zone is represented by very low pollen counts (8-37 grains), with a high representation of open-ground species (13.5-62.5 %) and small tree/shrubs (12.5-16.7 %). Montane taxa represent 0-16.2 %. Dacrydium is however, absent.

Zone 210-3: 24-0 cm (Younger than 13,110-12,910 cal years BP)

Pollen representation is again low (7-19 grains), except 87 grains at 23 cm. Montane taxa represent between 14.3-26.3 %, Vitaceae: 1.1 % at 24 cm, shrubs/small trees: 21.1-28.6 %. Macaranga is particularly noticeable: 5.7 % at 24 cm, then 21.1-28.6 %, and open-ground taxa represent 17.2-57.1 %, in which large scabrate Poaceae represent 5.3 % at 14 cm.

9.6: Interpretation of results

As explained in the methodology (Chapter Four), mainly due to time constraints it was not planned to analyse PDH 210; however, after the radiocarbon ages were measured and calibrated to ca. 29,000-13,000 cal BP, a period missing from the Bario and PDH 212 cores, it was decided to carry out pollen analysis on ten samples to provide a missing link between the Pleistocene and Holocene (no phytolith work was undertaken other than noting phytoliths which occurred within the pollen counts). Despite an age reversal at the top of the core and poor pollen preservation, a combination of the pollen taxa that could be identified, other palynomorphs, lithology and magnetic susceptibility, has provided a provisional environmental history throughout the latest Pleistocene. Due to uncertainties in the exact age sequence of this core, the results have been
interpreted into zones 210-1, 210-2 and 210-3, rather than as a time-line, and incorporate all of the results described in sections 9.2-9.5; from lithology to radiocarbon dates, magnetic susceptibility, pollen, other palynomorphs and phytoliths.

Zone-210-1 93-60 cm (29,560-26,890 and younger cal BP)
The accumulation of wood and particularly gravels is likely to be indicative of a high-energy fluvial environment, caused by strong short-duration runoff events into the channel, while the presence of bands of leaves and layers of silts point to episodes of low flow. Charcoal layers also highlight a number of burning episodes that could well have been caused by a much drier climate.

Pollen results demonstrate a higher proportion of montane taxa compared with all other zones (with the exception of Podocarpus, which remains relatively constant throughout), particularly Dacrydium, Podocarpus and Lithocarpus, but also Fagaceae and Phyllocladus. These results could either suggest optimal environmental conditions for these particular taxa, such as the fluvial deposition of nutrient poor sands (Mackinnon et al., 1996 & Wong et al., 1987), or that a drier montane dominated forest surrounded the palaeochannel (cf. Flenley, 1973). For example, the very high figures for Dacrydium and Podocarpus can be compared with Flenley’s (1973) sample, from the Dacrydium forest zone at 2400 m, on Mount Kinabalu. There are however, significant differences at this altitude, as Phyllocladus represents 10 % on Mount Kinabalu and only 0.8-4.4 % in the PDH 210 pollen record, whilst other types of high-montane taxa such as Drymis are absent from the PDH 210 diagram. This may be partly due to the low pollen counts in the PDH 210 record. Beaman (1999) also describes Phyllocladus, Dacrydium and Podocarpus species as found on the summit of Mount Murud in the Kelabit Highlands. These comparisons suggest that vegetation zones could have been significantly depressed altitudinally during this zone.

In zone 210-1 small trees/shrubs also appear to be well represented, especially Macaranga, Myrsinaceae and Sterculiaceae; as are the kerangas taxa Ericaceae and Syzygium. The representation of these taxa combined with a wide diversity of open ground taxa, including: Amaranthaceae, Compositae, Scirpus, Rumex, Scrophulariaceae, and Gleicheniaceae, indicate the presence of semi-open scrub-kerangas vegetation. If these results are compared with the lithology, of trough-cross-bedded alternating sands, clays and gravels, representing periods of high-energy fluvial activity (Briggs and Gilbertson, 1980), then these results signify very seasonal discharge, i.e. a highly seasonal climate (not good for tropical spp., thus breaking up the vegetation cover). The burning episodes would also have provided habitat for the scrub-open
ground taxa and a lack of vegetation cover could well have increased the intensity of fluvial activity during this time. A seasonal climate was probably more fire prone than a wet tropical climate. It should be noted, however, that zone 210-1 contains the highest overall pollen counts (100-175, which are well below the recommended pollen count of 300). Such low pollen counts will affect the overall representation of vegetation, because it is highly possible that some quite common taxa may not have been included in the counts.

**Zone 210-2:** 60-24 cm (Younger than 29,560-26,890 to 13,110-12,910 cal BP)

The appearance of bright orange mottled sediments in this zone is significant, as it demonstrates iron mottling can also be caused by natural events as well as from the wetting and drying processes involved during rice cultivation (see Chapter Seven-PDH 212). It probably suggests a period of low water levels and weathering.

Low water levels and the oxidation of sediments are likely to be responsible for very low pollen counts in this zone. There is a high representation of open-ground species and small tree/shrubs, suggesting an open landscape dominated by regenerating vegetation. The lithology shows a number of thick charcoal layers, with blue clays appearing after some of the charcoal bands. The clays are likely to reflect pool sediments. Gravel and sand was also identified in this zone, suggesting high energetic fluvial deposition also occurred. Magnetic susceptibility results imply that intense erosional in-wash took place on a number of occasions, represented by a number of peaks reaching above 100 SI units. Large scale forest fires and the subsequent lack of vegetation cover could have caused land-sliding on the surrounding slopes, which would explain the intense periods of inwash associated with the thick charcoal bands, gravels and sands. High intensity flooding and landsliding may have temporarily blocked the river causing the formation of pools, hence the appearance of blue clays, but alternatively lower-intensity, perennial rainfall and less-peaked discharges could have led to quieter silt-based sedimentation in the river (Briggs & Gilbertson, 1980).

**Zone 210-3:** 24-0 cm (Younger than 13,110-12,910cal BP)

An increase in iron mottling, which appears after 15 cm, could represent natural wetting and drying during or after the end of the zone. The organic sediments pass up into a 4 m section of brown clay, grey clay, gravel and sand of a major fluvial aggradation, which passes upslope into clayey colluvium. This represents a period of intense erosion and further suggests a high-energy
fluvial environment, whilst the iron mottling suggests that this is related to a more seasonal discharge.

Despite low pollen representation the pollen results demonstrate the presence of montane forest; however, the high shrub-herb representation and the presence of Macaranga are also likely to be indicative of a very disturbed semi-open landscape. Kessler et al. (1994) describe Macaranga as strongly associated with secondary woodland, although, Anderson (1980) states that Macaranga is found in both primary and secondary forest, depending on the species. For example Macaranga costulata was collected from the Kelabit Highlands in 2008 (see Appendix One), but this species is described by Pax and Hoffman (2009) as endemic throughout Borneo and found in both primary and secondary forest up to 1700 m. Hunt et al. (2012) note high percentages of Macaranga during some episodes in the late Pleistocene and argue that the disruption of vegetation through rapid climate change, rather than forest fires, would have left ‘ecological space’ for regeneration taxa, including Macaranga, at Niah, in the lowlands of Borneo. At Pa’Dalih; however, the frequency of burning episodes, as suggested by the charcoal record, has probably influenced Macaranga; although, an alternative explanation could also be because nearby landslide areas were re-vegetating.

An age reversal also appears in this zone (16,872-16,379 cal years BP) probably because of recycling of material from adjacent slopes, so the exact age of this zone is uncertain. Large scabrate Poaceae appear at 14 cm, which might be representative of wild Oryza growing in damp conditions in or near to quieter water or pool deposits, although certain types of other Poaceae can also be scabrate in morphology.

9.6: Summary

These results have demonstrated periods of high-fluvial energy during the late Pleistocene 26,870-29,560 cal BP to after 12,910-13,110 cal BP with the deposition of alternating sands, clays, gravels and wood. The climate was probably much drier than it is today, dominated by montane forest taxa such as Dacrydium, Podocarpus, Fagaceae, scrub and open ground vegetation with increased seasonality and periods of drought, and at times a far higher frequency of forest fires than during the Holocene. It is likely that at times temperatures and vegetation zones were significantly depressed, especially during zone PDH 210-1. The lack of vegetation cover caused by forest fires and seasonal climate probably intensified fluvial activity, whilst it is possible on more than one occasion lack of vegetation on the surrounding slopes (caused by fires
and climatic disturbance) may have resulted in land-sliding and increased local sediment supply to the river, which temporarily blocked the riverine system, resulting in the formation of temporary pools (blue clays). Alternatively lower-intensity, perennial rainfall and less-peeked discharges could have led to low intensity flood events.

Iron mottling during the Late Glacial is likely to have been associated with periods of low flow and the natural wetting and drying of the palaeo-channel sediments, and possibly reflects periods of non-deposition when weathering of the sediments occurred. The organic deposits pass up into several metres of inorganic but generally fine grained riverine sediments, which suggest a major episode of aggradation because of slope instability. It is uncertain at this stage whether this is a local or a regional phenomenon, but it would presumably correspond chronologically to the Younger Dryas.
CHAPTER TEN
PA’DALIH-CO1
Chapter 10-Pa’Dalih: PDH CO1

10.1 Site Description

Pa’Dalih is a small Kelabit village in the southern part of the Kelabit Highlands, situated next to the Diit, a tributary of the Baram River. The village lies in a steep-sided valley, floored by the deposits of a number of fluvial palaeochannels, which indicates a very dynamic landscape with unstable fluvial activity in the past. The ancient palaeochannels provide extremely fertile soils and are used extensively by the local inhabitants for rice cultivation. A 361 cm core was taken from a palaeochannel, now a fallow rice field, at the edge of the village of Pa’Dalih, immediately behind the primary school. The vegetation is dominated by grass, but the site is also surrounded by a number of fruit trees such as durian, passion fruit, coffee and dragons eye. The site was selected for its potential in providing evidence of early rice cultivation.

Fig 10.1: Location of CO1 in the village of Pa’Dalih (Author)
10.2 Radiocarbon results

Table 10.1 represents $^{14}$C and calibrated ages extracted from charcoal samples for CO1. Apart from sample PDH 161-163 cm, the other samples appear to be in chronological order, although some uncertainty exists, as the age margins between samples PDH 265.5-271.5 and PDH 324-326 (both of which were extracted from thick charcoal bands, so the dates themselves are accurate) overlap. According to the IntCal04 calibration curve (Reimer et al., 2004), the age of PDH 265.5-271.5 has a 71% chance of being between 144-24 BP and sample PDH 324-326 cm has an 81% chance of being between 297-141 BP.

<table>
<thead>
<tr>
<th>UBNo</th>
<th>Sample ID</th>
<th>$^{14}$C Age BP</th>
<th>Calibrated Age (2 σ) AD/BC</th>
<th>Calibrated Age (2 σ) BP</th>
<th>Material</th>
</tr>
</thead>
<tbody>
<tr>
<td>UBA-8126</td>
<td>PDH 161-163</td>
<td>972±28</td>
<td>1016-1155 AD</td>
<td>934-795 BP</td>
<td>Charcoal</td>
</tr>
<tr>
<td>UBA-8127</td>
<td>PDH 265.5-271.5</td>
<td>92±31</td>
<td>1683-1954 AD</td>
<td>267-27 BP</td>
<td>Charcoal</td>
</tr>
<tr>
<td>UBA-8128</td>
<td>PDH 324-326</td>
<td>190±26</td>
<td>1653-1952 AD</td>
<td>297-0 BP</td>
<td>Charcoal</td>
</tr>
<tr>
<td>UBA-8129</td>
<td>PDH 360</td>
<td>1180±32</td>
<td>729-966 AD</td>
<td>1221-984 BP</td>
<td>Charcoal</td>
</tr>
</tbody>
</table>

**Table 10.1**: Radiocarbon and calibrated ages for CO1

Sample PDH 161-163 consisted of fine charcoal fragments found in a very wet organic band of clay. The age reversal and lithology suggest the charcoal fragments are from eroded sediments, probably washed in when the rice field was flooded for wet rice cultivation in more recent times.
10.3 Lithology

The lithology is summarised below in Fig 10.2. The stratigraphy is characterised by alternating sands, silts and clays. A number of charcoal bands, flecks and pieces are also present. Iron mottled sediments appear around 277 cm but become more pronounced in the top 189 cm. A more detailed description of the lithology can be found in Appendix Three. Changes in the lithology are also discussed in section 10.5.

![Image of lithology](image)

*Fig 10.2: Lithology of core CO1*
10.4 Pollen, Phytolith and Palynomorph results

Pollen, phytolith and palynomorph results are summarised in Figs 10.3-10.5. Phytoliths occurred during pollen counts and were not prepared separately. Pollen percentages are expressed as percentages of total pollen and spores, due to the poor pollen representation, and phytoliths are expressed as counts. Appendix Eight provides measurements and photographs of potential *Oryza sativa* phytoliths.

Overall pollen preservation for core CO1 has been extremely poor. The top 3-6 cm is the only depth that has produced an adequate pollen count of over 300 pollen grains (not including spores). This is probably due to the unsuitable nature of the sediments for pollen preservation.

Between 357-361 cm palynofacies are low (counts of 218 compared to counts of 900 higher up the core) and burnt plant remains show a low representation (0.9 %). Only one Acanthaceae and one *Trema* (a disturbance indicator) pollen grain appear at 357-361 cm.

At 352 cm, no pollen or phytoliths occur; however, total palynofacies represent counts of 957, in which organic matter consists of 72.3 % total palynofacies, and burnt wood 27.7 %. SCPS (Spheroidal carbon particles) have also been found at this depth (0.8 %), indicating high levels of burning.

Between 241-243 cm, two Poaceae bulliforms were identified.

Between 161-163 cm, 26 pollen grains were counted. Most of these represent open ground species (83.3 %). Grass and sedge species appear to be dominant with Poaceae representing 45.8 % (11 grains) and Cyperaceae 20.8 % (5 grains). One large scabrate Poaceae was also identified, similar in appearance to *Oryza*, but other Poaceae species cannot be ruled out. One likely *Oryza sativa* bulliform was also identified, as well as two Poaceae bulliforms. Fern spore counts are particularly high with 26 spores of Cyathaceae, 21 spores of *Polypodium*, 7 spores of *Selaginella* and 28 spores of *Lycopodium*. The palynofacies results are well represented with plant remains representing 83.7 %, two diatoms appear and burnt wood represents 15.5 %.

Between 73-71 cm, no pollen grains were present and palynofacies counts were not undertaken; however, one *Oryza* type phytolith bulliform was identified. This could not be distinguished
between wild or domesticated and no photograph was taken, as unfortunately a camera was not available at the time.

Between 6-3 cm the pollen record shows a wide diversity of trees (25 %) including *Castanopsis*, Elaeocarpaceae, *Coffea*, the fruit tree Sapindaceae as well as the sago palm *Eugeissona*. Shrub counts are low (4.8 %) with a single grain of Acanthaceae and four grains of *Ilex*. Open-ground species show a high representation (60.1 %), in particular Poaceae (22.8 %/71 pollen grains) and Cyperaceae (21.9 %/68 pollen grains). Plant palynofacies are well represented, particularly organic matter and soil fungi (97 % total palynomorphs); burnt plant tissue represents 1.3 % and freshwater algae-diatoms 1.6 %. Poaceae and *Oryza* phytoliths were also identified and include three distinct bulliforms, likely belonging to *Oryza sativa*. 
Fig 10.3: A summary of montane, general forest and small shrubs/trees for CO1
Fig 10.4: A summary of open-ground, aquatic, catholic pollen, phytoliths and diatoms for CO1
Fig 10.5: A summary of other palynomorphs for CO1
10.5 Interpretation of results

Section 10.5 provides an interpretation of all of the results described in this chapter (sections 10.2-10.4) and includes lithology, $^{14}$C dates, loss on ignition, pollen, phytoliths and other palynomorphs. The interpretation represents 1,220 cal BP until present day.

At 1,220-980 BP (357-361 cm) fluvial deposition was influencing the palaeochannel, suggested by the presence of sand, and a low palynofacies count. During this period the palaeochannel may still have been part of the Diit tributary.

