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Holocene Sea-Level Change on Aitutaki, Cook Islands: Landscape Change and Human Response

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ABSTRACT

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Holocene sea-level changes profoundly affected the Pacific's human populations in the prehistoric past. Geoarchaeological studies on Aitutaki, southern Cook Islands, suggest sea-level fall coincident with the period of human occupation. The coastal beach barrier which formed along Aitutaki's central western coast after sea-level fall became the focus of human habitation over the last millennium. Faunal and floral assemblages from the earliest *in-situ* cultural occupation on the island demonstrate significant anthropogenic influences on the environment at 1000 BP, suggesting human colonisation occurred at an earlier, but as yet undetermined, date. Failure to unearth direct evidence of colonising settlements may in part be the consequence of a more exposed coastline prior to the Holocene sea-level fall.

ADDITIONAL INDEX WORDS: *Geoarchaeology; Pacific prehistory; coastal adaptations.*

INTRODUCTION

Throughout the period of human history in the Pacific, no single factor has influenced coastal environments more than sea-level fluctuations. Not only has sea-level variation alternately expanded and reduced island shores, but also the processes of shoreline progradation, valley infilling, and reef development have greatly altered the character of Pacific island environments (*e.g.*, ATHENS and WARD, 1993; CHAPPELL, 1982; KIRCH and YEN, 1982; NUNN, 1994A; SPRIGGS, 1981). The implications for the Pacific's early human populations, which were often concentrated in these coastal environments, were far-reaching. Land-bridges were exposed and flooded, settlement areas expanded and restricted, and critical natural resources enhanced or displaced. Equally important, sea-level histories have differentially affected records of human occupation in this region, with some conditions favouring and others limiting, the potential for preservation.

Archaeological work on the southern Cook island of Aitutaki offers an opportunity to investigate the effects of late Holocene sea-level change on the local landscape at a sub-millennial time scale. As OWENS (1993) observed, archaeological studies provide a useful complement to geological work in coastal environments, offering high-resolution chronological, sedimentological, and faunal records of specific localities. The Aitutaki program of augering, trenching, and controlled excavations provides one such detailed view of an island's changing coastal landscape and the attendant human responses.

BACKGROUND

The southern Cook Islands are situated between roughly 154–162 °W longitude and 18–23 °S latitude, and are part of the 2,000 km long Cook-Austral volcanic chain (Figure 1). In cultural terms, the archipelago lies on the western boundary of East Polynesia, a region defined by anthropologists on cultural and linguistic similarities and distinguished on the same bases from the West Polynesian islands of Fiji, Samoa and Tonga. The almost-atoll of Aitutaki (after STODDART, 1975a) is at the northwest end of the chain and consists of a 16 km^2 volcanic mainland, a 50 km^2 lagoon, and 14 small coralline islets (one which has coalesced with the mainland) along the eastern to southern periphery of the lagoon. Two small volcanic remnants, Rapota and Moturakau, are found within the lagoon. The volcanic mainland is characterised by low weathered hills which slope gently towards the lagoon on the eastern side and drop steeply to a sandy coastal plain along the western coast. The central region of Aitutaki's western coast was the focus of the present research, although work was also carried out on the northeast side of the volcanic mainland and on the offshore islet of Moturakau (ALLEN, 1992a).

The bulk of the Aitutaki mainland is composed of highly weathered Tertiary volcanics (TURNER and JARRARD 1982). Fertile agricultural soils (*e.g.*, Tautu Silt Loam) extend over much of the southern half of the island, while agriculturally-poor clay soils (*e.g.*, Anaunga Clay Loam) dominate the northern end (JOHNSTON, 1967). Surface water is limited, with no permanent streams; several fresh water springs and semi-permanent streams occur on the island. The dominant winds are easterlies. Much of the island's rainfall, in contrast, is brought by tropical storms, over half of which originate in the west. Rainfall is typically intense but of limited duration, often resulting in surface runoff and erosion (THOMPSON, 1986). Major storms pass across the island every three to five years (STODDART, 1975a; THOMPSON, 1986; VISHER, 1925).

The island's tectonic history is not well-known and may be rather complex. One of the more important processes in this regard is lithospheric flexure, that is, deformation of the

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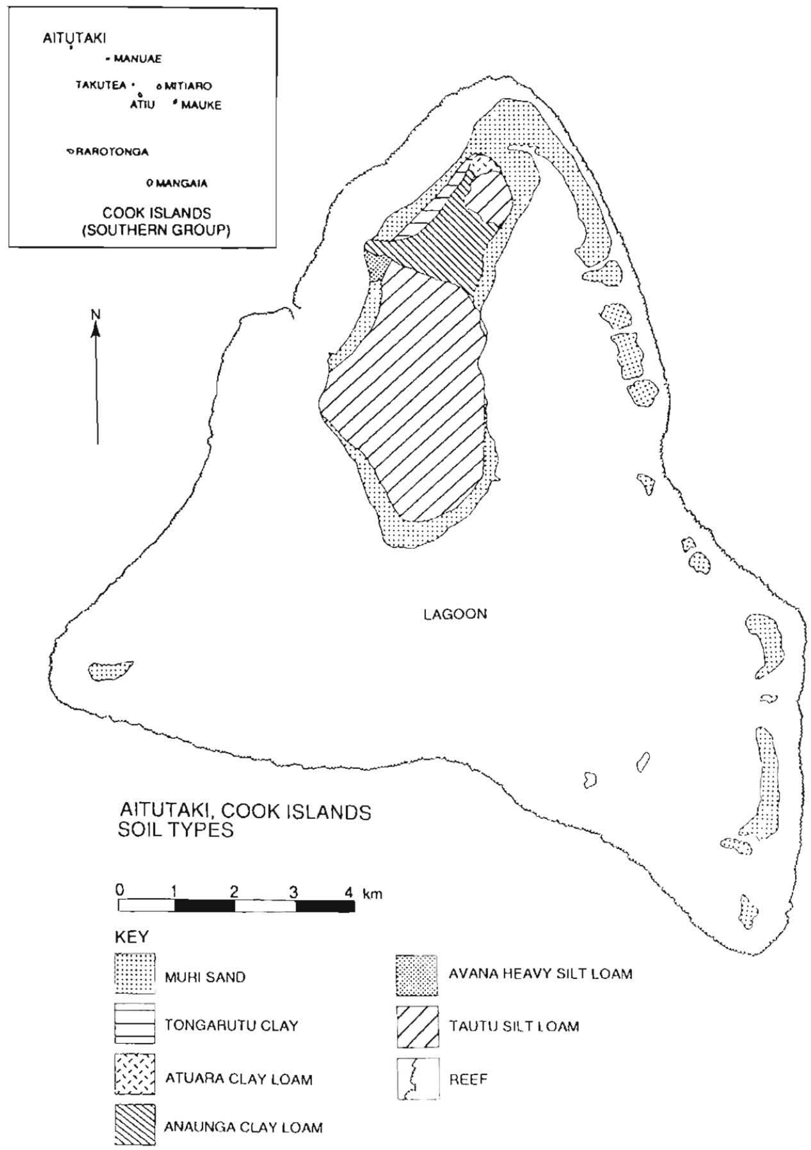

Figure 1. Map of Aitutaki and the Cook Islands.

lithosphere in response to volcanic loading (McNUTT and MENARD, 1978). In such situations, point-loading at one locality produces a correspondent moat-and-arch structure in the adjacent region. McNUTT and MENARD (1978; also SPENCER *et al.*, 1988) have suggested that Pleistocene volcanics on Rarotonga, Aitutaki, and Manuae produced this kind of local point-loading resulting in uplift of the islands of Ma'uke, Atiu, Mitiaro and Mangaia. Yet JARRARD and TURNER (1979) argued that the small scale of Pleistocene volcanics on Aitutaki would have contributed little to regional uplift. Rarotonga, in turn, may created some uplift on Aitutaki, as Aitutaki lies on Rarotonga's lithospheric flexural bulge (McNUTT and MENARD, 1979). Thus, the most recent Pleistocene vulcanism on Aitutaki possibly produced some local point-loading, while contemporaneous and earlier activity on Rarotonga probably uplifted Aitutaki. The foregoing is most relevant to the Pleistocene tectonic history of Aitutaki; there presently is no evidence for any significant Holocene tectonic activity.

The timing of human colonisation of the southern Cook Islands is currently unclear, and hotly debated. Islands to the west, including Fiji, Tonga, and Samoa, were settled some 3,000 years (see KIRCH and HUNT, 1988) ago by human populations carrying an elaborately decorated pottery known as Lapita. Some archaeologists have argued for a 1,300 to 1,600 year "pause" in West Polynesia, before people began to move eastward into the Cook Islands, Societies, and the like (SPRIGGS and ANDERSON, 1993). Others (*e.g.*, IRWIN, 1992) suggest a continuous settlement process out of Melanesia, with the Cook Islands being one of the earliest East Polynesian archipelagoes to receive human immigrants.

