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Holocene Vegetation, Savanna Origins and Human Settlement of Guam

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ABSTRACT. Palaeoenvironmental investigations not only provide information about past climate, geomorphological changes, and vegetation, but also can give a unique and complementary perspective to archaeological studies relating to the history of human settlement. The IARII Laguas core on the west coast of Guam yielded 28 meters of sedimentary deposition dating back 9,300 years from the present. Pollen analysis indicates that forested conditions dominated the upland and coastal landscape of southern Guam during the early part of the Holocene. At 4,300 cal. B.P. the earliest charcoal particles appear, suggesting human colonization. By about 3,900 cal. B.P. *Lycopodium* and *Gleichenia* ferns first become noticeable in the core record, probably indicative of gardening and resource collecting activities by small human populations. At 2,900 cal. B.P. these and other disturbance indicators (e.g., grasses, charcoal particles) become continuously present in quantity, signalling the demise of the upland forests in southern Guam and development of the degraded savanna landscape seen today. By 2,300 cal. B.P. there are only remnant patches of native forest in evidence. The sedimentary record of the Laguas core and another nearby sampling location suggest increased hillslope erosion along the coastal margins after about 1,700 cal. B.P., which is accompanied by higher charcoal particle concentrations. Although the exact date of major coastal deposition remains unresolved by the Laguas evidence—it could have been much later than 1,700 cal. B.P.—other studies of erosion and coastal deposition on Guam suggest a time frame sometime between the early first millennium B.P. and late second millennium B.P.

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Three related issues common in Oceanic archaeology studies are examined in a palaeoenvironmental study conducted on Guam, the southern-most island of the Mariana archipelago (Fig. 1). The first is the date of the earliest human colonizers, the second concerns the nature and intensity of prehistoric human impact on the natural environment, and the third, actually one aspect of the second issue, concerns the origin of the interior savannas of southern Guam, whether human or natural.

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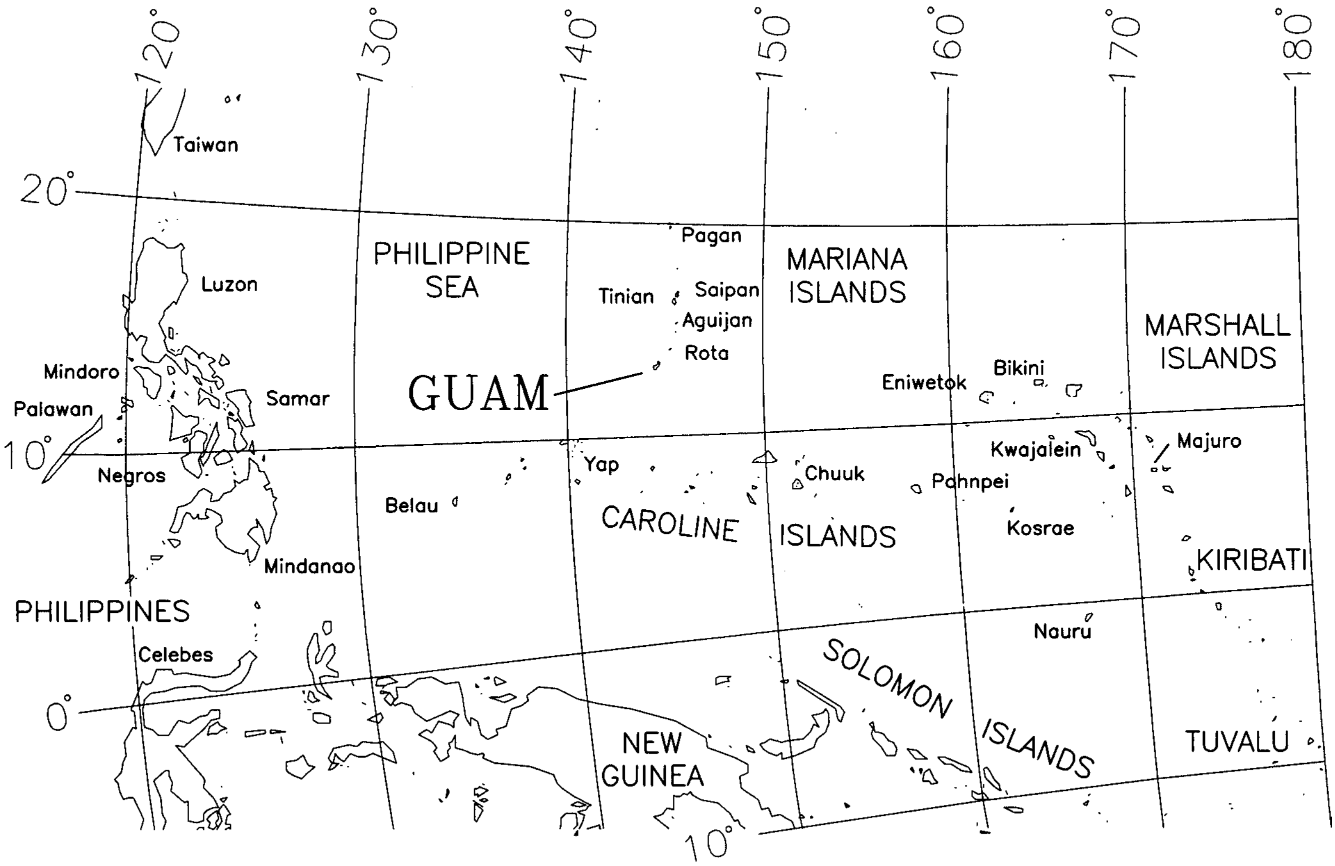


Fig. 1. Location of Guam and the Mariana Islands in western Micronesia.

These issues tend to be contentious in Pacific archaeology, with the amount of debate concerning particular islands more or less related to the amount of work conducted by different archaeologists. Witness the range of dates archaeologists have offered (and continue to offer) for the timing of initial human settlement in New Zealand and Hawai'i. The issue of human-induced changes versus climate induced changes of island landscapes, including the formation of savannas, also inspires heated debate (e.g., Nunn, 1997). Palaeoenvironmental methods potentially offer a highly sensitive approach that can provide relatively unambiguous results—or at least valuable insights—concerning all three issues.

With respect to the first issue, Kirch & Ellison (1994: 318) have noted:

> …carefully designed palaeoenvironmental research may be a more productive approach to dating the colonization of remote Pacific Islands than an elusive search for the "first colonization site," which becomes something of a Holy Grail.

Even in the best of circumstances, archaeologists can never be certain that they have found the earliest sites, or that the earliest traces of human settlement have not eroded away due to sea level changes or any number of other factors. Palaeoenvironmental studies can avoid this problem entirely, relying on wetland sedimentary cores that provide a continuous and highly sensitive record of environmental changes and perturbations of the island landscape. We feel that our work in Hawai'i, in particular, demonstrates this point (Athens, 1997; Athens & Ward, 1993*a*, 2000; Athens *et al*., 2002), though work by Flenley *et al*. (1991) on Rapa Nui is certainly illustrative (see especially Flenley, 1998, Butler & Flenley, 2000), and there are other examples as well (e.g., Newnham *et al*., 1998; McGlone & Wilmshurst, 1999 for New Zealand).

In terms of landscape change—particularly that concerning vegetation—palaeoenvironmental techniques are especially valuable for addressing this issue: (*a*) they provide a source of information independent of archaeology (i.e., the data are unbiased by human selection processes inherent in the formation of archaeological sites), and (*b*), as with the issue of earliest colonization, palaeoenvironmental studies on most Pacific islands provide an often continuous record of data from before and following the initial period of prehistoric human settlement.

While the palaeoenvironmental approach has been criticized by some investigators (e.g., Anderson, 1994; Spriggs & Anderson, 1993; Hunter-Anderson, 1998), the cited problems are really practitioner deficiencies rather than some inherent flaw in the methodology. Thus, interpretive errors arise as a result of an investigator's (*a*) failure to recognize sedimentary unconformities, (*b*) failure to obtain a sufficient number of radiocarbon dates, (*c*) use of inappropriate materials for radiocarbon dating, especially when working in ^{14}C-depleted water, (*d*) failure to understand possible source areas for pollen and charcoal influx, (*e*) failure to have an adequate reference base for pollen identifications, and (*f*) failure to achieve sufficiently high pollen counts. Our experience (e.g., Athens, 1997, Athens *et al*., 2002) like that of many others (e.g., Haberle, 1994; Flenley, 1994) has demonstrated that palaeoenvironmental data such as the appearance of microscopic charcoal particles and the rise of various floral indicators of disturbance in the pollen record are often highly sensitive markers of human presence. Disturbance indicators include pollen from a number of pioneering weedy plants that grow rapidly such as grasses, the Chenopodiaceae and Amaranthaceae (cheno-ams), *Pandanus*, and spores from ferns such as *Lycopodium cernuum* and *Gleichenia linearis*. With respect to the issue of initial human settlement, the propitious appearance of pollen from non-native plants and cultigens (i.e., plants introduced to the island by human colonizers) can provide the most unambiguous evidence, even before various archaeological manifestations become evident on the landscape (e.g., midden sites and artifacts). Pacific examples of plant introductions are provided in various palaeoenvironmental studies (Athens *et al.*, 1996, 2002; Athens & Ward, 2002).

Nevertheless, we do not take issue with the cry of some investigators that the appearance of charcoal particles and disturbance indicators in a sediment column are not inherently indicative of human presence. Logically, they could also be associated with climatic drying. Our experience, however, supports Haberle's (1994) optimism that such ambiguities can be avoided by using what he calls an "integrated methodology" (i.e., refined identification of pollen types with palaeoecological techniques). We would add, furthermore, that it is also important (*a*) to analyse the palaeoenvironmental data in light of the particular interpretive problems inherent to the study location; (*b*) to be particularly cautious of sources of radiocarbon dating errors; (*c*) to be mindful of the importance of the assumption of a continuous sediment column (i.e., no unsuspected unconformities to invalidate chronologies); and (*d*) to undertake close-interval radiocarbon and pollen sampling in portions of the core record that are particularly important for interpretive purposes (see also Hope *et al.*, 1999).

Aim

The aim of this paper is to present new data which will inform us about three archaeological problems relevant to human colonization and land use in the Mariana Islands.

1. Early human settlement in the Mariana Islands. It has been almost axiomatic among Micronesian archaeologists that human settlement first began about 3,500 years ago in the Mariana Islands. This date was assigned over four decades ago by Alexander Spoehr to the distinctive Pre-Latte pottery he documented (Spoehr, 1957: 168).