After 1,220-980 BP (352 cm) the presence of organic sands demonstrate that flows were beginning to slow so organic matter could be deposited by the river. This was likely caused by a weakening and the eventual isolation of the palaeochannel from the Diit. The changes in lithology (sands to clays) suggest quieter water. An increase in charcoal and the presence of spheroidal carbon particles (SCPs) indicate intense burning. The burning could be a natural occurrence, but the sequence in burning episodes after 352 cm suggest they are anthropogenic, whilst the presence of *Trema* indicates disturbance (Liguo *et al.*, 2003). No pollen was present between 352-161 cm. This is almost certainly because sedimentation was too rapid for much pollen to be deposited, and the channel intermittently dried out causing the pollen to be oxidised.

Between 1,220-980 and 300-0 BP (346.5-327 cm) graded bedding (natural sedimentation in a backwater) is represented by alternating clays and sands. This is caused by the flow of muddy, sandy water into the palaeochannel in a series of small floods. The heavier sand particles would fall out first, followed by the clay causing graded layers to form. The flooding may or may not be anthropogenic related.

Sometime between 300-0 BP (327-325.5 cm) another phase of intense burning took place, shown by the appearance of a thick charcoal band in the lithology. This is again followed by graded bedding (alternating sands-clays). At 279 cm very pale white clay is present, most likely caused by severe leaching of the soil. The presence of two Poaceae bulliforms between 243-241 cm indicates open or at least semi-open vegetation near to the site.

Between 161-159 cm a combination of organic very wet grey clay, palynomorphs (burnt vegetation, diatoms and large scabrate Poaceae), and one likely *Oryza sativa* phytolith suggest clearance and burning for the production of wet rice. The date of 934-795 BP probably originated from the recycling of eroded charcoal, washed into the palaeochannel as the field was flooded, during more modern times (between
270-30 BP), in preparation for rice cultivation and may represent the start of cultivation in the channel. Although pollen counts are low there is a high representation of open ground taxa, especially grass and sedge. This is shown in both the pollen and the phytolith record. Forest spore representation is also high and likely originates from the surrounding forest.

From 267-27 BP (199-0 cm) there is a change in the sediment characteristics, from grey clays and brown clayey sands to a very orange iron-mottled sandy clay with an occasional band of grey clay. In-wash from the clearance of adjacent hill slopes could be an explanation for the coarser and more oxidised nature of this upper deposit, but the mottling may be associated with rice cultivation.

In more recent times (between 6-2 cm) the pollen record demonstrates a primarily open environment on the palaeochannel, dominated by grass and sedges, although fruit trees such as Sapindaceae, *Coffea* and *Citrus* also existed on the channel or nearby, whilst 25% representation of tree taxa demonstrate forest-open forest in the vicinity. Clear evidence of wet rice cultivation can be seen in very recent times (the top 2 cm) with three distinct *Oryza sativa* bulliforms and the presence of fresh water diatoms.

**10.6 Summary**

Despite the lack of pollen at CO1 the complex lithology, phytolith and other palynomorph results reveal a landscape, which has over a period of 1,220 years been undergoing constant change, governed by both environmental and anthropogenic factors.

At 1,220-980 cal BP the palaeochannel was still influenced by the Diit, but at some point within the last 300 years it became isolated and was used for wet rice cultivation, particularly in more recent times, with direct evidence of *Oryza sativa* from phytolith bulliforms. Thick bands of charcoal also demonstrate that there was major burning nearby on several occasions.

Finally, an increase in iron mottled sediments, within the last 100 years, above 199 cm could be caused by in-wash from the clearance of adjacent hill slopes and rice cultivation.
CHAPTER ELEVEN

PA’BUDA (BPG)
Chapter 11-Pa'Buda (BPG)

11.1 Site description
Between the Pa’Buda tributary and the abandoned settlement site at Batu Patong, the valley floor is mostly occupied by a series of river terrace features, some of which are 5 m above the current river. On them are preserved fragments of ancient meander systems, now largely occupied by rice fields (Fig 11.1). The main vegetation surrounding the field systems consists of kerangas-secondary forest with giant bamboo a common feature. This site, a fallow wet rice field at Pa’Buda, was selected because the field systems are currently in use for rice cultivation and therefore had potential in providing evidence of earlier cultivation. A 2.03 m core was taken (Fig 11.2).

Fig 11.1: Map showing the location of Pa’Buda (Produced by the Cultured Rainforest Project and edited by the author)
Fig 11.2: A photo of the site location at Pa’Buda with Prof. Graeme Barker and Dr. Huw Barton assisting with the core sampling.
11.2 Radiocarbon results

Table 11.2 represents $^{14}$C and calibrated ages, extracted from five charcoal samples, for Pa’Buda. The main charcoal layer located at 89 cm, was aged to between 6,573-6,399 cal BP. Four further charcoal samples were later aged from lower down the profile. All of these samples are approximately the same age as the main charcoal layer. This could indicate either the ‘old wood’ effect, or that rapid sedimentation/infilling of the meander took place at this time; followed by very slow in-wash afterwards. Another possibility is that charcoal has been dragged down through the profile by the auger; however, given that the sediments are quite sandy, demonstrating faster or more intense fluvial deposition than what would occur with lighter clays, rapid infilling is quite likely. Evidence of rapid sediment deposition can also be seen within the first 200-300 years from Pa’Dalih CO1 (see Chapter Ten). Considering the finely stratified nature of the core sediments, it is considered unlikely that coring caused major mixing of the deposits and the widespread ‘smearing’ of charcoal down the borehole. It is far more likely that the ages appear ‘mixed’ because of the old wood effect and rapid deposition.

<table>
<thead>
<tr>
<th>Depth cm</th>
<th>UBNo</th>
<th>Sample ID</th>
<th>$^{14}$C Age BP</th>
<th>Calibrated Age (2 $\sigma$) AD/BC</th>
<th>Calibrated age (2 $\sigma$) BP</th>
<th>Sample type</th>
</tr>
</thead>
<tbody>
<tr>
<td>89</td>
<td>UBA-8130</td>
<td>BPG89</td>
<td>5692±43</td>
<td>4,684-4,449 BC</td>
<td>6,573-6,399 BP</td>
<td>Charcoal</td>
</tr>
<tr>
<td>152-154</td>
<td>UBA-9305</td>
<td>BPG152-154</td>
<td>6177±23</td>
<td>5,213-5,055 BC</td>
<td>7,163-7,005 BP</td>
<td>Charcoal</td>
</tr>
<tr>
<td>156-158</td>
<td>UBA-9308</td>
<td>BPG156-158</td>
<td>5396±27</td>
<td>4,335-4,173 BC</td>
<td>6,900-6,218 BP</td>
<td>Charcoal</td>
</tr>
<tr>
<td>170-172</td>
<td>UBA-9309</td>
<td>BPG170-172</td>
<td>5495±24</td>
<td>4,441-4,268 BC</td>
<td>6,320-6,218 BP</td>
<td>Charcoal</td>
</tr>
<tr>
<td>192-194</td>
<td>UBA-9306</td>
<td>BPG194-192</td>
<td>5633±23</td>
<td>4,529-4,372 BC</td>
<td>6,479-6,322 BP</td>
<td>Charcoal</td>
</tr>
</tbody>
</table>

Table 11.2: Pa’Buda Radiocarbon dates and calibrated age ranges
11.3 Lithology

The lithology and loss on ignition of core BPG is represented as a summary diagram below in Fig 11.3. The stratigraphy consists of alternating sands-clayey sands intermittent with organic bands below 79 cm. A lot of charcoal pieces appear between 113-79 cm. Between 79 cm and 50 cm, the sediments are clayey sand, then from 50 cm to 4.5 cm they are iron mottled sandy clay, then clay in the top 4.5 cm. See Appendix Three for a more detailed account of the lithology.

Fig 11.3: Lithology of core BPG
11.4 Pollen and Palynomorph Results

Appendix Six provides detailed descriptions of pollen, spore and palynomorphs identified in the Pa’Buda core. These results are summarised in Figs 11.4-11.10. Pollen percentages are expressed as percentages of total pollen, excluding spores; spores are expressed as percentages of total pollen and spores, whilst other palynomorphs and phytoliths are expressed as percentages of total palynomorphs and phytoliths, excluding charcoal and charred plant remains above 5 µm. Phytoliths were not prepared separately but appeared during the pollen counts. Charcoal and charred plant remains are expressed as a percentage of total palynomorphs. Initial pollen analysis showed low pollen representation for the Pa’Buda core. Three pollen slides were counted per sample and an attempt was made to count at least 150 grains where possible. Only the upper-most sample produced counts of over 200 grains. Spore counts showed a much better representation with average counts of 300-350. The top sample produced counts of 800, whilst at 199 cm and again at 165 cm counts are below 25. Other palynomorphs were well represented.
Fig 11.4: A pollen summary of montane forest for Pa’Buda. Spores have been excluded from the main pollen sum.
Fig 11.5: A pollen and spore summary of general forest for Pa'Buda. Spores have been excluded from the main pollen sum
Fig 11.6: A pollen and spore summary of lianes, small tree/shrubs and kerangas for Pa’Buda. Spores have been excluded from the main pollen sum
**Fig 11.7**: A pollen and spore summary of open ground taxa for Pa’Buda. Spores have been excluded from the main pollen sum.
Fig 11.8: A pollen and spore summary of catholic and aquatic taxa for Pa’Buda. Spores have been excluded from the main pollen sum
Fig 11.9: A pollen and spore summary for Pa’Buda. Spores have been excluded from the main pollen sum.
Fig 11.10: A summary of other organics for Pa’Buda. Palynomorphs have been calculated as percentages of total palynomorphs and phytoliths, excluding charcoal. Charcoal and charred organic remains have been expressed as percentages of total palynomorphs.
11.5 Zone description
Zones have been divided into Pa Buda-1 to Pa Buda-3. For a more detailed zone description see Appendix Six

Zone Pa Buda-1 (203-110 cm): >6,480-6,320 to <6,320-6,220 cal years BP
This zone has mainly been defined by small trees/shrubs, montane taxa and by Lycopodiaceae megaspores. Montane forest represents 19-41.8 % (all percentages in this zone are based on pollen counts above 150 grains). The highest representation of montane taxa occurs at 203 cm (41.8 %). The dominant montane forest spp are Fagaceae (11.56-28.85 %). Percentages of Fagaceae tend to be above 20 % in this zone; except for 11.56 % at 125 cm. Small trees/shrubs represent 8.8-22.2 % (based on pollen counts above 150 grains) and include Araliaceae, Gentianaceae, Juniperus and Myrica. Lycopodiaceae megaspores show a sharp rise at 159 cm (85.1 % total pollen and spores/297 counts).

Other taxa present in this zone include general forest taxa (7.14-20.23 %); open-ground taxa (15.3-29.08 %), which include Scrophulariaceae and Poaceae; and the aquatics Urticularia (0.97-3.7 %, although absent at 199 cm, 193 cm and 157 cm) and Myriophyllum (0.45-0.55 % at 157-153 cm). At 199 cm (from 337 to 22 counts) and at 165 cm, a sudden decline in pollen and spores takes place. A further decline in pollen grains takes place at 159 cm (from 234 to 18 grains) although spores are not affected. Tracheids, stomata, sieve plates, root hair and xylems are present throughout this zone, whilst two rice phytoliths were found at 192 cm. These were in a deteriorated state and have been classified as too small to be of cultivated varieties.

Zone Pa Buda-2 (110-52 cm): <6,320-6,220 cal BP
Pollen counts are quite low throughout this zone (between 48-100 grains); however, general forest and montane forest remain relatively constant, except for a slight decrease in montane taxa (from 25 % at 89 cm to 8.3 %) at 77 cm. The most prominent taxa in zone Pa’Buda-2 include Fagaceae, Cupressaceae, Cyathac eae and Polypodiaceae and Pteropsida. Pteropsida shows a higher representation compared to zones Pa Buda-3 and Pa Buda-1 (35.9-40.38 %). The aquatic Urticularia, which had been present throughout Pa Buda-1, disappears completely in this zone, as do megaspores. There is a significant reduction in palynofacies content (from 55.5 % to between 7.5-18.8 %, particularly hyphae: from 47 % to 4.1-7.04 %, stomata: from 0.54 % to 0 and tracheids from 0.54 % to 0). Small tree/shrubs show a marked decline in diversity. The diversity of kerangas taxa (except Ericaceae and Rhododendron) and open ground taxa also decrease.
Lianes disappear almost completely, with the exception of Menispermaceae at 53 cm (1.7 %). Open-ground taxa represent 32.8-62.4% cm (highest representation is at 77 cm) and include Iridaceae (37.5 %) and Scrophulariaceae (16.7 %). Shrubs represent 1.72-16.7 % (highest representation is at 77 cm) and include Sapindaceae (8.3 %), Sapotaceae (4.2 %) and Sarcococca (4.2 %). There is also a 6.25 % rise in the aquatic Potamogeton at 77 cm, whilst Arecaceae rise at 89 cm (13 %) and at 53 cm (10 %), but are absent at 77 cm.

**Zone Pa Buda-3** (52-0 cm): <6,320-6,220 to 0 cal years BP

Pollen counts are very low in this zone (14-34 pollen grains until 21 cm), although counts rise to 153 grains in the top sediments. This zone is mainly represented by a peak in the aquatic Isoetes (32.35-85.71 %), which is not present in zones Pa Buda-1 and Pa Buda-2. Montane forest species such as Fagaceae and Lithocarpus are also present. Between 47-37 cm there is a peak in Selaginella (26.8-21.5 %) and Liliaceae (11.76 %) at 37 cm. At 21 cm Arecaceae represents 11.76 %. Some small trees/shrubs are also present, including Myrica and also Sarcococca, which increases to 26.14 % in the top 1 cm. In the top 20 cm open-ground taxa are the dominant group and represent 26.5-37.3 %. This group includes Compositae, Malvaceae and Poaceae.

Zone Pa Buda-3 is also represented by the presence of long clear Poaceae phytoliths, which increase between 45-35 cm; although this is probably related to a decline in other palynomorphs, as counts increase from 9 at 37 cm to 37 by 1 cm. Hyphae also increase in the top 21 cm. Charcoal (from 7 to 83 counts) and SCPs also increase (from 0 to 3 counts) by 1 cm.

**11.6 Interpretation of results**

Section 11.6 provides an interpretation of all of the results described in this chapter (sections 11.2-11.5) and includes lithology, $^{14}$C dates, pollen, phytoliths and other palynomorphs. The interpretation has been divided into zones rather than as a unit of time due to uncertainties in the exact age sequence of this core.

**Zone Pa Buda-1** (203-110 cm): >6,480-6,320 to <6,320-6,220 cal years BP

At >6,000 cal BP the palaeochannel at Pa’Buda was not completely cut off from the river and was influenced by several flood events, which is demonstrated in the lithology by alternating sands, clays and organic bands. Alternating clays, sands and organic bands probably signify variations in the intensity of flow in the river system, with heavier sands deposited during increased fluvial activity, lighter silts and clays deposited during slower fluvial activity and organic bands.
deposited during periods of reduced flow. The presence of Lycopodiaceae megaspores, especially at 159 cm, is likely to be associated with fluvial deposition, as these are aquatic. Sudden declines in pollen and spores at 200 cm and at 165 cm, which appears to be associated with the presence of sands, suggest these heavier sands were deposited by flowing water, causing winnowing processes to take place and thus preventing the accumulation of pollen and spores. The presence of tracheids, stomata, sieve plates, root hair and xylems in the palynomorph record appears to be associated with the deposition of the organic bands. Charcoal flecks also appear to coincide with the organic bands. A number of charcoal pieces were extracted in this zone for radiocarbon dating, but only the two basal radiocarbon dates are in chronological order and higher dates are ‘older’. This suggests very rapid deposition of these sediments following a major fire and destabilisation of the catchment ca. 6,300 cal BP. Similar rapid accumulation rates are also demonstrated within the last 200-300 years in the Pa’Dalih core: CO1 (Chapter Ten). The range of dates between 6,000-7,000 cal BP most probably reflect old carbon effect and possibly the burning of trees up to 700 years old (i.e. primary rainforests).

The general vegetation around the channel, during this period, appears to have been relatively open, but surrounded by forest. This is reflected by the presence of both trees (montane and general forest); particularly Fagaceae and open ground taxa, such as Scrophulariaceae and Poaceae (throughout most of this zone). The presence of *Urticularia* suggests swampy conditions and may indicate reduced fluvial activity, whilst the absence of *Urticularia* at 199 cm, 193 cm and 157 cm and the presence of *Myriophyllum* at 157-153 cm, which prefers lakes, ponds, shallow reservoirs and slow moving water, but also fast moving water (Osmond, 2009), may be associated with increases in fluvial activity. Swampy conditions within the palaeo-channel are further reflected by rice phytoliths, characteristic of probable wild varieties, identified at 192 cm. At least four species of wild *Oryza* are known to grow in Borneo. These include: *Oryza rufipogon, Oryza granulata, Oryza ridleyi* and *Oryza minuta* (Gilliland, 1971).

