Landscape Evolution and Human Settlement Patterns on Ofu Island, Manu'a Group, American Samoa

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INTRODUCTION

Pacific Island coastlines are a valuable resource, exhibiting high biodiversity relative to inland areas. As such, these coastlines were attractive locations for initial settlement by human populations and continue to be used by modern populations (Lepofsky 1988; Nunn 2005). Over the last few decades, archaeologists and geologists have documented the dynamic nature of Pacific Island coastal landscapes. We now know that the present configuration of coastlines does not represent the prehistoric situation, and that prehistoric peoples lived through and adapted to changing environments (Kirch and Yen 1982; Spriggs 1981). Within the context of modern sea-level fluctuation in the region, the documentation of the human response to changing coastlines in the past serves as a valuable resource and model.

Of particular influence on Holocene coastal environments in the central Pacific was the mid-Holocene highstand and subsequent drawdown (Mitrovica and Peltier 1991). In conjunction with sea-level fall, many islands share a pattern of shoreline accretion that coincides with a modeled "crossover date" wherein ambient high tide fell below previous mid-Holocene low tide levels (Dickinson 2003). Some researchers have highlighted the positive impact of sea-level fall in the creation or expansion of land suitable for human settlement and cultivation (Allen 1998; Carson 2012; Dickinson 2003; Nunn 2007:53–58; Spriggs 1986). Others, however, cite the negative loss of marine environments adjacent to coastal flats as these coastal flats prograded due to sea-level decline or geotectonic factors (Kirch 1988; Kirch and Yen 1982). Variation in the timing of landscape change, and human response to these changes, highlights the need for continued examination of these issues to better

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understand the dynamic relationship between humans and the environment at this critical land–sea interface.

To gain a better understanding of the effects of the mid-Holocene drawdown on human populations in the Samoan Archipelago, we apply a geoarchaeological dataset to examine the prehistoric coastal dynamics on Ofu Island from island colonization to permanent settlement in the interior uplands c. 2700–900 B.P., a temporal span that coincides with regional sea-level and human settlement change. Although a preliminary sequence of coastal reconfiguration was proposed for the To'aga area on the south coast of Ofu by Kirch (1993*c*; see also Hunt and Kirch 1997), it has not been tested beyond To'aga nor explicitly linked to larger scale processes of human settlement on the island. Our study builds upon that previous work by examining the variability of coastal evolution on Ofu and comparing the Ofu sequence to regional processes of sea-level fluctuation (data that were unavailable to Kirch and Hunt 1993*b*). Of interest here is the temporal pattern of shoreline change and possible links to proposed sea-level crossover dates (Dickinson 2003). Expanding this model to include multiple coastlines allows an analysis of the correlation between human settlement change and landscape evolution. The results of this analysis demonstrate the importance of understanding the local variability of landscape evolution, even on small islands. Recognition of this variability contributes to our understanding of the human response to environmental change in the central Pacific.

The Socioecological Setting

The Samoan Archipelago is located in West Polynesia, roughly equidistant between Hawai'i (c. 4100 km to the NE) and New Zealand (c. 3500 km to the SW). The archipelago is separated into two political units, the Independent Nation of Samoa, consisting of 'Upolu, Savai'i, Manono, and Apolima islands, and the U.S. Territory of American Samoa, comprising the islands of Tutuila and Aunu'u in a western group, and Ofu, Olosega, and Ta'u (known collectively as the Manu'a Group) in the east (Fig. 1). The islands of the Manu'a Group are small, with Ta'u being the largest (39 km^2), followed by Ofu (7 km^2), and then Olosega (5 km^2).

Soils on Ofu can be classified as calcareous or terrigenous, reflecting their provenance. Calcareous soils, consisting of marine-derived sediments from offshore reef

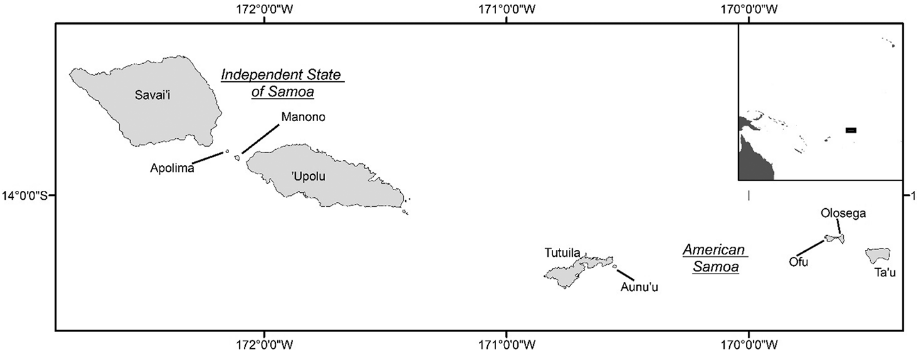

Fig. 1. The Samoan Archipelago.

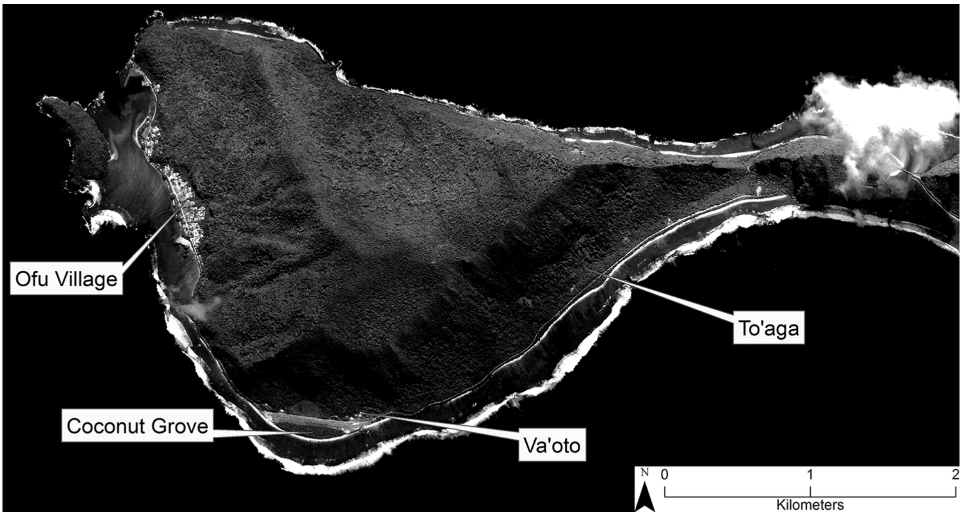

Fig. 2. Ofu Island with major coastal landmarks identified.

flats, are confined to the coast. Interior soils are weathered silty clays (Nakamura 1984), the result of the breakdown of volcanic materials. A mixture of calcareous and terrigenous soils is found at the interface between the inland slopes and the coastal plain.

A fringing reef skirts almost the entire island of Ofu, but is most developed off the southern and western coasts, where the widest coastal flats are found (Fig. 2). The To'aga and Va'oto coastal flats form the southern coast; access to the interior uplands from these locations is limited due to precipitous cliffs. The western coastal flat, where the bulk of the present population resides, is c. 1 km long and c. 200 m at its widest. Here, a fringing reef, with a width that ranges between c. 350 and 700 m, is protected by the small offshore islet of Nu'utele.

Archaeological Context

The cultural sequence of Ofu is reminiscent of many others in the region (Addison and Asaua 2006; Burley 1998; Clark 1996; Green 2002; Green and Davidson 1969, 1974; Jennings and Holmer 1980). Early settlement (pre-2500 cal B.P.) has been documented at To'aga on the southern coast (Kirch and Hunt 1993*b*) and at Va'oto and Ofu Village sites on the southern and western coasts, respectively (Clark 2011, 2013; Quintus 2015). Some questions regarding the chronology and process of island colonization remain (Addison and Morrison 2010; Rieth 2007; Rieth and Hunt 2008; Rieth et al. 2008; cf. Kirch 1993*b*), but recent dating of key deposits, including results presented in this article, indicate human habitation of Ofu prior to the sixth century B.C. and perhaps as early as the beginning of the eighth century. From colonization, settlement persisted on the coast through the first millennium B.C. and first millennium A.D.

Present evidence suggests that the interior uplands of the island were not permanently settled until the second millennium A.D. (Quintus 2015), although prior land use cannot be ruled out. The earliest earthen structural features in the interior—

terraces and ditches—have been dated to the eleventh and twelfth centuries A.D. in multiple locations. Further expansion is especially visible in surface features from the fifteenth century A.D. until sustained European contact after A.D. 1830.

Residential use of Ofu's southern coast in the second millennium A.D. appears to have been of a lower intensity relative to earlier occupation. Many features from the coastline dated to the second millennium A.D. are isolated subsurface combustion features (e.g., burn layers, fireplaces, earth ovens) implying a low level of occupation intensity.[1] Some cultural deposits or structural remains may date to this period (Hunt 1993), but few data are available to evaluate this. Most if not all of the cultural features present on the modern surface were built in the protohistoric period, between initial European contact in 1722 and 1830 A.D., when the To'aga coastal plain was the primary locus of settlement.