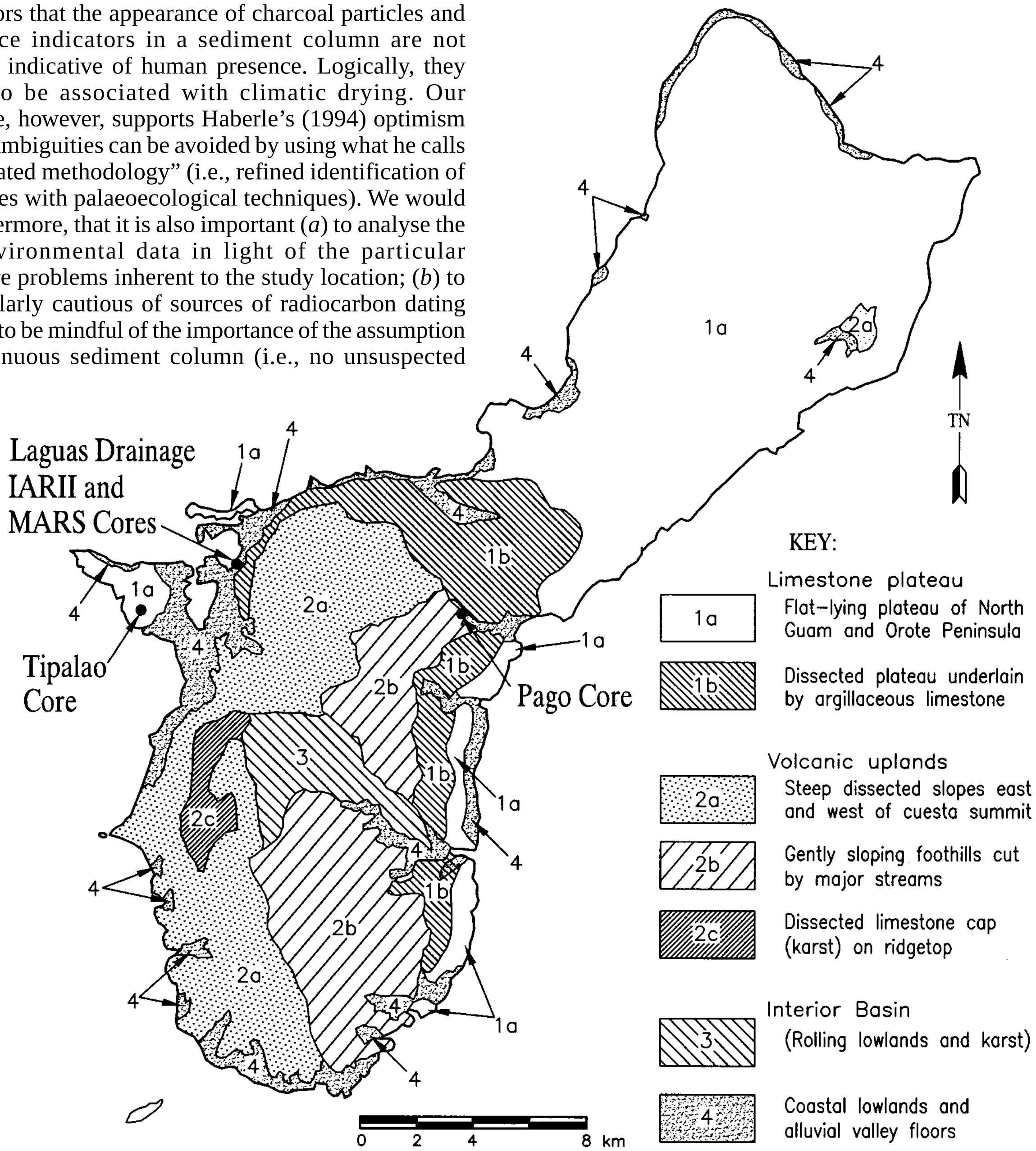


Fig. 2. Map of Guam showing major physiographic divisions (redrafted from Tracey *et al.*, 1964: A63) and locations of IARII Laguas, MARS Laguas, Pago, and Tipalao cores.

Archaeologists working in the Mariana Islands have not seriously challenged or modified this date since it was originally proposed. In this paper we will suggest that there is now good reason to challenge Spoehr's date. Based on recently obtained palaeoenvironmental evidence, we believe that human colonization occurred about 4,300 years ago, 800 years earlier than Spoehr's date.

2. The formation of savannas on Guam. The general location of the current savanna areas on Guam as delimited by the symbols for volcanic uplands is shown on Fig. 2 (2a, 2b, and 2c—compare to general vegetation map in Key, 1968: 23). The idea that the Guam savannas are anthropogenic in origin has been vigorously opposed by several investigators (Zan & Hunter-Anderson, 1987; Hunter-Anderson & Moore, 2000: 100). New palaeoenvironmental data, however, make this position untenable, indicating that prior to the arrival of humans, the uplands in southern Guam would have been entirely forested with a diversity of tree taxa. It was only as a result of human activities, probably due to the repeated burning of forest patches (for reasons that remain uncertain) in the highly weathered and impoverished upland soils, that the forest failed to regenerate and was replaced by savannas/grasslands.

3. Landscape change: vegetation history of Guam. Several investigators have identified significant landscape change around 780 to 1,780 cal. B.P. (Dye & Cleghorn, 1990: 271) and about 1,270 cal. B.P. (Hunter-Anderson, 1989: 61–62), including soil erosion in the interior areas of southern Guam with accompanying alluvial coastal build-up. Interestingly, the transformation from the earlier Pre-Latte Period to the later Latte Period in the Mariana Islands also occurred within this time frame, suggesting a possible causal connection.

The Latte Period takes its name from the upright pillars of stone with capstones in parallel rows, called *latte*, that began to appear around 850 to 950 cal. B.P. in the Mariana Islands (Graves, 1986: 141). This period is also identified by a distinctive pottery complex and other associated changes (Butler, 1990: 35, 42).

As noted by Butler (1990: 42), a substantial increase in population from Pre-Latte times is apparent from the fact that Latte Period sites are far more common than Pre-Latte sites. Latte sites are commonly found in interior areas while Pre-Latte sites are only rarely found in these areas, and those that have been found date to the late part of the Pre-Latte period (e.g., Moore & Hunter-Anderson, 1994: 37). Thus, an increase in the intensity of landscape use on Guam seems

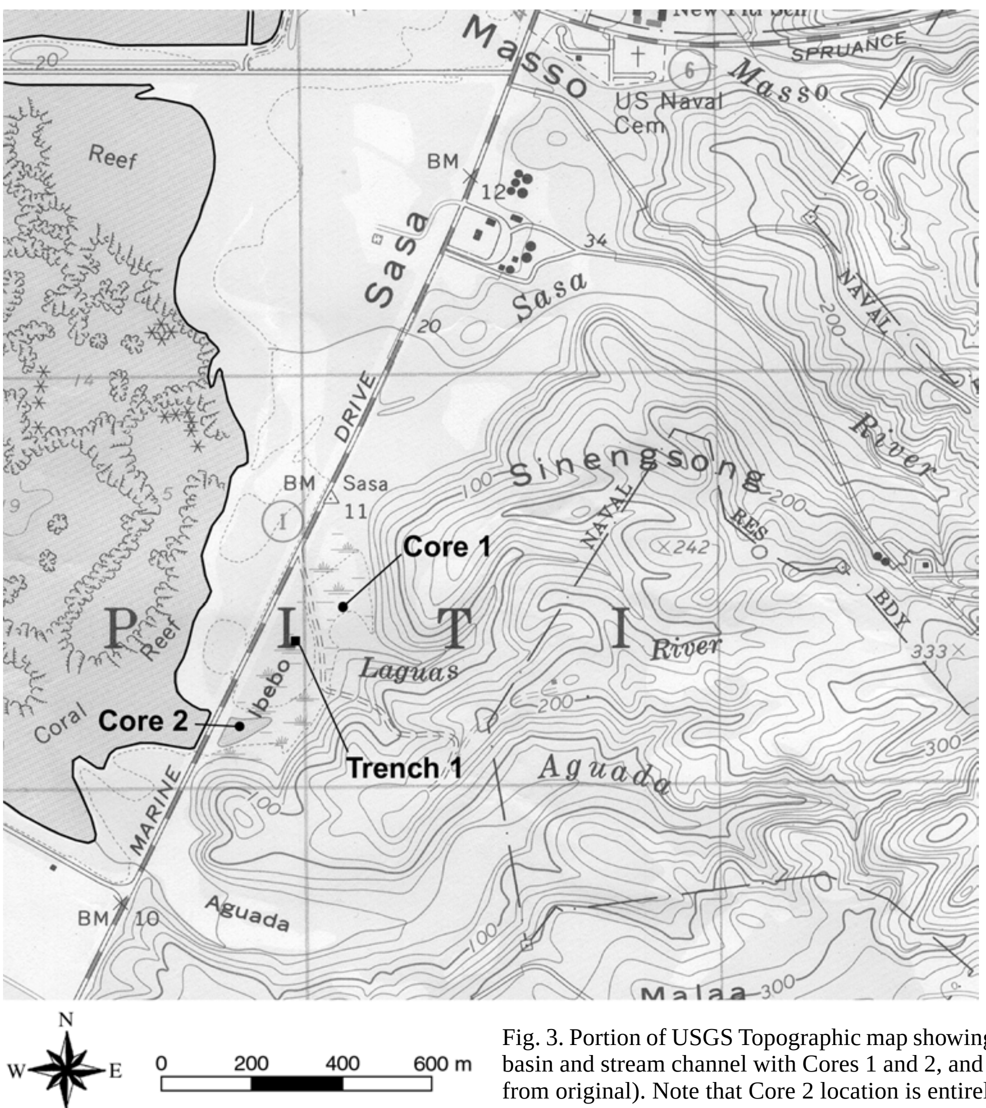


Fig. 3. Portion of USGS Topographic map showing location of the Laguas drainage basin and stream channel with Cores 1 and 2, and Trench 1 (map slightly modified from original). Note that Core 2 location is entirely a marsh and not open water as shown on map.

to have occurred starting just prior to the onset of the Latte Period. That this would have had some effect on slope erosion and coastal sedimentation does not seem surprising. It would nevertheless be of interest to further document the expected sedimentary changes with palaeoenvironmental coring studies, besides also addressing the question as to whether distinctive changes in the island's flora appeared concurrently. Further, little is known about prehistoric agriculture and possible plant introductions, which are also subjects potentially amenable to coring investigations.

To address these research aims, we present an analysis of the 28 m deep IARII Laguas core. It is the most detailed and complete palaeoenvironmental record from Guam in the Mariana Islands. The core was recovered in 1998 by the International Archaeological Research Institute, Inc., of Honolulu (the lead organization for the study) using standard palaeoenvironmental coring techniques as described in Athens & Ward (1999). This site is a wetland coastal location near the mouth of a small drainage basin that descends from the dissected and weathered volcanic uplands of southern Guam on the west side of the island (Figs. 2 and 3). It is roughly 125 m inland from the Apra Harbor shoreline.

Palaeoenvironmental data derived from four other cores have been previously reported for the Mariana Islands: the MARS Laguas core which was recovered by Micronesian Archaeological Research Services of Guam (Ward, 1995); the Pago core deep within an eastern valley in southern Guam (Ward, 1994); and a core from Tipalao Marsh at the Orote Peninsula on the west side of Guam (see Fig. 2; Athens & Ward, 1993*b*, 1995). Additionally, a core record was analysed from Lake Hagoi on Tinian (Athens & Ward, 1998). All of these records provide data for much of the Holocene; relevant information for the present discussion is summarized in Table 1.

While these previous records are instructive and provide useful and complementary information for the present study, they all suffer to some extent from either limited analysis and dating (MARS Laguas and Pago cores), or generally poor pollen preservation in the earlier intervals of interest regarding initial human settlement (Orote and Lake Hagoi). Another concern with the MARS Laguas and Pago records is that they were recovered by means of mechanized drilling equipment for engineering studies and it was uncertain whether such a recovery procedure could have compromised the palaeoenvironmental data. Furthermore, the sedimentary records of both of these cores were incompletely described. Finally, the Tipalao core, by virtue of its relatively isolated position on the Orote Peninsula with its correspondingly small catchment area, conceivably would not be representative of landscape changes on the main land mass of southern Guam.

IARII Laguas record

The stratigraphy of the IARII Laguas record is shown in Fig. 4. Twelve sedimentary layers were identified, and these fall into seven major depositional units (or DU) (Athens & Ward, 1999). Describing the latter from bottom to top, DU-7 consists primarily of terrestrial colluvium; the calcareous material that is present may derive from argillaceous limestone in the uplands. DU-6 is a black humic loam with abundant wood. It likely formed from a wetland that perhaps existed on a bench or terrace above the then lowered ocean. DU-5 is a transitional unit that contains a mixture of both terrestrial sediments from DU-6 and coarse marine sediments from DU-4. DU-4 consists of a light grey silty loam with abundant coral fragments and marine bioclastics. Deposition must have occurred in a relatively exposed or high energy (and presumably shallow water) environment. DU-3 is a greenish grey to grey clay loam with very fine calcareous sand and a very small amount of dispersed fragmentary shell. It was deposited in relatively shallow but protected marine waters (perhaps protected by a barrier reef). DU-2 consists of grey, dark grey, and black loam with fine calcareous sand. It has some fine fibrous macrobotanical remains and some finely fragmented shell. Humic content appears fairly high in this unit, though deposition was definitely in a protected, quiescent, and perhaps estuarine environment. Much of the sediment load of this depositional unit was probably derived directly from the Laguas River discharge. DU-1, a silty loam, is entirely of terrestrial origin, having no marine materials.