**Zone Pa Buda-2** (110-52 cm): <6,320-6,220 cal BP

Between <6,320-6,220 cal BP forest taxa was still a major component of the surrounding vegetation, in which the most prominent taxa (shown in the pollen record) included Fagaceae and Cupressaceae. Despite the presence of forest surrounding the site, this period was also marked by major disturbance, indicated through various changes in the lithology, pollen, spore and palynomorph record. For example, the aquatic *Urticularia*, which had been present throughout Pa Buda-1, disappears completely in this zone as do megaspores, there is a significant reduction in
palynofacies content, particularly hyphae, stomata and tracheids, fern spores Cyathaceae, Polypodiaceae and particularly Pteropsida show a higher representation when compared with zones Pa Buda-1 and Pa Buda-3, which according to Behling et al. (1997) could be representative of disturbance, whilst a marked decline takes place in the diversity of small tree/shrubs, lianes and kerangas taxa (except Ericaceae and Rhododendron). These results coincide with a rise in large charcoal particles recorded in the lithology and suggest a major burning episode near the palaeo-channel, resulting in a significant decline in plant diversity. An alternative explanation for the rise in charcoal particles is that the flow had finally slowed enough to allow charcoal to settle following the build up of sand during flood events shown in the previous zone.

After the charcoal-rich sandy clay, saturated clays appear and the open ground taxa Iridaceae, and Scrophulariaceae increase, as do the shrubs Sapindaceae, Sapotaceae and Sarcococca. The Iridaceae are associated with swampy conditions (Yutang et al., 2000). There is also a rise in the aquatic Potamogeton. Certain Potamogeton species are adapted to deeper water (Iida et al., 2009) and this may be an indication that the palaeo-channel was gradually being cut off from the riverine system creating an oxbow lake/pool. At 75 cm very saturated clayey sand appears, again indicating pool development. A rise in open-ground taxa (e.g. Scrophulariaceae) and the sand content in the clays suggest open ground coverage may have become more pronounced, which could have been maintained by human activity. Areceae also show a notable increase (except at 77 cm), The Areceae family includes several species (e.g. Areca, Arenga, Calamus, Daemonorops, Elaeis, Korthalsia, Licuala, Oncosperma, Pinanga, Plectocomia and Salacca), which have a number of ethno-botanical uses; including for baskets, mats, building material, edible shoots, fruit and sago, (Christensen, 2002). These taxa occur naturally in Borneo, but their sudden rise in the clay suggests an increase related to disturbance. This might be linked to human activity as the Sapindaceae and Sapotaceae contain important fruit trees, and regeneration taxa such as Macaranga would be expected if the fire was natural; however, not all species of Sapotaceae and Sapindaceae produce edible fruit. The fruit trees might also have been influenced to some extent by low pollen counts. In a recent phytolith study carried out by Dr. Carol Lentfer in 2011, as part of this and the Cultured Rainforest Project (Appendix Ten), a substantial rise in palm/ginger type phytoliths were recorded at the same depth as the rise in Areceae, Sapotaceae and Sapindaceae pollen and therefore could be a further indication of human activity, possibly related to palm use; although not from Eugeissona, as Eugeissona pollen grains are not represented in the pollen record.
Zone Pa Buda-3 (52-0 cm): <6,320-6,220 to 0 cal years BP

Between <6,320 to 0 cal years BP episodic wetting and drying was taking place in the channel. This is demonstrated by a change in sediments to very iron-mottled orange organic clay. As explained in Chapter Seven iron mottling forms when iron in previously aerated soils becomes saturated and with the presence of organic material, lack of oxygen, occurrence of anaerobic microorganisms, ferric iron is reduced to ferrous iron resulting in a mottled appearance (Hanson and Whittig, 1980). Episodic drying of the water body may correspond to the beginning of wet cultivation; the age is however unknown, as no radiocarbon dates are available. The very high fern spores in this zone are also a sign of oxidation of the sediments, as these are more resistant than pollen (Hunt, 1994). A major non-sequence may have taken place in this zone, shown in the abrupt rise in Selaginella and Isoetes. Isoetes can be found in either permanent lakes, ponds, streams, estuaries and bogs, or on persistently wet soil; whilst other species are temporary aquatics that pass into dormancy as the pools and streams that they inhabit dry (FNA, 1993).

Long clear Poaceae phytoliths and hyphae increase during the first part of Pa’Buda-3 and demonstrate the dominant vegetation on the palaeochannel was Poaceae ca. <6,320-6,220 cal BP, which could either be from rice or grass. Only preliminary phytolith counts were taken from the Pa’Buda core; however as explained earlier, in 2011 a more detailed phytolith investigation was conducted by Dr. Carol Lentfer (see Chapter Twelve and Appendix Ten for more detail), which suggests not only rice cultivation, but also banana cultivation in the more recent sediments.

Despite low pollen representation, the general results indicate mixed vegetation, with the presence of forest, scrub and open ground taxa, including Fagaceae, Lithocarpus, Arecaceae and Myrica. In more recent times there appears to be an increase in open-ground vegetation, particularly Poaceae, Malvaceae and Compositae and this may be reflective of more intense anthropogenic activity in the area. An increase in charcoal and SCP counts indicate very recent localised burning in the area.

11.6 Summary

Radiocarbon dates from 203-89 cm of the Pa’Buda core represent ca.6,000-7,000 cal BP. There is a strong possibility that these dates represent very rapid sediment accumulation following a major fire and destabilization of the catchment, ca. 6,300 cal BP. During this period oscillating, but energetic fluvial deposition takes place within the channel until after >6,000 years BP (Similar rapid fluvial deposition is represented in Pa’Dalih CO-1 (Chapter Ten) within the last 200-300
years). The high diversity of open ground taxa, shrubs and aquatics, particularly *Urticularia*, and the occurrence of organic bands, suggest quiet water deposition at times in the channel. The presence of montane and general forest taxa suggests forest surrounded the palaeo-channel at this time. Wild rice phytoliths were present in the lower part of the core, but these are very probably a natural occurrence.

After the major burning episode there is an alternation in the nature of the taxa (i.e. reduction in open ground, kerangas and shrubs, disappearance of *Urticularia* and lianes, and the reduction in organic palynofacies). The disappearance of *Urticularia* and *Myriophyllum*, and the replacement by *Potamogeton* in conjunction with the appearance of sandy clay and slower deposition, suggest relatively still and deepening water, possibly linked to the formation of the oxbow lake. The burning event may have been human induced, as suggested by the rise in Palm and fruit trees, rather than by the appearance of regeneration flora. Another option is a natural burning episode linked to a short dry period, perhaps an ENSO event, but this doesn’t explain the absence of a regeneration flora after the burn and there is no real evidence for drought in the pollen record; i.e. high counts of *Myrica* and *Casuarina* would be expected, but this does not occur, although *Myrica* and *Casuarina* do not show any significant fluctuations in any of the Pleistocene sediments (from cores Ba, PDH 212 or PDH 210) either. These results could have been affected by low pollen counts, which might explain why evidence for drought or regeneration flora is missing. After the burning episode very saturated clayey sand appears followed by sands, indicating pool development.

Finally, within the last 50 cm (dates are unknown) the lithology changes to very iron mottled clays, with a steep rise in the aquatic *Isoetes*. These changes may represent the field being made in the palaeo-channel, in-which increased wetting and drying could be associated with wet cultivation. Large scabrate Poaceae occur at the present day, and an increase in open ground taxa is represented above 20 cm. A more thorough phytolith investigation has also suggested rice and banana cultivation in the more recent sediments.

In the next chapter, Chapter Twelve, the results from all sites investigated will be discussed, compared and concluded with reference to both the environmental history over the last 50,000 years and particularly the anthropogenic signatures in the last 2000 years.
Chapter Twelve
Discussion

12.1 Introduction
The tropical rainforests of Borneo are among the most biologically diverse areas in the world; however, very little is known about human/environment relationships in inland Borneo and until recently only limited palynological research had been undertaken in the lowlands and none in the Highlands, except for Flenley and Morley (1978) on Mount Kinabalu.

One of the main aims of this PhD thesis was to gather evidence of past and present relationships between people and the rainforest in the Kelabit Highlands of Sarawak, in-order to determine the development of early plant exploitation, management and cultivation. This project has particularly focused on the sago palm *Eugeissona* and the antiquity and timing of early rice cultivation. A further aim of this thesis has been to demonstrate the cultural and archaeological significance of the landscape to its people and to the world, as part of collaborative research with the members of the Cultured Rainforest Project. Future opportunities to do so may not be possible because of the re-modelling of the landscape and soil erosion caused by logging, which will disrupt and destroy archaeological evidence (eg. Rumah Ma’on Da’an Berangan, an old ridge top settlement, which was split in half by logging roads in 2007. See Appendix Four).

The environmental evidence gathered in this thesis has also been used to gain a better chronological understanding of the environmental and climatic influences affecting vegetation stability, potentially contributing to current debates on the responses of tropical ecosystems to climate variations. The thesis has concentrated on the environmental evidence, mainly through pollen analysis but also through phytolith and palynofacies analysis, loss on ignition and magnetic susceptibility, to understand how people impacted and managed the landscape over time.

12.2 Type material and vegetation-pollen relationships
Due to the limited availability of pollen reference material for South East Asia and in particular Borneo, an initial collection of 256 plants from various different habitats around Bario and Pa’Dalih was undertaken, to aid fossil pollen identification (see Chapter Four). The pollen grains extracted from these plants have provided an important reference collection that has been extremely beneficial to this project in
the identification of fossil pollen. Appendix One provides a detailed description of pollen morphology and photographic representation of all of the pollen grains collected.

Before work commenced on the core samples, it was considered important to understand the modern vegetation-pollen relationships in the Kelabit Highlands to:

A) Become familiar with the vegetation from various modern environments, which would be expected to occur in the fossil record. This would therefore aid the identification process.

B) Demonstrate whether there is spatial patterning of pollen fallout associated with different vegetation and human activities.

Due to time and also financial restraints (see Chapter Four) it wasn’t possible to set up pollen traps or to carry out transects, and only a very limited number of surface samples (seven) could be taken. In an attempt to increase the number of modern samples, the core top samples were also examined. A limitation of using core top samples is that they may not always represent modern day environments. The Bario core is an example of this. To try to minimize limitations, data from the modern pollen collection has also been used to provide a general representation of the plants found in the Bario and Pa’Dalih regions (See Chapter 5.4). The 256 plants were collected from within a 3.5 km radius of the core sites and include a range of habitats from kerangas forest, secondary forest, cultivated and open environments. Plants not in flower or too difficult to reach, such as tall trees, are not included. For further information on the types of plants found in Bario and at a higher altitude on Mt. Murud, see Latiff et al. (1999) and Beaman (1999).

Anderson and Muller (1975), who examined pollen rain in Borneo peat swamps and Behling et al. (1997) who investigated modern pollen rain from tropical rainforests on the Reserva Volta Velha, South Brazil, also identified a number of issues that should be taken into consideration when examining modern pollen rain. These issues would also affect fossil pollen assemblages and include: 1) The area of pollen sampling, which is small relative to the total pollen rain area of the study site 2) Small flowers or anthers from flowering plants which can drop directly onto the sample site, causing a strong local effect 3) Inter-specific differences in pollen production and dispersal and 4) Pollen and spores that have been transported from outside the study area, (for example wind-pollinated species). Anderson and Muller (1975) and Behling et al. (1997) however, argue that pollen transport from rainforest species can be very limited and pollen is usually transported over short distances. In the mountain flora of Borneo, Flenley (1973) suggests that pollen movement from higher vegetation zones is minimal, but that significant pollen from
lower vegetation zones will be deposited above the highest occurrence of the parent plants, particularly in poorly-vegetated mountain-top environments. Elenga et al. (2000), who examined modern vegetation dynamics of the tropical forests of the South Congo, and Behling et al. (1997), also showed that several abundant tropical rainforest species were very rare in the modern pollen rain or not represented in the pollen spectra, and that this was either caused by very low pollen production or poor preservation. In Borneo, major components of the forest such as the family Lauraceae, produce pollen which does not preserve in the fossil record; others such as the family Dipterocarpaceae produce very little pollen (Anderson and Muller, 1975, 325-326). By contrast, other taxa were sometimes “over-represented” as a result of high pollen production or dispersal. Despite these restrictions Anderson and Muller (1975), Flenley (1973) and Elenga et al. (2000) found that other taxa show a good relationship between plant presence and pollen occurrence, and are well reflected in the modern pollen assemblages by the dominance of arboreal taxa versus taxa representing herbs, climbers and ferns. Results showed a strong local presence, i.e. forests that developed in swampy environments are always well differentiated from those developed on well-drained soils or between forests occurring on sandy soils and those occurring on ferralic soils. Behling et al. (1997) also report a strong local effect, and when interpreting pollen records from modern pollen advise one must consider the different environments from which pollen rain data were obtained and from where palaeo-pollen records were taken.

Despite the limitations described above, pollen and palynomorph results from the surface and core top samples (with the exception of the Bario top sample), generally demonstrate a high representation of the vegetation in the immediate environment at each site. Some taxa have been blown/washed in from outside, but these percentages tend to be very low and therefore have little effect on the accuracy of interpretation of fossil pollen spectra. Spatial patterning of pollen fallout associated with different human activities has been demonstrated in a number of the surface samples. Thus there was poor pollen fallout caused by anthropogenic use of a ditch and a dominance of Poaceae and Cyperaceae pollen as well as high spore counts associated with the playing field in Pa’Dalih. High representations of spores, particularly Cyathaceae, Pteridaceae and Polypodiaceae therefore suggest some association with open ground. A study on tropical ferns in Sulawesi carried out by Wheeler (2004/2005) also showed that ferns can inhabit areas other than forest. Sapindaceae pollen grains were highly represented, associated with an orchard in Pa’Dalih. The investigations undertaken by Anderson and Muller (1975), Flenley (1973), Behling et al. (1997) and Elenga et al. (2000) have demonstrated that some degree of caution should be applied when analysing past vegetational environments and that a number of points should be taken into consideration (described above). Another consideration for future modern pollen studies could be to use...
moss pollsters instead of surface sediments, particularly if surface sediments have been disturbed, as these may provide a more accurate representation of the modern vegetation. An argument, however, for the use of surface samples is that unless completely bare of vegetation, the surface sediments should still provide a reasonably good representation of the modern vegetation, despite some disturbance.

Providing that the limitations described above are taken into consideration, the surface sample and core top sample results, from the Kelabit Highlands, have confirmed the viability of this project, by showing the importance of pollen analysis as a tool for examining past vegetational environments in tropical landscapes, and as a way of determining anthropogenic signatures on the landscape. The use of other proxies such as phytoliths, other palynomorphs, lithology, magnetic susceptibility and loss-on-ignition, help to provide a more robust interpretation of the environmental record, where limitations occur in the pollen record.

12.3 Palaeoecology and radiocarbon dating

The next stage of the project involved the palynological analysis of the six cores to provide a palaeoenvironmental history. In terms of pollen preservation, peat bogs and lakes are widely known to provide the best record (Moore & Webb, 1991). There are no lakes in the CRF research area however, and peat bogs are rare. Of the two CRF research areas, one peat core (Ba) was extracted from a bog in Bario, although Ba is also located in a palaeochannel (this was not known until after the site was cored), with a base dating from 49,006-46,479 cal yrs BP. No peat bogs were available in the other CRF research area around Pa’Dalih. The other five cores analysed in this project were taken from palaeochannels, on old river terraces, mostly near to the village of Pa’Dalih and to Pa’Buda. There was an attempt to search for and core other sediments, such as within secondary forest, but although the Eijkelkamp Livingstone-type piston corer works well on peat and lake sediments it could not penetrate through the tough vegetation roots. Tapioca and rice fields were also cored, but these sites are too oxidised for pollen preservation. They may however, hold potential for future phytolith studies. Palaeochannels were selected due to the lack of other available sites for pollen analysis, but also a) for their potential in providing an insight into changing environments b) for their potential in providing an insight into the timing of the local start of wet rice cultivation, after the palaeochannels became isolated from the river system; if wet rice cultivation did not take place, other anthropogenic signals might be recorded in the palaeoecological record, and c) if the channels eventually developed into oxbow lakes, then preservation would become relatively good, and therefore the palaeochannels could potentially provide evidence of both environmental and human influences. Limitations of using palaeochannels might include material being
washed in from other locations during flood events (anthropogenic induced or natural flood events). The Pa’Buda palaeochannel, however, would only have been influenced by in-wash from one tributary within the near vicinity, with a source no more than 10 km away; whilst the palaeochannels at Pa’Dalih may have been influenced by two tributaries with sources within a 14-16 km radius (see Section 3.10). All of these sources are within the Kelabit Highlands and at altitudes not very far above the coring sites. Even if some intermixing from different sources took place within the palaeochannels, as explained in Chapter Four, it was thought that a combination of different strands of evidence including changes in lithology, charcoal, phytoliths, pollen, diatoms, other palynomorphs and radiocarbon dating would still provide sufficient evidence to determine environmental change or past anthropogenic signatures on the landscape, over different time periods. A serious limitation might be sediment disturbance caused by wet cultivation, which could affect the chronological sequence of events, but the cores showed fine stratification which would have been disrupted by cultivation, strongly suggesting that this was not the case.

