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Geological subsidence and sinking islands: the case of Manono (Samoa)

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ABSTRACT

W.R. Dickinson, as part of his wide study of the geological history of the Pacific islands, has linked the unique case of the deeply submerged Lapita site of Mulifanua in western Upolu (Samoa) to the slow subsidence of Upolu island. Recent archaeological research on the neighbouring small island of Manono has yielded new and detailed data on this geological process. A series of new dates has allowed us to define the speed of the subsidence and demonstrate the massive environmental changes to which the local population has had to adapt over the past 2000 years.

Keywords: geological subsidence, Samoa, Manono island, Pagai, resilience, intensification.

RÉSUMÉ

W.R. Dickinson, dans le cadre de ses études multiples sur l'histoire géologique des îles du Pacifique, a corrélé le cas unique du site Lapita ennoyé de Mulifanua dans l'ouest d'Upolu (Samoa) à un lent affaissement de l'île d'Upolu. Des recherches archéologiques récentes sur la petite île voisine de Manono, ont apporté de nouvelles données détaillées sur ce processus géologique. Un ensemble de nouvelles datations a permis de définir la vitesse de cet affaissement, soulignant les transformations environnementales majeures que la population locale a eu à subir au cours des derniers 2000 ans.

Mots Clés: affaissement géologique, Samoa, île de Manono, Pagai, resilience, intensification.

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INTRODUCTION

The geological diversity of the Pacific region defies any simple categorization. The region is divided between different tectonic plates and dissected on its western side by the active "belt of fire", with islands being derived from continental fragments to old eroding or still active volcanic summits to simple coral atolls. Volcanic activity, earthquakes and possible tsunami-related events, associated with episodes of extreme weather devastation through cyclones/typhoons or prolonged droughts, make Oceania a region contrary to the idyllic image built by Western imagination. Amongst the different natural events that shape everyday life in the islands, for generations oral traditions have transmitted stories of sinking and rising islands (Nunn 2009). While some of these stories might be related to small isostatic sea-level changes over time, the vast majority are unquestionably linked to tectonic activity. W.R. Dickinson, as a geologist, studied in detail the diversity of the geological building process of most of the archipelagos of the Pacific, explaining the structural specificities of each region though a number of scientific demonstrations. This paper presents an archaeological case of one of his most recently debated studies, focused on the Upolu–Savai'i alignment that forms the western part of Samoa in the central Pacific. After having synthesized the geological data on these two islands and some archaeologically related outcomes, we will outline the results of excavations undertaken on the small island of Manono, positioned at the western point of the Upolu plate. These demonstrate the progressive subsidence of this part of the archipelago, allowing us for the first time to date precisely the chronology of this process over the nearly 3000 years of human presence. The consequence of progressive subsidence in this case of a "sinking island" will be discussed.

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THE GEOLOGICAL SETTING OF THE UPOLU–SAVAI'I ISLANDS OF SAMOA

In Western Polynesia, the archipelagos of Samoa, Tonga, Wallis–Futuna and Tokelau have been defined as a coherent cultural entity (Burrows 1939). The region's geology, however, is characterized by two contrasting geological structures. The region is divided by the andesite line created by the Pacific plate subducting beneath the Indo-Australian plate. Most of the Tongan islands, as well as Fiji to the west, occur on the Indo-Australian plate, separated from Samoa by the Tongan Trench. The Samoan islands chain, which exceeds 1000 km in length from Wallis ('Uvea) island in the west to Rose Atoll in the east, results mainly from the volcanic activity of a "magmatic plume-driven hotspot" that progressively expands eastward due to plate movement (Staudigel *et al.* 2006). The islands of Upolu, Apolima and Savai'i are aligned on a south-east/north-west axis. No active volcano is present today on the 1119 km^2 Upolu, but a number of former cones can easily be identified on the main axis of the island, with the highest at 1100 m (Mount Fito). This is in contrast to Savai'i in the west, where active craters form the 1858 m high Mount Silisili and continue to build this 1707 km^2 shield volcano. The origin of recent volcanism on Savai'i is probably related to the relative migration of the edge of the Tonga Trench (Hart *et al.* 2004). While the eastern part of the Upolu coastline is rugged, the western part is enclosed today by reef with an extensive lagoon on its western point, enclosing the small island of Manono. The cause of this reef formation has been attributed to the growing volcanic load of Savai'i, creating a depression into which the western part of Upolu is slowly tilting (Dickinson 2007).

