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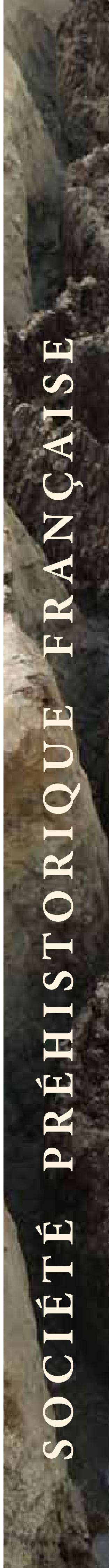

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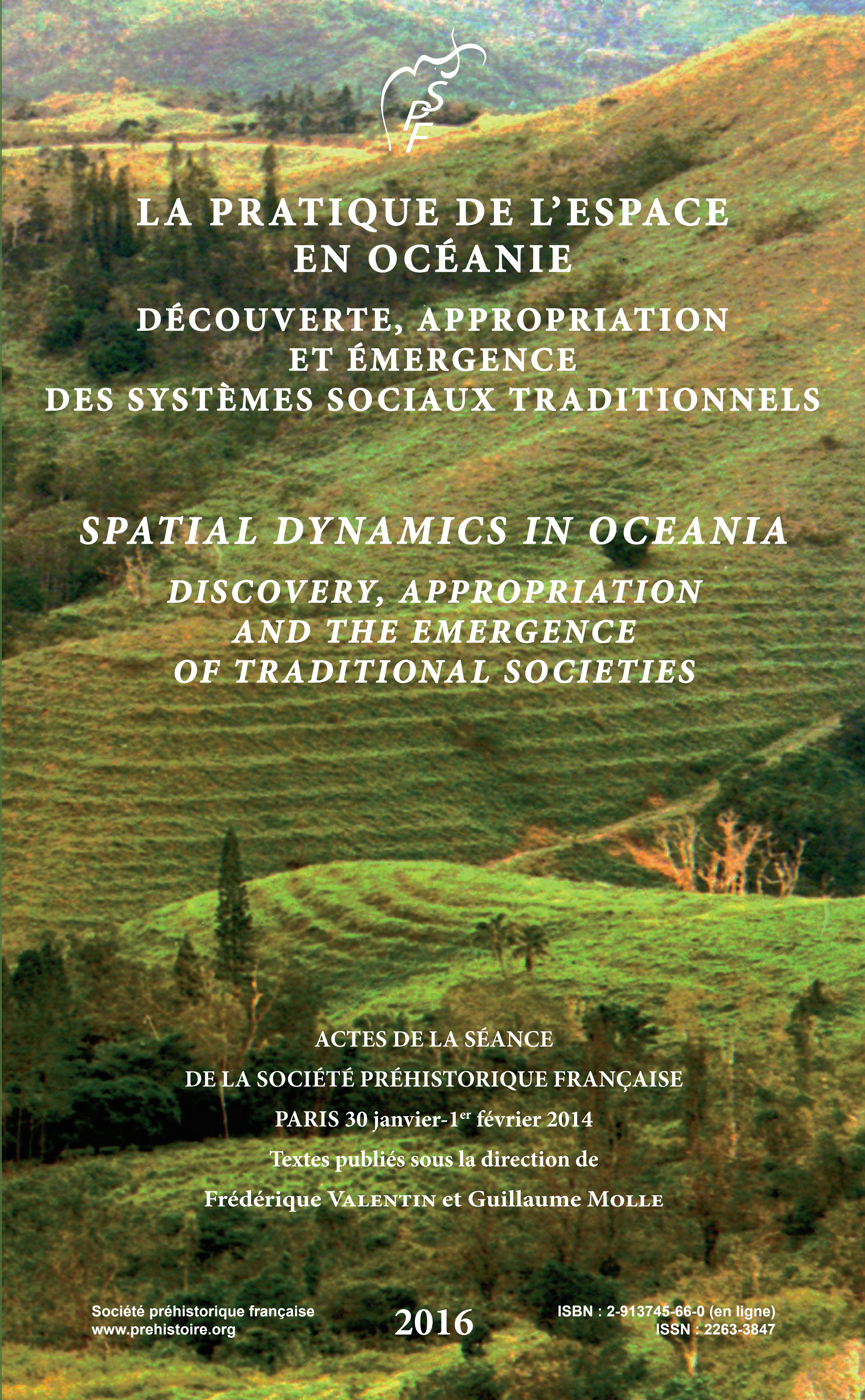

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DISCOVERY, APPROPRIATION AND THE EMERGENCE OF TRADITIONAL SOCIETIES

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PARIS 30 janvier-1er février 2014

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On the importance of freshwater access in successful island colonisation

Christian Reepmeyer, Geoffrey Clark, Jolie Liston and Ella Ussher

Abstract: Subsistence strategies of early colonisers in the Pacific and settlement locations of Lapita sites in close vicinity of freshwater streams have been employed to develop predictive models about potentials of different geomorphological settings to produce archaeological sites. It was concluded that islands with depauperate environments might have been actively avoided by the earliest colonisers because of lack of access to surface freshwater. This paper presents results from recent excavations on the Rock Islands of Palau where two ceramic containers with broken bases were found in stratigraphic levels associated with freshwater lenses in a beach setting. Radiocarbon age determinations of around 2800 cal. BP place the vessels into the early colonisation phase of the Rock Islands of Palau. It is suggested that these containers might have functioned as sumps tapping the freshwater lens, providing evidence that colonising populations were able to sustain settlements on small islands without surface freshwater.

Keywords: Rock Islands, Palau, colonization, freshwater, ceramic, adaptation.

De l'importance de l'accès à l'eau douce dans le succès de la colonisation des îles

Résumé : L'hypothèse selon laquelle les premiers colons du Pacifique se seraient installés à proximité de sources d'eau douce a été utilisée pour prédire la localisation des sites archéologiques Lapita. On en a conclu que les îles aux environnements appauvris pourraient avoir été volontairement évitées par les premiers colons en raison du manque d'accès d'eau douce en surface. Cet article présente les résultats de fouilles récemment conduites dans les Rock Islands (Palau), où deux contenants céramiques aux bases brisées ont été découverts en contexte de plage, dans des niveaux stratigraphiques associés à des lentilles d'eau douce. Des datations radiocarbones, autour de 2800 cal. BP, tendent à attribuer ces céramiques à la première phase de colonisation des îles Rock (Palau). Les auteurs suggèrent que ces poteries pourraient avoir été utilisées comme puisards pour contenir l'eau douce provenant de la lentille, apportant alors l'indication que des installations durables ont pu être développées dans des environnements dépourvus d'eau au tout début de la période de peuplement.