Table 1. Summary information for previous palaeoenvironmental cores on Guam and Tinian.

characteristics	Tipalao[a]	Pago[b]	MARS Laguas[c]	Lake Hagoi (Tinian)[d]
depth, m	4.98	33.8	41.8	6.58
age, base of core, cal. B.P.[e]	7,924	10,453	>9,100[f]	>7,632[g]
no. ^{14}C dates	5	4	6	10
no. pollen samples	26	17	14	46
earliest charcoal particles, cal. B.P.	3,561	4,857	3,602	3,444
earliest *Cocos*, cal. B.P.	4,600	4,328	>9,100[f]	3,444
earliest *Areca* (betel), cal. B.P.	5,638	4,857	9,080	—
earliest significant grass, cal. B.P.	1,399	3,222	2,225	3,289
earliest significant *Gleichenia*, cal. B.P.	—	3,222	2,761	—
earliest significant *Lycopodium*, cal. B.P.	—	4,857	2,761	—
earliest significant decline of *Pandanus*, cal. B.P.	2,145	4,328	1,957	not determinable
earliest significant decline in forest types, cal. B.P.	2,450	4,857–4,328	2,225	not determinable

[a] Athens & Ward, 1993*b*
[b] Ward, 1994
[c] Ward, 1995
[d] Athens & Ward, 1998
[e] Dates are based on age/depth interpolations derived from calibrated radiocarbon determinations.
[f] Dates extrapolated below the lowest radiocarbon determination at 27.4 m cannot be regarded as reliable without further radiocarbon determinations; dates below this depth, therefore, are designated as >9,100 cal. B.P.
[g] Dates extrapolated below the lowest radiocarbon determination at 4.65 m cannot be regarded as reliable without further radiocarbon determinations; dates below this depth, therefore, are designated as >7,632 cal. B.P.

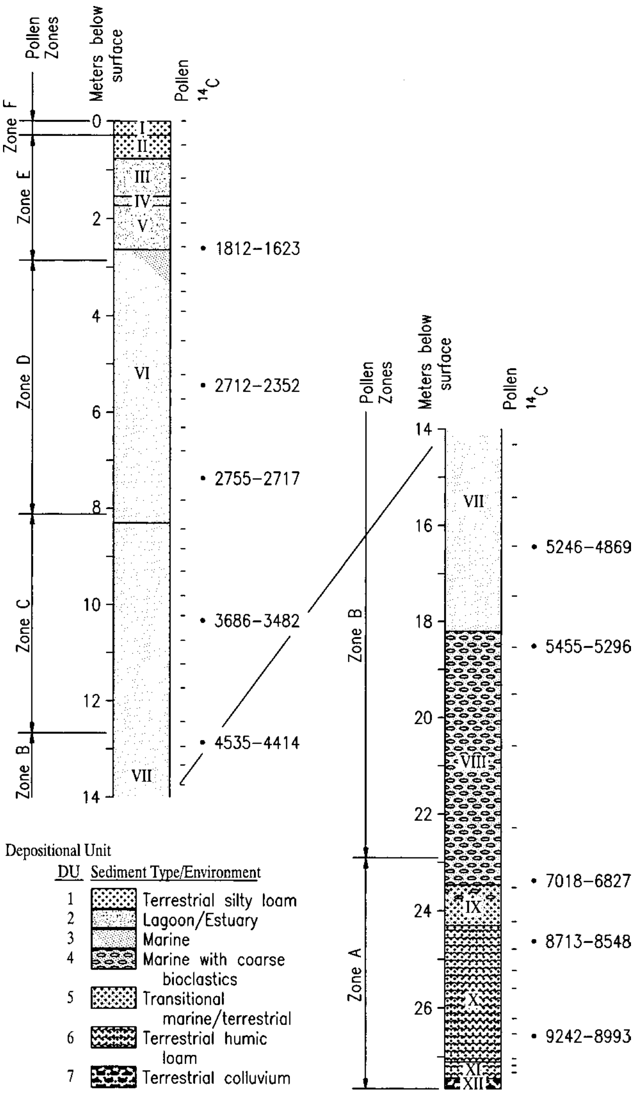


Fig. 4. Profile of IARII Laguas core. Note depositional units, calibrated radiocarbon determinations (1σ range), pollen samples, and pollen zones.

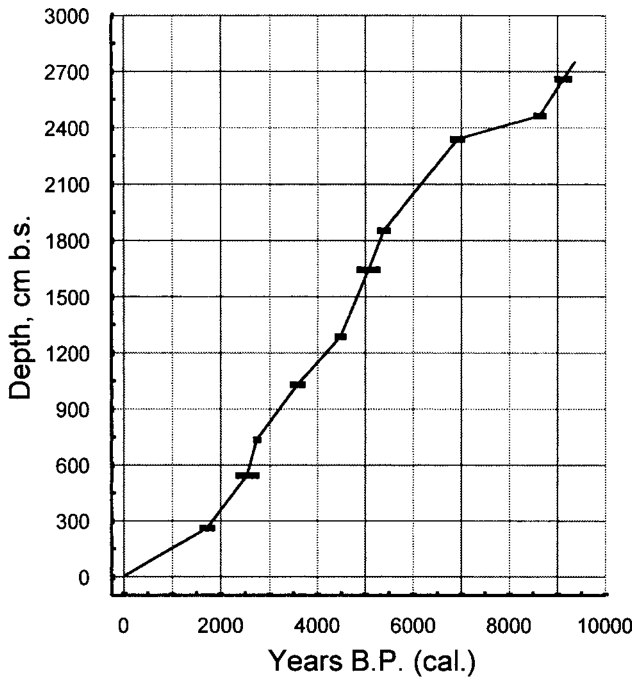


Fig. 5. Depth-age distribution of calibrated radiocarbon determinations (1σ range), IARII Laguas core.

The chronology of the IARII Laguas record is defined by 10 radiocarbon determinations (Table 2). As indicated by the depth-age graph (Fig. 5), all determinations are in proper chrono-stratigraphic order, suggesting continuous deposition for about 9,300 years, virtually the entire Holocene.

It appears that DU-1 (to the base of layer II) corresponds to the very late prehistoric and historical periods in Guam (i.e., the last 505 years), and that the base of DU-2 may represent the onset of estuarine deposition following marine regression after the mid-Holocene highstand (Dickinson, 2000). The date for the onset of DU-3 at 5,328 cal. B.P. could represent the onset of the Holocene highstand or transgression, creating slightly deeper inshore waters and promoting the growth of an offshore barrier reef. The base of DU-4, dating to 7,018 cal. B.P., represents the post-glacial

Table 2. Radiocarbon determinations, Laguas Core 2.

catalogue number	lab. number	provenance, depth below surface (cm)	submitted weight (g) and material	$^{13}C/^{12}C$ ‰	conventional age B.P.	calibrated age B.P.[b]
Lag-2,260–261	Wk-6995[a]	Layer V, 260–261	4.98 sediment	-26.0±0.2	1,804±59	1,812–1,623
Lag-2,541–543	Wk-6996[a]	Layer VI, 541–543	10.49 sediment	-24.1±0.2	2,441±63	2,712–2,352
Lag-2,734–736	Wk-6997[a]	Layer VI, 734–736	15.58 sediment	-23.2±0.2	2,583±56	2,755–2,717
Lag-2,1030–1032	Wk-6998[a]	Layer VII, 1030–1032	15.27 sediment	-24.5±0.2	3,372±56	3,686–3,482
Lag-2,1284–1286	Wk-6999[a]	Layer VII, 1284–1286	14.71 sediment	-23.3±0.2	4,020±56	4,535–4,414
Lag-2,1644–1646	Wk-7000[a]	Layer VII, 1644–1646	16.17 sediment	-22.5±0.2	4,424±73	5,246–4,869
Lag-2,1850–1852	Wk-7001[a]	Layer VIII, 1850–1852	11.76 sediment	-21.9±0.2	4,639±68	5,455–5,296
Lag-2,2337–2339	Wk-7002[a]	Layer VIII, 2337–2339	coral[d]	-0.7±0.2	6,574±73	7,018–6,827[c]
Lag-2,2463–2464	Wk-7003[a]	Layer X, 2463–2464	2.37 wood (probably bark)	-28.6±0.2	7,878±58	8,713–8,548
Lag-2,2655–2662	Wk-7004	Layer X, 2655–2662	15.81 wood (unidentified)	-28.6±0.2	8,190±60	9,242–8,993

[a] AMS procedure used to date sample; AMS determinations made by Nuclear Sciences Group, Institute of Geological and Nuclear Sciences, Ltd., Lower Hutt, New Zealand (sample preparation by Waikato Radiocarbon Dating Laboratory).
[b] Calibration from Calib 3.0.3 computer program of Stuiver & Reimer (1993); all dates have a 1σ age range. Data set 1 was used: bidecadal tree-ring data set to 9,440 cal. B.C. (c. 10,000 ^{14}C B.P.).
[c] Calib marine model used for calibration; ΔR of 115±50 from Athens (1986: 113) and Swift *et al*. (1991: 85).
[d] *Pavona* cf. *cactus* or *decussata*.

Table 3. Pollen Samples, IARII Laguas core.

catalogue no.	depth (cm)	layer	interpolated date cal. B.P.[a]	sediment acumulation (cm/yr)[b]
Lag-2,surf	surface	I	—	—
Lag-2,50–52	50–52	II	334	0.1513
Lag-2,117–119	117–119	III	776	0.1513
Lag-2,167–169	167–169	IV	1,107	0.1513
Lag-2,210–212	210–212	V	1,391	0.1513
Lag-2,258–260	258–260	V	1,708	0.1513
Lag-2,312–314	312–314	VI	1,870	0.3458
Lag-2,350–352	350–352	VI	1,980	0.3458
Lag-2,390–392	390–392	VI	2,095	0.3458
Lag-2,451–453	451–453	VI	2,272	0.3458
Lag-2,521–523	521–523	VI	2,474	0.3458
Lag-2,571–573	571–573	VI	2,564	0.9462
Lag-2,631–633	631–633	VI	2,627	0.9462
Lag-2,680–682	680–682	VI	2,679	0.9460
Lag-2,781–783	781–783	VI	2,871	0.3491
Lag-2,840–843	840–843	VII	3,041	0.3491
Lag-2,881–883	881–883	VII	3,157	0.3490
Lag-2,936–938	936–938	VII	3,315	0.3490
Lag-2,981–983	981–983	VII	3,444	0.3490
Lag-2,1021–1023	1021–1023	VII	3,558	0.3491
Lag-2,1071–1073	1071–1073	VII	3,728	0.2851
Lag-2,1121–1123	1121–1123	VII	3,903	0.2851
Lag-2,1171–1173	1171–1173	VII	4,079	0.2851
Lag-2,1241–1243	1241–1243	VII	4,324	0.2851
Lag-2,1291–1293	1291–1293	VII	4,486	0.6174
Lag-2,1331–1333	1331–1333	VII	4,551	0.6174
Lag-2,1371–1373	1371–1373	VII	4,616	0.6176
Lag-2,1431–1433	1431–1433	VII	4,713	0.6174
Lag-2,1541–1543	1541–1543	VII	4,891	0.6174
Lag-2,1641–1643	1641–1643	VII	5,053	0.6176
Lag-2,1747–1749	1747–1749	VII	5,217	0.6477
Lag-2,1852–1855	1852–1855	VIII	5,384	0.3148
Lag-2,1950–1954	1950–1954	VIII	5,697	0.3148
Lag-2,2057–2060	2057–2060	VIII	6,035	0.3148
Lag-2,2227–2229	2227–2229	VIII	6,574	0.3148
Lag-2,2352–2355	2352–2355	IX	7,134	0.0735
Lag-2,2422–2425	2422–2425	IX	8,087	0.0735
Lag-2,2479–2481	2479–2481	X	8,672	0.4005
Lag-2,2522–2525	2522–2525	X	8,781	0.4005
Lag-2,2560–2562	2560–2562	X	8,875	0.4005
Lag-2,2622–2624	2622–2624	X	9,029	0.4005
Lag-2,2654–2656	2654–2656	X	9,109	0.4005
Lag-2,2704–2706	2704–2706	X	9,234	0.4003
Lag-2,2718–2720	2718–2720	XI	9,269	0.4003
Lag-2,2732–2734	2732–2734	XI	9,304	0.4005

[a] Note that dates obtained for selected intervals by mean of linear interpolation have an undefined error range roughly similar to the radiocarbon determinations on which they are based.
[b] Sediment accumulation rate determined using computer program of Maher (1992).

marine transgression at a depth of 23.45 m below the surface. By this time sea level had already risen roughly three-quarters of the way to its modern level and the rate of rise had begun to slow (Fairbanks, 1989). DU-5 and 6 are unusual because they indicate the formation of a terrestrial wetland early in the Holocene, presumably on some sort of bench, terrace, or small basin on the seaward slope of Guam during the immediately post-glacial lowstand. It is possible that this wetland formed as a result of the deposition of coarse colluvial sediments during DU-7. Such sediments were carried down the Laguas drainage early in the Holocene presumably as a result of greatly increased rainfall that commenced in the immediately post-glacial period. These sediments apparently formed a barrier on an existing terrace or bench, which then trapped sediments and moisture that enabled the formation of a wetland.

