

## Paleoenvironment of the Orote Peninsula, Guam

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**Abstract**—Two sediment cores from the Orote Peninsula, Guam provide a Holocene environmental record beginning about 7900 years B.P. An active fault possibly separates the two cores, accounting for differences in their sedimentary records. Pollen analysis of one core differentiated six zones and subzones of vegetation. Among the more significant findings were an abrupt decline in *Pandanus* after 2150 years B.P., and a similarly abrupt decline of other littoral trees and shrubs after about 2700 years B.P. These declines are probably related to prehistoric human activities such as land clearance for agriculture. The construction of megalithic *latte* stone monuments apparently occurred well after the start of land use intensification. Coconut pollen in pre-human sample intervals suggests its arrival on Guam by natural rather than human transport. Charcoal particles first occur in the stratigraphic record ca. 3550 years B.P. Besides indicating the probable antiquity of human occupation on Guam, this date suggests that fires did not naturally occur during the Holocene.

### Introduction

A paleoenvironmental record was obtained from Tupalao Marsh, a wetland located near sea level at Orote Peninsula on the west side of Guam (Figs. 1 and 2). Analysis of two recovered cores provides a wealth of data relating to Guam's natural and cultural history during the Holocene.

Coring and paleoenvironmental studies have been previously conducted on Guam only with limited success (e.g., Cordy & Allen 1986, Hunter-Anderson 1989). However, several recent projects (Hunter-Anderson 1994, Ward & Hunter-Anderson, unpub. data) hold considerable promise for expanding knowledge concerning Guam's prehistoric and prehuman environmental past. Similar investigations in other parts of the tropical Pacific have proved quite valuable in terms

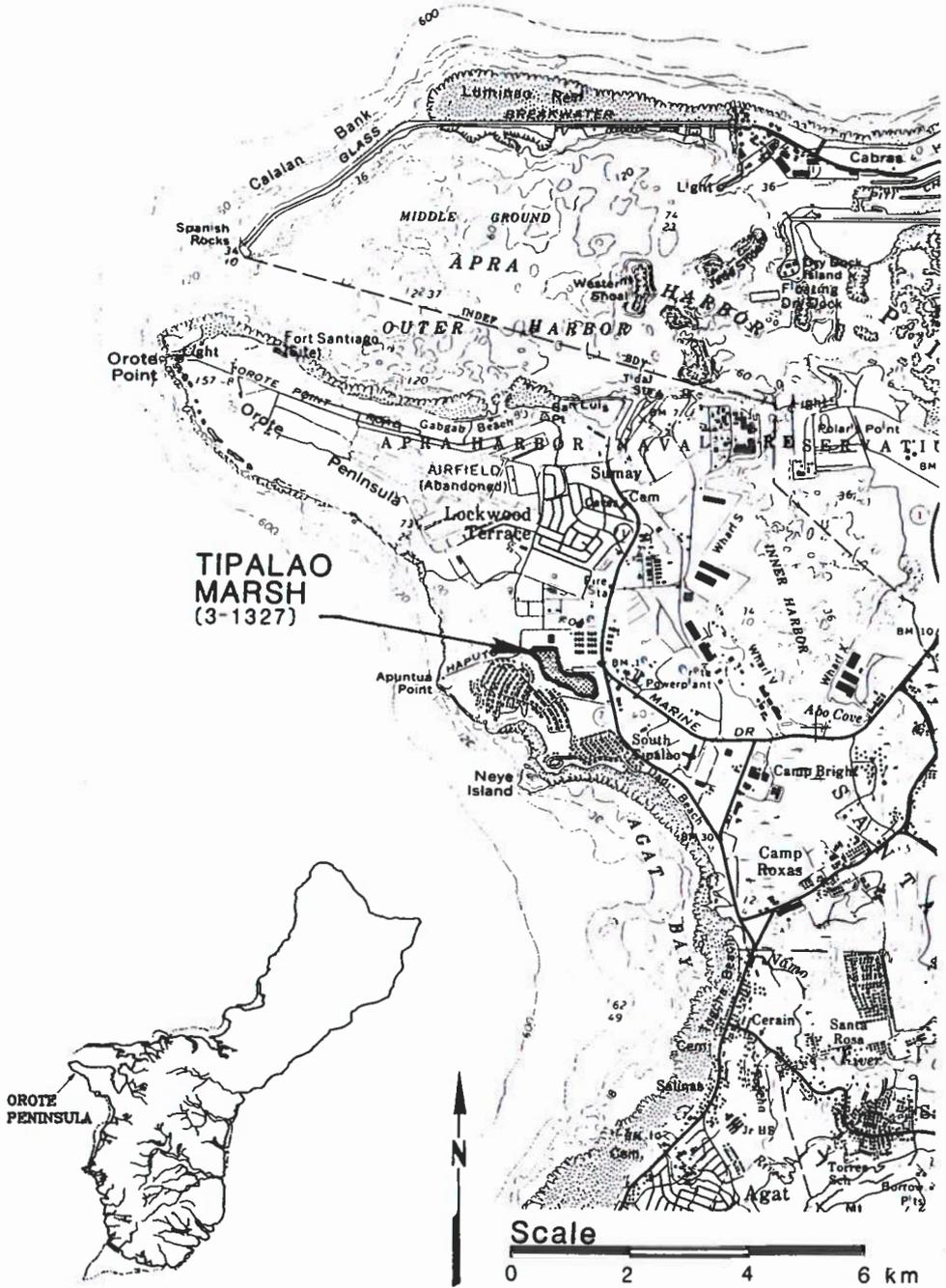


Figure 1. Portion of 1978 USGS topographic map showing Orote Peninsula and vicinity with location of Tipalao Marsh added (after USGS 1978).

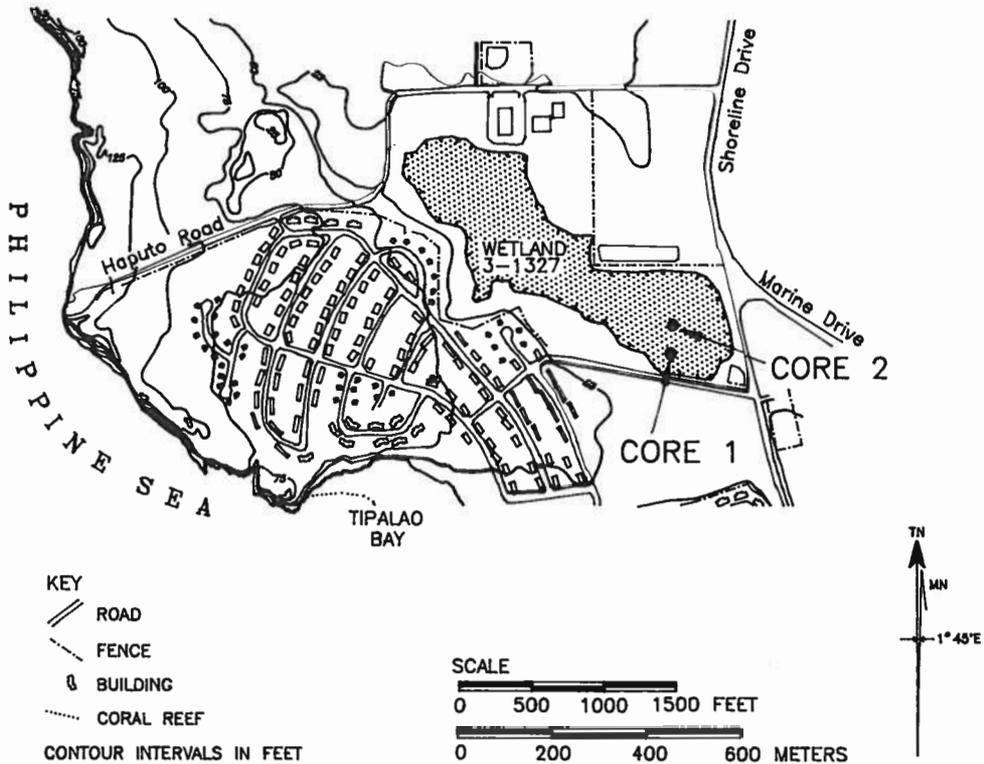


Figure 2. Map of Tupalao Marsh showing coring locations (after Helber et al. 1986).