Mots-clés : îles Rock, Palau, colonisation, eau douce, céramique, adaptation.

It must doubtless surprise the greatest parts of our readers, and perhaps stagger their belief when they are told of so many islands abounding with inhabitants, who subsist with little or no freshwater. Yet true it is, that few or none of the little low islands between the tropics have any water on the surface of the ground, except perhaps in a lagoon, the water of which is generally brackish; nor is it easy to find water by digging.
(Rickman, 1781, p. 91–92)

The availability of freshwater in newly discovered environments is an essential attribute influencing on human colonisation (Lepofsky, 1988, p. 42). Predictive models for early Lapita sites marking the founding culture of much of the Western Pacific incorporate vicinity to surface freshwater into their evaluation (Frimigacci, 1980; Lepofsky, 1988; Kirch, 1997; Spriggs, 1997). In contrast, surprisingly little is known about access to subterranean freshwater during initial colonisation. In a recent review, Specht and coworkers (Specht et al., 2014) pointed out that although Lapita colonisers preferred coastal and small-island locations in much of the south-western Pacific, none were outside the visible range of larger islands with abundant freshwater resources (see also Specht, 2007). In Micronesia, where freshwater is significantly scarcer than on the larger volcanic islands of the south-western Pacific, it has been suggested that the earliest colonisers actively avoided small islands devoid of surface freshwater in the initial settlement phase (Wickler, 2001; Liston, 2005).

However, there is evidence for early habitation of small islands lacking surface sources of freshwater. The colonisation of Walpole, an island without surface freshwater at the south-east edge of the Melanesia region, is believed to be initially inhabited at around 2750–2450 cal. BP (Sand, 2004). This age range is slightly later than Lapita sites on Tongatapu in West Polynesia, a low-lying limestone island also without surface freshwater (Hunt, 1979; Clark and Bedford, 2008; Burley et al., 2010). On Tongatapu, a site has been observed next to a solution channel where subterranean freshwater exits into the sea (Valentin and Clark, 2013). Spring-fed freshwater might also have been accessed by early colonisers in cave sites in Fiji, and Aiwa in the Lau Group (Best, 1984, p. 298). Additionally, it has been suggested that in Vanuatu inhabitants of small, off-shore islands without surface freshwater accessed subterranean freshwater during Lapita times (Bedford, 2006) although thus far no evidence supporting this hypothesis has been found (see Bedford, 2003, p. 155, for a discussion of excavation methodology creating a research gap). A pit feature at the Nenumbo site in the Reef Santa Cruz islands has been proposed by Green (1979, p. 35) to have been utilised to access freshwater; unfortunately, this evidence is ambiguous as the pit can be associated with a multitude of other functions.

Freshwater wells in coastal locations are abundant on Pacific islands today. Most evidence for the antiquity and significance of subterranean freshwater derives from the ethnohistoric record and recent observations of wells being utilised for irrigation (Spriggs, 1997); with their importance acknowledged in creation myths and chiefly place names (Hunt and Kirch, 1988, p. 165). Early European explorers in the Pacific frequently discuss the difficulties of accessing potable water, particularly in the Pacific's eastern regions. They simultaneously observed that native inhabitants seem to have no lack of freshwater. For example, on his second voyage Captain Cook describes the island of Tongatapu by stating:

> "[…] If nature has been wanting in any thing *(sic!)*, it is in the article of fresh water, which as it is shut up in the bowels of the earth and for which they are obliged to dig wells, of these we saw only one, so that it is probable there are but few. At Middleburg we saw none, nevertheless they are not without. [Footnote: a running stream was not seen and but one well at Amsterdam: at Middleburg no Water was seen but what the Natives had in Vessels, but as it was sweet and cool I had no doubt of its being taken up upon the isle and probably not far from the spot where I saw it.]" (Beaglehole, 1969, p. 273).

Considering the lack of information about the technology used by initial colonisers to access subterranean freshwater, we report the results of recent excavations in the Rock Islands of Palau. In 2012, a team from the Australian National University conducted research in collaboration with the Bureau of Arts and Culture Palau and the Conservation and Coastal Management Division of Koror State. Excavation encountered two complete pots with missing bases sitting upright in what would have been the intertidal zone at the time of settlement. These pots may have been deliberately placed to tap into the subterranean freshwater lens.

BACKGROUND

The islands of Palau (fig. 1) are located in Western Micronesia approximately 850 km north of New Guinea and about 900 km east of Mindanao in the Philippines. The Palauan archipelago includes the main volcanic island of Babeldoab with a multitude of uplifted limestone islands to the south, including the larger limestone islands of Peleliu and Angaur. The UNESCO World Heritage property Rock Islands Southern Lagoon area, inscribed as a mixed cultural and natural site in 2012, comprises 850 km^2 of lagoon in which about three hundred small raised limestone islands are enclosed by nearly 200 km of barrier reef. These Rock Islands are renowned for the existence of marine lakes containing a huge variety of endemic wildlife (Colin, 2009). Today, the beauty of the Rock Islands and the easy accessibility from Babeldoab obscures the fact that their very steep terrain, lack of cultivable soil deposits and, most importantly, a lack of surface freshwater results in a particularly harsh environment for permanent settlement (Clark, 2005; Clark and Reepmeyer, 2012).

The first Europeans visitors noted that all of the limestone Rock Islands south of Babeldoab and north of Peleliu were uninhabited (Keate, 1788). Palauans reported, however, that a population numbering in the thousands had once lived in the area, with traces of their abandoned village sites found on many islands (Osborne, 1966; also Reepmeyer et al., 2011). Oral traditions frequently place the origin of social groups and the invention of customary practices in the Rock Islands. The origin stories trace the migration of individuals, families and entire villages from the Rock Islands to contemporary villages on Babeldoab, many of which have village names, chiefly titles and community deities retained from the original village sites (Nero, 1987).

Once inhabited, the abandonment of the Rock Islands during the 16th century was recently linked with the onset of the 'Little Ice Age (LIA)' (Fagan, 2008). The 'Little Ice Age' (LIA) is in the western Micronesian region defined by a significant decrease in overall precipitation between AD 1250 and AD 1650 (Masse et al., 2006; Sachs et al., 2009; Clark and Reepmeyer, 2012; also Allen, 2006). The Rock Islands' depauperate terrestrial environment is highly susceptible to climatic fluctuations. In the karst topography soil accumulation suitable for gardening occurs only in sinkholes. The agricultural productivity of the sinkholes, however, is directly correlated with overall precipitation as they rely on the replenishment of subterranean freshwater by rain water (Clark and Reepmeyer, 2012). The archaeological record correlates well with traditional explanations referring to the lack of freshwater access, resource deprivation, and social conflict as the primary causes of the abandonment of permanent Rock Island settlements around 400 BP (Masse et al., 2006; Reepmeyer et al., 2011; Clark and Reepmeyer, 2012).