<table>
<thead>
<tr>
<th>Location</th>
<th>Core code</th>
<th>Age ranges</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bario. Peat bog next to the airport: N 03° 44, 0 and E 115° 29, 02. at 1064 m</td>
<td>Ba</td>
<td>49,167 to present (age/depth model on calibrated dates)</td>
</tr>
<tr>
<td>Pa’Dalih palaeochannel next to the airstrip: N 03° 33’ 29.6 and E 115° 33’ 21.6 at 957 m</td>
<td>PDH 212</td>
<td>47,468 ±611 C14 to present. (calibrated dates and age/depth model)</td>
</tr>
<tr>
<td>Pa’Dalih- palaeochannel just outside of the village gates: N 03° 34’ 06.2 and E 115° 33’ 11.7 at 957 m</td>
<td>PDH 210</td>
<td>26,886-29,563 to 13,105-12,907 cal BP (calibrated dates)</td>
</tr>
<tr>
<td>Pa’Buda- palaeochannel between the abandoned settlement sites of Batu Patong and Long Kelit: N 03° 32’ 1.4 and E 115° 33’ 15 at 954 m</td>
<td>BPG</td>
<td>Ca. 6,200-7,100 cal BP (calibrated dates, no dates above 89 cm)</td>
</tr>
<tr>
<td>Pa’Dalih- palaeochannel in a fruit grove next to the airstrip N 03° 33’ 51.4 and E 115° 33’ 20.2 at 957 m</td>
<td>PDH 223</td>
<td>2,352-2,322 to 1,715-1,604 cal BP to present (calibrated dates, no dates above 144 cm)</td>
</tr>
<tr>
<td>Pa’Dalih- palaeochannel behind the village school: N 03° 34, 04.1 and E 115° 33’ 11.4 at 957 m</td>
<td>PDH-CO1</td>
<td>1,221-984 to present (calibrated dates, but an age-reversal occurs at 163 cm)</td>
</tr>
</tbody>
</table>

Table 12.1: List of core locations and age ranges

To provide a chronological framework for the vegetational history for the Kelabit Highlands, radiocarbon dating was carried out on all cores. Table 12.1 provides a summary of core location and the age ranges for each core analysed. It should be noted that the sediments are in some cores discontinuous. Caution should therefore be applied when working with core samples in which age reversals occur. Howard et al. (2009) for example, report that macrofossils may produce younger ages as a result of root penetration and
that the use of multiple sequences of $^{14}$C dates would produce a more robust chronology. Further radiocarbon dating was not possible, due to limited funds. For future work, further radiocarbon ages might produce a tighter chronology. After samples were radiocarbon aged the statistical modelling program clam (Blaauw, 2010) was used to produce potential age/depth relationships for cores Ba, PDH 212 and PDH 223. This was not possible for the PDH 210, CO1 and BPG cores, due to an insufficient number of radiocarbon dates and the presence of some age reversals.

12.4 Natural Environmental Change: The Late Pleistocene

General vegetation

During the late Pleistocene, from ca. 50,000 years ago, semi-open montane flora dominated both the northern and southern Kelabit Highlands at Pa’Dalih and Bario. Outside of the flood plain on the Bario Plateau, for example, the Ericaceae family were particularly prevalent, but plants characteristic of vegetation at higher altitudes such as Fagaceae, Dacrydium, Podocarpus and Phyllocladus were also present. The general vegetation in Pa’Dalih (PDH 212) also consisted of very open upper montane flora, comparable with that recorded recently at 2400 m on Mount Murud (Beaman, 1999). The open ground taxa represented in PDH 212, however, show a lower representation than during the late Holocene, but with a more diverse range of regeneration flora, suggesting regular disturbance of the forest canopy. Climate was probably a major influence on the vegetation during this period, but there are some uncertainties to what extent upland plants were influenced by fluvial conditions and to what extent plants were being influenced by climate. Caution should also be applied when attributing taxa to temperature boundaries as some species may belong to more than one temperature range. This applies to Dacrydium which survives well in both montane habitats and on nutrient poor sands (Kitayama, 1992, Wong et al., 1987 and Mackinnon et al., 1998), and therefore could represent kerangas conditions on old braid plains rather than reflecting climate change. Hope et al. (2005) also report Dacrydium as occurring in swamp forest in the lowlands of eastern Kalimantan after 7500 years ago, whilst Anderson (1980) describes Podocarpus as predominantly a montane-sub montane species, although the species Podocarpus micropedunculatus (which has been recorded in the Kelabit Highlands) can occasionally be found in kerangas. When compared to the Holocene pollen record from Bario (see Chapter Six), however, the Ericaceae family, Phyllocladus, Podocarpus and Dacrydium generally show a much higher representation during the late Pleistocene and despite the fact that environmental conditions may have influenced these taxa to some extent, the results suggest, much cooler temperatures during the late Pleistocene than during the Holocene. Phyllocladus, Podocarpus and Dacrydium form forest above 2000 m on Mt. Kinabalu (Kitayama, 1992) and more locally between 1200-2424 m on Mount Murud (Beaman, 1999). These are
the main montane indicators for colder climates according to Canon (2001), whilst *Lithocarpus* and other Fagaceae spp, which are also representative of cooler climates, are lower montane taxa, largely found between 1000-2000 m and therefore likely to be indicative of cool temperatures. Beaman (1999) describes an oak-laurel lower montane forest after 1775 m, on Mount Murud in the Kelabit Highlands. Yulianto *et al.* (2005) also report that increased Fagaceae species may be an indication of increased precipitation. Between *ca.* >49,000-45,000 cal BP a significant representation of oak dominated woodland on the Barrio plateau could be associated with increased precipitation, although the presence of sands before 49,000 cal BP, representing high energetic fluvial activity, means the fluvial deposition of oak pollen grains from Mount Murud cannot be ruled out either. The only other dated late Pleistocene record from Sarawak, from the lowlands at Niah Cave, shows some pollen assemblages characterised by taxa such as *Quercus, Podocarpus*, Ericaceae and a few taxa now limited to the lower montane forest zone or above, such as *Prunus* (Hunt *et al.*, 2012). Hunt *et al.* (2012) also identified abundant regeneration taxa and open-ground species, alternating with lowland forest species. The high frequency of open-ground and regeneration taxa was interpreted as the result of climatic disruption of vegetation, while the assemblages typified by *Quercus, Podocarpus* and altitudinally-limited species, were interpreted as resulting from the depression of vegetation zones by annual mean temperatures 7-10º C cooler than present (Hunt and Premathilake, 2012). A similar pattern is seen at Lake Sentarum, in Kalimantan (Anshari *et al.* 2001, 2004). During drier-cooler climates Fagaceae forests might have migrated to lower altitudes and highland forests may have been replaced by more upper montane taxa. This would explain why a rise in Fagaceae at Barrio and Pa’Dalih might be linked to increased precipitation, and possibly increased temperature (particularly during the Holocene), but why a rise in Fagaceae in the lowlands might be linked to reduced temperatures.

**Fluvial activity and changing climates**

Both the northern (Barrio) and southern (Pa’Dalih) Kelabit Highlands show evidence of high energetic fluvial activity (i.e. deposition of sands, low organic content and aquatics) from *ca.* 50,000 years ago. The Barrio plateau may well have been part of a braid plain at this particular period. Thomas *et al.* (2007) have reported high energy fluvial deposition from NE Queensland, mainly during OIS3 (between 64-28 ka). Fig 12.1, a picture of the River Baram in the lowlands of Sarawak, is an example of river meandering, and demonstrates a low energy fluvial system. High energy systems are still present in the Highlands, but braided systems which are suggested by the Barrio core sedimentology are today only present in areas of very intense logging (Fig 12.2a and 12.2b). Morley (1981) suggests that the former presence of *Dacrycarpus imbricatus* in a peat bog in Kalimantan, which does not occur in the Sebunau River
catchment, and is currently restricted to above 1000 m, is an indication that local river patterns have in the past changed markedly. It could equally reflect dramatic climate change.

**Fig 12.1:** Evidence of low energy fluvial activity in Sarawak from the lower Baram River (N 3º 58'38.07 and E 114º 25'37.05 in the lowlands (Author, 2007)

**Fig 12.2a & 12.2b:** Fig 12.2a shows braid-bars found further up the Baram River (N 3º 17' 02.52 and E 114º 47' 48.65) in an area of intense logging (C. Hunt, 2008). Fig 12.2b shows clearly the intensity of logging in this area (Google Earth)

Between 49,000-30,000 cal BP diminishing fluvial activity is recorded in both the Ba and PDH 212 cores. These changes are reflected by fluctuations in sand, silt and clay deposits (Ba and PDH 212); decline in open ground taxa, diatoms and Poaceae phytoliths (PDH 212); iron mottled sediments (PDH 212) and a gradual increase in organic content (Ba). At PDH 212 bands of wood (451-459 cm, 442-440 cm, and 425-
422 cm) indicate that flow was virtually non-existent at these times. At site Ba the appearance and establishment of the Myrtaceae family and the appearance (e.g. Sapindaceae, Macaranga, Glochidion, Primulaceae and Vitaceae), increase (e.g. Loranthaceae and Lithocarpus) and decline (Angiopteris, Asplenium, Drosera, Annonaceae and Exallage) of other taxa (as discussed in Chapter Six) between 45,000-39,500 cal BP, may further reflect diminishing fluvial activity. These results also demonstrate the ability of vegetation to adapt to changing environments. The rate and extent of recovery is however, unknown. Another example of plants ability to adapt to changing environments is provided by Yassir et al. (2010), who examined secondary succession after fire in East Kalimantan. Results from this investigation show the average percentage of young trees and shrubs clearly increase with time after disturbance; although certain taxa (Melastoma, Eupatorium, Ficus sp., and Vitex) were found to be rare in secondary forest.

Despite diminishing fluvial activity at site PDH 212, flood events are likely to have continued, until ca.37,000 years ago. At site Ba a number of fluctuations took place in forest, shrub and herbaceous taxa between 42,000-30,340 cal BP, but no significant changes are represented in the lithology to suggest flooding, whilst sediments gradually become more organic. Fluctuations in montane forest, shrub, herbaceous and aquatic taxa may instead be related to variations in climate. A pronounced change in vegetation is particularly visible between 32,600-31,700 cal BP, with an increase in both open-ground vegetation and upper montane forest Phyllocladus, Podocarpus and Dacrydium, as well as a decline in certain wet soil taxa, including Elaeocarpaceae and wild Oryza types. These results suggest a period of increased aridity and possibly decreased temperatures, which may have led to a significant decline in canopy cover. Precipitation rates may have resumed between 31,700-30,340 cal BP, demonstrated by a rise in Myrtaceae, Cyperaceae, decline in upper montane forest and the appearance of wet unconsolidated organic sediments.

Noticeable fluctuations also take place in the Pa’Dalih 212 record, although these fluctuations appear to be associated with pollen preservation and burning events, rather than changes in pollen taxa: 1) Before 50,321 ¹⁴C yrs BP a number of major burning episodes took place. 2) Between 50,321-47,501 ¹⁴C yrs BP intense burning is recorded in the lithology and pollen preservation is poor. This is likely to have been caused by oxidation of the sediments after the burning event. 3) Before 47,501 ¹⁴C yrs BP another major burning event is recorded in the lithology and pollen preservation is again poor. The lack of vegetation cover caused by forest fires is likely to have resulted in more energetic fluvial activity, hence the deposition of sands shown in the lithology. 4) Between 47,501 ¹⁴C yrs BP-36,612 cal BP a further major
A burning episode is recorded combined with poor pollen preservation, shown by a drop in total pollen counts.

Burning episodes during the late Pleistocene have also been reported by Anshari et al. (2004), from a peat sequence at Lake Sentarum, W. Kalimantan. A substantial increase in charcoal, that probably occurred just before 30,000 cal BP, and is not clearly related to any major change in vegetation or sediment stratigraphy, has been suggested as being the result of anthropogenic burning rather than climate change. Van der Kaars et al. (2000) also attributes burning episodes from about 37,000 cal BP in the Banda Sea record to human impact and Thevenon et al. (2004) argues that micro-charcoal evidence at 53 ka, from the Caroline Basin in the Western Pacific, is from human induced fires. Although human activity cannot be ruled out, as we know from Niah Cave that people were in Borneo 50,000 years ago (Barker et al., 2007, Hunt et al., 2007), there is no strong evidence in the palaeoecological record at Pa’Dalih linking the burning episodes to people. There is also evidence to suggest people were more active on the landscape during the late Holocene, where thick charcoal bands are not represented. A combination of minimal anthropogenic fire activity and much drier climates during the late Pleistocene could have been enough to initiate major fires.

Alternatively both the Bario and Pa’Dalih results, discussed above, may reflect changing monsoonal patterns. Zhang et al. (2007) argue that precipitation is more variable than temperature in tropical monsoon regions, which therefore makes it an important climate variable. By comparing the ratio of iron oxide minerals from the South China Sea with δO¹⁸ data from the Hulu and Dongge caves, the results appear to show a much more arid environment between 50-39,000 years ago (see Fig 12.3). Fire episodes, occurring throughout the late Pleistocene ca. 40,000-10,000 cal BP at Nong Pa Kho in North East Thailand, have also been reported by Penny (2001), as representing moisture deficiency during the late Pleistocene. Kershaw et al. (1999) describe marine records around 50,000 cal BP as indicating a drier climate and suggest summer monsoon activity weakened during parts of the Quaternary period due to changes in the Pacific Ocean circulation. A more arid environment might explain the frequency of burning events shown in the lithology of PDH 212, although these results do not appear to agree with the Ba results. The Ba results show a rise in Fagaceae, possibly associated with increased precipitation, between >49,000-45,000 cal BP. No calibrated dates are however, available for the PDH 212 core until ca.36,000 cal BP, and therefore the rise in Fagaceae and the frequent burning events could have taken place during different time periods. The Fagaceae, as explained earlier could equally have been influenced by high energetic fluvial deposition. Burning events associated with increased aridity is
therefore quite plausible at PDH 212. Another explanation for the PDH 212 results could be fluctuations in aridity associated with ENSO oscillations. For example, Zhang et al. (2007) suggest from their results that El Niño and monsoon precipitation are correlated for the last 600,000 years, where during El Niño events precipitation decreased, and during La Niña events precipitation increased. Thevenon et al. (2004) argue that the northern hemisphere climate dynamics are connected with monsoon dynamics and ENSO patterns in the Indo-Pacific region. Research carried out by Thevenon et al. (2004) on black charcoal and micro-charcoal in the West Equatorial Pacific region appear to show a close relationship with changes in precession-originating insolation change.

Fig 12.3: Comparison of Hm/Gt (ratio of hematite to goethite) from ODP 1143 from the South China Sea and stalagmite oxygen isotopes from Hulu and Dongge Cave in south China (Zhang et al., 2007).
Fig 12.4: Kershaw et al. (2003): Relationship between charcoal peaks in the ODP 820 record of Moss (1999) and modelled ENSO activity, specifically the number of El Nino and La Nina events per consecutive 500-yr intervals, from Clement et al. (1999)
The results of Thevenon et al. (2004) also suggest that biomass burning emissions, associated with drought and ENSO like conditions over Papua New Guinea and northern Australia, were strongly constrained by monsoon circulation. Other evidence supporting variations in precipitation during the late Pleistocene, in South East Asia and the Pacific region, include Kershaw et al. (2003), who propose charcoal peaks in the Pacific region over the last 150 ka (several events can be seen between 46-36 ka) are associated with El Niño events (see Fig 12.4).

