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A multi-disciplinary method for the investigation of early agriculture: Learning lessons from Kuk

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Abstract

The multi-disciplinary methods used to investigate early agriculture at Kuk Swamp in the Highlands of New Guinea are outlined. Methods adopted during the original investigations in the 1970s (directed by Jack Golson, with Philip Hughes from 1974), as well as during renewed investigations at the site (directed by Tim Denham from 1997 under Golson's supervision) are considered. Three methodological contributions to the study of early agriculture and plant exploitation are highlighted: X-radiography, biostratigraphic markers, and the integration of macrofossil and microfossil analyses. One outstanding methodological problem is considered, the representativeness of different components of a feature fill for reconstructions of past cultivation practices. Thoughts on an integrated method (macrofossil, microfossil and molecular) for future research on early agriculture and arboriculture in the region are presented.

Keywords: Multi-disciplinary method; early agriculture; X-radiography; biostratigraphic markers; macrofossils and microfossils

Introduction

Multi-disciplinary investigations at Kuk Swamp in the Upper Wahgi Valley have confirmed New Guinea to be a centre of early and independent agricultural development (Denham et al. 2003, 2004a, 2004b; Golson 1977, 1991; Golson and Hughes 1980; Hope and Golson 1995). These investigations have identified successive periods of manipulation of the wetland margin for plant exploitation and swamp drainage for cultivation. Although claims for agriculture dating to 10,000 years ago are contentious (Phase 1; Denham 2004a; Denham et al. 2004a), there is general agreement that mounded cultivation occurred on the wetland margin at c. 7000/6500 cal. BP (Phase 2; Denham et al. 2003, 2004a). From approximately 4000 years ago to the present (from Phase 3 onwards), the wetland was periodically drained using ditches. The agricultural history at Kuk, at least from approximately 6000 years ago, is corroborated by archaeological and palaeoecological findings at other sites in the New Guinea Highlands (Denham 2003a, 2005a; Golson 1982; Haberle 2003; Powell 1982a).

In this paper, the multi-disciplinary methods used to investigate early agriculture at Kuk are summarised. The rationale of the methodological approach adopted is outlined and three significant methodological contributions are sketched. A subsequent methodological problem arising from the research is considered. The paper concludes with some thoughts on developing new integrated research methodologies for future investigations of plant exploitation in the Pacific.

The multi-disciplinary method: Description, rationale and value

Initial claims for early and independent agriculture in New Guinea were based on multi-disciplinary investigations at Kuk directed by Jack Golson from the 1970s onwards (and with Philip Hughes from 1974; Golson 1977, 1991; Golson and Hughes 1980; Hope and Golson 1995). As discussed elsewhere (Denham 2006), these claims were not universally accepted (Bayliss-Smith 1996; Spriggs 1996). The reasons for scepticism centred on limitations with the multi-disciplinary lines of evidence published for the early and mid-Holocene at Kuk. These limitations were:

- a lack of published archaeological evidence;
- uncertainties regarding the mode of formation and function of archaeological features;
- a lack of palaeoecological evidence contemporary with the earliest claimed agricultural remains; and,
- equivocal archaeobotanical evidence for the presence, use and cultivation of plants (cf. Powell 1982b; Wilson 1985).

Denham's multi-disciplinary investigations of early agriculture at Kuk, initiated from 1997 onwards, were designed to address these evidential deficiencies (Tables 1 and 2; Denham 2003b). A team of researchers from a range of disciplines was required because each contributed essential information to the investigation of early agriculture and plant exploitation:

- Archaeology: evidence of the features and artefacts associated with former cultivation and plant exploitation practices.
- Archaeobotany: evidence for the presence, use and cultivation of edible, and otherwise useful, plants.
- Dating: chronological resolution for interpretations of past human activities.
- Palaeoecology: evidence of environmental transformations associated with former practices, and their differentiation from climatic and tectonic-induced transformations.
- Stratigraphy: characterisation of former palaeosols and sedimentation through time, including evidence for past soil preparation and the effects of post-depositional processes.

Research components		Outcome
1. Archival study of previous multi-disciplinary investigations in 1970s and early 1980s	→	Integration of archaeological and multi-disciplinary investigations to determine types of plant exploitation associated with Phases 1, 2 and 3 at Kuk
2. New archaeological excavations at Kuk in 1998 and 1999	→	
3. New multi-disciplinary investigations using a suite of dating, palaeoecological and stratigraphic analyses	→	

Table 1. Overview of the three main research components for renewed (from 1997) multi-disciplinary investigations of early and mid-Holocene remains at Kuk.

Research Field	Period	Methods
Archaeology	Original	Excavation trenches (n=187) Archaeological and stratigraphic recording in plantation drain walls (n=>15 km)
	Renewed	Excavation trenches (n=19)
Dating[1]	Original	Conventional radiocarbon dating (n=52; RSES, ANU)
	Renewed	Conventional and AMS radiocarbon dating (n=36; RSES and ANSTO)
Palaeoecology	Original	Macrobotany: seeds and wood (n>500; J. Powell/L. Lucking) Phytoliths (n=30; S. Wilson) Pollen (n=31; J. Powell)
	Renewed	Diatoms[2] (n=50; B. Winsborough) Insects (n=10; N. Porch) Phytoliths[2] (n=40; C. Lentfer) Pollen[2] (n=60; S. Haberle) Tool residues (n=12; R. Fullagar, J. Field, C. Lentfer, M. Therin)
Stratigraphy	Original	Deposition rates (P. Hughes) Chemical and physical composition (M. Latham) Ferrimagnetism (R. Thompson and F. Oldfield) Physical composition (J. Powell) X-radiography (R. Blong)
	Renewed	Thin section description (T. Denham) X-radiography (A. Pierret with T. Denham) X-ray diffraction (L. Moore with T. Denham)

Notes:
[1] Conventional and AMS radiocarbon dating undertaken by Research School of Earth Sciences (RSES), Australian National University (ANU) and AMS dating by the Australian Nuclear Science and Technology Organisation (ANSTO).
[2] During the current project, diatom, phytolith and pollen analyses were undertaken by specialists on 40 'paired', or comparable, samples, with additional samples for some techniques. Several of these paired samples were also subject to AMS dating.

