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Results from the first analysis of lipid residues in Lapita pottery

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ABSTRACT

Biomolecular and isotopic characterization of absorbed organic residues has been performed on eight dentate-stamped and two plain Lapita potsherds from the site of Teouma, in Vanuatu. Lipid profiles associated with decorated pots are homogenous suggesting that similar food types or mixtures of food types were placed in these vessels. This suggests a high degree of consistency in the use of Lapita decorated pots, irrespective of the morphological and stylistic variation of these vessels. Data obtained from single-compound isotope analysis are also not consistent with marine resources as potential food sources for Lapita vessels. Overall, the absence of marine resources in decorated vessels sharply contrasts with the current accepted model of subsistence strategy during the early stages of Lapita occupations at Teouma, characterised by broad-spectrum foraging of marine and terrestrial species. The absence of such commonly consumed, ubiquitous and easily accessible resources in Lapita vessels suggests that these pots were not manufactured to be used for ordinary occasions and day-to-day food consumption. This is the first time tangible data related to the use of these vessels is provided to support this claim in addition to contextual inferences.

KEYWORDS

Lapita, Vanuatu, Pottery, Lipid analysis, Oceania, Organic residue, Marine resources

HIGHLIGHTS

- Organic residue analysis of Lapita pottery from Teouma (2940-2710 cal BP), Vanuatu
- Lipid profiles from decorated pots are homogenous
- Data are not consistent with marine resources as potential food sources
- Results suggest these pots were not manufactured to be used for ordinary occasions

1. INTRODUCTION

The first human settlers in Remote Oceania are recognised in the archaeological record by a set of cultural and material traits gathered together under the encompassing concept named the Lapita Cultural Complex (Earle and Spriggs 2015, Green 1991, 2000, Kirch 1997, Sand 2010a, Sand and Bedford 2010b, Sand et al. 2011, Sheppard 2011, Sheppard et al. 2015). The geographic extent of Lapita occupation is known to stretch from the Bismarck Archipelago and the south coast of New Guinea in the west to Tonga and Samoa in the east (Kirch 1997, McNiven et al. 2011, Skelly et al. 2014). Although it would be prejudicial to limit the complex entirely to its ceramic aspect (Green 1990: 33), the most distinctive element of the Lapita Cultural Complex remains its decorated pottery, characterized by fine dentate-stamped designs. The presence of Lapita vessels across such a wide geographical area suggests that these dentate-stamped vessels held a certain status within the social organisation of these colonising groups. The consensus is that the dentate-stamped Lapita vessels were probably used in special contexts (ceremonial, non-secular) rather than being a domestic cookware implement (Best 2002: 99-100, Spriggs 2003: 205, Chiu 2007: 257-260, Kirch 2000: 102-106, Terrell and Welsch 1997: 568). The main arguments supporting this idea are based on indirect contextual evidence from a number of Lapita sites, including the presence of decorated Lapita vessels in direct association with burials at the cemetery site of Teouma (c. 2940-2710 cal BP) in Vanuatu (Bedford et al. 2006, Bedford et al. 2010: 143). This article presents for the first time concrete data acquired directly from Lapita pottery from Teouma that clearly support this hypothesis.

The objectives of this paper are twofold:

I. To **propose an analytical method** able to **gain insights into the social role of dentate-stamped ceramics** by providing direct chemical evidence related to the original contents of these vessels. Previous attempts at analysing residues in Oceanic pottery have had limited success and/or targeted very specific aspects which hindered the widespread applicability of these techniques to archaeological assemblages (Hocart et al. 1993, Hill and Evans 1989, Fankhauser 1997, 1994, Hill et al. 1985). Until now, *direct* evidence of Lapita diets have been provided by i) bulk stable isotope analysis of human bone collagen (Kinaston, Buckley, et al. 2014, Kinaston, Bedford, et al. 2014, Valentin et al. 2010, Valentin et al. 2014), ii) the analysis of starch and phytolith microfossils in dental calculus (Horrocks et al. 2014), and iii) starch and phytolith analyses of pottery residues (Crowther 2009, 2005, Horrocks et al. 2009). Those studies have contributed significantly to scholarship but have important limitations when trying to reconstruct the use of Lapita pottery. Bulk stable isotope analysis of human bone collagen and the study of microfossils present in dental calculus of Lapita individuals provide direct evidence of the foods eaten by past people, but nothing indicates whether these foods were processed, cooked, stored, or displayed in Lapita vessels before being consumed. The analysis of starch and phytolith microfossils in soil adhering to sherds or preserved in carbonized deposits still adhering to the walls of ancient Lapita pottery have great potential for identifying precisely which plants have been processed or cooked in these vessels, but these techniques cannot be employed to document the use of animal resources. The biomolecular and isotopic analyses of lipids undertaken in the present study, on the other hand, shed light on a wider variety of food sources, including plant and aquatic oils, as well as animal fats.