Dynamic Coastlines

Several sequences of coastal landscape evolution have now been documented in Polynesia based on both archaeological and geological data (Allen 1994, 1997, 1998; Clark 1989; Clark and Michlovic 1996; Dickinson 2001 : 205–207, 2003, 2014; Dickinson and Athens 2007; Dickinson and Burley 2007; Dickinson et al. 1994; Hunt and Kirch 1997; Nunn 2005). These landscape changes are, in part, attributed to Holocene sea-level fluctuations. Following early Holocene glacio-eustatic sea-level rise throughout the Pacific, sea level reached a mid-Holocene highstand of 1–3 m above modern levels (Dickinson 2001, 2003, 2009; Nunn 1995). Dickinson has argued that the highstand conditions were reached and persisted over different temporal spans throughout the region, partially the result of local tectonic conditions, with the termination of islands, and as recently as 1200 B.P. in the Tuamotu Archipelago (Dickinson 2003 : 494, table 1). Sea-level drawdown from the mid-Holocene highstand eventually reached a crossover point, wherein ambient high tide fell below the low tide of highstand conditions. Reaching this crossover point allowed for more significant sedimentation of previously submerged areas, as former shallow marine environments and palaeoreef flats became supratidal (Dickinson 2004). A crossover point was reached on most islands within the first millennium A.D., but the range extends into the second millennium A.D. on some islands, notably atolls (Dickinson 2003, 2009).

Estimations of the extent of the mid-Holocene highstand in the Samoan Archipelago have a range of approximately 1.5–2.6 m (Dickinson 2001 : 213, 2014 : 5; Dickinson and Green 1998 : 256; Mitrovica and Peltier 1991 : 20069, fig. 8j). These regional processes were augmented by local tectonic activities, resulting in variable relative sea-level fluctuation and landscape evolution. Late Holocene volcanism on Savai'i is posited to have resulted, and continues to result, in flexural subsidence and uplift (Dickinson and Green 1998 : 250–251; Keating 1992). The formation of Ta'u, the youngest island in the group at 100,000 years old (McDougall 2010), may have resulted in flexural subsidence of the Manu'a Group (Dickinson 2001 : 213–214; Kirch 1993*c*). Holocene volcanic activity occurred on Tutuila (Addison and Asaua 2006; Addison et al. 2006; Stice and McCoy 1968), but the impact of that activity on relative sea level is largely unknown.

On Savai'i and 'Upolu, a general process of subsidence has been suggested based on the submerged nature of the lone Lapita site in the archipelago (Mulifanua) as well as the stratigraphic location of peat deposits (Bloom 1980). It has been hypothesized that different rates of subsidence can be calculated for different locations on ʻUpolu, suggesting the process is variable (Dickinson 2007; Goodwin and Grossman 2003). This variation in rates of subsidence and the impacts on relative sea level may have manifested in different sequences of coastal evolution. Whereas former beach ridges such as Mulifanua on the west side of ʻUpolu have been submerged (Dickinson and Green 1998), other coastlines have prograded as much as 100 m in the last millennium (Goodwin and Grossman 2003 : 13; Matsushima et al. 1984; Sugimura et al. 1988). Nevertheless, this situation is hypothesized using a limited number of data points. Future research is necessary to further test these ideas.

As hypothesized by Dickinson and Green (1998 : 256), coastal dynamics are similarly complex on Tutuila Island between Savai'i and Ta'u, where flexural subsidence and flexural uplift may counteract each other. This may have resulted in the relative tectonic stability of the island since the mid-Holocene, allowing for the documentation of highstand conditions. Emergent notches on the island of Aunu'u and other areas of Tutuila suggest relative sea level was approximately 1.8 m above modern levels at the mid-Holocene highstand (Nunn 1997), with further fluctuations suggested to have occurred in the last 1000 years (Nunn 1995, 1998). Summarizing a large corpus of radiocarbon dates from across the island, Addison and Asaua (2006 : 98–100) argue that extensive coastal progradation, tied to drawdown from the mid-Holocene highstand, occurred in the middle to late first millennium A.D. The impacts of relative sea-level changes on Tutuila are most pronounced on the northeast coast in ʻAoa Valley. Joint archaeological and geomorphological investigations of subsurface deposits demonstrated that at the mid-Holocene highstand, the present valley was a backbarrier embayment or lagoon (Clark and Michlovic 1996). As drawdown from the mid-Holocene highstand proceeded and as human land use caused erosion of terrigenous sediment on to the coastal reef and developing lowlands, the embayment and later lagoon environments infilled. This created marshy and dry areas for cultivation and habitation. Further sea-level fluctuation, of as much as 0.83 m, might have occurred within the last 700 years (Clark and Michlovic 1996 : 155; Nunn 1994, 2007). Substantial terrigenous deposition and valley infilling continued over the last 1000 years across much of the island (Clark and Michlovic 1996; Pearl 2006).

Comparable with the above evidence, Kirch (1993*c*; see also Hunt and Kirch 1997) developed a "morphodynamic" model to explain the formation history of the To'aga coastal flat on Ofu Island, with posited causal links to glacio-eustatic sea-level fluctuation and local tectonic processes. According to the model, the sea abutted the volcanic mass of the island until about 5000 years ago, creating the steep cliffs (Stice and McCoy 1968). As sea level stabilized at the peak of the mid-Holocene highstand, small coastal terraces developed against the volcanic mass of the island. As sea level fell from the highstand and as the island continued to subside (Dickinson and Green 1998 : 256), progradation began as the sediment budget increased, the result of erosion of coral reefs and the interior slopes. The exact timing of the onset of these processes is unclear at To'aga, but landforms created by late Holocene progradation were occupied by humans in the middle to late first millennium A.D., probably marking landform stability (Kirch 1993*b* : 88–89).

The morphodynamic model of coastal evolution on Ofu was developed utilizing "current geological and geomorphological knowledge of coastal processes in the southwest Pacific" (Kirch 1993*c* : 39), which should ensure the applicability of the model across the landscape. These interpretations have never been explicitly tested at other locations on the island or archipelago and coastal dynamics have never been compared to an island-wide settlement chronology. Recent understanding of the variability of coastal evolution in the archipelago highlights the need to further examine the timing and magnitude of these processes to begin to address how human populations were affected by these environmental changes. It is from this point that this article builds on previous work completed on Ofu.

GEOMORPHOLOGY AND SETTLEMENT IN OFU VILLAGE

To address questions about the relationship between landscape change and human settlement, an integrated geomorphological and archaeological field study was conducted in modern Ofu Village on the western coast of the island. A total area of c. 16 m^2 was excavated with controlled units and backhoe trenches (Fig. 3). The project was limited by the density of modern occupation. Sampling strategies were geared toward identifying the chronology and distribution of intact deposits that mark landscape stability and cultural activity.

Four controlled excavation units (labeled with the prefix XU for excavation unit) were dug by trowel in 10 cm arbitrary spits (levels) within cultural strata (layers), while

Fig. 3. Subsurface excavations in Ofu Village.

three trenches were dug with a backhoe. After each excavation had been completed, stratigraphic profiles were drawn and photographed. Each layer was described, noting color, inclusions, texture, structure, and characteristics of the interface/boundary. Texture was determined in the field using the USDA soil texture flow chart in the soil survey manual (USDA 1993:63). For comparison across the coastal flats, all layers were tied to the astronomical low tide of modern sea level using publicly available 1 m Lidar data with 15 cm vertical accuracy. Landscape profiles of the coastal plain were also generated using these data. Charcoal samples were taken in situ for dating and point plotted in 3D space.

Analyses of sediments were completed at the University of Auckland Particle Analysis and Sedimentology Lab utilizing a Malvern Mastersizer 2000 Laser Diffraction particle analyzer. Sediment samples were collected from all layers of XU-3, XU-4, and T1, and six of seven layers from T3. In total, 30 sediment samples were analyzed. All samples were mechanically sieved through ¼-inch mesh to remove clastics with a size over -1Φ. Samples with high clay content were treated with a dispersal solution to remove iron oxides and organic materials that may have otherwise bound sediments. Sand samples were not treated with a dispersion solution, but they were analyzed through the inbuilt wet dispersion system. Representative samples of each layer were ensured by mixing sediments, either by vortex or mechanical shaking. Raw data were calibrated based on optical properties of the samples (e.g., estuarine sediments, beach carbonates) and the results of analysis were classified using the Udden-Wentworth scale (Table 1).

Controlled Excavation Units

XU-1: XU-1 was located near the northern boundary of Ofu Village at an elevation of 3.0 m above low tide (abbreviated "malt" henceforth), approximately 70 m from, and perpendicular to, the modern shoreline (Table 2; Figure 4). Calcareous sand constituted the majority of the matrix in seven of eight layers. At least some terrigenous sediments were identified in Layers I, II, IV, and VII. Layer VI was derived from colluvial erosion from the interior; its matrix included a high density of particulate charcoal, reflecting vegetation burning. This layer is thickest in the inland half of the unit and thins out toward the sea. The opposite pattern was created by the culturally sterile sand strata of Layers III and V, which formed tongues that thinned from seaward to inland, being absent from the inland wall. Additionally, unweathered coral clastics were identified in both layers. Layer VIII was culturally sterile. Based on a mean tidal range of 1.12 m (NOAA Nautical Charts), the interface of Layers VII and VIII at 0.90–1.0 malt is situated around the modern astronomical high tide mark.

XU-3: XU-3 was situated approximately 120 m from the present shoreline at an elevation of 2.9 malt (Table 3). The first six layers likely relate to modern house construction, representing multiple episodes of fill. The matrices of Layers VII and VIII consisted of a mix of calcareous sand and terrigenous clay, within which was a significant amount of coral. Informants suggested that the layers may be derived from wharf construction, as it is known that sediments excavated while dredging the wharf were deposited in the area for ground leveling. Layer IX exhibited a higher sand content than layers above and below, while the highest proportion of clay particles from the basal four layers was noted in Layer X. In fact, soil in the southern half of the inland wall shared characteristics with layers of colluvium in XU-1, XU-2, and XU-4.