Despite various arguments for either increased or fluctuating periods of aridity during the late Pleistocene, Thomas et al. (2007) propose that although OIS3 climates were cool they were also considerably wetter than OIS2 (glacial climates) throughout much of the tropics and as a result this would have resulted in the appearance of high energy fluvial systems during OIS3. There is no doubt that a wetter climate would have increased runoff and that the Last Glacial Maximum was probably much drier than OIS3 at sites Ba and PDH 212, however, fluvial activity and vegetation during OIS3 in both the northern and southern Kelabit Highlands was probably influenced by variations in monsoonal precipitation. This may have been caused by either a change in the intensification of the winter monsoon, as suggested by Anshari et al. (2004), the summer monsoon, suggested by Zhang et al. (2007) and Hope et al. (2004) or linked to El Niño and La Niña events; with periods of extreme aridity and periods of intense rainfall. An opening of the vegetation cover caused by aridity, followed by intense rainfall, would have increased levels of erosion on the surrounding slopes, resulting in high energetic fluvial activity. Thomas et al. (2001) review stream sedimentation in the tropics (from NW Queensland, S Brazil, W Africa and Kalimantan) and argue that a prolonged depositional phase occurred during post-58 ka cooling, marked by extensive floodplains (now low terraces) and by fan deposits, whilst some cut-and-fill episodes at ca. 36 ka probably mark humid/arid fluctuations. This argument appears to be in agreement with the Bario and PDH 212 data.

Iron mottling was also recorded during the late Pleistocene in core PDH 212 and in core PDH 210, which could be further associated with natural fluctuations of the water-table, caused by changes in monsoonal precipitation. The water-table would have been much lower during dry events, caused by a reduction in and possibly more seasonal precipitation. As a result, wetting and drying of some fluvial channel sediments may have occurred, subsequently causing sediments to become mottled. Fig 12.10 summaries and compares the occurrence of iron-mottled sediments between cores.
12.5 Natural Environmental Change: The Last Glacial Maximum

Core PDH 210 contains sediments dating between 29,560-12,910 cal BP, and provides a partial link between the Pleistocene and Holocene record missing from Ba and PDH 212. In particular it was expected that the results from core PDH 210 might provide evidence of environmental and possible climatic conditions during the Last Glacial Maximum (LGM). Unfortunately there is an age reversal at the top of the core and there are insufficient radiocarbon dates to be certain if the other dates are in correct chronological order. This means it is not possible to pinpoint where the Last Glacial Maximum begins in the sediment record or to be able to compare variations in the pollen flora, occurring prior to the LGM (from 29,560 cal BP) with flora variations during the LGM. Despite these limitations and poor pollen preservation, a combination of the pollen taxa that could be identified, other palynomorphs, the lithology and magnetic susceptibility, has enabled an environmental history to be constructed and provides a general insight into the environmental conditions at site PDH 210, between 29,560 and 12,910 cal BP. The bottom of core PDH 210 is aged between 29,560-26,890 cal BP and this period may already have been experiencing changing climatic conditions, associated with the LGM. Thomas et al. (2001) for example, argue that after 28,000 cal BP, and certainly after 21,000 cal BP, river regimes altered radically due to increased aridity. The most noticeable event recorded throughout the PDH 210 record is fluctuating and very intense fluvial deposition; demonstrated by the deposition of alternating sands, clays and gravels with low carbon content. The climate may have been much drier-cooler than it is today and vegetation appears to be dominated by montane forest such as Dacrydium and Fagaceae. According to van der Kaars et al. (2000), there may have been up to a 30% reduction in precipitation, at least at lower altitudes in the Indonesian region during the Last Glacial Maximum. Thomas et al. (2001) suggest the cooling of tropical climates by more than 5°C at the LGM is now widely accepted, whilst the extent and amount of associated dryness are more disputed, but most views converge around rainfall reductions of (25) 30–50 (65) %, and this would not have been uniform throughout the tropics. Partin et al. (2007), however, argue for potentially small changes in northern Borneo rainfall during the LGM and instead suggest a reduction in temperature by 2-3.5 °C. This is based on three absolutely dated stalagmite oxygen isotopic (δ18O) records from northern Borneo. The oxygen isotope record also infers precipitation rates were at their lowest as Antarctic temperatures began to rise, during the early stages of deglaciations, 18-20,000 cal BP. A wet climate during the LGM, followed by increased aridity between 20-18,000 cal BP, does not appear to be reflected in the PDH 210 results. This may be due to the insufficient number of radiocarbon dates and low sample resolution. Several very thick charcoal bands in the PDH 210 record reflect a high frequency of intense forest fires, compared to what has been recorded during the Holocene at other core sites, and therefore could be representative of intense periods of drought. High open ground pollen, sands
and gravel deposition, and high magnetic susceptibility, demonstrate that the lack of vegetation cover caused by forest fires have probably intensified fluvial activity. A more seasonal climate with periods of aridity, followed by periods of heavy rainfall, may also have influenced fluvial deposition. A more seasonal climate might explain why aridity appears to be represented in the Kelabit Highland results, but why little change in precipitation is inferred from the LGM stalagmite record, in northern Borneo. On more than one occasion lack of vegetation on the surrounding slopes (caused by fires) at PDH 210 may have resulted in land-sliding, which temporarily blocked the riverine system resulting in the formation of temporary ponds/pools, demonstrated by the appearance of blue clays. It is also possible that slower fluvial deposition in pools simply reflects shifts in the braid-plain. Thomas et al. (2001) discuss a number of fluvial responses to increased aridity in tropical regions, post 28,000 cal BP. One of which includes fan deposition and/or braided river channels, caused by reduced rainfall with high seasonality, open forests and grassland. This appears to be what is taking place in the PDH 210 record.

Apart from core PDH 210, the LGM record is absent from cores Ba and PDH 212. Instead both these cores contain sediment hiatuses: 30,798 cal BP to 5,622 cal BP at Ba and 36,000-2,800 cal BP at PDH 212. The hiatus at PDH 212 appears after a burning event (37,940-36,610 cal BP), followed by a steep rise in diatoms and the appearance of pool sediments, which may be representative of an oxbow lake. Lake sediments do not appear in Ba. Fig 12.5 compares the hiatuses at Bario-Ba and PDH 212 with hiatuses occurring in sediment cores from South America (Sifeddine et al., 2001), Kalimantan (Anshari et al. 2004), Sulawesi (Hope, 2001) and Papua New Guinea (Hope, 1983). Most hiatus sites were selected within South East Asia, as regional climatic variations might be similar to the conditions experienced in the Kelabit Highlands, and therefore might provide an explanation for the Ba and PDH 212 hiatuses. Sites in South America were also selected to gain a more global perspective of hiatuses occurring in tropical regions and to understand if there is any potential link. Hope et al. (2004) describe chronological problems in many records from tropical regions between 24,000-12,000 years ago, and some sites show sedimentation hiatuses well into the Holocene. One theory for the hiatuses links them to human activity, as evidence from two of the core sites suggests people became more active within the landscape ca. 2000 years ago. In Kalimantan, Anshari et al. (2004) argue for burning attributed to human activity prior to 30,000 cal BP and between 18,400 to 5,120 cal BP; and Hope, (1998) argues that a hiatus occurring between 30,000 years until 1,770 years BP from a site in Irian Jaya is caused by fire associated with clearing (unknown if these dates are calibrated). At Ba and PDH 212 however, there is no other evidence in the palaeoecological record to link the hiatuses to human activity.
Sifeddine *et al.* (2001) describe a sedimentary hiatus between 22,000 and 13,000 $^{14}$C years BP (31,010-29,760 and 15,150-14,130 cal BP), at Carajas in the eastern Amazonian region of Brazil (see Fig 12.5), and relates these findings to drier conditions. Fig 12.5 also illustrates further sedimentary hiatuses in other regions of tropical South America. These have been compared with the Carajas record by Sifeddine *et al.* (2001) and are described as having variable intensity at different sites ranging from 30,000 and 12,000 cal BP. More locally a hiatus is also recorded between 22,200-19,500 to 6,700-6,000 cal BP at the Wanda site at Soroako, Sulawesi, and according to Hope (2001) either demonstrates episodes when sedimentation was very slow, had ceased or had even possibly been lost by erosion.

The research carried out by these authors has demonstrated that a number of factors both anthropogenic and natural can cause hiatuses to appear in tropical sediment records. It is interesting that the hiatuses occurring in the sediment records of cores Ba and PDH 212 are pronounced during the Pleistocene-Holocene transition. Intense aridity, during the Last Glacial Maximum with an opening of the vegetation, followed by increased precipitation during the onset of the Holocene, may well have increased runoff and intensified fluvial activity, causing severe down-cutting in the channels. The very dry conditions, frequent burning and intense fluvial activity represented in core PDH 210, demonstrates that the down-cutting theory for Ba and PDH 212 is quite plausible.
Fig 12.5: Comparison of hiatus occurrences from South American palaeoclimatic records (Sifeddine et al., 2001) with more local hiatuses occurring in Kalimantan (Anshari et al. 2004), Sulawesi (Hope, 2001), Papua New Guinea (Hope, 1983) and the Kelabit Highland hiatuses.
12.6 Natural Environmental Change: The Holocene

The general climate during the mid-late Holocene was probably much warmer than the late Pleistocene. This is suggested through a significantly lower representation of upper montane taxa than identified during the late Pleistocene in Bario (Ba) and in Pa’Dalih (PDH 212), particularly *Dacrydium*, *Phyllocladus* and *Podocarpus*. At PDH 223 and Pa’Buda (BPG) the upper montane taxa *Dacrydium* and *Phyllocladus* are generally significantly lower than the PDH 212 and Ba Pleistocene records, whilst Fagaceae show a pronounced representation in all cores. In New Guinea, Flenley (1984) also describes Fagaceae as dominant in lower montane forest. These results are likely to further reflect warmer-wetter climatic conditions during the mid-late Holocene in the Kelabit Highlands, as well as a migration of upper montane taxa to higher altitudes. When compared with the Pleistocene-Holocene record for Indonesia and Australia, Van der Kaars et al. (2000) equally describe the onset of the Holocene as experiencing a gradual migration of montane flora to higher altitudes and a return to more humid conditions in the lowlands. Morley (1982) reports, that climate amelioration during the early Holocene, in central Sumatra, saw a reduction in higher montane species such as *Podocarpus imbricatus*. The upper montane taxa *Podocarpus*, however, does not decline in the PDH 223 and BPG cores. Flenley (1979) states that although *Podocarpus* is dominant between 1800-2800 m in the highlands of Sumatra it can also be found at lower altitudes. The *Podocarpus* represented in PDH 223 and BPG may have been influenced by fluvial disturbance.

The Pa’Buda core (BPG) represents the earliest Holocene sedimentation record for the Kelabit Highlands, which is aged between 6,000-7,000 cal BP. Core BPG displays a different pattern of sediment accumulation compared to all of the other cores investigated (except CO1), in that all radiocarbon ages between 194-89 cm are 6,000-7,000 cal BP. There is a strong possibility that these dates signify very rapid sediment accumulation following a major fire and destabilization of the catchment *ca.* 6,300 cal BP (similar rapid fluvial deposition is represented in Pa’Dalih CO-1 (Chapter Ten) within the last 200-300 years). Forest fires are also recorded *ca.* 7000 years ago at Sikijang swamp, in Sumatra by Flenley and Butler (2001). They suggest probable anthropogenic disturbance 7000 years ago, but acknowledge that the evidence could equally represent natural forest fires. Similarly at site BPG, forest fires occurring 6,000-7,000 cal BP, could be associated with anthropogenic disturbance (see section 12.7 for a discussion on the potential evidence for anthropogenic activity), although natural disturbance is also a possibility and should not be ruled out either. A major natural forest fire, for example, could have taken place during a dry season, leading to canopy disruption, strong soil erosion and rapid river sedimentation. Hunt and Premathilake (2012) argue that high discharge around 10,370-8,310 cal BP at Loagan Bunut in the
Lowlands of Sarawak might be linked to the La Nina phase of ENSO oscillations and suggest an increase in ENSO events may have occurred earlier during the Holocene.

In Bario-Ba, sedimentation re-commences ca. 5,650-5,480 cal BP. A decline in kerangas may be further reflective of a warmer-wetter environment; however, the kerangas taxa Ericaceae, Vaccinium and Rhododendron are common around Bario today, and their low representation in the pollen record may be associated with both anthropogenic clearance and poor pollen dispersal. An increase in open-ground taxa could be a further indication of anthropogenic clearance episodes, although no other evidence has been recorded in the lithology, pollen or palynomorph record. Disturbance caused by erosion from intense precipitation or a low intensity flood event of the Dabpur River is also plausible, as sediments change into brown and then later grey clays, loss on ignition falls from 96.4 % to 83.7 %, and the aquatic Myriophyllum increases. Information obtained by Reedy, a guide from Bario, suggests that even today during periods of unusually intense precipitation, flood waters from the River Dabpur reach as far as the peat bog. Flood water from the catchment upstream is also a possibility. The flood event may be further representative of climate amelioration during the mid-Holocene, during which monsoonal precipitation reached its maximum. An alternative explanation for the flood could be a brief climatic event, with above average rates of precipitation. An increase in monsoonal precipitation during the mid-Holocene is represented at Ratanalkiri Province, north-eastern Cambodia, ca. 7,590-3,970 cal BP (Maxwell, 2001), whilst at Dongge cave, southern China, the oxygen isotope record suggests monsoonal precipitation was strongest between 9000-7000 years ago (Wang et al., 2005). Ratanalkiri Province and Dongge cave are however, on the mainland and may have been influenced by regional climatic variations. On the island of Borneo (based on isotopic evidence), Partin et al. (2007) suggest precipitation gradually increased from the Last Glacial Maximum to the mid Holocene, whilst Hunt and Premathilake (2012) identified the presence of wet monsoonal forest at Loagan Bunut (Fig 12.6) from 11,200 cal BP. Fig 12.6 demonstrates, with a chronology of inferred precipitation changes for selected sites in S and SE Asia, that monsoonal precipitation increased and reached its maximum between 12,000-5,700 cal years. Unfortunately due to the appearance of hiatuses in both the Ba and PDH-212 records, it is not possible to determine exactly when monsoonal precipitation began to increase in the Kelabit Highlands, although evidence from core Ba suggests a warmer-wetter climate prevailed by 5,650-5,480 cal BP. A rise in montane species in more recent times at PDH-212 could be associated with a late Holocene cooling. Thompson et al. (2006) suggest the latter part of the Holocene experienced widespread cooling, although some regions were cool and dry, whereas others were cool and wet. Maxwell and Liu (2002) also suggest decreased precipitation during the later Holocene (Fig 12.6). A rise in montane taxa is however, not represented in Bario-Ba and
therefore an alternative theory for the rise in montane taxa in Pa’Dalih could be a more open environment, caused by anthropogenic disturbance within the vicinity of the site. This would allow an increase in pollen blown in from higher altitudes.

So far the role of climatic influence during the Holocene has been discussed for the Kelabit Highlands, but more local environmental changes have also had an effect, particularly fluvial deposition. Past fluvial deposition is represented in the Pa’Buda core (BPG) and the Pa’Dalih cores (PDH 223 and CO1). At BPG, alternating sands, clays and organic bands >6,000 cal BP, suggest the palaeochannel was not completely cut off from the river and a number of flood events took place. These flood events may have been initiated by a major fire and subsequent destabilization of the catchment. After the major burning episode at Pa’Buda, the disappearance of *Urticularia* and *Myriophyllum*, in conjunction with the appearance of sandy clay and slower deposition, suggest relatively still and deepening water, possibly linked to the formation of an oxbow lake. At PDH 223, fluvial deposition with colluvial in-wash from the surrounding catchment, took place within the last 2000 years, but became less intense *ca.*1,870-1,720 cal BP. Iron mottling between 1,720-1,600 cal BP (Fig 12.10) probably reflects floodplain drying, caused by the gradual lowering of water levels and the seasonal wetting and drying of the channel. The channel dried up in more recent times, receiving only colluvial sediments. The youngest core, CO1, represents fluvial activity within the last 1000 years. Alternating sands and clays continue until 267-27 cal BP, which could suggest that slow fluvial deposition at this particular site continued until relatively recently.
12.7 Anthropogenic Activity and Impact

To determine whether or not evidence is anthropogenic, either specific proxies are needed (such as the identification of known cultivated crops) or a combination of proxies (e.g. sediment, pollen, phytolith, palynofacies, carbon content, magnetic susceptibility and charcoal), which together indicate human impact. The use of several rather than just one proxy provides stronger evidence for changes associated with climate (e.g. charcoal, a rise in open ground and a rise in montane taxa during cool-very dry climates), the local environment (e.g. sediments change to sands, clays, and gravels and a rise in open ground and aquatic taxa associated with fluvial deposition) or with people (e.g. the appearance of specific cultivated species (rice) or a rise in charcoal with different or increased percentages of open ground and disturbance indicators compared to what would normally be found during natural disturbance phases).

