Lack of suitable coastal plains likely influenced Lapita (~2800 cal. BP) settlement of Sāmoa: Evidence from south-eastern 'Upolu

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Abstract

Between 3050 and 2700 years ago, humans first colonized the islands of south-west Remote Oceania, a region stretching from Vanuatu to Sāmoa. These colonists created a dense archaeological record of Lapita pottery and other artefacts on island coastlines across the region. There is one striking exception to this pattern: Sāmoa, with only a single Lapita pottery colonization site dating to approximately 2800 years ago. There are two competing explanations for the unique Sāmoan colonization record. First, there was a dense Lapita colonization record, now displaced through sedimentation and coastal subsidence. Second, there were few coastal plains suitable for settlement 2800 years ago resulting in the lack of colonization sites. This article describes the first archaeological and geological research designed to systematically test these explanations. The research focuses on the south-eastern coastal plain of 'Upolu Island, an area where previous geological research and mid-Holocene sea-level indicators predict the least relative subsidence over the last 3000 years. Auger cores and controlled excavation units sampled the geological sequence and archaeological deposits across 700 m of coast. Sedimentary and dating analyses indicate coastal plain formation beginning 1200 years ago with the earliest archaeological deposits, including plain pottery, lithics, shellfish and vertebrate fauna, dating possibly 700 years later. Microfossil analyses identify burning and forest clearance coincident with the earliest archaeological remains. Compared with other Sāmoan archaeological deposits, the cultural materials and ecofacts represent very low-intensity occupation. These results support the proposal that there were few coastal plains suitable for Lapita pottery–bearing colonists approximately 2800 years ago.

Introduction

Between approximately 3050 and 2700 years ago, humans first colonized the islands and archipelagos of Remote Oceania (Figure 1a) stretching from the Reef/Santa Cruz Islands, to Vanuatu, New Caledonia, Fiji, Tonga and Sāmoa (Burley et al., 2012; Denham et al., 2012; Nunn and Petchey, 2013; Petchey, 2001; Petchey et al., 2014; Rieth and Cochrane, in press). There is a relatively dense archaeological record associated with these first human arrivals, commonly comprising deposits on beach ridges and coastal plains (Dickinson, 2014) with terrestrial and (mainly) marine faunal remains, introduced plant species, local and exotic lithics, and most famously, intricately decorated, Lapita pottery. The single exception is Sāmoa, where there is one archaeological site unambiguously associated with Remote Oceania's colonizing groups, the Mulifanua Lapita site on the western coastline of 'Upolu island (Figure 1b). The Mulifanua cultural deposit is dated to around 2800 years ago (Petchey, 2001) and contains Lapita pottery, turtle bone and a possible basalt artefact within a humus matrix below approximately 0.75 m of calcite-cemented paleo-beach rock that forms a lagoon floor, itself approximately 1.5 m below modern sea-level (Dickinson and Green, 1998). The Lapita

deposit was found while dredging a turning basin for the car-ferry that sails between 'Upolu and Savai'i. Dickinson (2007) argues that the presence of this intact cultural deposit approximately 2 m under water is a result of Savai'i volcanic loading, lithospheric depression and 'Upolu's subsidence since human colonization.

Following from the present geological context of the Mulifanua site, a typical reason given for the lack of Lapita sites in

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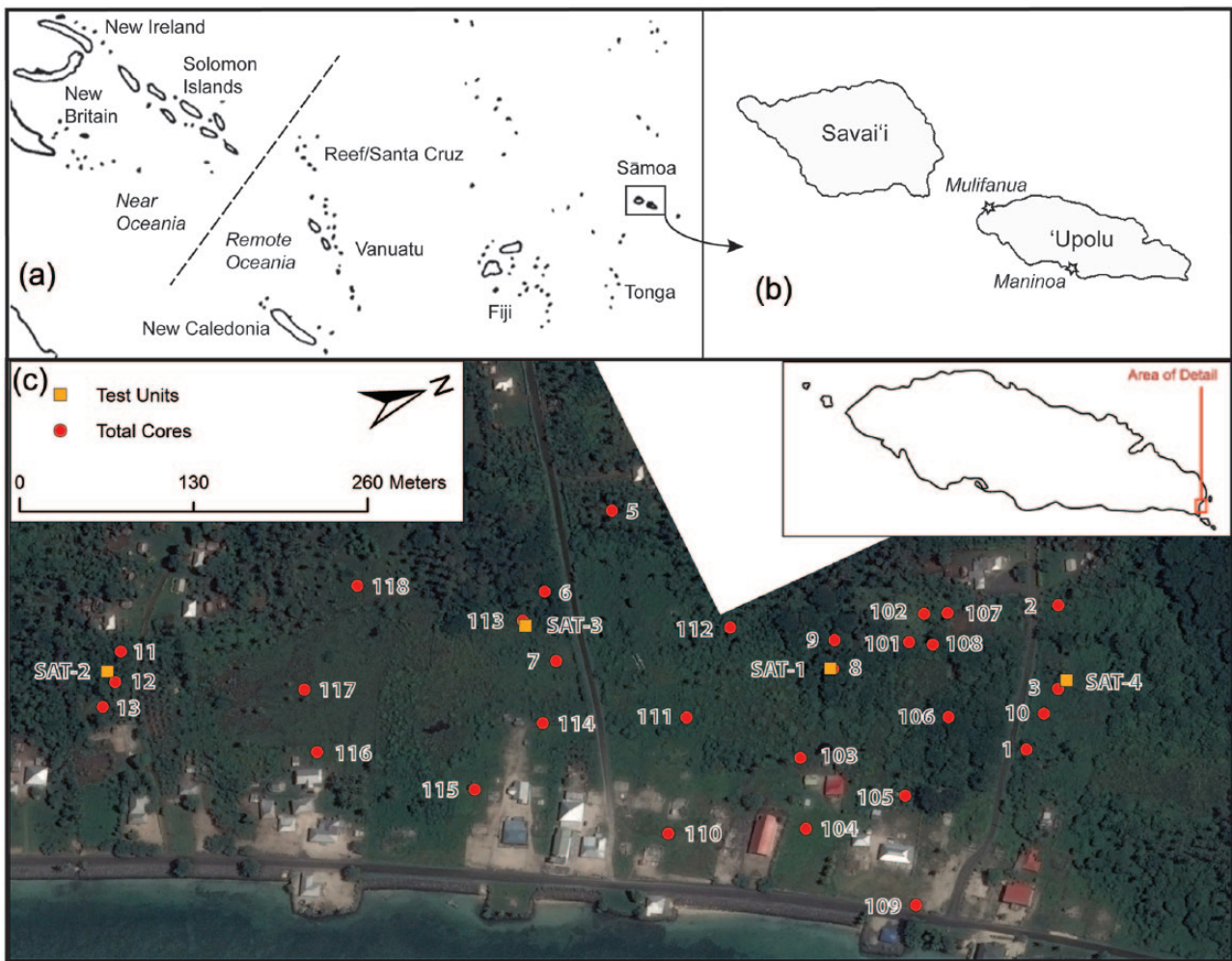Email: e.cochrane@auckland.ac.nz