Because of its significance for contributing to an understanding of the prehistory of Guam, the Guam Historic Preservation Office has designated Tupalao Marsh as an archaeological site and assigned it the official site register number of 3-1327.

of yielding new information concerning the date of initial human settlement, natural environmental conditions and vegetation prior to initial settlement, changes that occurred to the natural environment following settlement, the prehistoric introduction of plants, the inland expansion of settlement and agriculture, sea level change, climate change, and related issues (e.g., Athens et al. 1992, Athens & Ward 1993a, 1994, Flenley et al. 1991, Kirch et al. 1992, Kirch & Ellison 1994, Nunn 1991).

Tupalao Marsh is situated near the eastern part of Orote Peninsula next to the North Tupalao Naval housing area (Figs. 1 and 2). It is roughly 800 m long (NW to SE) and 200 m wide, and has an area of approximately 14 ha (35 acres). Before infilling along the eastern perimeter by the military, the marsh would have been larger, and possibly much larger if it extended all the way to Inner Apra Harbor (see below). The surface of the marsh is 1.5 to 1.8 m above mean sea level in the southeastern half and 2.1 m in the northwestern half (Helber et al. 1986).

## Environment

### GEOLOGY

Orote Peninsula is comprised of a Pliocene-Pleistocene limestone plateau of reef origin known as the Mariana Formation, which also comprises the plateau of the northern half of Guam. According to Easton et al. (1978:9-10), there has been a ca. 3 m uplift of Guam during the past 3000 to 4000 years. Recent investigations by Kayanne et al. (1993) indicate an age of 3200 years B.P. for the abrupt uplift and emergence of Holocene reefs in the Mariana Islands. The geological processes underlying the formation of Tupalao Marsh are unclear. No faults have been specifically mapped in this area; an inferred thrust fault at the western tip of Orote Peninsula (Tracey et al. 1992) would not have directly affected the marsh. The marsh may have formed from differential tilting of the peninsula through tectonic processes. This would explain why the eastern part of the peninsula is at or near sea level whereas the western part is nearly 60 m above mean sea level.

A broad area of alluvium east of Tupalao Marsh (Tracey et al. 1964:Fig. 31) may also be a result of tectonic tilting (see also Fig. 3). A 1913-1914 map (Corps of Engineers 1913-1914—also see Carucci 1993:25) depicts a large area of mangrove forest that almost touches the east side of the marsh. The present wetland, therefore, may be only a remnant of a much larger wetland that was at or near sea level before infilling. Thus, the eastern part of the peninsula clearly does not appear to be emerging despite general tectonic processes operative on Guam during the middle to late Holocene.

In addition to the tilting of the Orote Peninsula, the marsh appears to be constrained on its west and southwest margins by a possible fault. This may have uplifted the area on which the Tupalao housing developments (see Figs. 1 and 2) were built.

### VEGETATION

Although much of the original Orote limestone surface has been extensively modified by military development, there are several pristine areas having rugged karst topography north and south of the western part of Haputo Road (Fig. 2). These areas, some 30 to 40 m above sea level and having a pit and pinnacle landscape (cf. White 1988:45-40), are characterized by a limestone forest of mostly native plant species. Such vegetation was presumably much more widespread on the peninsula. Whistler (1992:18-19) describes the vegetation of the remnant limestone forest as,

... dominated by native tree species, the most common of which are *Ficus prolixa* (banyan), *Pisonia grandis*, and *Neisosperma oppositifolium*. Less common native trees include *Cynometra ramiflora*, *Intsia bijuga* (ifl), *Pipturus argenteus*, *Aglaia mariannensis*, *Premna serratifolia*, *Polyscias grandifolia*, *Pouteria obovata*, *Psychotria mariana*, *Guetarda speciosa*, *Melanolepis multiglandulosa*, *Pandanus tectorius* (screw-pine), and *Pandanus dubius*. Two other trees were noted to be less

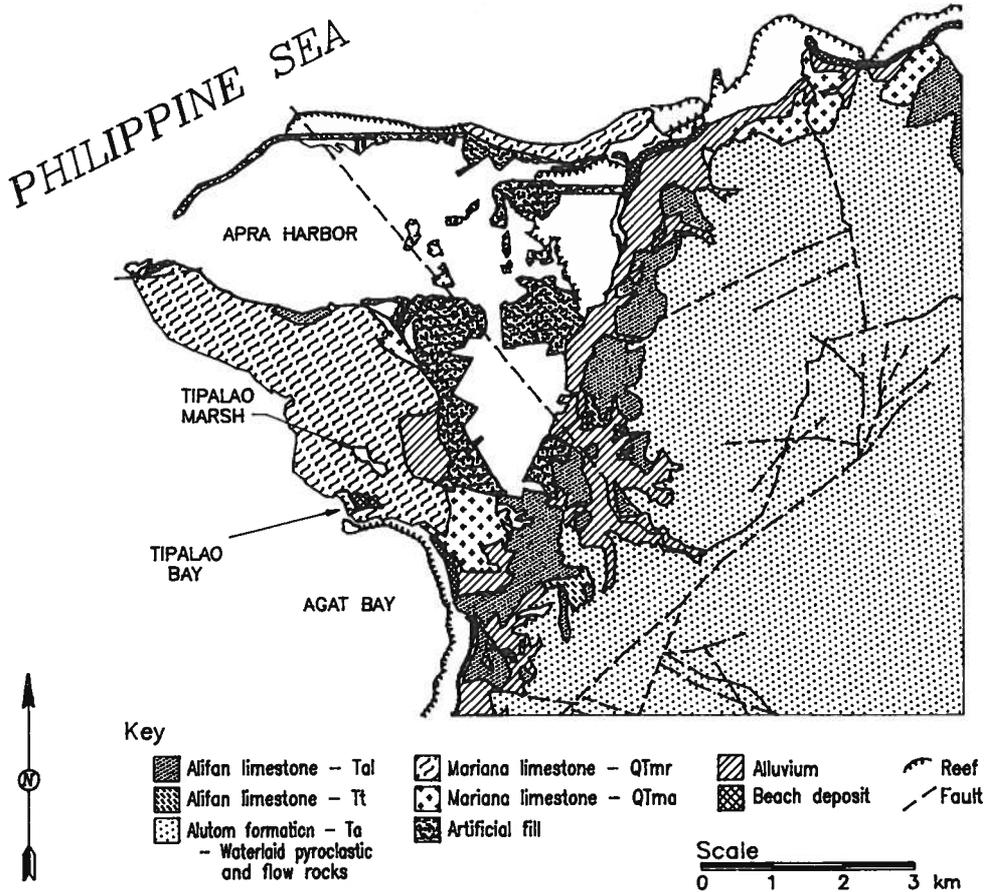


Figure 3. Geological map of Orote Peninsula, Guam (after Tracey et al. 1992). See Tracey et al. (1992) for complete description of map key.

common: *Tristeriopsis acutangula* and *Heritiera longipetiolata* . . . . Another rare . . . tree species, *Drypetes dolichocarpa*, is reported to occur in the limestone forest to the west on Orote Peninsula, and could conceivably also be found on this parcel. Also common in [the] Seabee Quarry forest [within the general area] is the native cycad *Cycas circinalis*, which is more of an understory species. Native epiphytic ferns, such as *Phymatosorus scolopendria*, *Microsorium punctatum*, and *Pyrrosia lanceolata*, are also present.