KIRCH and ELLISON (1994; see also ELLISON, 1994) maintain that vegetation changes and sedimentary disturbances recorded in Mangaian pollen cores indicate human settlement in the southern Cook Islands as early as 2500 BP. Yet direct evidence of a human presence at this early date is lacking and ANDERSON (1994, 1995) has raised methodological concerns relating to the use of palynological records as proxy measures for human activities. The earliest direct evidence of cultural activity in the southern Cook Islands dates to ca. AD 900–1000 (1050–950 BP), sites of this age being known from Aitutaki (ALLEN, 1994) and Mangaia (KIRCH *et al.*, 1995), and somewhat later from Rarotonga (BELLWOOD, 1978), Ma'uke (WALTER, 1990), and Atiu (SINOTO in ALLEN, 1988). The apparent discrepancy between the paleoenvironmental evidence of disturbance, and direct archaeological evidence of human settlements, has forced some researchers to more cautious conclusions as to the timing of people's early incursions into the southern Cook Islands (*e.g.*, ANDERSON, 1995; SPRIGGS and ANDERSON, 1993). The Aitutaki evidence, elaborated below, indicates that the southern Cook Islands were settled before 1000 BP but how much earlier remains uncertain. The East Polynesian settlement debate underscores the need to better understand the dynamics of Pacific coastal environments, where colonial Polynesians typically established their settlements, if we are to successfully locate these sites, or at least accurately evaluate the impact of geomorphic change on the archaeological record.

This paper looks specifically at the island of Aitutaki, one of the more neglected Cook Islands with respect to recent sea-level studies. I begin with an overview of research on Holocene sea-level change in the southern Cook Islands generally. This is followed by a review of the relevant sedimentary, chronometric, and archaeological evidence for sea-level effects on Aitutaki. In the two final sections, the implications of these findings for human settlement and for archaeological recovery are discussed.

PREVIOUS SEA-LEVEL STUDIES IN THE SOUTHERN COOK ISLANDS

SCHOFIELD (1970) was among the first to report emerged reef formations in the southern Cook Islands. On the island of Rarotonga, he noted a "fairly well-preserved flat-topped reef remnant" ca. 3 feet above the low tide level near the main town of Avarua (1970:202). He dated a sample of slightly recrystallised coral, in position of growth, to 2030 ± 60 BP. Schofield suggested the Avarua raised reef, along with raised beach rock at another Rarotongan locality, reflected a 1 m higher sea-level stand (see also CHIKAMORI, 1995). Around the same time, WOOD and HAY (1970) reported raised platforms and notches on Aitutaki, Rarotonga, and Mangaia, which they also took to indicate a 1 m higher Holocene shoreline.

More recently, YONEKURA *et al.* (1986; 1988) identified numerous emerged notches, benches, and microatolls on Mangaia. Their evidence indicates a maximum sea-level stand of 1.7 m above present level around 4,000 to 3,400 years ago. The Mangaian data further suggest that sea-level fall from this high was relatively rapid, probably within the succeeding 500 year period. On Aitutaki, YONEKURA *et al.* (1988) sampled a single emerged microatoll which suggested a 0.4 to 0.5 m higher stand at ca. 1530 ± 210 BP. SCOFFIN *et al.* (1985) report a +0.5 m sea-level stand on Suwarrow between 4,700 and 2,400 years BP. Recent surveys of Ma'uke, Mitiaro, and Atiu by Stoddart and colleagues (STODDART *et al.* 1990) have also identified raised notches and benches, the interpretation of which are generally consistent with the foregoing, although the elevations of these features are somewhat greater than in the Mangaian case. They suggest that the elevational discrepancies they encountered could relate in part to Holocene flexural uplift created by volcanic activity on Rarotonga.

At the outset of the Aitutaki work, the evidence from other southern Cook Island localities suggested that the Holocene sea-level fall would have a geomorphic signature on Aitutaki and could have initiated recent shoreline progradation. Any human occupations coincident with this regression (as dated by the above studies) would be inland from the present coast and might be deeply buried if aggradation and colluviation were active processes at this time. In an archaeological context, a prograding shoreline would be evidenced by a lateral sequence of occupations, as human settlements tracked expansion of the coastal flat, assuming both slow progradation and consistent settlement preferences. To test these propositions, archaeological work carried out in 1989 involved: (1) augering along inland-coastal transects; (2) shovel trenches; and (3) in areas of cultural deposition, careful excavation with three-dimensional control to recover samples for detailed radiocarbon, sedimentary, and faunal analyses.

METHODS AND RESULTS OF THE AITUTAKI FIELD STUDY

Augering

Seven auger transects were placed along the central western coast of the Aitutaki mainland, perpendicular to the shoreline and more-or-less evenly spaced (Figure 2). Modern residences, rugby fields, and commercial activities dictated to some degree where subsurface investigations could and could not be carried out. Augering was effected with a Dutch or Edelman auger fitted with one of two 10 cm bits, one designed for coarse sandy soils and the other for heterogenous soils. The topography of the transects also was mapped to identify large-scale geomorphic features.

The topographic profiles revealed a continuous and moderately well-defined beach ridge along the central western coast, with a marked swale on the inland side of the ridge (Figure 3). In at least two areas, in the vicinity of AIT-10 and inland from AIT-50, this swale was historically a brackish water marsh. The swale was interpreted as the pre-regression shoreline and subsequent trenching and excavations were aimed at locating early occupations along this hypothesized former shoreline. Unfortunately, none were identified, raising questions about the antiquity of human settlement on Aitutaki and making it difficult to directly assign an age to the beach ridge.

The augering did identify two other areas of cultural deposition. One was near the present shoreline and generally multiple cultural layers were recorded at any given local-

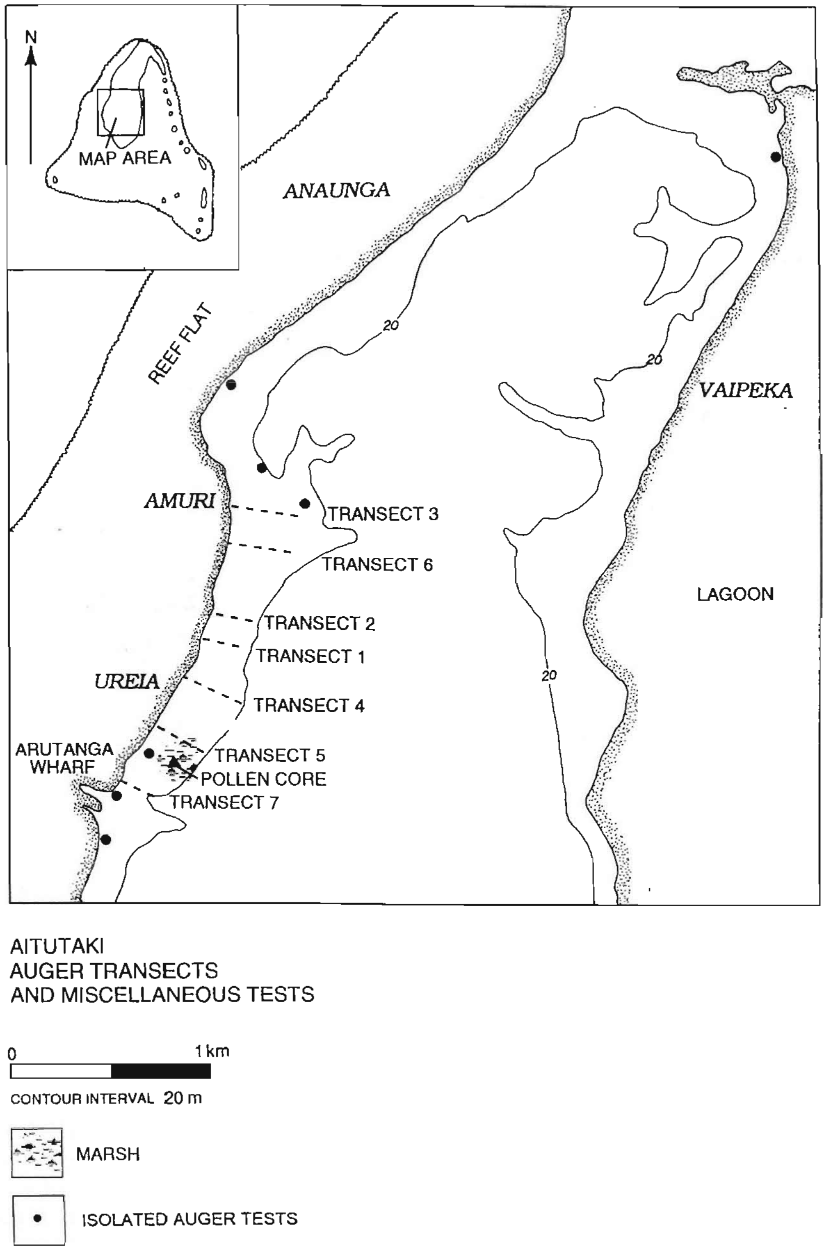

Figure 2. Location of auger tests.

ity. The cultural layers are routinely separated from one another by acultural storm deposits. A second area of cultural deposition was located near the base of the volcanic slope. Yet, contrary to expectations, these inland cultural deposits were not of significant age, nor were they deeply buried. Rather, they are typically surficial and often clearly historic in age, as indicated by the associated artifacts (*e.g.,* bottle glass and metal). Despite coring and trenching to depths of 3 to 4 meters in several places, no deeper, presumably older, buried cultural deposits in this inland area were identified.

