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Hypotheses to Explain the Few Early Coastal Archaeological Deposits in Sāmoa: Preliminary Evaluations

Ethan E. Cochrane[a*], Aumua Ausilafai Matiu Matavai Tautunu[b], Robert J. DiNapoli[c]

[a]The University of Auckland, Anthropology, Private Bag 92019, Auckland 1142, New Zealand

[b]The National University of Sāmoa, Centre for Samoan Studies, P.O. Box 1622, Le Papaigalagala Campus, To‘omatagi, Sāmoa

[c]Department of Anthropology, University of Oregon, 1218 University of Oregon, Eugene OR 97403, USA

*corresponding author: e.cochrane@auckland.ac.nz

Abstract:

The Remote Oceanic archipelagos from Vanuatu to Sāmoa were first occupied 3000 years ago by populations with Lapita pottery at over 100 colonization sites. In Sāmoa, however, the first millennium of settlement is comprised of only a few isolated archaeological sites, and only one with Lapita pottery. This unique archaeological record is typically explained as a result of isostatic subsidence that destroyed or displaced more numerous coastal colonization sites. Three additional hypotheses may account for this pattern. First, few coastal flats may have existed for settlement, limiting occupation of the archipelago. Second, terrestrial geological processes may have destroyed what were once more numerous sites. Third, the few early and isolated sites in Sāmoa may reflect a small population of colonists resulting from demographic processes, including wave-front population density, or the Allee effect. We conducted a preliminary examination of the first two alternative hypotheses through a programme of coring and excavation across three coastlines on ‘Upolu island, Sāmoa. Sub-surface sediment data suggest both hypotheses may be valid explanations in different coastal settings. We propose additional research to test this possibility.

Keywords: Sāmoa, Lapita, beach ridge, colonization

Highlights:

- Subsurface sampling in three contrasting coastal areas on ‘Upolu island.
- Sedimentological and chronological data reveals varied depositional histories
- Lack of coastal flats and geological destruction may explain archaeological record

1.0 Introduction

Lapita pottery sites in Remote Oceania date between approximately 3000 and 2700 cal BP (Sheppard et al. 2015; Rieth and Cochrane 2018) and are spread across beach ridges of the region’s archipelagos (Dickinson 2014), recording first human colonization of the southwest Pacific (Figure 1). In Sāmoa there is a distinct lack of Lapita sites, defined by the eponymous ceramics, a puzzle that has preoccupied archaeologists for almost 50 years (e.g., Clark 1996; Burley and Addison 2018; Green 1974, 2002). Post-Lapita sites, including deposits dated to the first 1000 years of Sāmoan settlement are also extremely limited compared to nearby Tonga and Fiji (Cochrane et al. 2013; Clark et al. 2016). The generally accepted explanation for Sāmoa’s unique archaeological record of the first 1000 years is that relative island subsidence has destroyed or displaced the archaeological deposits that must have existed in greater numbers along coastlines (Dickinson and Green 1998; Green 2002). This has been demonstrated for Sāmoa’s single Lapita pottery site at Mulifanua on ‘Upolu’s northwest coast (Figure 1; Dickinson 2007). The Mulifanua deposit containing Lapita pottery, lithics, and faunal remains dates to ca. 2750 cal BP and was discovered over 100 m offshore beneath a layer of beachrock during mechanical excavation for a car-ferry berth (Petchey 1995, 2001; Leach and Green 1989). Additional geoarchaeological and geological studies have shown that ‘Upolu is subsiding due to Savai‘i island’s lithospheric loading, and it is subsiding at a faster rate in the west near Savai‘i than in the east (Kane et al. 2017; Goodwin and Grossman 2003), although possible tectonic influences on differential subsidence along a north- to south-coast gradient have not been investigated.

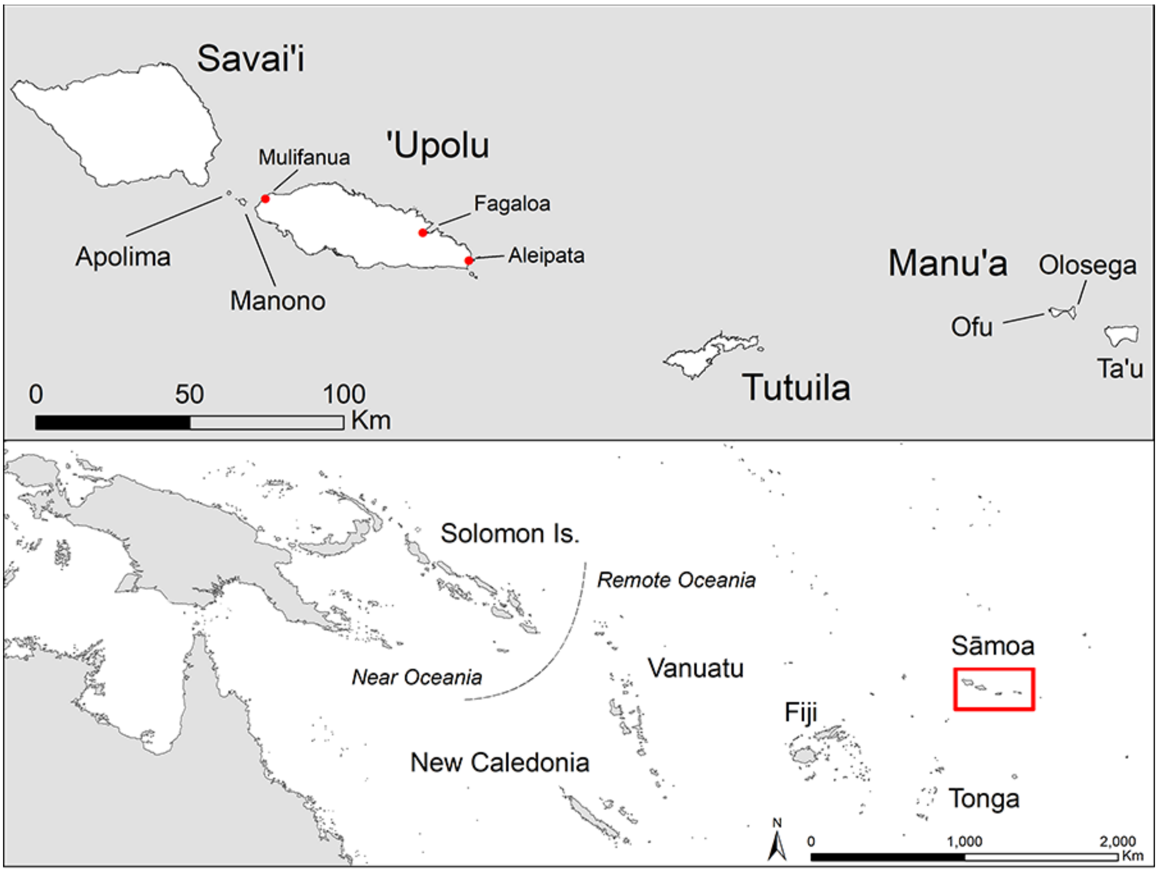

Figure 1. The southwest islands of the Pacific Ocean with the islands of Sāmoa and project areas (inset).

Island subsidence, however, may not be the correct explanation for the *general* lack of archaeological sites dating to first 1000 years of Sāmoan settlement. After extensive archaeological research on Tutuila island, the oldest documented site dates to approximately 300 years after Mulifanua (Rieth and Hunt 2008). In the small islands of the Manu‘a group farther east (Figure 1), Clark et al.’s (2016) Bayesian model suggests that the start of human occupation on Ofu begins *2774-2647 cal BP* (95.4% HPD), just after or coeval with occupation of Mulifanua (see also Petchey and Kirch 2019). Tutuila and the Manu‘a group are not subsiding under influence from Savai‘i as they are too far east, although Dickinson (2007) notes that other possible isostatic and eustatic effects have not been thoroughly investigated. Kirch (1993), too, has proposed that volcanic activity around Ta‘u may have caused the burial of early cultural deposits there by over 3 m of sediment. Therefore, other explanations besides island subsidence are necessary to account for the negligible archaeological record throughout Sāmoa for the first 1000 years.