Tipalao Marsh is entirely vegetated with no areas of open water. Whistler (1992:21), reports that it is dominated by,

*Brachiaria mutica* (California grass), *Cyclosorus [Thelypteris] interruptus* (marsh fern), *Acrostichum aureum* (swamp fern), *Lygodium micro-*

*phyllum* (a vinelike fern), *Paspalum vaginatum* (a littoral and coastal marsh grass), *Scirpus littoralis* (a sedge), *Eleocharis dulcis* (water chestnut), and *Polygonum minus* (an herb). A thicket of *Hibiscus tiliaceus* (beach hibiscus) covers the southeast side of the wetland.

*Scirpus* is present in wetter areas of the marsh. To Whistler's list may be added *Saccharum spontaneum* (wild sugarcane) on the marsh edge (Michael Subbert, pers. comm.), *Casuarina equisetifolia* (ironwood) on the southwest marsh edge, and *Cocos nucifera* (coconut) on the north edge.

As mentioned, a large area of mangrove forest was located east of the present marsh on the 1913–1914 Corps of Engineers map. Though this swamp community no longer exists, it may have been characterized by *Rhizophora apiculata* and *Avicennia marina*, which dominate a swamp at Polaris Point on the northeast side of Inner Harbor (Fig. 1; Whistler 1992:26). *A. marina* is described as common in the Apra mangrove areas, and besides *Rhizophora*, it is often associated with *Bruguiera* (Stone 1970:503).

Of relevance to the later pollen discussion are the two species of *Terminalia* reported for Guam: *T. catappa* and *T. littoralis*. The former is a medium to large tree, often cultivated, that grows in the uplands, but is also found on the edge of beaches. Stone (1970:440) reports that “[*T. catappa*] is not particularly common in Guam but is being planted now more extensively.” The latter species is a shrub or small tree, always found in littoral areas, on the beach, or among coral boulders (Stone 1970:439–440). Until reference pollen can be checked for *T. littoralis*, it is not known if these species can be distinguished palynologically. Whistler (1992:42) records the occurrence of *T. catappa*, which he regards as a recent introduction, only at Old Wives Beach south of the Tupalao Family Housing area on Agat Bay. *T. littoralis* does not appear to occur on Orote Peninsula.

### Methodology

Two cores were recovered from Tupalao marsh with a modified Livingstone piston sampler (Wright et al. 1984) on December 8 and 9, 1992 (Fig. 2). Core 1 reached a depth of 3.85 m, while Core 2 penetrated to 4.98 m. After recovery of the first core, several probes were made with the corer drive rod to locate deeper sediments. These were found in the vicinity of Core 2, whereupon the second core was taken. A systematic determination of sediment thickness throughout the marsh was not attempted.

The cored samples were extruded onto a board covered with clean plastic wrap, labeled with an indelible black marking pen, and the top and bottom depths carefully noted at the ends of each segment. The sediment from both cores was examined and described in detail at the IARII laboratory in Honolulu, and Core 2 was sampled for pollen analysis and radiocarbon dates. Sediment descriptions and profiles for both cores are presented in Tables 1 and 2 and Figure 4.

Twenty six sediment samples from Core 2 were processed for pollen and charcoal particle analysis in the usual manner for Pacific lowland sediments (e.g.,

Table 1. Sediment description, Core 1, Tupalao Marsh, Guam.

Layer	Depth cm	Munsell Color (dry)	Sediment Description
Ia	0-120	10YR 2/2	Very dark brown; humic silt with numerous fine rootlets; lens of brown loam 1 to 1.5 cm below surface; other macro-organics not present; water-saturated but firm; non-sticky, non-plastic; massive; lower boundary clear.
Ib	120-159	10YR 2/2	Very dark brown; humic silt/peat; few rootlets but other macro-organics very abundant; water-saturated but firm; non-sticky, non-plastic; massive; lower boundary clear.
Ic	159-182	7.5YR N2/	Black; humic silt/peat; few macro-organics; firm sediment; lower boundary clear.
Id	182-220	10YR 2/2	Very dark brown; peat with little silt; abundant macro-organics; non-sticky, non-plastic; massive; firm sediment; lower boundary clear.
Ie	220-343	10YR 2/2	Very dark brown; humic silt/peat; abundant macro-organics; non-sticky, non-plastic; massive; firm sediment; lower boundary abrupt.
If	343-353	10YR 2/2	Very dark brown; humic loam, some organics, slightly sticky, plastic; small amount of fine sand.
II	353-385	2.5Y 4/3	Olive brown; gleyed clay with small amount of fine calcareous sand; firm sediment; lower boundary abrupt.
III	385+		Limestone.

Athens et al. 1992:13). Before slide mounting, the processed sample residue was mixed in a Calgon solution to float off the finest clay-sized fraction. In addition, some samples from Layer III contained so much oil, attributed to dense colonies of *Botryococcus* alga (see Palynomorph section, below), that a preliminary acetone rinse was used before continuing with the aqueous extraction process.

### Sediment Description

Layer I of Core 1 consists almost entirely of black to very dark brown humic silt and/or peat sediments with organics. In Core 2 these sediments were found in Layers II and IV. The loam of Layer I in Core 2 was not observed in Core 1. Also, Layer III of Core 2 was not seen in Core 1. This layer is comprised of gelatinous silt having a bright reddish brown color in subunits IIIa and IIIb (the reddish brown sediment turned black on drying), and fine calcareous sand in subunits IIIc and IIIe. Subunit IIIc was a banded dark silt.

Continuing downward, both cores had the same gleyed clay layer (designated Layer II in Core 1 and Layer V in Core 2) above the basal rock. As may be noted on the profile (Fig. 4), the depth below surface of these gleyed layers was quite different in the two cores, a matter that will be addressed below. The clay layers contain a slight amount of fine calcareous sand.

Table 2. Sediment description, Core 2, Tupalao Marsh, Guam.

Layer	Depth cm	Munsell Color (dry)	Sediment Description
I	0-14	7.5YR N2/	Black; loam, very organic; sediment somewhat firm though water-saturated; massive; sticky, plastic; numerous fine rootlets; lower boundary diffuse.
IIa	14-130	10YR 2/1	Black; peaty silt with numerous fine and some thicker rootlets to ca. 100 cm; below this depth rootlets are absent; sediment relatively firm though water-saturated; massive; non-sticky, non-plastic; lower boundary diffuse.
IIb	130-200	10YR 2/1	Black; peaty silt with macro-organic remains; sediment relatively firm, but becomes much softer at 200 cm; massive; non-sticky, non-plastic; lower boundary somewhat diffuse.
IIc	200-250	10YR 2/1	Black; humic silt, less peaty but still macro-organic remains; much softer sediment than Layer IIb; weak, crumb; non-sticky, non-plastic; lower boundary diffuse.
IId	250-275	7.5YR N2/	Black; humic silt, no macro-organic remains; sediment becomes much firmer; non-sticky, non-plastic; lower boundary clear.
IIIa	275-292	7.5YR N2/	Black; gelatinous silt; transition zone, finely banded black and reddish brown when wet; sediment very cohesive (can be cut into slivers); no macro-organics; non-sticky, non-plastic; lower boundary abrupt.
IIIb	292-312	7.5YR N2/	Black; gelatinous silt but with slightly more of a crumb texture; reddish brown color when wet; non-sticky, non-plastic; lower boundary abrupt.
IIIc	312-327	10YR 8/3 and 10YR 2/1	Very pale brown and black; banded silt with whitish specks; the specks appear as clusters of grains but do not have the texture of sand—they are interpreted as decomposed calcareous sand grains; non-sticky, non-plastic; lower boundary abrupt.
IIId	327-351	10YR 7/3	Very pale brown; very fine calcareous sand with numerous lenses, some irregular; slightly gelatinous texture; scattered pieces of black organic remains; non-sticky, non-plastic; lower boundary abrupt.
IIIe	351-390	10YR 6/2	Light brownish gray; very fine sand with little black pieces of organic material; no lenses but otherwise very similar to Layer IIId; becomes slightly lighter in color at 369 cm; slightly gelatinous texture; non-sticky, non-plastic; lower boundary abrupt.
IV	390-472	7.5YR N2/	Black; humic silt with some macro-organics; slightly gelatinous; non-sticky, non-plastic; gleyed clay band between 465-466 cm; lower boundary abrupt.
V	472-498	2.5Y 4/2	Dark grayish brown; gleyed clay with a few sand mottles; sticky, plastic; lower boundary abrupt.
VI	498 +		Limestone.