Table 2. Summary of archaeological, dating, palaeoecological and stratigraphic work undertaken by individuals and organisations during the original (directed by Jack Golson with Philip Hughes) and renewed (directed by Tim Denham under Golson's supervision) investigations. Note that the renewed investigations solely focussed on early and mid-Holocene remains (Phases 1, 2 and 3).

Of particular concern during the renewed investigations at Kuk were issues concerning the cross-correlation of multi-disciplinary lines of evidence. The results of many previous analyses could not be readily cross-correlated with each other or with precision to stratigraphic and archaeological provenances. A high degree of integration and precision was subsequently sought during renewed investigations.

In the field samples were collected using sections of zinc piping. The location and survey levels of these tins were marked directly on excavation plans and stratigraphic profiles (see Figures 1a). In the laboratory multi-disciplinary sub-sampling of the tins occurred to enable the cross-correlation of results (see Figure 1b). The majority of diatom, phytolith and pollen samples, as well as some AMS samples, were paired, i.e., they were obtained from adjacent, comparable provenances. Three methodological contributions of these multi-disciplinary analyses are considered here.

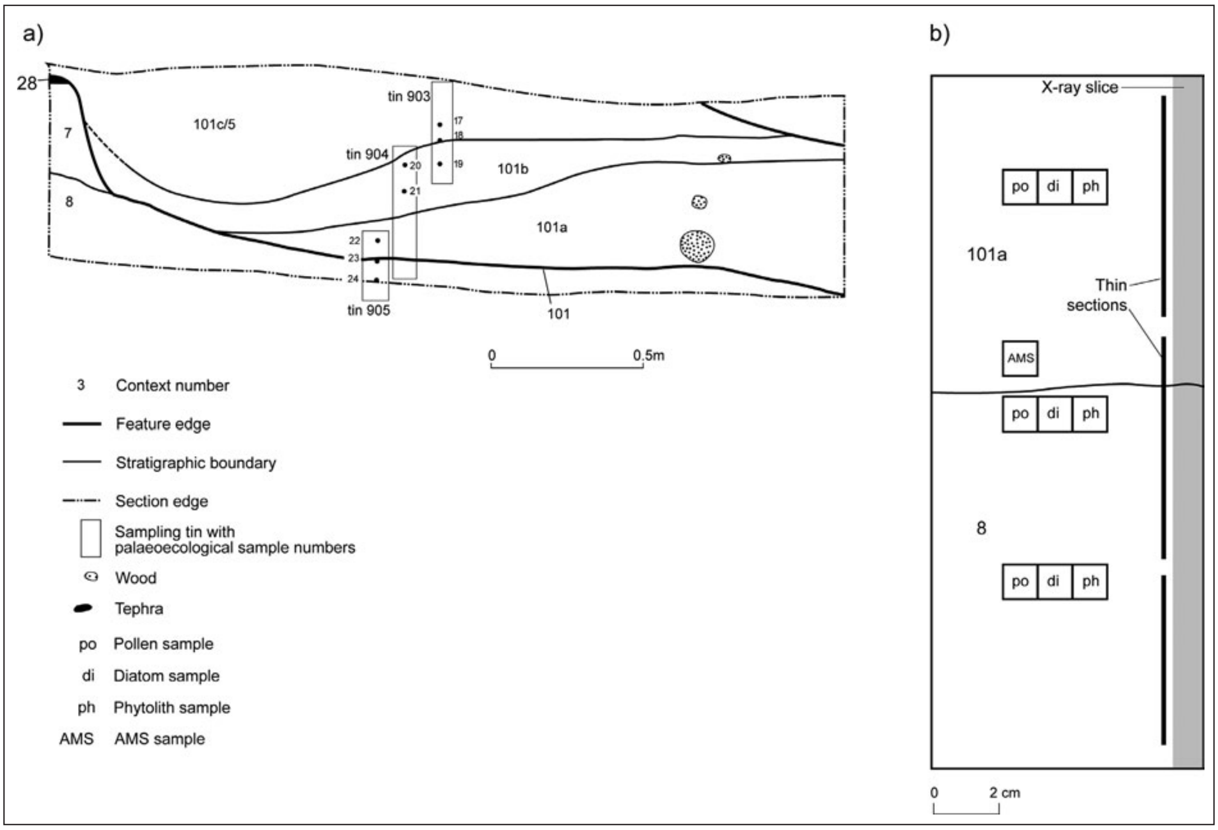

Figure 1. Field and laboratory sampling at Kuk: (a) Section of the stratigraphy indicating the location of monolith samples; and, (b) Idealised representation of multi-disciplinary sub-sampling from a monolith. In practice, thin sections and sometimes X-rays were often derived from a monolith paired with that used for dating, palaeoecological and sedimentological sub-sampling.

1. X-radiography

Comparative X-radiography and photography of undisturbed soil monoliths provide a meso-scale investigation of soil and sediment characteristics often missing in archaeological investigations (Gilbertson 1995). Meso-level analysis links macro-level field descriptions to extremely detailed micromorphological studies, i.e., thin section description. Following Hamblin (1962), Krinitszky has shown that '"thick bedded" or "massive" sedimentary deposits really contain many complex primary structures that are visible with X-rays but are otherwise poorly expressed or invisible' (1970:47). More recently, X-radiography has been used at archaeological sites to detect soil structures and pedoturbation (Butler 1992), to reveal tephra lenses in peats (Dugmore and Newton 1992), and to rapidly assess primary and secondary attributes of deposits prior to subsequent analysis (Barham 1995).