A possible explanation has been offered by Reith and colleagues (2008). Their *coastal flats* hypothesis proposes that there were very few sandy coastal flats (one form of beach ridge; see Dickinson 2014) in Sāmoa earlier than approximately 2300-2000 cal BP. As these landforms were favoured for occupation elsewhere in the Lapita and early post-Lapita range, would-be colonizers may have largely avoided Sāmoa for other islands where sandy coastal flats were prevalent. A second hypothesis proposes that terrestrial geological processes may have destroyed what were once more abundant archaeological sites in the first millennium of Sāmoan settlement. This *terrestrial destruction* hypothesis is not mutually exclusive with relative sea-level rise. A third hypothesis was proposed by Cochrane et al. (2013) who suggest Sāmoan colonists were both few in number and relatively isolated in different areas of the archipelago, such that the lack of Lapita and immediately post-Lapita sites accurately reflects demography. More recently, Cochrane (2018) further developed this *demographic* hypothesis, suggesting that the Allee effect (Allee et al. 1949; Courchamp et al. 1999) provided a mechanism by which small, isolated populations could experience low or negative growth due to a reduction in the number of cooperative interactions between individuals.

Here we report a preliminary investigation of the coastal flats and terrestrial destruction hypotheses. We deployed auger cores and excavation trenches in coastal settings of ‘Upolu, including Mulifanua, Fagaloa, and Aleipata (Figure 1). Our work supports the coastal flats hypothesis, but we argue that additional work is necessary to thoroughly test this and the terrestrial destruction hypothesis. We discuss how this additional work can best proceed.

2.0 Methods

Auger cores were excavated to identify subsurface layer characteristics and other data useful for preliminary reconstructions of paleocoastal landforms and depositional histories. Auger cores were generally placed in transects perpendicular to current coastlines and across the slope break from the coast to the interior. Auger locations were recorded with a GPS unit to approximately 0.5 m horizontal precision. Standard procedures were used to recover cores using an 8 cm diameter bucket. As sediments were not examined in situ, they were described using an abbreviated United States Department of Agriculture (USDA) system and grain sizes were estimated using the Wentworth scale. Layer transitions were described when possible. All layer data for each core are available at Cochrane et al. (2019). Similarly labelled layers (e.g., Layer III) in different cores in this dataset do not necessarily represent the same depositional unit.

Considering the coastal flats hypothesis, we also conducted geostatistical interpolation analyses on the most recent extent of subsurface carbonate sand layers. We modelled only the most recent extent as correlating the basal depths of theses layers from different cores was not possible due to large variation in the distinctiveness of lower boundaries. These geostatistical interpolations provide foundations for further geoarchaeological research (e.g., Morrison et al. 2018) to be coupled with detailed chronologies. We conducted Ordinary Kriging using either a Gaussian semivariogram model or a spherical semivariogram model. Models were selected to best optimize the fit between the sample and model variogram. Analyses were conducted in R (R Core Team 2017) using the gstat package (Pebesma and Heuvelink 2016). All code, core descriptions, GIS and other data needed to reproduce these analyses are available at Cochrane et al. (2019).

3.0 Results

3.1 Mulifanua

A submarine Lapita assemblage approximately 115 m offshore has already been identified at Mulifanua (Dickinson and Green 1998; Petchey 1995), but terrestrial archaeological excavation has never been conducted. Twenty-one auger cores were placed within an approximately 0.28 km area in Mulifanua village (Figure 2), primarily to the evaluate the terrestrial destruction hypothesis, but also to provide information on the possible extent of the paleo beach-ridge. Median core depth was 1.24 m, with a maximum of 2.63 m. Cores placed in the south-western portion of Mulifanua, and within about 100 m of the current coastline, typically revealed loamy sediments grading into sands. This area is also low-lying, swampy and the water-table was encountered between 0.6 and 0.9 m below ground. Cores here were abandoned at variable depths, typically about 1.4 m (see supplementary data at Cochrane et al. 2019), due to subsurface water that prohibited recovery of sediment in the auger bucket. The coastal-inland width of this low-lying area is variable across the village and silty clay sediments with basalt cobbles and boulders were encountered in cores placed inland of it, on the slope-break leading to higher elevation (cores 5, 6, 9, 10). These inland cores were all abandoned before reaching 1 m due to impassable rocks.

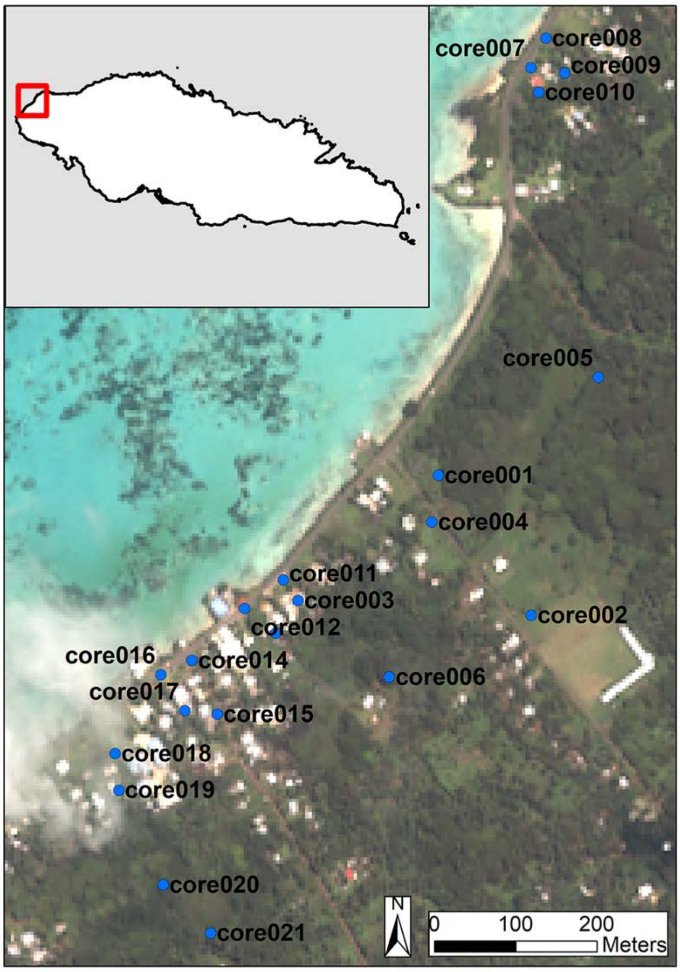

Figure 2. Mulifanua project area, ‘Upolu, Sāmoa.

Cultural material encountered in the cores amounts to archaeological shell in the top layer of core 1, and charcoal chunks and staining in cores 9 (at 0.9 m below surface) and 13 (from 0.74 to 1.4 m below surface). The charcoal was not collected as it was not clearly associated with a particular archaeological event. Aside from these finds, the cores reveal no clear evidence of human presence in any of the strata below the surface layer.

The lack of subsurface finds contrasts with Dickinson and Green’s (1998:243) characterisation of the Mulifanua offshore Lapita deposit as a terrestrial coastal midden. This midden subsided into the tidal zone after which superposed carbonate sand formed into beachrock. Possible beach rock was encountered in core 7 at approximately 1.5 m below the land surface, but this appears too shallow to be the same formation capping the Lapita deposit. Only Core 1 attained a depth approaching the Lapita deposit depth and revealed carbonate sand strata, but this core did not encounter beachrock or cultural materials. Multiple cores did, however, reveal sand sediments similar to that stratigraphically below the offshore Lapita deposit, carbonate sand with basalt pebbles and corals as found in Cores 4, 11, 17, 19, and 20. Taking these observations together, the auger cores suggest that a similar depositional environment of reef and shell derived carbonate sands with minor basalt inputs has prevailed in some coastal areas of Mulifanua since Lapita times up to the interface of the carbonate sand layer and the overlying terrigenous deposits identified in the cores. The top surface of this carbonate sand layer is modelled from Cores 1, 3, 7, 11-15, and 17-20. The Kriged interpolation of the depth of carbonate sand deposits within the Mulifanua cores reveals relatively shallow depths (e.g., 0.60-0.70 mbs) in the southwestern and northeastern portions of the survey area and deeper deposits (e.g., 1.40-1.60 mbs) in the central region of our study area (Figure 3).