EXCAVATIONS AT ULONG VILLAGE SITE

The Ulong island group (fig. 1) is located in the western part of the Rock Island Southern Lagoon area. The main island, Ulong, has a very steep topography with a central ridge rising almost 80 m above sea level. Thin infertile soils overlay limestone or calcareous sand beach deposits. There are no perennial streams on the island and no other surface freshwater can be found (Clark et al., 2006). On the west side of the main island the Ulong village site (fig. 2) extends inland, up the ridge slope, from the south half of the largest beach in the Ulong island group (Clark, 2005).

The cultural sequence of the Ulong village site is relatively well understood (Clark, 2005). Initial site occupation is dated to 3000 cal. BP when small and highly mobile groups used the island for short-term camps while harvesting marine resources from the adjacent reef (Clark, 2005; Masse et al., 2006; Ono and Clark, 2012). After initial colonisation of the island, mobile encampment most likely continued until the middle of the first millennium AD. The lack of soil accumulation at the site and the frequent intertidal and storm deposits suggest that beach flat stabilisation did not occur before 2000 cal. BP (Clark, 2004; Clark et al., 2006). Permanent settlement did not establish at the site until after stabilisation of the beach flat and Ulong village was abandoned around 400 cal. BP (Clark and Reepmeyer, 2012). The most prominent feature of the site is a large defensive wall enclosing an alcove at the southern end of the beach flat. The establishing of the wall and other more permanent coral limestone features on the slope of the central ridge can be dated after sedentary settlements were established on many of the Rock Islands around 900–1200 cal. BP (Clark, 2005; Liston, 2005; Clark and Reepmeyer, 2012).

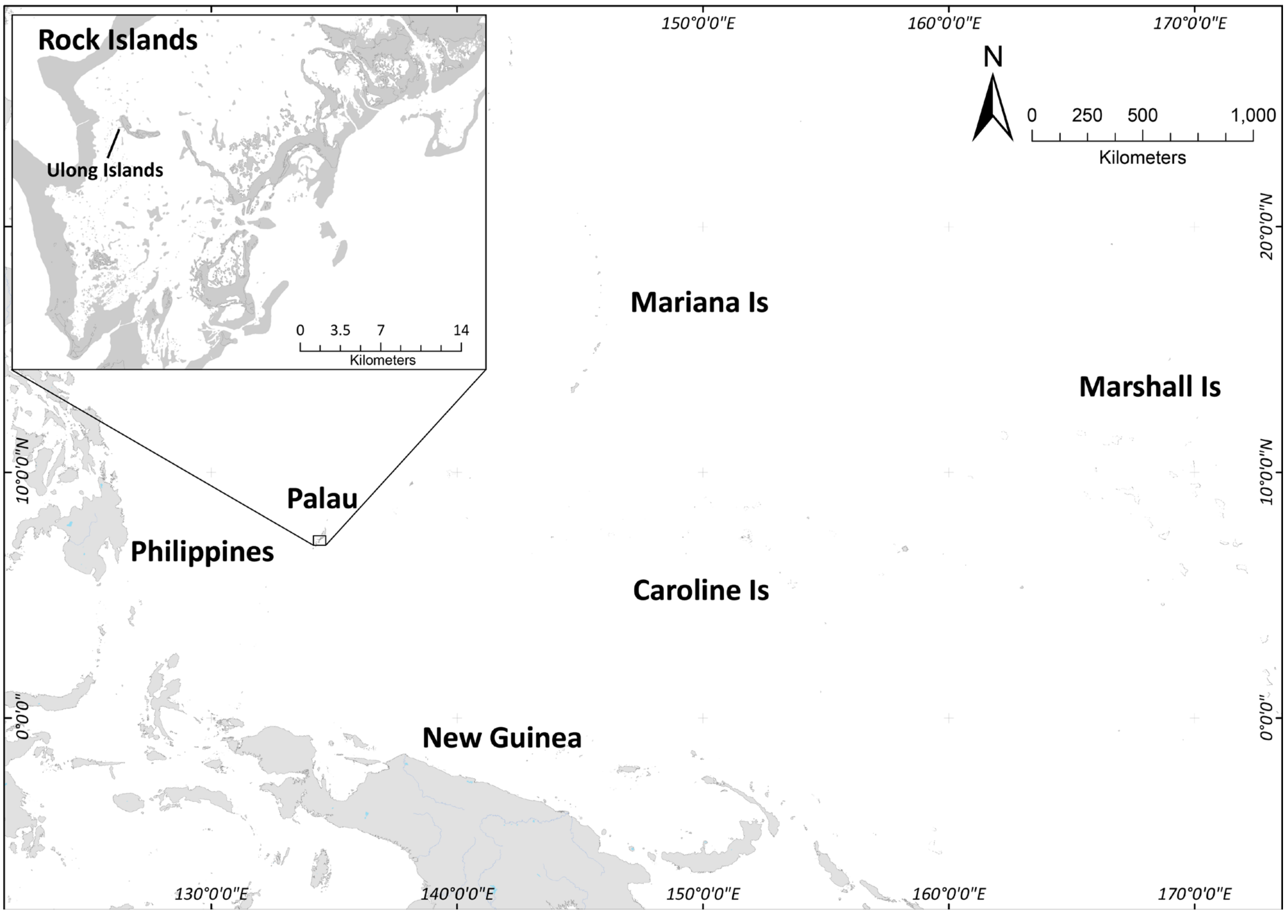

Fig. 1 – Map of the North-Western Pacific with the location of Palau, the Rock Islands and Ulong Island.
Fig. 1 *– Carte de la partie nord-ouest du Pacifique avec la localisation de Palau, des îles Rock et de l'île d'Ulong.*

In 2012, a 1 m × 3 m trench (unit 7) was excavated in the sand deposits at the back of the alcove (fig. 2), approximately 3 m from the base of the limestone slope and about 130 m from the current shoreline. The purpose of unit 7 was to determine if well-preserved material from the earliest occupation known on Ulong Island could be located as it had the potential to provide new knowledge about the first people to inhabit Palau. Previously, excavation of two 1 m^2 test pits in the alcove had investigated the cultural sequence (Clark, 2005) and helped understand resource exploitation during the later phases of village occupation (Ono and Clark, 2012). The discovery of a whole ceramic vessel dated to 2200 cal. BP in one of these test pits (Clark and Wright, 2007) suggested that other vessels may be interred in the sandy flat. As the alcove would be the most likely place for canoes to land, the location of unit 7 at the back of the alcove was chosen to test where the first beach would have formed following the mid-Holocene high stand.