At Kuk, X-radiography has been used to investigate massively structured fills of archaeological features, as well as major stratigraphic units, and to guide further sampling. During recent work, X-radiography has revealed structures associated with former palaeosols (Figure 2a) and the degree of pedogenic homogenisation within a sample. The differentiation of deposits that retain their original stratification (Figure 2b), as opposed to those that have been subject to extensive post-depositional pedogenic modification (Figure 2c), has proven highly significant for the choice of samples for subsequent analysis, for understanding site formation processes, and for the interpretation of analytical results (see below; Denham 2003b).

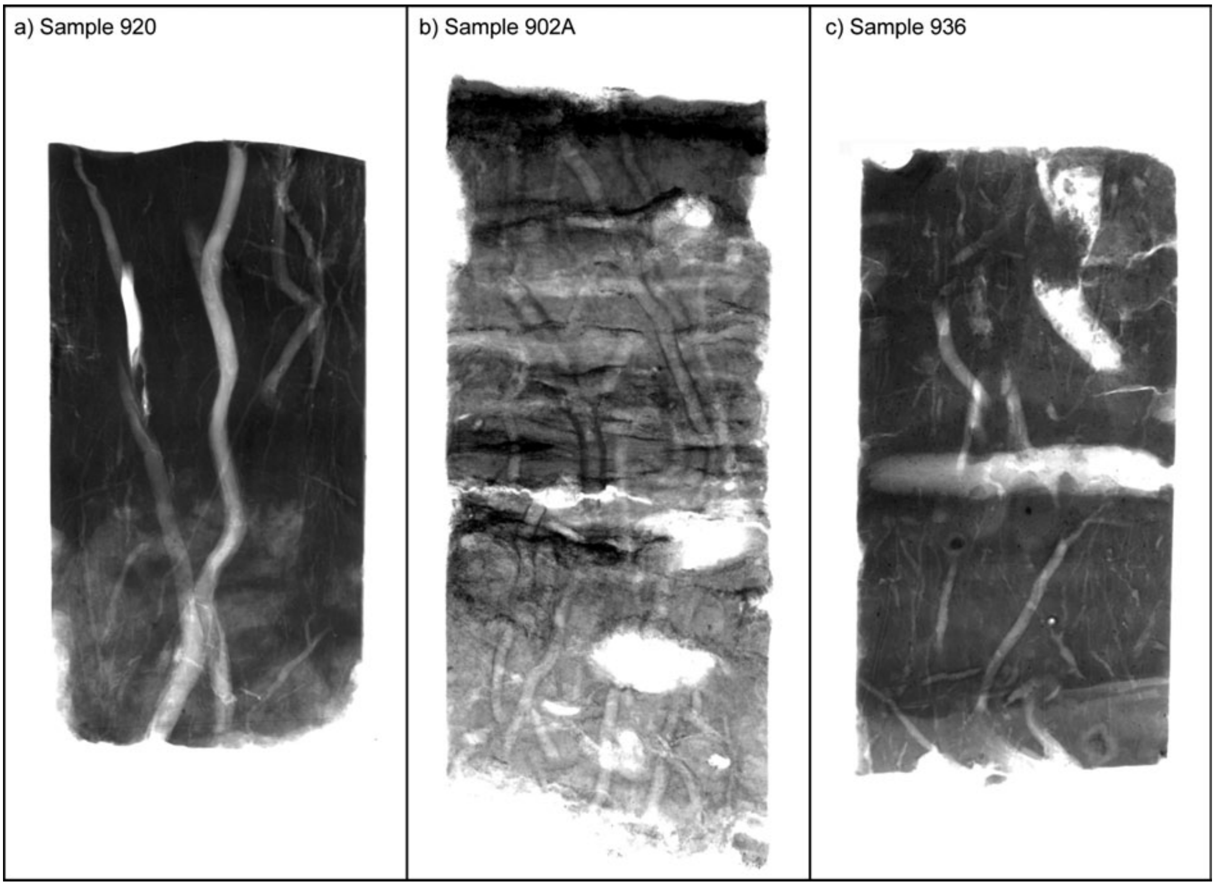

Figure 2. X-ray absorption images for samples from Kuk: (a) X-ray image showing recent vertically-oriented voids (light areas), which are traces of bioturbation by either soil macrofauna or plant roots, and older limited palaeosol development for the fill of a 10,000 year-old palaeosurface feature (Phase 1; sample 920); (b) X-ray image showing high degree of preservation of stratification within a 10,000 year-old palaeochannel fill (Phase 1, channel 101; sample 902A); and, (c) X-ray image showing well-homogenised black clay stratigraphic unit with superimposed vertically and horizontally oriented voids (lighter areas) representing recent root and microfaunal activity (mid-Holocene age; sample 936). Each sample is 8 cm wide.

2. *Biostratigraphic markers*

Multi-scale and mixed-method analyses (following Canti 1995; Denham 2003b), incorporating the results of the original and renewed investigations, have enabled characterisations of the archaeostratigraphy at Kuk (Denham 2003b). Of concern, and in contrast to previous sedimentary interpretations of the stratigraphy at Kuk (Hughes 1985; Hughes et al. 1991), the majority of the Holocene stratigraphy at the site appears to have been subject to considerable pedogenesis, or soil formation. Soil formation processes generally admix deposits through various forms of biological and mechanical pedoturbation. Consequently, the extent of pedogenesis needs to be taken into account in the interpretation of analytical results on samples used for dating and palaeoecological analysis.