TABLE 1. PARTICLE SIZE DISTRIBUTION OF SAMPLES FROM STRATA IN UNITS EXCAVATED IN OFU VILLAGE

	CLAY	VERY FINE SILT	FINE SILT	MEDIUM SILT	COARSE SILT	VERY FINE SAND	FINE SAND	MEDIUM SAND	COARSE SAND	VERY COARSE SAND
T1										
Layer I	0	0	0	0	0	0	6.7	42.7	42.1	8.3
Layer II	25.6	12.0	10.9	6.2	2.3	0.7	1.3	9.2	19.2	12.1
Layer III	2.3	1.5	1.5	1.27	1.3	1.5	4.1	21.3	40.6	24.1
Layer IV	39.3	16.4	17.2	13.9	7.8	1.9	0.1	0.5	1.7	0.8
Layer V	9.4	4.2	5.1	6.0	6.3	6.0	6.1	9.7	26.4	20.4
T3										
Layer I	0.1	0.3	0.2	0	0	0	6.0	36.2	43.6	13.4
Layer II	1.9	2.1	2.1	1.5	1.4	0.3	4.9	28.4	39.8	17.5
Layer III/V	26.8	8.2	7.5	5.5	3.6	3.3	14.7	23.2	7.1	0
Layer IV	1.6	0.8	0.7	0.1	0	0	10.7	56.0	29.8	0.3
Layer VI	2.8	1.4	1.1	0.6	1.2	0.1	10.3	50.1	30.6	1.7
Layer VII	0.3	0.3	0.3	0	0	0	6.7	47.7	39.8	4.8
XU-3										
Layer I	0	0	0	0	0	0	2.0	32.0	50.2	15.7
Layer II	0	0	0	0	0.9	0.7	9.2	47.2	38.3	3.6
Layer III	0	0	0	0	0	0	8.8	44.5	39.6	7.2
Layer IV	0	0	0	0	0	0	5.4	38.3	44.0	12.2
Layer V	0	0.3	0.6	0.6	1.2	2.0	9.5	37.4	38.3	10.2
Layer VI	0	0	0	0	0	0	5.6	36.8	44.5	13.1
Layer VII	1.6	2.2	2.4	2.1	1.9	1.9	9.4	29.4	34.4	14.7
Layer VIII	32.2	20.5	18.9	12.6	8.0	3.9	1.2	0.1	0.7	2.0
Layer IX	3.8	2.2	1.9	1.2	1.6	0.4	7.9	45.5	33.3	2.2
Layer X	0.3	0.6	0.9	1.4	2.9	7.2	22.3	38.3	22.2	3.4
Layer XI	1.2	0.6	0.6	0.1	0	0	7.5	53.2	35.7	1.1
Layer XII	0	0	0	0	0	0	5.6	51.4	40.4	2.5
XU-4										
Layer I	1.1	1.0	1.1	0.8	1.2	1.1	3.9	34.3	43.7	11.9
Layer II	3.7	3.7	4.1	3.6	3.2	2.1	4.4	24.8	35.9	14.5
Layer III	8.9	6.4	7.9	8.6	7.6	5.7	4.9	12.8	24.6	12.5
Layer IV	40.9	8.3	7.4	5.3	3.9	2.8	2.8	8.2	13.4	6.8
Layer V	18.2	8.6	10.3	9.8	7.2	4.1	3.2	9.5	18.3	10.8
Layer VIa	11.6	3.4	3.0	2.2	1.7	1.8	1.0	12.4	38.3	24.6
Layer VIb	9.6	2.2	2.1	1.4	0.5	0.8	0.1	6.3	43.3	33.7
Layer VIc	1.9	1.0	1.0	1.0	1.1	1.9	1.9	18.2	46.0	26.0
Layer VII	0	0	0	0	0	0	2.7	27.6	48.2	21.4

The final two layers were largely calcareous sand, featuring a decreasing terrigenous component with depth. Atop the culturally sterile basal layer were several coral boulders, all greater than 40 cm in length, suggestive of a high-energy depositional environment. Similar to XU-1, the interface between the culturally sterile Layer XII and the basal cultural deposit of Layer XI, at 1.0 malt, is located near the modern mean high tide elevation.

XU-2 and XU-4: The deepest and archaeologically most productive units in Ofu Village were identified near the base of the talus slopes (cf. Kirch and Hunt 1993*a* for To'aga). XU-2 and XU-4, c. 145 m and c. 165 m from the modern shoreline and

TABLE 2. STRATIGRAPHIC DESCRIPTIONS OF XU-1. METERS ABOVE LOW TIDE (MALT) MEASURED FROM THE LOWEST POINT OF EACH LAYER

	THICKNESS	COLOR	TEXTURE	STRUCTURE	CLASTICS (% OF TOTAL MATRIX)	RELATIONSHIP WITH LOW TIDE	CULTURAL MATERIAL
I	35–45 cm	10 YR 4/3 (brown)	Loamy sand	Granular	<5% sub-rounded coral and stone gravel	2.50 malt	Historic
II	20–35 cm	10 YR 3/2 (very dark brown)	Loamy sand	Granular	<5% sub-rounded coral and stone gravel	2.10 malt	Historic
III	0–25 cm	10 YR 5/4 (yellowish brown)	Sand	Granular	5–10% sub-rounded to sub-angular coral and stone gravel	2.05 malt	Sterile
IV	15–35 cm	10 YR 4/2 (dark grayish brown	Loamy sand	Granular	10–15% sub-rounded to angular coral and stone gravel and cobbles	1.85 malt	Prehistoric
V	0–40 cm	10 YR 6/3 (pale brown)	Sand	Granular	<5% angular and unweathered coral	1.50 malt	Sterile
VI	15–55 cm	5 YR 3/2 (dark reddish brown)	Sandy clay	Sub-angular blocky	15–20% rounded to sub-rounded coral and stone gravel	1.20 malt	Prehistoric
VII	20–50 cm	10 YR 5/4 (yellowish brown)	Loamy sand	Granular	<5% sub-rounded coral and stone gravel	0.90–1.0 malt	Prehistoric
VIII	uncertain	10 YR 7/3 (very pale brown)	Sand	Granular	5–10% rounded to sub-rounded coral and stone gravel and cobbles	n/a	Sterile

3.0 malt and 3.6 malt in elevation, respectively, featured similar stratigraphic sequences (Table 4). XU-2 was situated in a natural depression, wherein the surrounding landscape was 20–30 cm higher; the unit was terminated for reasons of safety prior to the exposure of a sterile sand layer. The following sequence describes the top five layers of both units, but the bottom two layers are representative of XU-4 (Fig. 5).

The first two or three layers were remnants of historic land use. The third layer may date to the end of the prehistoric sequence, but this is unclear. The fourth layer was colluvium, deposited on the coast from the slopes immediately inland. A feature was

Fig. 4. South wall of XU-1 illustrating Layers II–VII and identifying storm, colluvial, and cultural layers. Charcoal from Layer VII dated to cal A.D. 1408–1452 (2σ).

noted in Layer IV of XU-4, likely related to the burning of an in situ tree stump. Layer V was much darker than Layer IV, but in both cases sub-rounded coral gravel inclusions and particulate charcoal was common. Layer V was comparable to anthropogenic soils of other islands in the region in that it was formed by the mixture of terrigenous sediments eroded from inland slopes with calcareous sand, coral, and organic refuse from former occupations (Kirch 1988 : 38–41; Kirch and Yen 1982; Rogers 1974 : 312). These characteristics, specifically dark color and evidence of mixing, are consistent with the layer representing a garden soil (A_p horizon). Calcareous sand content increases with depth below Layer V of XU-4 resulting in three sublayers of Layer VI. The sublayers were defined by decreasing clay content with depth, suggesting increased erosion from the interior and redeposition in the coastal lowlands over time. Layer VII was coarse- to very coarse-grained sand that was culturally sterile reflecting a presettlement condition. The interface between Layers VI and VII is situated well below the modern mean high tide mark, located only 30–40 cm above modern low tide.