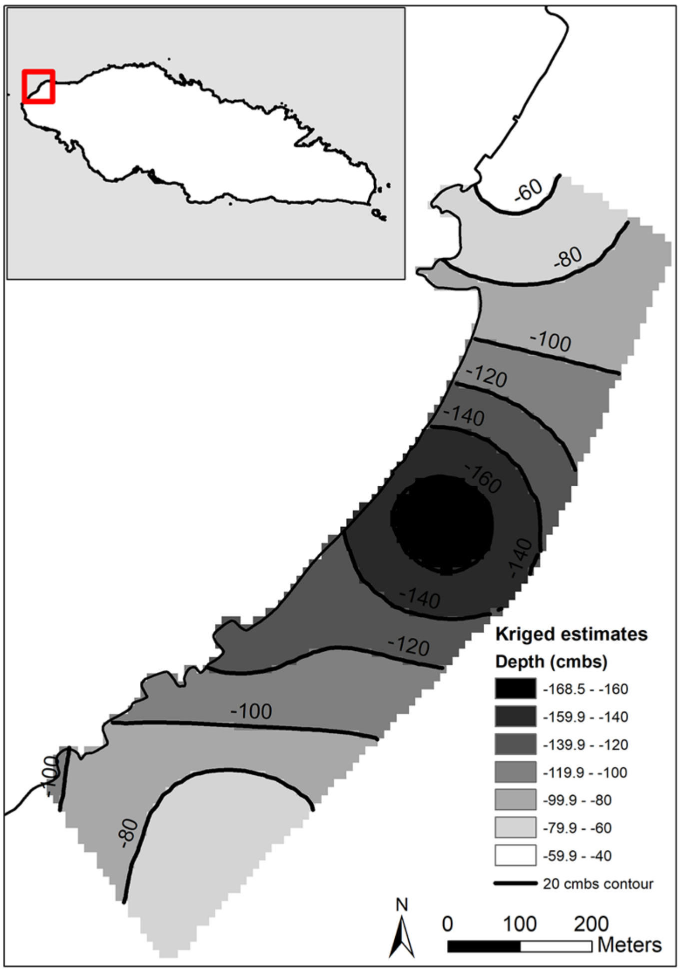

Figure 3. Kriged interpolation of the top of the Mulifanua subsurface carbonate sand deposit.

3.2 Fagaloa

Twenty auger cores were placed in four villages spread along approximately 2 km of coastline in Fagaloa (Figure 4). Median core depth was 1.26 m, with a maximum of 2.34 m. At the western end of the coastline in Talefaga Village, cores 14 and 18 reached a maximum depth of 1.45 and 1.89 m below the surface, respectively, after encountering impassable rock. Both cores contain carbonate sand sediments in the upper layers, a result of modern fill episodes (related by landowners), and lower layers of increasing clay content, and basalt gravels and cobbles. Charcoal is found throughout both cores. To the east in Maʻasina Village, cores 10, 13, and 20, all within 25 m of the ocean, encountered loams and sands (of both basaltic and carbonate composition), some layers with charcoal, but no clear evidence of occupation (cf., Morrison et al. 2018). These cores were excavated to a maximum depth of 1.8 m and were abandoned as increasing subsurface water prohibited recovery of sediment in the auger bucket.. Cores 11 and 12, 100 and 150 m inland respectively, encountered features associated with the present village (core 11), and a colluvial deposit (core 12), and both were abandoned due to impassable rock at 0.84 m and 1.26 m, respectively.

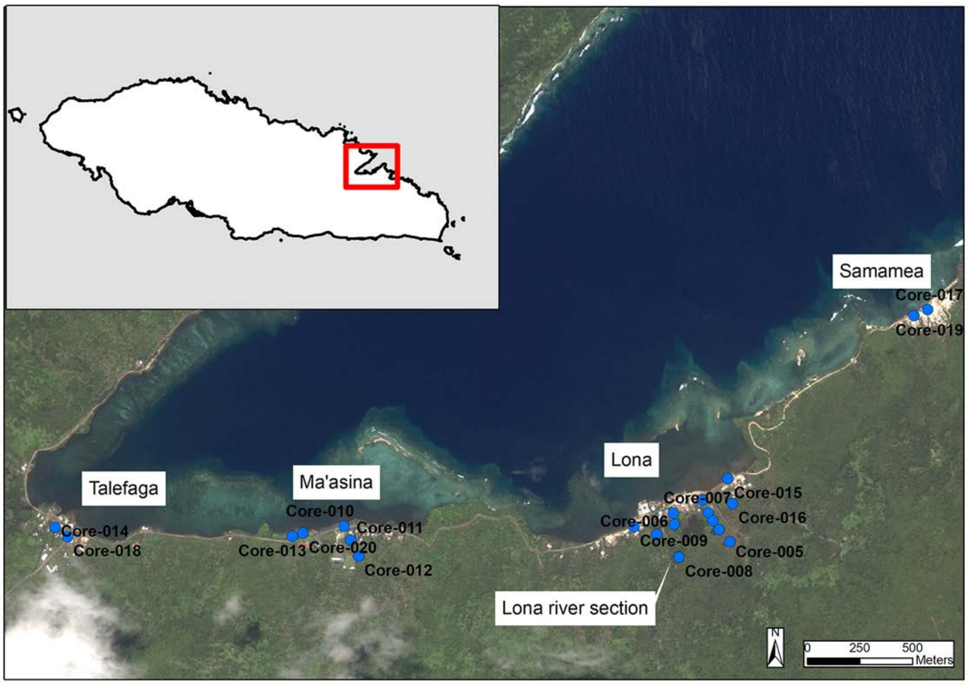

Figure 4. Fagaloa-tai project area, ʻUpolu, Sāmoa.

The majority of Fagaloa cores were placed in Lona, the largest village along this coastline. Cores (except core 9) were placed in transects running coast-inland and document layers of mostly clays and clay loams with an increasing abundance of larger sized basalt clasts with depth (e.g., gravel, cobbles). Maximum core depths varied greatly, some reaching 2 m, while others were abandoned at less than a metre. All cores were abandoned due to impassable rock, or after reaching the water table that prohibited recovery from greater depths. Charcoal, some deposited in thin bands, was encountered in cores 3-5, and 7.

A stratigraphic section exposed by stream-incising at the western end of the village was faced, profiled, and samples were obtained for charcoal and plant microfossil analysis. The depositional sequence revealed by the section (Figure 5 and Table 1) shows anthropogenic deposits, including large-scale burning events, atop alluvial boulders approximately 1.5 m below the ground surface. Like the cores (e.g., Cores 3-8) the stream section reveals increasingly cobbly deposits with depth. The burn events contain charcoal from short-lived species dating to 1173-962 cal BP (Beta-448392, 95.4%) for the lower Lens B, and 539-482 cal BP (Beta-448393, 95.4%) for the upper Layer II (Table 2). Charcoal from the approximately 1000 cal BP burn deposit includes breadfruit (*Artocarpus altilis*), a Polynesian introduced crop, Malvaceae and unknown hardwood, while the ca. 500 cal BP burn deposit also includes *A. altilis*, *Calophyllum* sp., cf. *Kleinhovia hospita*, and Fabaceae.