A way of assessing the effects of post-depositional processes, such as pedogenesis, is to compare the archaeostratigraphy of the site against biostratigraphic markers. It can be assumed that if post-depositional processes have predominated, then the characteristics of macrofossil and microfossil assemblages within samples of similar provenance and age would be partially inter-mixed with those from adjacent — most probably higher and lower — contexts. However, if archaeostratigraphic units retain their original palaeoecological characteristics, i.e., those that reflect the ecology of the environment at the time of formation, then samples from similar provenances and age should share similar biostratigraphic traits.

The method for assessing biostratigraphic integrity at Kuk is based on a Principal Components Analysis (PCA) of the pollen analysis (Figure 3; see Haberle et al. n.d. for a full discussion). An examination of groupings clearly shows that samples from the same major stratigraphic units, i.e., black clay, grey clay and Pleistocene organic peat, cluster together. Furthermore, the basal samples from Phase 2 feature fills form a tight cluster, which is significant, because it suggests that the basal fills of Phase 2 features have retained their original biostratigraphic characteristics and are reliable indicators of past environments when the Phase 2 palaeosurface was in use. In contrast, the biostratigraphic signatures for the fills of Phase 1 features are highly variable, which suggests that the Phase 1 palaeosurface is, in part, a palimpsest of features of different ages.

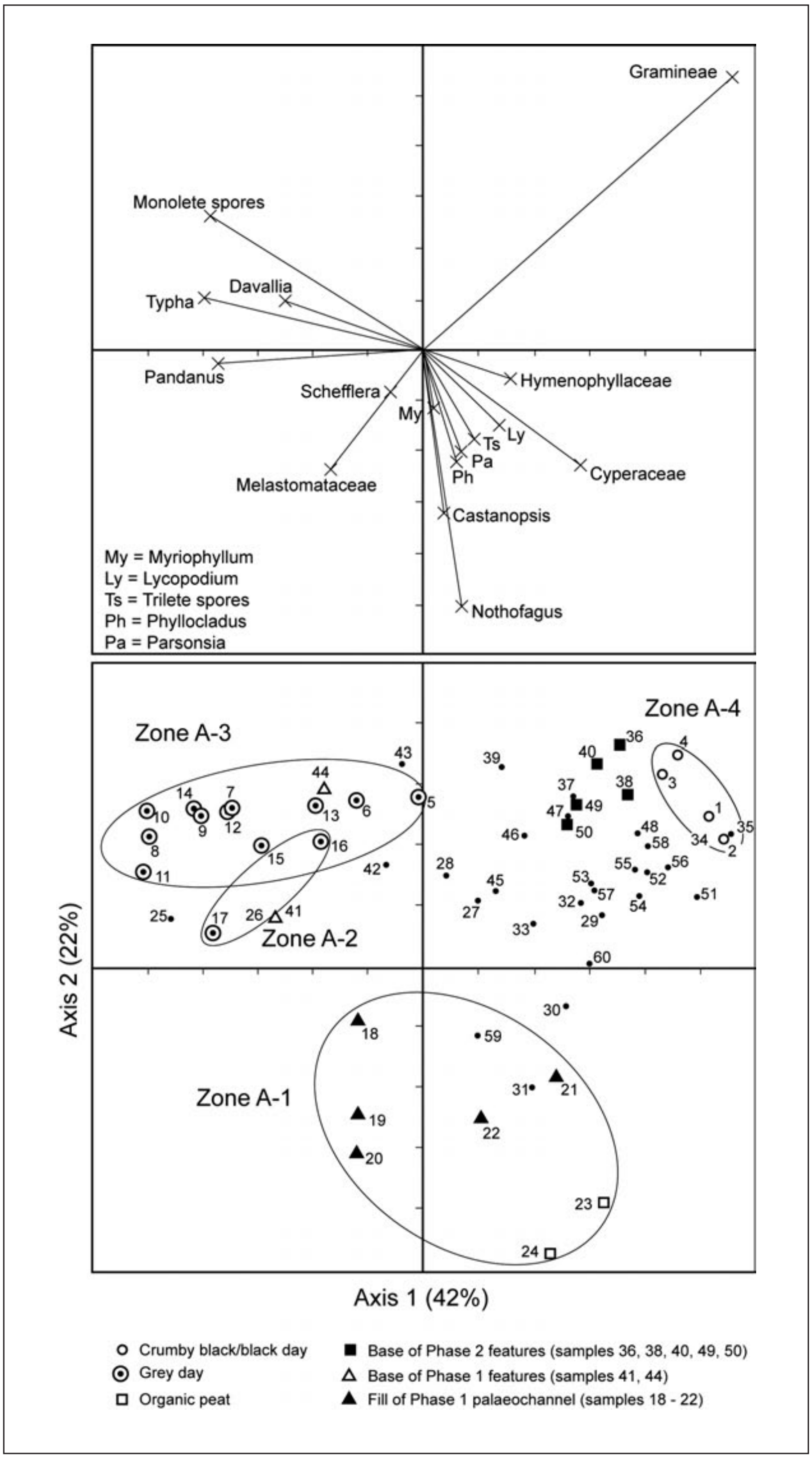

Figure 3. PCA plot of 60 pollen samples showing biostratigraphic groupings including major stratigraphic units and the relatively tight cluster of samples from the base of five Phase 2 features.

3. A suite of macrofossil and microfossil techniques

A combination of archaeobotanical and palaeoecological techniques (see Table 2) has yielded evidence for the presence, use and cultivation of a range of crop plants at Kuk from the Pleistocene to the recent past (Table 3). Only the earliest occurrences of plants are noted, after which food plants are considered to have been continuously present in the vicinity. Previous deficiencies in obtaining evidence of food plants based on macrobotanical and pollen analyses have been overcome by employing phytolith analysis of archaeostratigraphic samples and starch grain evidence of tool residues. These techniques have opened up new avenues for exploring subsistence in the past in New Guinea, as well as other parts of the world (see Piperno 2006 and Torrence and Barton 2005 for recent reviews). Of most significance are phytolith evidence for the cultivation of Musa bananas from 7000–6500 cal. BP (see discussions in Denham et al. 2003, 2004b) and starch grain analysis of residues from stone tools indicating the exploitation of taro (*Colocasia esculenta*) and a yam (*Dioscorea* sp.) from the early Holocene (Fullagar et al. 2006).