The process of geological subsidence has resulted in a progressive loss of coastal flats with implications for archaeology, since early settlement sites typically occur in coastal locations. The implications of this for understanding past human settlement patterns was made evident by the discovery in 1973 of c.2800-year-old Lapita sherds and other materials submerged 2.5 m in the Mulifanua lagoon at the north-west tip of Upolu (Jennings 1974; Green and Richards 1975; Leach and Green 1989; Dickinson and Green 1998; Petchey 2001). This example of a deeply submerged Lapita occupation led Dickinson to propose a subsidence rate of 1.1–1.4 mm per year for this part of Samoa (Dickinson 2007). Employing this rate, R.C. Green then extrapolated possible locations of other early sites along the now submerged coastline of Samoa (Green 2002).

ASSESSING THE CHRONOLOGY AND RATE OF SUBSIDENCE: FIRST RESULTS FROM MANONO

Most researchers generally accept the geomorphic processes and subsidence rate proposed by Dickinson (2007) to explain the geological setting of Upolu, but there has been criticism of different aspects of his model. One of the aspects highlighted is the rate at which tilting and subsidence occurs (Goodwin and Grossman 2003; Ishimura and Inoue 2006), while another focuses upon the Lapita site of Mulifanua and the processes by which it came about (Addison 2011, pers. comm). Recent archaeological data from the small island of Manono enable us to address these issues.

Manono is positioned on the edge of the large lagoon that forms the western tip of Upolu, directly opposite Savai'i (Figure 1). It is a gently raised volcanic cone about 2.4 km long and 1.8 km wide, in the form of a large keyhole. The summit at about 60 m altitude is the remnant of a former crater. Although of small size compared to its two large neighbours, Manono holds a major position in the oral traditions of Samoa, having been a powerful political centre (Kramer 1994: 209). Today, the island is divided into two entities, Faleu/Lepuia'i in the southern half and Salua/Apai in the northern half. Settlements are restricted to the narrow coastal flats, as elsewhere in Samoa since European times (Davidson 1969), although a great number of former occupation remains are visible inland.

The Institute of Archaeology of New Caledonia and the Pacific (IANCP) and the National University of Samoa carried out a research program on the archaeology of Manono between 2012 and 2015. The main aim of the project was to study former settlement patterns on the island through mapping of surface sites and recording of oral traditions. As part of the overall understanding of the chronology of human occupation of Manono, excavations were undertaken on the coastal flats of Salua village. Some of these excavations provide a unique record on the process of geological subsidence that has occurred on Manono.

EXCAVATION EX.1 OF PAGAI

Pagai is a coastal ridge on the east coast of Manono island, directly facing the Lapita site of Mulifanua and the large lagoon of western Upolu. The site was chosen for excavation because it is the main sandy flat on this side of Manono, extending more than 45 m inland, with only a gentle rising slope at its back. The shore is being severely eroded, with many stone artefacts found during surveys on the rocky beach at low tide. This appeared to be an ideal location to test the model of a progressive subsidence of western Upolu. Moreover, the landowner informed us that earlier excavation for house-building had discovered large basaltic boulders in the sand. The 1 m^2 test-pit EX.1 was positioned 20 m from the eroding shore-cliff, with surface elevation 150 cm above high tide. This excavation led to the identification of four different episodes of formation for the site (Figure 2):

Layers 1–4: From the surface to a depth of 45 cm, the remains are related to post-European settlement. Layer 3 is the rock-paved surface of a house platform, while Layer 4 forms the sub-floor fill for the house. European items were found both on the surface of the house floor and in Layer 4 below.

