Geophysical and Geoarchaeological Investigations at Aganoa Beach, American Samoa: An Early Archaeological Site in Western Polynesia

Frederic B. Pearl[1],* and William A. Sauck[2]

[1] Maritime Studies Program, Texas A&M University Galveston, Galveston, Texas
[2] Department of Geosciences, Western Michigan University, Kalamazoo, Michigan

Correspondence
*Corresponding author;
E-mail: pearlf@tamug.edu

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Archaeological investigations at Aganoa, a coastal site in American Samoa, western Polynesia, revealed a marine resources exploitation base for the early inhabitants of the island. A series of 19 radiocarbon age determinations indicates the principal period of site utilization began no later than 570 B.C., and probably earlier, and lasted for about 300 years. This site is squarely in the phase identified by previous scholars as "ancestral Polynesian." Geophysical survey in the form of long, shore-perpendicular transects showed the accretionary history of this beach and ridge area. Surprisingly, it revealed that the earlier ridges were directly below the modern ridge (i.e., progradation of this geomorphic feature had not occurred). The survey revealed a buried paleosol with little or no disturbance, which yielded a well-preserved assemblage of plain and decorated ceramics, stone artifacts, fishhooks, and archaeofauna. No evidence of archaeological continuity was seen between the end of the terminal Lapita occupation and the later reoccupation of the site after about A.D. 700. This study demonstrates the utility and feasibility of using ground-penetrating radar for the discovery of deeply buried coastal sites. © 2014 Wiley Periodicals, Inc.

INTRODUCTION

The predominant model of Polynesian cultural development posits that Polynesian culture developed in western Polynesia after settlement by Lapita colonists in about 3000 cal. yr B.P. (Green, 1981; Kirch, 1984, 1997; Kirch & Green, 1987). Indeed, Ancestral Polynesian Society is defined as the culture that emerged from the Late eastern Lapita as it climaxed and was subsequently isolated from the West (Kirch, 1984; Kirch & Green, 2001). In this model, the transformation from Lapita to Polynesian was complete by about 1000 cal. yr B.P., when the Polynesians began their great exploration and migration into the vast uninhabited expanses of the Pacific Ocean. The gap in oceanic exploration that stretches between the discovery of western Polynesia by Lapita seafarers and the renewal of exploration by the Polynesians is commonly referred to as "the long pause" (Irwin, 1992), and is occupied by the ancestral Polynesian archaeological phase.

Recently, however, Smith (2002) has argued that evidence of Polynesian culture as we know it does not appear in the archaeological record of western Polynesia until around 1000 cal. yr B.P., well after eastern Polynesia had been settled. Thus, in her view, no part of the period between 3000 and 1000 cal. yr B.P. should be referred to as ancestral Polynesian. However, the mechanism by which Polynesian culture came to western Polynesia is not specified, and if true, we are back to "square one" so to speak, as to determining the origins of Polynesian culture. Archaeologists take this new view seriously and the two competing models will have to be reconciled at some point.

Unfortunately, because very few sites of this period have been studied, little is empirically known about the ancestors in western Polynesia. This paucity of archaeological data makes it difficult to adequately evaluate the models strictly on the basis of the archaeological record. Without a more complete early archaeological record in western Polynesia, it is not possible to know the true relationship between the west and east Polynesian cultures.

For these reasons, a recently discovered archaeological site known to have a well-preserved early Samoa archaeological component was selected for further study. The site, Aganoa (AS-22-43) on Tutuila, American Samoa, had been discovered and tested during a 1990's utilities improvement project (Moore & Kennedy, 2003). Archaeologists excavated a limited number of test excavation units and determined that the site consisted of buried features, decorated ceramics, fishhooks, stone tools, and flaking debris, and other artifacts. The toolkit had a distinctly "early" look to it, and radiocarbon dating (*ca.* 760–630 B.C.) confirmed its antiquity.

We planned the archaeological investigation with four major goals:

1. Fix the site in time by reconstructing the cultural and geological chronology of Aganoa through extensive geoarchaeological and geophysical investigations accompanied by radiocarbon dating of archaeological samples;
2. Document the extent and structure of an early (3000–2000 ^{14}C yr B.P.) residential area;
3. Characterize the social organization and household economies of Aganoa through analyses of the residential features and material culture recovered through excavation;
4. Evaluate the effectiveness of remote-sensing techniques for paleoenvironmental reconstruction and archaeological prospection in shoreline sediments.

We believed that an investigation directed toward these aims would, in turn, make possible a further consideration of ancestral Polynesia. The principle investigators along with Texas A&M University students, faculty, and Samoan volunteers, spent June and July 2007 on the site of Aganoa conducting archaeological excavations and geophysical survey over a wide area. This paper reports the cultural and geological chronology of Aganoa and describes the methods used to obtain and interpret the data.

SITE MORPHOLOGY AND GEOLOGIC CONTEXT

The volcanism that forms the Samoan chain is quite complex due to the interaction between the Samoan plume and the subducting Tonga plate (Stearns, 1944; Natland, 1980, 2003; Hart et al., 2004). Tutuila, the island upon whose eastern shore the site of Aganoa is located (Figure 1), is a typical high basaltic island of the Samoan group, consisting of a number of coalesced volcanic episodes and substantial post-erosional deposition. Its coastline is generally rugged and steep due to the high erosion rate, although its southeastern coastal plain is predominated by late Quaternary deposition. Large parts of the shoreline are occupied by fringing reefs, with a flat coral breccia platform extending to the beach. The beach is steep and consists largely of sands of coral and shell origin. At some locations, beach rock, or coquina, is exposed below the modern beach sands. There are various eruptive centers on the island, as well as a rather young vent that forms the island of Aunu'u, about 2 km offshore from Aganoa.

The Aganoa site occupies a semicircular reentrant into the steep coastline (Figure 1). Morphologically, this embayment is very different from most, in that the coastline does not take a concave shape. Rather, both the fringing reef and the shoreline are convex, or protrude out into the ocean. The site is bounded on the interior by a concave dike, rising steeply to a height of 120 m above sea level. The dike surrounds the site, and at one time reached unimpeded to the sea on both the eastern and western ends of the area, creating the small embayment (possibly a remnant eruptive center). These seaward extensions act as groins, trapping sand that is otherwise moved by littoral drift. The shoreward edges of the geologic feature were blasted away during the construction of a coastal road in the 1940s as part of the U.S. Navy's effort to defend the island in World War II (Kennedy, Bevan, & Elmore, 2005). One consequence of the road construction has been the stabilization of some late Quaternary sediments deposited upslope of the road along the southern coastline of Tutuila. This is particularly noticeable on the southeastern coast, between Aganoa and Tula, where late Quaternary sediments are thickest.

The beach profile can be divided into a number of zones, each with its own diagnostic characteristics. Sedimentary characteristics are generally thought of as being products of the driving forces (especially waves and currents), and the offshore lithology. At Aganoa, a fringing reef and offshore sand banks provide a continuous supply of new and recycled marine sands. Under a hypothetical equilibrium condition, wave energy decreases as it moves up the beach face, depositing larger entrained sediments near shore and on the lower foreshore, and leaving progressively finer sands at the top of the foreshore, at the limit of the swash zone. However, under real-life dynamic conditions the foreshore is constantly reworked, and high-energy storm surges propel some coarse sediments to the backshore. As sea level falls, the entire beach profile advances shoreward (beach progradation). This migration brings about the overlap of landward over shoreward deposits. Holding sediment supply and climate constant, this results in an upward fining sequence when