Species/Genus[1]	**Exploited Form**[2]	**Edible Part(s)**[3]	**Evidence**[4]	**Earliest Record**[5]
Abelmoschus sp.[6]	c	l, sh	s	Pleistocene
Acalypha sp.	w, t	l	s, w, p	Pleistocene
Castanopsis sp.	w, t	n	w, p?	Pleistocene
Cerastium sp.	w	p	s	Pleistocene
Coleus sp.	w	l	s	Pleistocene
Ficus cf. copiosa[6]	c, w	f, l	s	Pleistocene
Ficus spp.	c, w	l, f	s, w	Pleistocene
Garcinia sp.	w	f, l, b	w	Pleistocene
Hydrocotyle sp.	w	l?	s	Pleistocene
Lycopodium spp.	w	sh	p	Pleistocene
Maesa sp.	w	f	w	Pleistocene
Musaceae	c, w	f, c	ph	Pleistocene
Oenanthe javanica	c, w	l, sh	s, p	Pleistocene
P. antaresensis	w	d	p	Pleistocene
P. brosimos	c, w	d	p	Pleistocene
Pandanus sp.	c, w	d	s, p	Pleistocene
Parsonsia sp.	w	n	p	Pleistocene
Phragmites karka	w	l, r, sh	ph	Pleistocene
Pouzolzia hirta	w	l, st	s	Pleistocene
Rubus moluccanus	w	f	s	Pleistocene
Rubus rosifolius	w	f	s	Pleistocene
cf. *Setaria palmifolia*	c, w	s	ph	Pleistocene
Solanum nigrum	c, w	l, sh	s	Pleistocene
Syzygium sp.	w	f	w	Pleistocene
cf. Zingiberaceae	c, w	r, l, sh	ph	Pleistocene
Colocasia esculenta	c	c, l	st	P1
Dioscorea sp.	c, w	t	st	P1
Elaeocarpaceae	w	n	p	P1
Ipomoea sp.	w	sh	p	P1
Typha sp.	w	st	p	P1
Wahlenbergia sp.	w	p	s, p	P1
Musa section bananas[7]	c, w	f, c	ph	P1?
Ingentimusa section bananas[7]	w	f, c?	ph	P1?
Solanum sp.	c, w	f, l, sh, t	s	pre-P2
Commelina sp.[6]	c, w	l, sh	s	P2

Species/Genus[1]	Exploited Form[2]	Edible Part(s)[3]	Evidence[4]	Earliest Record[5]
Drymaria cordata[6]	w	l?	s	P2
Floscopa sp.[6]	c, w	l, sh	s	P2
Viola arcuata	w	l?	s	P2/P3
Amaranthus sp.[6]	c	l, p	s	P2/P3
Bidens pilosa[6]	w	s	s	P2/P3
Selaginella sp.	w	l	p	P3

Notes:

1 List of edible species at Kuk based on ethnographically documented use of plants in New Guinea (M. Bourke n.d. and pers. comm. 2002; French 1986; Haberle 1995; G. Hope pers. comm. 2002; Powell 1976:108–12; Powell and Harrison 1982:57–86; Powell et al. 1975:15–39). Edible species have been reported from other early to mid Holocene sites in the Highlands[8, 9, 10].

2 Exploited form: c = cultivated, w = wild, t = transplanted.

3 Edible part(s): c = corm, d = drupe, f = fruit, g = gourd, l = leaf, n = nut, p = plant, r = rhizome, s = seed, sh = shoot, st = stem, t = tuber.

4 Evidence: ph = phytolith (by Carol Lentfer), p = pollen (by Simon Haberle), s = seed (by Jocelyn Powell and Laurie Lucking), st = starch (by Richard Fullagar and Judith Field), w = wood (by Jocelyn Powell and Laurie Lucking). Only those techniques relevant for the earliest recorded occurrence are listed.

5 Earliest record: Pleistocene (Pleistocene); Phase 1 contexts (P1); possible Phase 1 association or immediately post-dating Phase 1 (P1?); contexts post-dating Phase 1 and pre-dating Phase 2 (pre-P2); Phase 2 contexts (P2); Phase 2 or Phase 3 contexts (P2/P3); and, Phase 3 contexts (P3).

6 Identification to the genus or species level should be considered provisional because it is based on a single seed sample.

7 The identification of Australimusa phytoliths from a Phase 2 context at Kuk (Wilson 1985:Table 3) is excluded because it was based on a single sample and no Australimusa phytolith morphotypes were identified by Carol Lentfer from Phase 1–3 contexts at Kuk during renewed investigations (Denham et al. 2003:192).

8 Gourd from a mid-Holocene context dating to 5665–5325 cal. BP at Warrawau (ANU 288 and 2086; Golson 2002:74) was originally reported as *Lagenaria siceraria* (Powell 1970b:144–5) and *Lagenaria cf. siceraria* (Powell 1970a:199). Golson (2002:73–5) considers it more likely to be *Benincasa hispida* based on the identification of this species from a late Holocene context at Kana (Matthews 2003). Given the lack of macrobotanical investigation conducted on the gourd remains collected in 1966 and 1977, and which could not be located in archival materials during renewed investigations, they are regarded to be 'gourd (species unknown)'.

9 *Saccharum officinarum* dating to c. 5200 cal. BP at Yuku was reported by Bulmer (1975:31) although the basis for the identification is unknown (Yen 1998:168).