Figure 1. Location of study: (a) south western Pacific showing major archipelagos or islands and the boundary between Near and Remote Oceania; (b) the two main islands of the nation of Sāmoa, showing location of sites discussed in text; (c) the study area focused on Satitoa Village showing cores and archaeological test pits. Not all cores from 2013 are shown as they were located outside Satitoa Village; 2014 cores have three-digit identifiers.

Sāmoa is relative island subsidence and the associated difficulty of finding intact offshore archaeological deposits that human colonists would have generated around 2800 years ago on the, then extant, beach ridges and coastal plains (Clark, 1996; Dickinson and Green, 1998; Green, 1974, 2002). Colluvial and alluvial processes, in concert with isostatic and eustatic changes, may have also displaced Sāmoan Lapita sites relative to former shorelines (Kirch, 1993; Quintus et al., in press). Considering this, Green (2002) predicted the locations of 13 Lapita sites around the coastline of 'Upolu based on nearshore bathymetry and coastal topography, and a hypothesis of generalized island subsidence of 1.4 mm/yr from 5000–1500 years ago (Dickinson and Green, 1998: 247–248). Most of these proposed Lapita site locations are along the northwest coast of 'Upolu, two are on the south coast and one is in the middle of the east coast.

More recently, Rieth et al. (2008) argued that the lack of Lapita sites in Sāmoa may reflect a true absence of these sites (see also Cochrane et al., 2013). They conducted a simple GIS-based analysis where they reconstructed the 3000 BP shoreline of Tutuila and Anu'u islands, noting the increased sea-level associated with the mid-Holocene highstand and paleoshoreline evidence on the islands that suggests no significant subsidence or emergence (Dickinson and Green, 1998: 256). To the coastline reconstruction, Rieth et al. added a series of environmental variables to predict the most favourable settlement areas after ~3000 BP. They identified seven locations on Tutuila and one on Anu'u that might have been available for Sāmoa's first colonists. Two of

these locations ('Aoa and Utumea) have been previously excavated without finding Lapita deposits, and Rieth et al. (2008) 'propose that sandy coastal flats had not formed in many areas prior to ~2500 cal. BP, limiting suitable area for Lapita settlement' (p. 235).

Considering the work of Dickinson and Green (1998; Dickinson, 2007; Green, 2002), Rieth et al. (2008) and others mentioned above, we propose that either the lack of Lapita sites in Sāmoa is explained by millennia of geological displacement and destruction of a previously large Lapita record similar to that found in nearby archipelagos of Tonga and Fiji, or the lack of Lapita sites is explained by few suitable coastal habitation areas in Sāmoa around 2800 years ago such that would-be colonists did not form many permanent settlements, leaving a negligible Lapita record. Of course, dichotomizing the explanations of the Sāmoan Lapita record neglects possible variations of the two positions. For example, natural displacement and destruction of an already negligible record could further diminish the number of Lapita deposits. Or Lapita deposits could have been more prevalent in areas where geological and other activities disproportionately obscure the record (e.g. western 'Upolu), such that a dense and spatially restricted Lapita record is less likely to be archaeologically visible compared with a less dense, but more spatially expansive Lapita record. Regardless, we believe that setting up this research within a framework of opposing hypotheses is a good starting point and note that these hypotheses can be refined as more data are generated.

To evaluate the possible explanations for the lack of Lapita sites in Sāmoa, we must precisely reconstruct Sāmoa's mid- to late-Holocene coastline evolution, identify locations where coastal plains and beach ridges would have been available for settlement during this time and sample these paleolandforms for archaeological deposits and environmental indicators. Here, we present the first results from our new research programme undertaking these tasks. The archaeological and geological results derive from our field work on the south-eastern coast of 'Upolu island (Figure 1c), focused on Satitoa Village, and suggest the current coastal plain there did not form until about 1200 years ago and that limited human presence after this time has resulted in a sparse archaeological record in the area.

Field and laboratory methods

The eastern coast of 'Upolu was chosen as our initial study area as Dickinson's (2007) hypothesis of Savai'i volcanic loading predicts the least amount of subsidence along this coast, and thus the comparatively best chance of locating terrestrial archaeological deposits of sufficient age. We concentrated on the southern end of the eastern coast, and during two short field sessions in 2013 and 2014, we excavated 59 cores with a hand-driven bucket auger and four 2 m × 1 m controlled archaeological units. Core locations were typically arrayed in transects approximately perpendicular to the coastline and running inland to investigate variations in both sedimentology and depositional environment potentially associated with coastal plain formation, or they were placed to investigate particular topographic features (see Figure 1c).

Archaeological and geological coring

The cores were excavated with a T-handle and extensions attached to an 8.3-cm (3.25 in) diameter regular or sand auger-bucket, depending on the substrate. The auger was drilled into the ground and removed once the bucket was filled with sediment. Successive bucket-loads of sediment were sequentially laid out on a prepared surface and the depth was recorded whenever a sediment change was encountered. For the 40 cores excavated in 2013, the primary goal was to locate subsurface carbonate sand deposits and archaeological remains. Accordingly, sediment descriptions were made for depositional units encountered in the core and were based on field-only observations of the excavated sediments and not recorded in situ (see Supplemental Material, available online). Textural classifications of sediments were generated using the US Department of Agriculture (USDA) soil texturing field flow chart. The percentage of clasts greater than 2.0 mm (very coarse sand) was estimated when these larger grains were present, but this was rare and typically only near the bottom of the cores for those not abandoned because of the water-table. Sediment Munsell colour was recorded under natural light.