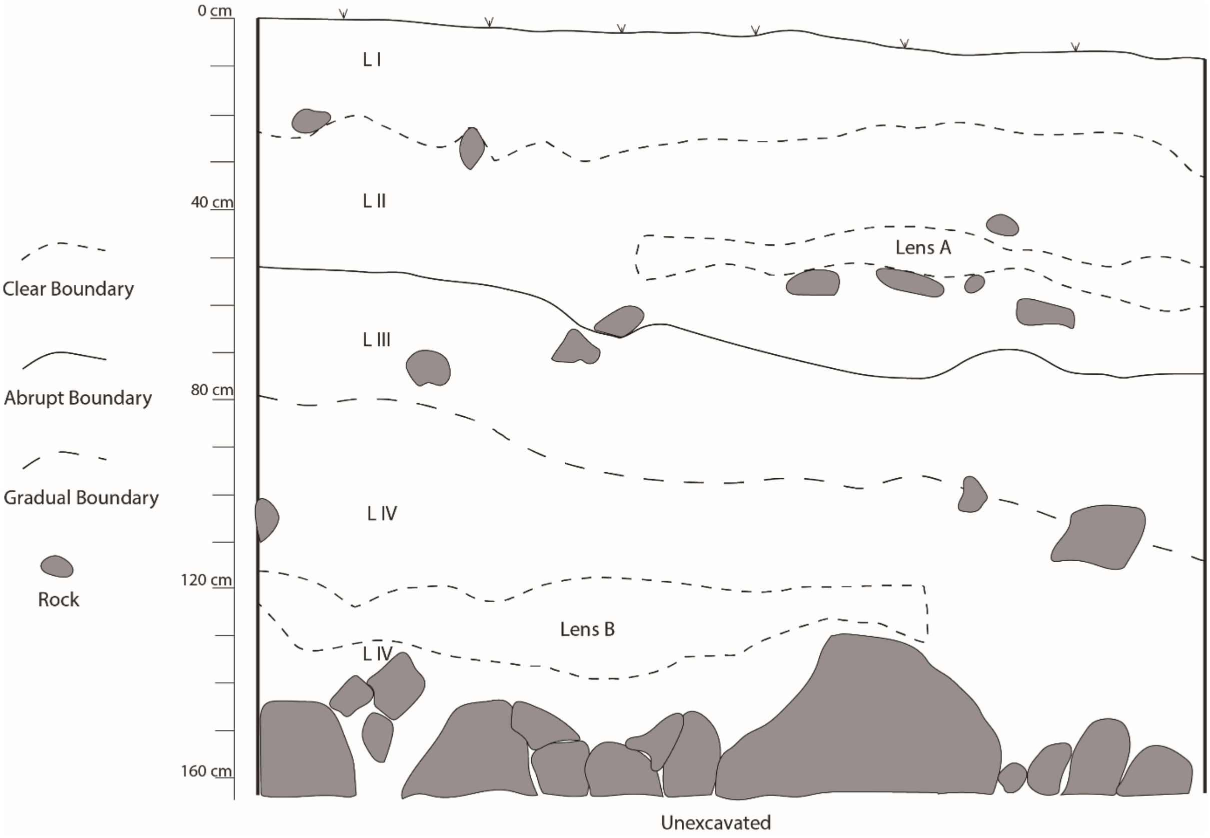

Figure 5. West profile of Lona river section, Lona, Fagaloa-tai, ‘Upolu.

Table 1. Archaeologically identified deposits in Lona river cut.

Depositional Unit	Description	Depositional interpretation
I	10YR 3/2; sandy clay loam; clear, wavy boundary; very fine sub-angular blocky structure; very friable consistence; few micro roots; < 10% gravels – cobbles, rounded – well-rounded; charcoal flecks	Recent topsoil
II	10YR 2/1; sandy clay; abrupt – gradual, wavy boundary; very fine sub-angular blocky structure; friable consistence; very few micro roots; ~ 10% gravels – cobbles, very angular – well-rounded; abundant charcoal chunks, flecks, staining	Anthropogenic large-scale burning
Lens A	10YR 3/2; sandy clay; clear boundary; very fine, sub-angular blocky structure; very friable consistence; no roots; <10% gravels – pebbles, sub-angular – well-rounded;	Deposit of Layer III within Layer II suggesting possibly associated with disturbance from Layer II event
III	10YR 4/3; sandy clay; gradual, wavy boundary; very fine, sub-angular blocky structure; friable consistence; no roots; <5% gravels – cobbles, sub-angular – well-rounded; charcoal flecks	Anthropogenic origins similar to Layer IV, but with less alluvial input

Lens B	10YR 3/1; sandy clay; clear lower boundary, gradual boundary to profile right; firm consistence; 30-40% gravels – pebbles, sub-angular – well-rounded; abundant charcoal chunks, flecks, staining	Anthropogenic, large-scale burning; lens appears discontinuously along exposed river section
IV	10YR 4/3; sandy clay; clear, irregular boundary; firm consistence; very few, medium roots; 30-40% pebbles – cobbles; sub-angular – well-rounded; charcoal chunks	Combination of anthropogenic & high-energy alluvial deposition

Table 2. Radiocarbon sample data for Lona and Samamea. See Cochrane et al. (2019) for Bayesian estimates for Samamea.

Provenience	Lab No.	Sample Material	$^{13}C/^{12}C$ Ratio ($^{0}/_{00}$)	Conventional Radiocarbon Age (BP)	Calibrated 2 sd age range (BP)*
Lona River Section, Layer II	Beta-448393	cf. *Erythrina* sp. charcoal	-26.0	460 ± 30	539-482 (95.4%)
Lona River Section, Lens B	Beta-448392	cf. *Guioa* sp. charcoal	-25.0	1130 ± 30	1090-962 (86.6%) 1145-1108 (5.6%) 1173-1159 (3.2%)
Samamea, Unit 1, Layer V, 118-130 cmbs†	Beta-472208	cf. *Commersonia bartramia*	-25.1	220 ± 30	309-267 (36.7%) 215-145 (44.7%) 17-0 (14%)
Samamea, Unit1, Layer X, 196-215 cmbs	Beta-472207	Unknown hardwood charcoal	-25.5	280 ± 30	452-447 (0.8%) 438-350 (54.3%) 334-284 (38.2%) 166-155 (2.1%)
Samamea, Unit 1, Layer XII, 242-270 cmbs†	Beta-472206	Unknown hardwood charcoal (Leguminosea-Fabaceae)	-26.9	340 ± 30	481-311 (95.4%)
Samamea, Unit 1, Layer XII, 270-280 cmbs†	Beta-472205	Unknown hardwood charcoal	-29.7	280 ± 30	452-447 (0.8%) 438-350 (54.3%) 334-284 (38.2%) 166-155 (2.1%)

* Oxcal 4.3, IntCal 13 curve (Bronk Ramsey 2017; Reimer et al. 2013)
† sample retrieved in situ within layer sediment at indicated depth range

Two cores (17, 19) were placed in Samamea, the eastern-most village in Fagaloa-tai, and retrieved sediment to depths of 2.34 m and 1.52 m, at which point they encountered impassable rock. These cores uncovered a deep sequence of (carbonate) sandy deposits with charcoal and shellfish food remains. A 2 x 1 m test unit was excavated nearby to further explore the area. The excavation trench (Figure 6 and Table 3) revealed a depositional sequence, comprising cultural colluvium with charcoal, lithic artefacts, shell and bone, interspersed with marine deposits, some with high-energy inputs. Dates (Table 2) obtained on charcoal in the cultural deposits were modelled in OxCal v.4.3.2 (Bronk Ramsey 2017) using a sequential multi-phase model to estimate the start of deposition, and the ‘Span’ command was used to estimate the overall duration of the entire deposit. The agreement index for the model is 97.5 and 102.7 overall. The results indicate rapid deposition, with the lowest cultural layer (XII) excavated to 2.8 mbs most likely originating between *479-304 cal BP* (95.4% HPD) and an estimated span of 0-367 years (95.4%). OxCal script and modelled results of this analysis are in Cochrane et al. (2019). Subsurface layer depth interpolation was not undertaken with the Fagaloa sediments due to the difficulty of correlating layers in cores over any likely meaningful spatial extent.