Unit 7 was excavated in 10 cm spits to a depth of 281 cm below datum (fig. 3) with sediment wet sieved through 3 mm and 6 mm mesh. The unit descended to basal sterile sand and revealed eight distinct strata (table 1). The upper layers consist of a dark brown silty sand with abundant pottery, marine shell, fish bone and charcoal. These layers contain pottery with later period attributes, as well as some mammalian bones such as pig *(Sus scrofa)* and rat *(Rattus exulans)*. The permanent settlement horizon is at approximately 122 cm underlain by a 15–20 cm thick grey sandy silt deposit representing beach stabilisation. In the lower layers from 150 cm to about 250 cm calcareous sand with pockets of darker sediment, possibly resulting from bioturbation by crabs and tree roots, show beach flat development involving tidal and storm events. In these layers, the rarely occurring cultural material includes mineral sand-tempered pot sherds, large marine shells *(Tridacna* and *Hippopus)* with intact valve.

The cultural status of the lower levels of unit 7 was confirmed by the discovery of two substantially intact pots, pots 1 and 2, each in its own shallow pit dug into the sterile sand of the lower beach deposit that were subsequently covered by accreting sediments. Both vessels were placed upright in the pits after the vessels' bases had been broken. Pot 1 was set in a pit filled with coral boulders. It is unclear whether the coral boulders were intentionally placed to stabilise the vessel or washed in during later storm or tidal events. The rim of pot 1 was at 210 cm below datum at the same level as three large *Hippopus* and *Tridacna* sp. valves, and was located around the middle of the 1 m × 2 m area that was fully excavated to sterile sand. Substantial damage to the pot 1 rim and the presence of coarse coral gravel in the mouth of the vessel indicate that the feature was within reach

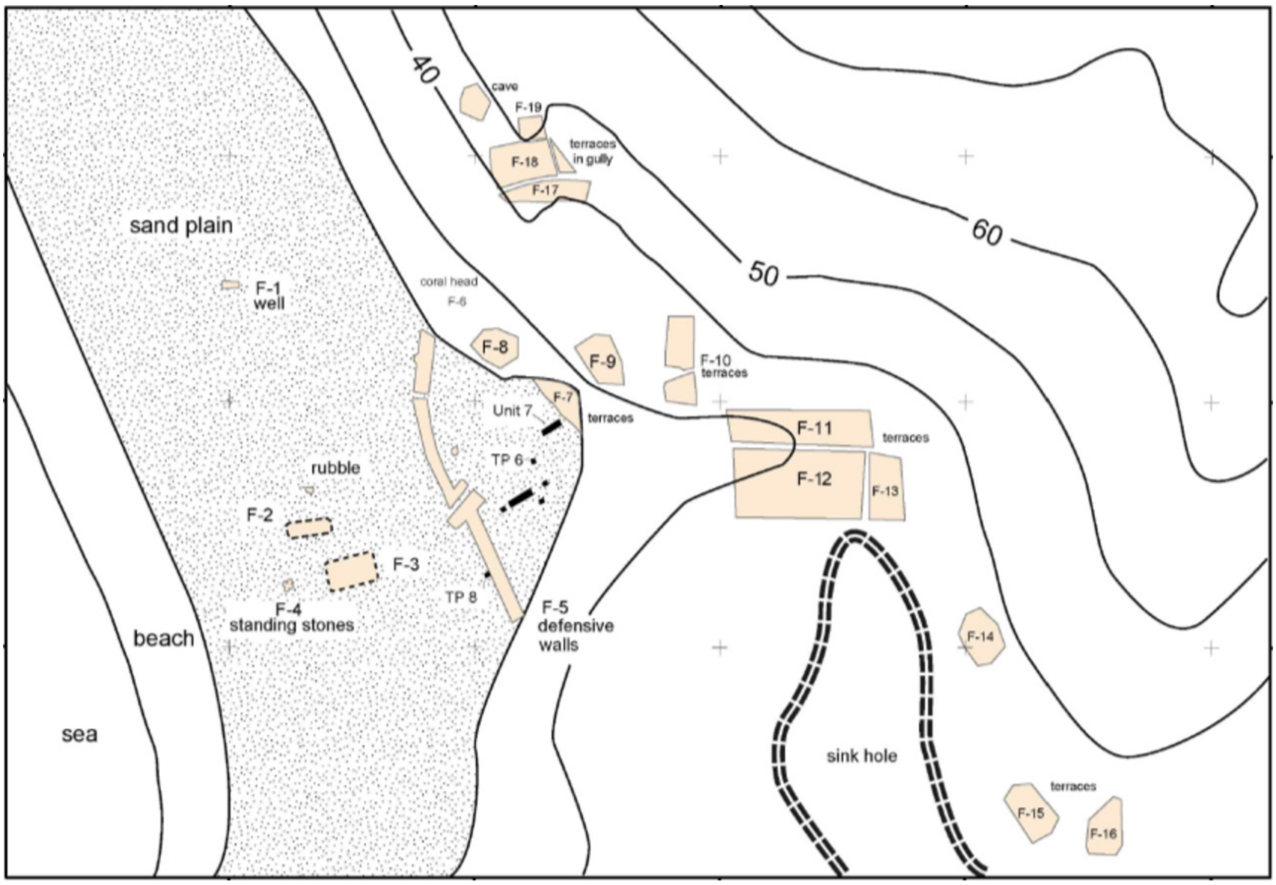

Fig. 2 – Ulong Island and Ulong village site with location of unit 7.
Fig. 2 – *L'île d'Ulong et le village d'Ulong avec la localisation de l'unité 7.*