For the 19 cores excavated in 2014, the primary goal was to generate data on the evolution of the modern coastal plain and earlier land forms. Similar to the 2013 cores, field descriptions included boundaries within depositional sequences, texture and composition of loam and carbonate units, and the presence of dateable coral clasts. Carbonate sediments from the 2014 cores were retained for grain size analysis, detailed composition analysis and dating. Coral clasts retained for dating were pre-treated with ultrasonic washing and acid etching.

Controlled archaeological excavations and artefact analyses

The four controlled archaeological test pits were excavated in 2014 with three of these placed to sample subsurface carbonate sand deposits identified in cores the previous year. One test pit was located next to a 2014 (geologically focused) auger core in which artefacts and anthropogenic sediments were encountered. Archaeological test pits were excavated with shovels and trowels in 10 cm arbitrary levels within stratigraphic layers (i.e. a new level initiated at stratigraphic changes, regardless of depth). All excavated matrix was passed through 3 mm sieves and all artefacts collected. In one test pit (SAT-2), approximately 2.3 m of terrigenous sediments, from the ground surface to the top of a carbonate sand layer, were excavated without sieving or employing 10 cm levels as this deposit was considered unlikely to yield useful data pertinent to the research. The water-table was typically encountered near the base of the archaeological excavations, and a petrol-powered sump-pump was used to remove water so that excavation could continue until water-flow into the excavation exceeded the pump's ability to clear it effectively. Some artefacts reported below were recovered from surface contexts near the excavation pits and were opportunistically collected.

Descriptions of sediments from the archaeological test pits followed the same procedure used for sediments recovered from cores in 2013, except that additional observations possible on in situ deposits were also made. Identification of archaeological shellfish remains was made by J Loader through comparison with the University of Auckland Pacific archaeological shellfish reference collection and standard texts (e.g. Cernohorsky, 1972) and checked by A Morrison. Identification of other faunal material was made by M Allen and J Littleton through comparison with the University of Auckland Pacific archaeological faunal reference collection. Archaeological charcoal taxa identifications were made by R Wallace at the University of Auckland.

Topographic point data were collected with a Leica TS12 robotic total station over the period 2–7 September 2014. An Ashtech LOCUS survey grade integrated L1 Global Positioning System (GPS) receiver/antennae base station was used to reference survey points to geographic coordinates and ellipsoid heights relative to World Geodetic System 1984 (WGS84). Because the tidal relationship between the Satitoa Village study site and the Apia tide gauge is not established, and we only use elevation data for interpreting dated material, the surveyed elevations were adjusted to local low water observed on the Satitoa shoreline. Low water positions from Satitoa were adjusted to mean sea-level (MSL) using the location of average low tide observed on 9 and 10 April 2014 as recorded at the Apia Tide Station (http://www.ioc-sealevelmonitoring.org/station.php?code=upol). Topographic survey data were then reprojected to Universal Transverse Mercator (UTM) zone 2 South. Triangular irregular networks (TIN) were derived from processed survey points and interpolated into a 2-m horizontal resolution DEM using the nearest neighbour method.

Microfossil analyses

A sample each from Layers III and IV of the archaeological unit at SAT-1 were analysed for pollen, phytoliths and starch. The samples were prepared for pollen and phytolith/starch analysis by the standard acetolysis method (Moore et al., 1991) and density separation (Horrocks, 2005), respectively.

Results

Geology

In 2014, five shore-perpendicular transects of cores were collected to interpret the geologic history of the coastal plain (see Figure 1c) and to sample subsurface carbonate sand deposits that were identified in cores in 2013. The landward-most cores of each transect were composed entirely of either clay or loam. Just seaward of this boundary, core P113, located 205.0 m from the current shoreline, is representative of the landward extent of the

carbonate sand layer. Core P104 is located 77.90 m from the current shoreline and represents an example of the carbonate sand layer located closer to the modern shoreline. Both of these cores were analysed for grain size and composition (Figure 2). The sand was very poorly to moderately well sorted with a mean grain size of 0.2–0.9 mm. Sand grains are of marine origin and dominated by foraminifera (*Baculogypsina sphaerulata, Amphisorus hemprichii, Marginopora vertebralis, Amphistegina* sp.), echinoderms, molluscs, red algae, *Halimeda* sp. and coral fragments typical of the adjacent reef flat and lagoon.

Two coral fragments in carbonate sand located at the base of core P113 (located immediately adjacent to the SAT-3 archaeological test pit) and core P104 were dated (Table 1). The core P113 coral and carbonate sand sample date range is 1278–1133 (95.4%) cal. BP and represents our most inland and deepest dated material with an elevation of −0.55 m relative to modern MSL. The coral and carbonate sand sample from P104 was located at −0.37 m relative to MSL and returned a date range of 1039–867 (95.4%) cal. BP.

The surface elevation of core P113 is 1.48 m and that of core P104 is 1.71 m, and the uppermost unit in these cores, comprising the ground surface, is a sandy loam that shows evidence of marine influence in the form of sparse carbonate sand (potentially wind-blown or deposited by tsunami inundation; Richmond et al., 2011). The mean thickness of the loam in the two cores is 0.86 ± 0.04 m. The base of the sandy loam forms a sharp contact with the underlying marine sands. The average elevation of the contact in both cores is 0.74 ± 0.09 cm. We use this elevation to place a lower bound on paleo-sea-level.