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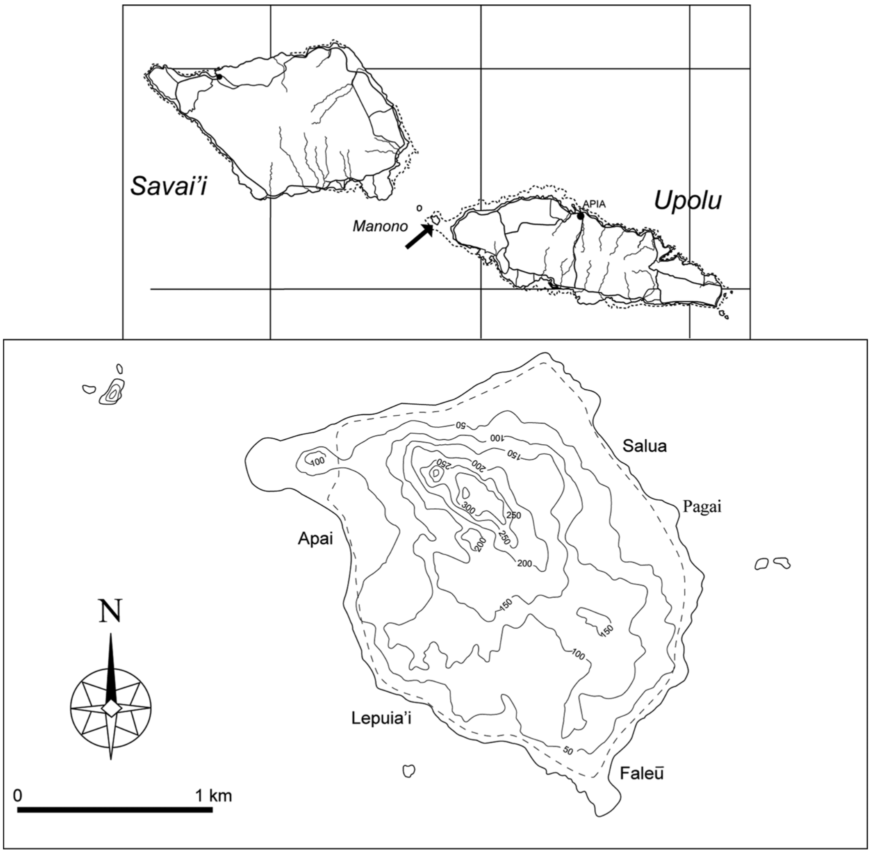
Figure 1. The position of Manono island in between Savai'i and Upolu, and a map of the island locating the area of Pagai.



Layers 5–8: Layer 5 is sterile sand approximately 10 cm thick. Beneath this, from 55 cm down to about 135 cm are Layers 6–8, also of sand but with evidence of cultural occupation. Artefacts are nearly absent but shellfish remains, a posthole and a pit feature identify human activities.

Layer 9: Between 135 cm and 210 cm, Layer 9 is a thick sand stratum containing a few natural shells but without evidence of human presence. To prevent wall collapse, the excavation was reduced to a centrally located smaller test pit of 50 × 50 cm in subsequent layers.

Layers 10–11: At 210 cm there is an abrupt transition to Layer 10, a compact dark soil with clay. This soil incorporates potsherds, volcanic glass, fish bones and shell remains. Layer 11, also with cultural material, is of the same general soil texture but extends below the water table. The excavation was stopped at a depth of 275 cm without having reached the bottom of this layer, because of inundation.

