9

Palaeoecology

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The nature of palaeoecology

Palaeoecology is the branch of ecology that studies the relationship of ancient plants and animals to their environments and as such can reveal the nature of environmental change through time.

This chapter reviews the history of human–environment interactions at Kuk as determined through the examination of subfossil evidence, mainly pollen and charcoal, for environments of the past. The palaeoecological results are interpreted below with respect to change through time with a focus on the archaeological phases. These results are then considered in terms of the palaeoecological records for the upper Wahgi Valley regionally and New Guinea more widely: the differentiation of climatically and humanly induced changes to environments in the past, changes in landuse pattern through time and resource availability.

In the upper Wahgi region of the Papua New Guinea (PNG) highlands, palaeoecological research has focused on the analysis of pollen and charcoal in sediment samples as a way of determining vegetation and fire response to past environmental (mainly climatically and humanly induced) change. The impact of people on the environments of highland PNG is most clearly documented by the replacement of primary rainforests and swamp forests with grasslands, secondary forests and gardens at times when other possible drivers of change, like climate, do not provide an adequate explanation (Fig. 9.1; Haberle 1994; Hope and Haberle 2005). Valley infill, eroded slopes and altered waterways may also at times be caused by human actions, together with the deliberate creation of terraced slopes and ditched plains. This is not to deny that dramatic climate change has also impacted upon the landscape and affected human societies over the same period. The separation of natural from human factors in landscape change is one of the key problems that is current in palaeoecological research.

Several different palaeoecological techniques have been used to reconstruct past environments for the Kuk wetland and its immediate environment. These include:

- pollen analysis (palynology) (Bennett and Willis 2001; see Textbox 9.1 here)
- charcoal analysis (Whitlock and Larsen 2001; see Textbox 9.1 here)
- entomological analyses (Porch 2008; see Textbox 9.2 here)
- diatom analyses (Battarbee et al. 2001; see Textbox 9.3 here)
- macrobotanical analyses (Fairbairn 2008; see Textbox 10.1 here)
- phytolith analyses (Piperno 2001; see Textbox 10.2 here)

Figure 9.1 Map of New Guinea showing the location of important archaeological and palaeoecological sites. The inset depicts wetland sites in the PNG highlands.

Source: Denham (2005a: Fig 1), reproduced with permission. Drawing by Kay Dancey, CartoGIS Services, College of Asia and the Pacific, ANU.

Textbox 9.1 Pollen and microcharcoal analyses

Simon G. Haberle

Pollen

The study of pollen and charcoal preserved in sediments is one of the main ways we can reconstruct past vegetation patterns and changes to the landscape through time (Bennett and Willis 2001). The techniques have been in use for nearly a century in the study of climate change, archaeology and human impact on the environment through to industrial application in petroleum geology.

Pollen grains are plant parts that play a role in fertilisation during plant reproduction and are found in the flowers of angiosperms and gymnosperms. Pollen is dispersed from one plant to another in many ways, but the most common are by wind (anemophilous) and by insects (entomophilous). Pollen grains are usually spherical or elliptical and vary in size from approximately 10 μm (0.01 mm) to 100 μm (0.1 mm). Their shape and surface texture can be used to identify them to a parent plant family, genus and sometimes even species. The tough structure of pollen grains means that they are readily preserved in anaerobic (low oxygen) environments, such as bogs and lakes (Fig. 9.T1.1). The sediments are sampled by coring and the pollen grains extracted from them using a series of chemical and physical treatments that concentrates them (along with other inert organic fractions such as microscopic charcoal). They can then be identified and quantified using light-transmitted microscopy (400–1000x magnification, Fig. 9.T1.2).

Figure 9.T1.1 Model of pollen dispersal mechanisms from the source plant to the point of deposition. Microcharcoal is dispersed in a similar fashion. Sediment cores are extracted from suitable anaerobic sites in the landscape.

Source: Drawing by Simon Haberle.

Figure 9.T1.2 Common pollen grains and microscopic charcoal from the highlands of PNG.

Source: Photograph by Simon Haberle.

By looking at the proportion of each pollen type that is preserved in sediments of known age, we can produce an 'index' of the vegetation surrounding the site. A time series of pollen spectra can be constructed by examining samples at intervals down a sediment profile. This provides us with a window into past vegetation changes at a particular point in the landscape (Fig. 9.T1.3).