Backhoe Trenches

Trench 1 and Trench 2: T1 and T2 were excavated to the south and north of XU-4, located 4.5 malt and 2.6 malt, respectively (Table 5). The top layer of each represents fill associated with the households presently in each area. In T1, the two subsequent layers, one a sandy loam with coral inclusions and the other a layer of coral gravel, also appeared to represent historic construction. In both trenches, the bottom two layers were different from basal layers identified elsewhere. Layer IV of T1 and Layer II of T2 were loamy clays, each similar in texture but different in color from surrounding volcanic soils on adjacent slopes. This layer was much darker, suggestive of a higher organic content. The basal layer of each was saprolitic clay with numerous clasts of various sizes and stages of decay. No additional soil strata or bedrock were identified

Table 3. Stratigraphic Descriptions of XU-3. Meters above Low Tide (Malt) Measured from the Lowest Point of Each Layer

	thickness	color	texture	structure	clastics (% of total matrix)	relationship with low tide	cultural material
I	0–5 cm	10 YR 7/2 (light gray)	Sand	Structureless	<5% sub-rounded coral gravel	2.80 malt	Historic
II	5–10 cm	10 YR 1/1 (black)	Sandy loam	Granular	<5% sub-rounded coral and stone gravel	2.70 malt	Historic
III	10–15 cm	10 YR 4/3 (dark brown)	Sand	Granular	<5% sub-rounded coral and stone gravel	2.60 malt	Historic
IV	0–5 cm	10 YR 5/3 (brown)	Sand	Granular	<5% sub-rounded coral and stone gravel	2.50 malt	Historic
V	10–15 cm	10 YR 3/2 (very dark graysih brown)	Coral	Structureless	80–90% rounded to sub-rounded coral gravel	2.40 malt	Historic
VI	10–15 cm	10 YR 8/4 (very pale brown)	Sand	Structureless	<5% sub-rounded coral and stone gravel	2.30 malt	Historic
VII	10–20 cm	10 YR 2/2 (very dark brown)	Loamy sand	Granular	35–40% sub-rounded to sub-angular coral gravel and cobbles	2.20 malt	Historic
VIII	15–30 cm	10 YR 3/3 (dark brown)	Silty clay loam	Granular	30–35% sub-rounded to sub-angular coral gravel and cobbles	1.90 malt	Historic
IX	5–20 cm	10 YR 3/3 (dark brown)	Loamy sand	Granular	15–20% sub-rounded coral gravel	1.60 malt	Prehistoric
X	30–40 cm	10 YR 3/3 (dark brown)	Sandy loam	Granular	20–30% rounded to sub-angular coral and stone gravel and cobbles	1.30 malt	Prehistoric
XI	15–40 cm	10 YR 4/4 (dark yellowish brown)	Sand	Granular	5–10% sub-rounded coral and stone gravel	0.95–1.05 malt	Prehistoric
XII	Uncertain	10 YR 6/5 (light yellowish brown)	Sand	Structureless	10–15% rounded to sub-rounded coral and stone gravel and large cobbles	n/a	Sterile

Table 4. Stratigraphic Descriptions of XU-2 and XU-4. Meters above Low Tide (Malt) Measured from the Lowest Point of Each Layer

	THICKNESS	COLOR	TEXTURE	STRUCTURE	CLASTICS (% OF TOTAL MATRIX)	RELATIONSHIP WITH LOW TIDE	CULTURAL MATERIAL
XU-2							
I	15–20 cm	Heterogeneous	Sand	Granular	5–10% sub-rounded coral and stone gravel	2.70 malt	Historic
II	5–15 cm	10 YR 7/6 (yellow)	Sand	Granular	<5% sub-rounded coral gravel	2.60 malt	Historic
III	10–15 cm	10 YR 2/2 (very dark brown)	Loam	Sub-angular blocky	15–20% sub-rounded coral and stone gravel	2.40 malt	Historic
IV	80–95 cm	5 YR 3/2 (dark reddish brown)	Clay	Sub-angular blocky	20–30% rounded to sub-angular coral and stone gravel and cobbles	1.65 malt	Prehistoric
V	25–45 cm	10 YR 2/2 (very dark brown)	Loam	Sub-angular blocky	15–20% sub-rounded coral and stone gravel	1.25 malt	Prehistoric
VI	Uncertain	7.5 R 3/4 (dusky red)	Loamy sand	Granular	10–15% sub-rounded coral and stone gravel	n/a	Prehistoric
XU-4							
I	35–50 cm	10 YR 3/3 (dark brown)	Sand	Granular	5–10% sub-rounded coral and stone gravel; stone boulder	3.10 malt	Historic
II	10–35 cm	5 YR 3/3 (dark reddish brown)	Sandy loam	Sub-angular blocky	5–10% sub-rounded coral and stone gravel; stone boulder	2.75 malt	Historic
III	0–25 cm	10 YR 2/2 (very dark brown)	Loam	Sub-angular blocky	15–20% sub-rounded coral and stone gravel; stone boulder	2.70 malt	Historic
IV	50–60 cm	5 YR 3/2 (dark reddish brown)	Clay	Sub-angular blocky	20–30% sub-rounded to angular coral and stone gravel and cobbles	2.15 malt	Prehistoric
V	30–50 cm	10 YR 2/2 (very dark brown)	Loam	Sub-angular blocky	10–15% sub-rounded coral and stone gravel and cobbles	1.75 malt	Prehistoric
VI	100–145 cm	7.5 YR 3/4 (dusky red)	Loamy sand	Granular	10–15% sub-rounded to angular coral and stone gravel and cobbles	0.40 malt	Prehistoric
VII	Uncertain	10 YR 7/3 (pale brown)	Sand	Structureless	5–10% sub-rounded coral and stone gravel and cobbles; one coral boulder	n/a	Sterile

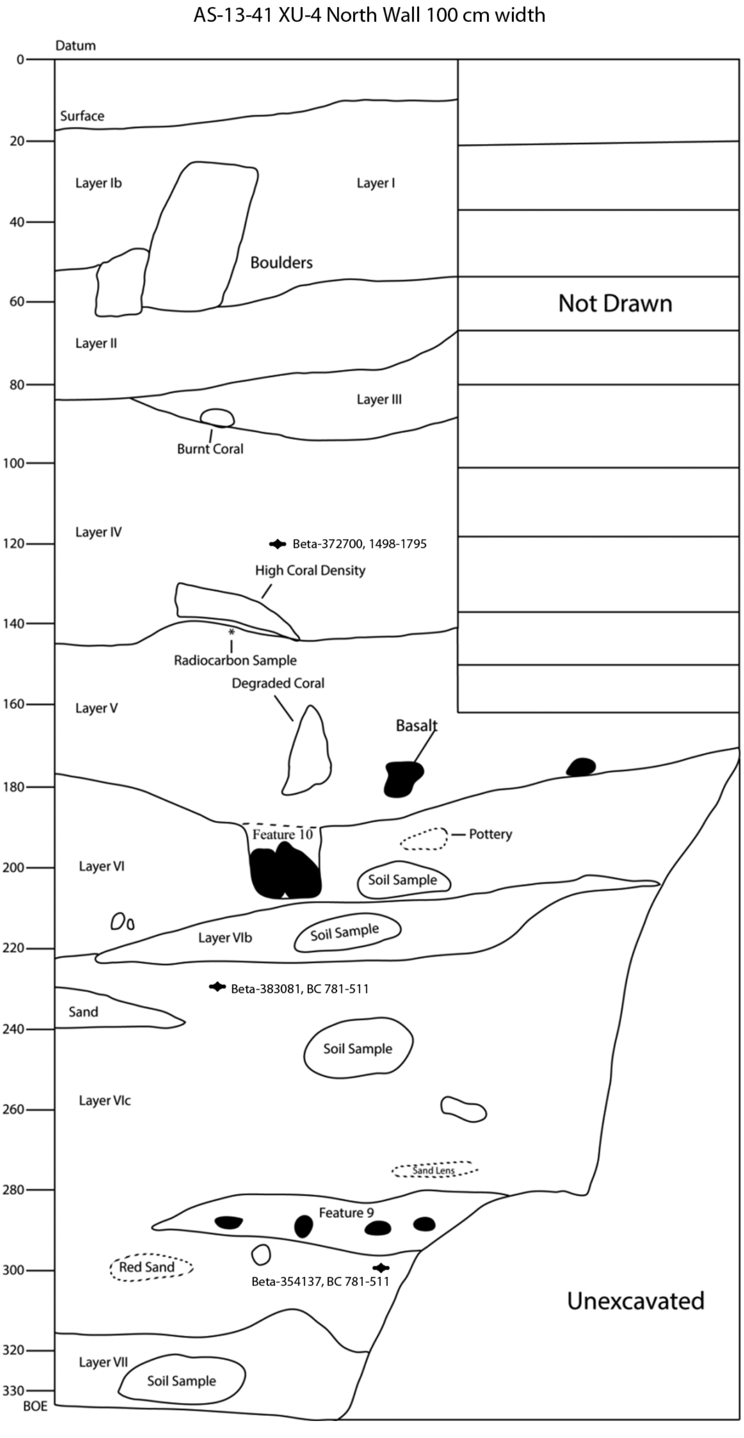

Fig. 5. Profiled section of the north wall of XU-4. Faunal remains were recovered in all layers, but were most common in Layer VIa–c. Basalt artifacts were recovered from Layers V–VI. In situ volcanic glass and ceramics were identified in Layer VIa–c. Radiocarbon ages are quoted as 2σ.

Table 5. Stratigraphic Descriptions of T1 and T2. Meters above Low Tide (Malt) Measured from Lowest Point of Each Layer

	THICKNESS	COLOR	TEXTURE	STRUCTURE	CLASTICS (% OF TOTAL MATRIX)	RELATIONSHIP WITH LOW TIDE
T1						
I	35–40 cm	10 YR 6/3 (Pale brown)	Sand	Structureless	<5% rounded to sub-rounded coral pebbles and gravel	4.1 malt
II	10–15 cm	10 YR 4/2 (Dark grayish brown)	Sandy loam	Granular	15–20% sub-rounded coral gravel	3.95 malt
III	5–10 cm	Coral gravel	Coral	Structureless	90–99% rounded to sub-rounded coral gravel	3.85 malt
IV	20–70 cm	10 YR 3/2 (very dark grayish brown)	Clay loam	Sub-angular blocky	20–25% sub-rounded coral and stone gravel	3.15 malt
V	Uncertain	5 YR 3/3 (dark reddish brown)	Clay	Angular blocky	15–20% sub-rounded to angular stone gravel and cobbles	n/a
T2						
I	50–70 cm	Heterogeneous	Sand	Structureless to Granular	20–25% sub-rounded coral gravel	1.9 malt
II	10–60 cm	10 YR 3/1 (very dark gray)	Clay loam	Granular	15–20% sub-rounded coral gravel	1.4 malt
III	Uncertain	5 YR 3/3 (dark reddish brown)	Clay	Angular blocky	10–15% sub-rounded to angular coral and stone gravel and cobbles	n/a

below this layer prior to unit termination. Given this, the layer may be an in situ C-horizon or deep pseudo C-horizon of colluvial materials eroded from the interior slopes (landslide).