THE ARCHAEOLOGICAL MATERIAL

Archaeological material from EX.1 was recovered wet-sieving using 3 mm sieves. Table 1 presents the complete record of the material found. Other than the upper historic house platform, data indicating cultural occupations occur in the sandy Layers 6–8 as well as in the lower soil Layers 10 and 11. Unexpectedly, the sandy layers are poor in cultural material but do incorporate shellfish indicative of human presence. The only artefact found in the lower part of the sand deposit (Layer 8) was a fragment of a small basalt adze (Figure 3c), possibly of type I (Green and Davidson 1969). This overall absence of cultural remains contrasts with the assemblage from the lower soil Layers 10 and 11, where pottery and small volcanic glass flakes are present. The ceramic sherds are mostly of small size, with a thickness between 4 and 7 mm. The temper identified visually is terrigenous. The outer colour of the sherds is brown, with only a few having a blackened surface. The two rim types identified are straight (Figures 3a,b) and come from bowls of the Samoan thin ware type (Green 1974a, 1974b).

Bone fragments and crustacean pieces were present in low numbers in all the layers. Overall, shell remains are not abundant. Comparison between layers shows a difference between the density of shell remains from the sand matrix (Layers 6–8) and those in the soil matrix (Layers 10–11). The density of shell within the upper sand layers is lower, suggestive of an occupation floor. Gastropods compose the highest amount of shells in these layers, with *Cerithium salebrosum* (565 g) being most frequent, followed by Cypraeidae spp. (310 g), Trochidae spp. (185 g), Conidae spp. (143 g), Strombidae spp. (91 g) and Turbinidae spp. (42 g). Bivalves are represented near exclusively by

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Table 1. Remains from excavation EX.1 at Pagai, Manono.

Layer(s)	Spits	Gastropods (g)	Bivalves (g)	Urchins (g)	Coral (g)	Bone (*n*)	Crustaceans (*n*)	Sherds (*n* – *d*)	Sherds (*d*)	Lithics	Metal	Other
1–2	0–10					55					Four needles	One button, one cement
2–3	10–20	107	36			22						
3–4	20–30	60	26			34	1					One porcelain marble
4–5	30–40	68	5			13						
5	40–50	44				6						
5–6	50–60	154	14			8		1				
6	60–70	220	44			11						One human tooth
6–8	70–80	170	40			15						
7–8	80–90	102	26			8						
7–8	90–100	144	8			10						
8	100–110	340	60			13						
8	110–120	224	68		78	15	1					
8	120–130	190	25			6				1		
8–9	130–140	145	49		22	6						
8–9	140–150	96	9			8						
8–9	150–160	60	5			10						
9	160–170											
9	170–180											
9	180–190											
9	190–200											
9	200–210											
10	210–230	156	48	3	115	6	10	19	1			
10	230–250	191	34		290	5	4	9		2		Two volcanic glass flakes
10	250–265	116	12	4		7		7	1	5		Three volcanic glass flakes
11	265–275	6		1	56	2	12	2		1		One flake

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Figure 2. The stratigraphic profile of excavation EX.1 at Pagai.