Shovel Trenches

Following augering, shovel trenches (Figure 4) were placed in areas where either the auger was ineffective because of the clayey soils (particularly near the inland cliffs), or where interesting stratigraphic features had been identified by the augering. Shovel trenches were also opened on the northeast side of the island to allow comparisons between the two coastal regions.

Augmenting the auger tests, these shovel trenches further demonstrated that: (1) the coastal flat is composed largely of

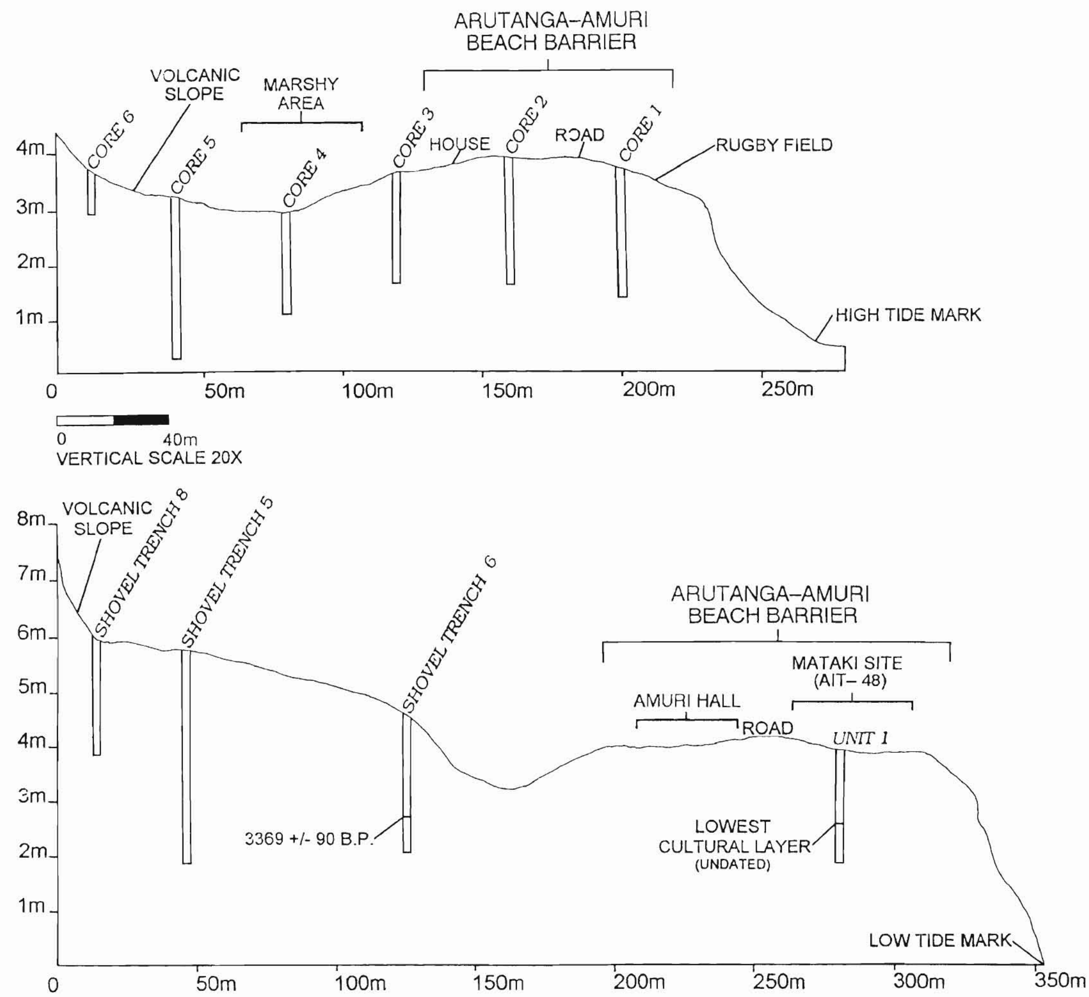

Figure 3. Profile of Transects 2 and 5.

marine sands; and (2) terrigenous deposition is restricted to the base of the volcanic slopes. In a couple of cases, European materials were found under a meter or more of volcanic clays near the base of the slope, allowing us to date these terrigenous deposits to the historic (post-1773) period. The relatively late age of this terrigenous sedimentation contrasts with many other Pacific areas, where increased erosion, slopewash, and mass-wasting often correlate with the arrival and inland expansion of Polynesians (*e.g.*, KIRCH 1993).

One shovel trench, along Transect 2 and on the inland side of the swale, provided further insights into pre-regression shoreline conditions. Here a buried paleosol was identified 180 cm below the surface (Figure 3). Fresh shells from beneath the paleosol were radiocarbon dated to cal BP 3460–3260 at one sigma, with an intercept at BP 3360 (see Table 1). Given that their death probably preceded development of the A-horizon by no more than a few centuries, the date suggests that some portion of the coastal plain was stable and thus available for habitation during the time when human populations were colonizing islands to the west. Yet the extent of this stable surface, represented in only one excavation unit, is uncertain, as discussed further below. Also of note, the relative shallow depth of the dated sample (*e.g.*, 180 cm below surface) indicates only a moderate rate of sediment build-up on this side of the swale.

Archaeological Excavations

Controlled excavations were opened in areas of high to moderate cultural activity identified during the course of augering and trenching. These excavations allowed us to date and model the developmental history of Aitutaki's central western coastal flat. Excavations were carried out with hand trowels and followed natural stratigraphy. All sediments were screened with ¼ and ⅛ inch sieves to recover floral and faunal remains and artifacts. Subsurface features, such as postmolds, hearths, and pavements, were located in three-dimensional space and plotted on excavation records. Altogether 12 cultural sites were investigated in this manner (Figure 4; ALLEN, 1992a); only the five that are critical to the

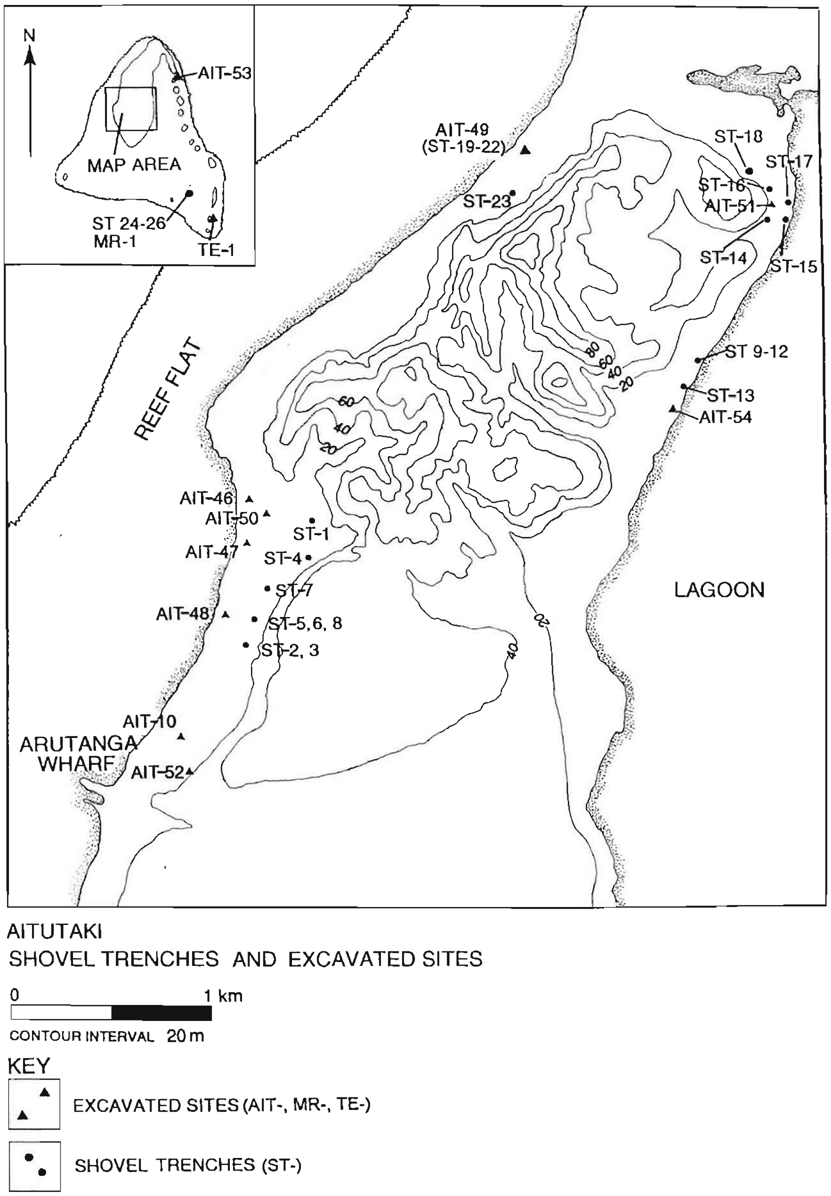

Figure 4. Location of shovel trenches and excavated sites.

interpretation of the geomorphic history of the central western coast are discussed here.