Archaeology

The archaeological excavations and preliminary artefact analyses document anthropogenic deposits with sparse artefact assemblages (Table 2) on the top of carbonate sands. The SAT-1 archaeological test unit (Figure 3) depicts this sequence with layer V comprising non-cultural carbonate sands separated by an irregular, clear boundary (2.5–7.5 cm) from an anthropogenic loamy sand, layer IV. The irregular boundary between layers V and IV may result from human activity on the unconsolidated sand surface. A fire feature (Feature 1) within layer IV rests upon layer V, and a date range obtained from *Cocos nucifera* nutshell charcoal in the fire feature, 554–512 cal. BP (see Table 1), is definitive evidence of human presence and provides a *terminus ante quem* for the marine sand deposit contacting the sandy loams as described in cores P113 and P104 above, at this distance inland from the current shoreline. A similar date range, 652–580 and 571–549 cal. BP, was obtained from unidentified charcoal recovered in Core 8, less than 1 m from the archaeological excavation, in the same layer IV sediment (described in 2013 as sandy loam). The variation between layers IV and III, separated by an abrupt boundary, indicates a significant

change in depositional regime, although still anthropogenic, with layer III's predominantly terrigenous sediments deposited through colluvial and possibly water-transport agents related to nearby ephemeral water-courses and swamps (currently within about
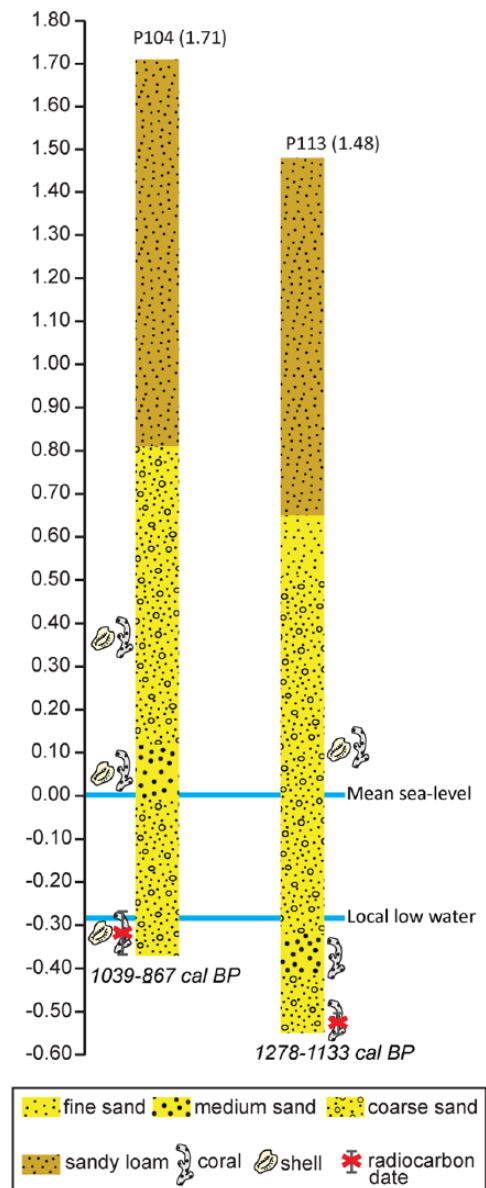

Figure 2. Cores P104 and P113 are representative of the subsurface coastal environment. Elevations (m) are referenced to mean sea-level based upon tidal values recorded at the Apia tide gauge.

Table 1. Radiocarbon data for Satitoa samples.

Provenience	Lab no.	Sample material	$^{13}C/^{12}C$ ratio ($^0/_{00}$)	Conventional radiocarbon age (BP)	Calibrated 2σ age range (BP)[a]
SAT-1, Layer IV, Feature 1 (82–98 cmbs)	Wk-40750	*Cocos nucifera* nutshell	–	523 ± 20	619–612 (2%) 554–512 (93.4%)
Core 8, 60–105 cmbs	Wk-38055	Unidentified charcoal	−24.5	607 ± 20	652–580 (75.3%) 571–549 (20.1%)
Core P104, 200–201 cmbs	NOSAMS-125025	Coral and carbonate sand	−0.61	1420 ± 20	1039–867
Core P113, 200–210 cmbs	NOSAMS-125024	Coral and carbonate sand	−1.08	1670 ± 15	1278–1133

[a]Calibration performed using OxCal 4.2 (Bronk Ramsey, 2009) with the Marine13 curve and a ΔR 28 ± 26 (Petchey et al., 2009) for the coral and carbonate sands, and the Northern Hemisphere curve for charcoal samples (Reimer et al., 2013). The Northern Hemisphere curve was used because the boundary between the northern and southern hemisphere atmospheres lies along the thermal equator or the Inter-Tropical Convergence Zone (ITCZ) (McCormac et al., 2004: 1088), with Sāmoa lying within the limits of the ITCZ.

Table 2. Descriptions of deposits encountered in archaeological test units.