Microcharcoal

Fine fragments of charcoal are preserved alongside pollen remains in sediments and can be used to reconstruct fire occurrence through time in the landscape (Whitlock and Larsen 2001). Microcharcoal is generally considered to be the fraction between approximately 5 µm (0.005 mm) and 100 µm (0.1 mm) and is quantified alongside analysis of the pollen. Peaks in charcoal abundance are interpreted as representing fire episodes in the past that may have contributed to changes in vegetation recorded in the pollen record. In some cases, increased charcoal occurs when forest pollen proportions are reduced, which may indicate that people have been clearing and burning the local forest (Fig. 9.T1.3).

Figure 9.T1.3 Example of a pollen spectrum derived from the Tari Basin.

The summary pollen record shows the changing proportion of pollen from forest, herbs and fern taxa through time (the last 30,000 years). Microscopic charcoal fragments have been quantified.

Source: Drawing by Simon Haberle.

Textbox 9.2 Insect assemblages from Kuk

Nick Porch

The use of insect remains—especially of beetles—in palaeoecology is well established in the temperate areas of the northern and southern hemispheres (Elias 1994; Porch and Elias 2000; Marra 2003). Tropical assemblages have been largely ignored for a range of reasons: the focus of palaeoecological and palaeoclimatic research on temperate regions; the perceived lack of suitable sites; and, perhaps, the understandable fear that the overwhelming diversity of tropical insects would render the task of identification and interpretation impractical. The analysis of Holocene insect faunas from Kuk was, at the time it was undertaken, a first for Quaternary entomology in the tropics.

Insect remains were recovered by Porch from samples (Table 9.T2.1) of basal ditch fill sediment using standard techniques that included sieving and kerosene flotation (Elias 1994). Insects were picked from floated residues under a binocular microscope and stored on micropalaeontological slides or, for fragile specimens, in ethanol. Figure 9.T2.1 shows a typical example of an insect assemblage composed of many different species and body parts, freshly picked from the floated sample. Identifications were made by comparison with material in the Bernice P. Bishop Museum, Honolulu, or with reference to publications describing the New Guinea fauna.

Table 9.T2.1 Summary of age, origin (bag, name of channel and location) and size of Kuk insect samples (total weight 21.598 kg).

Phase	Approximate Age (cal. BP)	Bag	Name of Baret	Location	Weight (g)
5/6	750–100	39	Simon's	A10g	1667
4	2000–1100	41	Ketepa's	A10f/g	2256
4	2000–1100	42	Ketepa's	A10f/g	2475
4	2000–1100	7	Neringa's	A10f	1850
3	c. 2800	-	Nema's	A10d	1739
3	c. 3000	18	Kui's	A10f/g	1684
2/3	c. 4000	43	Kum's	A10f/g	2305
2/3	c. 4000	19	Kui's	A10f/g	1602
2/3	c. 4000	26	Joseph's	A10f/g	2150
2/3	c. 4000	27	Joseph's	A10f/g	1800
1	10,000	20	Kundil's	A10f/g	2070
				Total	21,598

Source: Data collated by Porch.

Assemblage types

Not all sediment samples yielded equally diverse assemblages: older samples were richer and better preserved, whereas the youngest samples had fewer species and often poorly preserved individuals, reflecting intensive oxidation of material either before it was incorporated into the site or subsequently.

There are essentially two assemblage types with little overlap in composition:

- The single sample from Phase 1 is quite different from other samples.
- Samples from Phases 2, 3 and 4 are more similar to each other than they are to the Phase 1 sample; the single Phase 5/6 sample had a very small and poorly preserved fauna and is not discussed further.

Figure 9.T2.1 A typical subfossil insect assemblage including beetles, ants, bugs and mites.

Source: Photograph by Nick Porch.

What do the differences mean?

The Phase 1 sample contains a wide range of saproxylic and saprophilic beetles; saproxylic organisms are associated with dead and decaying wood (Grove 2002) and saprophiles live in decaying organic matter, often but not always on the forest floor. The abundance of these taxa, especially some that are obligate forest beetles, indicates that the assemblage is derived from closed forest. This is supported by the abundance of plant-eating taxa (phytophages), especially the presence of several platypodine and cossonine weevils that bore into living—often stressed—trees. There are relatively few aquatic or riparian taxa in the Phase 1 sample; those that are present are relatively uninformative in regard to the specific nature of the aquatic environment, but are consistent with a pool in forest. The absence of the flowing water species that characterise later phases implies that the channel from which the sample was derived did not have abundant flowing water.