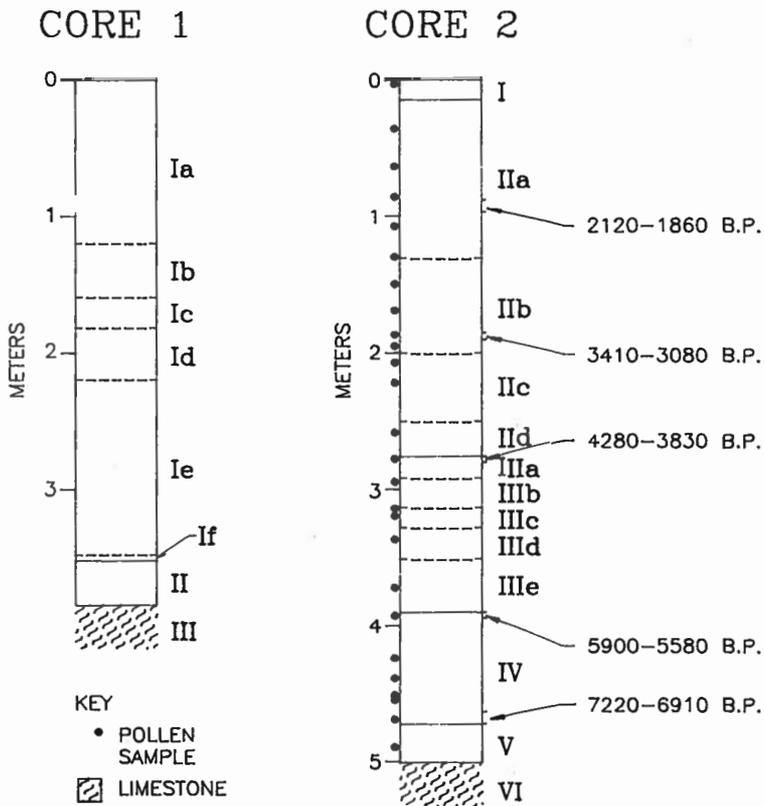


Figure 4. Profiles of Cores 1 and 2, Tipalao Marsh. Note locations of pollen and radiocarbon samples in Core 2. The radiocarbon dates represent the most probable calibrated date range at a 95% confidence interval.

Both cores terminated on solid limestone, fragments of which were in the base of the final drives. The limestone did not appear to be lagoonal detritus or a coral head.

### Chronology of Core 2

Five sediment samples were submitted from Core 2 to Beta Analytic Inc. for radiocarbon dating. The resulting dates and other relevant information are presented in Table 3. The samples have been adjusted for isotopic fractionation and calibrated using the CALIB 3.0.3 computer program of Stuiver & Reimer (1993). The sediment profile of Core 2 illustrates the dates along with their stratigraphic locations. As may be seen, all dates are in proper stratigraphic order and show a reasonable progression of age with depth beginning about 7,000 years ago at the base of Layer IV.

Table 3. Radiocarbon dating results, Core 2, Tupalao Marsh, Guam.

Area	Catalog #	Beta #	Provenience	Weight/ Material g	Age B.P.	C13/C12	Adjusted Age B.P.	Calibrated Age <sup>1</sup> B.P.	Proba- bility, %
Tipalao Marsh	Tip 88-97	62497	Core 2, IIa, 88-97 cm b.s.	122.0 sediment	2060 ± 60	-27.4	2030 ± 60	2120-1860 1850-1820	96 3
Tipalao Marsh	Tip 185-190	60077	Core 2, IIb, 185- 190 cm b.s.	80.2 sediment	3130 ± 70	-28.6	3080 ± 70	3410-3080 3450-3430	98 2
Tipalao Marsh	Tip 275-280	60078	Core 2, IIIa, 275- 280 cm b.s.	74.7 sediment	3670 ± 80	-23.1	3700 ± 80	4280-3830	100
Tipalao Marsh	Tip 390-395	60079	Core 2, IV, 390- 395 cm b.s.	74.3 sediment	4950 ± 80	-28.3	4950 ± 80	5900-5580 5510-5490	98 2
Tipalao Marsh	Tip 464-472	60080	Core 2, IV, 464- 472 cm b.s.	136.4 sediment	6210 ± 70	-24.8	6210 ± 70	7220-6910	100

<sup>1</sup> Calibration from Calib 3.0.3 computer program of Stuiver & Reimer (1993); 95% probability age range.

The radiocarbon dates can be used to determine sediment accumulation rates, which beside providing interpolated dates for any point along the core, are informative about infilling processes. To this end, the computer program DEP-AGE (Maher 1992:13–17) was used. This program has the advantage of providing a series of alternative mathematical models for determining sediment accumulation rates.

For the present study, only two models, illustrated as graphs in Figure 5, were considered. One was a 3-degree polynomial function, and the other was based on a simple linear interpolation obtained by connecting the mid-points of all of the radiocarbon dates. A comparison of ages and sediment accumulation rates at 1-meter intervals is presented in Table 4. While the difference between the two graphs is minor, for purposes of the present discussion the polynomial model is preferred because of its smooth transitions between the radiocarbon dates. While interpolated sediment accumulation dates appear to represent precise age determinations for particular points, it must be emphasized that they are based on radiocarbon ages and therefore are only convenient approximations. Interpolated dates are rounded in the text to the nearest 50 years to facilitate discussion.

Using the polynomial model, the estimated ages of all of the sedimentary units in Core 2 were determined (Table 5). Since Layers I and V do not have radiocarbon age determinations, the interpolated dates for these layers should be regarded with caution. For example, there is no real basis for assuming that the clay of Layer V was deposited over a 700 year period. Nevertheless, the interpolated dates should be reasonably accurate for most of the core, and it is convenient to treat Layers I and V in the same manner.

### Palynomorphs

Palynomorph preservation in the core was not uniform perhaps as a result of oxidation due to sediment mixing or exposure to a well-aerated aqueous environment. Palynomorph counts that were too low to use for comparative purposes in the pollen diagram include eight intervals as indicated in Table 6. These have total sums of 100 or less. In addition, five intervals contained pollen sums of around 60 or less but were included in the diagram since the combined sum with spores was over 200. A pollen sum of 200 is generally considered sufficient to provide statistical reliability.