A total of 14 radiocarbon determinations were secured from the five relevant mainland sites (Table 1; ALLEN, 1994). The oldest dates come from the Ureia site (AIT-10), where the basal *in situ* cultural stratum dates to cal. AD 900–1040 at one sigma. Notably this site is located near to a major reef passage, Te Rua-i-kakau, which appears to have been an important criterion for many early Pacific colonists, presumably because they were actively involved in long-distance voyaging (*e.g.*, ALLEN and JOHNSON, 1994; GREEN, 1991; IRWIN, 1992). Other sites along this central western coast date to a few hundred years later (see Table 1).

The most important sedimentary record is also found at the Ureia Site (Table 2; Figures 5, 6; soil descriptions in ALLEN, 1992a) where the following depositional sequence consistent with a prograding shoreline is revealed:

(I) At the base of the excavation, a relatively low-energy reef flat is indicated by very fine-grained sands which rest on a coralline basement (Zone M);

(II) This is followed by an active foreshore, as indicated by coarser sands in graded beds, some which include redeposited cultural materials (Zones J, I, H);

(III) Finally, a backshore beach ridge begins to develop. This unit contains three successive *in situ* cultural occu-

Table 1 *Aitutaki radiocarbon determinations*

Site	Zone	Lab No. (BETA)	Material	RC Age BP[1]	δ13C	Cal Age AD[2]
Mainland Sites						
Ureia						
AIT-10	J	-27439	wood charcoal	790 ± 70	−26.5	1210–1290
AIT-10	J	-25246	wood charcoal	270 ± 80	−27.5	1520–1950
AIT-10	I	-40759	marine shell	1,120 ± 60	+2.9	1280–1380
AIT-10	G	-25250	wood charcoal	1,040 ± 80	−28.8	900–1040
AIT-10	G	-25247	wood charcoal	560 ± 70	−28.4	1310–1430
AIT-10	E	-25249	wood charcoal	760 ± 60	−27.1	1230–1290
AIT-10	E	-25248	wood charcoal	720 ± 60	−29.5	1270–1300
AIT-10	C	-25251	wood charcoal	200 ± 50	−28.5	1660–1950
Hosea						
AIT-50	G	-31604	wood charcoal	620 ± 80	−27.3	1290–1410
AIT-50	E	-41062	wood charcoal	320 ± 70	−24.9	1480–1660
Aretai						
AIT-49	G	-34330	wood charcoal	400 ± 50	−26.3	1440–1620
AIT-49	E	-40762	wood charcoal	310 ± 60	−25.6	1490–1660
Poana						
AIT-47	M	-40760	wood charcoal	620 ± 80	−23.8	1290–1410
Mataki						
AIT-48	E	-40761	wood charcoal	210 ± 50	−25.8	1650–1950
Geological Site						
	X	-41061	marine shell	3,540 ± 90	+1.4	3460–3260
Moturakau Islet						
MR-1A	K	-25767	wood charcoal	840 ± 80	−26.4	1060–1280
MR-1B	D	-41573	wood charcoal	840 ± 60	−26.0	1160–1280
MR-1B	H	-33445	wood charcoal	670 ± 60	−23.3	1290–1390
MR-1B	F & H	-40341	wood charcoal	670 ± 60	−26.2	1290–1390
MR-1A	F	-40339	wood charcoal	640 ± 60	−27.6	1290–1400
MR-1B	H	-44373	wood charcoal	560 ± 70	−25.4	1310–1430
MR-1A	C	-25766	wood charcoal	540 ± 70	−27.2	1320–1440
MR-1B	F	-40340	wood charcoal	530 ± 60	−26.2	1400–1440
MR-1B	D	-42573	wood charcoal	390 ± 50	−27.3	1450–1630
MR-1A	A	-44371	wood charcoal	230 ± 50	−25.9	1650–1950
MR-1B	C	-44372	wood charcoal	180 ± 50	−27.7	1660–1950
MR-1B	B	-41572	wood charcoal	50 ± 60	−26.4	1820–1955

[1] Conventional radiocarbon age after Stuiver and Polach (1977)
[2] Calibrated age AD at 1 sigma using CALIB 3.02 (Stuiver and Reimer, 1993)

pations (Zones G, E, C) and the modern surface (Zone A), which are separated from one another by storm deposits (Zones F, D, B). The *in situ* nature of the cultural occupations is indicated by undisturbed architectural elements such as hearths, postmolds, pavements and pit features.

The sedimentary sequence in the Ureia profile is broadly consistent with the late Holocene sea-level fall recorded for other southern Cook Islands through features such as elevated notches, cliff-foot benches, and emergent reef flats (SCHOFIELD, 1970; SCOFFIN *et al.*, 1985; STODDART *et al.*, 1990; WOOD and HAY, 1970; YONEKURA *et al.* 1988). Radiocarbon dates of the redeposited cultural materials associated with the hypothesized active foreshore are somewhat problematic but overlap at two sigma with the overlying *in situ* cultural layer, which is dated to ca. 1000 BP, both by ALLEN (1994) and by the earlier study of BELLWOOD (1978) at the same site. This 1000 BP cultural layer provides a minimal date for stabilization of the beach barrier, as all other cultural deposits investigated along this coast postdate 1000 BP (see Table 1). The underlying redeposited cultural materials suggest the ridge began to form no more than a few centuries earlier—probably after 2000 but before 1200 BP.

Notably the hypothesized *timing* of barrier initiation is not consistent with the Mangaian evidence for sea-level fall (3400 to 2900 BP; YONEKURA *et al.*, 1988). Yet it does fit comfortably with French Polynesian evidence for a post-1500 BP sea-level fall of 0.8 m (PIRAZZOLI *et al.*, 1988; PIRAZZOLI and MONTAGGIONI, 1986) and the lone emerged microatoll from Aitutaki which YONEKURA *et al.* (1988) dated to 1530 + 210. Once the barrier had stabilized, growth was primarily upward but episodic. Under calm conditions there is little coastal sedimentation, as Aitutaki's fringing reef is one-half kilometer from the shore and protects the island from normal wave action. The bulk of the barrier growth was thus through storm events, but even in the storm layers the sedimentary particles are primarily medium to coarse sands (see Figure 6; Table 2).

Table 2. *Ureia (AIT-10) sieve analysis.*

		GRAVEL[2]	*Very Coarse* ←		SAND[3] →		*Very Fine*	PSA[1]
ID[4]	Total Wt	2.0 mm	1.0 mm	0.5 mm	0.25 mm	0.125 mm	0.062 mm	<0.06 mm
A	72.69	0.29	9.98	25.94	21.01	11.76	1.83	1.87
B	73.66	0.28	9.15	25.18	26.53	11.03	0.79	0.69
C	80.67	0.35	5.45	19.84	26.97	20.89	3.05	4.13
D	73.58	0.12	7.06	21.86	28.12	14.09	1.40	0.93
E	77.69	0.13	3.56	21.66	28.52	19.90	2.42	1.50
F	no data							
G	67.16	0.12	0.87	9.26	26.79	26.22	2.76	1.14
H	76.70	0.03	0.54	12.04	36.13	25.76	1.50	0.72
I	66.37	0.39	4.22	24.41	26.29	9.38	0.84	0.83
J	78.34	0.06	1.98	17.57	33.68	21.63	2.10	1.32
K	67.45	0.03	0.32	7.20	25.83	30.37	2.65	1.04
L	74.19	0.02	0.44	11.59	33.84	25.18	1.97	1.17
M	67.25	0.46	1.37	11.52	19.99	27.45	4.70	1.77

[1] Weight percents based on total weight of sample
[2] Fraction analyzed with graduated geological seives
[3] Fraction analyzed with the GALAI CIS-100 laser-based size analyzer
[4] Sample A surface, Sample M basal (see profile)

Two lines of evidence tentatively suggest that initial growth of the beach barrier was rapid, but slowed within the last few centuries. The three *in situ* cultural layers at Ureia allow for a rough age-depth curve. Together with the nearly contemporaneous underlying redeposited materials, they suggest a rapid build-up of sediments initially, followed by slower sedimentation rates in the last few centuries. Additionally, excavations both at Ureia and elsewhere on the western coast do not evidence any clear cut age-progression in the lateral location of cultural occupations, as would be expected in a slowly prograding shoreline. This evidence tentatively suggests that sea-level fall was fairly rapid, occurring within a few centuries—a scenario consistent with the Mangaian data.