In contrast to Phase 1, the samples from Phases 2–4 are dominated by aquatic and riparian taxa and contain a limited saprophilic fauna. A range of taxa indicates open environments, especially in the vicinity of the ditches. In these ditches, the presence of the elmid beetle *Austrolimnius* shows that clean, well oxygenated water flowed over sand/gravel, while other taxa suggest a mosaic of faster water and slower weedy habitats. Several riparian taxa are found predominantly on open sunny sand and mud beside running or standing water. The absence of platypodine and cossonine weevils and saproxylic taxa further supports the interpretation of open environments in contrast with the Phase 1 sample.

Textbox 9.3 Diatom analysis at Kuk

Krystyna M. Saunders

Diatoms are unicellular algae with a siliceous cell wall that preserves well in most sedimentary environments (Battarbee et al. 2001). They occur in all types of aquatic habitats and are highly sensitive to changes in their environment (Fig. 9.T3.1; Stoermer and Smol 1999). As a result, they are excellent indicators of a wide range of water types and quality, such as nutrient concentrations, pH, salinity, temperature and water depth (Stoermer and Smol 1999). However, diatoms have not been widely used in archaeological studies, despite several authors highlighting their potential value (e.g. Battarbee 1988) and their widespread use in palaeoecological studies (Smol 2008).

Diatom analyses have formed part of the multi-proxy palaeoecological analyses at Kuk (Denham, Sniderman et al. 2009). The major diatom taxa identified in the fills of Phase 1, Phase 2 and early Phase 3 features indicated that there were substantial changes, particularly from open water conditions in the Late Pleistocene to saturated and exposed soil conditions by the mid Holocene (Phase 2; Fig. 9.T3.2). A short-lived drying event c. 10,000 years ago (Phase 1) was associated with formation of an immature soil profile on the wetland margin. A marked transition occurs at the time of mounded cultivation at 6950–6440 cal. BP (Phase 2), when aerophilous, soil diatoms dominate.

Although mid to late Holocene assemblages are dominated by aquatic taxa, the assemblages are distinct from those of the Late Pleistocene when Kuk was an open water environment. High proportions of *Aulacoseira* sp. 1, and to a lesser extent *Synedra ulna* and *Eunotia praeurupta*, are common to both periods, but overall diatom compositions vary. These variations represent, in part, differences between an open water system (Late Pleistocene) and standing water environments within abandoned palaeochannels and ditches (Phase 3; mid to late Holocene). The lower abundance of species tolerant of high nutrients, pollution and turbidity in the mid to late Holocene also represents, in part, better water quality within the abandoned waterways. The retention of fine stratification within the fills of channel 107 indicates that they have remained waterlogged, whereas the fills of ditch 353 are shallower below ground surface, drier and have been admixed by a variety of soil formation processes.

1. *Aulacoseira italica* (Ehrenberg) Simonsen¹
2. *Caloneis bacillum* (Grunow) Mereschowsky²
3. *Eunotia praerupta* Ehrenberg²
4. *Navicula cryptotenella* Lange-Bertalot²
5. *Synedra ulna* (Nitzsch) Ehrenberg²

¹Diatoms of the United States

²Kelly et al. (2005)

Figure 9.T3.1 Common diatoms in the Kuk Swamp palaeoecological record. Scale bar is 10 microns.

Sources: 1. Diatoms of the United States (2013); 2. Kelly et al. (2005), reproduced with permission.

Substantial shifts have also been observed in an unpublished study of diatom assemblages at Kuk, as results of analyses undertaken by Barbara Winsborough (2003), in an appendix in Denham's doctoral thesis (2003a). These were undertaken for a range of archaeological and stratigraphic contexts dating to the early (Phase 1), mid (Phase 2) and late (Phase 3) Holocene. As noted above, the taxa associated with the late Holocene are distinct from taxa associated with the early and mid Holocene (with the exception of *Aulacoseira* sp. 1, *Synedra ulna*, *Eunotia praerupta* and *Luticola mutica*). Consequently, the diatom assemblages enable the local palaeoenvironments for different periods to be characterised: the early Holocene (Phase 1) was characterised by higher nutrients, and acidic and wetter conditions, likely reflecting at least some periods of standing water; whereas, the mid Holocene (Phase 2) was characterised by a dominance of 'soil' diatoms and drier conditions.

Figure 9.T3.2 Summary of dominant diatoms ($\times 10\%$ relative abundance) and the proportion of aerophilous and aquatic taxa in the Kuk Swamp palaeoecological record over the last c. 10,000 years.