This article details the results from the first organic residue analysis undertaken on Lapita pottery combining gas chromatography mass spectrometry (GCMS) and gas chromatography-combustion-isotope ratio mass spectrometry (GC-c-IRMS) analysis of lipids. When used in concert with stable isotope analysis of human bone collagen and faunal analysis, as we do here, these state-of-the art techniques in organic residue analysis have been shown to provide more accurate reconstructions of pottery use(s) than was traditionally possible (Craig et al. 2013, Craig et al. 2011, Craig et al. 2007, Craig et al. 2005, Outram et al. 2009, Reber and Evershed 2006, Evershed et al. 1991, Taché and Craig 2015). Absorbed residues were targeted in the analyses reported here, since none of the Lapita pottery sherds recovered at the site of Teouma had visible foodcrusts, or carbonized deposits, adhering to their interior walls. Absorbed residues result from the contact and subsequent absorption of a ceramic container's original content into its porous and permeable wall during use (Heron and Evershed 1993). Such residues allow the identification of what has been placed in a vessel over its lifetime, as opposed to visible residues, which are usually formed from a single or a small number of cooking accidents that resulted in the carbonization of the vessel's content.

II. To test the hypothesis that the importance of Lapita dentate-stamped pottery had more to do with ideology (perhaps expressed in ceremony/ritual) than mundane use, with data directly acquired from the vessels via organic residue analysis. This idea that dentate-stamped vessels were not primarily used for cooking but rather for exceptional circumstances has been suggested originally by Groube (1971: 305) and the detailed analysis of the dentate-stamped assemblages of Lapita sites in the Arawe (Summerhayes 2000a) and Mussau Islands (Kirch 1997: 120-122) in Papua New Guinea later suggested that "dentate-stamped vessels are one specialised component of a larger assemblage" (Summerhayes 2000b: 301). If this hypothesis is today largely accepted, it still relies on inferences and has yet never been demonstrated by tangible data directly related to the usage of these vessels.

The rationale for conducting this study is that determining *what* was placed in these vessels has great potential to further our understanding as to *why* they were used. This project aims to determine what food items were placed in Lapita pottery in order to gain insights on the ways these vessels were used. By comparing data obtained from organic residue analysis of Lapita pottery with past study of soil microfossils, the composition of faunal assemblages, and current information on Lapita subsistence patterns and availability of resources, we hope to reveal whether commonly eaten food or unusual food items were placed in Lapita vessel. Established criteria employed to define 'special types' of food, such as rarity, difficulty of preparation and acquisition (labour investment), will also be considered to assess further the significance of these pots and determine whether Lapita vessels were special containers reserved for special occasions (Appadurai 1986, Berry 1994, Curet and Pestle 2010, Dietler 2012, Hayden 1996)[i], or if they were more likely used in mundane day-to-day food preparations. Overall, the concept of Lapita cuisine has been little explored in the archaeological literature (cf. Kirch 1997, Kirch and Green 2001, Pollock 1992) and this paper aims at beginning to fill this void.

2. LAPITA POTTERY: THE CURRENT CONSENSUS

The analysis of the decorative aspects of Lapita pottery revealed that specific decorative motifs and quite rigid organisational rules were shared across a region covering 4000 km (Ambrose 1997, Chiu 2007, Mead 1975, Sand 2007, Siorat 1990, Spriggs 1990). Such a complex and organised decorative system implies that the iconography on the pots held an important cultural significance for the people who were manufacturing and using them. Current models assume that the cultural connection between Lapita communities, attested by the homogeneity of the dentate-stamped decorations across Lapita sites, was associated with ideology rather than materiality; ideas were transferred more than objects, and the ideological signification of these vessels was more important than their economic value (Earle and Spriggs 2015). Accordingly, Best (2002), Chiu (2007) and Summerhayes (2000a) have argued that dentate-stamped Lapita ceramics, especially the ones displaying face motifs, were used to promote, signal and convey information about the social status and power of Lapita communities, notably in the contexts of special events and/or ceremonies (e.g., funerals, feasts, etc.).