Corroborative evidence for a higher sea level in the recent past comes from STODDART's (1975b) work on Aitutaki's offshore islets. On Akaiami, *Tridacna maxima* valves from clastic conglomerate platforms were dated to 2040 ± 90 BP (uncorrected). Similar specimens from Muritapua were dated to 160 ± 80 BP. These dates indicate both the recency of the materials composing these platforms and suggest that some or all of Aitutaki's islets may not have emerged or stabilized until after 2000 BP. As such, they were not available for human occupation until relatively late in prehistory. NUNN (1991), commenting more generally on geomorphic processes in coral reef settings, observes that if vertical reef growth kept pace with early Holocene sea-level rise, then the emergence of offshore islets would have occurred during the late Holocene regression.

The foregoing suggested that human occupations on Aitutaki's offshore islets would not to date to earlier than the Holocene maximum high stand, that is before ca. 2900 BP (based on the Mangaian evidence) or before 1500 BP (based on French Polynesian studies). Archaeological evidence, although negative, is consistent. Survey of 11 of Aitutaki's 15 offshore islets yielded almost no archaeological sites of significant antiquity. The one exception is Moturakau, a small volcanic islet within the lagoon where a 1.75 m deep cultural deposit with 12 distinct strata and numerous overlapping hearths was found within two small adjoining rockshelters (see Table 1). Notably, Moturakau's protected location within the lagoon, coupled with the leeward location of the two shelters, created an environment favorable to archaeological preservation. This is reflected in the 700 BP basal date of the site, which is unusually old for Aitutaki's islets.

While the Aitutaki archaeological evidence is consistent with a post-1500 BP islet emergence, the vulnerability of these islets to storms must also be considered. Dates on acultural sediments from Muritapua Islet ranged from modern to 470 ± 80 BP, with the oldest date coming from a former beach ridge in the islet's interior (STODDART, 1975b). These dates suggest that in some cases the bulk of islet sediments may be relatively recent accumulations and that the lack of older cultural deposits could reflect erosional processes. The possibility of a post-1500 BP human colonization of Aitutaki could also explain the lack of pre-1500 BP archaeological sites.

IMPLICATIONS FOR HUMAN SETTLEMENT

The overall effect of sea-level fall in the case of Aitutaki was to enhance this coast as a prospective site for human settlement. The period of greatest change preceded AD 900–1050 (1050–900 BP), following a sea-fall of 0.5 to 1.7 m (based on other southern Cook Island data). Initially, only a narrow coastal strip was available for settlement but as the shoreline prograded in response to sea-level fall, more land became exposed. The central-western beach barrier, in particular, provided new dry land which became a focus of human settlement over the following 1000 years. Shoreline expansion was accompanied by the development of near-coastal marshes in the swale of the beach barrier. These areas were important agricultural resources, being conducive to the cultivation of wet taro (*Colocasia esculenta*), a highly valued traditional cultigen (ALLEN, 1971). These marshes continue to be used in this manner today, especially on the eastern side of the island, and are among the few areas on Aitutaki where wet taro can be grown.

The marshes also provided habitats for edible fauna. The remains of three water-fowl were recovered from the AIT-50 and AIT-10 cultural layers: *Porzana tabuensis*, *Dendrocygna*, and *Anas superciliosa* (ALLEN, 1992a). Archaeological representation of *Porzana* in particular increases through time and may reflect growth of brackish water habitats as the beach barrier developed. On Mitiaro and Atiu, where *Porzana* is extant, this small rail lives in thick grasses and rushes along the margins of brackish or freshwater marshes (HOLYOAK, 1980).

Sea-level fall also saw emergence of Aitutaki's offshore islets. These landforms were colonized by seabirds and turtles, both of which are represented in the Moturakau Islet faunal assemblages. Birds that probably once nested here include the extirpated Tahiti Petrel (*Pterodroma rostrata*), now-rare migrants like the Bristle-thighed Curlew (*Numenius tahitiensis*), and shorebirds—all species represented archaeologically on Moturakau (ALLEN, 1992a; STEADMAN, 1991). Accumu-

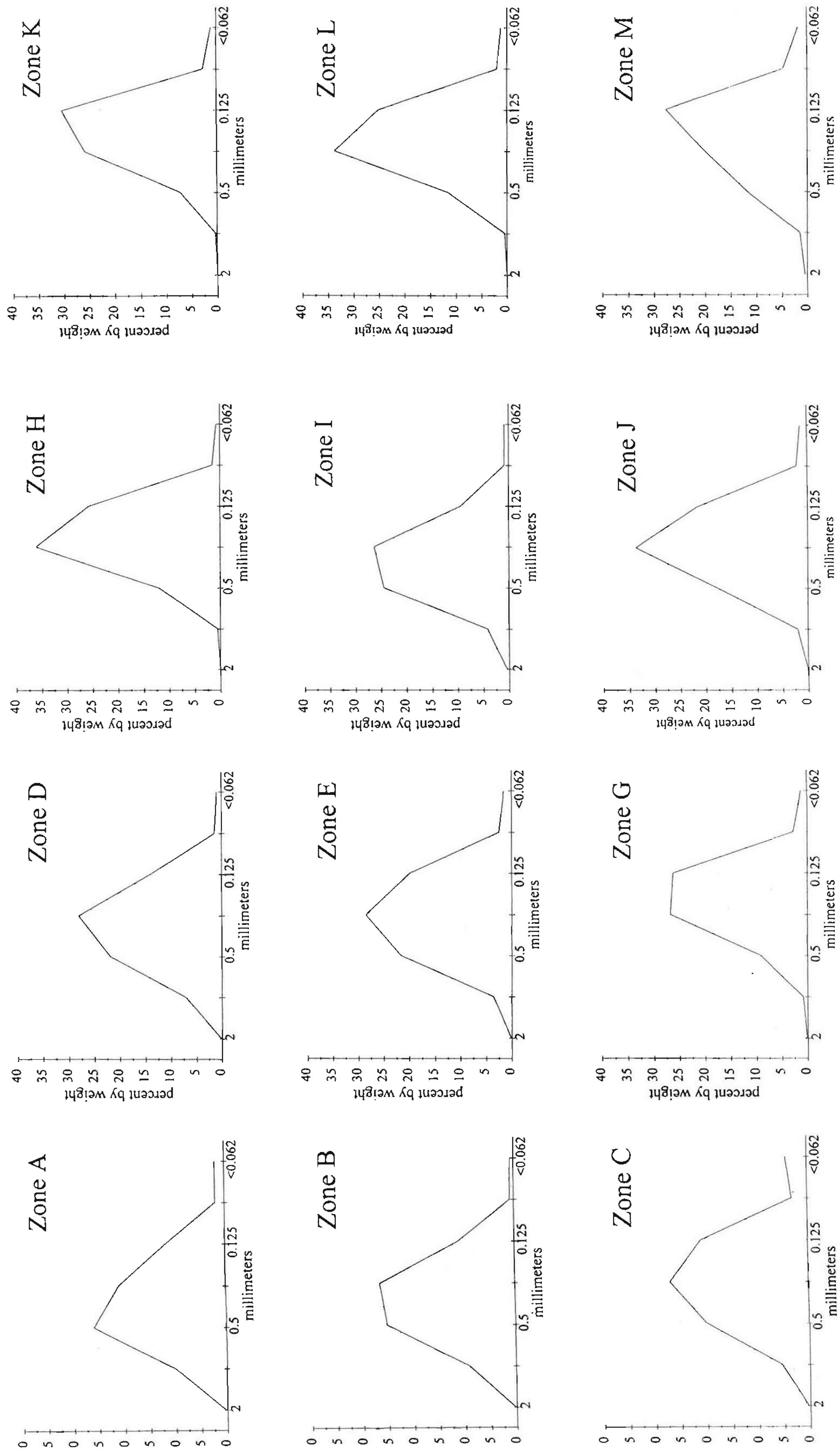

Figure 5. Ureia (AIT-10) grain-size distributions of gravel, sand, and coarse silt fraction (no data available for Zone F).