A total of 45 pollen samples were analysed with all sample intervals yielding good results. Details of the pollen processing methodology are provided in Athens & Ward (1999). An age was assigned to each sampled interval based on linear interpolation using the depth-age model; a listing of the samples and their respective ages, layer derivations, and sediment accumulation rates are provided in Table 3. Palynomorph counts are compiled in Athens & Ward (1999); Fig. 6 provides a graphical presentation of the pollen data.

Pollen zones. The IARII Laguas core was divided into six pollen assemblage zones based on shifts in the frequencies of pollen and spore types, and in charcoal particle concentrations. The location of these zones with respect to the sedimentary units is illustrated in Fig. 4. The pollen zones may be summarized as follows.

Zone A: 9,304–6,854 cal. B.P. Zone A includes a number of well-known pollen types, and also an abundance of unknowns. The basal portion of the profile is represented by *Aglaia*, Arecaceae indet. (indeterminate palm pollen), and Araliaceae types. Curves for *Colubrina*, *Cycas*, and *Freycinetia* show slightly higher abundances than the former group while *Pandanus* and Myrtaceae display the strongest signals among the Trees and Shrubs. The Swamp/Mangrove group is dominated by *Bruguiera*, *Rhizophora apiculata*, and *R. mucronata* pollen, which are indicative of the minor influence of mangrove conditions. The unknown pollen types include the monosulcate, granulate and reticulate types with conspicuous occurrence of the following tricolporate types: microreticulate (small and with ear-like ora), reticulate and psilate.

The Pteridophyte presence is relatively weak with monolete, psilate type dominant at c. 25 percent of total followed by *Polypodium pellucidum*-type, *Adiantum*, psilate type and *Angiopteris*. *Lycopodium phlegmaria* spores are present, and these are joined by a stronger contribution from *Pteris* in the upper part of Zone A.

Zone A records the early Holocene at Laguas with dominance by a diverse pristine forest. The large number of unknown pollen types in this zone can be reasonably assumed to pertain primarily to forest taxa in the absence of disturbance indicators. Grassland and savanna pollen types are virtually absent in Zone A.

Zone B: 6,854–4,405 cal. B.P. In Zone B there is a decline in *Aglaia*, Arecaceae indet., and Araliaceae comp. *Colubrina* pollen also drops off significantly from the Zone A abundance. Both *Cycas* and *Freycinetia* persist at levels established in Zone A. *Guettardia* and *Ixora* display low levels of abundance in this and the following zone. *Cocos* appears at the base of Zone B intermittently and always in low numbers. *Metroxylon* displays a minor abundance in Zone A, increasing gradually to a position of co-dominance with *Pandanus* by mid-Zone B. *Pandanus* shows an early decline in this zone but begins to increase especially after

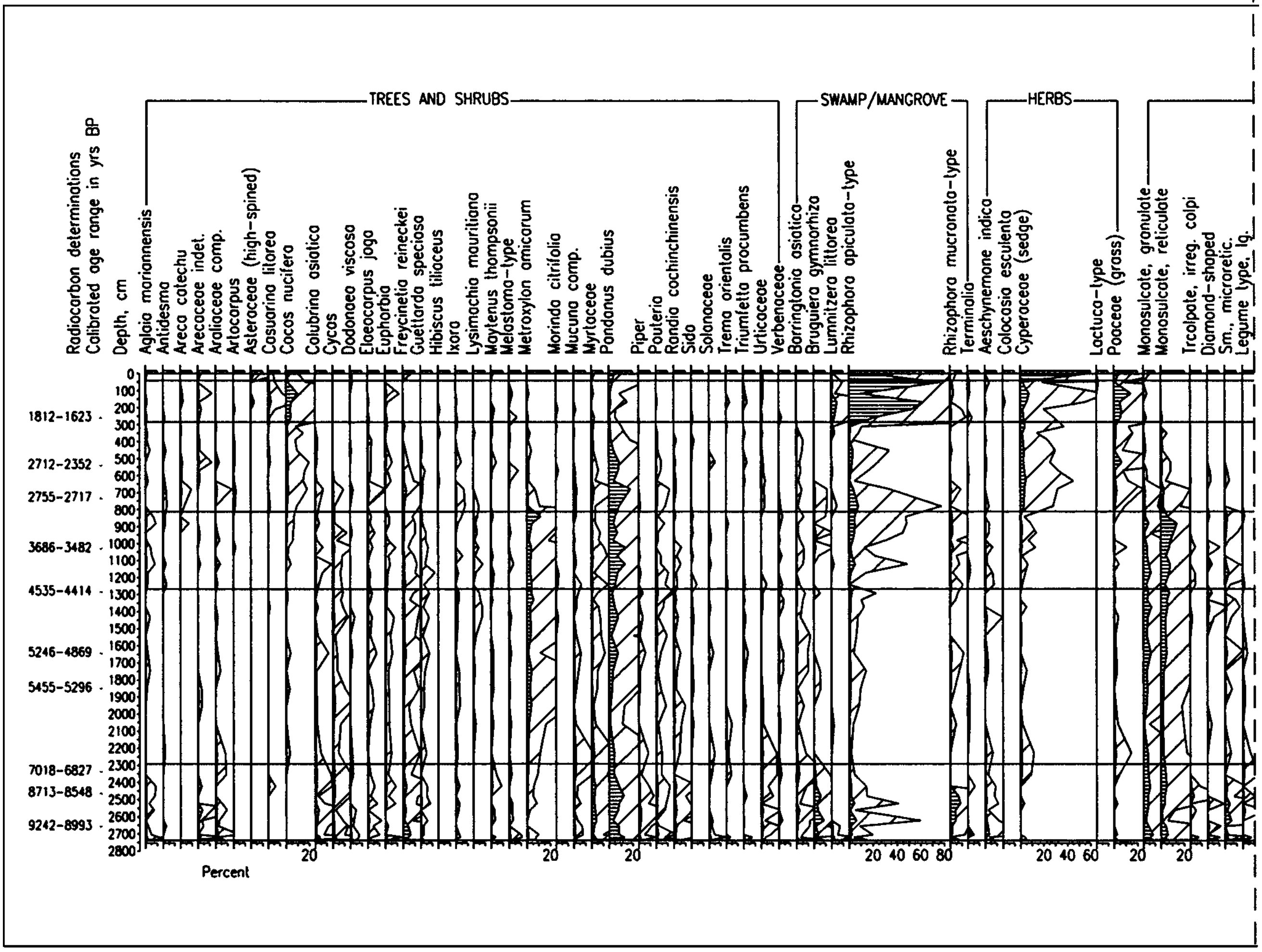


Fig. 6 [above and facing page]. Pollen diagram from IARII Laguas core plotted in silhouette style (tenfold exaggeration indicated by diagonal hatching). Palynomorph and charcoal concentration as well as pollen sum graphs are plotted in histogram style. Two pollen sums were used in calculating percentages: One sum was based on total pollen (Trees and Shrubs, Swamp/Mangrove, Herbs, Unknowns) and Pteridophytes, excluding monolete, psilate spores and the aquatic spore, *Pseudoschizaea*. For the monolete, psilate and *Pseudoschizaea* curves the sum was based on total pollen and spores.

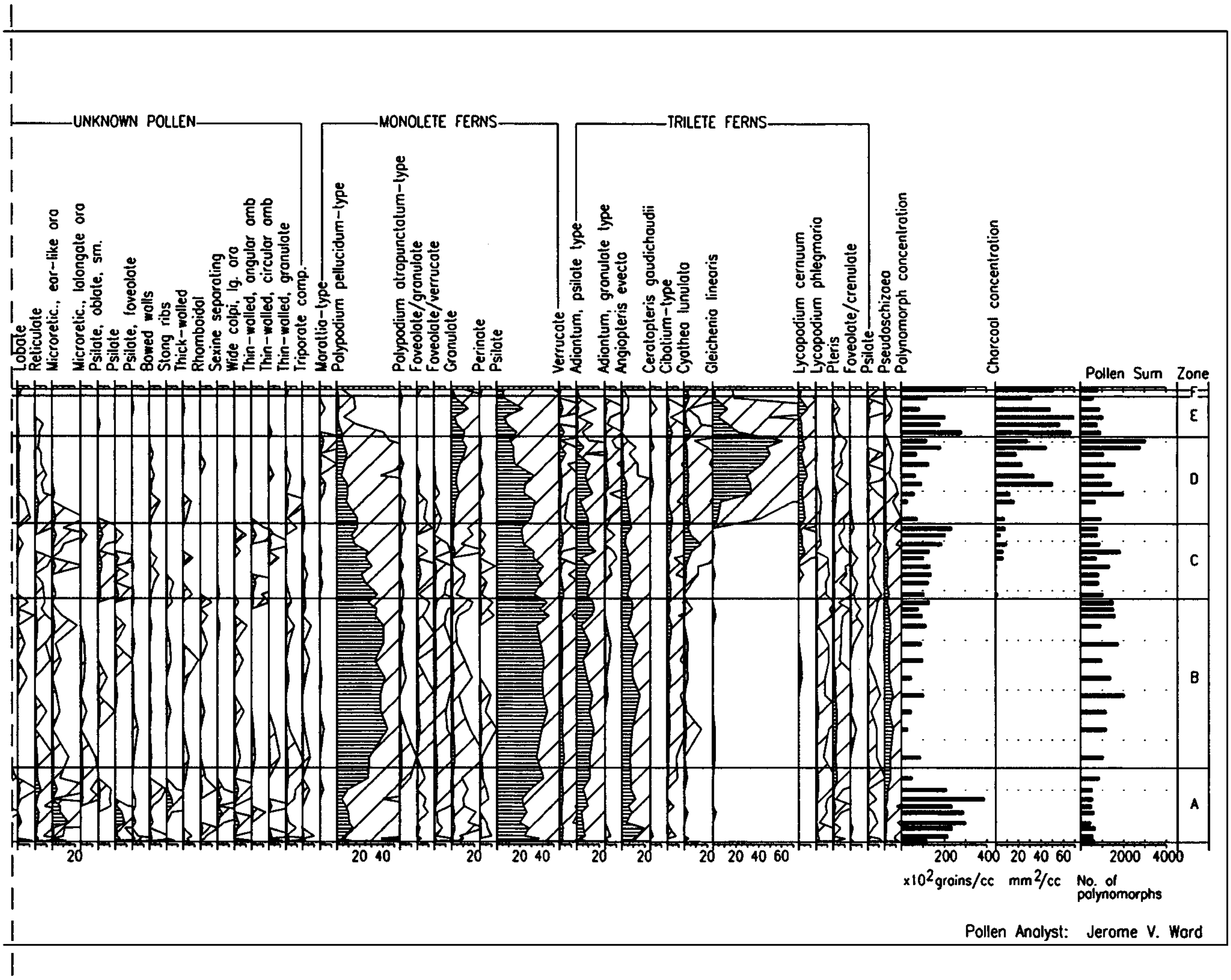
the 1852–1855 cm interval. Pollen of *Piper, Pouteria,* and *Randia* have fallen to half their values in the basal zone. *Barringtonia, Bruguiera*, and *Rhizophora* pollen begin at low amounts at the base of Zone B and regain less than half values seen in Zone A. Among the unknown pollen types, the monosulcates (granulate and reticulate) hold to levels established in Zone A. Most of the other unknown types have declined perhaps by half the levels seen in Zone A.