It is possible that the charcoal bands documented in the Pleistocene deposits, in PDH 212 are anthropogenic, but there is no other evidence to support this in the pollen, phytolith and other palynomorph record. BPG, as described earlier in section 12.1, also shows disturbance ca.6,000 cal BP, in the form of a burning episode (burning episodes for all cores are also summarised in Fig 12.11). The burning episode is subsequently followed by an increase in open ground, shrub taxa, palm trees and an increase in fruit trees, which could be related to anthropogenic management of the surrounding forest. A recent unpublished phytolith report produced by Dr. Carol Lentfer, as an extension to this project and as part of the Cultured Rainforest Project (see Appendix Ten); further argues for anthropogenic disturbance, possibly associated with palm cultivation. This is predominantly based on a rise in palm type phytoliths after the burning event. Other evidence stated in the phytolith report, for potential anthropogenic activity at the site, include a): continuity of increasing forest disturbance, b) a spike in burnt phytoliths, perhaps representative of hot fires that would result from burning dried plant material associated with garden plot or clearing maintenance and c) a decrease in vegetation biomass as a result of garden plot or clearing maintenance. This is indicated by a decrease in phytolith abundance. There are however, some uncertainties in both the pollen and phytolith evidence to be absolutely confident of anthropogenic clearance. For example, the palm type phytoliths identified by Dr. Carol Lentfer, could not be identified down to genus or species, whilst no Eugeissona pollen grains were identified in the pollen record. Barton (2005) has demonstrated people were processing sago in Borneo during the late Pleistocene at Niah, in the lowlands of Sarawak, which means that, despite an absence of Eugeissona pollen grains at site BPG, other palms might have been used for sago instead. Caryota and Arenga for example, can also be used for sago (Langub,1989; Puri,1997); however, Eugeissona utilis, a starch staple for the eastern Penan, are the
most common palm trees used for sago in the Borneo interior (Brosius, 1993). If palm trees were being cultivated at site BPG then representation of *Eugeissona* pollen grains might therefore be expected. Fruit trees belonging to the Sapindaceae and Sapotaceae family were also identified in the BPG pollen record, but as with the phytoliths could not be identified down to genus or species. The rise in fruit trees also coincides with a noticeable decline in pollen counts, which may have influenced the fruit tree results. Both edible and inedible fruit trees grow wild in the Kelabit Highlands. If the fruit trees are secondary forest species, then their increase could equally be associated with a natural opening of the canopy. These results do not rule out human related disturbance, but as described earlier natural burning should not be ruled out either.

By 2,840-2,740 cal BP people were likely altering the landscape around Pa’Dalih. A burning episode is recorded in the lithology at PDH 212, which coincides with a decline in forest taxa, and most importantly open-ground taxa increase to 77.5-78.9 % throughout the later Holocene until the present day, compared with 12.6-26.4 % during the late Pleistocene. An open environment is also represented in the phytolith record with Poaceae bulliforms, bilobates and elongated types increasing to 61 %. A combination of all of these different environmental indicators signifies anthropogenic maintenance of a cleared area from 2,840-2,740 cal BP around this site, until the present day. This may be representative of a more systematic management of the surrounding environment.

### 12.8 Sago

Christensen (1997) suggests sago may have been an important crop before rice. Barton (2005) identified palm starch belonging to either *Eugeissona* or *Caryota* at Hell Trench in Niah Cave, dated to ca. 40,000 cal BP and states this is almost certainly a result of human foraging activities. It is clear that Pleistocene hunter-gatherers already had the knowledge of plant distribution in the tropical rainforest, as well as the technical knowledge, to extract useful carbohydrates from roots, tubers and palm pith. The most significant evidence for sago use in the Kelabit Highlands takes place within the last 2300 years and is demonstrated in Pa’Dalih (PDH 223) and in Bario (Ba). Fig 12.7 represents a comparison of anthropogenic activity recorded from the northern and southern Kelabit Highlands in Bario and Pa’Dalih. In Pa’Dalih, PDH 223, there is strong evidence to suggest sago cultivation. This is demonstrated by above average representation of *Eugeissona* (both in comparison with other pollen taxa identified within PDH 223 and with *Eugeissona* pollen identified in the other core samples), indicating nearby sago cultivation/manipulation around 2,290 cal BP until *ca.1,760 cal BP*. After *ca.1,760 cal BP* there is
considerable reduction in *Eugeissona*. A plausible explanation for this reduction might be attributed to a combination of increased forest fires (recorded in the lithology), associated with increased anthropogenic activity on the landscape, and poor pollen preservation after ca.1,480 cal BP, which would have masked any further evidence for sago use. At Ba *ca*. 1,640-1,330 cal BP, a sharp rise in *cf. Campanulaceae*, age reversal and the appearance of the disturbance indicators Asteraceae, Caprifoliaceae, Lythraceae and Malvaceae suggest some form of disturbance, which could be anthropogenically induced. *Eugeissona* appears for the first time *ca*. 1,300 cal BP and remains consistent in small numbers until the present day, both in the pollen record and shown by a rise in spiny phytoliths. The fact that *Eugeissona* does not occur in the palynological record before 1300 years ago at Bario (single counts are present during the late Pleistocene in Pa’Dalih, PDH 212) and is then consistently present, despite low numbers, suggests palm trees were deliberately being manipulated for their edible sago *ca*. 1300 years ago, in the northern Kelabit Highlands. The rise in *cf. Campanulaceae* and the presence of disturbance indicators followed by the appearance of *Eugeissona* might be an indication of anthropogenic clearance to encourage the growth of sago palms. A flood event also takes place prior to and during the spike in *cf. Campanulaceae*. The flood could be a natural event or a subsequent effect of clearance, causing the area to be more susceptible to flood waters. One piece of charcoal with a reversed age (2,703-2,351 cal BP) appears during the deposits of the flood event, suggesting soil erosion and recycling of charcoal. If large areas were being burnt, more charcoal might be expected; however, the charcoal may have been washed away. Within the last 660 years an increase in echinate phytoliths, may represent intensification in sago use. From anthropological work it is known that sago has, until recently, been a staple crop for the Penan (Langub, 1975 and Voeks and Sercombe, 2000) and a number of sago groves are still present today in the Kelabit Highlands (Fig 12.8). Land clearance for other purposes could also have resulted in an accumulation of echinate phytoliths on the plateau. For example the burning of sago trees or erosional in-wash from adjacent hillslope cultivation might result in increased concentrations of palm phytoliths in the soil. Erosional in-wash is however, unlikely, as the deposition of eroded slope sediments has not been recorded in the lithology.
Fig 12.7: A palaeoecological summary of anthropogenic activity identified at Bario, Pa’Buda and in the Pa’Dalih cores: 212, 223 & CO1. White areas represent gaps in the record. Grey areas represent insufficient evidence to determine anthropogenic from natural disturbance. Black areas represent likely anthropogenic disturbance with enlarged areas, signifying a rise in agricultural practices.
12.9 Rice

Rice appears to have been first utilized in China around 14,000 cal BP with modern cultivated varieties appearing between 8,200-7,200 cal BP (Liu et al., 2007). Fuller (2007) argues however, that domesticated varieties of rice, indicated by a shift to predominantly mature-grained harvests (and inferred non-shattering), did not take place until 4,000 cal BC (ca. 6,000 cal BP). Bellwood, et al., (1992) and Doherty et al. (2000) suggest domesticated varieties of rice may have reached Borneo by 4,990-4,280 cal BP with Austronesian settlers, although local people may have been manipulating wild varieties as early as 8,000 cal BP (e.g. At Loagan Bunut: Hunt and Premathilake, pers.comm). Evidence of rice cultivation then remained uncommon in coastal Borneo until historic times. Barton (2012) argues that rice was not successful during the mid-Holocene, and in fact might not have been adopted until prehistoric times. Rice appears to be an illogical crop choice in the rainforests of Borneo, according to Barton (2012); it is difficult to grow, prone to failure and often low-yielding. By contrast, people had access to many other high yielding plants, particularly the sago palms. There was no evidence before the CRF project for the antiquity of rice in highland Borneo, although Christensen (2002) suggests that rice was introduced 1450-950 years ago. Domesticated rice (Fig 12.9, 12.12) is today an important food source to some of the people living in the Kelabit Highlands and according to Janowski (2003) is a symbol of status. Barton (2012) suggests rice may have been grown, not as a staple crop, but because its successful cultivation is inherently 'risky' and prone to failure. During the Pleistocene, only wild varieties of rice have been
documented, with one double peaked glume phytolith and scabrate Poaceae pollen appearing at <34,940-
<30,220 cal years BP at Ba, sometime between 37,940-2,740 cal BP at PDH 212 and between ca. 6,200-
7,100 cal BP at Pa’Buda. These were probably growing in the wet swamps around Bario, Pa’Buda and
Pa’Dalih. Undetermined rice bulliforms were identified dating between 2,840-2,740 cal BP, at PDH 212,
and a cf. Oryza sativa bulliform was identified 2,340-2,180 cal BP, at PDH 223, which could suggest
experimental forms of shifting rice cultivation 2800-2300 years ago. Some uncertainty, however, remains
and these bulliforms could perhaps belong to wild varieties growing in or near to the channel. A
description of shifting wet cultivation carried out by Dyak and Malay communities in Kalimantan
(Seavoy, 1973) provides a potential image on how shifting swamp cultivation could have taken place
2000 years ago in the Kelabit Highlands “The preferred location for wet shifting agriculture (paya) is
small interior valleys with flat floors drained by permanent water courses. The gradients of the streams
must be low enough so that water is on the ground and the valleys are shallow swamps for most of the
year, but the gradients must also be steep enough to drain the swamps during the dry season so that the
cut vegetation will burn. The ordinary succession of vegetation after the rice has been harvested is the low
glass Isachne glabosa, followed by a mixture of saplings and the tall sedge Scleria bancara. The saplings
would rapidly grow into a mature forest if left undisturbed, so generally would have been cut and burnt
every three to five years”.

The first certain evidence for rice domestication appears between 1,990-1,720 cal BP with the appearance
of one typical Oryza sativa bulliform, one Oryza sativa double peaked glume and several other near-
typical specimens at PDH 223. Frequent burning episodes, however, and increased magnetic
susceptibility at the time of the appearance of some of the identified sativa bulliforms, could be an
indication of dry shifting cultivation (Fig 12.9) rather than wet. A more detailed study is needed to
investigate this further. Wet cultivation (Fig 12.12) is also plausible, but not substantiated from the
channel sediments. In Pa’Dalih, the Kelabit say they have only cultivated dry rice until recently, as dry
fields also enable other crops besides rice to be grown (Janowski, 2003), whilst Seavoy (1973), writes that
dry cultivation is the one usually described, rather than wet. He also explains that wet cultivation (in
natural habitats, not established fields) is associated with greater risks, such as the dry season being too
short to cut and burn Scleria, or excessive rains drowning the seedlings. It is probable that the
domesticated varieties originated from exchange with lowland Borneo, where it is possible rice may have
been introduced from as early as 8,000 cal BP (Hunt and Premathilake, pers.comm). Exchange into
lowland Borneo also brought ceramics of Chinese origin (unpublished data from the CRF) into the
Highlands.
After 1,720-1,480 cal BP in core PDH 223, disturbance indicators increase (eg. *Macaranga*), burning becomes more frequent and iron-mottled sediments appear in the core. Iron-mottled sediments could suggest deliberate control of the channel for rice cultivation, but evidence for domesticated rice disappears after 1,720 cal BP. Alternatively the mottled sediments could be associated with lower water levels in the channel and seasonal wetting and drying, becoming more pronounced with lack of vegetation cover from anthropogenic slope clearance. Fig 12.10, which compares the sediment profiles for all cores where iron mottling occurs, demonstrates the presence of iron-mottled sediments both in the Pleistocene and during the Holocene. Natural wetting and drying probably occurred in the channels during the late Pleistocene, whilst a combination of natural and anthropogenic wetting and drying possibly occurred during the late Holocene. It is, however, impossible to determine natural from anthropogenic iron mottling from the sediments alone. Clearance of the surrounding slopes after 1,720 cal BP may have been for dry rice cultivation, as despite the lack of cultivated phytoliths, large scabrate Poaceae are present (it should be noted however, that some other species of Poaceae also produce scabrate pollen). If rice cultivation occurred further away from the channel, phytolith deposition may have been too far away to register in this record.

**Fig 12.9:** Dry rice field (*late luum*) with forest behind (Photograph: Dr. Monica Janowski, University of Sussex)
Rice cultivation is again apparent 400 years ago, with an increase in domesticated rice phytoliths appearing in core PDH 212. This coincides with a marked increase in magnetic susceptibility and a decline in diatoms and could again be associated with dry rice rather than wet cultivation on the surrounding slopes, with erosional inwash washing phytoliths from the adjacent slopes into the channel. Wet cultivation is however, also plausible, although not on the coring site, as there is no disruption of stratigraphy expected from cultivation. A decline in diatoms could instead be associated with a drier than average dry season and vegetation succession on the channel, followed by subsequent burning of the vegetation on the channel. An increase in magnetic susceptibility may reflect burning for rice cultivation but could equally be related to vegetation clearance for other reasons (sago, fruit trees, hunting, settlements etc.). Between 270-30 cal BP, further *Oryza sativa* bulliforms appear in the palaeochannel, just adjacent to the village of Pa’Dalih in core CO1. The domesticated bulliforms appear in very wet clay and could represent wet cultivation, or again could have been washed into the channel from elsewhere. Today CO1 is fallow and surrounded by fruit trees, such as durian, mango, passion fruit and coffee, although the site has been used for wet rice cultivation in the very recent past.

12.10 Other plants

Other species may have been cultivated/manipulated besides sago and rice during the mid-late Holocene. Pollen from fruit trees such as Sapindaceae, Sapotaceae and *Syzygium* have been identified in the majority of the cores, as well as pollen from trees that are used today for fire wood, craft material and wrapping food, such as *Glochidion* and *Macaranga* (Christensen, 2002). The fruit trees *Durio* and *Ficus* occur in Bario-Ba, whilst *Ficus* is also present in PDH212. Even if people were not cultivating these trees they may well have been encouraging them. Table 12.2 highlights the most common plants of economic value that have been identified in the Bario, Pa’Dalih and Pa’Buda records. Evidence is however, insufficient to assert with any certainty about the manipulation of plants other than *Eugeissona* and *Oryza sativa*, as pollen percentages for other fruiting and useful trees-shrubs tend to be low. For example, both Sapotaceae and Sapindaceae are also found throughout the late Pleistocene in PDH 212, PDH 210 and Ba-l and no significant increases occur during the Holocene, except ca. 6,000 cal BP at Pa’Buda (this could be related to anthropogenic encouragement although as explained earlier this could equally be associated with a natural opening of the canopy). *Durio, Syzygium* and *Ficus* are also present in both Pleistocene and Holocene deposits from Bario and again percentage values are low.
Fig 12.10: A timeline comparing the sediment profiles for all cores, in which iron mottling occurs. Orange squares represent all samples containing iron-mottled sediments. Question marks on BPG represent uncertainties in the exact age of iron mottling. White squares represent no sediment. Grey squares represent all samples with no iron mottle.
**Fig 12.11**: A timeline comparing the sediment profiles for all cores, where distinct charcoal bands occur. Black squares represent all samples containing charcoal. White squares represent no sediment. Grey squares represent all samples where no charcoal occurs.
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<td>P</td>
<td>P</td>
<td>P</td>
<td>P</td>
<td>B</td>
<td>B</td>
<td>B</td>
<td>P</td>
<td>B</td>
<td>P</td>
</tr>
<tr>
<td></td>
<td>Oryza sativa</td>
<td>P</td>
<td>P</td>
<td>P</td>
<td>P</td>
<td>P</td>
<td>P</td>
<td>P</td>
<td>P</td>
<td>P</td>
<td>P</td>
<td>P</td>
</tr>
<tr>
<td></td>
<td>Sapindaceae</td>
<td>P, B</td>
<td>P</td>
<td>P</td>
<td>P</td>
<td>P</td>
<td>B</td>
<td>D</td>
<td>B</td>
<td>B</td>
<td>P</td>
<td>B</td>
</tr>
<tr>
<td></td>
<td>Ficus</td>
<td>B</td>
<td>B</td>
<td>B</td>
<td>B</td>
<td>B</td>
<td>B</td>
<td>B</td>
<td>B</td>
<td>P, B</td>
<td>B</td>
<td>B</td>
</tr>
<tr>
<td></td>
<td>Durio</td>
<td>B</td>
<td>B</td>
<td>P, B</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Stenochlaena</td>
<td>B</td>
<td>B</td>
<td>B</td>
<td>B</td>
<td>B</td>
<td>B</td>
<td>B</td>
<td>B</td>
<td>B</td>
<td>B</td>
<td>B</td>
</tr>
<tr>
<td></td>
<td>Macaranga</td>
<td>P</td>
<td>P</td>
<td>B</td>
<td>D</td>
<td>B</td>
<td>B</td>
<td>P, B</td>
<td>B</td>
<td>B</td>
<td>B</td>
<td>B</td>
</tr>
</tbody>
</table>

Table 12.2: Plants, of economic value, appearing most frequently in the pollen and phytolith records of Bario, Pa’Dalih and Pa’Buda.