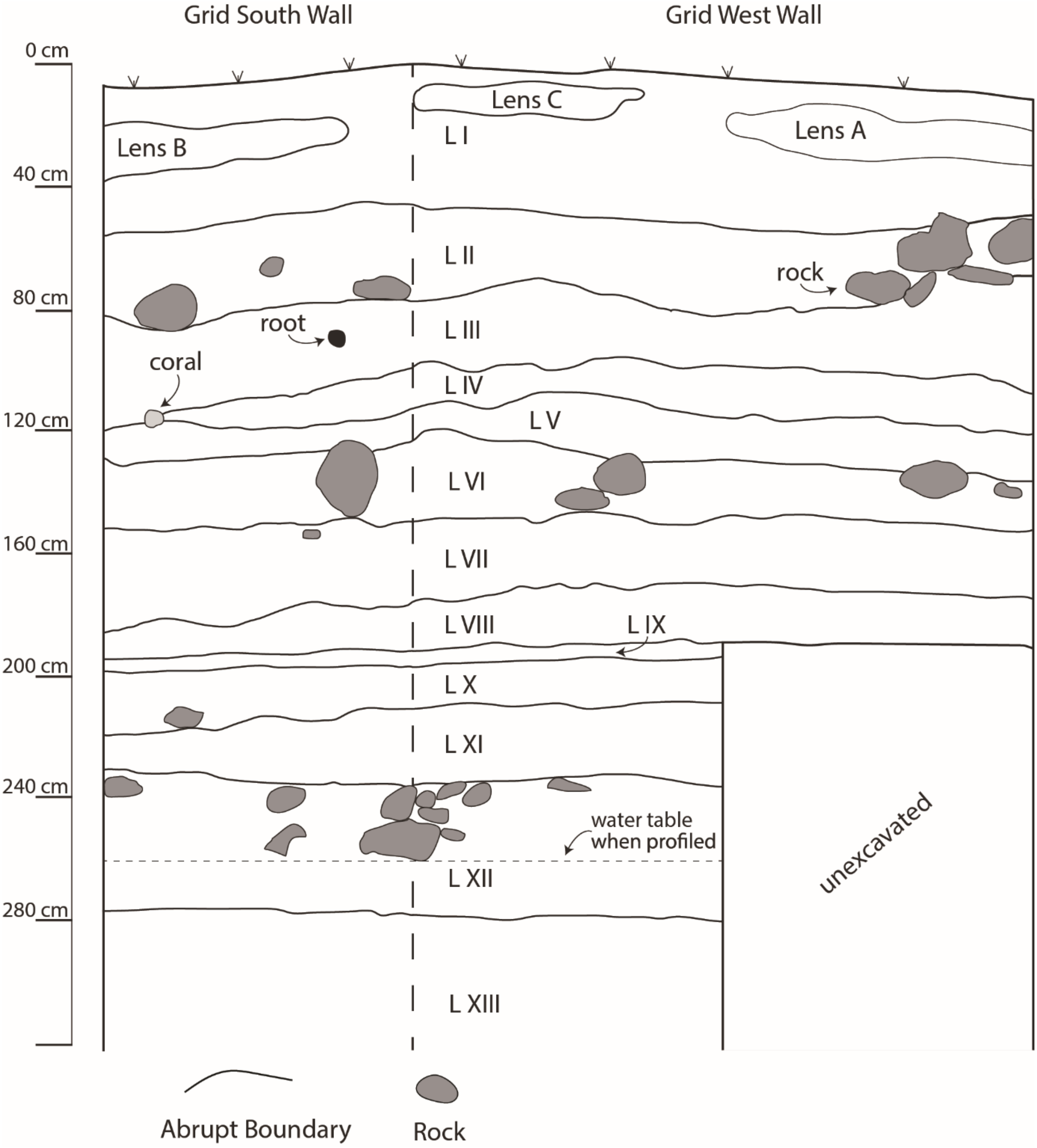

Figure 6. South and West walls of Test Unit 1, Samamea, Fagaloa-tai, ‘Upolu.

Table 3. Archaeologically identified deposits in Samamea excavation.

Depositional Unit	Description	Depositional interpretation
I	2.5Y 6/3, light yellowish brown; abrupt (1 mm – 2.5 cm), smooth, lower boundary; weak, fine, crumb structure; very fine - medium (all sizes use Wentworth scale) sand; loose dry-consistence; very few medium roots; < 1% pebbles, basalt, not spherical & rounded (sphericity 0.5, roundness 0.7; Krumbein [1963]); ~ 5% pebbles, coral, not spherical & subangular (0.5, 0.3). Lens A: 5YR 2.5/2, dark reddish brown; abrupt, wavy lower boundary; weak, very fine, subangular blocky; sandy clay loam; very friable moist-consistence; ; < 1% pebbles, basalt, not spherical & subrounded (0.5, 0.5); ~ 5% pebbles, coral, not spherical & subangular (0.5, 0.3); Lenses B & C: same as A, but greater than granule-sized clasts consist of ~ 80% cobbles, coral, not spherical & subrounded (0.5, 0.5)	Modern village surface sediment with coral sand & anthropogenic inputs
II	7.5YR 3/1, very dark gray; clear (2.5 - 7.5 cm), wavy lower boundary; weak, very fine, subangular blocky structure; sandy clay; friable moist-consistence; common, medium roots; ~ 20% cobbles - boulders, basalt, spherical - not spherical & subrounded (0.3 - 0.9, 0.5); > 50% pebbles, coral, not spherical & subrounded (0.5, 0.5)	Anthropogenic colluvium, abundant charcoal & shell with some marine deposition
III	7.5YR 3/1, very dark gray; abrupt, wavy lower boundary; weak, very fine, subangular blocky; friable, moist-consistence; sandy clay; very few coarse, few medium - fine, roots; ~ 5% pebbles, basalt, not spherical & rounded - subrounded (0.5. 0.7 - 0.5)	Anthropogenic colluvium, abundant charcoal & shell; rock & coral feature at base of layer, resting on surface of IV
IV	2.5Y 6/3, light yellowish brown; abrupt, wavy lower boundary; weak, fine crumb structure; loose dry-consistence; fine - medium sand; ; ~ 1% pebbles, basalt, not spherical & subrounded (0.5, 0.5); ~ 5% pebbles - cobbles, coral, not spherical & subrounded (0.5, 0.5); very few, fine roots	Marine deposit
V	10YR 3/2, very dark grayish brown; abrupt, wavy, lower boundary; weak, very fine, subangular blocky structure; very friable moist-consistence; sandy clay; ~ 5 - 10% pebbles - cobbles, basalt, not spherical & rounded - subrounded (0.5, 0.7 - 0.5); very few, fine roots; charcoal flecks & chunks (~ 2 cm)	Anthropogenic colluvium; abundant charcoal
VI	10YR 6/3, pale brown; abrupt, smooth lower boundary; weak, fine crumb structure; very friable moist-consistence; very fine - medium sand; ~ 15 - 20% cobbles - boulders, basalt, not spherical & rounded -subrounded (0.5, 0.7 - 0.5); ~ 1 - 5% pebbles - cobbles, coral, not spherical & sub-angular - subrounded (0.5, 0.3 - 0.5)	Marine deposit with some high-energy inputs; relatively unbroken, sparse shell, probably natural
VII	7.5YR 3/2, dark brown; abrupt, wavy lower boundary; weak, very fine subangular blocky structure; friable, moist-consistence; silty clay; ~1 - 5%	Anthropogenic colluvium with