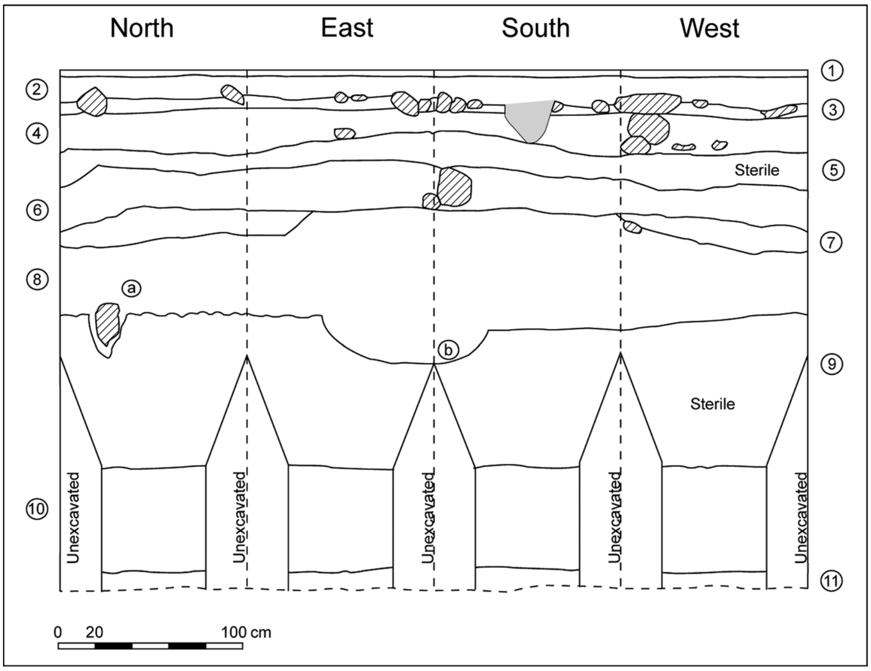
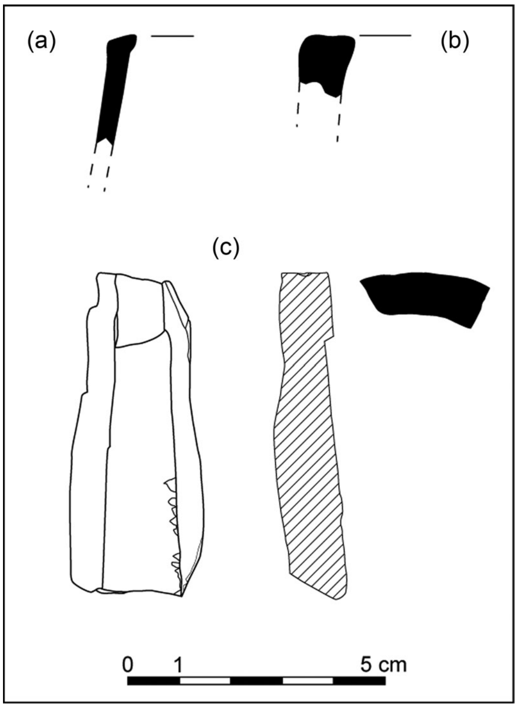


Figure 3. Rim sherds (a,b) and an adze fragment (c) from excavation EX.1 at Pagai.



Tridacnidae spp. (111 g) and *Paphies striata* (64 g). Taking into consideration the small size of the lower excavation unit for Layers 10 and 11 (about 0.25 m^2), it is estimated that shellfish quantities were about three to four times greater in the soil layers than in the sand layers above. Only two species have been identified from the lower layers, however – Trochidae spp. (98 g) for the gastropods and Tridacnidae spp. (90 g) for the bivalves – with more than a third of the shells unidentifiable due to fragmentation.

THE DATING SEQUENCE

The results from excavation EX.1 show clearly that Manono is subsiding, with the oldest layers occupied by humans during the ceramic period now within the water table. In order to get a better understanding of the chronology identified through the excavation, a series of samples collected from EX.1 were sent for radiocarbon dating to the Waikato Radiocarbon Dating Laboratory. The results are presented in Table 2. With one exception, these provide a coherent set of calibrated dates at 95.4% probability from which to define a stratigraphic chronology.

The uppermost radiocarbon date (Wk-37438) is modern, in line with historical artefacts found in the house platform of Layers 3–4. Three radiocarbon dates (Wk-37440–41 and Wk-37443) for Layer 8, the lowest sand layer with cultural occupation, provide a range of AD 660–880. A fourth sample (Wk-37442) from this layer had an anomalous result of AD 1160–1260 and is considered an outlier. The sterile sand of Layer 9 is dated on shell (Wk-37444) to AD 240–440. The upper part of the soil layer, between 210 and 220 cm is dated to 170–1 BC (Wk-37445), while a shell date (Wk-37446) slightly below at 225 cm is consistent at 100–120 BC. By association, the latter two dates provide an upper age for plainware pottery in the excavation unit. The deepest sample that was able to be collected from EX.1 at 246 cm was dated to 360–110 BC (Wk-37447).

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Table 2. ^{14}C samples of excavation EX.1 at Pagai.