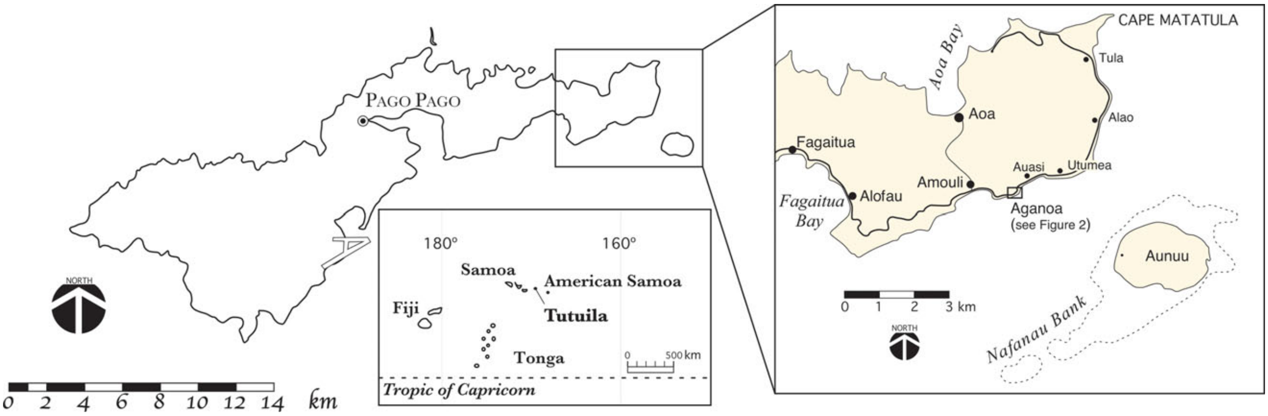

Figure 1 Tutuila, American Samoa in relation to West Polynesia, with inset of site area in eastern Tutuila.

seen in a vertical profile (i.e., low-energy berm/mixed-energy backshore/high-energy foreshore).

Modern houses at Aganoa Village are on the topographically highest part of the site, occupying a low linear beach berm (Figure 2). Behind the berm (to the north) is the backshore, a lower area of dark organic soils extending to the base of the basalt cliffs, creating catchments for both storm wash (over the berm) and alluvium from the mountainside. Presently this area is in the agricultural production of coconut, breadfruit, papaya, and banana.

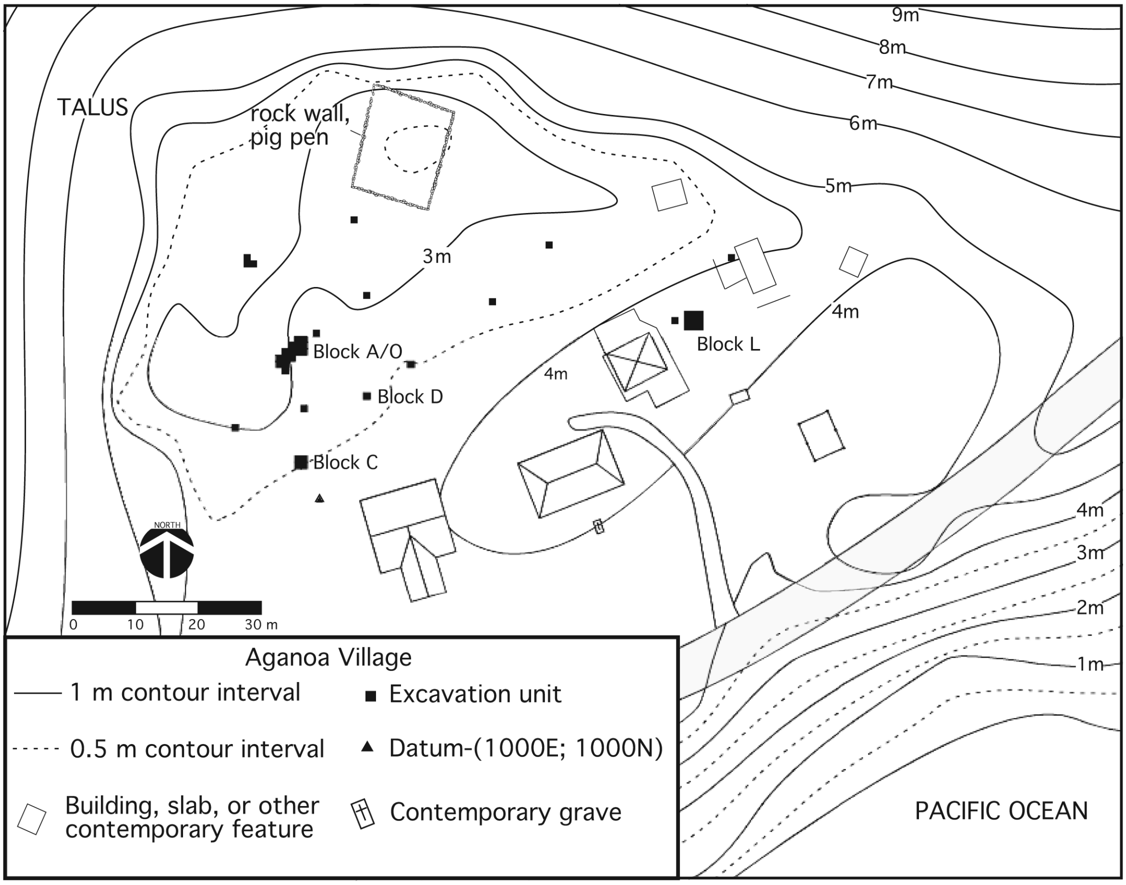

Figure 2 Aganoa (AS-22-43) topography, major buildings, and excavation areas.

The geologic model initially used to explore for buried living surfaces was based on the presumption that the shoreline and parallel features such as the beach berm have prograded with time (i.e., migrated seaward). With this assumption one might hypothesize that the paleoridge or topographic high that was occupied several millennia ago would be found inland of the present-day ridge. The location of the artifact scatters described by Moore and Kennedy (2003) support this idea as well. Their testing suggested that the site, however, did not extend more than 50 m from the modern beach ridge, leaving about 150 m of culturally sterile deposits between the site and the valley wall.

Intensive investigations by Kirch and Hunt at To'aga, on neighboring Ofu Island, revealed that the archaeological deposits containing early pottery were restricted to the inside edge of the coastal terrace; that is, to the rear edge of the coastal plain (Hunt & Kirch, 1997). They argue that in ecological settings that have experienced sea level fall, early ceramic sites will be encountered at the rear of coastal plains and valleys, possibly buried in colluvium, as was the case at To'aga. Indeed, this has been a common theme in Lapita research—due to sea level fall, Lapita sites are commonly found inland along paleoshorelines (Kirch & Hunt, 1993; Clark & Michlovic, 1996; Hunt & Kirch, 1997; Dickinson, 2003, 2014)—and has been a consideration of archaeologists working in Samoa since the 1980s. This also was important for our initial model of Aganoa: we hypothesized that the oldest deposits there might also be found at the rear of the valley, having escaped notice by archaeologists due to burial in colluvium.

METHODS

A key goal of the current project was to determine the natural formation processes that have shaped the site in the late Holocene, and to determine its geochronology. Geoarchaeological investigations were carried out concurrently with archaeological excavations. Commonly in archaeology, excavation units serve as the principle means of observing the subsurface geology of an archaeological site. At Aganoa we used both geophysical methods and standard field descriptions of the sediment profiles exposed in the excavation units to interpret subsurface geology. Further descriptive analyses were carried out in the Coastal Geology Laboratory at Texas A&M University at Galveston.

The geochronology was determined through radiocarbon assay and stratigraphic correlation among sedimentary profiles. Nineteen samples were selected from key stratigraphic contexts for radiocarbon dating. When possible, wood charcoal samples were identified to species before they were submitted for dating. Other samples were unidentifiable, but their key stratigraphic position made their ages key to reconstructing the site chronology. All of the identifiable woods were from relatively short-lived species and it is probable that other samples are from similar species. Generally speaking, "old" wood is not considered a significant problem in American Samoa since the site and its environs were not forested by old growth trees. Moreover, high precipitation in American Samoa (in contrast to the dry leeward areas of Hawaii's islands) decreases the probability that wood preserves for very long.