10 *Benincasa hispida* has been reported from Kana and dated to 2950–2000 cal. BP (ANU 9487; Matthews 2003; Muke and Mandui 2003).

Table 3. List of the earliest occurrence of edible plants documented for all phases at Kuk (augmented and updated version of Denham 2005b: Table 2).

The suite of food plants present at Kuk is similar to those harvested wild and cultivated in gardens across the Upper Wahgi valley today (Powell 1976; Powell et al. 1975). The range of food plants potentially available to former inhabitants includes starchy staples, vegetables, and fruit and nut-bearing trees (see Denham 2005b and Denham and Barton 2006). Although residue analysis provides evidence for the use of taro, a yam, and as yet unidentified plants, most techniques solely indicate the availability of a wide range of edible plants. However, taken together, the suite of plants could have supported broad-spectrum subsistence practices from the beginning of the Holocene, and potentially earlier (Powell 1982a:211).

The findings at Kuk indicate the importance of using a combination of macrofossil and microfossil techniques in the investigation of plant exploitation in the past. Although macrofossil techniques — primarily the macrobotanical investigation of the hard parts of nuts and fruits, as well as seeds and wood — have formerly predominated in New Guinean research, it has long been recognised that these techniques provide only a partial view of plant exploitation in the past (Golson and Ucko 1994; Powell 1970a). Only with recent advances in phytolith (Bowdery 1999; Denham et al. 2003, 2004b; Lentfer and Green 2004), pollen (Haberle 1995), starch grain (Fullagar et al. 2006; cf. Loy 1994) and parenchyma (Hather 2000) research have archaeobotanists been able to investigate people's use of the major starch-rich staples of Pacific agriculture. At Kuk, microfossil analyses have provided evidence from the early Holocene for the presence or exploitation of three of the major starch-rich staples of Pacific agriculture, namely taro, yam and bananas of Musa section (formerly Eumusa). These archaeobotanical finds broadly corroborate phytogeographic hypotheses and genetic interpretations for the domestication of these, as well as other, plants in the New Guinea region (see de Langhe and de Maret 1999; Lebot 1999; Matthews 1995).

An outstanding problem: Sample representativeness

At most sites in the Australasian region, multiple samples from an archaeological context or feature fill are rarely subject to detailed archaeobotanical, dating or palaeoecological analysis. Although there are exceptions, these are usually larger features such as midden deposits, e.g., the Dongan midden (Fairbairn and Swadling 2005; Swadling et al. 1991), and palaeochannels, e.g., at Kuk (Powell 1982b; Wilson 1995). For smaller features, it has been common practice to interpret a subsample of fill — particularly a basal fill — as representative of the human practices accompanying the formation or use of the feature as a whole.

During the renewed investigations at Kuk, multiple samples were taken from larger (i.e., palaeochannels) and smaller (i.e., palaeosurfaces) features. Multiple subsamples of fill were subject to multi-disciplinary and paired analyses. Although the results indicated quite high degrees of variability in the biostratigraphic signatures and age for the fills from several palaeochannels, such results were anticipated based on studies of channel fill composition and chronology in other parts of the world (Brown 1997:48–54). Surprisingly, multiple samples from the fills of shallow palaeosurface features also indicated relatively high degrees of biostratigraphic variability — both within and between features; variability was more marked for Phase 1 features and less so for Phase 2 features. However, even for Phase 2 features, for each of which three subsamples were analysed, there was considerable variability between the upper, intermediate and lower subsamples, even if there was good agreement for the basal fills of all five Phase 2 features analysed (as discussed above). These findings suggest that different environmental conditions and different processes of formation are associated with different parts of a fill. Although it has been assumed that the basal portion of the fill is the most representative of past plant exploitation and cultivation associated with the formation and use of the feature, this assumption requires further investigation.

Different hypothetical interpretations of the processes leading to the formation of, and hence representativeness of, the basal and other parts of the fill can be advanced (see Figure 4). These hypothetical interpretations cast doubt on the reliability of assuming that the basal portion of the fill is representative of — at least in the case of Phase 2 features — cultivation practices associated with formation and use. For example, is the basal portion of the fill formed shortly after initial digging of the feature, thereby comprising largely inwashed residual materials, or does it represent materials that slowly accumulated during cultivation on adjacent mounds (Figures 4a–c)? Additionally, the extent of pedogenesis accompanying and subsequent to the infilling of the feature is unknown (Figure 4d). Depending upon the formation scenario, plant macro- and microfossil assemblages in the basal portions of the feature fill may or may not be representative of cultivation on adjacent mounds (Figure 4e). Although in part these concerns can be addressed through X-radiography and thin section analysis of the relevant fills, some uncertainties remain and are largely a function of trying to understand the rates at which infilling of the features occurred during the year or so of use.