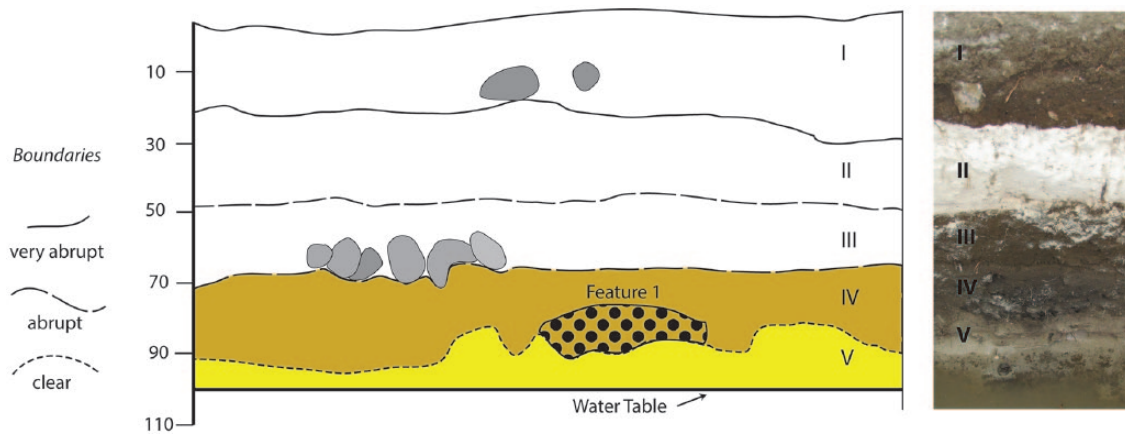| Archaeological unit	Depositional unit	Description	Depositional interpretation
SAT-1	I (0–26 cmbs)	20.5–34.5 cm thick; 10YR 3/2, very dark greyish brown; smooth, very abrupt (<1 mm) boundary; moderate, very fine, subangular blocky structure; silty clay loam, <1% subangular cobbles (6–26 cm), very few micro–medium roots	Anthropogenic deposition, humus with 2009 tsunami carbonate sand inputs
	II (26–51 cmbs)	21.3–28.2 cm thick; 10YR 8/2, very pale brown; wavy, abrupt (1–2.5 cm) boundary; structureless, very fine, single grain; sand, medium to fine, well sorted, many medium–coarse roots	Anthropogenic sand fill
	III (51–74 cmbs)	14.8–24.3 cm thick; 10YR 3/2, very dark greyish brown; smooth, abrupt boundary; weak, very fine, subangular blocky structure; silty clay, 10% subangular cobbles, few micro–fine roots; charcoal flecks	Continued anthropogenic & alluvial/fluvial/colluvial deposition with decreased carbonate sand inputs
	IV (74–94 cmbs)	14.8–27.7 cm thick; 10YR 4/2, dark greyish brown; irregular, clear (2.5–7.5 cm) boundary; weak, very fine, crumb structure; loamy sand, few micro–fine roots, many medium roots, charcoal flecks	First anthropogenic deposition, fire feature at base of unit resting upon V.
	V	Lower boundary unexcavated; 10YR 7/3, very pale brown; structureless, very fine, granular; sand, coarse to fine, poorly sorted; few micro–fine roots	Non-cultural carbonate sand unit identified in cores (e.g. cores 8, P106)
SAT-2	I (0–34 cmbs)	33.6–52.5 cm thick; 7.5YR 2.5/1, black; wavy, abrupt boundary; moderate, very fine subangular blocky structure, loamy sand, 10% gravels (2–4 mm), 10% pebbles (4–6 mm), 5% cobbles, all subangular, common fine–coarse roots, very few micro–very fine roots	Gardening soil, likely same geological depositional unit as II, but increased carbonate sand deposition because of human activity
	II (34–76 cmbs)	20.6–41.6 cm thick; 7.5YR 3/2, dark brown; wavy, very abrupt boundary; moderate, very fine, subangular blocky structure; sandy clay loam, very few medium–coarse roots	Likely colluvial deposition with some possible human activity
	III (76–90 cmbs)	11.1–21.2 cm thick; 7.5YR 4/2, brown; wavy, abrupt boundary; weak very fine–coarse, single grain structure; well-rounded gravel (2–4 mm), 20% very coarse (1–2 mm) poorly sorted subangular terrigenous sand, 10% well-rounded pebbles (4–6 mm)	Slope wash
	IV (90–176 cmbs)	80.4–95.1 cm thick; 7.5YR 4/2, brown; smooth, diffuse (>12.5 cm) boundary; weak, very fine, subangular blocky structure; sandy clay loam, <1% subangular pebbles and cobbles, very few fine roots, few medium–coarse roots, charcoal flecks	Increased terrigenous deposition with minimal evidence of human activity (charcoal flecks)
	V (176–~226 cmbs	Approximately 56 cm thick; 7.5YR 4/2, brown, lower boundary unobserved; weak, very fine, subangular blocky structure; sandy clay loam (increased sand content compared with IV), few medium roots, charcoal flecks	Some terrigenous deposition with minimal evidence of human activity (charcoal flecks)
	VI	Carbonate sands recovered with bucket auger at base of SAT-2 and under the water-table, some sand concreted; subrounded basalt pebbles–cobbles in matrix	Non-cultural carbonate sand unit
SAT-3	I (0–10 cmbs)	Root mat	Complete sediment descriptions not made
	II (10–20 cmbs)	2009 tsunami debris in carbonate sand matrix; wavy abrupt boundary	Complete sediment descriptions not made
	III (20–50 cmbs)	Approximately 30 cm thick; 10YR 3/1, very dark grey; wavy, abrupt boundary; weak very fine subangular blocky structure; sandy clay loam, few micro–fine roots, charcoal chunks	Anthropogenic deposition with artefacts, carbonate sand and terrigenous sediments
	IV	10YR 5/2, greyish brown; loamy sand; other characteristics unobservable because of water-table	Mixture of carbonate sand and terrigenous deposits also identified in geological cores (e.g. P113); no unequivocal evidence of human activity
SAT-4	I (0–14 cmbs)	9–15 cm thick; 10YR 3/2, very dark greyish brown; wavy, abrupt) boundary; moderate, very fine, subangular blocky structure; silty clay loam, very few micro–medium roots; carbonate sand lens within unit	Anthropogenic deposition, humus with 2009 tsunami sands
	II (14–42 cmbs)	16–33 cm thick; 7.5YR 3/2, dark brown; wavy, clear (2.5–7.5 cm) boundary; moderate, very fine subangular blocky structure; sandy clay loam, <1% subrounded pebbles, very few coarse roots, few micro–fine roots, charcoal flecks and chunks	Anthropogenic deposition with artefacts, carbonate sand and terrigenous sediments
	III	10YR 8/2, very pale brown; structureless, very fine, single grain; medium–fine subrounded-subangular sand, very few coarse roots, charcoal flecks (confined to top of unit)	Largely non-cultural carbonate sand unit, charcoal flecks near interface with II and likely derive from human activity during deposition of II (cf. core P106)

Figure 3. South profile of SAT-1 archaeological test pit. Photo shows column including Feature 1 in Layer IV.

Table 3. Artefactual content of excavated deposits. Deposits not listed have no artefacts.