Samples were submitted to Beta Analytic, Inc., where standard pretreatments were performed prior to radiometric or AMS analyses. Each sample was corrected for isotopic variations (fractionation) by the radiocarbon facility. For interpretive purposes, the conventional radiocarbon ages were calibrated with the OxCal 4.2.2 radiocarbon calibration software (Bronk Ramsey, 1995, 2001), using the INTCAL09 atmospheric carbon curve for calibration (Reimer et al., 2009).[1]

Large-scale spatial data (especially topographic data, excavation unit locations, and geophysical survey transects) were collected with a Nokia DTM-332 Total Station, while fine-scale measurements were often taken by tape measure from a local datum. Site maps were made in the field and compared with maps from the previous excavation in order to locate old test units and site boundaries. We placed our 1 × 1 m excavation units, 43 in all, to avoid intersection with previously disturbed areas, and to maximize the sample across the site area. Some excavation units were placed beyond the previously determined site boundaries. For organizational purposes, excavation units were assigned "blocks" so that groups of contiguous units could be referred to together. Due to our concern with finding deeply buried Lapita materials, all excavation units were excavated a minimum of 20 cm to 1 m below the last cultural find, with an additional shovel probe extending to a half-meter or more beneath the last excavation level. Each team of excavators collected geological data during excavation, and the project geoarchaeologist (F. Pearl) recorded additional details at the completion of the excavated block. A key goal of our research was to

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[1] The SHCAL04 database (McCormac et al., 2004) was not used because (a) pre-industrial calibration records are not currently available for low latitudes in the southern hemisphere; (b) variances in the Intertropical Convergence Zone (ITCZ) that comprises the definition of the hemispheric transition in the SHCAL04 database cause additional uncertainty in the tropics; and (c) in any case, the location of the paleo-ITCZ is not known. Consequently, the much better-documented decadal INTCAL09 curve was used here. However, several scenarios using mixed calibration curves are explored in the Discussion.

test the utility of magnetometer and ground-penetrating radar (GPR) for coastal archaeological studies in Samoa, as it has been for continental research (Conyers, 2004).

Geophysical data were collected intensively over a two-week period. We used both a magnetometer (Geometrics G-856 Cesium Vapor Gradiometer, operated in the mapping mode) and a GPR (RAMAC XM3 with 500 MHz antennae operated with a scan time of 100 nanoseconds). Postprocessing was done with the RADAN package. Velocity calibration was achieved by driving a 1.5 m length of rebar horizontally into the sandy wall of one of the open excavation pits at 1.25 m depth and making several GPR profiles over it. This procedure provided a radio wave velocity of 0.089 m/ns, corresponding to a relative permittivity of 11.4.

The backshore target area was quite densely vegetated and required considerable clearing effort to open even a 3 × 5 m clearing. On the main part of the site, standing architecture provided a considerable inconvenience. Thus, only small blocks covering proposed excavation units were initially surveyed with GPR in a manner suitable for creating 3D displays, with 0.5 m line separations. Later, long survey transects were completed from the road to the base of the steep cliffs behind the plantation. These long lines proved to be the key to understanding the accretionary history of this site.

Unfortunately, magnetometry did not prove to be that helpful from an archaeological standpoint. Even though we had excellent equipment with a gradiometer, subsurface basalts that might have been part of house foundations or other structural alignments were not distinguishable. This is probably due to the tremendous background magnetism of the island and its volcanic sediments. However, a profile along the shoreline was surveyed in an attempt to locate subsurface extensions of the dikes visible north of the road. This profile did show an anomaly over the southern projection of the dike at the eastern side of the site. Relative to a commonly used depth estimator, this anomaly seemed to lay 4.7 m below the surface.

GPR proved much more helpful. The only major limitations were that buried salty sediments toward the ocean and the fine-grained sediments of the backshore had relatively poor penetration, most likely due to the increased conductivity of the salty and/or saturated sediments. No other major problems were encountered.

RESULTS OF GEOPHYSICAL EXPLORATION

The long GPR profiles extending from the road, across the modern berm, and through the backshore and colluvial sediments revealed the true subsurface structure, or accretional history, of the site. They showed clearly that the original exploration model, assuming prograding shoreline features, was incorrect. Rather, the ancient back-beach ridge or berm is located almost directly *below* the modern berm, along or slightly to the north of the row of modern houses (Figure 3). Additionally, one of these profiles crossed a strong reflector about 5 m in extent. When draped beneath the topography, this reflector became nearly horizontal, and was interpreted as a flat floor surface at about 1.5 m below the surface. The left half of this profile also shows imbricate progradational or accretionary structures to depths as great as 3 m (*cf.* Buynevich, Jol, & Fitzgerald, 2009). The continuation of the profile to the right (north-northwest) shows increasing attenuation in the fine-grained colluvial facies. Transverse profiles across the floor feature revealed a similar dimension in the east–west direction, defining a floor of approximately 5 × 5 m. Finally, a 5 × 6 m GPR grid, with a line spacing of 0.25 m and lines in both the north–south and east–west directions, was surveyed over the anomalous feature interpreted as an ancient floor. This was processed and displayed directly on the RAMAC field console using the XV11 program to generate slices at every centimeter of depth (Figure 3). This slice, which is just above the strongly reflective floor, shows reflective objects whose alignments appear to define some diagonally oriented rectilinear structures.

As a result of the GPR discovery and mapping of this feature, an initial 1 × 1 m excavation unit was dug to the target depth of 1.5 m. This excavation revealed a compacted floor of ash, charcoal, coral and basalt gravels, decorated ceramics, numerous tools of shell and basalt, and thousands of ecofacts (mostly faunal remains related to marine resource foraging, Figure 4). The verification of this feature as an occupation surface with *in situ* cultural remains led to the concentration of effort by the entire crew in opening a 3 × 3 m excavation block to a depth of more than 1.7 m (plus deeper shovel probes). Block L produced thousands of artifacts, including many datable samples.

GEOCHRONOLOGY OF AGANOA

Sediments at Aganoa are divided into two categories based on their origins. Over 99% of the sediments within the site boundaries are coral sands of marine origin. Less than 1% are terrestrial clastic sediments, ranging from basalt boulders to clays. Terrestrial sediments were generally restricted to the top 0 to 40 cm, and then only in the zone behind (north) of the modern linear berm. The terrestrial sediments are thickest at the back of the

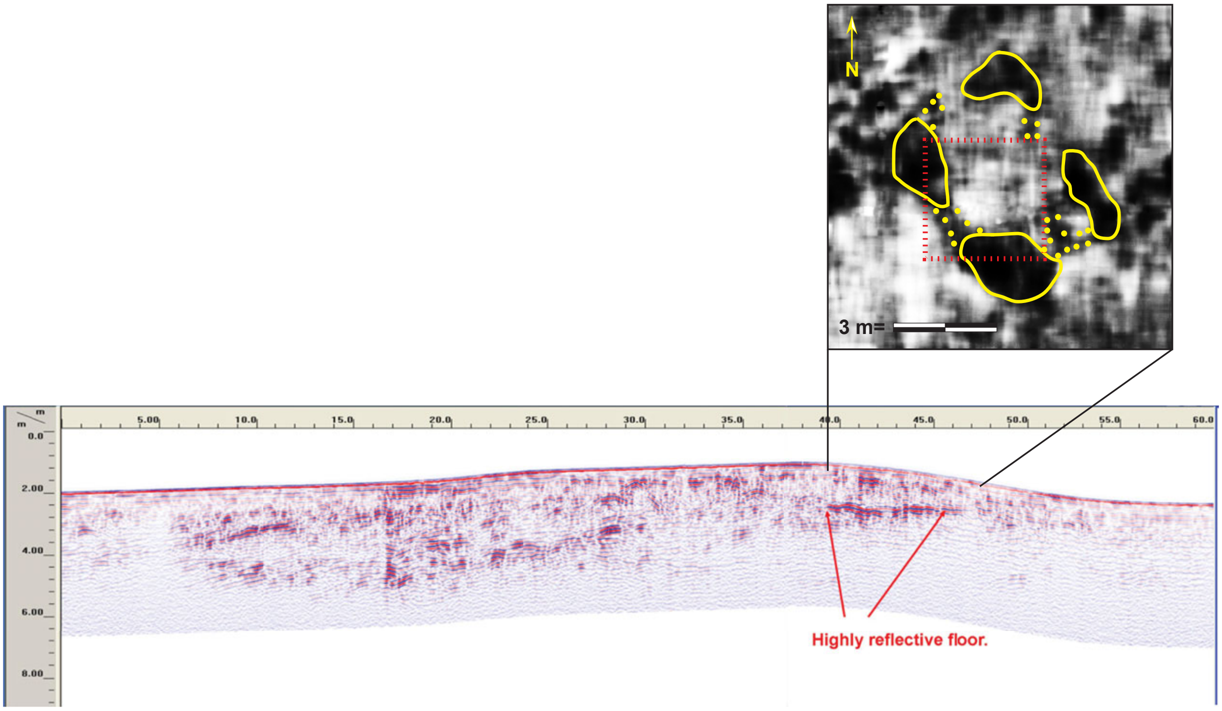

Figure 3 Radar profile of the geophysical survey transect across block L. Inset shows a top-down (plan) view showing a subrectangular outline (indicated in yellow). This turned out to be boulders just below the surface. The highly reflective floor contained a much older archaeological assemblage.