Even if generally accepted, the idea that dentate-stamped ceramics were involved in special activities rather than prosaic domestic cooking relies on little information regarding how these vessels were used (see Kirch 1997, Osmond and Ross 1998). The general absence from Lapita pottery assemblages of soot or carbonised residues indicative of cooking (Kirch 1997: 120-121, 2000: 106), as well as the forms (notably the flat-bottomed dishes and the open bowls elevated on a pedestal) and technological characteristics of Lapita pottery have been used to suggest that these containers are not well suited to use directly over a fire (Ambrose 1997, Clough 1992). This was in turn interpreted to mean that dentate-stamped Lapita vessels were primarily used for food display/consumption rather than cooking. However, this does not exclude completely the possibility that Lapita pottery was also involved in certain forms of cooking, through indirect stone boiling for example, as suggested by the presence of foodcrusts on a very small number of Lapita vessels (Crowther 2009, 2005) and Proto Oceanic reconstructed words for food preparation involving pottery (Osmond and Ross 1998: 68, Lichtenberk 1994: 275). Besides these technological and use-wear inferences, most of the arguments used to support the assumption that dentate-stamped Lapita ceramics were involved in ceremonial and/or ritual activities, as convincing as they might seem, rely on indirect contextual information, as detailed below.

i) The Talepakemalai (ECA) site (Mussau Islands, Papua New Guinea) represents one of the largest Lapita villages known and is noted for its well preserved spatial integrity amongst waterlogged deposits (Kirch 2001, Kirch 1997). Two distinct activity areas with contrasting assemblages have been identified on this 82,000m^2 site dating back to perhaps 1350 cal B.C at the earliest (Kirch 1997, Kirch 2001, Kirch et al. 2015: 50, Specht and Gosden 1997: 181-187). While one area yielded a ceramic assemblage dominantly composed of plain globular jars accompanied by obsidian flakes, fish bone and evidence of conus shell ring manufacturing (Kirch 1997: 172), the other yielded finely dentate-stamped sherds from vessels displaying various forms, a variety of tools (e.g., shell scrapers and peelers, fishhooks, oven stones), ornamental objects (shell ornaments, anthropomorphic figure carved of porpoise bone) and evidence of a stilt-house (Kirch 2000). Based on the concentration of decorated ceramics and uncommon objects in the latter area, it was suggested that the structure could have hosted special activities related to food preparation and consumption in a non-domestic context, a feast for example. In contrast, a more conventional habitation is thought to have occupied the area where artefacts were found dedicated to the completion of quotidian activities.

ii) Amongst other findings, excavations at the eponymous Lapita site WKO013 (Foué, New Caledonia) revealed a double pit dated to 1020-820 cal B. C., where two Lapita complete pots had been buried and 15 other half-broken decorated pots had been purposefully placed (Sand et al. 1998, Sand 2013: 3). It is unquestionable that the burying was intentional, as suggested by the organised position of the pots and surrounding sherds and by the characteristics of the filling, more compatible with a rapid filling than a natural and slow packing (Sand et al. 1998: 37, Sand 2013: 3). Such behaviour has been interpreted as an indication that the vessels were treated with special consideration, which in turn would imply that they had some cultural significance for the occupants of the site.

iii) The exceptional preservation conditions at the site of Vao, an offshore island in northeast Malekula, Vanuatu, allowed the recovery of paint remains on the surfaces of some dentate-stamped sherds (Bedford 2006a). It was determined that multiple paint coatings were applied on the decorated vessels, as white and red paint were sequentially applied, leading ultimately to obscuring the dentate-stamped decorations. The presence of paint over intricate decorations could have held some special social or cultural significance and has been seen as supporting the idea that Lapita dentate-stamped vessels "were associated with ceremonial activities rather than domestic cooking or storage" (Bedford 2006a: 553).

iv) The unequivocal association of dentate-stamped pottery with burials at the Lapita cemetery site of Teouma (Vanuatu) also attests to the special value of these vessels (Bedford et al. 2010: 145-147, Bedford and Spriggs 2007, Bedford et al. 2007, Bedford et al. 2006). It has been demonstrated recently that some of the vessels recovered at Teouma were probably deliberately smashed and deposited as part of a ritual (Ravn et al. 2016). The dentate-stamped ceramic collection of Teouma is remarkable for its variability both in forms and motifs (Bedford 2007: 190, Bedford and Spriggs 2007, Bedford et al. 2006: 819). The designs on a number of Teouma vessels show some similarities with the earliest Lapita ceramic assemblages from New Caledonia, Reefs-Santa Cruz and further west in the Bismarck Archipelago (Bedford et al. 2006, Bedford and Spriggs 2007). It also seems that there was a much greater proportion of dentate-stamped decorated pottery in the cemetery area, compared to the adjacent cooking area where incised and plain or notched rim pottery predominated over dentate-stamped vessels (Spriggs and Bedford 2013). Petrographic and chemical analysis of the Lapita ceramic collection revealed that the majority of the vessels was produced on Efate, although 11% of the pots examined have been identified as exotics (i.e. not manufactured on Efate), with provenances from other islands in central Vanuatu and from New Caledonia (Dickinson et al. 2013, Leclerc 2016, Chiu et al. 2016).