Source: Drawing by Krystyna Saunders.

Although each technique provides a different type of record, the results complement one another to build up a coherent picture of past environments for the local Kuk wetland and its catchments. At present, the most comprehensive palaeoecological information is available for early and mid Holocene contexts (Phases 1–3), which were considered most significant for understanding the emergence and nature of early agricultural practices. There is limited information on the more recent archaeological phases at Kuk, i.e. Phases 4, 5 and 6.

Palaeoecological reconstruction at Kuk

Pollen and charcoal data have been used to reconstruct the palaeoecology of the Kuk wetland and catchments from the Late Pleistocene to late Holocene. The data are derived from a number of studies that have documented past vegetation in the region with a focus on understanding the timing and nature of past human influence on vegetation (Powell 1970a, 1976b, 1982a, 1982b, 1984; Denham et al. 2003; Denham, Haberle and Lentfer 2004; Denham and Haberle 2008; Denham, Haberle and Pierret 2009; Denham, Sniderman et al. 2009; Haberle et al. 2012). The nature and chronology of early and mid Holocene vegetation change and human impacts were established using palynology corroborated and supplemented by paired phytolith data (Denham et al. 2003). Seed and wood data have also been of some value for inferring environmental change (Powell 1970a, 1982a). Here we outline the environmental changes as interpreted primarily from pollen and charcoal preserved at Kuk Swamp and the wider Wahgi Valley from before 25,000 years ago to the present.

Sites selected for palaeoecological reconstruction in the Wahgi Valley were chosen to provide insight into the nature and timing of human impacts, including forest clearance, burning and the management of cultivated and non-cultivated plants (Table 9.1 and Fig. 9.1 for locations). These sites generally lie close to archaeological excavations, like Lake Ambra, or are directly associated with archaeological features, like the infilled ditches and pits on palaeosurfaces at Kuk Swamp. One of the limitations of the sediment sequences investigated lies in the apparent time gaps in the records. Most of the sites have continuous sedimentation from 5000 years ago to the present, but prior to this date there are major gaps in the records back to the Late Pleistocene. More recent analysis of samples from already dated sections of the Kuk Swamp sedimentary sequence belonging to the late glacial period and the early Holocene has allowed a more complete pollen record for the basin to be constructed (Denham et al. 2003; Denham, Haberle and Lentfer 2004; Denham, Haberle and Pierret 2009; Denham, Sniderman et al. 2009).

Table 9.1 Palaeoecological sites in the Wahgi Valley.

Site	Map ref. no. in Fig. 9.1	Altitude	Age range years ago	Reference
Kuk	1	1580 m	30,000–16,000; >9000–present	Powell 1984; Denham et al. 2003; Denham, Haberle and Lentfer 2004; Denham and Haberle 2008; Haberle et al. 2012; and this chapter
Warrawau (Manton's Baret)	5	1590 m	5000– present	Powell 1982a, b
Kindeng	4	1600 m	2000– present	Powell 1982a, b
Lake Ambra	8	1620 m	32,000–25,000; >5000–present	Powell 1982b
Ambra Crater	8	1680 m	4000–500	Sniderman, Denham and Finn 2009
Draepi-Minjigina	7	1890 m	36,000–18,000; >5000–present	Powell 1976b, 1982b

Source: Data collated by Haberle.

Figure 9.2 Late Pleistocene to late Holocene stratigraphy, radiocarbon ages and summary pollen diagram (pollen sum based on total forest and woody non-forest taxa) based on two cores from Kuk Swamp.

The Kuk 5A site is in C10W, the east drain of N-S Rd 4, 5 m south of its junction with the south drain of E-W Rd 3. The Kuk A10f/g site is 89 m south of E-W Rd 1 in the west wall of A10f/g. Their locations are shown in Chapter 6, Figure 6.4. The Pleistocene radiocarbon dates from the cores are on peats/organic muds which are prone to younger contamination and are therefore minimum age estimates (see Appendix 6.1 here).

Sources: Drawing by Simon Haberle. Kuk 5A and Kuk A10f/g cores redrawn from Powell (1984); and the Lake Ambra core redrawn from Powell (1982b). Reproduced with permission.

Visual or statistical comparison of pollen assemblages preserved in these sites across time and space makes it possible to group assemblages that reflect similar plant communities, such as rainforest or grassland, into pollen zones. This approach allows us to assess the extent and timing of change from one vegetation community to another and, in the present case, develop an understanding of the changes in vegetation community composition preceding and following the development of early agriculture in the area.