Among Pteridophytes, *Polypodium pellucidum* is the strongest contributor in the diagram at c. 35 percent of the total, while the monolete, psilate type is at 30 percent of the total spectrum. The foveolate/granulate and foveolate/verrucate spore types increase in this zone. *Adiantum*, psilate type, and *Angiopteris evecta* increase slightly from Zone A. The *Cibotium*-type begins to show some prominence in this zone although the values are still low. *Lycopodium phlegmaria* and *Pteris* are slightly more abundant in this zone but are still of minor importance.

Pseudoschizaea spores peak in this zone, essentially doubling in importance from the previous zone. This suggests a greater influx of freshwater into the catchment and possibly the accumulation of this water in a protected lagoon.

No grassland or savanna indicators are present in Zone B.

Zone C: 4,405–2,956 cal. B.P. In Zone C there is a slight increase in *Aglaia*. About midway through the zone in the 981–983 cm interval, *Cocos* begins a gradual rise in importance, which continues into the next zone. This probably marks the rising importance in agroforestry by recently arrived human colonizers (as suggested by the advent of fires—see below). *Cycas* pollen continues at levels displayed in Zone B, but starts to decline near the top. *Areca catechu* pollen appears late in Zone C, and continues to manifest itself in low numbers in most intervals thereafter. With *Cocos*, it is probably also a part of what may be a developing agroforest. Pollen of *Freycinetia, Guettardia*, and *Ixora* hold to abundance levels seen in Zone B, but decline in Zone C. Similarly, *Metroxylon* displays a frequency seen in Zone B, then peaks at the top of Zone C before almost disappearing from the profile. Both Myrtaceae and *Pandanus* show slight increases in importance from the previous zone. Other forest elements are in decline here, including *Piper, Pouteria*, and *Randia*. Also, Urticaceae continues to decline in comparison to Zone A where it was more common. Among the Swamp/Mangrove types, *Barringtonia* follows a declining trend similar to the previous pollen types. At the same time *Bruguiera*, and both



species of *Rhizophora* gradually increase toward the top of this zone. Sedge and grass pollen begin to show slight increases from their very minor presence in Zone B. Both the unknown monosulcate pollen types (granulate and reticulate) remain steady throughout this zone. Other unknowns show increases, especially the microreticulates (small and ear-like ora types), reticulate, psilate/oblate, psilate, and the thin-walled angular amb type.

Polypodium pellucidum-type spores decline throughout this zone from about 35 percent to around 20 percent, a trend mirrored by the monolete, psilate type. Other monolete types hold to previous levels while the granulate type increases in the upper part, and the perinate type almost disappears after the top of this zone. Trilete type fern spores persist and maintain previous levels, including *Adiantum*, psilate type and *Cibotium*-type, while spores of *Angiopteris evecta* register at lower levels than in Zone B. In the 981–983 cm sample *Cyathea lunulata* spores increase and peak in the upper part of the zone. This pattern is duplicated in the *Lycopodium cernuum* curve. Of interest is that the *Lycopodium phlegmaria* curve drops from importance at the same interval that *L. cernuum* begins to rise, suggesting an ecological shift to a more open habitat at this time.

Charcoal particles first appear at the base of Zone C in minor amounts. In the first four samples of the zone the charcoal concentration values average 0.9 mm^2/cc, while in the upper half the values average 6.8 mm^2/cc. The entire zone averages 4.2 mm^2/cc. These values suggest low levels of fire but with an increase in the upper part of the zone. The consequent rise in *Cocos* pollen and *L. cernuum* spores points to both a more open and a fire-managed landscape during this zone.

Zone D: 2,956–1,789 cal. B.P. In Zone D, *Cocos* and *Pandanus* are the dominant contributors to the dryland pollen sum. These are joined by minor signals from *Aglaia, Areca*, and *Colubrina*. Several types appear to decline by mid-zone, including *Freycinetia* and Myrtaceae, while *Pandanus* declines throughout the zone. The Swamp/Mangrove pollen types are less conspicuous here than in Zone C. Of importance are the signals from sedge and grass, which begin their rise in importance in the plant community. Marsh conditions in the Laguas drainage were beginning to expand, and more of the forest was converted to open areas with grass cover. The unknown monosulcate (granulate and reticulate) types decline especially after the 571–573 cm interval. Most of the unknown pollen types disappear from the profile after this interval or are in steep decline. The exceptions are triporate pollen types, which increase in abundance slightly towards the top of this zone.

Polypodium pellucidum-type and psilate monolete spores steadily decline throughout this zone inversely to the monolete, granulate group. *Angiopteris evecta* and *Adiantum*, psilate both decline in this zone while *Adiantum*, granulate peaks in this zone. Similarly, *Gleichenia* surges to the highest level of any spore type in the profile, here exceeding 50 percent of the total sum. *Lycopodium cernuum*, *Pteris*, and trilete, psilate spores display modest gains in this zone. *Pseudoschizaea* levels decline through this zone.

Charcoal particle concentrations average 26 mm²/cc in Zone D, which represents a sixfold increase in abundance from Zone C. They are especially abundant after the 571–573 cm interval, after which they average 33 mm²/cc. These data suggest continued and increased fire use in the Laguas watershed area.

Zone E: 1,789–est. 200 cal. B.P. In Zone E *Casuarina*, *Cocos*, and *Euphorbia* are present but only in minor quantities. *Pandanus* registers about half of the level seen in the previous zone. Mangrove types including *Lumnitzera*, *Rhizophora apiculata*, and *R. mucronata* are dominant in this zone, comprising almost 70–80 percent of the total pollen spectrum. They clearly indicate the presence of a mangrove plant community at the Laguas coring site. Sedge pollen rises in importance while grass pollen peaks in this zone. Almost all of the unknown pollen types have disappeared from the profile in Zone E, and those that remain are represented by single grain occurrences. In general, the types and abundances of all pollen except mangrove, sedge and grass have fallen steeply, especially in comparison to Zone C

Among the Pteridophytes, the monolete (granulate and psilate) spore types are most prevalent. Trilete fern spores are markedly reduced from Zone D with only *Cyathea*, *Cibotium*-type, and *Gleichenia* present. *Gleichenia* spores decline abruptly throughout this zone.

The charcoal particle concentration values suggest further increases of burning frequency. The mean value for this zone is 54.5 mm²/cc which is twice that estimated for Zone D. Clearly, there was continued and possibly intensified burning activity during the period represented by Zone E.

Zone F: Modern. Zone F comprises a single surface pinch sample (with multiple pinches) recovered from the immediate vicinity of the core. This sample therefore records modern conditions at the Laguas site. The main contributors to the arboreal dryland pollen spectrum include *Artocarpus*, *Casuarina*, *Cocos*, and *Pandanus*. Among the Swamp/ Mangrove types, *Rhizophora apiculata* is dominant. In the Herb group, sedge pollen reaches almost 60 percent and dominates the pollen spectrum, attesting to continued marsh habitat at the coring site.

Most of the pteridophyte spore types have disappeared from the profile in Zone F. Minor signals are seen from monolete (granulate and psilate), *Cyathea* and *Gleichenia* spores.

The estimated charcoal particle concentration from this zone is 51.5 mm²/cc, which compares favourably to the mean of Zone E. Thus, the modern pattern of fire use in the Laguas watershed apparently was similar to that of Zone E based on this evidence alone.

Discussion

Early human settlement. Analysis of the IARII Laguas core shows that microscopic charcoal particles are entirely absent between 9,300 and 4,300 cal. B.P., and at 4,300 cal. B.P. they first appear in low concentrations. Because charcoal particles are entirely absent from this and other palaeo-environmental records for the preceding 5,000 years in Guam, we believe their appearance is likely the result of anthropogenic activities.

Interestingly, other disturbance indicators—pollen and spores—are not in evidence at this earliest time, and only

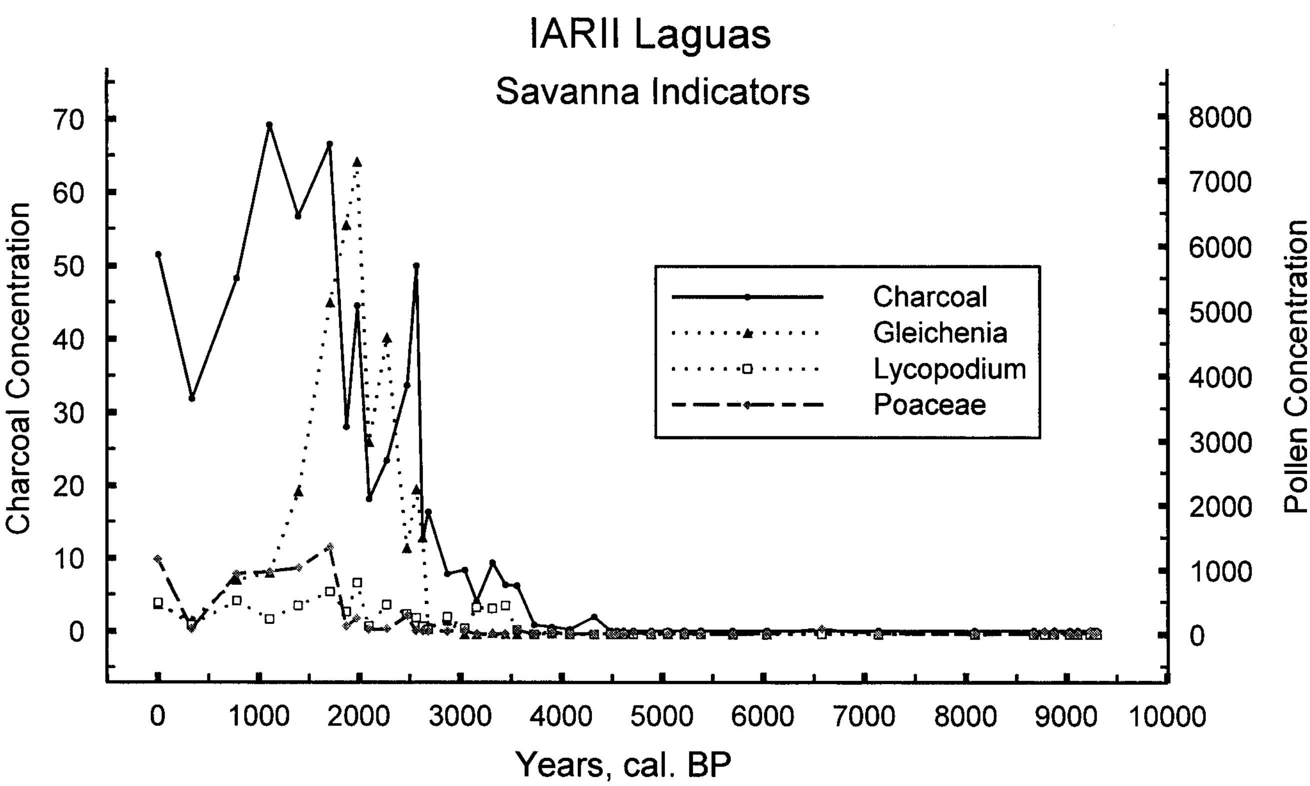


Fig. 7. Graph of charcoal particle concentrations and pollen concentrations of main savanna indicators for IARII Laguas core.

first become noticeable, albeit in low densities, in the core record about 3,900 cal. B.P. We believe this speaks of the sensitivity of charcoal particles for detecting human settlement, which is likely due to their wider dispersion as a result of atmospheric transport (Clark, 1988; Morrison, 1994). The absence of detectable signs of disturbance indicated by pollen and spores before 3,900 cal. B.P. may have to do with the small scale of human settlement and gardens located on the coastal fringes. These activities would not have produced a pollen signal indicative of disturbance in the more interior locations, where much of the pollen in the core presumably originated.

It might be argued that charcoal particles were derived from natural burning during drier conditions. However, any climatic change towards more arid conditions should show a broader scale impact, such as an increase in firing in the interior. No such increase is visible, nor is any evidence of increased long-term drought seen elsewhere in the global palaeoclimatic record. We therefore believe that the earliest appearance of charcoal particles results from human activities.