	pebbles - cobbles, basalt, not spherical & subrounded (0.5, 0.5); very few fine - medium roots; charcoal flecks & chunks (up to 1 cm)	relatively more artefactual material than shallower layers
VIII	10YR 2/3, dark yellowish brown; abrupt, wavy lower boundary; weak, very fine subangular blocky structure; very friable moist-consistence; sandy clay	Anthropogenic deposit, lower transport energy than shallower deposits
IX	2.5Y 5/3, light olive brown; abrupt, wavy lower boundary; weak, very fine, crumb structure; very friable moist-consistence; fine - medium sand; < 1% pebbles, coral, spherical & subrounded (0.7, 0.5)	Low energy marine deposit
X	10YR 3/2, very dark grayish brown; abrupt, wavy lower boundary; weak, very fine, subangular blocky structure; friable moist-consistence; sandy clay loam; ~ 1% cobble, basalt, spherical - not spherical & rounded - subrounded (0.9 - 0.5, 0.9 - 0.5); ~20% pebble, coral, not spherical & rounded (0.5, 0.9); very few, very fine roots; charcoal flecks	Anthropogenic deposit
XI	7.5YR 3/2, dark brown; abrupt, wavy lower boundary; weak, very fine, subangular blocky structure; very friable moist-consistence; silty clay; ~ 50% gravel to small pebble, basalt, spherical & subrounded - rounded (0.9, 0.7-0.9); very few, fine - very fine roots	Anthropogenic deposit
XII	7.5YR 2.5/2, very dark brown; sandy clay; ~ 70% cobbles, basalt, not spherical, & subrounded (0.5, 0.7); ~ 10% cobbles, coral (decomposing), not spherical & subangular (0.5, 0.3); very few, medium - fine roots; beach rock present; complete description not possible due to fluctuating water table in excavation	Anthropogenic deposit
XIII	Systematic layer description not possible as layer under water table; layer texture is carbonate sand with ~ 30% basalt sand (possibly derived from Layer XII); not spherical & subrounded coral cobbles & basalt granules - pebbles present.	Marine deposit

3.3 Aleipata

Forty-one auger cores were placed along ‘Upolu’s eastern coastline (Figure 7). Cores 36-41 are located inland, between the two norther clusters of cores, but lack precise location data and are not discussed (other core data included in supplementary material). Median core depth was 1.65 m with a maximum depth of 2.8 m. Cores were abandoned when they encountered impassable rock or the presence of the water table prohibited recovery from greater depth. A string of villages along the eastern coastline of ‘Upolu blend into each other, so the following summary is not organized strictly by village, but proceeds from north to south. Cores 29-34 all revealed clay sediments up to 2.8 m deep, while core 35 uncovered a loam and sand up to 2 m deep comprised of olivine rich terrigenous clasts. The coastline between these most northern cores and cores 1-3 is swampy and was not investigated. The subsurface sediments uncovered in cores 1-28 comprise a carbonate-sand paleobeach ridge overlain by silty clays and silty clay loams up to 1.8 m thick. The subsurface carbonate sand layer extends up to approximately 215 m inland in the north (core 3) and 130 m inland in the south (core 21), associated with a narrowing of the current beach ridge at the southern end. Cochrane et al. (2016) and Kane et al. (2017) previously identified the paleobeach-ridge through analysis of the recovered core sediments from Satitoa Village (cores 1-13). Furthermore, Kane et al. (2017) generated geophysical models of Holocene sea level and combined these with both high-precision topographic data and sedimentological analyses such as grain micromorphology to determine that the beach ridge began to form about 2000 years ago during a marine transgression following the mid-Holocene high-stand. No carbonate sand paleobeach-ridge was present before this time.

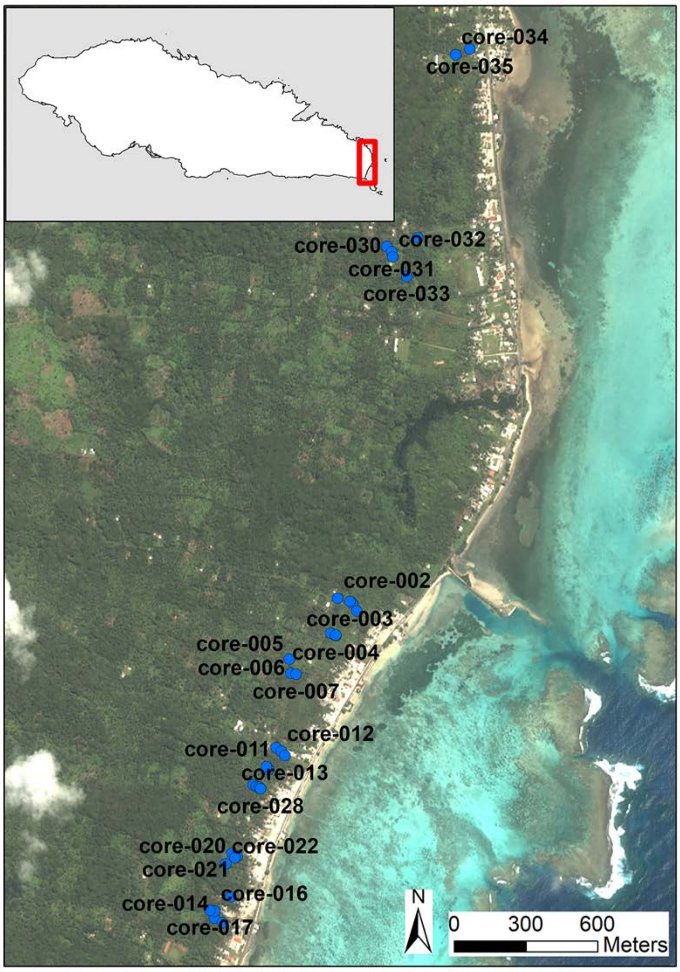

Figure 7. Aleipata project area, ‘Upolu, Sāmoa.

Cores 1-13 used in the Cochrane et al. (2016) and Kane et al. (2017) studies can now be combined with Cores 14-28 to the south in which the same carbonate sand layer was encountered (Cores 19, 21, 23, 25, and 35). The top depth of the carbonate sand across all these cores was interpolated to estimate the extent of the carbonate sand beach ridge and its more recent depositional history. Core 35 was removed from the interpolation given its large separation distance (> 2 km) from the other usable cores. Convergence of the modelled variogram on the sample variogram for Aleipata was unsuccessful after 200 iterations, though a reasonable fit was still obtained with a spherical model (see Cochrane et al. 2019). The Kriged interpolation of the top depth of carbonate sand deposits within the Aleipata cores reveals relatively lower depths (e.g., 0.60-0.80 mbs) in the northern portion of the study area trending to deeper deposits (e.g., 1.60-1.80 mbs) in the southern region portion (Figure 8). This corresponds to probable increased colluvial deposition on top of the carbonate sand layer in the south where there is a steeper coastal to inland gradient.