valley, but pinch out at the berm. Essentially, the berm forms a basin that catches the colluvium and other outwash from the landward side. Presumably, a fraction of the marine sediments also consist of terriginous material, but their presence is undetectable without microscopic or geochemical analyses, both of which were beyond the scope of our interest.

During excavations at Aganoa, every test unit encountered marine sands that coarsened with depth. In many cases the coarsening was accompanied with an increase in the angularity of sediments; the sands are predominately crushed marine shells and corals, a diagnostic characteristic of the modern shoreface. Based on the individual analysis of sediments in each excavation unit, a generalized stratigraphic column has been reconstructed that represents the sequence of depositional events at Aganoa (Figure 5C). Not all of these sedimentary units are represented at each sampling locus, but they always co-occur in the same sequential order as given here. Correlations were made based on lithology and soil

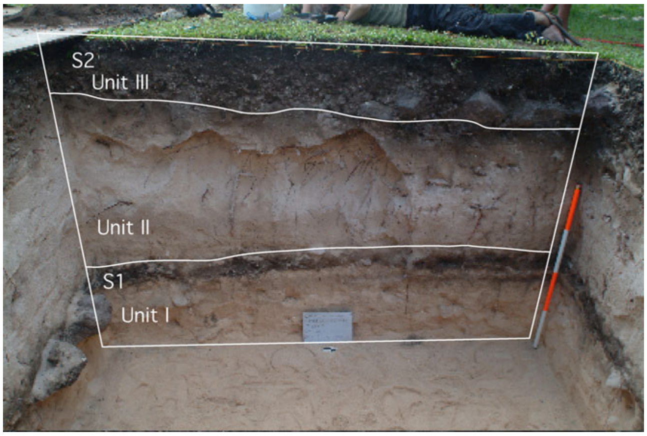

Figure 4 Photograph of block L stratigraphy (west wall). Paleosurface S1 is a major stratigraphic marker capping unit I in the sandy portions of the site. Cultural materials associated with S1 include ceramics, stone tools and debit age, shell fishhooks, charcoal and ash, and marine fauna.

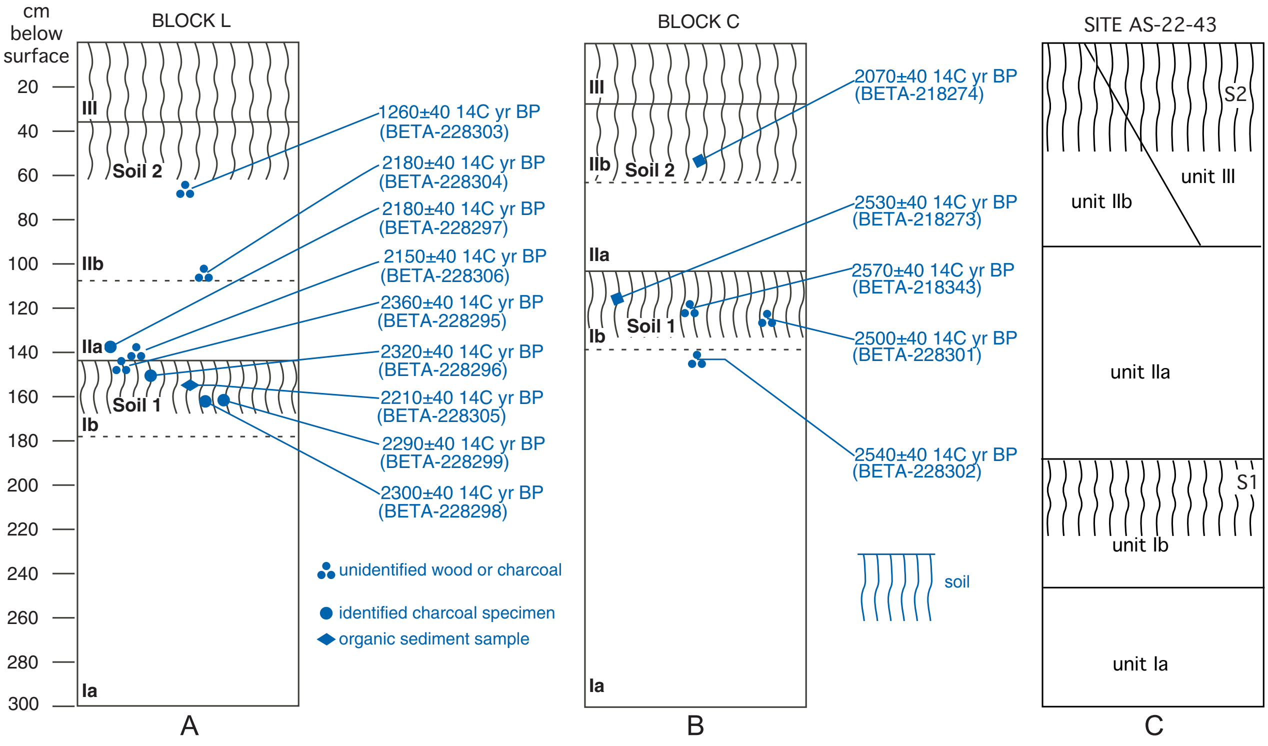

Figure 5 Generalized stratigraphy for Aganoa (AS-22-43) showing radiocarbon dates and relative arrangement of major stratigraphic units. From left to right: (A) block O, (B) block L, and (C) a generalized stratigraphic column. Units indicated by Roman numeral I-III are major lithostratigraphic units. Note that units IIb and III co-occur at the surface in different parts of the site. Two soils are indicated as S1 and S2 (S2 is forming from the modern surface). Paleosurface S1 is a major stratigraphic marker capping unit I in the sandy portions of the site.

characteristics when appropriate. Geophysical data confirmed some stratigraphic relationships, and also allowed the inference of interfingering deposits and the angle of paleosurfaces.

Generalized Stratigraphic Column and Interpretation

By convention, lithological strata are numbered sequentially from the oldest to the youngest (i.e., unit I is older than unit III). Soils are also numbered from the oldest to the youngest. The following sedimentary descriptions correspond to the generalized stratigraphic column (Figure 5C). No single location has this exact profile; rather, the generalized stratigraphic column is a "schematic" view of the sediments. Individual profiles are discussed later.

Unit Ia

Unit Ia is a predominately medium-to-coarse-grained, well-sorted sand displaying subhorizontal parallel laminations and low-angle, seaward-dipping crossbeds. Occasional scattered pebbles and pebble lenses are also present. Generally, the sediments are massive, but infrequently, low-angle, landward-dipping cross-beds were observed. Coral gravels and cobbles increase dramatically with depth (2–5%, increasing to 80%). The color is highly variable, as at its maximum depth, this unit is predominately composed of invertebrate remains, but it was generally described as "pale yellow" (Munsell 2.5Y8/3). The coarse sand fraction is well sorted, with few or no fines. Grains were observed as loosely compacted, and subangular or subrounded. These deposits closely resemble the upper shoreface deposits of the modern beach. The transition from unit Ia to unit Ib is gradual, suggesting a slow transition of depositional regimes.