Table 6 provides age determinations for each sample interval as derived from sediment accumulation calculations and it also provides information on particulate charcoal and palynomorph abundance. In Figure 6 the taxa are grouped into broad ecological categories: littoral forest types, which may include some species more at home in upland or wet-mesic forest environments, such as *Elaeocarpus*, *Freycinetia*, *Wikstroemia* and certain Urticaceae; mangrove forest; herbs, comprised mainly of grasses and sedges; and 10 unknown types which probably belong to the littoral forest group. The pteridophyte spores are distinguished by aperture type, whether monolete or trilete, and secondly by sculpture

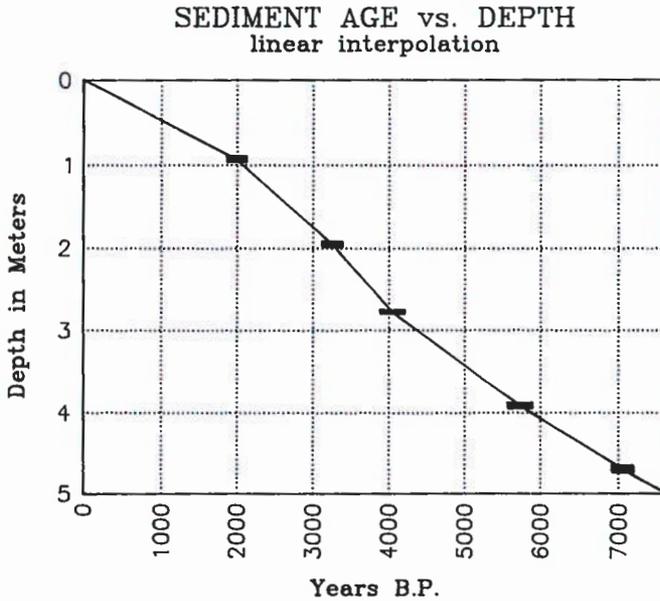
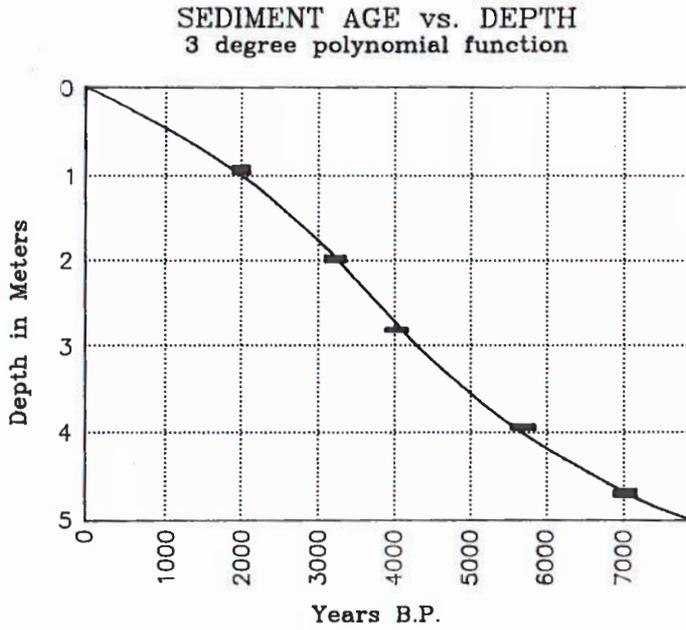


Figure 5. Sediment accumulation graphs for Core 2: top, using a 3-degree polynomial function, and bottom, using linear interpolation. Radiocarbon dates are calibrated at a 1 sigma confidence interval.

Table 4. Age and sediment accumulation rate at 1-meter intervals for Core 2.

Depth m	Age B.P. <sup>1</sup>		Sediment Accumulation Rate cm/yr	
	Polynomial	Linear	Polynomial	Linear
surface	0	0	—	—
1	2,030	2,081	0.0641	0.0829
2	3,314	3,280	0.0914	0.1000
3	4,387	4,385	0.0881	0.0682
4	5,754	5,872	0.0594	0.0570
5	7,924	7,627	0.0365	0.0570

<sup>1</sup> Age based on most probable calibrated radiocarbon date range at 1 sigma confidence interval.

Table 5. Interpolated ages for soil layers, Core 2.<sup>1</sup>

Layer	Depth cm	Age B.P.
I	0-14	0-368
IIa	14-130	368-2468
IIb	130-200	2468-3314
IIc	200-250	3314-3845
IId	250-275	3845-4111
IIIa	275-292	4111-4297
IIIb	292-312	4297-4525
IIIc	312-327	4525-4705
IIId	327-351	4705-5015
IIIe	351-390	5015-5589
IV	390-472	5589-7206
V	472-498	7206-7924
VI	498+	7924

<sup>1</sup> Interpolated ages based on 3-degree polynomial function regression model from DEP-AGE program of Maher (1992). Total of 5 calibrated radiocarbon dates used in program.

type if the species was not readily identified or was of a generalized morphology. Monolete spores number 7 while there were 9 in the trilete group, including three species of *Lycopodium* and *Selaginella*, which are actually more primitive than ferns and called 'fern allies.' Other types of palynomorphs include stellate hairs or trichomes from leaf surfaces and microforaminifera indicative of marine conditions.

Also observed but excluded from the palynomorph sum were fungal spores, plant cuticle, conducting tissue, and amorphous plant debris. The only algal type present was that of *Botryococcus*, a colonial green alga which produces large amounts of oil in cells that are embedded in an orange-colored mucilaginous sheath (Prescott 1962, Smith 1950). *Botryococcus* is a widely distributed type occurring in eutrophic freshwater pools or lakes (Round 1981). In the Tupalao core it was abundant in Layer III samples from 276 to 373 cm.

Table 6. Interpolated dates for pollen samples, samples with low palynomorph counts, and charcoal particle abundance, Core 2.

Sample Number	Age <sup>1</sup> Years B.P.	Low <sup>2</sup> Palynomorph Counts	Charcoal Particles <sup>3</sup>
Tip 2 0-3	53	—	C
Tip 2 36-38	883	—	C
Tip 2 62-64	1399	—	S
Tip 2 84-86	1787	—	S
Tip 2 105-110	2145	—	R
Tip 2 128-130	2454	—	R
Tip 2 146-152	2718	—	R
Tip 2 167-169	2951	X	—
Tip 2 184-190	3170	—	—
Tip 2 195-196	3265	X	—
Tip 2 205-211	3401	—	R
Tip 2 222-224	3561	—	R
Tip 2 258-260	3940	X	—
Tip 2 276-278	4132	—	—
Tip 2 294-296	4330	X	—
Tip 2 311-317	4549	X	—
Tip 2 319-321	4620	X	—
Tip 2 336-338	4831	—	—
Tip 2 371-373	5312	—	—
Tip 2 392-394	5638	—	—
Tip 2 423-425	6182	—	—
Tip 2 436-441	6466	—	—
Tip 2 450-452	6728	X	—
Tip 2 452-457	6805	—	—
Tip 2 467-469	7111	—	—
Tip 2 488-490	7630	X	—

<sup>1</sup> Interpolated ages based on 3-degree polynomial function regression model from DEP-AGE program of Maher (1992). Total of 5 calibrated radiocarbon dates used in program.

<sup>2</sup> X = low palynomorph count; less than 100 in total.

<sup>3</sup> Scale utilized is Abundant, Common, Sparse, and Rare.

#### POLLEN ZONES AND ASSEMBLAGES

From changes in dominant pollen types, the pollen diagram (Fig. 6) is divided into Zones 1 through 4, the lower and upper of which are further divided into subzones 'a' and 'b' (Table 7).