Based on the statistical analysis of pollen assemblages from palaeoecological sites in the Kuk Swamp region, we can present an account of the vegetation history of the region spanning the Late Pleistocene to the present. This time span can be divided into three broad periods comprising the Late Pleistocene (prior to 25,000 years ago), the Last Glacial Maximum (LGM, 25,000–18,000 years ago) to early Holocene (before 7,000 years ago) and the mid to late Holocene (7,000 years ago to the present). These periods are identified in Figures 9.2–9.4 as distinct pollen zones (Zones A–C), generally recognisable across the Wahgi Valley and applying specifically at Kuk Swamp. Analysis of the pollen from the three cores tells a parallel story of vegetation composition and change, which is divided into three shared episodes that register this: Pollen Zone A (before 25,000 years ago), Pollen Zone B (25,000–7,000 years ago) and Pollen Zone C (7,000 years ago to present).

Figure 9.3 Terminal Pleistocene to late Holocene composite pollen diagram of archaeological and stratigraphic contexts at Kuk Swamp, primarily of early and mid Holocene age.

The diagram shows selected pollen, spore and phytolith taxa plotted according to sample age and association with agricultural phases/features (left of diagram): gaps in the phytolith record relate to samples that have not been analysed; charcoal density refers to microscopic charcoal particle concentration from pollen samples. Four significant pollen zones are recognised, K-1 to K-4. Comparable pollen assemblages found throughout Kuk Swamp sediments are assigned to Pollen Zone B (25,000–7000 years ago) and Pollen Zone C (7000 years ago to present). See also Figures 9.2 and 9.4.

Source: Drawing by Simon Haberle.

Late Pleistocene, Pollen Zone A, before 25,000 years ago

Pollen records from Kuk Swamp from core 5A and drain A10f/g, in combination with that from nearby Lake Ambra, document vegetation change from before 25,000 years ago through to the late Holocene (Fig. 9.2). The summary pollen and charcoal records from these three sites show that prior to 25,000 years ago the valley floor was covered in almost 100 per cent mixed montane forest. This forest was dominated by a canopy of *Nothofagus* and *Castanopsis* with an understorey of Cunoniaceae and gymnosperms such as *Podocarpus*. The lack of charcoal particles and very low percentages of grass pollen and woody non-forest pollen point to an environment subject to little or no disturbance. Climatic conditions in the highlands prior to 25,000 years ago are considered to have been essentially cool, probably 2–4°C cooler than present, wet and relatively stable (Haberle, Hope and van der Kaars 2001).

Figure 9.4 Palaeoenvironmental reconstruction for the Kuk Swamp basin based on the composite pollen, charcoal and phytolith record in Figure 9.3, plus drain A10f/g from Figure 9.2 (% based on total pollen and spore sum excluding aquatics for both sections).

Comparable pollen assemblages found throughout Kuk Swamp sediments are assigned to Pollen Zone A (before 25,000 years ago), Pollen Zone B (25,000–7000 years ago) and Pollen Zone C (7000 years ago to present). See also Figures 9.2 and 9.4. Climate summaries follow Haberle, Hope and van der Kaars (2001).

Source: Drawing by Simon Haberle.

While the earliest indications of people in the Wahgi Valley date to around 37,000–31,000 years ago (see Appendix 6.1), the Kosipe area of the Owen Stanley Range has given archaeological evidence of human occupation as early as 49,000–44,000 years ago (Summerhayes et al. 2010). It is entirely possible that people were present in the Wahgi Valley, if only temporarily or seasonally, by this time, but without so far registering in the palaeoecological records. At Kuk Swamp there is a suggestion that people may have been having an impact on the valley floor vegetation as early as 25,000 years ago from the palaeoecological evidence, which shows an increase in woody non-forest pollen and charcoal around this time in the 5A core (Fig. 9.2). This would suggest a shift towards a more sustained use of the region by people that was significant enough to register in the vegetation history record.