Archaeological unit	Depositional unit	Pottery	Lithics	Shellfish (top four rank orders by shell weight)	Vertebrate fauna	Other
SAT-1	III			*Tridacna* sp., *Turbo* sp., *Conus* sp., *Trochus* sp.	Unidentified mammal	
	IV			*Turbo* sp., *Trochus* sp., *Conus* sp., *Cyprea* sp.,	*Sus scrofa*, unidentified mammal	Fire feature
SAT-2	V			*Codakia* sp., *Purpura* sp.		
SAT-3	III	1 rim and 1 body sherd	14 pcs shatter (21.2 g)	*Turbo* sp., *Cyprea* sp., *Trochus* sp., *Tridacna* sp.	*Sus scrofa, Labridae, Scombridae, Elasmobranchii*, unidentified fish, human (right, lateral orbit fragment)	One-piece shell fish-hook; adze fragment (from nearby geological core (P113))
SAT-4	II	1 body sherd	1 flake	*Cyprea* sp., *Turbo* sp., *Conus* sp., *Trochus* sp.	Unidentified fish and mammal	
	III			*Trochus* sp., *Cyprea* sp., *Pita pellucidis*		
Surface		1 body sherd	3 adze frags			

300 m of excavation unit). The subangular cobbles at the IV–III interface and throughout layer III also indicate a change of transport agent. Charcoal flecking, shellfish and vertebrate faunal remains (see below) in layers IV and III attest to human activity. Layers II and I represent an anthropogenic sand fill layer and modern humic layer, respectively. There is no evidence of post-depositional mixing of layers.

Archaeological test pits SAT-3 and SAT-4 reveal a similar depositional sequence as SAT-1, having marine sand deposits at the base overlain by layers with increasing terrigenous sediments and evidence of human activity. SAT-3 was excavated next to a geological core that encountered an adze fragment and shellfish remains in a sandy loam atop fine carbonate sand (as described from the core sediments). SAT-3 sampled this cultural deposit, although its proximity to the water-table (even with pumping) made it impossible to clearly describe the interface between the cultural deposit, layer III and the presumed non-cultural marine sands of layer IV below (note that the layer designations between different archaeological test pits are not synonymous). All of the deposits in the SAT-3 excavation had a high water content. Presumably, these deposits originally contained less water, and the water content of the sediments increased after deposition of the artefacts and charcoal chunks in layer III as the coastal plain prograded. There is some evidence of mixing between layers II and III in the SAT-3 excavation with small bits of modern material (e.g. plastic, milled timber) in layer III, likely displaced downward through the 2009 tsunami and modern gardening as the area was previously used as a taro plantation.

The lowest layer of excavation at SAT-4 is the largely non-cultural marine sand layer (III), and this is overlain by an anthropogenic sandy clay loam (II) with charcoal flecks and chunks, and a thin, silty clay loam (I) that also incorporates a sand lens from the 2009 tsunami. Layer I can more accurately be described as a poorly developed A-horizon. There is some post-depositional mixing of layers II and III, particularly because of an approximately 4-cm diameter tree root moving down through layer II into layer III. Artefacts, shellfish and vertebrate fauna were recovered from layer II and the upper few centimetres of layer III.

SAT-2 is the only archaeological unit with no artefactual evidence of human activity. The unit was placed on a level area just inland of the slope break from the coastal plain and uncovered approximately 2.25 m of terrigenous loams atop a marine sand layer. One layer (III) represents a slope-wash event. There are charcoal flecks in layers V and IV, immediately above the basal marine sands.

Cultural materials. Artefacts, shellfish and vertebrate faunal remains were recovered from all archaeological excavation units, except for SAT-2 (Table 3). Approximately 2305 g of shellfish remains was recovered with the top four taxa by weight including species typically found in Sāmoan archaeological deposits (e.g. Morrison and Addison, 2008; Nagaoka, 1993), *Turbo* sp., *Tridacna* sp., *Cyprea* sp. and *Trochus* sp. While these are all coral reef dwellers, rocky shoreline and soft sediment species were also recovered, but in lesser amounts. The single largest shellfish deposit was from SAT-3, layer III, with 1188 g recovered from the sandy clay loam. The species composition and sediment textures (e.g. sandy clay loam) of the shellfish deposits indicate that, except for SAT-2, they are not natural death assemblages. The SAT-2 shellfish assemblage consists of two species and
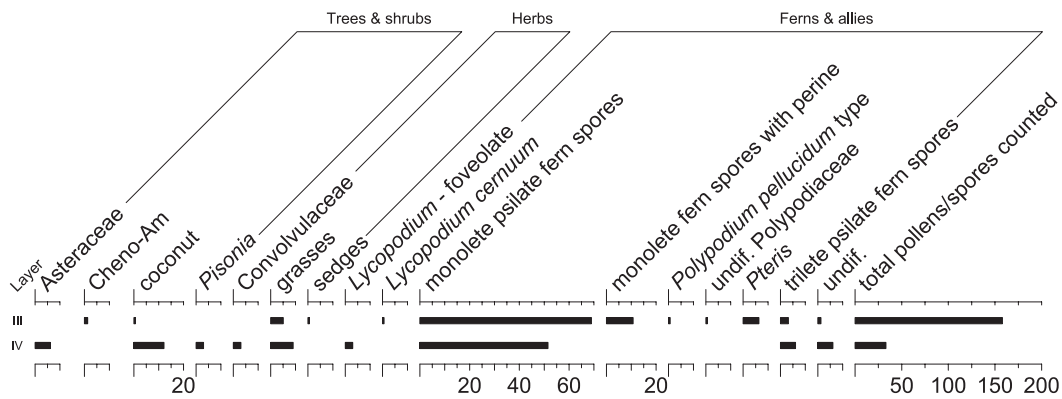
Figure 4. Pollen percentage diagram of samples from SAT-1, layers IV and III.
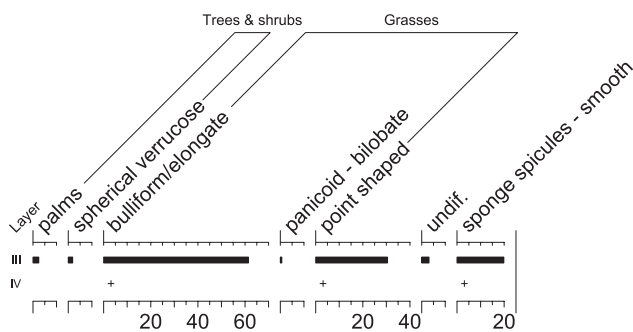

Figure 5. Phytolith percentage diagram from SAT-1, layers IV and III (+ = present in very low concentration; sponge spicules not included in count (at least 150 phytoliths) from which percentages calculated).

unidentified fragments amounting to approximately 10 g and may be natural beach shell incorporated into the deepest deposits that overlie the marine sands. Vertebrate faunal remains were recovered from all archaeological units except test unit 2. The assemblage is small, approximately 38 g of material. In addition to unidentified fish and mammal, pig (*Sus scrofa*) is found in the deepest cultural deposits at SAT-1 and SAT-3, while the richer SAT-3 assemblage also contains nearshore and benthic fish taxa (*Labridae* and *Scombridae*), as well as shark or ray (*Elasmobranchii*). The SAT-3, layer III assemblage also contained a fragment of a human right lateral orbit. No other human remains or evidence of any burials was encountered, although there are almost certainly burials in the area that have been impacted by centuries of gardening and other disturbances.