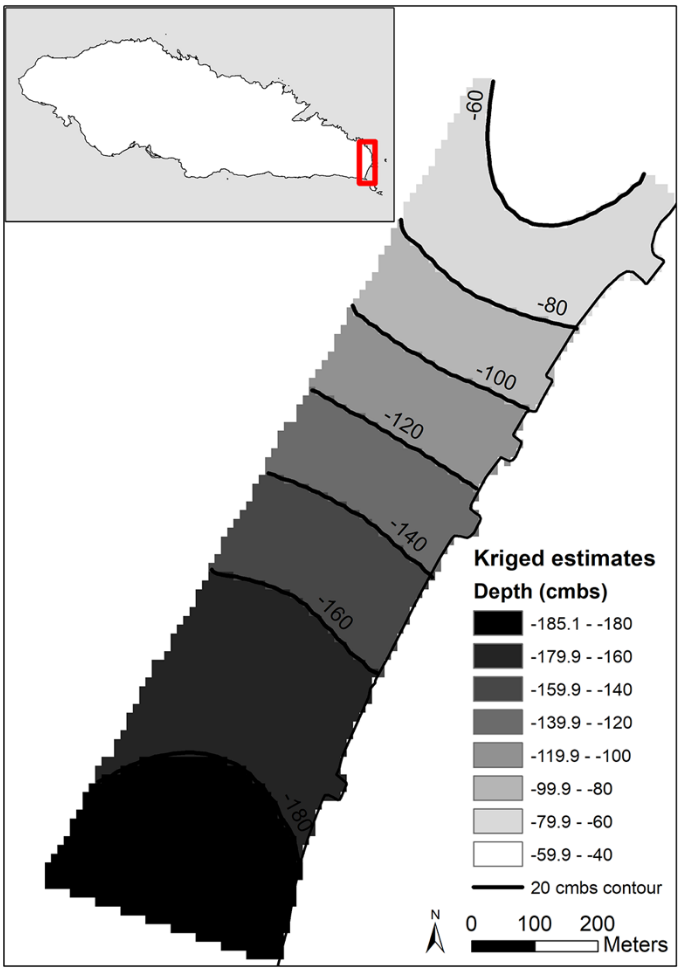

Figure 8. Kriged interpolation of Aleipata sand deposits.

4.0 Discussion

The core, excavation, and chronological data from Mulifanua, Fagaloa and Aleipata provide a useful starting point for evaluating two geological explanations, the coastal flats and terrestrial destruction hypotheses, that may account for the negligible coastal archaeological record over approximately the first millennium of Sāmoan settlement. The Mulifanua core data revealed a terrestrial, subsurface, carbonate sand in the proximity of the submarine Lapita deposit and former coastal flat. The subsurface carbonate sand deposit has a modelled top depth between 0.6 and 1.6 m below the current surface and the model suggests it is spatially extensive (see Figure 3). Even without absolute chronological data, the stratigraphically superior position of the carbonate sand layer relative to the Lapita deposit suggests similar depositional processes, including the generation of a carbonate sand coastal flat and relative subsidence, have occurred in the area since the Lapita assemblage formed . The sparse and ambiguous cultural material in the Mulifanua cores also suggests extensive archaeological deposits are not present within the top approximately 1.5 m of sediment. The general lack of archaeological materials may be attributed to terrestrial geological destruction of these deposits, or a small or absent population on the coast during the time represented by the deposits. The latter is a possibility given that there appears to be varying intensity of coastal use over time at nearby Manono, a small island offshore from Mulifanua (Sand et al. 2016). To test the terrestrial destruction hypothesis as an explanation for the lack of early terrestrial archaeological deposits, deeper excavations, chronological, sedimentological, and a micromorphological analyses (e.g., Kane et al. 2017) are required. Ideally, this work should focus on deposits near Core 1, the only core that approached the depth of the submarine Lapita deposit, and should use an engine-powered corer (e.g., vibra-corer) to recover sediments between the bottom depth of the auger cores and confirmed Lapita-age deposits. Such work would also be relevant to identifying catastrophic events such as tsunami that may affect the archaeological record (Goff et al. 2017). A systematic coring programme throughout the area could also evaluate the density of early cultural remains to address the demographic hypothesis proposed by Cochrane (2018).

In Fagaloa, the Lona village stream section at the western end of the coastal flat revealed subsurface deposits approximately 1000 cal BP at about 1.5 m deep and this section comprises a depositional sequence similar to identified core transects from the middle of the beach flat (Cores 1, 3-5 and 6-8; see Cochrane et al. [2019] for core descriptions). Excavation in Samamea village uncovered a 2.8 m sequence of cultural deposition that did not begin until after about *479-304 cal BP*, at the earliest, a time similar to the more recent burn layer in the Lona village stream profile. The widely dispersed Fagaloa auger cores from Talefaga, Ma‘asina, and Lona identified a general depositional sequence, conceivably accounting for the last 1000 years based on the Lona stream section, to include terrigenous colluvial deposition, and possible in situ weathering of parent rock, as indicated by increasingly cobbly sediment with depth. To test both the coastal flats and terrestrial destruction hypotheses deeper excavations are required in these villages. Again, engine-powered coring might first be used to retrieve sediments beneath the cal. 1000 year old basal stream section deposits in Lona to determine if coastal flats dating to the first 1000 years of Samoan settlement exist. Sedimentological and micromorphological analyses, along with absolute chronological data, will also be required to asses both hypotheses here.

The Samamea cores and excavation uncovered a dramatically different depositional history even though Samamea is only about 1 km along the coast from Lona. This 2.8 m thick sequence of carbonate sands and anthropogenic sediments, interspersed with storm deposits, probably formed over less the last 400 years according to our Bayesian model (Cochrane et al. 2019). If an early coastal flat exists here, it is likely to be much deeper and will require sufficient tools to access such as a drill-truck, excavator, and shoring for excavation. If the last 400 years are a guide, terrestrial destruction of deposits seems unlikely, even in this highly dynamic depositional environment, but the aforementioned tools, along with appropriate geoarchaeological analyses and dating will be required to evaluate this.

Finally, along the eastern coastline of Aleipata, previous excavation and analysis of auger cores in Satitoa village indicated that the current coastal flat began to form ca. 2000 cal BP (Kane et al. 2017). The earliest cultural deposits on this landform are ca. 500 cal BP in age (Cochrane et al. 2016), similar to Samamea. Geostatistical interpolation of the newly reported core data from the north and south of Satitoa Village augment these findings and suggest the subsurface carbonate sand beach-ridge extends southward to Core 21 and northwards to Core 1, a distance of 1.7 km over the approximately 7 km eastern Aleipata coastline. The additional core data presented here confirms the extent of the subsurface carbonate sand beach ridge and supports the coastal flats hypothesis that there were few beach-ridges present during the first several hundred years of Samoan settlement (Rieth et al. 2008). Additionally, the terrestrial destruction hypothesis is not supported in the Aleipata study area, nor is relative island subsidence as an explanation for a lack of early archaeological sites. Additional coring and sedimentological analyses should be undertaken along the most northern portion of the Aleipata coastline to further evaluate these hypotheses.

4.1 Conclusions

Our program of coring and excavation in three different coastal environments widely dispersed on ‘Upolu provides a preliminary evaluation of two hypotheses to account for the relative lack of early coastal archaeological assemblages. Along with relative island subsidence in Mulifanau, the (lack of) coastal flats hypothesis is supported for Aleipata, as a reason for the relative scarcity of early archaeological assemblages. Terrestrial destruction may also account for unique coastal archaeological record in some areas of Sāmoa and we have suggested engine-powered coring to reach sediments of relevant depth and geoarchaeological analyses to assess depositional history.

The Mulifanua (western) and Aleipata (eastern) sides of ‘Upolu have similar terrestrial subsurface deposits of carbonate sand, but these result from different processes. In the west, long-term, at least since 3000 years ago, carbonate sand beach-ridge formation and subsidence characterises coastal landform evolution (Dickinson 2007; Green and Dickinson 1998). In the east, beach-ridge formation and progradation began after about 2000 cal. BP with the change from a transgressive to a regressive coastal setting that promoted reef-derived sand deposition on the coast (Kane et al. 2017). Thus, there are very likely more sub-marine Lapita and early archaeological assemblages on, and near, the west coast of ‘Upolu, but there should be no such assemblages along the east coast. Coastal landforms along the western half of southern ‘Upolu have been investigated by Goodwin and Grossman (2003) who note a change from estuaries and barrier spits to a dominance of mangrove swamps with some coastal plains and progradation after about 1000 cal. BP. Their work suggests that archaeological assemblages on the coast dating to the first millennium or more of settlement, if they exist, will be in deposits modified by these landform changes. No such detailed assessment of coastal landform evolution along northern ‘Upolu has been completed, but our work suggests a varied set of processes, rapid colluvial deposition, and alluviation has transformed the coast of Fagaloa, at least in the last 1000 years. The recovery of older archaeological deposits there should proceed using deep mechanical excavation to assess potential.