In view of the palaeoenvironmental evidence for a 4,300 cal. B.P. date for the initial settlement of Guam, it is very interesting to reconsider an often dismissed or ignored archaeological radiocarbon determination obtained by Joyce Bath in the 1980s for the San Vitores Road project. The charcoal date has a calibrated range of 4,419–4,150 cal. B.P. (1σ), which was derived from "…a dense firepit deposit, and thus of cultural origin" (Bath, 1986: 41). This date seems to be telling us exactly what the palaeoenvironmental evidence is telling us: people arrived on Guam well prior to the 3,500 year old time frame indicated by Spoehr and other archaeologists. The only other pre-3,500 cal. B.P. date for the Mariana Islands that appears reasonably secure is a determination of 3,866–3,576 cal. B.P. (1σ) from the Achugao site on Saipan (Butler, 1994). Unfortunately, the woods of both the Achugao and the San Vitores samples were not identified, which would have allowed only the short-lived plant parts or taxa to have been selected for dating. Thus, because of the potential problem for "in-built" ages in these dating results (Anderson, 1991: 779–782, McFadgen, 1982: 384), it cannot be known with certainty if the archaeological materials are actually as old as the samples seem to indicate.

Origin of interior savannas. With respect to the development of a savanna landscape in the interior upland areas of southern Guam, the data are about as unambiguous as it is possible for palaeoenvironmental data to be. As may be seen from the graph of the savanna (or disturbance) indicators (charcoal, *Gleichenia linearis* and *Lycopodium cernuum* ferns, grasses—see Fig. 7), there were none whatsoever prior to 4,300 cal. B.P., the date when the first evidence for burning began to appear. It is very unlikely that a major environmental zone of savanna or grasslands was present above the Laguas watershed and did not leave evidence in the palaeoenvironmental record. At 3,900 cal. B.P. two ferns suggestive of savanna formation and landscape disturbance began to appear, *Lycopodium* and *Gleichenia*. As already mentioned, their appearance probably denotes small-scale gardening activities within the Laguas watershed, and perhaps even the formation of small patches of savannas or grasslands. Limited environmental disturbance persisted until about 2,900 cal. B.P., when *Lycopodium*, *Gleichenia*, and other disturbance indicators became a conspicuous part of the palaeoenvironmental record. At this time the extent of the savanna/grasslands clearly underwent a substantial increase. Concurrently, pollen types representing different species of Guam's native

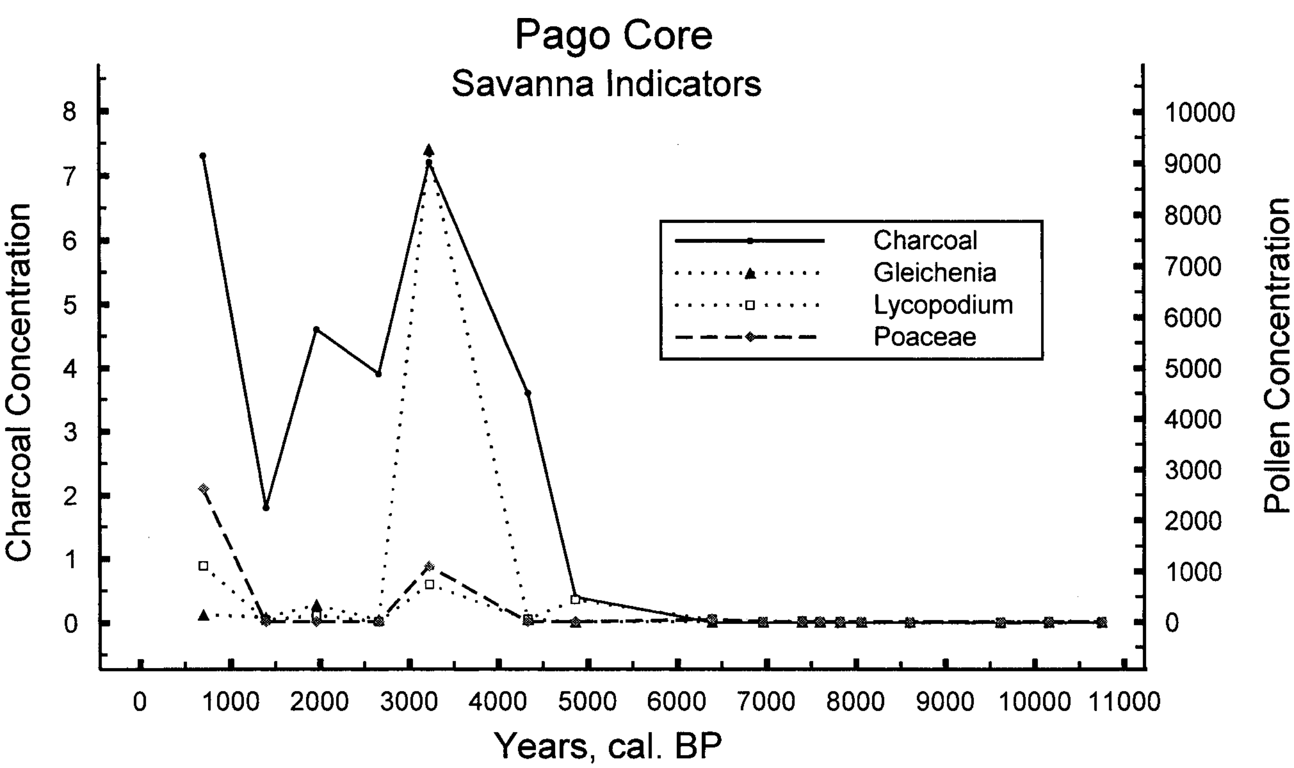


Fig. 8. Graph of charcoal particle concentrations and pollen concentrations of main savanna indicators for the Pago core (data from Ward, 1994).

forests declined steeply. By about 2,300 cal. B.P. it appears only remnant patches of the native forest remained. Presumably the savanna/grasslands of the interior uplands also began to assume their present appearance and extent by this time.

By way of comparison, the Pago core, despite the coarseness of its sampling record, mirrors the IARII Laguas findings (Fig. 8).

Landscape change and prehistoric agriculture. The pollen record shows that around 2,900 cal B.P. there was a steep decline in native forest about the time savannas became a significant landscape feature, and by c. 2,300 cal. B.P. only remnant patches of native forest were left.

Thus, in scarcely 2,000 years the entire appearance and natural history of Guam were transformed as a result of human settlement.

Direct pollen evidence for prehistoric agriculture is limited. One important finding (corroborating findings in the MARS Laguas and Tipalao cores—Ward, 1995; Athens & Ward, 1995) is that *Cocos* is not an introduced tree, but was among the native plants already existing on Guam when the first human colonists arrived. The IARII Laguas data show that this economically important tree increased gradually in the record after about 3,444 cal. B.P. from its pre-human sporadic occurrences, and did not decline until the start of the historical period.

Another cultigen, *Areca catechu*, the betel palm, also appears to be a native plant on Guam rather than an introduction. While in the IARII Laguas core its earliest appearance is at 3,157 cal. B.P., which is well after initial human colonization, it is present in the earlier prehuman Holocene intervals in the Tipalao and MARS Laguas cores (Table 1; Athens & Ward, 1993*b*; Ward, 1995). The IARII Laguas record suggests that *Areca catechu* became more common on the landscape beginning about 3,157 cal. B.P., possibly implying a long history of use by Guam's prehistoric population.

The only other definite cultigen to appear in the Laguas record is that of taro, *Colocasia esculenta*. Two grains of its pollen are present in the 167–169 cm interval, which dates to 1,107 cal. B.P. This appears to be the first time prehistoric *Colocasia esculenta* pollen has been documented in the Mariana Islands. Loy (2001, 2002) also recently identified *Colocasia esculenta* starch grains from the interior residues of Pre-Latte and Latte Period pottery sherds recovered from Guam sites (see also archaeological discussions in Moore & Hunter-Anderson, 2001: 102–112, 213, 230; Moore 2002: 43–47). *Colocasia esculenta* is a shy pollen producer and tends to be only infrequently observed in coring records. Its presence in the Laguas core suggests that taro was likely grown in the vicinity of Core 2 c. 1,100 years ago (i.e., the coastal wetlands were used at this time for growing taro).

An indefinite cultigen appearing in the Laguas coring record is that of *Artocarpus*, or breadfruit. Its occurrence as a cultigen is regarded as indefinite because there are four species on Guam, one of which (*A. mariannensis*) is considered to be native and wild (Stone, 1970: 247). All have edible fruits or seeds. Only *A. altilis* and *A. mariannensis* are common in Guam, and the latter has extensively hybridized with the former. The cooked seeds of the *A. mariannensis* are said to be "particularly tasty" (Stone, 1970: 249). Of interest for the present discussion is that *Artocarpus* first appears in the IARII Laguas record only sporadically as one or two grains just after 3,558 cal. B.P. Its regular appearance in the record at all after 3,558 cal. B.P. may indicate that either the native species or an introduced domesticated type (*A. altilis*) became more common on the landscape due to their incorporation into a human-managed coastal agroforest (with *Cocos* and *Areca catechu*).

Several important grasses were likely used by the prehistoric people of Guam, including rice (confirmed archaeologically, Hunter-Anderson *et al*., 1995), sugarcane, and bamboo. These plants are all regarded as introduced. The IARII Laguas pollen counts do indicate that grass pollen rose substantially after human arrival, particularly in Zones D and E. It is reasonable to suppose that possibly a small portion of the pollen sum was comprised of these introductions. However, because pollen in the grass family is not easily differentiated due to similar morphology (monoporate, granular), separation of these ethnobotanically-important species is not feasible using pollen analysis.

As for evidence of infilling or coastal progradation, the sedimentary evidence of the IARII Laguas core indicates that with the onset of Depositional Unit 2 around 1,700 B.P., the sedimentary regime changed from being primarily marine to terrigenous. Unfortunately, there is no basis for relating this change to human activities in the watershed as opposed to primarily natural processes. In fact, rather than an increase in the sedimentation rate, as would be expected from anthropogenic disturbances, it substantially decreased (Table 3).

Nevertheless, two nearby sampling areas (Core 1 and Trench 1) on the coastal plain c. 0.5 km north of the IARII Laguas core (Fig. 3) do point to significant terrigenous deposition along the coast during late prehistoric times. Neither of these sampling areas receives direct discharge from the Laguas River or any other stream. An initial auger/core effort (Core 1) roughly 100 m west of the point where the foothills begin their rise toward the interior revealed a brown clay loam to a depth of 145 cm below the surface, and bioclastic materials (sand with silt) to a depth of 207 cm below the surface; at 207 cm solid limestone rock was encountered. A sample of *Porites* sp. coral from the top of this limestone reef rock, located 85 cm below the surface in an excavation unit at a slightly more seaward location (Trench 1, about 50 m west of the auger/core unit) was dated to 2,455–2,298 cal. B.P. (1σ) (Athens & Ward, 1999: 126, 133, 142). This evidence confirms the identification of this slightly raised reef as Merizo Limestone (Easton *et al*., 1978), and provides a terminal date for its formation. Clearly, the heavy clayey sediments on top of this reef post-date the age of the reef. However, the date for the onset of deposition cannot be determined with more precision since deposition may not have begun immediately upon cessation of coral growth. Nevertheless, these results suggest that considerable coastal infilling occurred during the past roughly 2,000 years. Future investigations will be required to determine more precisely the time when major coastal deposition occurred in the Laguas area, but in general our data do not contradict the previous findings of Dye & Cleghorn (1990) and Hunter-Anderson (1989).

Conclusion

The palaeoenvironmental data are provocative for their implications about early human settlement in Guam (and presumably the other major Mariana Islands). Interestingly, the changes in the IARII Laguas record mirror changes in our cores from Palau concerning the dating of initial human settlement (Athens & Ward, 2002). This strengthens our belief that these changes are real and that enough work has been accomplished to seriously consider that human colonization of western Micronesia (including Palau) occurred by the mid-fifth millennium B.P. (Yap may also fit this pattern, but the palaeoenvironmental evidence is not conclusive—see Dodson & Intoh, 1999). Such evidence is consistent with the chronology postulated by the various models for Austronesian ethno-linguistic expansion in island southeast Asia (see Oppenheimer & Richards, 2001 for an informative diagram and discussion of the three main models—see also Terrell *et al*., 2001 for recent arguments). The significance here is, first, that the initial settlement of western Micronesia, presumably by Austronesians, occurred about 1,000 years before the advent of the Lapita cultural complex in Melanesia (around 3,500–3,400 cal. B.P.—see Bellwood, 1991, Kirch, 2000: 91–93). Second, it was apparently tied to the early, possibly initial, period of Austronesian ethno-linguistic expansion in island southeast Asia.