A single AMS radiocarbon date on charcoal yielded a result of 2540 ± 40 ^{14}C yr B.P. (Beta-228302, Figure 5B, Table I). A second sample (Beta-228300) contained too little datable material to produce a result.

Unit Ib

Unit Ib is a predominately medium-to-coarse-grained, well-sorted sand with a significant input of ash, charred material, and other cultural materials indicative of an archaeological deposit. Coral gravels and cobbles compose

Table I Radiocarbon data for blocks C, D, L, and O sorted by provenience and stratigraphic position.

Beta lab no.	Depth (cm)	Lithology	δ13C value (‰)	^{14}C	Material	1σ calibrated results	2σ calibrated results
Block C							
218274	53	IIb	−25.2	2070 ± 40	Soot from sherd	165 B.C. (18.2%) 130 B.C. 120 B.C. (50.0%) 40.B.C.	195 B.C. (94.6%) A.D. 5 A.D.10 (0.8%) A.D. 20
228301	127–37	Ib[S1]	−29.5	2500 ± 40	Charcoal	770 B.C. (13.5%) 730 B.C. 690 B.C. (11.4%) 660 B.C. 650 B.C. (43.3%) 545 B.C.	790 B.C. (92.2%) 505 B.C. 460 B.C. (1.0%) 450 B.C. 440 B.C. (2.2%) 420 B.C.
218273	118	Ib[S1]	−24.9	2530 ± 40	Soot from sherd	790 B.C. (22.2%) 750 B.C. 690 B.C. (12.2%) 665 B.C. 645 B.C. (25.3%) 590 B.C. 580 B.C. (8.5%) 560 B.C.	800 B.C. (94.8%) 535 B.C. 530 B.C. (0.6%) 525 B.C.
218343	123	Ib[S1]	−23.3	2570 ± 40	Charcoal	805 B.C. (49.8%) 750 B.C. 685 B.C. (11.4%) 670 B.C. 630 B.C. (1.3%) 630 B.C. 610 B.C. (5.7%) 595 B.C.	815 B.C. (55.5%) 735 B.C. 690 B.C. (13.8%) 660 B.C. 650 B.C. (26.2%) 545 B.C.
228302	142	Ia	−28.1	2540 ± 40	Charcoal	795 B.C. (28.3%) 750 B.C. 690 B.C. (12.9%) 665 B.C. 640 B.C. (23.3%) 590 B.C. 580 B.C. (3.8%) 570 B.C.	800BC (36.8%) 705BC 695BC (58.6%) 540BC
Block D							
231699	35	IIb	−21.7	2410 ± 40	Charcoal	700 B.C. (1.2%) 695 B.C. 540 B.C. (67.0%) 400 B.C.	755 B.C. (15.7%) 685 B.C. 670 B.C. (4.8%) 640 B.C. 595 B.C. (74.9%) 395 B.C.
Block L							
228303	66	IIb	−24.8	1260 ± 40	Wood	680 A.D. (68.2%) 780 A.D.	A.D. 670 (95.4%) A.D. 870
228304	104	IIb	−27.7	2180 ± 40	Charcoal	355 B.C. (40.1%) 285 B.C. 235 B.C. (28.1%) 180 B.C.	380 B.C. (92.3%) 155 B.C. 135 B.C. (3.1%) 115 B.C.
228297	139	IIa	−24.4	2180 ± 40	Charcoal *Cananga odorata*	355 B.C. (40.1%) 285 B.C. 235 B.C. (28.1%) 175 B.C.	380 B.C. (92.3%) 155 B.C. 135 B.C. (3.1%) 115 B.C.
228306	139	IIa	−24.0	2150 ± 40	Charcoal	350 B.C. (23.9%) 298 B.C. 230 B.C. (1.6%) 220 B.C. 210 B.C. (32.1%) 150 B.C. 140 B.C. (10.6%) 110 B.C.	360 B.C. (30.0%) 275 B.C. 260 B.C. (61.9%) 85 B.C. 80 B.C. (3.6%) 55 B.C.
228295	146	Ib[S1]	−23.6	2360 ± 40	charcoal	510 B.C. (38.0%) 440 B.C. 420 B.C. (30.2%) 390 B.C.	730 B.C. (5.0%) 690 B.C. 660 B.C. (0.8%) 650 B.C. 545 B.C. (89.6%) 370 B.C.
228296	151	Ib[S1]	−23.9	2320 ± 40	Charcoal *Cocos nucifera*	410 B.C. (62.8%) 360 B.C. 275 B.C. (5.4%) 260 B.C.	515 B.C. (78.7%) 350 B.C. 295 B.C. (15.9%) 230 B.C. 220 B.C. (0.8%) 210 B.C.
228305	155	Ib[S1]	−26.0	2210 ± 40	Organic sediment	360 B.C. (8.7%) 345 B.C. 320 B.C. (28.1%) 270 B.C. 260 B.C. (31.4%) 205 B.C.	385 B.C. (95.4%) 185 B.C.
228298	161	Ib[S1]	−23.9	2300 ± 40	Wood *Cocos nucifera*	405 B.C. (55.8%) 358 B.C. 280 B.C. (12.4%) 258 B.C.	415 B.C. (59.4%) 345 B.C. 320 B.C. (36.0%) 205 B.C.
228299	161	Ib[S1]	−27.2	2290 ± 40	Wood *Szygium sp.*	400 B.C. (46.4%) 355 B.C. 280 B.C. (16.5%) 255 B.C. 245 B.C. (5.3%) 235 B.C.	405 B.C. (52.5%) 350 B.C. 315 B.C. (42.9%) 208 B.C.
228300	180		–	–	Ash	n/a	n/a
Block O							
231698	30	IIb	−26.0	Modern	Charcoal	n/a	n/a
231700	32	Ib[S1]	−24.6	410 ± 40	Charcoal	A.D. 1435 (58.7%) A.D. 1495 A.D. 1600 (9.5%) A.D. 1620	A.D. 1425 (72.0%) A.D. 1525 A.D. 1555 (23.4%) A.D. 1635
231701	32		−24.6	370 ± 40	Charcoal	A.D. 1450 (44.5%) A.D. 1525 A.D. 1575 (3.7%) A.D. 1585 A.D. 1590 (20.0%) A.D. 1625	A.D. 1445 (95.4%) A.D. 1635

Each sample was corrected for isotopic variations (fractionation) by the radiocarbon facility. For interpretive purposes, the conventional radiocarbon ages were calibrated with the OxCal 4.2.2 radiocarbon calibration software (Bronk Ramsey 1995, 2001, 2009), using the INTCAL09 atmospheric carbon curve for calibration (Reimer et al., 2009).

up to 10% of the sandy matrix. The field description of the color was "dark grayish brown" (Munsell 2.5Y4/2) to "light gray" (Munsell 2.5Y4/2). The coarse sand fraction is well-sorted, with few or no fines. Grains were observed as loosely compacted, and subangular or subrounded. These deposits closely resemble the foreshore of the modern beach.

Soil 1 (S1, a paleosol) is formed on unit Ib sediments. It is weakly expressed by an increase in total organic content, possibly the exclusive result of anthropogenic inputs. These inputs are undoubtedly what give the soil (and underlying sediment matrix) its dark-gray character. Significantly, S1, which was observed in multiple excavation blocks as well as in geophysical profiles, represents a brief period of landscape stability across the valley (the length of which shall be investigated below). Notable cultural content includes curved shell fishhooks, abundant spines of at least two rare species of giant echinoderm (*Heterocentrodus* sp. and *Eucidarus* sp.), decorated ceramics in the terminal Lapita/Plainware tradition, stone tools and debitage, and abundant burned wood and shell. The uncharacteristically large number of invertebrate remains associated with S1 is undoubtedly subsistence related. S1 caps unit I, but is slightly truncated by erosion, providing an abrupt boundary to overlying unit II.