Trench 3: T3 was the most seaward trench excavation, 85 m from the present beach and at an elevation of 2.3 malt (Table 6). The top layer was historic sand fill. The second layer was similar to Layer III in XU-2 and XU-4, defined as a dark clay loam with coral gravel and a high organic content. The third and fifth layers were colluvium, similar to Layer IV in XU-1, Layer IV in XU-2 and XU-4, and parts of Layer X in XU-3. Significant charcoal flecking was observed in both layers. Layer IV was a sand layer that separated the colluvial layers, displaying characteristics (i.e., color) comparable to beach or dune sand. Layer VI was loamy sand in which a thin combustion feature was noted, which may be related to cooking. Layer VII was only uncovered in the eastern half of the trench, with large (30–40 cm in length) coral boulders

Table 6. Stratigraphic Description of T3. Meters above Low Tide (Malt) Measured from the Lowest Point of Each Layer

	THICKNESS	COLOR	TEXTURE	STRUCTURE	CLASTICS (% OF TOTAL MATRIX)	RELATIONSHIP WITH LOW TIDE
I	30–40 cm	10 YR 5/3 (brown)	Sand	Structureless	<5% sub-rounded coral gravel	1.95 malt
II	15–30 cm	10 YR 3/1 (very dark gray)	Clay loam	Granular	10–15% sub-rounded coral pebbles and gravel	1.70 malt
III	30–40 cm	10 YR 3/4 (dark yellowish brown)	Clay loam	Blocky	5–10% sub-rounded coral gravel	1.40 malt
IV	5–10 cm	10 YR 4/3 (brown)	Sand	Structureless	<5% sub-rounded coral gravel	1.35 malt
V	5–15 cm	10 YR 3/4 (dark yellowish brown)	Clay loam	Blocky	<5% sub-rounded coral gravel	1.25 malt
VI	30–40 cm	10 YR 4/2 (dark grayish brown)	Loamy sand	Granular	<5% sub-rounded coral pebbles and gravel	0.85–0.95 malt
VII	Uncertain	10 YR 5/3 (brown)	Sand	Structureless	<5% sub-rounded coral gravel	n/a

identified just below Layer VI in the seaward half of the unit. Such clastics could mark a high-energy depositional environment.

SUMMARY OF ARCHAEOLOGY

Analysis of materials recovered from Ofu Village is ongoing. A preliminary summary can be provided illustrating important vertical and horizontal patterns within the area, which may aid in understanding the variation in the archaeological record across the coastal flat. This discussion will be restricted to controlled excavation units for which cultural material was collected (Fig. 6).

Historic artifacts were present in all units. Glass, metal, and plastic speak to modern village activities in the area. No historic-era diagnostic artifacts such as bottles or buttons were recovered in excavation. Faunal remains from historic layers were limited, consisting of mammal bone, notably pig (*Sus scofa*), fish bone, and shellfish.

Basalt flakes were the most ubiquitous prehistoric artifact type recovered. Thirteen basalt artifacts were recovered from XU-1 (Layers IV, VI, and VII), twenty-four from XU-3 (Layers IX, X, and XI), one from XU-2 (Layer V), and twenty-six from XU-4 (Layers IV, V, and VI). Most of these artifacts were small flakes (<3 cm in length), some exhibiting polish indicative of adze rejuvenation or retooling. Only a few formal tools such as adzes or scrapers were recovered, all from XU-4. A grinding stone (*fo'aga*) was also recovered from Layer VI of XU-4.

Shell artifacts have a more limited distribution, found only in XU-1 and XU-4. A single unfinished fishhook made of *Turbo* was collected from XU-1, while a larger

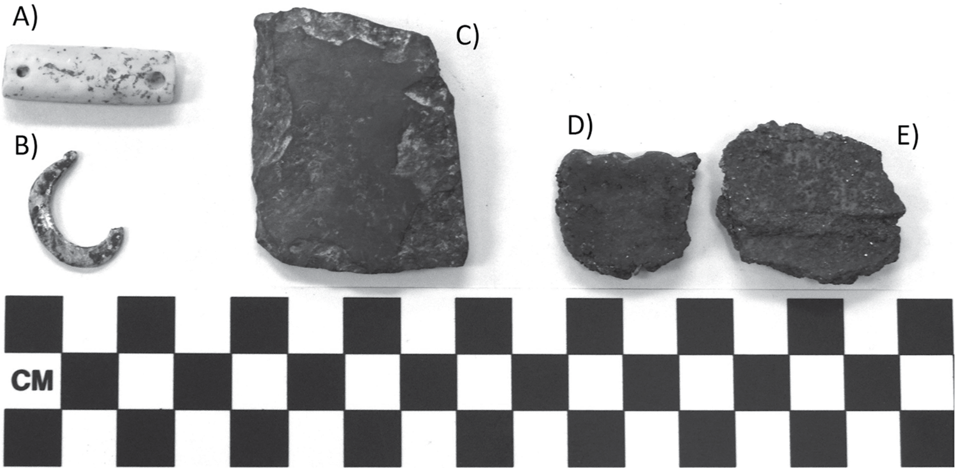

Fig. 6. Select artifacts from Ofu Village, XU-4, Layer VI: A) shell ornament, B) *Turbo* fishhook, C) adze, D) notched ceramic rim, E) ceramic sherd with red slip and surface decoration.

assemblage of shell beads, fishhooks, and modified shell was recovered from XU-4. Of particular interest, a total of four fragmented *Turbo*-shell fishhooks were recovered from XU-4 Layers V and VI.

Volcanic glass flakes and ceramics were only found in XU-4. Ceramics were identified in Layers IV, V, and VI, but the small quantity and eroded nature of these artifacts in Layers IV and V imply that they were in secondary context. In situ ceramics and volcanic glass were recovered from Layer VI, largely from sublayer VIc; the assemblage consisted of over 700 ceramic sherds and 100 volcanic glass pieces (flakes, cores, fragments). All volcanic glass artifacts are small (<2 cm in length) and fairly homogenous as an assemblage. Analysis of ceramics is under way, but preliminary examination of sherds indicates the presence of calcareous temper and some surface decoration (i.e., rim notching, red slips), but no dentate stamping.

Subsurface features were rare. Thin (<10 cm thick) cooking features were present in Layers IV and VII of XU-1, Layer VI of T3, and Layer VIc of XU-4. All of these were defined by abundant charcoal and fire-cracked rock. Possible postholes were identified in wall profiles of XU-1 (Layer VI) and XU-4 (Layer V), but no other remains indicative of permanent prehistoric structures were noted.

Since faunal analysis is still ongoing, only preliminary statements can be made regarding the bearing of faunal evidence on this study. In conjunction with the distribution of material culture, the faunal assemblage from Layer VI of XU-4 is the largest identified in Ofu Village. This faunal assemblage is largely constituted of shellfish—mostly *Turbo*, *Tridacna*, and *Trochus*—with sea urchin and fishbone also represented. Human bone was recorded at the bottom of the layer, though an intact burial was not located and all bones were reinterred. As of yet, no unambiguous dog or pig bone has been identified from the ceramic-bearing deposit. Qualitatively similar faunal assemblages were identified in all other excavated units, but the density of such remains appears to have been significantly lower. For instance, the shellfish assemblage from XU-1 with a weight of 3.8 kg from all prehistoric layers is a fraction of that reported for ceramic-bearing deposits elsewhere on the island (Nagaoka 1993).

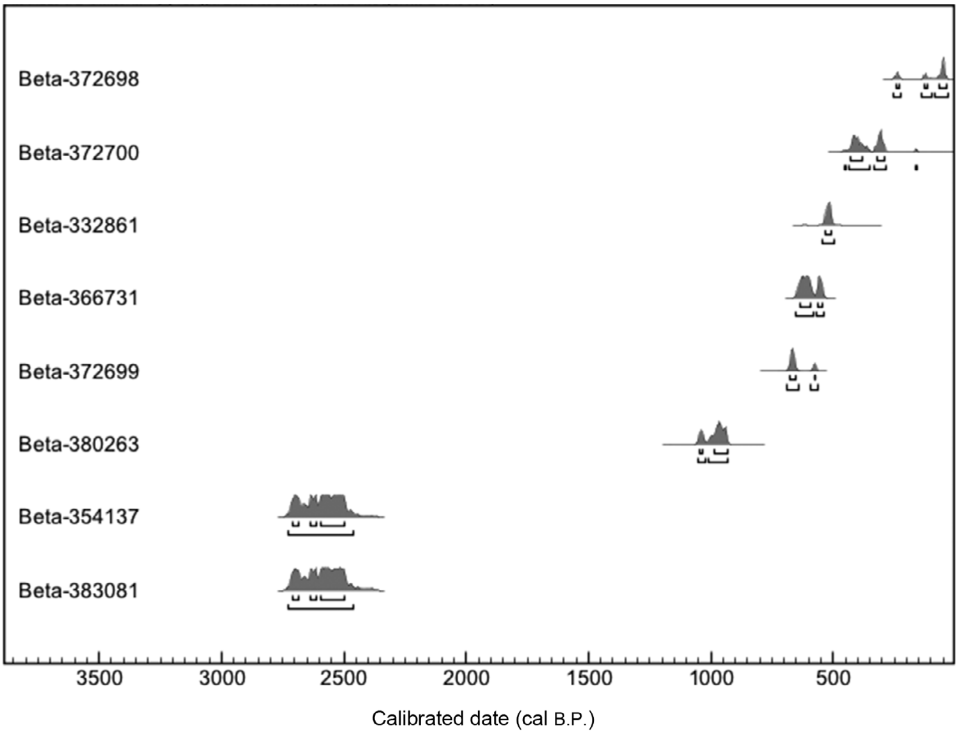

Fig. 7. Radiocarbon calibration results of eight determinations from Ofu Village. Source: OxCal v4.2.3 (Bronk Ramsey 2013); r:5 IntCal13 atmospheric curve (Reimer et al. 2013).