The Last Glacial Maximum to the early Holocene, Pollen Zone B, 25,000–7000 years ago

LGM, 25,000–18,000 years ago

While our knowledge of climatic conditions during the period of earliest settlement in the highlands is extremely sketchy, there is a better understanding of LGM to early Holocene climates, thanks in part to long environmental records from marine sediments, coral cores and glacial records (Hope et al. 2004). From these archives it is known that the Ice Age climates of New Guinea were drier than the present, grasslands and savannah probably extended right across the Torresian Plain, the land exposed between New Guinea and northern Australia during periods of low sea level. The climate at high altitudes was also colder, with ice caps on many mountains along the central ranges. Long-term climatic and environmental trends based on the dynamics of equatorial glaciers and pollen records of treeline fluctuations indicate that conditions were dry and possibly as much as 5–7°C cooler during the Last Glacial Maximum (Haberle and David 2004) than at the beginning of the Holocene when a modern temperature regime took hold.

Alpine vegetation covered over 50,000 km² above 2700 m at the height of the glaciation about 25,000–18,000 years ago (Hope 1996), compared to some 800 km² today above 3900 m. Apart from changes in plant species composition through time, the vegetation boundaries on the lower mountain flanks and northern coasts may not have changed very much. Pollen evidence from peat sections near Mt Trikora (Hope, Flannery and Boeari 1993), Kosipe (Hope 2009) and Lake Sentani (Hope and Tulip 1994) provide records back 50,000 years or more. These data suggest that closed tropical and montane forests have continuously occupied many areas from before the likely arrival times of people. The wet conditions that supported the rainforests seem to have been maintained all along, indicating that the tropical waters of the Western Pacific Warm Pool north of New Guinea persisted through the Late Pleistocene (Thunnell et al. 1994), providing moisture to the high inland regions of New Guinea. Under these conditions it might be expected that the highland valleys lying below the altitudinal treeline would have maintained their forest cover throughout the LGM to the early Holocene. However, this is not the case, as at least two pollen records, from Tari (Southern Highlands Province, Haberle 1998b) and Kuk Swamp (Denham et al. 2003), have evidence for episodes of increased burning and loss of forest cover during the LGM to the early Holocene. Details of these vegetation changes at Kuk Swamp are presented here in Figures 9.3 and 9.4.

The period of postglacial warming, 18,000–10,000 years ago

The Kuk Swamp region in the period from 18,000–7000 years ago is very dynamic in terms of vegetation change, including a loss of the montane forest cover with shifts in forest composition towards a dominance of understorey and light-demanding components represented by genera like *Trema*, *Acalypha*, *Macaranga* and *Dodonaea*. The period saw the first evidence for major burning events followed by grassland expansion, showing that grasslands had expanded under the influence of fire. This process of punctuated forest loss, burning and changing forest composition continues to the end of the early Holocene, suggesting a dynamic pattern of forest and grassland persisted through this period. The reasons for these changes are not clear, though it is possible that people may have been responsible for an increase in the frequency of fire events. Alternatively, regional palaeoclimatic indicators point towards rapid and high-amplitude changes in temperature and precipitation, extended dry periods and high-frequency El Niño–Southern Oscillation (ENSO) events from around 18,000–10,000 years ago (Haberle, Hope and DeFretes 2001; Denham and Haberle 2008), that may have been of sufficient magnitude in the highland valleys to impact upon natural vegetation cover and fire regimes.

The argument for people being a factor in vegetation change in the Wahgi Valley from the LGM to the early Holocene is limited to inference from what is known of the nature of human occupation and resource exploitation in the region during this period and the changes recorded in the pollen records. The human occupants of the Wahgi Valley during the LGM inhabited a largely forested valley floor, with a gradually decreasing proportion of upper montane forest (dominated by *Nothofagus*) and a corresponding increase in the proportion of lower montane forest (dominated by *Castanopsis-Lithocarpus*) through time. In addition to faunal resources, the landscape offered ready access to the nutritious members of the high-altitude *Pandanus brosimos/iwenjuiulianettii* complex (Haberle 1995), as well as to diverse resources of the lower montane forests (Golson 1991a).

Rather than merely passively gathering resources, it may be suggested that people were already opening up patches in the forest using fire and, arguably, stone tools to ringbark and clear vegetation (after Groube 1989). People possibly focused on gaps in the forest canopy, such as those caused by tree-fall and landslides, as well as riverbank and wetland ecotones, where resources may have been different and potentially more diverse than those found under the forest canopy (Denham and Barton 2006; Haberle 2007). Some gaps in the forest would have been maintained through fire and clearing and patches of grassland would potentially have formed adjacent to wetlands and along river corridors due to localised and sustained forest disturbance. As patches became maintained foci of activity, so too the resources within those gaps—including herbs (*Musa* spp.), tuberous plants (potentially including taro and yams), grasses (*Saccharum* spp. and *Setaria palmifolia*) and a wide variety of leafy vegetables—were brought under increasing management (see Table 10.1). Although people may not have resided permanently in the Wahgi Valley at this time, there are many reasons to believe that mobile groups lived permanently within the forested interior of New Guinea during the Pleistocene (Denham 2007c).