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References Cited

Allee, W.C., Emerson, A.E., Park, O., Park, T., Schmidt, K.P., 1949. Principles of Animal Ecology. Saunders, Philadelphia.

Bronk Ramsey, Christopher. 2017. Methods for Summarizing Radiocarbon Datasets. *Radiocarbon* 59 (6):1809-1833.

Burley, David V, and David J Addison. 2018. Tonga and Sāmoa in Oceanic Prehistory: Contemporary Debates and Personal Perspectives. In *The Oxford Handbook of Prehistoric Oceania*, pp. 231-251, edited by E. E. Cochrane and T. L. Hunt. New York: Oxford University Press.

Clark, Jeffrey T. 1996. Samoan Prehistory in Review. In *Oceanic Culture History: Essays in Honour of Roger Green*, edited by J. Davidson, G. Irwin, F. Leach, A. K. Pawley and D. Brown. Dunedin: New Zealand Archaeological Association.

Clark, Jeffrey T, Seth J Quintus, Marshall Weisler, Emma St Pierre, Luke Nothdurft, and Yuexing Feng. 2016. Refining the chronology for west polynesian colonization: New data from the Samoan archipelago. *Journal of Archaeological Science: Reports* 6:266-274.

Cochrane, Ethan E, Haunani Kane, Charles Fletcher, Mark Horrocks, Joseph Mills, Matthew Barbee, Alexander E Morrison, and Matiu Matavai Tautunu. 2016. Lack of suitable coastal plains likely influenced Lapita (~2800 cal. BP) settlement of Sāmoa: Evidence from south-eastern ‘Upolu. *The Holocene* 26 (1):126-135.

Cochrane, Ethan E, Timothy M Rieth, and William R Dickinson. 2013. Plainware ceramics from Sāmoa: Insights into ceramic chronology, cultural transmission, and selection among colonizing populations. *Journal of Anthropological Archaeology* 32 (4):499-510.

[dataset] Cochrane, Ethan E, DiNapoli, Robert J, and Aumua Ausilafai Matiu Matavai Tautunu, 2019. Samoa Archaeological Core Data & Analyses. Figshare, v4, https://doi.org/10.17608/k6.auckland.7647218

Cochrane, Ethan E. 2018. The Evolution of Migration: the Case of Lapita in the Southwest Pacific. *Journal of Archaeological Method and Theory* 25 (2):520-558.

Courchamp, Franck, Tim Clutton-Brock, and Bryan Grenfell. 1999. Inverse density dependence and the Allee effect. *Trends in Ecology & Evolution* 14 (10):405-410.

Dickinson, William R. 2007. Upolu (Samoa): Perspective on Island Subsidence from Volcano Loading. *The Journal of Island and Coastal Archaeology* 2 (2):236 - 238.

Dickinson, William R. 2014. Beach Ridges as Favored Locales for Human Settlement on Pacific Islands. *Geoarchaeology* 29 (3):249-267.

Dickinson, William R, and Roger C Green. 1998. Geoarchaeological Context of Holocene Subsidence at the Ferry, Berth Lapita Site, Mulifanua, Upolu, Samoa. *Geoarchaeology* 13 (3):239-263.

Goff, J., Golitko, M., Cochrane, E., Curnoe, D., Williams, S. & Terrell, J. 2017. Reassessing the environmental context of the Aitape Skull – The oldest tsunami victim in the world? *PLoS ONE*, 12, e0185248.

Goodwin, Ian D, and Eric E Grossman. 2003. Middle to late Holocene coastal evolution along the south coast of Upolu Island, Samoa. *Marine Geology* 202 (1):1-16.

Green, Roger C. 1974. Pottery from the Lagoon at Mulifanua, Upolu (Report 33). In *Archaeology in Western Samoa*, edited by R. C. Green and J. M. Davidson. Auckland: Auckland Institute and Museum.

Green, Roger C. 2002. A Retrospective View of Settlement Pattern Studies in Samoa. In *Pacific Landscapes: Archaeological Approaches*, edited by T. N. Ladefoged and M. W. Graves. Los Osos, CA: Easter Island Foundation Press.

Kane, Haunani H., Charles H. Fletcher, Ethan E. Cochrane, Jerry X. Mitrovica, Shellie Habel, and Matthew Barbee. 2017. Coastal plain stratigraphy records tectonic, environmental, and human habitability changes related to sea-level drawdown, ‘Upolu, Sāmoa. *Quaternary Research* 87 (2):246-257.

Kirch, Patrick V. 1993. *The To'aga Site: Modelling the Morphodynamics of the Land-Sea Interface*. In: Kirch, P. V. and Hunt, T. L. (eds.) The To'aga Site: Three Millennia of Polynesian Ocupation in the Manu'a Islands, American Samoa. Berkeley: University of California.

Leach, Helen M, and Roger C Green. 1989. New Information for the Ferry Berth Site, Mulifanua, Western Sāmoa. *Journal of the Polynesian Society* 98:319-329.

Morrison, Alex E, Ethan E Cochrane, Timothy Rieth, and Mark Horrocks. 2018. Archaeological and sedimentological data indicate Lapita settlement on a newly formed coastal plain: Tavua Island, Mamanuca Group, Fiji. *The Holocene* 28 (1):44-55.

Petchey, Fiona J. 1995. The Archaeology of Kudon: Archaeological Analysis of Lapita Ceramics from Mulifanua, Samoa and Sigatoka, Fiji, Anthropology, University of Auckland, Auckland.

Petchey, Fiona. 2001. Radiocarbon determinations from the Mulifanua Lapita site, Upolu, western Samoa. *Radiocarbon* 43:63-68.

Petchey, Fiona, and Patrick V Kirch. 2019. Redating of the To’aga site (Ofu Island, Manu'a) and a revised chronology for the Lapita to Polynesian Plainware transition in Tonga and Samoa. doi: https://doi.org/10.1101/532648

Reimer, Paula J, Edouard Bard, Alex Bayliss, J Warren Beck, Paul G Blackwell, Christopher Bronk Ramsey, Caitlin E Buck, Hai Cheng, R Lawrence Edwards, Michael Friedrich, Pieter M Grootes, Thomas P Guilderson, Haflidi Haflidason, Irka Hajdas, Christine Hatté, Timothy J Heaton, Dirk L Hoffmann, Alan G Hogg, Konrad A Hughen, K Felix Kaiser, Bernd Kromer, Sturt W Manning, Mu Niu, Ron W Reimer, David A Richards, E Marian Scott, John R Southon, Richard A Staff, Christian S M Turney, and Johannes van der Plicht. 2013. IntCal13 and Marine13 Radiocarbon Age Calibration Curves 0–50,000 Years cal BP. *Radiocarbon* 55 (4):1869-1887.

Rieth, Timothy M, and Ethan E Cochrane. 2018. The Chronology of Colonization in Remote Oceania. In *The Oxford Handbook of Prehistoric Oceania*, pp. 133-161, edited by E. E. Cochrane and T. L. Hunt. New York: Oxford.

Rieth, Timothy M, and Terry L Hunt. 2008. A radiocarbon chronology for Samoan prehistory. *Journal of Archaeological Science* 35 (7):1901-1927.

Rieth, Timothy M, Alex E Morrison, and David J. Addison. 2008. The Temporal and Spatial Patterning of the Initial Settlement of Sāmoa. *Journal of Island and Coastal Archaeology* 3:214-239.

Sand, C., Bolé, J., Baret, D., Ouetcho, A.-J., Petchey, F. J., Hogg, A. & Asaua, T. 2016. Geological subsidence and sinking islands: The case of Manono (Samoa). *Archaeology in Oceania*, 51 (2):99-107.

Sheppard, Peter J, Scarlett Chiu, and Richard Walter. 2015. Re-dating Lapita Movement into Remote Oceania. *Journal of Pacific Archaeology* 6 (1):26-36.