Chronology

Eight charcoal samples were dated from five units (Figs. 7 and 8; Table 7); all were identified by Jennifer Huebert (University of Auckland). Short-lived materials were sought for dating, but economic plants were selected to provide an age for the use of these plants when no short-lived materials were available. The radiocarbon determinations were calibrated in OxCal 4.2 (Bronk Ramsey 2009) using the IntCal13 atmospheric curve (Reimer et al. 2013).

Three determinations from two units dated prior to the second millennium A.D. Two dates from XU-4 Layer VIc calibrate at two sigma between 781 and 511 cal B.C. (Beta-354137 and Beta-383081), one vertically above the other (separated by 75 cm) (Fig. 8). While indistinguishable in radiocarbon terms, these two dates do not originate from the same piece of coconut endocarp and it is likely that the lower date originates from a small fire feature (Feature 9 in Fig. 5). The third determination, from the transition between Layers V and VI in XU-2, dates to the end of the first millennium A.D. (Beta-380263; 2σ cal A.D. 895–1021).

All other samples postdate the twelfth century A.D. The earliest of these was from the base of Layer XI of XU-3, close to the interface with sterile sand of Layer XII, interpreted to date the onset of cultural activity in this area (Beta-372699, 2σ cal A.D. 1261–1387). The next two determinations are fairly consistent, dating T3 and XU-1, respectively (Beta-366731, 2σ cal A.D. 1299–1413; Beta-332861, 2σ cal A.D. 1408–1452). The charcoal sample from XU-1 was taken from the basal cultural layer, above

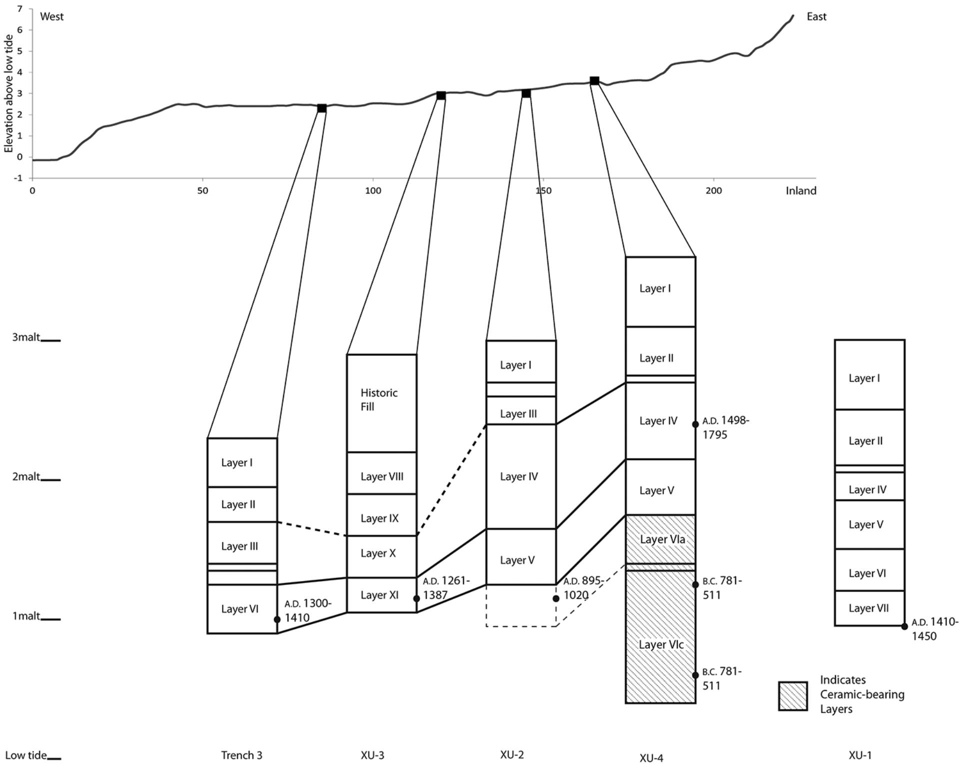

Fig. 8. Profile view of dated deposits in Ofu Village plotted along an inland-sea transect. XU-1 was not located within this transect. Solid line represents a confident correlation, and a dashed line represents a preliminary correlation (malt = meters above low tide). Basalt artifacts were recovered in XU-1 (Layers IV, VI, VII), XU-3 (Layers X, XI), XU-2 (Layer V), and XU-4 (Layers IV–VI). Calibrated radiocarbon determinations at 2σ.

culturally sterile Layer VIII. Excavation of T3 was terminated prior to the positive identification of a sterile layer. However, similarities in particle size and color between the basal layer of XU-3 (Layer XII) and Layer VII of T3 suggest that Layer VII represents a sterile sand layer. These three post–twelfth century A.D. basal cultural deposits are consistently located between 0.9 and 1.0 m above the modern low tide mark.

The single sample dated from a colluvial deposit, a piece of carbonized tree root from Layer IV of XU-4 (Beta-372700, 2σ cal A.D. 1498–1795), suggests the layer was deposited in the sixteenth century A.D. or later. That the determinations from T3 and XU-1 are from layers beneath colluvium implies that deposition of colluvium occurred across the entire coastline in the fifteenth century A.D. or later. The layer of colluvium in XU-1 is capped by a deposit within which was found only traditional artifacts, bolstering our interpretation that the layer was deposited in the prehistoric period.

A SEQUENCE OF GEOMORPHOLOGICAL CHANGE IN OFU VILLAGE

Based on the distribution of dated units in Ofu Village, only a small coastal terrace had formed by the time of initial human colonization, in the eighth to sixth centuries B.C.

Table 7. Summary Information of Radiocarbon Determinations from Ofu Village

SAMPLE NUMBER	UNIT	LAYER	DEPTH	MATERIAL	δ13C	CONVENTIONAL DATE	CALENDAR DATES (2σ)	CONTEXT
Beta-332861	XU-1	VII	206 BD	Small-diameter wood	−28.3	480 ± 30	A.D. 1408–1452	Below cooking feature
Beta-380263	XU-2	VI	190 BD	*Cocos nucifera* wood	−25.8	1070 ± 30	A.D. 895–1021	In situ point-plotted charcoal
Beta-372699	XU-3	XI	174 BD	Rubiaceae, cf. *Tarenna*	−23.5	700 ± 30	A.D. 1261–1387	In situ point-plotted charcoal
Beta-354137	XU-4	VI	301 BD	*Cocos nucifera* endocarp	−23.0	2490 ± 30	781–511 B.C.	In situ point-plotted charcoal below feature
Beta-383081	XU-4	VI	226 BD	*Cocos nucifera* endocarp	−23.4	2490 ± 30	781–511 B.C.	In situ point-plotted charcoal
Beta-372700	XU-4	IV	120 BD	Unidentified small tree root	−26.1	280 ± 30	A.D. 1498–1795	From feature
Beta-372698	Trench 2	II	93 BS	*Cocos nucifera* wood	−25.5	30 ± 30	A.D. 1695–1919	In situ point-plotted charcoal
Beta-366731	Trench 3	VI	133 BS	*Artocarpus altilis* wood	−24.8	590 ± 30	A.D. 1299–1413	From feature

No archaeological deposit other than Layer VI of XU-2 and XU-4 dates prior to the second millennium A.D. (Fig. 8). While approximate, the spatial distribution of dated basal deposits, combined with similarities between XU-4 and XU-2, implies that the palaeoshoreline was positioned inland of or near XU-3. The two determinations from Layer VIc of XU-4 are indistinguishable, even though they are vertically separated by 70 cm, indicating either rapid and significant coastal aggradation shortly after human colonization or sediment mixing within a loose sand matrix. We find the former more likely given the presence of an intact cultural feature in the layer (Feature 9 in Fig. 5).

After the deposition of Layer VIc of XU-4, the proportion of terrigenous sediments (clay and silt particles) increased, documented through Layers VIb and VIa (Fig. 9). It is unclear whether there was also a decrease in the deposition of calcareous sediment, although this seems likely given the time period represented by the two layers (up to 1500 years) in comparison to Layer VIc.