The early Holocene, 10,000–7000 years ago

This period has been a particular focus of recent palaeoenvironmental research at Kuk (Fig. 9.3, Zone K-2 to K-3) because of a lack of information about it in the upper Wahgi Valley in general. The situation was remedied by targeting samples from a continuous series of monoliths extending from the Late Pleistocene to the late Holocene, as well as by collecting and radiocarbon dating samples from the fills of palaeochannels and palaeosurface features (Denham, Sniderman et al. 2009). This has enabled detailed reconstructions of palaeoenvironments during both the early and mid Holocene (see Fig. 9.3 for detail). In addition, a composite diagram from Kuk Swamp is reproduced here to illustrate the vegetation history from before the LGM to the present (Fig. 9.4).

In the first thousand years of the early Holocene (Fig. 9.3, zone K-2), mixed montane forest was replaced by a more open forest environment, with local swamp forest dominated by *Pandanus* (probably *P. antaresensis*) and *Schefflera*. The deposition of a massive grey clay unit across the swamp surface (Fig. 9.3, zones K-2 and K-3) occurred at a time when grasslands and fern flora increase at the expense of forest under the influence of periodic fire episodes. At the same time, the catchment forest became more open, with subcanopy taxa, particularly *Pandanus*, dominant. The grey clay unit has long been considered a result of erosional processes associated with catchment destabilisation due to forest clearance under shifting cultivation (see Chapters 6 and 11). However, increased sediment mobilisation due to natural processes associated with increased precipitation and vegetation destabilisation at the end of the period of postglacial warming cannot be ruled out.

Denham (2005b: 301) discusses the nature of agricultural practices at this early period and suggests that the earliest gardens were likely to have been small areas of specially prepared ground, actively planted for only a short time and characterised by the vegetative propagation

and intercropping of plants from wild and heavily tended sources. The most significant evidence for the emergence of more intensive forms of plant exploitation is associated with microscopic remains from two major edible plants present in the Kuk vicinity at this time, namely *Colocasia* taro and *Musa* (until recently *Eumusa*) section bananas (Denham et al. 2003; see Table 10.T2.1 for bananas and Fig. 10.T3.2 for taro; on the change of section name in banana see Table 10.1, note 7).

Banana phytoliths are present at the base of the grey clay unit (see Fig. 9.3). Their frequencies within later grey clay contexts are significant, with intact phytolith chains indicating that the parent plant was growing on the spot (Table 10.T2.1). *Colocasia* taro has been identified from starch residues on the cutting edge of a flake collected from the fill of an early Holocene feature (see Fig. 10.T3.2). The same is true of artefacts collected from within grey clay (see Chapter 20, section 'Between Phases 1 and 2'). There were starch grains of yam, *Dioscorea* sp., on a used stone from the base of the Phase 1 palaeochannel (see Fig. 10.T3.3), while a felsic volcanic core tool low down in the grey clay above the Phase 1 palaeosurface had residues of both yam and taro starch (Chapter 20, section 'Between Phases 1 and 2'; Fullagar et al. 2006: 605).

Mid to late Holocene, Pollen Zone C, 7000 years ago to present

At the beginning of the mid Holocene, around 7000 years ago (Figs 9.3 and 9.4, Pollen Zone C), there was a rapid loss of forest together with increased burning at Kuk and an open grass and sedge swampland was established. These developments were associated with the beginnings of archaeological Phase 2, a period of mound cultivation that represents the earliest evidence for more intensive forms of plant exploitation, in the context of swidden agriculture and extensive foraging and gathering (Denham et al. 2003; Denham, Sniderman et al. 2009; cf. Chapter 12 here). The evidence for similar mound cultivation at Mugumamp and Warrawau at a somewhat late date (Denham 2003b: 173–174) suggests that forest clearance, widespread use of fire and the establishment and maintenance of disturbed environments were regional processes in the upper Wahgi Valley, reflecting the emergence of an agricultural landscape from around 7000–6500 years ago. This predates Powell's (1982b: 218) pollen record from Warrawau, but when the latter does begin, around 6000 years ago (calibration of ANU-252, Powell 1970a: 146), it shows the environmental changes that we are discussing to be well under way.