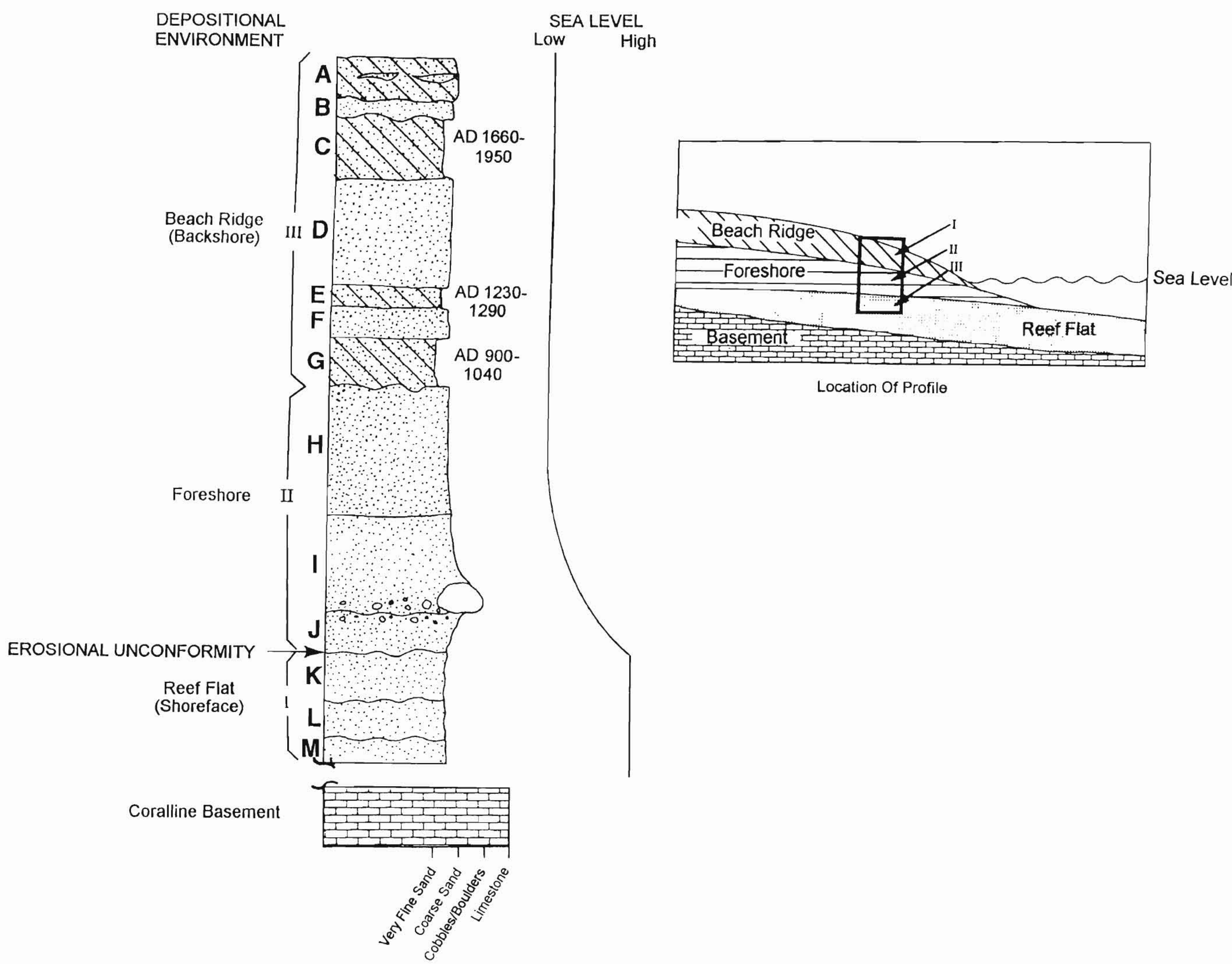

Figure 6. Idealised sedimentary sequence summarising changing depositional environments through time at the Ureia Site (AIT-10).

lations of sandy-to-rubbly sediments around and between the islets offered new territory for edible burrowing bivalves as well. For example, the large edible Box Sunset Shell (*Asaphis violascens*) is well-represented early in the Moturakau sequence relative to mainland localities of comparable antiquity (ALLEN, 1992a). Overall, islet stabilization provided new hunting and foraging opportunities and, through temporary campsites, increased accessibility to the outer reef habitats which were rich in fish and shellfish.

One negative effect of coastal progradation was the diminution of the immediately adjacent reef flats and the corresponding effect on faunal resources. These effects were probably most dramatic during the initial period of shoreline growth (*e.g.*, ca. 2000 to 1200 BP), a period for which there presently is no archaeological record. In the last 1000 years, the most notable change has been a decline in the availability of pearlshell (ALLEN, 1992b, 1995), an important raw material for fishhooks. Pearlshell hooks are common in Aitutaki's earliest cultural occupations but after the 16th century AD become increasingly rare. At this same time, pearlshell also disappears from other southern Cook localities, where it was an exotic import (KIRCH *et al.*, 1995; WALTER, 1990). The loss of pearlshell on Aitutaki may stem from increased terrigenous sedimentation along the eastern coast of the mainland, possibly the result of intensified or expanding agricultural activities. Although the onset of terrigenous sedimentation has not been dated, shovel trenches on the eastern coast revealed massive clay deposits over a meter in depth. Extensive mudflats occur along this shore and notably the deepest portion of the lagoon, critical habitat for pearlshell, is found in this northern area.

After ca. 1000 BP, significant storm activity is registered throughout the archaeological sequence with no well-defined periods of abatement or intensification. While settlement locations remained relatively constant, the storm deposits mark the periodic disruption of human occupations along this western coast. In the proto-historic to early historic period, inland localities near the base of the volcanic slopes were settled. Areas closer to the coast also continued to be occupied, as for example, the Ureia site. The relatively recent settlement of inland coastal areas could relate to a variety of factors, including but not limited to, sharply increased precipitation around 650 BP (NUNN, 1994b) and the storminess hypothesized to have characterized the Little Ice Age between 650 and 50 BP (after NUNN, 1991).

IMPLICATIONS FOR ARCHAEOLOGICAL RECOVERY

Initially, I hypothesized that older deposits would be inland from the present coast and possibly deeply buried; the 1989 field studies were formulated with this geomorphic model in mind. Yet extensive testing failed to locate any cultural activities earlier than *ca.* 1000 BP on Aitutaki's western coastal plain. Was the island unoccupied prior to this time, or is the lack of earlier cultural deposits the result of geomorphic change? In this regard, NEUMANN and MACINTYRE's (1985) discussion of three kinds of Holocene reefs may be pertinent. Give-up reefs are those which fail to keep pace with rising sea levels and are essentially drowned during a transgressive phase. Keep-up reefs, in contrast, track sea-level rise and afford some coastal protection. Most relevant here are catch-up reefs which lag behind sea-level rise, as in the Society Islands where they approached the sea surface only *ca.* 2,000 to 1,000 years ago (MONTAGGIONI, 1988). The effect of catch-up reefs was to leave coastal zones susceptible to erosion and sediment reworking around the time of the Holocene sea-level maximum. Under such conditions, archaeological records of human activities, especially small-scale and discontinuous records, may be poorly preserved. The redeposited cultural materials of Zones I and J at Ureia suggest that prior to sea-level fall, Aitutaki's central western coast was more exposed than at present. While other kinds of data are needed to fully evaluate Holocene reef growth on Aitutaki, the possibility that pre-1000 BP cultural deposits have been eroded can not be rejected in light of the Zones I and J sedimentary evidence.

Another important concern is whether or not the 1000 BP occupation conforms to our expectations for a early Polynesian site? This question is particularly important in light of KIRCH and ELLISON'S (1994) argument for a human presence at 2500 BP on Mangaia, 385 km southwest. If their pollen cores do indicate human disturbances at this early date, then penecontemporaneous colonization of other nearby southern Cook Islands would be no surprise. Yet ANDERSON (1995; also SPRIGGS and ANDERSON, 1993) has challenged the suggestion that initial settlement in the southern Cook Islands was as early as Kirch and Ellison suggest, and argues that the relative abundance and taxonomic variety of extinct fauna may be more useful indicators of colonization. The Ureia assemblages are evaluated using these criteria.

Looking first at the avifaunal record, in the earliest *in-situ* cultural layer of the Ureia site, one bone of a single indigenous bird was recovered, *Porzana tabuensis*, a species which persisted into the historic period but is now extirpated from the island (ALLEN, 1992a; STEADMAN, 1991). Two other native birds were found at Ureia, but not until the late prehistoric to early historic period. Each of these is also represented by a single specimen: the extant *Anas superciliosa* and the extinct *Dendrocygna* (ALLEN, 1992a; STEADMAN, 1991). At other later sites on the Aitutaki mainland, similarly small and species-poor avifaunal assemblages were recovered (see ALLEN, 1992a). The Aitutaki assemblages contrast with colonial assemblages from other small (*e.g.*, less than 60 km^2) Polynesian islands, which are typically taxonomically diverse, rich in avifaunal remains, and often dominated by seabirds (*e.g.*, STEADMAN, 1989, 1993; STEADMAN and KIRCH, 1990; STEADMAN and OLSON, 1985; STEADMAN and ROLETT, 1996; STEADMAN *et al.* 1990).

In the Aitutaki land snail assemblages, three taxa considered to be Polynesian introductions (CHRISTENSEN and KIRCH, 1981; HUNT, 1981) and associated with disturbed and/or anthropogenic environments comprise ca. 50% of the earliest *in-situ* cultural layer: *Allopeas gracile* (= *Lamellaxis gracilis*), *Lamellidea oblonga*, and *Gastrocopta pediculus*. Some probably lived around coastal residences; others, stained with a red clay, apparently originated in a volcanic soil. As the sedimentary matrix at Ureia is essentially marine sands, a reasonable interpretation is that the clay-stained snails were introduced to the site by people utilizing the interior volcanic regions of the island. Unfortunately, there are few ecological data on how quickly these adventives become established and comparative assemblages from other colonizing Polynesian occupations are few in number and small in size (but see CHRISTENSEN and KIRCH, 1986, 1981; HUNT, 1981). Yet the abundance of adventives in the earliest Ureia layer clearly reflects an anthropogenic, as opposed to a pristine, environment.