Pottery sherds, a shell fishhook, adze fragments, lithic shatter and a flake were recovered from archaeological excavation units and the modern surface in the general area of the excavation units. The four pottery sherds, three of these from excavated contexts, are all without surface modification. Although not directly dated, the pottery sherds likely do not significantly pre-date the fire feature (i.e. about 500 cal. BP) as the fire feature was encountered in the basal cultural deposit within the study area, resting on non-cultural sand. The sherds were recovered from the same cultural deposit containing the fire feature, albeit from different excavation units (see Table 3), and there is no evidence, such as rounded sherd margins, of significant post-depositional movement of the sherds. The single rim sherd is of a bowl form, in-curving and flat-lipped. Aplastics in the sherd pastes viewed under low-power magnification include quartz, ferromagnesian mineral grains and trachytic grains, all locally available, although more detailed petrographic and chemical work is necessary to confirm sherd raw material provenience.

The adze fragments are made from fine-grained rock and two have identifiable cross-section shapes, one triangular and one quadrangular, although none are complete to a degree that allows assignment to previously described adze types such as those described by Green and Davidson (1969). The lithic shatter and flakes (no evidence of use as tools) are of similar fine-grained material as the adze fragments.

The single complete shell fishhook is small, 15.5 mm wide from the exterior margins of the shank limb to point limb and 23.2 mm tall from the base of the bend to the top of the shank, and would have been used for smaller nearshore taxa. An exterior notch near the top of the shank serves as a lashing device.

Plant microfossils

Pollens and spores are abundant in the sample from SAT-1, layer III, and sparse in the sample from layer IV; hence, a lower count was made for the latter (Figure 4). Microscopic fragments of charcoal are abundant in both samples. The pollen assemblages are dominated by ferns with monolete spores, reflecting local ground fern growth. Several Sāmoan fern species have this spore type, which is difficult to differentiate. Pollens of grasses (Poaceae) and coconut (*Cocos nucifera*) also feature in both samples. Trees and shrubs record very small amounts of pollen.

Phytoliths were sufficiently preserved for analysis only in the sample from layer III, with the assemblage dominated by grasses (Figure 5). Trees and shrubs record very small amounts of phytoliths. A large amount of sponge spicules, another biosilicate, was also present in this sample. The layer IV sample contained very low concentrations of highly degraded grass phytoliths and sponge spicules. Starch analysis did not reveal any significant starch preserved in the two samples.

Discussion and conclusion

In the central Pacific, several researchers predict that the Holocene sea-level highstand occurred approximately 4000 BP at an elevation of 1.0–2.5 m above present sea-level (Dickinson, 2001; Goodwin and Grossman, 2003; Mitrovica and Peltier, 1991). Cores P113 and P104 show that carbonate sands comprising the coastal plain have an increasing age with depth as well as distance from the current shoreline. We interpret this pattern as an indicator that the sedimentological architecture of the coastal plain is the product of a retreating (regressive) shoreline that formed with the fall of a higher sea-level that must have peaked prior to our earliest date, probably associated with the Holocene highstand. Lacking a clear sea-level indicator for the peak phase of the highstand, we adopt the published values of 1.0–2.5 m above present MSL for this region. This would have placed the shoreline against the clay upland, likely prior to our earliest carbonate sand date of 1278–1133 cal. BP. During the highstand, there would have been a shallow water shore zone adjacent to the clay upland, in the location of the modern coastal plain. Typical of all fringing reef

shore zones, this environment was probably characterized by poor water quality, occasional anoxia tied to heavy rainfall events, persistent turbidity from upland runoff and wave erosion of the clay embankment, and daily thermal extremes (Fletcher et al., 2008). This shallow area would likely not have held rich resources for marine foragers. Further offshore, however, there was probably a flourishing reef ecosystem as water quality would not be limiting and the highstand would have added 1–2 m of additional water depth (compared with present) over the reef so that wave-scour would have been less likely to impede reef growth. Following the highstand, as sea-level lowered and the shoreline migrated seaward, a narrow carbonate beach developed upon a zone of colluvial- and surf-rounded basalt (found at the base of our cores), similar to what was observed at the Mulifanua site (Dickinson and Green, 1998). As sea-level fell, the narrow carbonate beach grew with time, developing dunes, revealing an expanding coastal plain that displaced the shallow water shore zone and creating an environment with increased land surface area available for settlement and providing easier access to the ocean. Today, the nearshore marine environment is variable with a wide lagoon in places, protected reef systems in the lee of offshore islands and similar coral cover before and after the 2009 tsunami (McAdoo et al., 2011).