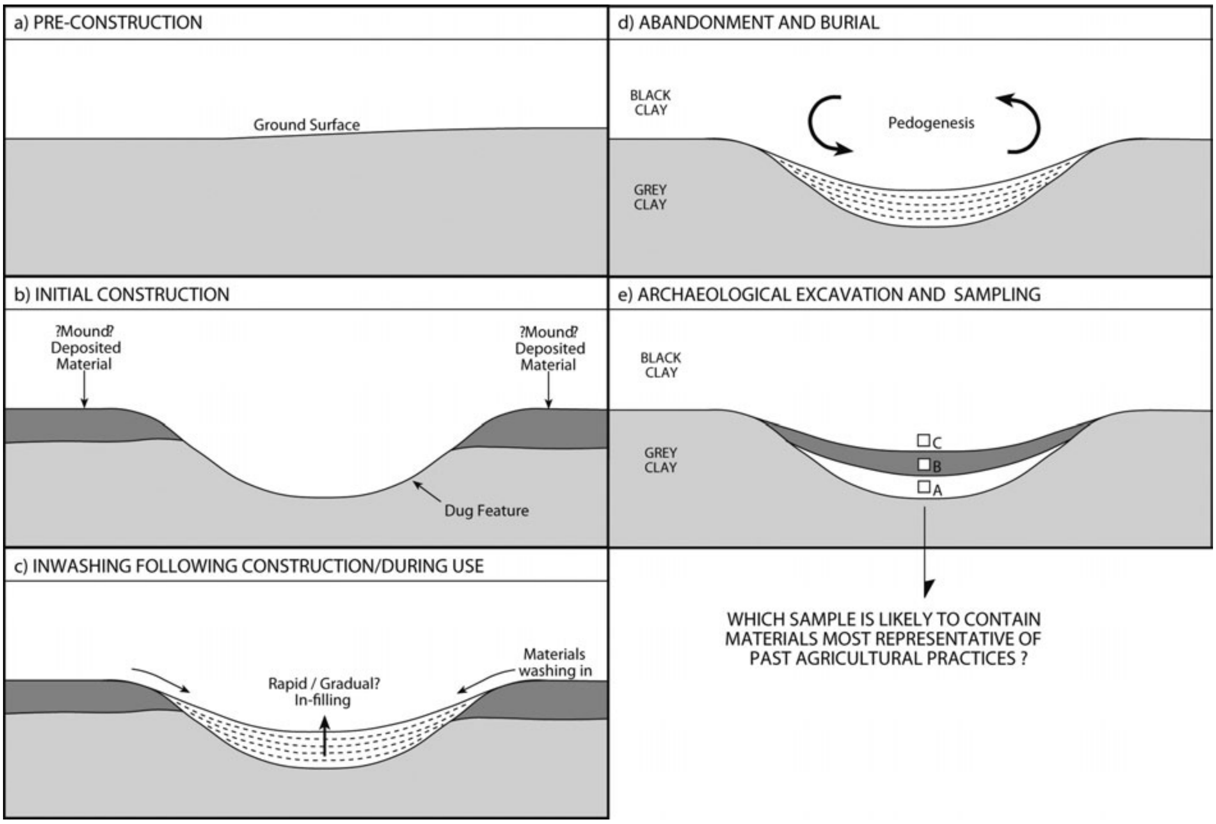

Figure 4. Schematic representation of a former land surface (a), subject to mound construction (b), inwashing following construction and during use (c), abandonment and burial (d), and archaeological excavation and sampling (e).

In an attempt to gain greater interpretative resolution, it has been necessary to adopt continuous, multi-proxy (diatom, phytolith and pollen analyses) and paired sampling strategies through the fills of the feature and underlying deposits (Figure 5). The 1 cm wide slices used for X-radiography of the stratigraphy have been subsampled for Phase 1, Phase 2 and Phase 3 feature fills — with the location of all subsamples marked on the X-ray image. Although the results of these analyses are incomplete, preliminary indications based on diatom and pollen analyses do facilitate greater interpretative resolution and show clear patterns in multi-proxy data that can be readily interpreted with regard to site formation processes and former cultivation practices.

The basal portion of the X-ray image depicts limited aggregate formation at the base of a 10,000 year-old (Phase 1) feature (Figure 5a). The palaeosol was buried beneath massively structured grey clay. The vertically-oriented voids indicate recent pedoturbation. The summary pollen diagram (Figure 5b) shows an increasing and then stable forest signal (samples H–D), which then dramatically declines (samples C–B). The decline in forest cover corresponds to the period when the Phase 1 feature had formed and was in use; manipulation of the wetland was occurring locally in conjunction with a form of plant exploitation. In the uppermost sample (A) the forest signal increases dramatically, although it is