Finally, the early wood-charcoal assemblage from Ureia is informative (ALLEN, 1992a). Four species were recovered from the 1000 BP layer. In descending order of abundance (by weight), these include an unknown, *Artocarpus altilis* (breadfruit), *Hibiscus tiliaceus*, and an unidentified palm. The small number of taxa and the absence of typical strand species other than *Hibiscus* (see MERRILL, 1981; STODDART, 1975c, 1975d) is notable, as is the use of an important tree crop and timber source (*i.e.*, *Artocarpus*) for firewood. Although inconclusive based on a single sample, at face value, the taxa recovered are more representative of an anthropogenic environment than they are of a natural one.

Environmental change on small islands can be quite rapid. This is especially true when aggressive, ecologically tolerant taxa are introduced coincident with the destruction of native habitats, as with adventive land snails. Nevertheless, archaeological evidence from other islands comparable to, or smaller than, Aitutaki suggest that colonizing human settlements will have certain biotic signatures, including a high relative abundance and diversity of native taxa. In this regard, the small species-poor avifaunal assemblage of Aitutaki's earliest cultural occupation differs significantly from those found in other colonizing Polynesian settlements. Broadly supportive, the Ureia land snail and wood charcoal data unambiguously document the establishment of Polynesian introductions at 1000 BP and their abundances also suggest that this basal *in-situ* layer is not an early human occupation. Thus, overall, the Aitutaki biotic evidence does not conform to the expected colonial signature and, along with the underlying redeposited cultural materials, suggests human occupation sometime prior to 1000 BP.

Following Holocene sea-level fall, sedimentary conditions changed dramatically on Aitutaki. Sea-level fall drained shallow reef flats and offshore reefs immediately provided a more protective front. With sea-level stabilization, the central-western beach barrier began to develop and a low marshy area formed along its inland side. As inland areas were increasingly protected from high storm surges, *depositional* rather than *erosional* processes came to dominate at the shore. Storm deposits not only buried older cultural deposits but also reduced the possibilities of subsequent post-depositional disturbances. As a result, the last millennium of human activities on Aitutaki is relatively well-preserved.

In conclusion, Aitutaki Island is another reminder of the dynamic nature of Pacific coastal environments throughout the period of human settlement. For small islands like Aitutaki, the impact of sea-level rise (or fall) can be considerable. Understanding these processes has importance not only for the past but also the future. As modern sea level rises once again, the geomorphic and cultural history of these islands may be a window on the future which could help small island nations prepare for change.

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LITERATURE CITED

ALLEN, B. 1971. Wet-field Taro Terraces on Mangaia, Cook Islands. *Journal of the Polynesian Society* 80, 371–8.

ALLEN, M.S., 1992a. *Dynamic Landscapes and Human Subsistence: Archaeological Investigations on Aitutaki Island, Southern Cook Islands.* Ann Arbor: University Microfilms International.

ALLEN, M.S., 1992b. Temporal variation in Polynesian fishing strategies: The southern Cook Islands in regional perspective. *Asian Perspectives*, XXXI, 183–204.

ALLEN, M.S., 1994. The chronology of coastal morphogenesis and human settlement on Aitutaki, southern Cook Islands, Polynesia. *Radiocarbon*, 36, 59–71.

ALLEN, M.S., 1995. Style and function in Polynesian fish-hooks. *Antiquity* 70, 97–116.

ALLEN, M.S. AND JOHNSON, K., 1994. Patterns of Interaction in the Southern Cook Islands: Recent Geochemical Investigations on Aitutaki. Paper presented at *Society for American Archaeology 59th Annual Meeting,* April 20–24, 1994, Anaheim, California.

ALTONN, H., 1988. Broken pottery adds weight to the legends of Polynesia. *Star Bulletin*, June 29, 1988.

ANDERSON, A., 1994. Palaeoenvironmental evidence of island colonization: A response. *Antiquity*, 68, 845–7.

ANDERSON, A., 1995. Current approaches in east Polynesian colonization research. *Journal of the Polynesian Society*, 104, 110–32.

ATHENS, S.J. AND WARD, J., 1993. Environmental change and prehistoric Polynesian settlement in Hawai'i. *Asian Perspectives*, 32, 205–223.

BELLWOOD, P., 1978. *Archaeological Research in the Cook Islands.* Pacific Anthropological Records 27. Honolulu: B.P. Bishop Museum.

CHAPPELL, J., 1982. Sea levels and sediments: some features of the context of coastal archaeological sites in the tropics. *Archaeology in Oceania*, 17, 69–78.

CHIKAMORI, M., 1995. Development of coral reefs and human settlement: Archaeological research in the northern Cook Atolls and Rarotonga. *In:* CHIKAMORI, M., S. YOSHIDA, and YAMAGUCHI, T., (eds.), Archaeological Studies on the Cook Islands. Series 1. Department of Archaeology and Ethnology, Keio University, Tokyo, pp. 3–14.

CHRISTENSEN, C.C. AND KIRCH, P.V., 1981. Nonmarine mollusks from archaeological sites on Tikopia, southeastern Solomon Islands. *Pacific Science*, 35, 75–88.

CHRISTENSEN, C.C. AND KIRCH, P.V., 1986. Nonmarine mollusks and ecological change at Barbers Point, O'ahu, Hawai'i. *Bishop Museum Occasional Papers*, 26, 52–80.

DAVIDSON, J., 1971. *Archaeology on Nukuoro Atoll.* Bulletin of the Auckland Institute and Museum Number 9.

ELLISON, J., 1994. Paleo-lake and swamp stratigraphic records of Holocene vegetation and sea-level changes, Mangaia, Cook Islands. *Pacific Science*, 48, 1–15.

GREEN, R.C., 1991. The Lapita cultural complex: current evidence and proposed models. *In:* BELLWOOD, P. (ed.), *Indo-Pacific Prehistory 1990.* Canberra: Bulletin of the Indo-Pacific Prehistory Association No. 11, pp. 295–305.

HOLYOAK, D.T., 1980. *Guide to Cook Island Birds.* Privately published.

HUNT, T.L., 1981. New Evidence for early horticulture in Fiji. *Journal of the Polynesian Society*, 90, 259–269.

IRWIN, G., 1992. *The Prehistoric Exploration and Colonization of the Pacific.* Cambridge: Cambridge University Press.

JARRARD, R.D. AND TURNER, D.L., 1979. Comments on 'Lithospheric flexure and uplifted atolls' by M. McNutt and H.W. Menard. *Journal of Geophysical Research*, 84, 5691–4.

JENNINGS, J., 1971. The Ferry Berth Site, Mulifanua District, Upolu. *In:* GREEN, R.C. and DAVIDSON, J., (eds.), *Archaeology in Western Samoa*, vol. 2. Bulletin of the Auckland Institute and Museum 7.

JOHNSTON, K.M., 1967. *Village Agriculture in Aitutaki, Cook Islands.* Pacific Viewpoint Monograph 1. Wellington: Department of Geography, Victoria University.

KIRCH, P.V., 1993. The To'aga Site: Modelling the morphodynamics of the land-sea interface. *In:* KIRCH, P.V. and HUNT, T.L., (eds.), *The To'aga Site: Three Millennia of Polynesian Occupation in the Manu'a Islands, American Samoa.* Berkeley: Contributions to the University of California Archaeological Research Facility No. 51, pp. 31–42.

KIRCH, P.V. and ELLISON, J., 1994. Paleoenvironmental evidence for human colonization of remote oceanic islands. *Antiquity*, 68, 310–21.

KIRCH, P.V. and HUNT, T.L., 1988. The spatial and temporal boundaries of Lapita. *In:* KIRCH, P.V. and HUNT, T.L., (eds.), *Archaeology of the Lapita Cultural Complex: A Critical Review.* Seattle: Thomas Burke Memorial Washington State Museum Research Report No. 5, pp. 9–32.

KIRCH, P.V.; STEADMAN, D.W.; BUTLER, V.L.; HATHER, J., and WEISLER, M.I., 1995. Prehistory and human ecology in Eastern Polynesia: excavations at Tangatatau Rockshelter, Mangaia, Cook Islands. *Archaeology in Oceania*, 30, 47–65.

KIRCH, P.V. and YEN, D.E., 1982. *Tikopia: The Prehistory and Ecology of a Polynesian Outlier.* Honolulu: *B.P. Bishop Museum Bulletin* 238.

McNUTT, M. and MENARD, H.W., 1978. Lithospheric flexure and uplifted atolls. *Journal of Geophysical Research* 83, 1206–12. 1979 Reply. *Journal of Geophysical Research*, 84, 5695–97.

MERRILL, E.D., 1981. *Plant Life of the Pacific World*. Rutland: Charles E. Tuttle Co.