P: Pa’Dalih, B: Bario, D: Pa’Buda. Bold letters indicated a rise is a species, whilst a combination of bold and enlarged font size represent a substantial rise in species.
12.11 Recent Impacts

In more recent times the palaeoecological record has demonstrated anthropogenic use of the landscape in a number of different ways. In core PDH 212, Poaceae increase towards the top of the core and may be associated with the construction of the grass runway. Kerangas, shrub and montane taxa begin to increase again and may reflect wider environmental changes, as there are no traces of typical kerangas species or any montane taxa around the coring site today. Instead the coring site and surrounding area, which may have originally been the location of the previous Pa’Dalih longhouse, contains a group of fruit trees. The presence of *Oryza sativa* phytoliths until 16 cm (probably equivalent to ca. 220 cal BP) suggests rice cultivation continued until relatively recently at site PDH 223. Today rice cultivation is still taking place ca. 6 m away from PDH 223. Janowski (2003) explains that in the southern Kelabit Highlands, around Pa’Dalih, the construction of the runway during the 1960s-70s led to an increase in wet rice fields (Fig 12.12). At PDH 223, the palaeoecological record has also demonstrated the drying up of the channel and appearance of trees, particularly Sapindaceae, Sapotaceae and Moraceae. Today the channel is used as a fruit grove and a number of fruit trees belonging to these families represented in the pollen record are found growing in and around the channel.

![Fig 12.12: Wet rice field (Author, 2008)](image-url)
In core Ba a rise in certain open ground taxa in the top 7 cm (e.g. *Lygodium*, Scrophulariaceae, Malvaceae Capparidaceae and Pteropsida), drop in loss on ignition (87.8 % - 85 %), and increase in Pteropsida and in testate amoebae, may represent clearance for the construction of the new runway in Bario and peat development. The surface of the deposit has however, probably been eroded during forest fires. In core BPG, a change in sediments to very iron-mottled clays, within the last 50 cm (dates are unknown), and steep rise in the aquatic *Isoetes*, could be associated with wetting and drying during managed permanent wet cultivation. Seasonal wetting and drying, associated with monsoonal precipitation, is also a possibility (described earlier), and may have taken place as fluvial activity meandered progressively away from the palaeo-channel. Large scabrate Poaceae were recorded in the modern sediments and open ground taxa were recorded above 20 cm. Both likely represent rice cultivation, which is being undertaken on the palaeo-channel today. This evidence is supported by the phytolith report produced by Dr. Carol Lentfer (Appendix Ten), who argues that there is unequivocal evidence for rice and banana cultivation in the top sequence, suggesting an earlier traditional preference for other crops including sago and possibly taros and yams, or preferential modes of land use with crop specialization in the Batu Patong region. Table 12.4 summaries all of the palaeoecological evidence for anthropogenic activity and compares it with the archaeological evidence (see section 12.12 and Appendix Four).

12.12 Comparison with the Archaeological and Anthropological results of the CRF Project
The archaeological and anthropological investigations are not directly part of the PhD thesis, although they are part of the Cultured Rainforest Project. For this reason it was decided to put all relevant archaeological information associated with the Cultured Rainforest Project into the appendices (Appendix Four); however, both the archaeological and anthropological findings do support the overall palaeoecological results and therefore this next section will discuss and compare these results in more detail.

The earliest date of human activity from archaeological excavations (4,260-3,980 cal BP) was taken from a possible buried soil horizon at Ruma Ma’on Dakah, an abandoned settlement site at Long Kelit, to the South of Pa’Dalih. The site shows evidence for repeated occupation; although, there are some uncertainties to whether this date is correct and may mean settlement occurred much later. If the date is correct then it may pre-date the palaeoecological record for likely anthropogenic activity (Dates for archaeological sites are represented in Table 12.3), presuming that the BPG burning event is a natural event. This however, remains unclear. A rock shelter at Lepo Batuh, in the southern Kelabit Highlands, has been dated to between 2,760-2,480 cal BP. At this site 194 artefacts were recovered (see Appendix
Four for more detail), including various types of pottery, metal, mollusc shell, dammar and bone. This may be the earliest confirmed archaeological site, although some uncertainties remain on whether this was a previous occupation site. The date from Lepo Batuh is contemporary with palaeoecological findings for the earliest evidence, as yet, for likely *Eugeissona* manipulation, around 2,290 cal BP.

Rumah Ma’on Taa Payo, a ditched promontory near to an abandoned settlement site at Long Kelit (Fig 12.13) has been dated to 1,610-1,400 cal BP (Table 12.3). This may represent a transition from a nomadic to a more settled lifestyle by the Kelabit people. A more settled lifestyle would also explain the increased episodes of burning seen after 1,760 cal BP in core PDH 223, which could be the result of systematic management of the surrounding vegetation. A stone pounder, which when analysed was found to contain palm starch (identified by Dr. Huw Barton from the University of Leicester, pers.comm), was also recovered from a post-hole at the site (Fig 12.13) and further supports the pollen data for *Eugeissona* manipulation (Table 12.2), whilst the appearance of echinate phytoliths (probably of Palmae: Piperno, 2006) ca.2,840 cal BP from core PDH 212 may also be indicative of sago use, although sago pollen counts are low at that site and the pollen also appears in the late Pleistocene. At Niah Cave in the lowlands of Sarawak, however, evidence indicates the processing of sago palms before 40,000 years ago (Barton, 2005). Despite insufficient evidence for sago use ca.2,840 cal BP in the Kelabit Highlands, a much higher representation of *Eugeissona* pollen in comparison to most other plant species in Pa’Dalih (PDH 223) suggests *Eugeissona* was likely being managed for sago from at least 2,290 cal. No excavations were carried out in the northern Kelabit Highlands, although palaeoecological work has also demonstrated probable sago use from at least ca.1,300 cal BP.

**Fig 12.13:** Excavation site at Taa Payo: Stone pounders, iron blade and glass beads were excavated, and palm starch was also identified on the stone pounder, by Dr Huw Barton from the University of Leicester.
A rise in burning episodes after 1,760 cal BP (burning episodes are summarised in Fig.12.11) at PDH 223 (based on the frequent appearance of charcoal bands in the lithology after 1,760 cal BP, consistent appearance of *Trema*, which according to Liguo *et al.* (2003) is often associated with disturbed or degraded habitats, and a dominance of open-ground taxa, indicating a more open environment) combined with the archaeological site at Taa Payo (the use of the site is currently unknown, however, pottery, stone pounders, an iron blade and glass beads were excavated) may be an indication of increasing human activity such as the construction of the megalithic cemetery at Long Diit (Fig 12.14), where charcoal from a foundation trench of one of the stone jars has been dated to 1,262-1,080 cal BP (Table 12.3). An increase in palm phytoliths, recorded in the northern Kelabit Highlands (Bario) within the last 600 years might be a further indication of a more systematic management of the surrounding vegetation and a change to a more settled way of life.

**Table 12.3: CRF 07 Archaeological sample radiocarbon dates**

<table>
<thead>
<tr>
<th>Site</th>
<th>Notes</th>
<th>Sample</th>
<th>Lab. No</th>
<th>Date BP</th>
<th>Calibrated (2 Sigma)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rumah Ma’on Dakah/Long Kelit</td>
<td>Possible buried soil horizon from earlier phase of settlement occupation</td>
<td>Charcoal</td>
<td>Beta-237849</td>
<td>3770±40 BP</td>
<td>2310 - 2030 BC</td>
</tr>
<tr>
<td>Lepo Batuh</td>
<td>Lowest layer of shallow rock shelter deposit (max 20 cm). Probably entire depth of sediment bio-turbated.</td>
<td>Charcoal</td>
<td>Beta-237853</td>
<td>2550±40 BP</td>
<td>810 - 530 BC</td>
</tr>
<tr>
<td>Menatuh Long Diit</td>
<td>Megalithic stone jar cemetery</td>
<td>Charcoal</td>
<td>UBA-12420</td>
<td>1238±22 BP</td>
<td>AD 688-870</td>
</tr>
<tr>
<td>Rumah Ma’on Da’an Berangan</td>
<td>Fill of probable (longhouse?) post-hole at ridge top settlement site</td>
<td>Charcoal</td>
<td>Beta-237854</td>
<td>400±40 BP</td>
<td>AD 1430 – 1640</td>
</tr>
<tr>
<td>Benatuh Long Kelit</td>
<td>Packing fill in foundation trench of standing stone jar</td>
<td>Charcoal</td>
<td>Beta-237848</td>
<td>240±40 BP</td>
<td>AD 1510 – 1960</td>
</tr>
</tbody>
</table>
In the palaeoecological record experimental forms of shifting rice cultivation may have been taking place 2,800-2,300 cal BP, although the first certain evidence of domesticated rice in the palaeoecological record appears between 1,990-1,720 cal BP, which pre-dates evidence for rice in the archaeological record. Archaeological evidence for rice does not appear until relatively recently with charred rice identified in the fill of a foundation trench, containing an isolated stone jar, at Benatuh Long Kelit (close to Pa’Buda, Fig 12.15), dating to 440-0 cal BP (Table 12.3). The archaeological results suggest that rice had not only become an important food source, but had become ritually significant within the last 400 years. These results are complemented by the palaeoecological record, which also show an increase in domesticated rice phytoliths, at Pa’Dalih-PDH 212, during the same period. Both the archaeological and palynological evidence support the theory of Barton (2012), in that rice may not have become widely adopted until prehistoric times. According to Janowski (2003), before the Second World War rice was closely associated with status. Seavoy (1973) describes the transition, from shifting cultivation to more labour intensive continuous cultivation, only took place in response to population growth; although Barton (2012) suggests the risk of growing rice was attractive as a playing piece, in games of social competition between individuals. In the Kelabit Highlands a major increase in the construction of terraced wet rice began after the 1950s, as metal tools became more readily available after the Second World War, and also after the construction of the runway in Pa’Dalih during the 1960s-1970s (Janowski, 2003).
There is no evidence for the use of fruit trees or other plants in the archaeological record, although ethno-botanical work has identified 1,144 species, representing 172 botanical families, which have ethno-botanical importance to both the Kelabit and the Iban; these comprise of fungi, lichens, mosses, ferns, gymnosperms, monocotyledons and dicotyledons (Christensen, 2002). The only possible representation of other plant use in the palaeoecological record is a rise in both Sapindaceae and Sapotaceae at Pa’Buda, ca.6000 years ago. As explained earlier, evidence is insufficient to determine whether this rise has been caused by a natural opening of the canopy or by human activity.

Fig 12.15: Benatuh Long Kelit (The Cultured Rainforest Project)

Overall the archaeological, anthropological and palaeoecological results demonstrate the importance of inter-disciplinary approaches to the understanding of past human-environment relationships. Human activity became established within the Kelabit Highlands by ca.2,800-2,480 cal BP. Archaeological results from the Kelabit Highlands may go back further than the palaeoecological results with possible settlement 4,260-3,980 cal BP, however this remains speculative. At Niah cave in the lowlands of Sarawak, Barker et al. (2002) report various burials between 4,050-2,750 cal BP, of people using Neolithic pottery, who were assumed to be agriculturalists. Hunt and Rushworth (2005) report earlier cultivation at Niah, from 6,000 cal BP. At Logan Bunut, Hunt and Premathilake (pers.comm) argue for sago and wild rice use between 11,300 and 10,540 cal BP. In the Kelabit Highlands the palaeoecological
results demonstrate sago manipulation by *ca. 2,290 cal BP*, although if the phytolith record is correct, propagation of other palm types might have been taking place *ca. 6000 years ago*, at Pa’Buda.

<table>
<thead>
<tr>
<th>Age</th>
<th>Archaeology</th>
<th>Palaeoecology</th>
</tr>
</thead>
<tbody>
<tr>
<td>6,000 cal BP</td>
<td></td>
<td>Major burning, Appearance of fruit trees in the pollen record and palm trees in the phytolith record, but more evidence needed to confirm whether a natural occurrence or anthropogenic.</td>
</tr>
<tr>
<td>4,260-3,980 cal BP</td>
<td>Occupation at Ruma Ma’on Dakah at Long Kelit???</td>
<td>–</td>
</tr>
<tr>
<td>2,760-2,480 cal BP</td>
<td>Rock shelter occupation?? (Lepo Batuh)</td>
<td>–</td>
</tr>
<tr>
<td>2,480-1,700 cal BP</td>
<td>–</td>
<td>Episodic charcoal bands. Sago use: <em>Eugeissona</em> appears for the first time with above average representation in Pa’Dalih, between 2,290-2,180 cal BP until 1,990-1,720 cal BP. Rice cultivation: One domesticated rice bulliform (wet or dry cultivation and 2 * cf. domesticated rice bulliforms.</td>
</tr>
<tr>
<td>1,700 cal BP</td>
<td>Riverside settlement, iron, beads, stone (sago?) pounders (Taa Payo)</td>
<td>–</td>
</tr>
<tr>
<td>1,400 cal. BP</td>
<td>Pre-Megalithic settlement (Long Diit)</td>
<td>Both pollen and phytolith evidence in Bario beginning at 1,370-1,300 cal BP indicating cultivation of <em>Eugeissona</em> palms for sago.</td>
</tr>
<tr>
<td>ca. 1,000 cal BP</td>
<td>Earliest megaliths??</td>
<td>Continued sago use in Bario</td>
</tr>
<tr>
<td>600-200 cal BP</td>
<td>Probable increase in Megalithic activity. Re-use of older megalith: association with rice and dragon jar burials. Rumah Ma’on Da’an Berangan ridge top settlement. Taa’ Payo: Deer enclosure??</td>
<td>Intensification of <em>Eugeissona</em> use <em>ca. 600 cal BP</em> in Bario An increase in domesticated rice phytoliths from 400 years ago until present day at Pa’Dalih. (wet or dry cultivation)</td>
</tr>
<tr>
<td>219 cal BP</td>
<td>Stone jar burial at Long Kelit (440-0 cal BP)</td>
<td>Charcoal and domesticated rice phytoliths, 1 rice type pollen and diatoms: cultivation. Possible hill slope clearance-Pa’Dalih</td>
</tr>
<tr>
<td>82.5 cal BP</td>
<td>–</td>
<td>Charcoal possible hill slope clearance-Pa’Dalih</td>
</tr>
<tr>
<td>Present</td>
<td>–</td>
<td>Domesticated rice phytoliths-Pa’Dalih</td>
</tr>
</tbody>
</table>