Eight AMS radiocarbon dates were obtained from unit Ib (Figure 5B and C; Table I): 2530 ± 40 ^{14}C yr B.P. (Beta-218273), 2570 ± 40 ^{14}C yr B.P. (Beta-218343), 2360 ± 40 ^{14}C yr B.P. (Beta-228295), 2320 ± 40 ^{14}C yr B.P. (Beta-228296), 2300 ± 40 ^{14}C yr B.P. (Beta-228298), 2290 ± 40 ^{14}C yr B.P. (Beta-228299), 2500 ± 40 ^{14}C yr B.P. (Beta-228301), and 2210 ± 40 ^{14}C yr B.P. (Beta-228305).

Excavation of a single test pit at block D revealed the presence of a shell midden extending from about 35 cm below surface to 70 cm below surface (at which point the shell content was similar to the normal "background" shell content). Though closer to the surface than the paleosol, this midden is interpreted as a discard pile that accumulated contemporaneously with the S1 surface. A single piece of charcoal derived from the midden produced a radiocarbon date of 2410 ± 40 ^{14}C yr B.P. (Beta-231699), thereby supporting this interpretation. The shell midden contains some lithic and ceramic artifacts.

Unit IIa

Unit IIa consists of upward-fining coarse-to-fine-grained, well-sorted sand with occasional scattered pebbles and pebble lenses. Generally, the sediments are massive, but infrequently, thin sets of low-angle, landward-dipping laminations and faint small-scale eolian trough cross-bed sets were observed. Coral gravels and cobbles comprise 2–5% of the matrix. These sediments were generally described as "pale yellow" (Munsell 2.5Y8/2). The coarse sand fraction is well-sorted, with few or no fines. Grains were observed as loosely compacted, and subangular or subrounded. These deposits closely resemble the upper foreshore (including beach berm) of the modern beach.

Two AMS radiocarbon dates were obtained from stratigraphic unit IIa (Figure 5A and B; Table I): 2180 ± 40 ^{14}C yr B.P. (Beta-228297) and 2150 ± 40 ^{14}C yr B.P. (Beta-228306).

Unit IIb

Unit IIb consists of upward-fining coarse-to-fine-grained, well-sorted sand with occasional scattered pebbles and pebble lenses. Generally, the sediments are massive, but infrequently, thin sets of low-angle landward-dipping laminations and faint small-scale eolian trough cross-bed sets were observed. Coral gravels and cobbles comprise 2–5% of the matrix. Sediments were generally described as "pale yellow" (Munsell 2.5Y8/2). The coarse sand fraction is well-sorted, with few or no fines. Grains were observed as loosely compacted, and subangular or subrounded. These deposits closely resemble the upper foreshore (including beach berm) of the modern beach.

Three AMS radiocarbon dates were obtained from unit IIb (Figure 5; Table I): 2070 ± 40 ^{14}C yr B.P. (Beta-218274), 1260 ± 40 ^{14}C yr B.P. (Beta-228303), and 2180 ± 40 ^{14}C yr B.P. (Beta-228304).

Unit III

Only present in the backshore area, unit III consists of colluvium of terrestrial origin, anthropogenic inputs (especially paving gravels and occasional architectural boulders), and storm wash deposits of marine origin. The dominant lithology of unit III, however, is its colluvial deposits. Most of the colluvium is fine-grained clays derived from the physical weathering of basalt parent material. Occasionally, larger pieces of basalt from the mountain slope have fallen into the backshore (ranging from cobble to boulder size). Obviously, the fraction of these larger pieces increases with nearness to the valley edge. Where archaeological deposits were encountered, the clay fraction ranged from 30% to 55%, cobbles and boulders less than 5%, and anthropogenic gravels up to 20%, with the remainder made up of storm wash deposits (usually coarse sand).

Soil 2 (S2) is formed on the modern surface. Its expression is variable, and highly dependent on location; that is, it forms on both unit IIb and unit III parent material where these occur at the surface. Soil formation is low to nonexistent near the beach, but increases as one climbs the foreshore to the contemporary village

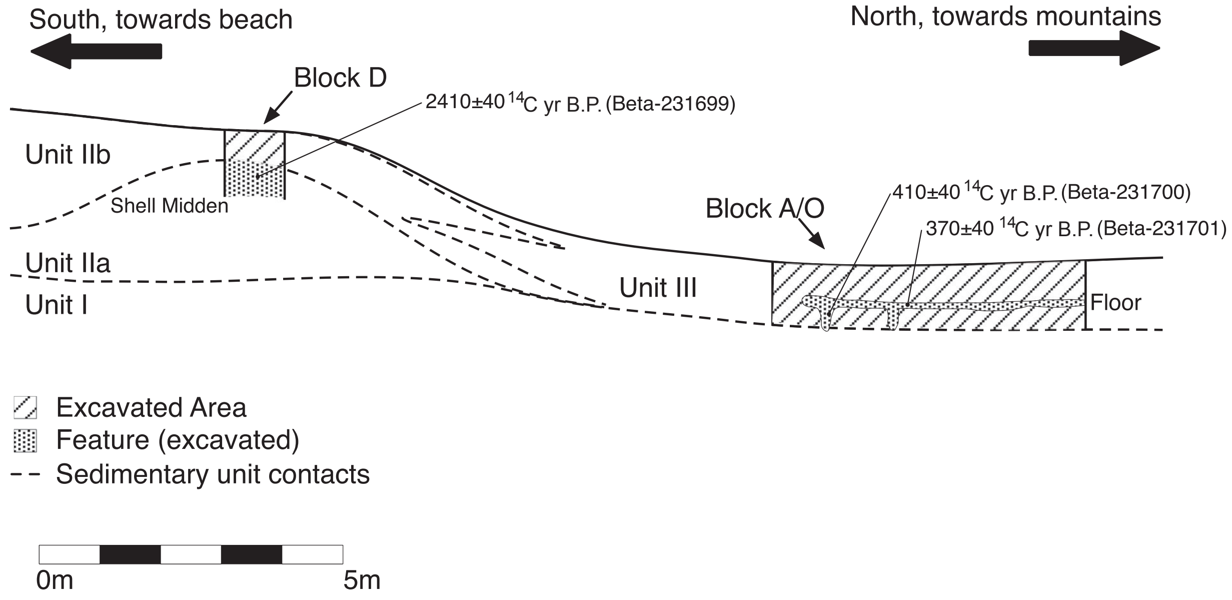

Figure 6 Diagram showing the relationship between the ceramic-bearing shell-midden in Block D with the post-14th century features of Block A.

structures. Here, anthropogenic inputs (especially paving gravels) are important, and low grasses dominate. However, in the backshore area, cultivation and forest vegetation are thick, leading to more substantial soil formation. Translocation of clays, for example, is limited to the backshore area where the parent material is rich in inorganic clay minerals.

No dates were obtained on these upper stratigraphic units, as it is thought that intensive modern agricultural and other secondary uses have made radiocarbon results unreliable.

ARCHAEOLOGY AND GEOCHRONOLOGY OF THE BACKSHORE

Our geophysical investigations have revealed that the oldest and most well-preserved portion of the site is protected deep beneath the beach berm (the upper foreshore) in line with the contemporary houses. However, in 1998, Kennedy and Moore reported that the main portions of the site were in the cultivated plantation area behind the contemporary homes (in the backshore zone). Here, Kennedy and Moore encountered a number of preserved features, some of which they identified as prehistoric house foundations (or alignments) dating to between 2400 and 400 ^{14}C yr B.P. (calibrated to between 410 B.C. and A.D. 1470). Furthermore, the later age was associated with Polynesian Plainware. If confirmed, this would lend support to the "late ceramics" hypothesis that suggests that the use and manufacture of pottery lasted until 300–400 years ago in American Samoa (Clark, 1996; Clark & Michlovic, 1996; Clark, Sheppard, & Jones, 1997).