Studies by Dickinson and Green (1998) and Goodwin and Grossman (2003) characterized Holocene coastal evolution at Mulifanua (western 'Upolu) and Maninoa (southern 'Upolu), respectively (see Figure 1b). Dickinson (2007) modelled differential subsidence of 'Upolu, which accounts for a decrease in subsidence rates with increasing distance from the volcano load at the nearby island of Savai'i. Subsidence rates were calculated by dividing modelled sea-level for a specified time by the age of the archaeological or geological unit. The model takes into consideration additional subsidence that may be required to account for vertical displacement of a feature from where it was believed to have formed. For example, at Mulifanua, beachrock (an intertidal paleoshoreline feature) was found at 2.25 m below modern MSL and dated 2750 years BP. Sea-level at this time was modelled to be 1.2 m higher than present (Mitrovica and Peltier, 1991). Mulifanua, located approximately 20 km from Savai'i, is thus modelled to have a subsidence rate of 1.25 ± 0.15 mm/yr (Eq. 1), while Maninoa located 30 km farther from Savai'i is modelled to have a subsidence rate of 0.52 ± 0.12 mm/yr (Dickinson, 2007):

$$\frac{\text{Depth below elevation of formation + sea level}}{\text{Age}} \qquad (1)$$
$$= \frac{2.25\,\text{m} + 1.2\,\text{m}}{2750\,\text{yr}} = 1.25\,\text{mm/yr}$$

Dickinson (2007) inferred from this pattern a subsidence rate of less than 0.1 mm/yr for the east end of 'Upolu where our Satitoa study area is located. Based upon this subsidence rate and assuming that the carbonate sands we have cored represent an intertidal feature and do not require additional subsidence to account for dry occupation, sea-level between our marine sand date ranges of 1278–1133 and 1040–866 cal. BP would have been between 0.38 and 0.3 m above present. Our data seem to support Dickinson's (2007) subsidence rate as the projected value of sea-level falls within Mitrovica and Peltier's (1991) modelled range for this time period. With additional dating throughout the vertical profile of our cores, and further compositional analysis, a more accurate subsidence rate may be generated.

While the geological evidence suggests coastal plain formation began after approximately 1200 cal. BP, the depositional, artefactual and microfossil evidence indicates a relatively small human presence here about 700 years later. Evidence for a human presence around 500 cal. BP includes a radiometric date on a fire feature originally placed on top of the non-cultural sand surface, artefacts, shell and faunal remains, and charcoal chunks and flecking in the deposits overlying the non-cultural sand layer. The presence in SAT-1, layers IV and III, of sponge spicules reflects partial marine origin of the sampled deposits. The pollen assemblages, however, with the exception of *Pisonia* (littoral) in layer IV, suggest terrestrial as opposed to marine-influenced vegetation. A nearby wetland environment during the formation of SAT-1 layers IV and III seems likely.

The relatively sparse artefactual and faunal remains recovered in excavation indicate infrequent human activity in the area or a small population or both, at least relative to other archaeological deposits in similar settings. To illustrate, on the Tula coastal plain on Tutuila island in American Sāmoa, we (Cochrane et al., 2013; Rieth and Cochrane, 2012) excavated three layers (60 cm total depth) of loamy sands, representing a maximum of 600 years of deposition, atop non-cultural sand in a 1 m × 1 m excavation unit and recovered 391 pottery sherds, 129 lithic artefacts, 10 shell artefacts, over 9 kg of shellfish remains and 6195 vertebrate faunal elements. The amount of material in the Tula deposit is not unusual for its first millennium BC time period, but even considering the likelihood of different depositional processes at Tula and Satitoa, the relative paucity of artefacts recovered from the Satitoa Village excavations indicates a minimal human presence in comparison. The artefacts that were recovered document low-intensity marine subsistence practices, use of vertebrate terrestrial fauna, pigs and possibly other mammals, minimal pottery use and lithic tool use and manufacture. Macro- and microscopic charcoal particles indicate burning activity in the area and, coupled with the presence of grass pollen, large amounts of ground fern spores and small amounts of tree and shrub pollen demonstrate landscape disturbance. The very large amount of grass phytoliths and small amount of tree and shrub phytoliths in the sample from SAT-1 layer III support this. Because of the small number of samples analysed from a single test pit, the lack of microfossil evidence of introduced cultigens, such as banana, yam and taro (see, for example, Horrocks and Nunn, 2007; Horrocks et al., 2009), does not mean that these crops were not present and more microfossil samples are required to determine the diversity of plants in the environment. Pollen of coconut (*Cocos nucifera*) palm was identified in both layers IV and III, but it is uncertain whether this is from an indigenous or introduced type of this species (Whistler, 2009).

The excavated and cored deposits span a little more than 700 m of coastline, and our results are immediately applicable to this area, slightly greater than 10% of 'Upolu's eastern coastline between Lalomanu and Amaile villages. These results suggest that would-be Lapita colonists, at about 2800 years ago, would have encountered little or no coastal plain in the area with the uplands only easily accessible from inland. The immediately adjacent shallow water zone would have been resource poor, but a resource-rich reef ecosystem could likely be found further offshore. By approximately 500 years ago, possibly centuries after a coastal plain was present, there is evidence of only a small human presence. These findings support previous work suggesting Sāmoa was colonized by small and isolated groups (Burley and Addison, 2015; Cochrane et al., 2013) and that this limited colonization of Sāmoa is related to a lack of suitable land forms and habitats (Rieth et al., 2008). Two additional ramifications of these findings are of interest. First, if the lack of Lapita sites is an accurate measure of a very small original population in Sāmoa compared with nearby archipelagos, this begs the question of Lapita colonists' population structure. What were the variable density, distributional, migratory, reproductive and interaction characteristics of the populations that colonized Remote Oceania (cf. Clark and Bedford, 2008)? Identifying Lapita colonists' population structure will be necessary to understand, for example, the later development of similar Polynesian populations in Sāmoa and Tonga from Lapita populations (Burley, 2013), despite the increasing evidence (Burley et al., 2011; Cochrane et al., 2013) of relatively little interaction between those archipelagos after colonization (at least until about 500 years ago). Second,

the likelihood that the coastal plain in our study area was only sparsely inhabited perhaps 700 years after it began to form suggests that population pressure, that is, the ratio between population density and the density of available resources (Keeley, 1988: 373), was low throughout much of 'Upolu's human history (cf. Burley, 2007 for Tonga). This likelihood does not support the proposal that population pressure in West Polynesia, as it applies to suitable agricultural land, was a factor leading to the colonization of East Polynesia (Kennett et al., 2006). The colonization of East Polynesia from West Polynesian began at least several hundred years before the Satitoa coastal plain was inhabited (Wilmshurst et al., 2011). Future research on the issues of Lapita population structure and later demographic change in Remote Oceania will add much to our understanding of Sāmoan prehistory.

Acknowledgements

Funding

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