The basal zone, divided into Zones 1a and 1b, represents a marine deposit in part based on the presence of microforaminifera. In Zone 1a, dating between 7650 and 7100 years B.P. (467-490 cm), *Terminalia* and *Pandanus* attain their highest levels in the core with values of 33 and 26 percent, respectively. The percentage of fern spores is low, *Acrostichum* being chief among them at 26 percent. Abundant opaque sulfide (pyrite) spherules in Zone 1a are interpreted as representing a wetland with marine influence. The peak levels of *Terminalia* and *Pandanus* pollen seen in this zone suggest high local production and close

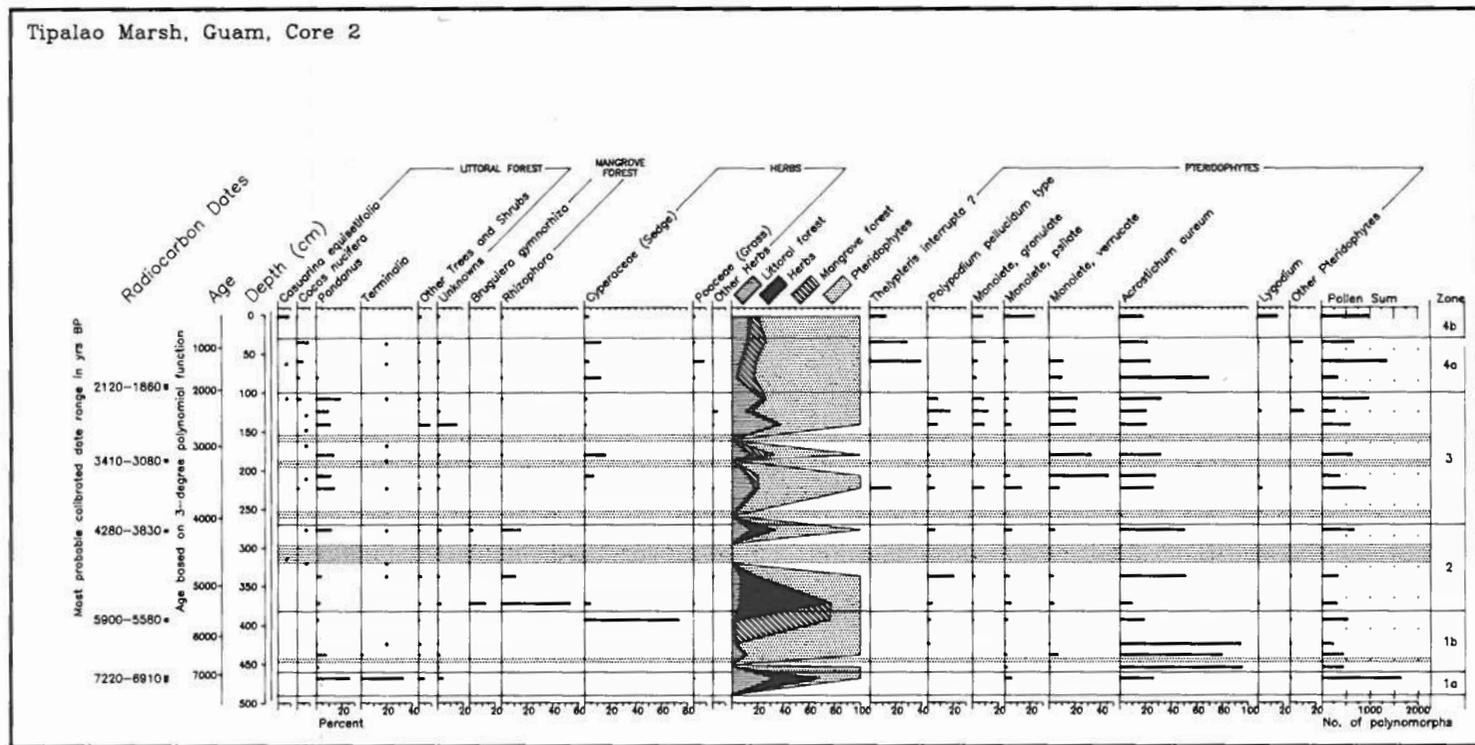


Figure 6. Pollen and spore percentage diagram from Core 2, Tipalao Marsh, Guam. Low count intervals are indicated with a screen pattern. Dots indicate presence (count too low to show graphically).

Table 7. Pollen zones compared to the sediment layers, showing the dominant types present in a given zone.<sup>1</sup>

Pollen Zone	Depth cm	Sediment Layer	Dominant Types	Environment of Deposition
4b	0-3	I	<i>Casuarina</i> , monolete psilate, <i>Lygodium</i> , <i>Acrostichum</i>	freshwater marsh
4a	36-84	IIa	<i>Cocos</i> , Cyperaceae, Poaceae, <i>Thelypteris</i> , <i>Acrostichum</i>	freshwater marsh
3	105-260	IIb,c,d	<i>Pandanus</i> , various fern taxa	freshwater marsh
2	276-373	III	<i>Botryococcus</i> bloom, <i>Rhizophora</i> , <i>Bruguiera</i> , <i>Acrostichum</i> , <i>Polypodium pellucidum</i> type	late open freshwater pond; early mangrove/swamp
1b	392-452	IV	Cyperaceae, <i>Acrostichum</i>	brackish marsh
1a	467-490	IV, V?	<i>Terminalia</i> , <i>Pandanus</i>	strand

<sup>1</sup> Zone intervals are discontinuous due to sampling gaps.

proximity to the strand habitat. With retreat of the strand, *Terminalia* pollen disappears from the upper zones.

In Zone 1b, dating from 6700 to 5600 years B.P. (392 to 457 cm), pollen percentages of arboreal taxa decline, and *Acrostichum* spores increase to 95 percent and then decline while Cyperaceae (sedge) reaches its maximum at 73 percent. Brackish conditions are suggested by the presence of both microforaminifera and *Acrostichum*. The diminished levels of *Terminalia* and *Pandanus* in this zone, which were dominant types in Zone 1a, suggest increased distance from the strand habitat.

Pollen Zone 2, dating between 5300 and 4100 years B.P. (276-373 cm), is dominated by the mangrove taxa *Rhizophora* and *Bruguiera*, which together reach over 65 percent in the basal sample. Grindrod (1985) has shown that pollen samples containing over 50 percent mangrove taxa represent mangrove swamps. In the later part of this zone, mangrove pollen falls to 15 percent or less, indicating perhaps a mangrove community marginal to the lagoon fringe. Other important components in this zone include *Pandanus* among the arboreal taxa at 2 to 12 percent, *Acrostichum* up to 50 percent, and the *Polypodium pellucidum* type up to 20 percent. Freshwater algal spores of *Botryococcus* are also abundant in this zone. Their presence indicates that the saline effect of the marine incursion must have been somehow mitigated. The gelatinous nature of the upper two subunits of Layer III (IIIa and IIIb) is especially suggestive of freshwater conditions. The calcareous sand in the lower two subunits (IIIc and IIIe), however, indicates an earlier direct marine influence, perhaps in the form of a tidal swamp.

In pollen Zone 3, dating between 3950 and 2450 years B.P. (128 to 260 cm), the main taxa include *Pandanus*, several monolete ferns including *Acrostichum*, *Polypodium pellucidum* type, and in the lower interval what is thought to be *Thelypteris interrupta*. The latter taxa in particular suggest that Zone 3 was a freshwater marsh.

Pollen Zone 4a, dating between about 1800 and 900 years B.P. (36–86 cm), is dominated by sedge and grass, *Cocos*, and among the pteridophytes, *Acrostichum* and *Thelypteris*. *Acrostichum* continues to be abundant but its dominance is shared by *Thelypteris* in the upper levels of Zone 4a beginning about 1400 years B.P. *Acrostichum* soars to 69 percent in the 84–86 cm interval (1787 years B.P.).

Pollen Zone 4b, represented by a single modern surface sample from 0–3 cm, contains a distinct assemblage dominated by *Casuarina* and ferns. The ferns, listed in order of dominance, are monolete psilate, *Acrostichum*, *Lygodium*, and *Thelypteris*. *Thelypteris* is indicative of a freshwater marsh. The monolete psilate and *Lygodium* types suggest a disturbed or open habitat.