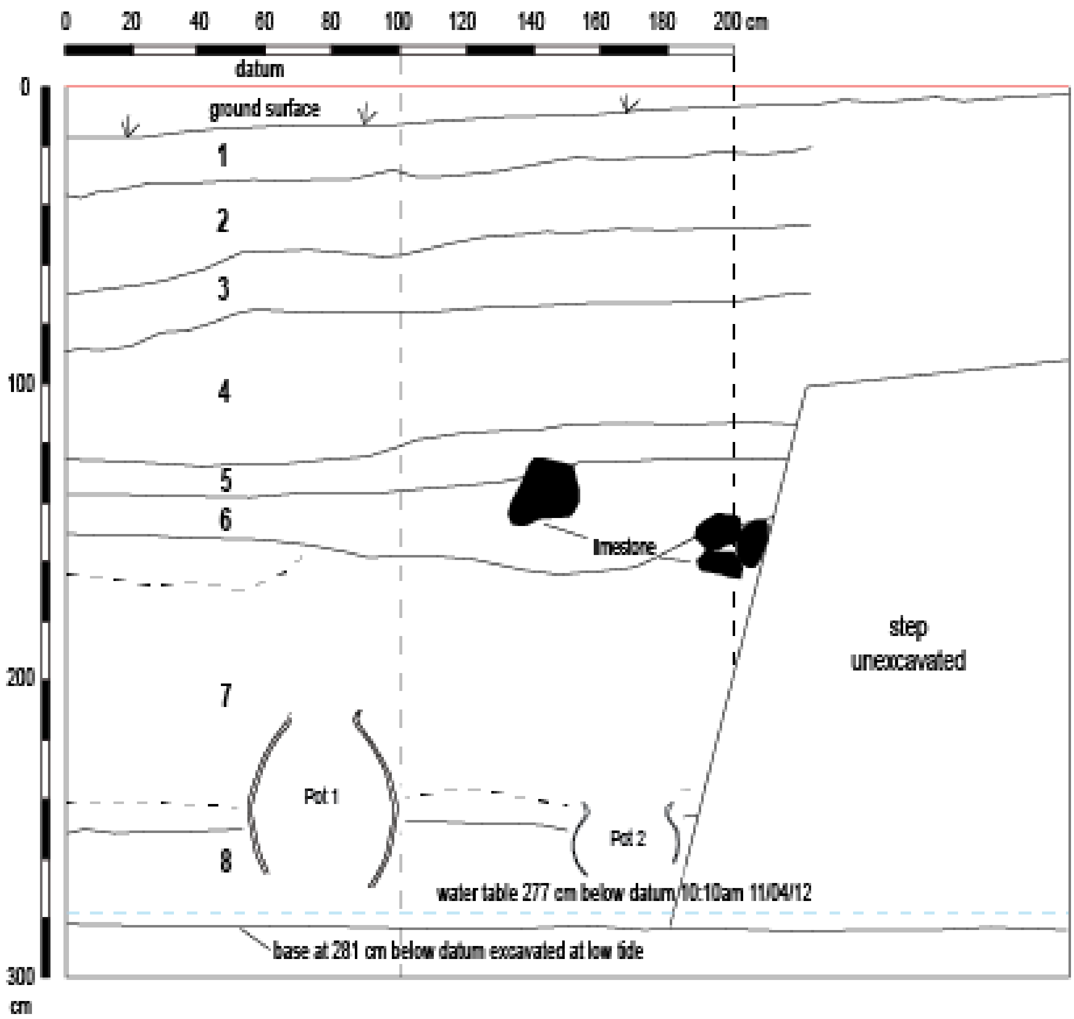

Fig. 3 – Unit 7 stratigraphy, North section, with the location of the two vessels.
Fig. 3 – *Stratigraphie de l'unité 7, section nord avec la localisation des deux récipients.*

	Colour and texture	Content
Layer 1	(10YR 3/2) Dark brown fine-medium silt with high humic content and frequent roots.	Abundant limestone gravel. Some thick walled ceramics.
Layer 2	(10YR 5/1) Medium brown sandy silt with high humic content, frequent roots.	Frequent coarse limestone fragments. Some thick walled ceramics.
Layer 3	(10YR 6/1) Light brown-grey sand with high humic content, increasing amounts of medium beach sand.	Some thick walled ceramics.
Layer 4	(10YR 3/2) Dark brown sandy silt.	
Layer 5	(10YR 3/2) Thin lens of dark brown humic material marking the transition between the silty beach flat sediments and beach sand deposits and probably representing early vegetation growth on the stabilized beach flat.	
Layer 6	(10YR 8/1) Yellow-white fine mottled limestone sand.	Limestone cobbles.
Layer 7	(10YR 7/1) Grey-white medium sand. At the base of the layer at 236–252 cm below datum is a thin lens of grey sand.	Cobbles of limestone at base, chunks of coral and some large clam valves distributed throughout the deposition. Rarely cultural material such as pottery fragments.
Layer 8	(10YR 8/1) Pale yellow-white medium sand.	No cultural material, limestone, coral or shell.

Table 1 – Description of unit 7 stratigraphy.
Tabl. 1 *– Description de la stratigraphie de l'unité 7.*

of tidal and storm waves. Pot 2 was located only 50–60 cm inland of pot 1 with the rim recorded at 242 cm below datum. The pot 2 pit contained fine sandy sediment with no coral boulders. The vessel's largely intact rim suggests it was probably quickly buried by beach sand.

RESULTS

Vessel forms

Pot 1 is an ovoid bodied vessel with an external orifice diameter of 24.4 cm and an everted rim with an orientation angle of 29 degrees (fig. 4). Extrapolation of vessel wall contours indicate a total vessel height of roughly 60 cm and a maximum body width of 46.5 cm. Body wall thickness varies from 0.8–1.6 cm with the thickest section at the juncture of the body and neck where a clay coil was added and shaped upward to form the neck-rim. The rim profile gradually thickens to terminate in a sub-rounded lip. The lower part of the vessel's exterior is fire blackened with carbonized residues adhering to the interior walls indicating use-life of the vessel included cooking. Mineral grains visible in the fabric under low-power magnification comprise quartz and ferromagnesian particles along with oxidized lithic fragments and calcareous inclusions. These minerals are typically found in ceramics collected in Ulong's basal levels (Fitzpatrick et al., 2003). One temper inclusion contained small linear quartz fragments in an irregular grey-black matrix. This suggests use of andesitic breccia, or possibly the early use of chamotte (low-fired clay/pottery), as a source of temper.

Pot 2 is a sub-globular vessel with an estimated height of 31 cm and a maximum body diameter of 38 cm (fig. 5). Its neck-orifice diameter is 26.8 cm and external lip diameter is 32.2 cm. The outcurving rim has an orientation angle of 31 degrees. The surface of the rim's interior displays four small depressions arranged in a column and bordered by two incised lines; this pattern may identify the pot's maker or owner. Body wall thickness varies from 0.5–0.3 cm with the thickest part of the pot below the neck where a clay coil was added to make the neck-rim. The thinnest wall sections are above and below the area of maximum body diameter.