When we arrived on the site it immediately became clear that getting a reliable numerical age from the backshore plantation would be problematic. Surface burning of trash and cleared vegetation is a persistent behavior. Cultivated trees and plants infiltrate the soil to a minimum depth of 40 cm, with some larger species having a much greater depth of penetration. When we excavated in block O (Figure 6) we soon encountered well-preserved buried features: *'ili'ili*, basalt stones, and post-holes indicative of a house floor. However, these features appeared only 23–35 cm below the modern surface. Once the *'ili'ili* surface was penetrated, we immediately began to encounter Plainware. Two radiocarbon dates were obtained on charcoal associated with the subfloor: Beta-231700 yielded an age of 410 ± 40 ^{14}C yr B.P., and Beta-231701 yielded an age of 370 ± 40 ^{14}C yr B.P. (Table I).

The question of dating the ceramic component can be boiled down to two simple questions: Are the radiocarbon samples associated with the house floor? And, are the ceramics associated with the house floor? Due to cultivation activities and shallow burial, it is not possible to rule out contamination. However, the burial depth and level of preservation of the post-holes in the clayey stratigraphic unit III deposits makes the ages plausible, even likely. The samples were separated by several meters and are statistically indistinguishable, adding weight to this conclusion.

Whether the ceramics are associated with the house feature is a more difficult question—when we were excavating the feature we believed they were. Upon further review, it is notable that the ceramics only appear within the floor, not on top of it, making it quite possible that the ceramics in the floor are in secondary context, having been incorporated into the subfloor as part of the construction process. This feature is within 5 m of the shell midden (block D). Although buried now, parts of this shell midden were probably still visible at that time, and ceramics from that midden might have found their way into block O.

DISCUSSION

At Aganoa, archaeological materials were encountered at the surface and buried as deeply as ~150 cm below the surface (the upper part of Stratigraphic unit Ia). However, archaeological materials were not evenly distributed throughout the stratigraphic column. Notably, the decorated ceramic assemblage is restricted to stratigraphic unit I (a and b), and generally within the S1 soil.

The signature archaeological assemblage associated with unit I includes fishhooks, stone tools, and ceramics. The excavations at Aganoa resulted in the recovery of a ceramic assemblage totaling over 1400 sherds. Combined with the ~900 sherds recovered by Moore and Kennedy (Moore & Kennedy, 2003; Eckert, 2006), this ceramic assemblage is the largest from a single site on Tutuila. The majority of the sherds are from Polynesian Plainware vessels. Fewer than 10 sherds, all from stratigraphic unit I, have decoration consisting of a fugitive red slip on the exterior of vessels and indented rims. As many as 15 fishhooks were also recovered from this context (analysis pending), as well as fishhook "tabs." This assemblage is very similar in composition to that described for To'aga on nearby Ofu Island (Kirch et al., 1990; Kirch & Hunt, 1993).

The Depth and Extent of the Deposits at Aganoa

A key question is whether or not there are additional Lapita deposits beyond their currently known lateral distribution, or possibly buried deep beneath the S1 horizon. No test that we performed can prove the absence of such deposits, but based on our observations we find no evidence to suggest additional deposits beyond the site's current liberal definition.

The marine sands that comprise the sedimentary matrix of the site coarsen with depth. The paleosurface morphology, as determined with the GPR, provides additional confirmation that we are looking at a prograding shoreface. Over 1 m of culturally sterile, coarsening sands was encountered beneath S1. Altogether, these data suggest a deepening foreshore, with the likelihood of a land-based settlement decreasing with depth. Since there is no buried reef or lagoon facies at this location, the presence of a "stilt" habitation is also unlikely. No further buried "surface" signatures were detected through geophysical investigation.

Excavation block L was put in as a 3 × 3 m unit in order to (a) provide an areal exposure of the "surface" that had been identified through geophysical investigation, and (b) allow deep excavation and maintain a proper safety ratio of depth:width in the excavated units. Excavations ceased at 20 cm below the cultural layer; a secondary test pit down to 3 m produced only the previously described coarsening sands. Thus, despite interest in finding a deeply buried Lapita site, we rationally conclude that the likelihood of finding such evidence at Aganoa is low.

The early cultural horizon at Aganoa follows a natural paleosurface that is seen in the geophysical profiles and is easily found in excavated contexts. It is buried ~1.65 m beneath the linear dune, and about 40 cm beneath the agricultural field. In the agricultural setting, it lies in the marine sands that directly underlie the muddy colluvium/topsoil zone and is easily traced. We followed this horizon inshore with both excavation test units and geophysical exploration and found no evidence that the site extends any further than indicated in Figure 2.

Radiocarbon Determinations

Eleven of the samples are of importance for determining the age range of the early occupation phase. These come from two different excavated contexts, block L and block C (Figure 5A and B, respectively). These two excavation blocks were positioned at either end of the beach berm, and both penetrated the S1 paleosol. Block L was positioned specifically to take advantage of the target identified in the geophysical survey. It should be noted that Beta-228302 is the earliest ^{14}C date in this phase, and that Beta-228297 and Beta-228306 overlie it, providing a *terminus ante quem* for the early deposits.

CONCLUSIONS

A simplified interpretation of the duration of the early phase can be made by taking the upper and lower age limits of these determinations and establishing a possible range (in this case 802 B.C. to 114 B.C. at 2σ). However, if we posit *a priori* that the radiocarbon dates represent two distinct phases at the site and that the group of dates are randomly sampled from a uniform distribution, we are able to model the phase boundaries using methods developed by Buck, Litton, and Smith (1992), and implemented in Oxcal 4.2.2 (Bronk Ramsey, 2009). Figure 7 shows the probability density function (PDF) for all the