**Table 12.4:** Summary of Archaeological (from the Cultured Rainforest Project) and Palaeoecological (from the author) results (Question marks demonstrate where there is some degree of uncertainty).
The establishment of domesticated rice in the Kelabit Highlands took place by at least 1,990-1,720 cal BP, although perhaps as early as 2,800-2,300 cal BP (Table 12.4). The rice phytoliths identified between 2,800-2,300 cal BP, however, could be representative of experimental forms of shifting rice cultivation. People may also have been manipulating the vegetation on the neighbouring island of Sulawesi, ca. 2,000 cal BP, based on a rise in charcoal fragments and low values of arboreal pollen (Kirleis et al., 2010), whilst in north-eastern Bali rice appears to have been important ca. 2,800 cal BP, based on rice husk-tempered pottery (Bellwood et al., 1992). In Thailand however, early rice agriculture was taking place by ca. 5,400 cal BP (Gorman, 1971). The archaeological, anthropological and palaeoecological results from the Kelabit Highlands all suggest increasing anthropogenic activity within the last 1000 years, although particularly within the last 400-600 years with a possible increase in sago and rice production. These results may indicate a shift from a nomadic to a more settled lifestyle, with the appearance of stone jar burials and later Chinese dragon jar burials, and the ritual association of rice with wealth and status. These results probably also reflect waves of migration into Borneo. For example, the appearance of rice/experimental forms of rice cultivation between 2,800-1,900 cal BP and the probable manipulation of *Eugeissona* palms for sago ca. 2,300 cal BP may reflect early Neolithic migration. Bellwood (1992) suggests by 5,400-2,000 years ago Neolithic Austronesian settlers may have entered Borneo from the Philippines and expanded rapidly around the coasts and up the rivers with little resistance from the existing populations. These results are supported by the appearance of boat burials, 4,950-2,750 BP (Barker et al., 2002) and cave paintings, 2,000-1,000 cal BP (Pyatt et al., 2005), at Niah cave in the lowlands of Borneo. A second wave of migration by Malaysian settlers, along the coasts and lower river-side regions of Borneo (Williams, 1976) may account for the increase in anthropogenic activity within the last 400-600 years in the Kelabit Highlands, particularly rice cultivation. The transfer of knowledge and metal tools may also have contributed to rice cultivation becoming culturally important to the Kelabit. Bellwood (1992) describes knowledge of iron and bronze metallurgy was introduced into the islands of Southeast Asia by 2000 years ago. According to Thiessen (2008), however, during the 11th and 13th centuries there was an explosion of trade between the China and Indo-Malaysian archipelago, in forest products, metals, gemstones and spices and by the 14th-15th centuries Islamic sultanates had become established in Brunei. The establishment of Islamic sultanates correlates to the same time period, in which rice cultivation appears to have become more established in the Kelabit Highlands. This may characterise a more systematic management of trade between the Malaysian settlers and indigenous populations in the interior of Borneo, which subsequently influenced the Kelabits perception of rice with wealth and status.
12.13 Summary
This chapter has drawn together the results from the six sites investigated from Bario, Pa’Dalih and Pa’Buda, and provides a palaeoecological history spanning 50,000 years (albeit not fully continuous), from the northern and southern Kelabit Highlands of Borneo, yielding the first information about the vegetation, environment and climates of inland Borneo during the late Pleistocene, Last Glacial Maximum (LGM) and mid-late Holocene. This project has used a number of different palaeoecological indicators to explore the relationship between people and the rainforest over time, with possible anthropogenic clearance recorded between 7,100-6,200 cal BP (although natural disturbance is equally plausible), probable anthropogenic clearance *ca*.2,800 cal BP, anthropogenic manipulation of sago palms *ca*.2,300 cal BP, rice domestication 2,000-1,700 cal BP and an increase in agricultural practices around 600-400 cal BP. The chapter has compared this evidence with findings from elsewhere in the region. The next chapter, Chapter Thirteen concludes the results discussed in this chapter, discusses the importance of the results and the potential for future research.
CHAPTER THIRTEEN:

CONCLUSION AND RECOMMENDATIONS
Chapter Thirteen

Conclusion

This thesis has produced an environmental record, spanning a period of 50,000 years for the Kelabit Highlands of Sarawak, Malaysian Borneo. The results are based primarily on pollen analysis, but also on the lithology, radiocarbon dating, other palynomorphs, phytoliths, loss on ignition and magnetic susceptibility. The results reveal patterns of vegetation change as a result of varying climatic, fluvial and cultural influences. Results discussed in Chapter Twelve and their potential implications are summarised below in sections 13.1a-13.1c. Contribution of results is discussed in section 13.2. Potential future research in section 13.3, followed by a final summary in section 13.4.

13.1a Vegetation

The general vegetation during the late Pleistocene, from 50,000 years ago, appears to have been dominated by semi-open upper montane flora, both in the northern and southern Kelabit Highlands, particularly *Dacrydium*, *Podocarpus* and *Phyllocladus*, although between 49,000-45,000 cal BP in Bario, oak forest showed a strong representation. The Ericaceae family were also particularly prevalent during this period. In Pa’Dalih small trees/shrubs and a wide diversity of open-ground taxa also existed, whilst after 45,000 cal BP in Bario, a decline in fluvial deposition allowed the Myrtaceae family to become well established. The mid-Holocene period experienced a general decline in upper montane forest and Ericaceae, whilst open-ground coverage increased (species diversity is lower than during the late Pleistocene in Pa’Dalih), both in the northern and southern Kelabit Highlands. During the late Holocene, kerangas, shrub and upper montane forest began to increase in Pa’Dalih. In Pa’Buda and Pa’Dalih grass also became more established during the late Holocene and in more recent times. Aquatics such as *Urticularia* and *Myriophyllum* have fluctuated throughout the late Pleistocene and Holocene record at all the sites investigated.

13.1b Climate and Environmental Implications

Changes in monsoonal precipitation and aridity during the late Pleistocene are likely to have been responsible for the frequent burning episodes, represented in PDH 212, and the development of high energetic fluvial systems, represented in PDH 212, PDH 210 and Ba, causing regular disturbance of the forest canopy. The Bario site was possibly part of a braid plain 49,000-40,000 years ago, suggested by the deposition of sands, with potentially wetter conditions or increased seasonality between 49,000-45,000 years ago. This is demonstrated by the high representation of oak forest, although Fagaceae pollen could equally have been washed onto the plateau by fluvial in-wash. Braid plains are only seen today in areas...
that have been extensively logged. These results highlight the instability of fluvial systems to both climate change and to openings in the forest canopy, not only in Borneo, but also potentially in other tropical regions of the world. Instable fluvial systems could have a disastrous affect on local communities, and also at a more regional level on corporate farmsteads and small towns. The vegetation has, however, shown ability to adapt after high energetic fluvial deposition in the past, with an increase in canopy cover after fluvial activity diminished (particularly shrubs and small trees. e.g. the Myrtaceae family in Bario and the fruit grove now growing on the site of PDH 223 in Pa’Dalih). The rate and extent of forestry recovery, however remains unknown. After 45,000 cal BP seasonality may have reduced in the Kelabit Highlands, shown by an increase in canopy cover and reduction in fluvial activity in the Ba record.

Higher percentages of upper montane taxa (particularly *Phyllocladus*, *Podocarpus* and *Dacrydium*), recorded during the late Pleistocene, than recorded during the Holocene period, identified both in the Bario and Pa’Dalih records, probably reflects much cooler temperatures. Despite cooler temperatures, small fluctuations in vegetation during the late Pleistocene have also occurred on the Bario plateau and may be related to changes in precipitation, rather than oscillations in temperature or fluvial activity (see Chapter Six). During the late Pleistocene in Pa’Dalih there appears to be a wider diversity of open-ground taxa than during the Holocene, although open-ground taxa representation is much higher than during the late Pleistocene. The change in composition of open-ground taxa here is likely to be associated with natural and more sporadic openings of the canopy during the late Pleistocene, allowing a wider diversity of open ground taxa to survive; whilst during the Holocene, there is a much more pronounced human signature on the landscape, particularly within the last 2,800 years. Frequent and intense anthropogenic clearance episodes during this period probably limited the diversity of open-ground taxa. This may mean that the diversity of forest taxa, if the forest was allowed to recover after extensive logging, taking place today, would also be much lower than what would be expected after natural disturbance episodes.

Although this project has provided an environmental record spanning the last 50,000 years, the Last Glacial Maximum record is missing from the Bario (Ba) and Pa’Dalih (PDH 212) cores, and age reversals occur in the PDH 210 core. The hiatuses in the sediment record at Bario (*ca.*30,800 cal BP to 5,620 cal BP) and at Pa’Dalih (*ca.*36,000-2,800 cal BP) may have been caused by highly energetic fluvial downcutting of the sediments, associated with a very dry and open landscape during the Last Glacial Maximum and subsequent intense precipitation and runoff into the channels. Despite the limitations of PDH 210, the lithology, palynology and magnetic susceptibility also indicate a much drier environment between 29,560 and 12,910 cal BP with very intense fluvial deposition and burning events, and these results therefore extend the Ba and PDH 212 results.
13.1c Land-use implications

A further aim of this PhD Project, in collaboration with the ‘Cultured Rainforest Project’, was to present the people of the Kelabit Highlands with an insight into their past, and to demonstrate the cultural and archaeological significance of the landscape to its people and to the world. The earliest archaeological date for the Kelabit Highlands is 4,260-3,980 cal BP at Rumah Ma’on Dakah, although there are some uncertainties to whether this date is correct. The palaeoecological results have shown a cultured landscape at least 2800-2000 years ago, with the appearance of clearance episodes, sago and domesticated rice; however, a lack of well-dated and informative sites for the period 11,000-2,500 cal BP makes it impossible to be sure of the exact time of arrival of domesticated rice into the Kelabit Highlands. At Pa’Buda some form of disturbance occurs between 7,000-6,000 cal BP, which might be associated with anthropogenic clearance for sago palms, although a natural event should not be ruled out. More research is needed to determine the events taking place at Pa’Buda.

The palm tree *Eugeissona* (which anthropological evidence tells us is still an important staple for the Penan) appears frequently from 2,300 until 1,700 cal BP at Pa’Dalih and from *ca.*1,300 cal BP in Bario, both in the pollen and phytolith record. The results corroborate the sago-pounder (identified by Dr. Huw Barton, University of Leicester), dated to 1,600-1,400 cal BP, from Taa Payo and suggest people were manipulating *Eugeissona* palms for sago. Experimental forms of shifting rice cultivation may have been taking place between 2800-2300 years ago, although the first certain evidence for rice domestication appears between 1,990-1,720 cal BP. The probable manipulation/cultivation of *Eugeissona* palms for sago *ca.* 2,300 cal BP and the appearance of rice/experimental forms of rice cultivation between 2,800-1,700 cal BP may reflect early Neolithic migration into the Kelabit Highlands. Clearance phases with abundant charcoal and open-ground pollen, as well as the settlement site excavated at Taa Payo (by the Cultured Rainforest Project), may also represent a more systematic management of the surrounding vegetation after 1,800 cal BP.

The phytolith results from Bario suggest possible intensification in the use of sago within the last 660 years. An increase in palm phytoliths could equally be related to clearance episodes on the surrounding slopes for other purposes, as pollen counts decline; although evidence for in-wash in the lithology is absent. There is also some evidence to suggest dry cultivation was being practised 460-300 years ago in Pa’Dalih. The presence of rice at a burial site at Long Kelit (excavated by the Cultured Rainforest Project) suggests that after 400 cal BP (although this may be site specific) it was not only considered an important food source, but according to anthropologists had also become a symbol of status. Today rice is still
considered a symbol of status by the Kelabit. Both the palaeoecological results and archaeological findings suggest increasing cultural activity within the last 1000 years, particularly within the last 400-600 years. These results may be linked to establishment of Brunei sultanates during the 14th-15th centuries, which could have encouraged a more systematic trade between the coast and Borneo interior. The results may also represent a shift from a nomadic to a more settled lifestyle by the Kelabit people.

13.2 Contribution of results

Preliminary results from this thesis and from the ‘Cultured Rainforest Project’ have so far been presented to Sarawak Museum staff; to Ose Marang, Kelabit Resident of the Miri Division (the administrative officer for the Kelabit Highlands); to the community of Pa' Dalih; at the BRC 9th Biennial International Conference 2008, Kota Kinabalu, Sabah; at the European Association for South-East Asian Studies (EUROSEAS) 2010 conference, University of Gothenburg; at the Southeast Asian Archaeology workshop, Oxford (2010); and at the ASA09 conference, University of Bristol. The work of the team was also reported on 'e-Bario', an internet site based in Bario, an important communications system for Kelabit people throughout Sarawak. The project is also sharing information with the International Timber Trade Organization (ITTO), an NGO working for the Sarawak government on a development plan for the Kelabit Highlands. The project has further developed existing links with the Sarawak archaeological service (Sarawak Museum) and local government structures, as well as deep relations with particular Kelabit and Penan communities. These will be important in developing future research plans.

In addition to an academic monograph and papers (see Appendix Eleven for publications so far), the project will also involve an exhibition at Sarawak Museum (Autumn 2012), and Cambridge University's Museum of Archaeology and Anthropology (date to be announced), helping to reach a large general audience (both exhibitions involve collaboration with the British Museum). Results from this thesis will also be presented at the BRC conference 2012 in Sabah and the EurASEAA 14 conference in Dublin.

13.3 Recommendations for Future Research

The results of this thesis provide potential for further research projects regarding

A) A maximum understanding of climatic and environmental impacts on the surrounding vegetation during the late Pleistocene. This would require higher resolution sampling strategies of Pleistocene sediments, the use of phytoliths, pollen and other palaeoecological proxies, as well as
further core sampling sites (potential long sequence sites may exist in the Kelabit Highlands on the Indonesian side of Kalimantan).

B) A better understanding of the sediment hiatuses occurring between the Pleistocene-Holocene transition. This would again require higher resolution sampling, a multi proxy record and further core samples to examine and compare changes taking place during the Pleistocene-Holocene transition. It would also require more geomorphological analysis than was possible during this project.

C) To understand the environmental, climatic, vegetational history during the early Holocene from further core sites as this record is currently missing from sequences located in the Kelabit Highlands.

D) To pin-point the beginning of rice and sago cultivation in inland Borneo, particularly between 11,000 and 2,500 cal BP, where there is a gap, with higher resolution phytolith and pollen analysis.

E) To examine the potential manipulation of other fruit trees and plants in the palaeoecological record. This again would require more core sites for comparison, a multi proxy record with phytoliths, pollen and other palaeoecological indicators and a more comprehensive understanding of ethnobotanical plants, which are either today being manipulated in the Kelabit Highlands, have in the recent past been manipulated or are completely wild but have or have had ethnobotanical uses.

F) To provide a tighter chronology with the archaeological sites, in order to gain a deeper understanding of the cultural significance of the landscape and the changing cultural signatures between different nomadic and settled forest communities.

G) Far more detailed vegetation-pollen and vegetation-phytolith studies, to explore the signature of the present vegetation in the palaeoecological record.

13.4 Summary
Overall, this project has produced a detailed history of the vegetation in the Kelabit Highlands, providing an insight into climate and environmental change (including fluvial deposition) during the late Pleistocene, Last Glacial Maximum and mid-late Holocene. This project has also demonstrated a clear cultural relationship between people and the environment from 2800-2000 years ago (with clearance
episodes, sago and rice cultivation). Earlier activity may have occurred at Pa’Buda, but further work is needed to confirm this. The results of this thesis provides potential for further research projects, particularly regarding climate modelling during the late Pleistocene and in gaining a better understanding of the sediment hiatuses during the Last Glacial Maximum; but also projects involving integrated pollen and phytolith analysis to try to pin-point the beginning of rice and sago cultivation in inland Borneo, particularly between 11,000 to 2,500 cal BP, and also to differentiate between wet and dry cultivation.
Bibliography


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Christensen, H. (2002) Ethnobotany of the Iban & the Kelabit, Forest Department Sarawak, Malaysia, NEPCon, University of Aarhus


Behavioural Ecology and the Transition to Agriculture, University of California Press, California: 237-264


Desein, S. & Groom, Q. [accessed from Spermacoce from Australia, 2009], National Botanic Garden of Belgium: http://spermacoce.myspecies.info/


Huang, T.C. (1972) ‘Flora of Taiwan’, Taiwan Univ Press. Taiwan


264


Malaysian Timber Council:


268


Murata, G. (1976) ‘Contributions to the Flora of South East Asia: Additions and corrections to the knowledge of Labiate in Thailand’, South East Asian Studies, 14(2)


North Greenland Ice Core Project Members (NGRIP) (2004), High resolution record of northern hemisphere climate extending into the last interglacial period: Nature, v. 431, pp. 147–151


Wong, K.M. & Kamariah, A.S. (1999), *Forests and Trees of Brunei Darussalam*, Natural History Publications, University of Brunei Darussalam, the Brunei Forestry Department and Brunei Shell Petroleum Co


Zhao, Z. (1998) ‘The Middle Yangtze region in China is one place where rice was domesticated: phytolith evidence from Diaotonghuan Cave, Northern Jiangxi’, Antiquity 72: 885-901