Pots 1 and 2 are very different in height and shape. A point of similarity between the two vessels is the shape of the everted rim and lip, which in both vessels was made by the addition of a clay coil. Temper grains in the fabric of pot 2 are similar to those in pot 1 although pot 2 has a greater abundance of calcareous particles that likely

Fig. 4 – Vessel 1: reconstructed version of the pot and cross section drawing with opening and outer rim diameter (estimated).
Fig. 4 *– Récipient 1: reconstitution et dessin du profil avec le diamètre à l'ouverture et le diamètre du bord extérieur (estimés).*

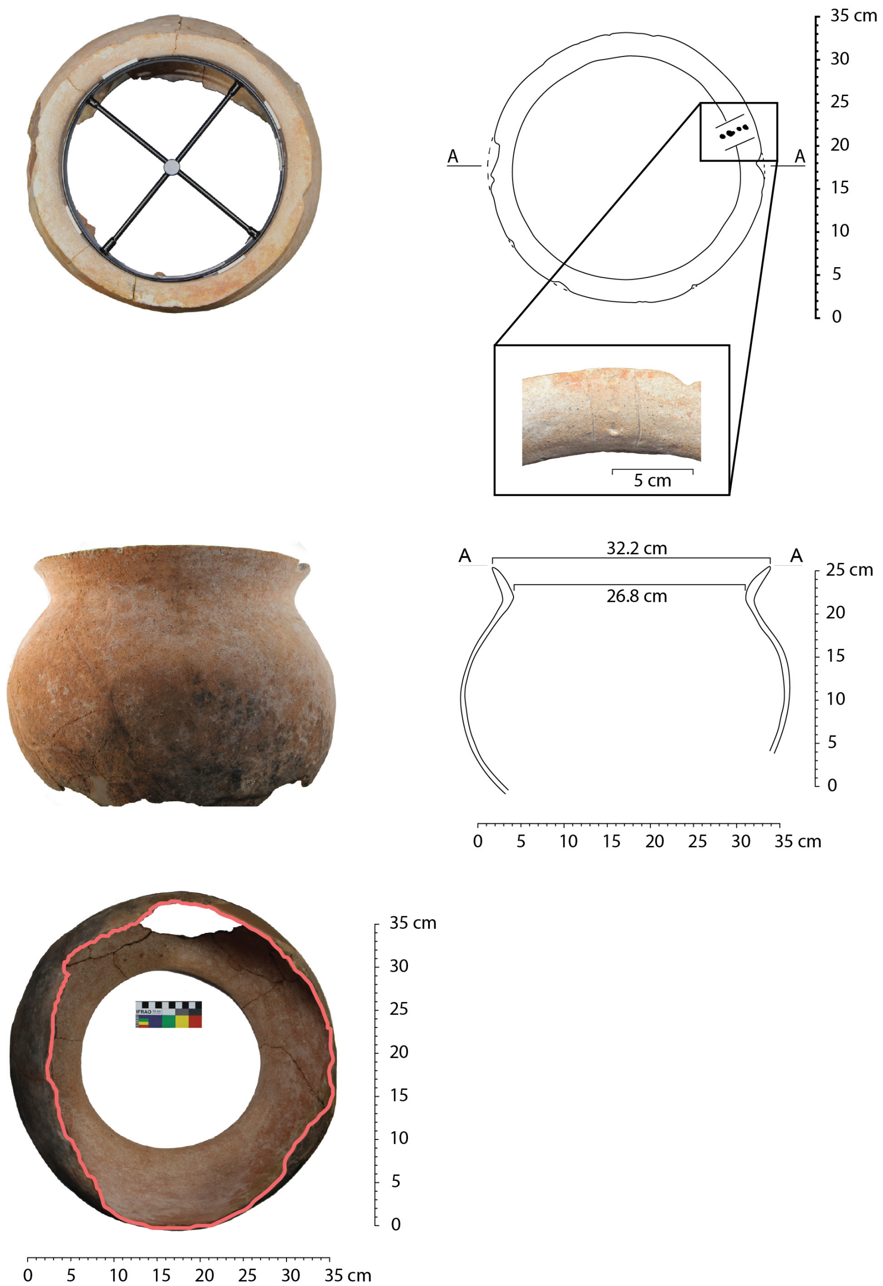

Fig. 5 – Vessel 2: reconstructed version with rim and cross section drawing. Detailed photo of rim indentation as described in the text with rim and opening diameter ; AA: Outer rim diameter.

Fig. 5 *– Récipient 2: reconstitution avec bord et dessin du profil. Photo détaillée du bord dentelé comme décrit dans le texte avec le diamètre du bord et le diamètre à l'ouverture; AA: diamètre du bord extérieur.*

reflects a lower firing temperature or heat exposure. Voids marking the removal of calcareous particles from repeated heating are common in the fabric of pot 1 near the vessel's base. The rim and manufacturing similarities indicate that the pots are probably from the same ceramic tradition. The difference in vessel forms suggests the pots served different functions before they were interred on Ulong Island.

A carbonized residue sample obtained from the interior of pot 1 and a charred twig collected at 220–230 cm below datum were submitted to the University of Waikato's Radiocarbon Dating Laboratory for AMS analysis. Once calibrated with Calib Rev 6.1.0 the radiocarbon ages indicate pot deposition occurred 2,800–2,900 years ago (table 2).[(1)]

Vessel function and relative sea level during the Late Holocene

The placement of complete pots upright into beach deposits at the Ulong site appears to be a repeated action of early visitors to the island. Clark and Wright (2007) excavated an intact upright vessel at Ulong that, similar to pots 1 and 2, had part of its base missing. In contrast, their

Lab number	CRA	Cal. BP Age 2SD	^{13}C	Material	Provenance
Wk-34934	2691 ± 32	2760–2850 (1.0)	−27.2 ± 0.3	Unidentified twigs	Unit 7: 220–230 cm
Wk-34944	2842 ± 25	2770–2890 (0.97)	−11.8 ± 0.2*	Pot 1 residue	Unit 7: 250 cm

* The ^{13}C value suggests that marine foods may have been cooked in the vessel and incorporated in the pot residue. As a result the calibrated age was calculated using the mixed Marine Northern Hemisphere curve using a 30% marine contribution.

Table 2 – Radiocarbon dates.
Tabl. 2 – *Dates ^{14}C.*

vessel was resting on three large sherds which covered the hole in the base (Clark and Wright, 2007, p. 175). Although the role of the previously unearthed vessel remains unclear, Clark and Wright (2007, p. 187) in their review of complete vessels from the Pacific discussed a variety of possible functions, suggesting that after usage as a domestic cooking vessel, the pot was possibly recycled as storage container, but that final placement may have entailed ritual deposition. Ritual or symbolic deposition has been discussed for a series of complete pots from a multitude of archaeological sites throughout the Pacific (Sand, 1995, p. 150–152; Bedford et al., 2007; Sand, 2010, p. 228–232), but the reported vessels have in common that none of their bases are missing completely. At Ulong site, however, we suggest a novel function for these vessels.