Sample ID	Laboratory number	Context (cm)	Material	$\delta^{13}C \pm 0.2‰$ (IRMS)‡	CRA (BP)	Calibrated age (68.2% probability)§	Calibrated age (95.4% probability)§
IANCP-263	Wk-37438†	20–30	Charcoal	−27.9	100.1 ± 0.3%	Modern	Modern
IANCP-265	Wk-37440†	115	Charcoal	−25.4	1227 ± 20 BP	AD 720–870	AD 690–880
IANCP-266	Wk-37441†	120–130	Charcoal	−24.1	1235 ± 20 BP	AD 690–860	AD 680–750
IANCP-267	Wk-37442†	150 (feature)	Charcoal	−25.6	834 ± 20 BP	AD 1180–1250	AD 1160–1260
IANCP-268	Wk-37443†	150 (feature)	Charcoal	−25.8	1287 ± 20 BP	AD 680–770	AD 660–770
IANCP-269	Wk-37444	180	Shell, *Tridacna* sp.	2.0	2061 ± 25 BP	AD 300–410	AD 240–440
IANCP-270	Wk-37445†	210–230	Charcoal	−27.9	1971 ± 21 BP	120–40 BC	170–1 BC
IANCP-271	Wk-37446	225	Shell, *Tridacna* sp.	2.1	2347 ± 25 BP	40 BC – AD 70	100 BC – AD 120
IANCP-272	Wk-37447†	246	Charcoal	−26.5	2155 ± 20 BP	350–170 BC	360–110 BC

†Radiocarbon dates measured by AMS at the Waikato Radiocarbon Dating Unit.
‡Isotope ratio mass spectrometer value measured directly on CO_2 collected during combustion of sample for dating.
§All radiocarbon dates were calibrated in OxCal v4.2 (Bronk-Ramsey 2015), using the Marine13 and Intcal13 curves (Reimer *et al.* 2013). A location-specific reservoir correction value (ΔR) of 28 ± 26 ^{14}C years has been applied to calibrations of the shells to adjust for regional oceanic variation in ^{14}C (Petchey *et al.* 2008).

ANALYSIS

Stratigraphic data from the test-pit excavation EX.1 undertaken at Pagai on the east coast of Manono reveal a record of sedimentary change, from a basal soil to alternating layers of sand with and without evidence for cultural occupation. The Layer 10 and Layer 11 soil strata, the earliest identified occupation in the unit, indicate a locale inland of the back beach, perhaps in an area used for gardens. Numerous potsherds, volcanic glass and shell suggest some type of habitation, possibly that of a garden dwelling. This soil is abruptly capped by a thick, sterile layer of beach sand that, based on a single radiocarbon date (Wk-37444), would have been deposited sometime in the interval AD 240–440. We have no direct evidence to identify the process by which this sand deposit was laid down. The volume of sand, however, suggests an extreme event such as a tsunami, one in which a new back beach was formed upon which reoccupation took place by AD 660–880 in Layer 8 (Wk-37443). We suspect that the impact of this event was amplified by the effects of coastal subsidence, where the former inland area was by then lower and more susceptible to tidal wash. A similar capping of the soil layer by sand has been observed in a number of other excavations undertaken in Salua (Sand *et al.* 2016). Whether this is the result of the same event or the cumulative results of subsidence occurring by the beginning of the first millennium AD is unknown.

The dating of Layer 8 to AD 660–880 provides a reasonable benchmark to define the rate of coastal subsidence. By then, sea levels had stabilized at current levels, eliminating any effects created by the mid-Holocene hydro-isostatic highstand in sea level and its drawdown (Dickinson *et al.* 1994). The lower stratigraphic break for Layer 8 is ~1.3 m below surface (Figure 2). If we assume that this break falls within the dated range for Layer 8, then the effective subsidence rate for AD 660 is 1.0 mm per year, while that of AD 880 is 1.2 mm per year. These rates overlap the range of 1.1–1.4 mm per year predicted by Dickinson (2007). If consistent over the period of human occupation at this part of the site, the rate of 1.0–1.2 mm per year should also be able to be used to predict the depth of deposit for Stratum 10, the upper soil layer dated to 100–120 BC (Wk-37445). It does so accurately, with the rate of 1.0 mm predicting a depth of 2.05 m for 100 BC and 2.17 m for 120 BC. Both occur in the upper part of the Layer 10 soil stratum.