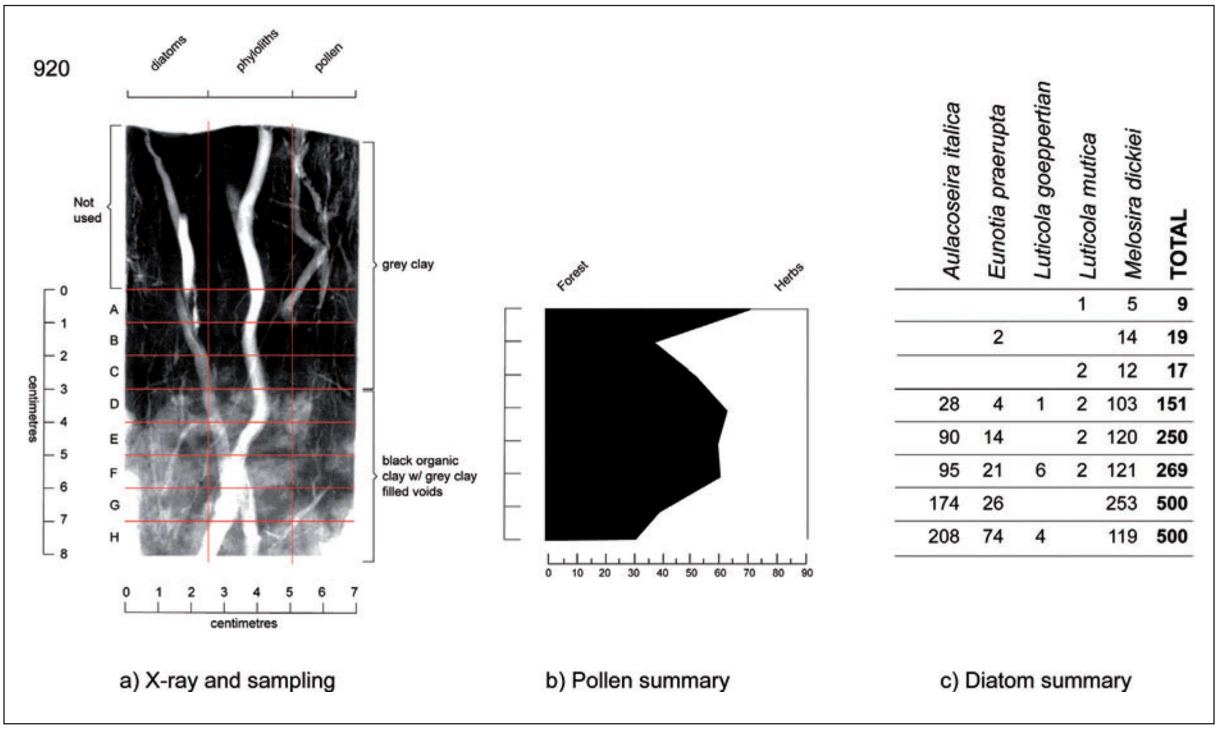

Figure 5. Panel showing the preliminary results of continuous and multi-proxy sampling strategy adopted during ongoing work at Kuk: (a) X-ray absorption image overlain with locations of subsamples for diatom, phytolith and pollen analyses; (b) Summary pollen data (courtesy of Kale Sniderman); and, (c) Summary table of diatom data (courtesy of Barbara Winsborough). Note that the sample had partially desiccated and shrank to c. 7cm wide by the time of continuous sampling.

uncertain whether this is due to forest regeneration following cessation of plant exploitation locally, or inwashing of older sediments from the edge of the feature. The diatom record indicates locally wetter conditions prior to feature formation (samples H–D), but the much lower frequencies of diatoms in samples C–A indicate drier conditions locally when the feature was in use and had infilled.

All three techniques — stratigraphic, pollen and diatom — provide complementary lines of evidence. Together they indicate wetter and forested conditions locally, prior to manipulation of the wetland margin for plant exploitation at 10,000 years ago. The feature was dug and in use during a short-lived period of locally drier conditions that were accompanied by a reduction in forest cover and limited soil formation.

A look to the future

In a series of papers, Bruce Smith has advocated and demonstrated the need for greater rigour in the investigation of the archaeobotanical record (Smith 1998, 2001, 2005; Erickson et al. 2005). Smith has developed a research methodology that utilises archaeobotany (primarily macrobotanical analysis) and the direct AMS dating of identified macrobotanical remains, in conjunction with comprehensive genetic fingerprinting of modern crop plant distributions. By adopting this multi-disciplinary approach, the present-day locations of wild progenitor populations of several domesticated crop plants have been identified using genetics and compared to the earliest archaeological evidence demonstrating the domestication of the same crop plants.

Although a wholesale application of Smith's method to the Pacific context is unlikely in the short term, given the paucity of archaeobotanical data and a reliance on microfossils to identify former starch-rich staple crops, there is certainly a case for partial adoption. Indeed, recent direct AMS dating of macrobotanical remains at the Dongan midden site has already yielded significant results (Fairbairn and Swadling 2005); the original report of mid-Holocene betelnut (*Areca catechu*) at the site (Swadling et al. 1991) has proved incorrect and the betelnut has been shown to be a modern intrusion. There is certainly scope for the greater direct AMS dating of other potentially significant, yet controversial, archaeobotanical finds, such as the putative sugarcane (*Saccharum officinarum*) at Yuku (Bulmer 1975:31; cf. Yen 1998:168).

However, there is an urgent need to improve, perhaps revamp, the methodologies used to investigate plant exploitation in the Pacific. Firstly, the systematic and tandem employment of macrofossil and microfossil techniques is essential to recover evidence for the presence, use and cultivation of a range of edible plants, as discussed above with reference to Kuk. Without a suite of techniques, only a partial view of plant availability and use in the past can be reconstructed.

Secondly, molecular databases for the major Pacific cultivars require to be systematically compiled with accessions from all regions of the Pacific and Southeast Asia. Although this work is ongoing, there is some variability in geographical coverage. For example, Lebot et al.'s (2004) genetic characterisations of taro (*Colocasia esculenta*) include accessions from several regions of Melanesia, Indo-Malaysia and Southeast Asia, whereas a similar study of the genetic relatedness of yam species (*Dioscorea* spp; Malapa et al. 2005) excluded potentially significant centres of yam diversity, namely New Guinea and the Indo-Malaysian archipelago. In the Americas, the resultant phylogenetic data for crop plants have been compared against macrofossil (Smith 2001) and microfossil (Sanjur et al. 2002) records.

Thirdly, ancient DNA research (aDNA) offers numerous potential avenues of research from the identification of archaeobotanical finds to the construction of phylogenetic chronologies that could theoretically track domestication, hybridisation, and the formation of new species and subspecies (e.g., Erickson et al. 2005; Jaenicke-Després et al. 2003). Only once such an integrated methodological approach is adopted in the Pacific will it be possible to fill out recently proposed conceptual frameworks for the emergence of early agriculture (Denham 2004b, 2005b, 2007) and arboriculture (Fairbairn 2005) in the region.

Finally, although the investigation of early agriculture in the Highlands of New Guinea has been ongoing for 40 years (Golson et al. 1967), there are still major research lacunae. Few archaeological excavations have been undertaken in the Highlands over the last 30 years; consequently few wetland agricultural and contemporary occupation sites have been investigated or reported in detail, and most of these studies were undertaken before several microfossil techniques (parenchyma, phytolith and starch grain analyses) were developed and applied. Furthermore, the few readily available specialists in these new technical fields are often hindered by partial reference collections. Given these realities, it is essential that researchers of early plant exploitation practices in Melanesia co-ordinate their activities to maximise outcomes with respect to the limited available resources, and maintain a spirit of co-operation in their pursuit of common goals.

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