There might be a simple explanation for the deliberate placement of the two older vessels. During the majority of excavation in the base of unit 7, the pots were in dry to semi-dry sand. It was not until the vessels were completely exposed and excavation of the pit features in which they rested had begun, that the tide rose and freshwater began to seep up from the floor of the unit. Despite supporting no surface freshwater, Ulong Island's porous bedrock allows rainwater to percolate through the limestone to accumulate on the saltwater intrusion layer to form the Ghyben-Herzberg lens (Cheng and Ouazar, 1999). The accumulated freshwater builds up as a lens floating on the heavier saltwater that rises and falls with the tidal fluctuations of the underlying seawater and can been detected by small rivulets of freshwater forming in the intertidal zone. The deliberate placement of the pots in this intertidal zone allowed freshwater to accumulate in the pots during periods of high tide. We therefore propose that the pots were used as sumps for collecting freshwater by Ulong's early inhabitants.

One of the most persistent problems in interpreting archaeological features as wells or sumps used to access subterranean freshwater in intertidal areas are long-term changes in sea-level (Peltier, 2002; Dickinson, 2003) and the very active geology throughout the Pacific (Hall, 2002). Tectonic and volcanic uplift has resulted in a number of early colonising sites being situated up to hundreds of metres inland of and several metres above the current shoreline (Bedford et al., 2006). On the other hand, island subsidence has submerged many early settlement sites (Leach and Green, 1989). A lack of understanding of uplift and subsidence on Palau had been a problem that had resulted in inaccurate assumptions about the timing of the archipelago's colonisation and early settlement pattern (Masse, 1990; Athens and Ward, 2001).

Research by W. Dickinson and his colleagues suggests Palau and other parts of Micronesia subsided under added water load resulting from the post-Pleistocene melting ice cover with a subsidence rate for Palau estimated at 0.55 mm/year (Dickinson, 2003 and 2009; Dickinson and Athens, 2007). However, mapping of a buried limestone notch on Ulong Island showed that it has the same relative elevation as the current tidal range indicating a decline in relative sea-level that has tracked subsidence (Clark et al., 2006; but see Dickinson et al., 1994, p. 94, fig. 5).

DISCUSSION

Potable water is central to human life and a prerequisite for long-distance ocean travel (Bulbeck, 2007; also Ellis, 1997). Colonisation of remote Oceanic islands required technological and behavioural strategies to store and replenish water supplies during long ocean voyages and to find freshwater after arrival in new landscapes. However, a series of questions remain: Where does the innovation of accessing subterranean freshwater originate? Did the knowledge of accessing a wide variety of possible freshwater resources enable colonisers to adapt to new environments faster? Would the availability of freshwater guide colonisation movements?

In Northern Australia coastal hunter-gatherer populations may have had knowledge of the presence of subterranean water as early as the Late Pleistocene (O'Connor, 1992; see also McCormick, 1977, p. 210). This might indicate an even longer history of knowledge about island hydrology in Island Southeast Asia. The selection of cave and rock shelters as habitation sites might be a factor of not only the need for shelter, but also the availability of easily collectable rain-fed spring water percolating out the bedrock.

A more archaeologically visible proxy for this technological innovation being available for the Pacific's colonising populations derives from its early use in agriculture (rice irrigation, Udatsu et al., 1998; Ruddiman et al., 2008, p. 1294; Qin et al., 2011). Plant species are in general highly susceptible to salinity stress in water supplies (particularly sodium-chloride salts; Parida and Das, 2005). The common reaction to increased salinity load is reduced productivity or, depending on the amount of salinity, inability to complete the metabolism cycle. Domesticated plant species in the tropical Pacific (for example *Colocasia esculenta*) react distinctively negative to only small increases in salinity loads (Hill et al., 1998). In this context, knowledge of a subterranean freshwater lens suitable for drinking is evident from early aroid pit agriculture on low lying carbonate atolls in Micronesia (Weisler, 1999; Chazine, 2012). The innovative nature of aroid pit agriculture, particularly for *Cyrtosperma chamissonis* (giant swamp taro), is pointed out by Marshall Weisler in his research on agriculture systems in the atoll world of the Marshall Islands in Micronesia:

> The use of the subterranean fresh water lens for the cultivation of giant swamp taro was an ingenious technique that was probably a natural extension of planting aroids along the margins of low-lying swampy areas on other kinds of islands. And it was probably a period of trial and error that made it clear that the salt-tolerant giant swamp taro was better adapted to increased aridity and salt spray on low coral atolls than the *Colocasia* taro (Weisler, 2001, p. 127; see also Spriggs, 2002, p. 87).

It is unclear whether aroid pit agriculture was a Micronesian innovation or was brought in with the first colonisers at least some of whom came from Island Southeast Asia. J.-M. Chazine (Chazine, 2008, p. 121) favours the latter scenario in his hypothesis that the technique might derive from atolls in the Sulu Sea and Borneo, although there is yet no conclusive evidence (see also Yamaguchi et al., 2005). The possibility is indirectly supported by the early age of initial aroid pit agriculture in the Marshalls suggesting that this technology was available when the atolls were first colonized around 2,000 years ago (Weisler, 1999, p. 640). However, other parts of Micronesia such as Palau, the Mariana Islands and probably Yap had already been colonized for a millennium before settlement of the Marshalls and these might have been locations where aroid pits were developed.

The case for local invention of aroid pit cultivation is strengthened by the natural distribution of *Cyrtosperma ch.* which is not reported as occurring in wild forms in western Malesia and northern Island Southeast Asia (Whistler, 1991; Lebot, 1999; Mitsuru, 2002). Rather wild forms of *Cyrtosperma* extended out of eastern Malesia to include much of Micronesia (Athens and Stevenson, 2012). Today, *Cyrtosperma* agriculture is wide-spread in the Palau archipelago, particularly in the lower marshlands (*omrekongel* field system or, if mix-planted with wetland taro *(Colocasia esculenta)* or *dechel*, where it is used as a famine food or during droughts for its higher salt resistance (Koshiba et al., 2014).

In the absence of surface freshwater, liquid storing plants, such as *Cocos nucifera* (Harris, 1978) were potentially important during human colonisation. The natural dispersal range of *Cocos* is unclear (Harris, 1978), but includes much of the tropical Pacific (Ward and Brookfield, 1992; Prebble and Dowe, 2008; Athens and Stevenson, 2012; Harris and Clement, 2014). Its genetic signature suggests that the domesticated form was also transported by colonisers from Island Southeast Asia to the Pacific (Gunn et al., 2011), showing its importance as an agricultural crop and source of liquid.