The emergence of more intensive plant exploitation at Kuk in the form of mounded cultivation is associated with further microscopic evidence for *Colocasia* taro and *Musa* section bananas, two major edible plants that were identified in early Holocene Phase 1 contexts at the site, as discussed above. Relatively high frequencies of banana phytoliths, including those of the *Musa* section, in early Phase 2 contexts are, in view of their association with the mound technology, especially significant (Denham et al. 2003: Fig. 3; Table 10.T2.1 and Fig. 10.T2.1 here). Given the low productivity of phytoliths in bananas relative to grasses, elevated frequencies in Phase 2 contexts have been interpreted as indicating the cultivation of bananas on the wetland margin within a landscape degraded to grassland (Denham et al. 2003: 191–192). *Colocasia* taro starch has been identified on an artefact found in the fill of a Phase 2 feature (see Chapter 20, 'Phase subdivision 2C'; cf. Fullagar et al. 2006: 607).

During the mid Holocene, plant exploitation is likely to have been extremely diverse and have included gathering, patch creation, swidden cultivation and intensive forms of mounded cultivation. These practices would all have co-occurred across the landscape, with a gradually increasing reliance on plot cultivation as access to primary or disturbed forest became more restricted for groups inhabiting the valley. Following several thousand years of persistent forest disturbance, most of the valley floor and slopes were degraded to grassland (Figs 9.2–9.4). A major loss of high-diversity valley-floor swamp forests (Haberle 2007) and the expansion

of dryland environments are indicative of persistent agricultural activity during this period. By around 2500 years ago, only isolated pockets of disturbed forest survived within the valley, with stands of heavily utilised primary forest confined to the higher slopes above 2000 m. The extensive grasslands carpeting the floor of the Wahgi Valley were periodically burned and would have been depauperate in large to medium-sized mammals and in edible plants. Within this highly degraded but intensively settled landscape, people had less access to land for swidden cultivation and foraging. Although these activities were still likely to have been practised by people living on the valley floor where and when possible, such people became increasingly reliant on intensive forms of cultivation, mounds and other types of raised bed cultivation on dryland and ditched field systems in wetlands.

Several archaeological sites of wetland drainage for cultivation besides Kuk are on record for the upper Wahgi Valley and adjacent regions, like Kana, Mugumamp, Warrawau, Draepi-Minjigina and Tambul (Fig. 9.1 inset), with Mogoropugua and Haeapugua further afield in Southern Highlands Province (Golson 1982; Denham 2003b, 2005a, 2007a). Rectilinear ditch networks like those of Kuk Phase 3 were in use in the Wahgi and at Tambul by 4000 years ago, the Tambul site producing an early wooden agricultural implement of that date (Golson 1996), while there is evidence at a number of sites of phases of abandonment and reuse on the Kuk pattern (Denham 2005a: Table 2). Current evidence suggests that these developments were indigenous (Chapters 5 and 13; cf. Denham 2005a). Not only would the drainage of wetlands to create ditched field systems have greatly increased the area available for cultivation, but the drained land, particularly compared with heavily weathered valley slopes, would have been extremely fertile, amenable to cultivation for several years without fallow and relatively resistant to the increased frequency of ENSO-induced droughts.

Complementary developments in the dryland sphere are discussed for Phases 4 and 5 in Chapters 14 and 15, respectively. They comprise the adoption of soil tillage around 2500 years ago, *Casuarina* agroforestry techniques around 1200 years ago and raised-bed cultivation sometime between 1000–500 years ago. All these represent strategies to alleviate the consequences of forest loss followed by soil nutrient depletion. In the case of deliberate planting of *Casuarina* close to settlements, this development would have removed the need for further forest destruction for timber and thus reduced the resource loss that such destruction entailed.

A final word

The story of agricultural development in the highlands of New Guinea is one of continuing indigenous innovation in agricultural techniques in the face of increased land degradation and climate change (cf. Haberle 1994; Haberle and David 2004). Further insights into how agriculture transformed these highland valleys can be gained through application of new approaches such as high-resolution sampling and multi-proxy palaeoenvironmental reconstructions (Denham, Haberle and Pierret 2009; Denham, Sniderman et al. 2009). These insights bring us one step closer to understanding how people adapted to major environmental perturbations such as changing climates, land degradation and volcanic eruptions.

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