MONTAGGIONI, L.F., 1988. Holocene reef growth history in mid-plate high volcanic islands. *In:* CHOAT, J.H.; BARNES, D.; BOROWITZKA, M.A.; COLL, J.C.; DAVIES, P.J.; FLOOD, P.; HATCHER, B.G.; HOPLEY D.; HUTCHINGS, P.A.; KINSEY, D.; ORME, G.R.; PICHON, M.; SALE, P.F.; SAMMARCO, P.; WALLACE, C.C.; WILKINSON, C.; WOLANSKI, E., and BELLWOOD, O., (eds.), *Proceedings of the Sixth International Coral Reef Symposium, Townsville, Australia, 8–12th August 1988*, Vol. 3, pp. 455–60.

NEUMANN, A.C. and MACINTYRE, I., 1985. Reef response to sea level rise: Keep-up, catch-up, or give-up. I: *Proceedings of the 5th International Coral Reef Congress*, 3, 105–10.

NUNN, P.D., 1991. *Keimami sa Vakila na Liga ni Kalou. Feeling the Hand of God: Human and Nonhuman Impacts on Pacific Island Environments*. Honolulu: Environment and Policy Institute, East West Center

NUNN, P.D., 1994a. *Oceanic Islands*. Oxford: Blackwell.

NUNN, P.D., 1994b. Beyond the naive lands: human history and environmental change in the Pacific Basin. *In:* WADDELL, E. and NUNN, P.D., (editors). *The Margin Fades: Geographical Itineraries in a World of Islands*. Suva, Fiji: Institute of Pacific Studies, pp. 5–27.

OWENS, M., 1993. The geoarchaeology of beach ridges and cheniers: studies of coastal evolution using archaeological data. *Journal of Coastal Research*, 9, 126–46.

PIRAZZOLI, P.A. and MONTAGGIONI, L.F., 1986. Late Holocene sea-level changes in the northwest Tuamotu Islands, French Polynesia. *Quaternary Research*, 25, 350–68.

PIRAZZOLI, P.A.; MONTAGGIONI, L.F.; SALVAT, B., and FAURE, G., 1988. Late Holocene sea level indicators from twelve atolls in the central and eastern Tuamotus (Pacific Ocean). *Coral Reefs*, 7, 57–68.

SCHOFIELD, J.C., 1970. Notes on late Quaternary sea levels, Fiji and Rarotonga. *New Zealand Journal of Geology and Geophysics*, 13, 199–206.

SCOFFIN, T.P., STODDART, D.R.; TUDHOPE, A.W., and WOODROFFE, C.D., 1985. Exposed limestones of Suwarrow Atoll. *Proceedings of the 5th International Coral Reef Congress*. (Tahiti), 3, 137–40.

SPENCER, T.; STODDART, D.R.; WOODROFFE, C.D., and HARMON, R.S., 1988. Lithospheric flexure and raised reef limestones, S. Cooks-Austral Islands. *In:* CHOAT, J.H.; BARNES, D.; BOROWITZKA, M.A., COLL, J.C.; DAVIES, P.J.; FLOOD, P.; HATCHER, B.G.; HOPLEY D.; HUTCHINGS, P.A.; KINSEY, D.; ORME, G.R., PICHON, M.; SALE, P.F.; SAMMARCO, P.; WALLACE, C.C.; WILKINSON, C.; WOLANSKI, E., and BELLWOOD, O., (eds.), *Proceedings of the Sixth International Coral Reef Symposium*, (Townsville, Australia, *8–12th August 1988*), Vol. 3, pp. 485–89.

SPRIGGS, M.J.T., 1981 Vegetable Kingdoms: Taro Irrigation and Pacific Prehistory. Unpublished Ph.D. dissertation, Department of Prehistory, Australian National University, Canberra.

SPRIGGS, M.J.T and ANDERSON, A., 1993. Late colonization of East Polynesia. *Antiquity*, 67, 200–17.

STEADMAN, D.W., 1989. Extinction of birds in Eastern Polynesia: A review of the record, and comparisons with other Pacific island groups. *Journal of Archaeological Science*, 16, 177–205.

STEADMAN, D.W., 1991. Extinct and extirpated birds from Aitutaki and Atiu, southern Cook Islands. *Pacific Science*, 45, 325–47.

STEADMAN, D.W., 1993. Bird bones from the To'aga Site: prehistoric loss of seabirds and megapodes. *In:* KIRCH, P.V. and HUNT, T.L., (eds.), *The To'aga Site: Three Millennia of Polynesian Occupation in the Manu'a Islands, American Samoa*. Berkeley: Contributions of the University of California Archaeological Research Facility, Number 51, pp. 217–228.

STEADMAN, D.W. and KIRCH, P.V., 1990. Prehistoric extinction of birds on Mangaia, Cook Islands, Polynesia. *Proceedings of the National Academy of Sciences*, 87, 9605–9.

STEADMAN, D.W. and OLSON, S.L., 1985. Bird remains from an archaeological site on Henderson Island, South Pacific: Mancaused extinction on an "uninhabited" island. *Proceedings of the National Academy of Sciences*, 82, 6191–5.

STEADMAN, D.W. and ROLETT, B., 1995. A Chronostratigraphic analysis of landbird extinction on Tahuata, Marquess Islands. *Journal of Archaeological Science*, 23, 81–94.

STEADMAN, D.W.; PAHLAVAN, D.S., and KIRCH, P.V., 1990. Extinction, biogeography, and human exploitation of birds on Tikopia and Anuta, Polynesian outliers in the Solomon Islands. *Bishop Museum Occasional Papers*, 30, 118–153.

STODDART, D.R., 1975a. Scientific studies in the southern Cook Islands: Background and bibliography. *In:* STODDART, D.R. and GIBBS, P.E., (eds.), *Almost-Atoll of Aitutaki: Reef Studies in the Cook Islands, South Pacific*. Atoll Research Bulletin 190. Washington, D.C.: Smithsonian Institution, pp. 1–30.

STODDART, D.R., 1975b. Almost-atoll of Aitutaki: geomorphology of reefs and islands. *In:* STODDART, D.R. and GIBBS, P.E., (eds.), *Almost-Atoll of Aitutaki: Reef Studies in the Cook Islands, South Pacific*. Atoll Research Bulletin 190. Washington, D.C.: Smithsonian Institution, pp. 31–58.

STODDART, D.R., 1975c. Vegetation and floristics of the Aitutaki motus. *In:* STODDART, D.R. and GIBBS, P.E. (eds.), *Almost-Atoll of Aitutaki: Reef Studies in the Cook Islands, South Pacific*. Atoll Research Bulletin 190. Washington, D.C.: Smithsonian Institution, pp. 87–116.

STODDART, D.R., 1975d. Mainland vegetation of Aitutaki. *In:* STODDART, D.R. and GIBBS, P.E. (eds.), *Almost-Atoll of Aitutaki: Reef Studies in the Cook Islands, South Pacific*. Atoll Research Bulletin 190. Washington, D.C.: Smithsonian Institution, pp. 117–122.

STODDART, D.R.; WOODROFFE, C. and SPENCER, T., 1990. *Mauke, Mitiaro and Atiu: Geomorphology of Makatea Islands in the Southern Cooks*. Atoll Research Bulletin 341. Washington, D.C.: Smithsonian Institution.

STUIVER, M., and REIMER, P.J., 1993. Extended ^{14}C data base and revised CALIB 3.0 ^{14}C age calibration program. *In:* STUIVER, M.; LONG, A., and KRA, R.S. (eds.), Calibration 1993. *Radiocarbon*, 35, 215–230.

THOMPSON, C.S., 1986. *The Climate and Weather of the Southern Cook Islands*. New Zealand Meteorological Service Miscellaneous Publication, 188 (2).

TURNER, D.L., and JARRARD, R.D., 1982. K-Ar dating of the Cook-Austral island chain: A test of the hot-spot hypothesis. *Journal of Volcanology and Geothermal Research*, 12, 187–220.

VISHER, S.S., 1925. Tropical Cyclones of the Tropical Pacific. Honolulu: B.P. *Bishop Museum Bulletin* 20.

WALTER, R., 1990. The Southern Cook Islands in Eastern Polynesian Prehistory. Unpublished Ph.D. dissertation, Department of Anthropology, Auckland University.

WOOD, B.L. and HAY, R.F., 1970. Geology of the Cook Islands. *New Zealand Geological Survey Bulletin* 82.

YONEKURA, N.; ISHII, T.; SAITO, Y.; MAEDA, Y.; MATSUSHIMA, Y.; MATSUMOTO, E., and KAYANNE, E., 1988. Holocene fringing reefs and sea-level change in Mangaia Island, southern Cook Islands. *Palaeogeography, Palaeoclimatology, Palaeoecology, 68, 177–188.*

YONEKURA, N.; ISHII, T.; SAITO, Y.; MATSUMOTO, E., and KAYANNE, H., 1986. Geologic and geomorphic development of Holocene fringing reefs of Mangaia Island, the south Cooks. *HIPAC Team, Sea-Level Changes Tectonics in the Middle Pacific, Report HIPAC Project, 1984, 1985*, pp. 44–67. Kobe: Kobe University.