However, supplying freshwater requirements of colonisers purely from plants such as *Cocos nucifera* is arithmetically unlikely (Grimwood, 1975). The amount of water necessary for a founding population of twenty-five to fifty people (Kelly, 2003, p. 51; Rallu, 2007, p. 20), estimated at 525–1,050 litres per week or in excess of 250–500 hectolitres per year, would quickly deplete an island's plant resources. In contrast, during short stays of small groups of highly mobile foragers, an adequate water supply can be sustained by employing plants such as coconuts. *Cocos* grew on the volcanic island of Babeldoab prior to human arrival (Athens and Ward, 2001), but on Ulong, it is unlikely that coconut trees were able to grow in any large quantity until the beach flat stabilised and expanded in the past 2,000 years. We assume that there were no coconut trees on the island, and accessing alternative water sources was necessary.

Landscape learning, coastal settlements, mobility and implications for colonisation events

It is unclear whether the knowledge of subterranean water was an adaptation to new, more depauperate environments in Micronesia or whether colonists arrived on these islands with a full skill-set already established as discussed above. One additional argument for an already established skill-set might derive from the distances covered while exploring the eastern regions of the Pacific. The need for immediate return voyages due to the lack of accessible freshwater sources is implicitly expressed in arguments which relate island discovery and colonisation events with suitable wind-directions (Irwin, 1992 and 2008; Anderson, 2003; Anderson et al., 2006; but see Avis et al., 2008 for a contrasting view of island discovery). Furthermore, the more remote an island, the more logistical planning is necessary to ensure survivability of a founding population. In extreme cases, if no suitable freshwater resources were available, deliberate colonisation would be prohibitive with archaeological evidence most likely reflecting accidental inhabitation, and island abandonment would be frequent (Kirch, 1984; Terrell, 1986; Anderson, 2001; Di Piazza and Pearthree, 2001).

A common strategy used to mediate environmental risk is high mobility (Binford, 1980; Halstead and O'Shea, 1989; Kelly, 1992; Winterhalder et al., 1999), particularly in cases where storage is unavailable. This is discussed by M. Weisler (Weisler, 1996) and by A. Di Piazza and E. Pearthree (Di Piazza and Pearthree, 2001) who relate environmental factors such as 'dryness' to the length of stay during the settlement process (see also Anderson, 2001 and 2011). Small off-shore islands with depauperate ecosystems, termed 'satellites' in these models, were most likely only used during exploration and short-to-medium term visits, for example fishing expeditions. On the other hand, it is suggested that larger islands were targeted in East Polynesia and Micronesia and became permanent 'mother communities' due to their abundance of freshwater and the quantity and variety of terrestrial resources, particularly agricultural soils (Di Piazza and Pearthree, 2001; Weisler, 2001). The correlation between size and remoteness of islands with the type and age of settlement is documented not only in the Pacific but also in other parts of the world (Cherry, 1981; Anderson, 2011; Phoca-Cosmetatou, 2011).

We therefore argue that discovery and colonisation processes have to be investigated separately (Anderson, 2003). Highly mobile groups of sailors on the periphery of settled areas were able to survive for short-term stays on islands with extremely depauperate ecosystems. These sailors would then disperse the knowledge of the potential of these islands for colonisation to the more sedentary population.

Implications for the islands of Palau

The example from Ulong Island shows that early visitors had sufficient knowledge to survive, at least in short to intermediate terms, in the most marginal of environments. In the case of Ulong, the data supports a settlement model where permanent settlement was not established until beach flat stabilisation at 2000 cal. BP. The data also shows how important access to freshwater was in these highly marginal islands and that, apart from rain water collection, there was no alternative method for acquiring freshwater other than accessing the subterranean freshwater lens on the beach flat.

This data does not suggest that early colonisers understood the specifics of freshwater hydrology on these small Rock Islands as different hydrological processes can result in similar resource availability. From a consumer's perspective, accessing groundwater originating from inland aquifers in a coastal setting would not be dissimilar to accessing the Ghyben-Herzberg freshwater lens situated on top of the seawater intrusion layer. The ratio established in the Ghyben-Herzberg relation of forty times the amount of freshwater below versus above sea-level would necessitate digging a well of significant depth to reach the underlying salt water layer. Accessing the subterranean freshwater lens would be possible in certain locations. Selection of the Ulong site for short-term camps might indicate that specific geomorphological features, such as steep slopes or small rivulets in the intertidal area, were seen as an indication of possible freshwater sources, an adaptation most likely based on previous knowledge (Kelly, 2003; Erlandson and Fitzpatrick, 2006; Phoca-Cosmetatou, 2011).

It has been argued (Masse et al., 2006; Clark and Reepmeyer, 2010 and 2012) that the abandonment of the Rock Islands was most likely due to unpredictable rainfall patterns and decreasing overall precipitation during the 'Little Ice Age'. As the earliest evidence for accessing subterranean freshwater in the Pacific, the discovery of vessels used as sumps for gaining access to the freshwater lens supports the initial finding that freshwater was likely of continuous importance throughout Ulong Island's occupation.

CONCLUSION

The Palau excavations discovered the earliest evidence for people accessing a subterranean freshwater lens in the Pacific. The discovery also adds an additional role to pottery functions in the Pacific by identifying the novel use of recycled cooking vessels as sumps in a coastal island setting. At 2800 cal. BP island visitors were aware of the existence of the freshwater lens, with the only indication of its existence being rivulets in the intertidal area. It is unclear whether this new technology was an innovation driven by local adaptation to a depauperate environment not encountered before or derived from earlier technological advancements transported to the island. The advanced age of the sumps favours the latter scenario.

The Palau evidence shows that access to freshwater was a continuous challenge throughout the Rock Islands' settlement history. It also supports the hypothesis that the abandonment of islands was connected to environmental factors that pushed otherwise resilient communities to migrate to areas with more secure subsistence bases. When early colonisers spread out from Island Southeast Asia to Micronesia, they encountered a set of low-lying limestone islands with unfamiliar and challenging environments. The evidence provided here suggests that technological knowledge and landscape adaptability was well established in these colonising communities, so that the lack of potable surface water was not viewed as an obstacle, but rather a technicality to be overcome.

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NOTES

(1) The ^{13}C value suggests that marine foods may have been cooked in the vessel and incorporated in the pot residue. As a result the calibrated age was calculated using the mixed Marine Northern Hemisphere curve using a 30% marine contribution.

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