The Philippines and Sulawesi often have been referred to as likely points of origin for the initial Austronesian settlers of the Mariana Islands (e.g., Bellwood, 1979: 282–286, Kirch, 2000: 171–173). Although both the Mariana and Palau archipelagos seem to have been first settled at approximately the same time (by the mid-fifth millennium B.P.), we do not wish to imply similar origins for the settlers. Present evidence, in fact, suggests very different origins and complex histories for the various western Pacific archipelagos, as others also have argued.

As to the Laguas palaeoenvironmental data, the finding that humans are responsible for the creation of the savannas that presently extend over broad areas of the interior uplands of southern Guam appears indisputable. This finding, while presumably solving one important research problem, opens up another. This concerns why people were burning the interior of Guam? We agree with Hunter-Anderson (1998) that it is probably not because the earliest prehistoric inhabitants sought out these areas as the most favourable locations for slash-and-burn agriculture as some models of oceanic agriculture suggest (e.g., Barrau, 1961).

Although the ancient volcanic and highly weathered interior soils of Guam tend to be very poor for agriculture, there are patchy areas with better soils as indicated on soil maps (see Young, 1988). Presumably these patches were the focal interior areas sought out and settled by at least a few people in late Pre-Latte times, and then much more extensively during the Latte Period. While recent studies have shown that archaeological sites are not rare in interior savanna areas during the Latte Period (e.g., Moore & Hunter-Anderson, 1994), they were obviously not the most desirable places to live. The truth, it seems, is that prehistoric populations preferred living near the coast and tending gardens in nearby alluvial and wetland areas if at all possible (especially as these areas increased as a result of coastal sedimentary deposition after c. 2,000 cal. B.P.). Some movement to the interior likely occurred as a result of population growth beginning as early as late Pre-Latte times, but presumably these interior settlements were located in alluvial valleys and patchy upland areas where edaphic conditions for agriculture were relatively more favourable than the older weathered soils that typify much of the area.

To account for the formation of the savannas, it appears that dry season fires must have been intentionally set on occasion, perhaps by individuals making forays into the interior for wild tubers or other wild food resources. These fires might have been set with the intention of increasing the production of certain wild forest products, to facilitate travel through these areas, or for pure entertainment. The actual reason is probably not determinable. The result, however, was that with exposure to the sun and tropical rains, and continued firing at irregular intervals during dry seasons, the fragile soils of the upland landscape quickly became degraded and could no longer support forest vegetation.

With respect to the issue of landscape change, the palaeoenvironmental record suggests that coincident with the rise of savannas beginning about 2,900 cal. B.P., there was a steep decline in the native forest, and that by about 2,300 cal. B.P. there were only remnant patches of native forest left. With the onset of pollen Zone E c. 1,800 cal. B.P., charcoal concentration values increased markedly, possibly suggesting greater land use intensification and/or population increase.

Unfortunately, the pollen data in regard to prehistoric agriculture are very limited and cannot provide much useful information. Apparently arboriculture with coconut, breadfruit, and betel nut was an aspect of the cropping system. *Colocasia* taro was present at least by 1,100 cal. B.P., though it is such a poor pollen producer that it may have been cultivated for a long time prior to this date (as suggested by the pottery residue analyses of Loy). There were undoubtedly other cultigens, such as tubers and grasses, but thus far these are not visible palynologically.

The Laguas sedimentary evidence (from Merizo limestone sampling areas north of the IARII Laguas core) makes it clear that sometime after about 2,400 cal. B.P. there was an increase in coastal deposition as a result of erosion from the surrounding hillslopes. This implies that the landscape came under more intensive utilization, presumably for agriculture, though exactly when this happened in the Laguas area is not clear from either the coring data or the Merizo limestone excavation. As noted, the charcoal particle evidence suggests increasing intensification of land use beginning c. 1,800 cal. B.P., but there is no corresponding increase in the rate of deposition in the IARII Laguas core. Investigations elsewhere in Guam (e.g., Dye & Cleghorn, 1990, Hunter-Anderson, 1989) indicate that coastal deposition of inland sediments occurred sometime between the early first millennium B.P. and late second millennium B.P., suggesting a later date for a quantum increase in land use of the coastal hill slopes and interior valleys. As this seems to occur immediately prior to the change from the Pre-Latte to the Latte Period, there may have been a causal connection. Though this may well also be the case in the Laguas area (more studies are needed to pin down the timing of coastal deposition), it is nevertheless clear from the IARII Laguas record that land use intensification was an ongoing process on Guam and not an event that suddenly occurred.

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References

Anderson, A., 1991. The chronology of colonization in New Zealand. *Antiquity* 65(249): 767–795.

Anderson, A., 1994. Palaeoenvironmental evidence of island colonization: a response. *Antiquity* 68(261): 845–847.

Athens, J.S., 1986. *Archaeological Investigations at Tarague Beach, Guam*. Report prepared for Base Civil Engineering, Andersen Air Force Base, Dept. of the Air Force, Guam. Honolulu: International Archaeological Research Institute, Inc.

Athens, J.S., 1997. Hawaiian native lowland vegetation in prehistory. In *Historical Ecology in the Pacific Islands: Prehistoric Environmental and Landscape Change*, ed. P.V. Kirch and T.L. Hunt, pp. 248–270. New Haven/London: Yale University Press.

Athens, J.S., & J.V. Ward, 1993*a*. Environmental Change and Prehistoric Polynesian Settlement in Hawai'i. *Asian Perspectives* 32(2): 205–223.

Athens, J.S., & J.V. Ward, 1993*b*. Paleoenvironment of the Orote Peninsula. In *The Archaeology of Orote Peninsula: Phase I and II, Archaeological Inventory Survey of Areas Proposed for Projects to Accommodate Relocation of Navy Activities from the Philippines to Guam, Mariana Islands*, ed. J. Carucci, chapter X, pp. 153–197. Report prepared for Dept. of the Navy, Pacific Division, Naval Facilities Engineering Command, Pearl Harbor, Hawai'i, under contract to Belt Collins and Associates, Honolulu. Honolulu: International Archaeological Research Institute, Inc.

Athens, J.S., & J.V. Ward, 1995. Paleoenvironment of the Orote Peninsula, Guam. *Micronesica* 28(1): 51–76.

Athens, J.S., & J.V. Ward, 1998. *Paleoenvironment and Prehistoric Landscape Change: A Sediment Core Record from Lake Hagoi, Tinian, CNMI*. Report prepared for Dept. of the Navy, Pacific Division, Naval Facilities Engineering Command, Pearl Harbor, Hawai'i, under contract to Belt Collins Hawaii, Honolulu. Honolulu: International Archaeological Research Institute, Inc.

Athens, J.S., & J.V. Ward, 1999. Paleoclimate, vegetation, and landscape change on Guam: the Laguas core. In *Archaeological Inventory Survey of the Sasa Valley and Tenjo Vista Fuel Tank Farms, Piti District, Territory of Guam, Mariana Islands*, ed. B. Dixon, J.S. Athens, J.V. Ward, T. Mangieri, and T. Rieth, chapter V, pp. 121–151. Report prepared for Department of the Navy, Pacific Division, Naval Facilities Engineering Command, Pearl Harbor, Hawai'i. Honolulu: International Archaeological Research Institute, Inc.

Athens, J.S., & J.V. Ward, 2000. Paleoenvironmental study of fishponds at Fort Shafter, O'ahu, Hawai'i. Appendix F in *Fort Shafter: Cultural Resource Investigations at Hawai'i's First U.S. Military Post*, by M.J. Tomonari-Tuggle, S. Hamilton and K. Slocumb, pp. F-1, F-58. Report prepared for the U.S. Army Corps of Engineers, Pacific Ocean Division, Fort Shafter, Hawai'i. Honolulu: International Archaeological Research Institute, Inc.

Athens, J.S., & J.V. Ward, 2002. Paleoenvironmental evidence for early human settlement in Palau: the Ngerchau core. In *Pacific 2000: Proceedings of the Fifth International Conference on Easter Island and the Pacific*, ed. C.M. Stevenson, G. Lee and F.J. Morin, pp. 165–177. Los Osos, California: Easter Island Foundation.

Athens, J.S., H.D. Tuggle, J.V. Ward & D.J. Welch, 2002. Avifaunal extinctions, vegetation change, and Polynesian impacts in prehistoric Hawai'i. *Archaeology in Oceania* 37: 57–78.

Athens, J.S., J.V. Ward & G.M. Murakami, 1996. Development of an agroforest on a Micronesian high island: prehistoric Kosraean agriculture. *Antiquity* 70(270): 834–846.

Barrau, J., 1961. *Subsistence agriculture in Polynesia and Micronesia*. Bernice P. Bishop Museum Bulletin 223. Honolulu: Bishop Museum Press.

Bath, J.E., 1986. The San Vitores Road Project, Part 1: Final Report. Prepared for Maeda Pacific Corporation and Maeda Road Construction Co., Ltd., A Joint Venture. Copy of volume in library at International Archaeological Research Institute, Inc., Honolulu.

Bellwood, P., 1979. *Man's Conquest of the Pacific: The Prehistory of Southeast Asia and Oceania*. New York: Oxford University Press.

Bellwood, P., 1991. The Austronesian dispersal and the origin of languages. *Scientific American* 265(1): 88–93.

Butler, B.M., 1990. Pots as tools: the Marianas case. *Micronesica* Supplement 2: 33–46.

Butler, B.M., 1994. Early prehistoric settlement in the Mariana Islands: new evidence from Saipan. *Man and Culture in Oceania* 10: 15–38.

Butler, K., & J. Flenley, 2000. Further investigation of vegetation and human impact on Easter Island. In *Proceedings of the Twentieth Geography Conference*, ed. M. Roche, M. McKenna and P. Hesp, pp. 24–27. Palmerston North: New Zealand Geographical Society.

Clark, J.S., 1988. Particle motion and the theory of charcoal analysis: source area, transport, deposition, and sampling. *Quaternary Research* 30: 67–80.

Dickinson, W.R., 2000. Hydro-isostatic and tectonic influences on emergent Holocene paleoshorelines in the Mariana Islands, western Pacific Ocean. *Journal of Coastal Research* 16(3): 735–746.

Dodson, J.R., & M. Intoh, 1999. Prehistory and palaeoecology of Yap, federated states of Micronesia. *Quaternary International* 59: 17–26.

Dye, T., & P.L. Cleghorn, 1990. Prehistoric use of the interior of southern Guam. *Micronesica* Supplement 2: 261–274.

Easton, W.H., T.L. Ku & R.H. Randall, 1978. Recent reefs and shore lines of Guam. *Micronesica* 14(1): 1–11.

Fairbanks, R.G., 1989. A 17,000–year glacio-eustatic sea level record: influence of glacial melting rates on the Younger Dryas event and deep-ocean circulation. *Nature* 342: 637–642.

Flenley, J.R., 1994. Pollen in Polynesia: the use of palynology to detect human activity in the Pacific islands. In *Tropical Archaeobotany: Applications and New Developments*, ed. J.G. Hather, pp. 202–214. London: Routledge.

Flenley, J.R., 1998. New data and new thoughts about Rapa Nui. Easter Island in Pacific Context: South Seas Symposium. In *Proceedings of the Fourth International Conference on Easter Island and East Polynesia*, ed. C.M. Stevenson, G. Lee and F.J. Morin, pp. 125–128. Los Osos, California: Easter Island Foundation.

Flenley, J.R., A.S.M. King, J.T. Teller, M.E. Prentice, J. Jackson & C. Chew, 1991. The Late Quaternary vegetational and climatic history of Easter Island. *Journal of Quaternary Science* 6(2): 85–115.