#### CHARCOAL PARTICLES

The interpretive value of charcoal particles on pollen slides has been established by a number of investigators (e.g., Burney & Burney 1994, Clark 1988, Patterson et al. 1987). Following the example of these and other investigators, the charcoal particle data from Tupalao Marsh are presented in Table 6. A qualitative estimate was used to determine the relative abundance using four increasing levels: rare, sparse, common, and abundant. The size range of the particles was between 5 and 250  $\mu\text{m}$ . All of the charcoal particles noted belonged to the woody dicotyledon rather than grass or monocotyledon category.

Below the 222–224 cm interval (3550 years B.P.) there were no particles. From this interval up through the 105–110 cm interval (2150 years B.P.) charcoal was rare, indicating that fire occurrence was present in the environment but not widespread or intense. After the 62–64 cm interval (1400 years B.P.) it became more common. The absence of charcoal particles in some of the intervals between its initial occurrence and the surface of the core (Table 4) may have more to do with its rarity (i.e., sample bias) than lack of fires in the environment. Since none of the samples contained abundant charcoal, it would appear that fire was never heavily used in the vicinity of Tupalao Marsh.

When charcoal first appears at 3550 years B.P., it is probably more than just a coincidence that this is also the time when initial human settlement is thought to have occurred in the Mariana Islands (Butler 1994, Hunter-Anderson & Butler 1991, Moore et al. 1992). There is no evidence for the onset of drier climatic conditions at this time to account for the natural ignition of fires. The initial occurrence of charcoal at 3550 years B.P., therefore, suggests that the earliest settlement of Guam was as early as elsewhere in the Mariana Islands (i.e., Saipan) even though no archaeological sites are presently known to date prior to the third millennium B.P. on Guam (Athens 1986).

#### RECORD OF PLANT INTRODUCTIONS

This discussion relies on Fosberg et al. (1979, 1987) to determine whether a taxon is native or naturalized. The latter category refers to human introductions that have become established in the wild.

*Artocarpus* pollen, found in the surface sample only, could be one of three species present on Guam today. These are *A. altilis*, *A. heterophyllus*, and *A. mariannensis*, the latter of which is considered indigenous. *Artocarpus* pollen is uniform at the generic level, but its occurrence suggests that it may represent one of the introduced species.

*Cocos nucifera* pollen was seen most abundantly in the near surface samples to 105 cm (2150 years B.P.), but was also common in the 222–224 cm interval (3550 years B.P.), followed by single grain occurrences at the 276–278 cm (4150 years B.P.) and 319–321 cm (4600 years B.P.) intervals. The abundance of *Cocos* pollen at the 222–224 cm interval suggests that it was already established on Guam by the time the earliest human settlers arrived on Guam. The occurrences below this date presumably would have been well before initial human settlement in the Mariana Islands. Coconut, therefore, is probably indigenous, having arrived on Guam by natural means. Though Stone (1970:28) and Fosberg et al. (1987) listed the species as naturalized, this now seems incorrect. In addition to its occurrence at Tipalao Marsh, *Cocos* pollen has been recently found in an early Holocene pollen assemblage from another core on Guam (Ward & Hunter-Anderson, unpub. data).

*Hibiscus tiliaceus* pollen occurred in the surface sample, and at 105–110 cm (2150 years B.P.) and 222–224 cm (3550 years B.P.) intervals, supporting the belief that it is indigenous on Guam (Fosberg et al. 1979, Stone 1970). Its rarity in the fossil record may be explained by the fact that it produces large pollen grains which are carried by insects. *Hibiscus* species (non-*H. tiliaceus*) occurred in four samples, including two which represent pre-human horizons. These data imply the existence of additional indigenous *Hibiscus* taxa on Guam that have not been previously recognized (Fosberg et al. 1979, Stone 1970).

Only six grains of the cheno-am type pollen were recovered from Core 2. These represent pollen of the Chenopodiaceae and/or Amaranthaceae families, which are not distinguishable. Since all of the chenopods are naturalized while there are six species of indigenous amaranths, the record in prehistoric layers should represent that of the latter family. In younger layers a mixture of types would be expected.

A single grain of *Ipomoea* pollen was seen in the 222–224 cm sample (3550 years B.P.), which keys to *I. batatas* based on overall dimensions and size of the spines and pores. However, the presence of this species on Guam at such an early date seems unlikely based on present knowledge of its origin and prehistoric distribution in the Pacific (Hather & Kirch 1991). There are twelve other species of *Ipomoea* found on Guam today, five of which are indigenous. Since the indigenous species have not been described palynologically, the possibility that the Tipalao specimen represents one of these seems likely.

The record of *Casuarina equisetifolia* dominates the surface sample and appears in the 61 cm (1400 years B.P.), 105–110 cm (2150 years B.P.), and 311–317 cm (4550 years B.P.) intervals before disappearing entirely from the profile. Its appearance in the three intervals below the surface implies that *Casuarina* was present on Guam prior to historic contact, and the deepest sample indicates

that it was present before human colonization. *Casuarina* therefore is a native tree as suggested by Stone (1970:27) and Fosberg (1979). The prehistoric occurrence of *Casuarina* on Guam was previously documented in deposits dating to about 1500 to 1000 years B.P. in the Agat area (Ward 1989).

### Interpretation of the Sedimentary Record

An obvious and interesting question concerning the two cores is how to interpret the pronounced sedimentological differences between such closely spaced cores, separated by only about 60 meters. A major aspect of this difference concerns the fact that there is no corresponding unit in Core 1 to the Layer III reddish gelatinous silt and fine calcareous sand of Core 2. A possible clue to the reason behind this may have to do with the very different elevations of the limestone bedrock and the gleyed clay layer in the two cores. (It is assumed that the surface elevations of the two cores are the same as indicated in the Fig. 4 profile; however it is possible that Core 1 is actually about 30 cm lower as suggested by the topographic map of Helber et al. [1986], though the map elevations are derived from interpolated elevation contours and therefore may not be accurate.) Since the difference in elevation of the clay layer in the two cores is 119 and 113 cm for the top and bottom, respectively, variation in the actual surface elevation of the two cores, presumably not more than 30 cm, would not be nearly enough to account for the difference.

Although an uneven substrate is not unusual in itself and even would be expected in a karst environment, the formation of the same gleyed clay layer of the same approximate thickness but at very different elevations does seem unusual. In consideration of how wetland clay layers often form—under alternating wet and dry conditions—and the fact that the post-Pleistocene rise in sea level probably created a broad and shallow protected estuary, it is difficult to account for the same clay layer forming at different elevations in such a small area. It is therefore postulated that following the formation of the clay layer within a nearly level basin, there was vertical movement along an underlying fault in which one side was displaced with respect to the other. This displacement created a deeper basin in the Core 2 area relative to that of the Core 1 area, and this allowed the retention of standing water in the Core 2 area. With rain and runoff, this portion of the basin became essentially a freshwater pond. Such a pond would account for the evident high density of *Botryococcus* alga and the gelatinous sediment of Layer III in Core 2. The Core 1 side of the Marsh evidently was more of a swamp, presumably supporting a mangrove forest given the pollen findings for Layer III of Core 2. As the gleyed clay layer formed between 7200 and 7900 years B.P. (Table 5), movement of the fault presumably occurred about the time when deposition of the clay layer ceased about 7200 years B.P., but before the start of Layer IIIe at 5600 years B.P.

If the above explanation is correct, the sediment sequence of Core 1 should encompass the entire temporal span represented in Core 2, including that represented by Layer III. While the fault model cannot be considered proven with

the available evidence, other possible explanations (e.g., that the clay layer in the two cores actually formed at different times) do not seem reasonable.