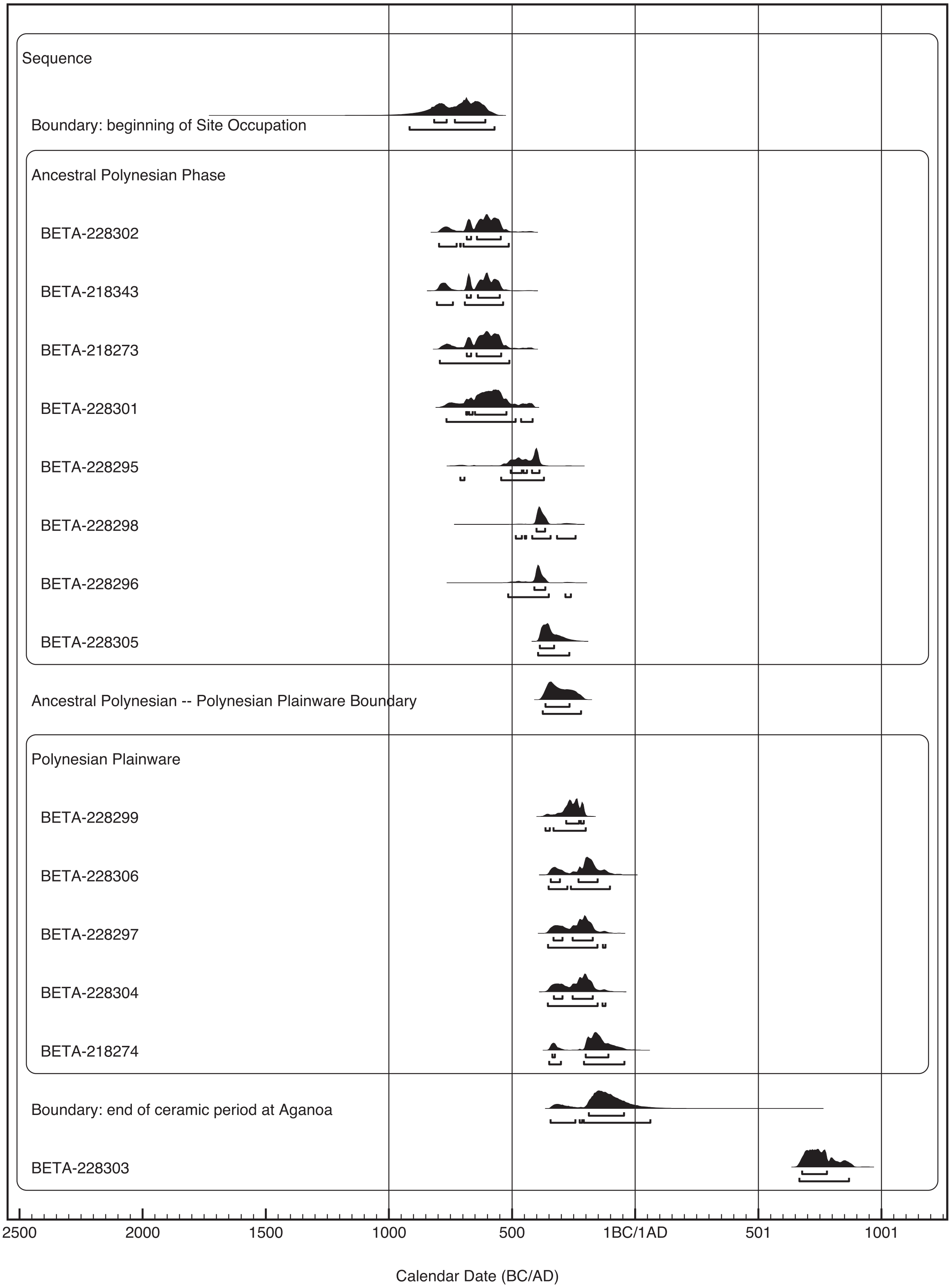

Figure 7 Probability density functions (PDF) for all the Aganoa AMS dates, along with their proper stratigraphic correlations and interpreted boundaries. Boundary interpretations are based on a Bayesian analysis that assumes the dates represent two "phases" of occupation.

Aganoa AMS dates, along with their proper stratigraphic correlations and interpreted boundaries. We use these inferred phase boundaries for the site chronology.

The earliest evidence for occupation of the Aganoa site comes from Block C at the western end of the site where a group of samples clustered at the top of the oldest observed geological unit confirms that occupation of the site was well underway by the 7th century B.C., and probably much earlier. At that time relative sea level was higher than at present (Nunn, 1995, 1998; Dickinson & Green, 1998; Dickinson, 2001) and the geological deposits of unit I suggest an upper shoreface deposit. This is probably too close to the surf zone for a permanent habitation site, but well suited for an activity area. Abundant burned material (including wood, coral, shells, and, infrequently, bone), fishhooks, and expedient tools also indicate a marine-resource processing site. The presence of fishhooks shows that pelagic resources were being harvested, but the abundance of reef invertebrates demonstrates a broad subsistence strategy. A key invertebrate resource at this time was several species of giant Slate Pencil Urchins (*Heterocentrodus* sp. and *Eucidarus* sp.) now rare in Samoan waters (Coles et al., 2003). Our encounter with these urchins closely parallels the findings at Faleasi'u (Jane's Camp) where hundreds of Slate Pencil urchin spines, and a large number of tools made from them, were recovered almost exclusively from a stratigraphic layers dated to ~2100 years ago (Janetski, 1976a, 1976b).

Though the site may have been initially occupied any time prior to 800–510 B.C. (2540 ± 40 ^{14}C yr B.P.), given the clustering and distribution of ^{14}C ages associated with this occupation, our model suggests that the most likely period for the initial occupation of the site was between 920 and 570 B.C. With other sites along the southeastern coastline of Tutuila and the island of Aunu'u, Aganoa provides good access to submerged offshore banks in the lee of Aunu'u (Figure 1).

The formation of a paleosurface (S1) suggests modest landscape stability, at least for a short period, during the ancestral Polynesian phase. The approximate timing of this "high stand" is represented by the transition between stratigraphic units I and II. In our model the "ancestral Polynesian/Polynesian Plainware boundary" represents this, which is 376 to 221 BC. The transition of upper foreshore deposits of unit I to the progressively finer shoreface deposits of subsequent stratigraphic levels show that after this point sea level fell until it reached its modern position. No late-Holocene variance in surficial processes related to climate (e.g., Little Ice Age, etc.) is seen in this stratigraphic record, and it may be posited that such records are better preserved in areas with fluvial deposits (e.g., Pearl, 2006). The irregular contact between stratigraphic units I and II shows that beach progradation was accompanied by localized reworking of the surface sediments, but the preservation of most of the S1 paleosurface indicates that the disturbance was not severe. Shoreward migration of the beach is also clearly demonstrated by the results of the geophysical survey, as is the subsequent buildup of the modern berm in its current position.

The clustering of ages within the ancestral Polynesian phase, but at different loci on the site, suggests impermanent camp positions. The artifact assemblages also hint that this location may have been more of a work area associated with marine harvesting than a habitation site.

After 376–221 B.C., the archaeological signature changes, as does the depositional regime. Under the berm and shoreward, deposits are upward fining, but always are dominated by marine sands (the smallest being about 0.5 mm). The distinction between stratigraphic units IIa and IIb is subtle, but IIb had infrequent faint eolian trough cross-bed sets, suggesting at least occasional wind transport. Echinoderm spines and abundant fire-affected marine invertebrates discontinue above the S1 surface, as do fishhooks and other tools strictly associated with marine resource utilization. Stone tools and ceramics are still found, but ceramics are undecorated and described as Polynesian Plainware, and even their numbers diminish rapidly. Stone tools are characterized less by utilized flakes and other expedient tools, and have a stronger representation of formal types, especially adzes (Crews, 2007). The association of echinoderm spines with the Ancestral Polynesian Society (APS) phase and their subsequent disappearance is a striking indicator. The same pattern present at Faleasi'u suggests that (a) predation by Samoa's early inhabitants may have played a major role in the local extermination of the giant echinoderms, and (b) the presence of large numbers of giant echinoderm spines in an assemblage is probably a good indication of a site's antiquity and association with the APS phase.

According to our data, irregular use of the site continued for about 100 years. The end of regular use of the site is modeled by the "Boundary Polynesian Plain Ware/Aceramic" at 344 B.C.–A.D. 63.

After the first occupation series we have very little dated evidence for regular utilization of Aganoa until the 15th century A.D. During this gap, Aganoa may have been intermittently used, or a habitation may, as of yet, be archaeologically unknown. We currently have no features or extensive scatters of artifacts dating to this gap. However, by the 15th century A.D. we see an occupation of the site with abundant evidence for permanent habitation, yet very little evidence for marine exploitation. Habitation features extend from the berm crest into the backshore area, with agricultural terrace features along the valley wall. Based on the density of surface and buried features, as well as agricultural features no longer in use, the population density may have been two to three times higher (at least) in the 15th and 16th centuries A.D. than at present.

The purpose of this paper was to demonstrate the stratigraphic integrity of Aganoa, and to accurately characterize its geochronology. Artifactual analysis of the recovered material is ongoing. The results of those studies will help characterize two important periods in Samoa's prehistory: the transitional Plainware phase, and the late classic Samoan to ethnohistoric period (17th century A.D. onward). This site's greatest advantage, however—an undisturbed early stratum with culturally sterile overburden—also presents an interpretive challenge if the subject of study is post-ceramic cultural change and transition. Certainly, the site does not provide evidence of a gradual transformation of ancestral Polynesian to classic Samoan society, but the absence of evidence in this instance leaves numerous possibilities. We suggest that additional work focus on the broader coastal plain areas north of Aganoa (and to some extent south), where more direct access to fresh water would have been more conducive to permanent, or larger, settlements. In those cases, geophysical exploration, detailed stratigraphic analysis, and careful consideration of radiocarbon sampling strategies and methods of analysis will build toward understanding the postpottery transition. This geochronological study gives us a high degree of confidence that the results of the material analyses will provide exclusive insight into the coastally adapted culture that first colonized Samoa.

Finally, we have demonstrated the exceptional utility of GPR studies for illustrating the paleoenvironmental setting of coastal sites where relative sea-level has dropped. This study adds to the growing body of literature highlighting the successful application of GPR to solve archaeological problems (e.g., Safi et al., 2012; Vermeulen, Corsi, & de Dapper, 2012). Indeed, GPR studies are rapidly proliferating and it is particularly exciting to imagine their potential for enhancing our understanding of early sites in Polynesia.

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