Graves, M.W., 1986. Organization and differentiation within late prehistoric ranked social units, Mariana Islands, western Pacific. *Journal of Field Archaeology* 13(2): 139–154.

Haberle, S., 1994. Anthropogenic indicators in pollen diagrams: problems and prospects for Late Quaternary palynology in New Guinea. In *Tropical Archaeobotany: Applications and New Developments*, ed. J.G. Hather, pp. 172–201. London: Routledge.

Hope, G., D. O'Dea & W. Southern, 1999. Holocene vegetation histories in the western Pacific—alternative records of human impact. In *Le Pacifique de 5000 à 2000 Avant le Présent. Suppléments à l'Histoire d'une Colonisation. The Pacific from 5000 to 2000 B.P. Colonisation and Transformations*, ed. I. Lilley and J-C. Galipaud, pp. 387–406. Actes du Colloque Vanuatu, 31 Juillet-6 Aout 1996. Editions de l'ORSTOM. Collection Colloques et Séminaires. Paris 1998.

Hunter-Anderson, R., 1989. Archaeological Investigations in the Small Boat Harbor Project Area, Agat, Guam. Report prepared for the U.S. Army Engineer District, Pacific Ocean Division, Ft. Shafter, Hawaii. Honolulu: International Archaeological Research Institute, Inc.

Hunter-Anderson, R., 1998. From Palau to Rapanui, are the Pacific Island grasslands recent "artifacts" or natural formations? Paper presented at the 63rd Annual Meeting of the Society for American Archaeology, Seattle, Washington, 25–29 March. Copy of paper in library at International Archaeological Research Institute, Inc., Honolulu.

Hunter-Anderson, R., & D.R. Moore, 2000. *Phase I archaeological survey and specialized studies in undeveloped portions of Nimitz Hill, Territory of Guam, Mariana Islands*. Report prepared for Department of the Navy, Pacific Division, Naval Facilities Engineering Command, Pearl Harbor, Hawai'i. Report prepared by Micronesian Archaeological Research Services, Inc., Guam. Honolulu: International Archaeological Research Institute, Inc.

Hunter-Anderson, R.L., G.B. Thompson & D.R. Moore, 1995. Rice as a prehistoric valuable in the Mariana Islands, Micronesia. *Asian Perspectives* 34(1): 69–89.

Key, R.E., ed., 1968. A Naturalist's Guide to Guam. Guam Science Teachers' Association. Agana, Guam: Star Press.

Kirch, P.V., 2000. *On the Road of the Winds: An Archaeological History of the Pacific Islands before European Contact*. Berkeley: University of California Press.

Kirch, P.V., & J. Ellison, 1994. Palaeoenvironmental evidence for human colonization of remote oceanic islands. *Antiquity* 68(259): 310–321.

Loy, T.H., 2001. Cooking residues on four potsherds, Nimitz Hill, Guam. In *Phase II archaeological survey: detailed recording of sites on the lands to be retained by the Navy, Nimitz Hill, Territory of Guam, Mariana Islands*, by D.R. Moore and R.L. Hunter-Anderson, appendix B, pp. B-1, B-31. Report prepared for Department of the Navy, Pacific Division, Naval Facilities Engineering Command, Pearl Harbor, Hawai'i. Report prepared by Micronesian Archaeological Research Services, Inc., Guam. Honolulu: International Archaeological Research Institute, Inc.

Loy, T.H., 2002. Analysis of pottery sherds from two archaeological sites: Guam. In *Guam's prehistoric pottery and its chronological sequence*, by D.R. Moore, appendix D, pp. 125–157. Report prepared for Department of the Navy, Pacific Division, Naval Facilities Engineering Command, Pearl Harbor, Hawai'i. Report prepared by Micronesian Archaeological Research Services, Inc., Guam. Honolulu: International Archaeological Research Institute, Inc.

Maher, L.J., Jr., 1992. Depth-age conversion of pollen data. INQUA—Commission for the Study of the Holocene, Working Group on Data-Handling Methods. *INQUA Newsletter* 7: 13–17.

McFadgen, B.G., 1982. Dating New Zealand archaeology by radiocarbon. *New Zealand Journal of Science* 25: 379–392.

McGlone, M.S., & J.M. Wilmshurst, 1999. Dating initial Maori environmental impact in New Zealand. *Quaternary International* 59: 5–16.

Moore, D.R., 2002. Guam's prehistoric pottery and its chronological sequence. Report prepared for Department of the Navy, Pacific Division, Naval Facilities Engineering Command, Pearl Harbor, Hawai'i. Report prepared by Micronesian Archaeological Research Services, Inc., Guam. Honolulu: International Archaeological Research Institute, Inc.

Moore, D.R., & R.L. Hunter-Anderson, 1994. Summary of sites and feature descriptions. In *Archaeology in Manenggon Hills, Yona, Guam, vol. III, Results of Analyses*, ed. R.L. Hunter-Anderson, chapter 1, pp. 1–43. Report prepared for MDI Guam Corporation, Leo Palace Resort Country Clubhouse, Yona, Guam. Micronesian Archaeological Research Services, Guam.

Moore, D.R., & R.L. Hunter-Anderson, 2001. Phase II archaeological survey: detailed recording of sites on the lands to be retained by the Navy, Nimitz Hill, Territory of Guam, Mariana Islands. Report prepared for Department of the Navy, Pacific Division, Naval Facilities Engineering Command, Pearl Harbor, Hawai'i. Report prepared by Micronesian Archaeological Research Services, Inc., Guam. Honolulu: International Archaeological Research Institute, Inc.

Morrison, K.D., 1994. Monitoring regional fire history through size-specific analysis of microscopic charcoal: the last 600 years in south India. *Journal of Archaeological Science* 21(5): 675–685.

Newnham, R.M., D.J. Lowe, M.S. McGlone, J.M. Wilmshurst & T.F.G. Higham, 1998. The Kaharoa Tephra as a critical datum for earliest human impact in northern New Zealand. *Journal of Archaeological Science* 25(6): 533–544.

Nunn, P.D., 1997. Late Quaternary environmental changes on Pacific islands: controversy, certainty and conjecture. *Journal of Quaternary Science* 12(5): 443–450.

Oppenheimer, S., & M. Richards, 2001. Fast trains, slow boats, and the ancestry of the Polynesian Islanders. *Science Progress* 84(3): 157–181.

Spoehr, A., 1957. Marianas prehistory: archaeological survey and excavations on Saipan, Tinian and Rota. *Fieldiana: Anthropology* 48. Field Museum of Natural History, Chicago.

Spriggs, M., & A. Anderson, 1993. Late colonization of east Polynesia. *Antiquity* 67(255): 200–217.

Stone, B.C., 1970. The flora of Guam. *Micronesica* 6: 1–659.

Stuiver, M., & P.J. Reimer, 1993. Extended ^{14}C Data base and Revised CALIB 3.0 ^{14}C Age Calibration Program. *Radiocarbon* 35(1): 215–230.

Swift, M.K., S. Wickler & J.S. Athens, 1991. Archaeological subsurface investigations of the Gentle Breeze, Inc. project area, Achugao, Saipan. Report prepared for Gecko Consulting Services, Saipan. Honolulu: International Archaeological Research Institute, Inc.

Terrell, J.E., K.M. Kelly & P. Rainbird, 2001. Foregone conclusion? in search of "Papuans" and "Austronesians". *Current Anthropology* 42(1): 97–124.

Tracey, J.I., Jr., S.O. Schlanger, J.T. Stark, D.B. Doan & H.G. May, 1964. *General Geology of Guam*. Geological Survey Professional Paper 403–A. Washington, D.C.: United States Government Printing Office.

Ward, J.V., 1994. A Holocene pollen record from the Pago River Valley, Guam. In *Archaeology in Manenggon Hills, Yona, Guam, vol. III, Results of Analyses*, ed. R.L. Hunter-Anderson, Chapter 9.B, pp. 9.34–9.52. Report prepared for MDI Guam Corporation, Yona, Guam. Guam: Micronesian Archaeological Research Services.

Ward, J.V., 1995. A Holocene pollen record from Laguas River, Guam. In *Archaeology in the Marine Drive corridor from Agana to Agat, Guam*, by E.F. Wells, U.K. Prasad and R.L. Hunter-Anderson, Appendix B, pp. 205–224. Draft final report prepared for Guam Department of Public Works, Agana, Guam. Guam: Micronesian Archaeological Research Services.

Young, F.J., 1988. *Soil survey of Territory of Guam*. U.S. Department of Agriculture, Soil Conservation Service in cooperation with Guam Department of Commerce and University of Guam.

Zan, Y., & R.L. Hunter-Anderson, 1987. On the origins of the Micronesian "savannahs": an anthropological perspective. Paper presented at the 3rd International Soil Management Workshop: Management and Utilization of Acid Soils of Oceania. Belau, 2–6 February 1987. Copy of paper in library at International Archaeological Research Institute, Inc., Honolulu.

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Attenbrow and Fullagar, vol. eds, 2004, *Rec. Aust. Mus., Suppl.* 29, pp. i–v
http://dx.doi.org/10.3853/j.0812-7387.29.2004.1483

Taçon et al., 2004, *Rec. Aust. Mus., Suppl.* 29: 1–8
http://dx.doi.org/10.3853/j.0812-7387.29.2004.1396

Khan, 2004, *Rec. Aust. Mus., Suppl.* 29: 9–14
http://dx.doi.org/10.3853/j.0812-7387.29.2004.1397

Athens, 2004, *Rec. Aust. Mus., Suppl.* 29: 15–30
http://dx.doi.org/10.3853/j.0812-7387.29.2004.1398

Bolton, 2004, *Rec. Aust. Mus., Suppl.* 29: 31–36
http://dx.doi.org/10.3853/j.0812-7387.29.2004.1399

Bonshek, 2004, *Rec. Aust. Mus., Suppl.* 29: 37–45
http://dx.doi.org/10.3853/j.0812-7387.29.2004.1400

Denham, 2004, *Rec. Aust. Mus., Suppl.* 29: 47–57
http://dx.doi.org/10.3853/j.0812-7387.29.2004.1401

Galipaud, 2004, *Rec. Aust. Mus., Suppl.* 29: 59–64
http://dx.doi.org/10.3853/j.0812-7387.29.2004.1402

Knowles, 2004, *Rec. Aust. Mus., Suppl.* 29: 65–74
http://dx.doi.org/10.3853/j.0812-7387.29.2004.1403

Lentfer, 2004, *Rec. Aust. Mus., Suppl.* 29: 75–88
http://dx.doi.org/10.3853/j.0812-7387.29.2004.1404

Lilley, 2004, *Rec. Aust. Mus., Suppl.* 29: 89–96
http://dx.doi.org/10.3853/j.0812-7387.29.2004.1405

Pavlides, 2004, *Rec. Aust. Mus., Suppl.* 29: 97–108
http://dx.doi.org/10.3853/j.0812-7387.29.2004.1406

Sand, 2004, *Rec. Aust. Mus., Suppl.* 29: 109–122
http://dx.doi.org/10.3853/j.0812-7387.29.2004.1407

Sheppard, 2004, *Rec. Aust. Mus., Suppl.* 29: 123–132
http://dx.doi.org/10.3853/j.0812-7387.29.2004.1408

Smith, 2004, *Rec. Aust. Mus., Suppl.* 29: 133–138
http://dx.doi.org/10.3853/j.0812-7387.29.2004.1409

Spriggs, 2004, *Rec. Aust. Mus., Suppl.* 29: 139–144
http://dx.doi.org/10.3853/j.0812-7387.29.2004.1410

Summerhayes, 2004, *Rec. Aust. Mus., Suppl.* 29: 145–156
http://dx.doi.org/10.3853/j.0812-7387.29.2004.1411

Swadling, 2004, *Rec. Aust. Mus., Suppl.* 29: 157–161
http://dx.doi.org/10.3853/j.0812-7387.29.2004.1412

Torrence, 2004, *Rec. Aust. Mus., Suppl.* 29: 163–172
http://dx.doi.org/10.3853/j.0812-7387.29.2004.1413

Wilson, 2004, *Rec. Aust. Mus., Suppl.* 29: 173–186
http://dx.doi.org/10.3853/j.0812-7387.29.2004.1414