With the presumed continued rise of sea level, possibly after a brief pause around 7500 years ago (see Shackleton's [1987] sea level curve), the Tupalao basin would be expected to come under even more influence of marine conditions. Initially, this does in fact seem to be the case. Layers IIIe and IIIId, which are just above the gleyed clay layer, consist largely of very fine calcareous sand. A marine influence is certainly suggested, albeit one in a very low energy environment. The high counts of mangrove pollen (*Rhizophora* and *Bruguiera gymnorrhiza*) present during the IIIe and IIIId intervals also support the inference for some kind of marine influence. The base of IIIe and the top of IIIId date to between 5600 and 4700 years B.P.

The remainder of Layer III (i.e., subunits IIIa, IIIb, and IIIc) is of quite a different character. Here the sediment is mostly a gelatinous silt and the sand of the lower subunits disappears. The gelatinous texture may be produced by *Botryococcus*, a freshwater alga, though specific proof is lacking. Although pollen analysis indicates an abundance of the tidal mangrove *Rhizophora*, the presence of *Botryococcus* is suggestive of more open freshwater conditions or perhaps a lens of freshwater on top of salt or brackish water. Perhaps mangrove trees and *Acrostichum* ferns (there were abundant spores) were present around the shallow edges of what was apparently a pond. Whatever the interpretation, both the abundance of *Botryococcus* and the lack of calcareous sand suggest that the basin had become more isolated from direct marine influence beginning with Layer IIIc, which dates to 4700 years B.P. It is suspected that the Core 1 side of the marsh may have undergone a second period of uplift at this time. With uplift, open water conditions favoring an abundance of *Botryococcus* alga may not have been prevalent on this side; thus the reddish brown gelatinous layers of Core 2 did not form in the Core 1 area.

For the period represented by Layers I and II—about the last 4100 years—standing water evidently no longer accumulated in the basin, or at least it was sufficiently intermittent to minimize the growth of *Botryococcus*. Pollen analysis (see below) indicates freshwater marsh conditions during the time span represented by Layers I and II.

In general, Core 2 appears to represent an approximately continuous sequence of wetland sediment accumulation. Poor pollen preservation in some of the sampling intervals, however, may indicate periodic interruptions of depositional processes. Nevertheless, the nearly linear distribution of radiocarbon dates (Fig. 5) and the lack of wide variation in the values for sediment accumulation rates (Table 4) are suggestive of a more or less continuous depositional history. Uplifting during the past 3000 to 4000 years (Easton et al. 1978:9–10, Kayanne et al. 1993) apparently did not directly affect the marsh basin or else this uplifting event actually occurred slightly earlier than previous investigations indicate.

### Discussion and Conclusions

The core record demonstrates that Tupalao Marsh has undergone a series of environmental transformations since sediment first began to accumulate some

7900 years ago. These changes include both the depositional context within the marsh basin (primarily a result of tectonic processes and sea level change) and the vegetation within and surrounding the basin. Some of the late vegetational changes are likely the result of human impacts and land use. However, earlier transformations, predating 3550 years B.P., are not related to human influence given the presently understood time frame of ca. 3500 year B.P. for initial human settlement of the Mariana Islands.

The most significant change in vegetation following human settlement is the rapid decline of *Pandanus* between 2150 and 1800 years B.P. in upper pollen Zone 3. Even earlier—by 2450 years B.P.—the “other” forest trees and unknowns (littoral forest types) had declined to a very low percentage of the total pollen.

At about 1400 years B.P. grass suddenly becomes a notable component of the vegetation record. This in particular suggests habitat disturbance within the Tupalao watershed, presumably a result of prehistoric agriculture. The grass record then drops to a very low percentage by 900 years B.P., climbing only slightly at the recent near-surface interval.

Although a substantial drop in grass pollen would be expected with the likely agricultural abandonment of the peninsula during the historic period, its decline at 900 years B.P. is too early for such an interpretation. It is possible, of course, that this interpretation is correct but that the interpolated date, derived from radiocarbon dates and therefore properly interpreted as incorporating a statistical range, is too old for the depth. It is also possible that the depth-age curve from which the interpolated dates derive behaves somewhat differently at the top part of the curve.

Because coconut counts are high for both the 62–64 and 36–38 cm intervals, agricultural use of the landscape may have been relatively intensive since about 1400 years B.P. or slightly earlier but after 1800 years B.P., the next lower interval. The higher charcoal particle counts beginning about this time also suggest more intensive human use of the landscape. The initiation of megalithic *latte* construction throughout Guam at least by 800 years B.P. (Graves 1986:141) suggests widespread and intensive use of the landscape late in prehistory. Of interest in this regard is that the Tupalao paleoenvironmental data suggest that the onset of *latte* construction comes well *after* land use intensification begins. Thus, megalithic construction either was not directly related to the process of land use intensification, or there was a time lag in the social response.

There is no pollen evidence that Tupalao Marsh was ever used for taro cultivation. However, the possibility of prehistoric rice cultivation, particularly in the 62–64 cm interval (1400 years B.P.) where grass counts are high, cannot be dismissed since grass pollen is not identifiable beyond the family level. Rice, however, is identifiable through phytolith analysis (Umlauf 1994), and this should be attempted in the future.

The appearance of charcoal particles at 3550 years B.P. on Guam coincides with the date for initial human settlement in the Mariana Islands as known from archaeological investigations on Saipan (Butler 1994, Hunter-Anderson & Butler 1991:20–21, Moore et al. 1992). Prior to that time charcoal is absent. Furthermore,

there is no indication that at 3550 years B.P. the climate suddenly became drier or more seasonal, which would have increased the potential for natural ignition of fires. The Tupalao charcoal record, therefore, supports the assumption that all of the Mariana Islands were initially occupied about the same time, though the earliest dated archaeological sites on Guam are not quite as old as the charcoal or dated sites elsewhere. The charcoal presumably derives from forest burning by prehistoric settlers for clearing small agricultural plots.

An anthropogenic origin for Guam's interior savannas has been argued by some investigators, believing that they are the result of a cycle of forest burning, farming, and eventual land degradation (e.g., Fosberg 1960). Countering this view, Zan & Hunter-Anderson (1987) argue for a natural origin based on botanical, geological, archaeological, and ethnographic data. The Tupalao core, being in a peripheral area on Guam, is obviously not ideally situated for dealing with this question. However, the very small size of the Tupalao charcoal particles suggests that they may be mostly of non-local origin, perhaps reflecting regional conditions on Guam. If so, the type of charcoal present—all from woody dicotyledons—is most interesting because it suggests that savanna grass, if present, was not being burned even during the prehistoric period.

The introduction of coconut to Guam seems to have been by natural rather than human transport since its pollen occurs in the Tupalao core both at the postulated time of earliest colonization and in two definitely earlier and presumably pre-human intervals. Guam, however, appears not to be alone in Micronesia in being a recipient of this tree through natural transport. Kosrae, for example, appears to have pre-human coconut (Athens 1995, Ward 1995). Other examples of long distance transport of coconut by natural means to distant islands during the Holocene are from the South Pacific (Spriggs 1984, Kirch et al. 1992:175).

In sum, the Tupalao Marsh core has revealed a complex paleoenvironmental sequence for the Holocene on Guam that reflects both natural and cultural processes of environmental change. The Tupalao cores clearly demonstrate the value of such records and the wealth of information that can be obtained using palynological techniques. Importantly, such paleoenvironmental records can provide significant new information concerning prehistoric human occupation not ordinarily attainable by standard archaeological methods. Although the Tupalao cores have provided many new insights on Guam's natural and cultural past, additional coring investigations must be undertaken to confirm and/or resolve findings concerning many of the issues discussed in this study. Also, a more geographically representative sample of data for Guam are essential for accurately characterizing regional paleoenvironmental patterns.

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