Based on our projections and those of Dickinson (2007), Manono would have been at the end of a large peninsula that covered part of what is today the Wasa lagoon at 850 calBC, when Samoa was first settled (Figure 4). Flat cultivable land originally extended over an area of at least 10 km^2, before its size shrank rapidly over the succeeding centuries, finally ending in the separation of Manono from Upolu. The loss of a massive proportion of cultivable soils through subsidence must have fostered a radical although progressive change in settlement pattern for the groups centred on what is today the small island. The period around

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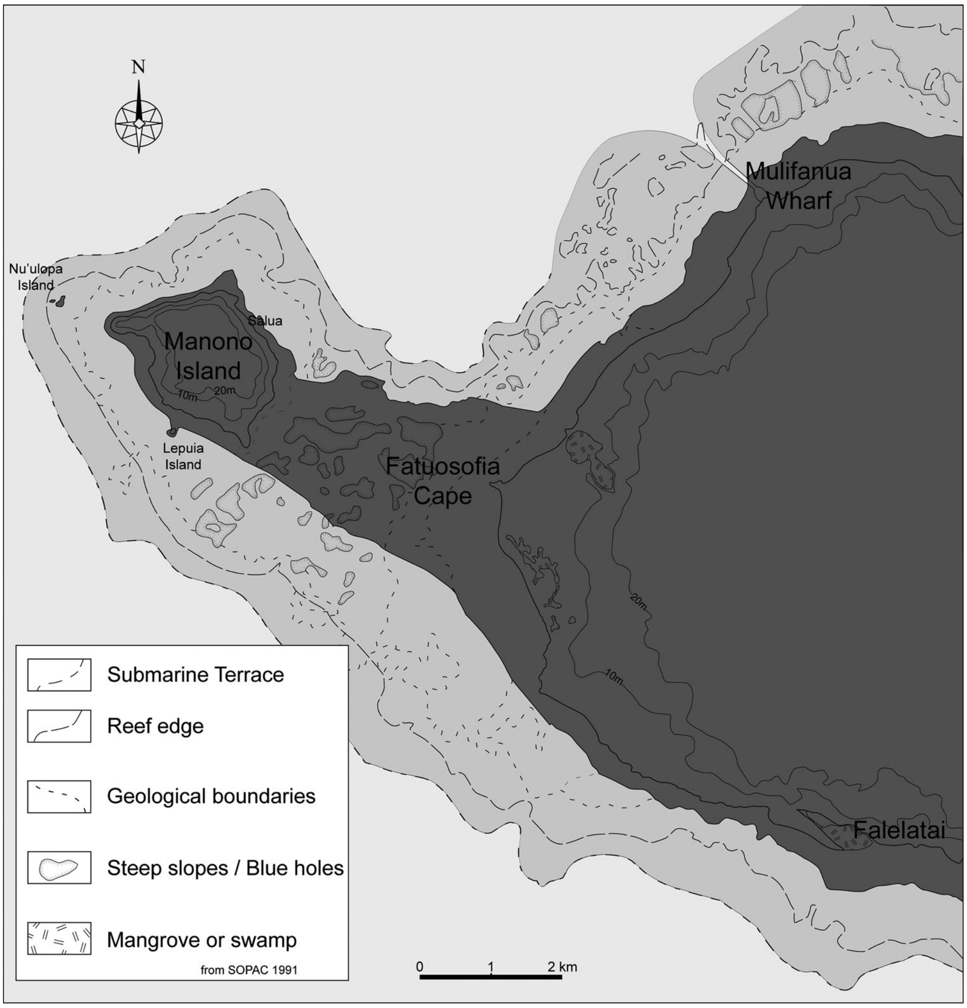
Figure 4. The estimated broad coastal limits of the western end of Upolu at the first human settlement of Samoa 2800 years ago (–3–5 m sea-deep contour, dark grey) (after Richmond 1991).



the beginning of the first millennium AD also marks the end of pottery production in Samoa, as well as elsewhere in the West Polynesian region (Rieth and Hunt 2008). The data from the Manono excavations point to the end of pottery production sometime around 150–250 calAD.