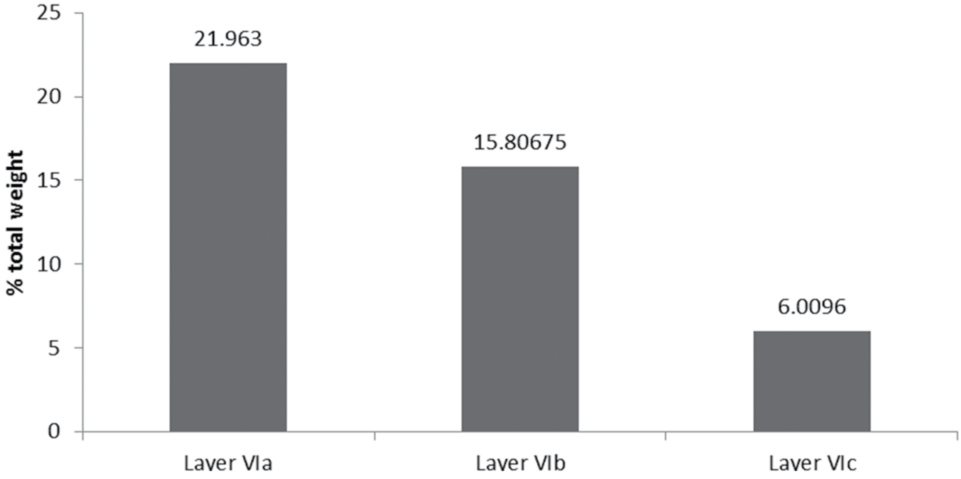

Fig. 9. Changing frequency of silt and clay particles in the sublayers of Layer VI in XU-4 reflecting increased terrigenous deposition onto the coastal flats.

Layer V is an organic-rich loam similar to anthropogenic garden soils found elsewhere in the region. The formation of this surface points to relative geomorphological stability for vegetation growth. The lack of calcareous deposition in this area at this time might be evidence of reduced coastal marine sediment transport, although some eolian sedimentation likely still occurred. The best explanation for this increased landform stabilization and decreased calcareous deposition is the movement of the shoreline seaward from XU-2 and XU-4. We posit that the date from the interface between Layer V and Layer VI of XU-2 (Beta-380263; 2σ cal A.D. 895–1021) provides a minimum age (*terminus ante quem*) for the progradation of the shoreline.

A process of shoreline progradation is supported by radiocarbon dates (basal cultural deposits in XU-1, XU-3, and T3) from areas seaward of XU-2 showing first use of that land in and after the thirteenth century A.D. The consistency in chronology and elevation of these basal deposits, all located between 0.9 and 1.0 m above modern low tide (Fig. 8), is suggestive of a process of progradation and eventual landform stabilization on the west coast that made available a wide stretch of land in the relatively short time span of 100–200 years. Multiple storm intrusions have been recorded in the seaward-most units (T3, Layer IV; XU-1, Layers III and V) and terrigenous deposition, over a meter thick in some areas, occurred in the fifteenth century A.D. or later (XU-1, Layer VI; XU-2 and XU-4 Layer IV; XU-3, Layer X; T3, Layers III and V). A likely source of those terrigenous deposits would be erosional sediments from the inland slopes, perhaps triggered by the clearing of vegetation for cultivation. Given the degree of late-prehistoric and early-historic deposition, most, if not all, archaeological surface features on the coastline probably date to the historic or protohistoric period.

Comparisons within To'aga

The sequence of coastal evolution documented in Ofu Village is broadly consistent with that identified at To'aga, although some chronological differences are apparent.

On both coasts, initial human habitation was restricted to narrow coastal plains abutting talus slopes at the base of the uplands. The continued deposition of marine sediments in ceramic-bearing deposits—Layer VIc of XU-4 in Ofu Village and layers in several units at To'aga such as Unit 15 of Transect 5 and Layers II, III, IV, and V of the Main Trench (Kirch and Hunt 1993*a*: 56, 64–66)—indicates that areas of human habitation were proximal to the shoreline.

The timing of changes in the rate of calcareous sedimentation and the formation of stable beach ridges is still not well understood. At To'aga, a decrease in the deposition of marine sediments and the formation of palaeosols were posited to have occurred at the beginning of the first millennium A.D. (Kirch and Hunt 1993*a*: 56, 67, 78). The precise chronology of beach ridge stabilization and the relationships between different units across the coastline is yet to be assessed. A stable beach ridge may have developed in Ofu Village in the area around XU-2 and XU-4 in the first millennium A.D., reflected by Layers VIa and VIb, but this is unclear; more precise chronological data are unavailable.

As discussed above, the formation of Layer V in XU-2 and XU-4, of Ofu Village implies a more stable land surface and a reduction in marine-transported calcareous sand, providing a *terminus ante quem* for beach ridge stability. Additionally, we interpret such a situation as providing a minimum date for the movement of the shoreline prior to the ninth through eleventh centuries A.D. The progradation of the shoreline during marine regression is also evidenced by the formation of cultural deposits in hypothesized previously submerged areas. Progradation may have begun earlier along the southern coast at To'aga or resulted in landform stability earlier, as human use of landforms created by progradation appears to have occurred by the sixth through tenth centuries A.D. (Kirch 1993*b*: 88–89; Rieth and Addison 2008: 93).

What these differences indicate is that island-wide coastal evolution on Ofu was not uniformly rapid, illustrating that the influence of local topographic factors on shorelines may have been important. Nevertheless, detailing to what extent Nu'utele Island (just offshore of a section of Ofu Village), for example, affected progradation rates is not feasible without additional data. Even when considering this variability, the western and southern coasts represent a shared process. Most ceramic-bearing deposits—which date from initial settlement to perhaps the middle of the first millennium A.D.—at Ofu Village and To'aga are located 100–150 m from the present shoreline. This pattern, coupled with the timing of land use seaward of ceramic deposits, is best explained by an island-wide process of shoreline progradation and marine regression. Based on the proxy measure of reduced calcareous sedimentation in back-beach areas and archaeological evidence in previously submerged areas, landscape change appears most marked in the middle to late first millennium A.D.

While several other factors (e.g., human-induced sedimentation, local wave and current activity) likely contributed to progradation on Ofu, our data set aligns with the sea-level change model originally posited by Kirch (1993*c*; Hunt and Kirch 1997). The documentation of processes of progradation at several spots on the same island as well as on different islands in the archipelago (Addison and Asaua 2006; Clark and Michlovic 1996; Goodwin and Grossman 2003) and region more generally (Allen 1998; Dickinson and Burley 2007; Nunn 2005) speak to factors beyond local topographic and sediment situations, specifically sea-level change.

Coastal reconfiguration on Ofu may be correlated with the proposed date of sea-level crossover for the Fiji-Tonga-Samoa region c. 500 A.D. (Dickinson 2003: 256), wherein ambient high tide fell below mid-Holocene low tide conditions. The proposition that extensive progradation, especially in Ofu Village, may not have occurred until slightly after this crossover point, and after coastal progradation on Tutuila (Addison and Asaua 2006), might be explained by subsidence of Ofu Island. Subsidence has not been demonstrated by geological measures, but the location of prehistoric cultural deposits in relation to modern sea level has been used as evidence for subsidence by Dickinson and Burley (2007) for Vava'u, Tonga, and by Kirch and Hunt (1993*a*: 68) for Ofu. Evidence consistent with the findings of Kirch and Hunt on Ofu is found at Ofu Village: Layer VIc of XU-4 lies 30–40 cm above modern low tide levels (Fig. 8). If subsidence was not occurring, the deposit would have been at least 1.5–2.5 m below high water at the time of the mid-Holocene highstand. It is unlikely that the population was using stilt house technology given the lack of documented postholes. Given the presence of an intact combustion feature, it is also unlikely that the layer was submerged when it was deposited. Such a situation is also reflected in the vertical location of the basal deposits in XU-1, XU-3, and T3. Without subsidence, and given that sea level reached near its modern level 1000 years ago, these layers would be located in the intertidal zone, but this is not supported by the archaeological record of intact cultural features.

Landscape Change and Human Settlement Patterns

Generally, the intensity of coastal residential occupation declined at the beginning of the second millennium A.D., contrary to what would be expected for an expanding terrestrial landscape. This inference is based on the lack of archaeological material associated with most, if not all, post–1500 cal B.P. deposits (Hunt and Erkelens 1993; Kirch 1993*a*; Nagaoka 1993; Quintus 2015). For instance, the total artifact assemblage of XU-1 (basalt = 13; shell = 1) and XU-3 (basalt = 24) of Ofu Village is significantly smaller than that of the single ceramic-bearing deposit of XU-4 (ceramics > 700; volcanic glass = 100; basalt = 22; shell > 10). Similarly, the shell faunal assemblage of the lone unit quantified in Ofu Village is far less than a single layer in one unit of the ceramic-bearing Va'oto site on the southwest tip of Ofu—compare 3.8 kg from XU-1 (post–1400 A.D.) to 14.2 kg in one layer of one unit in Va'oto (Layer IV of 37E/9N; 2200–2400 B.P.).[2]

At the same time, in the eleventh and twelfth centuries A.D., earthen modifications such as terraces and ditches began to be constructed in the interior of the island (Quintus 2015). Although previous land use likely occurred there, as demonstrated by erosion caused in part by vegetation clearance recorded in coastal deposits, the construction of these earthen structures is the first evidence of permanent habitation. The earliest dates from the interior are chronologically situated between the date from the top of Layer VIa in XU-2 (Beta-380263, 2σ cal A.D. 895–1021) and the initial human use of landforms constructed by coastal progradation on the western coast as seen in XU-1, XU-3, and T3 (Beta-372699, 2σ cal A.D. 1261–1387; Beta-366731, 2σ cal A.D. 1299–1413; Beta-332861, 2σ cal A.D. 1408–1452) (Fig. 10).