By 750 calAD, when people started to use the now sandy flat of the Pagai plain, pottery was no longer being manufactured. Mapping of the inland area of Manono around Salua has highlighted a massive intensification of land use on the hillsides (Sand *et al.* 2015). This is identified by the dense array of walled enclosures with house platforms and roads covering the slopes leading to the central flattened hilltop. This central part of the island is itself covered with numerous platforms of a more ritual/political function, including high stone platforms, star-mound shaped platforms, possible pigeon-catching structures of Tongan type, raised roads and other features. The hill itself is defended on most of its sides by a set of stone walls built along the cliff side or as proper structures, some reaching over 7 m in height. Radiocarbon dates obtained from shell collected in the building material of these different structures indicate that this escalated period of construction was confined to the second millennium AD. For Manono, loss of land due to tilting and subsidence did not lead to abandonment of the island. Rather, it led to intensification of land use, illustrating resilience to geomorphic change.

CONCLUSION

W.R. Dickinson has been instrumental in Oceanic archaeology for his research and insights into geological data over the past 40 years. For Polynesia as well as Melanesia, his long-term commitment in understanding the subtle processes of land rise and subsidence that affected coastal areas since first human settlement, alongside isostatic fluctuations (Dickinson 2001), have been critically important for our understanding of archaeological site locations. It is a complementary process, however, since archaeological data are able to highlight with precision the geological processes identified, through the study and dating of human-related activities. It is an exercise of this type that has been proposed in this paper, allowing us, with the help of data from coastal excavations on the small island

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of Manono, to propose a process of subsidence of the western part of Upolu at a rate of about 1.1–1.2 mm/year. This is in line with what Dickinson had proposed through other data. The concluding outcome of this research is that geology and archaeology are in this case able to produce compatible results for a better and more coherent understanding of Oceania's past. Associated with sea-level fluctuations and sometimes massive erosional processes that have covered early settlement sites, the recent tectonic histories of the Pacific islands are today one of the important natural hazards that archaeologists need to integrate into their analysis of former settlement patterns, to disentangle the complex processes of human occupations in the geologically active islands chains of the wide Pacific plate.

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C. Sand would like to thank W.R. Dickinson for his long-lasting interest in the archaeological research that he carried out in the Western Pacific. He first started exchanging letters with Bill in the late 1980s, as a young scholar trying to make sense of pottery types in Wallis and Futuna. A decade later, Bill was kind enough to analyse some of our sherds from Cikobia island in Northeastern Fiji, complaining that we hadn't had the good idea to sample the sand from each beach. He proposed a number of times to study the New Caledonia potsherds retrieved from our excavations, although it must be confessed that in most cases, we have still not finalized the papers/monographs that should have been published as an outcome. When Bill joined the conference celebrating the 50th anniversary of the first excavation at Lapita in 2002 in New Caledonia, we made sure to organize for him a visit to the nickel mines on the peridotite plateaus of Grande Terre: seeing his excitement when he came back was so rewarding! After much other correspondence, it was with great excitement that C. Sand wrote to him in late 2013 to inform him of the discoveries in Manono. He replied instantly, getting into geological details and calculations. Thanks to the invitation of David and Marshall to present this paper at the SAA session in San Francisco in April 2015, we had a last opportunity for a short discussion on the details of the Pagai results. As life sometimes follows strange paths, the team of the IANCP flew over Tongatapu on the 2nd of August 2015, on our way to Manono, just a few hours after Bill had been put into Polynesian soil for his eternal rest in Nukuleka. A last fa'afetai to a Big Man.

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