In this context, even if habitation and gardening of the coastline persisted into the second millennium A.D., settlement expansion into the interior uplands cannot be accounted for by simple population growth. Permanent expansion of habitation into the uplands is better explained by a model that incorporates the influence of coastal landscape evolution. The magnitude of change along the coastal flats of the island led

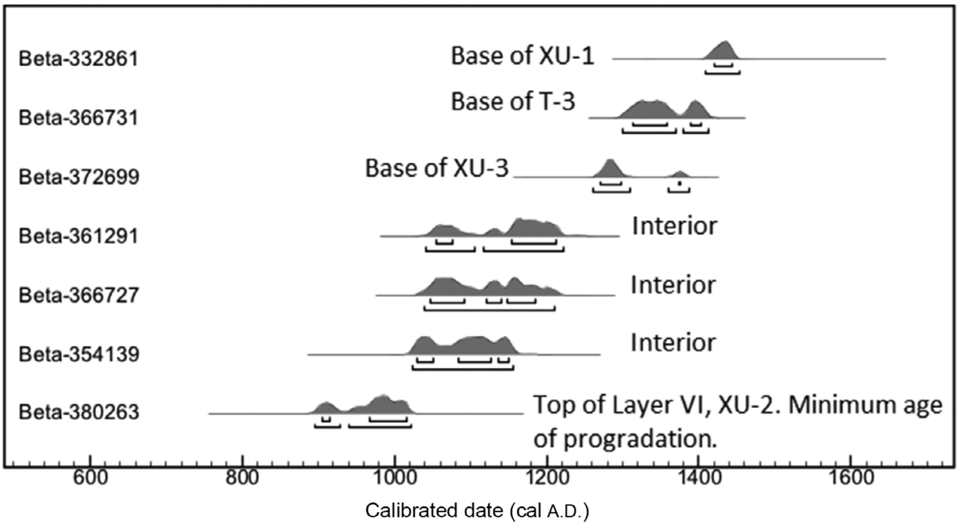

Fig. 10. Correlation between the construction of permanent modifications in the interior and coastal landscape change. Source data: Quintus 2015; OxCal v4.2.3 (Bronk Ramsey 2013); r:5 IntCal13 atmospheric curve (Reimer et al. 2013).

to an increase in available arable land and a decrease in shallow marine environments. This certainly does not preclude the continued and significant use of marine resources by human populations, but increased food acquisition via terrestrial production was enabled by the expansion of arable land in the back-beach areas of the coastal flats, signified by the creation of anthropogenic and highly edaphic soils (Kirch and Hunt 1993*b*; Layer V of XU-2 and XU-4). Cultivation in these zones is documented by the end of the first millennium A.D. or beginning of the second millennium A.D. Expansion into the interior may have been part of a general process of increased terrestrial exploitation as the size of marine environments declined and as geomorphological instability continued on the coastal flats. Additional research and analyses of faunal remains is necessary to assess the impact of landscape change on marine ecosystems.

DISCUSSION AND CONCLUSIONS

The productivity of marine environments made coastal landscapes attractive locations for initial human settlement in the Pacific. It is now well documented that these landscapes are highly dynamic, that the present configurations of these environments do not reflect the prehistoric situation, and that archaeological evidence is useful for understanding sequences of coastal landscape change. The situation detailed here provides further evidence of the dynamism of individual island coastlines over the period of human occupation. The geomorphological sequence on the coast of Ofu is comparable to those found elsewhere, notably for Moturiki in Fiji (Nunn et al. 2007 : 101) and Tonga (Dickinson 2014 : 5–6; Dickinson and Burley 2007), where marine regression and landform progradation resulted in a lateral expansion of human land use over time. As previous authors have argued and is now well documented, drawdown from the mid-Holocene sea-level highstand had dramatic effects on coastal environments throughout the Pacific. However, the extent to which these effects influenced human populations, and the variation of human response to environmental change, remains to be addressed in many parts of the region.

Sea-level fall created additional lands for human use throughout the Pacific (Dickinson 2003; Nunn 2007). The migration of human groups into East Polynesia is temporally correlated with the mid-Holocene sea-level drawdown (Dickinson 2003). Terrestrial landscapes expanded within the western Pacific, including West Polynesia, as well (Dickinson 2001, 2003, 2014). Archaeological sites representing colonization-era settlement are commonly situated 100–300 m from the present shoreline. Several researchers have explained this situation as the result of shoreline progradation and argue that most early settlements were positioned atop beach ridges adjacent to the palaeoshoreline (Carson 2011, 2012, 2014; Dickinson 2014; Dickinson and Burley 2007; Dickinson et al. 1994; Nunn 2005; Nunn et al. 2007). Expansion of this extent resulted in the expansion of coastal settlements, typified by the situation documented for Ritidian, Guam (Carson 2012). Expanded coastlines became valuable agricultural landscapes, as freshwater marshes suitable for the cultivation of *Colocasia esculenta* formed through valley infilling after marine regression (Allen 1998; Clark and Michlovic 1996; Kirch and Yen 1982). Landscape evolution reduced the amount of exploitable reef, however, which had been a valuable resource for human populations since island colonization. Shallow marine environments were reduced by as much as 50 percent on Niuatoputapu (Kirch 1988 : 248), a process Dickinson and colleagues (1999 : 698) correlate with drawdown from the mid-Holocene highstand. A similar situation was identified in Tikpoia, where landscape evolution tied to sea-level drawdown, both from the mid-Holocene highstand and possible later episodes (Nunn 2007 : 109–112), caused a 41 percent reduction in exploitable reef area (Kirch 2007 : 89).

On Ofu, too, coastal evolution created opportunities and, presumably, constraints to settlement and subsistence. The lone ceramic-bearing deposit in Ofu Village, indicative of c. pre–1500 cal B.P. occupation, is inland of what appears to be a paleobeach ridge marking the approximate location of the paleoshoreline (see position of XU-4 in Figure 8). The stabilization of back-beach areas and reduction of storm wash after progradation had commenced was particularly important for gardening activities, evidenced in the formation of Layer V in XU-2 and XU-4. The process seen on Ofu appears analogous to edaphic soil development elsewhere in the region (Kirch 1988; Kirch and Yen 1982). Negative impacts of sea-level fluctuation and shoreline progradation can also be posited but not empirically demonstrated for Ofu. Similar to Niuatoputapu and Tikopia, the progradation of the shoreline may have buried or infilled adjacent shallow marine environments. Landscape evolution on Ofu extended the shoreline 100–150 m along some points of the west coast. If we assume that this extension buried previously shallow marine environments and not intertidal mud flats, this constituted a c. 25 percent reduction in shallow marine environments. This value is certainly heuristic and subject to continued empirical testing, but it does illustrate the magnitude of landscape change on the small island of Ofu.

Correlated with changes to the coastal environment of Ofu was the expansion of human settlement into the interior uplands of the island. This pattern is in contrast to situations elsewhere where landscape stability was correlated with and likely enabled the growth of coastal residential sites (Carson 2012). The coastal flats on Ofu continued to be used for terrestrial production and marine resource acquisition, but the primary locus of human habitation shifted from coast to interior. Even though correlation is not causation, the temporal consistency of these patterns hints that landscape evolution was at least one factor in human decisions to modify their settlement patterns and begin using the interior uplands more intensively.

The chronological data of inland settlement reported here are not fully in sync with some sequences of coastal–inland movement recorded elsewhere in Fiji–West Polynesia (Field 2003:300–307, 2004:92–93; Nunn 2012; Pearl 2004, 2006), though possibly similar to others (Kirch 1988:250). Temporal variability implies that human movement into upland locations in the region was not a shared process. Many of the above cited population movements are posited to be associated with an "A.D. 1300 event" (Nunn 2000:732–733, 2007:117–119, 2012:17; Pearl 2004, 2006), but the situation on Ofu cannot be explained by possible climatic changes during the transition between the Medieval Climatic Optimum and Little Ice Age. This temporal variability, though slight, signifies that no one factor can explain all examples of the movement of human population into interior upland areas documented in the region.

Human response to changing environmental conditions was as dynamic and variable as the changing coastal landscape itself. A particular response to environmental change is dictated by the local magnitude of the change as well as by local cultural history. The variation in the manifestation of mid-Holocene highstand conditions and the relative uniqueness of regional cultural sequences demonstrate that neither was constant in the region, so we should not expect shared patterns of human response to environmental and landscape change. The continued recognition and appreciation of this variation, based on case studies such as the one described here, allow us to better understand human resilience and adaptation to changing environmental conditions.

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NOTES

1. Based on unpublished data held in site files at the archaeology offices of the American Samoa Power Authority (ASPA).
2. Based on unpublished data held at North Dakota State University, collected by the authors and analyzed in 2014.

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ABSTRACT

This study summarizes the impacts of geomorphological processes on human settlement strategies on the island of Ofu in the Samoan Archipelago from island colonization to permanent settlement in the interior uplands (c. 2700–900 B.P.). Previous archaeological research on Ofu has documented a dynamic coastal landscape at one location, To'aga, on the southern coast. Using a new geoarchaeological data set, our study extends this assessment to a site on the western coast of the island. We conclude that although the sequence of coastal evolution is broadly consistent between the two areas there are also differences indicating that island-wide coastal evolution did not progress everywhere at the same rate. Using this data set, we record changes in human settlement patterns temporally correlated with coastal progradation—perhaps related to continued drawdown from the mid-Holocene sea-level highstand—and sediment aggradation. We suggest that coastal landscape change on Ofu may have been one factor in the expansion of the terrestrial component of the human subsistence base and the more intensive use of the interior uplands of the island. The timing of this settlement change was slightly earlier than elsewhere in the region, demonstrating the variability of human response to regional-scale environmental changes. KEYWORDS: coastal geomorphology, settlement pattern, geoarchaeology, Samoa, Polynesia.