3. LAPITA SUBSISTENCE STRATEGY IN REMOTE OCEANIA

In the early days of Lapita research, the significant presence of shellfish and fish remains in the earliest layers of Lapita sites in Fiji and Tonga triggered the hypothesis that the Lapita potters were 'oceanic strandloopers', a model suggesting ephemeral settlements and an emphasis on the exploitation of coastal resources before developing horticulture later on (Groube 1971, Davidson and Leach 2001 for a review). Multiple data sources have since discredited this model and revealed that a generalist subsistence strategy combining marine and terrestrial broad spectrum foraging, hunting and the cultivation of native and introduced plant species (so-called 'transported landscapes') characterises Lapita settlements. Among the data supporting this new consensus are stable isotope ratios of human bone collagen (Bentley et al. 2007, Kinaston, Buckley, et al. 2014, Kinaston, Bedford, et al. 2014, Valentin et al. 2010), Lapita faunal assemblages (e.g., Hawkins 2015, Worthy et al. 2015), microfossils from Lapita deposits and pottery (Crowther 2009, Lentfer and Green 2004, Matthews and Gosden 1997, Crowther 2005, Tromp 2016, Horrocks et al. 2014, Horrocks et al. 2009, Horrocks and Nunn 2007, Horrocks and Bedford 2005) and linguistic reconstruction of Proto Oceanic including terms related to plant crops and horticulture (Kirch 1997, Ross 1996). Moreover, it is generally accepted that Lapita subsistence strategy comprised a diversity of activities, with people adapting to a range of different environments through equally diverse subsistence strategies (Burley et al. 2001, Kinaston, Buckley, et al. 2014, Sand and Bedford 2010a, Valentin et al. 2010).

3.1 Terrestrial animal resources

It is well documented that the consumption of indigenous animal populations by Lapita settlers in Remote Oceania resulted in an impoverishment of natural environments following human arrival, particularly in terms of avifaunal (Bedford 2006b, Steadman 2006, 1995, Worthy et al. 2015, Worthy and Clark 2009) and megafaunal species such as iguanids, crocodiles and tortoises[ii] (Burley 1999, Hawkins et al. 2016, Irwin et al. 2011, Mead et al. 2002, Pregill and Steadman 2004, White et al. 2010). Fruit bats also represent a terrestrial species known to have been heavily exploited by Lapita communities (Bedford 2006b, Kirch and Yen 1982, Worthy and Clark 2009, Hawkins 2015). Evidence also suggests that some domesticated animals and commensals (pigs, chicken, rats, but probably not dogs) were introduced into Remote Oceania by Lapita settlers (Storey et al. 2008, Anderson 2009, Matisoo-Smith et al. 1998, Hawkins 2015) even if the intensity and the degree of reliance on these domesticates during the early phases of Lapita occupations remain a matter of discussion (Davidson and Leach 2001, Lentfer and Torrence 2007, Torrence 2011).

3.2 Terrestrial plant resources

Edible plants naturally available in Remote Oceania probably consisted of leafy greens, fruits and nuts although their exact distribution is unknown (Kinaston, Buckley, et al. 2014: 7, Lebot and Sam in press, Walter and Lebot 2007). In addition to the species naturally distributed in Remote Oceania, it is generally agreed that Lapita populations practiced some form of horticulture/agriculture based on introduced crops (Green 1979, Kirch 1997, 2000, Kirch and Green 2001, Spriggs 1997, Kennett et al. 2006). This is supported by the presence of microfossils (starch grains and/or phytoliths) of *Colocasia esculenta* (common taro) and *Dioscorea esculenta* (lesser yam) in sediments from putatively Lapita deposits in Fiji (Horrocks and Nunn 2007), banana (*Musa*) from Lapita and immediately Post-Lapita deposits in Vanuatu (Horrocks et al. 2009), and by microfossil analysis of Lapita potsherds from various sites in the Reef /Santa Cruz Islands and Samoa that yielded starch grains associated with taro (*Colocasia esculenta*), lesser yam (*Dioscorea esculenta*) and banana (*Musa*) (Crowther 2009).

3.3 Importance of marine resources

The current model favours generalist and diverse subsistence strategies adapted to a variety of environments, but it should be emphasized that marine resources are systematically present in the vast majority of Lapita sites and their consumption is indisputable (Nagaoka 1988). Multiple lines of evidence confirm that Lapita occupants significantly integrated marine resources into their diet. Sites from all across the Lapita distribution have yielded fish and shellfish assemblages that are often in great abundance. Faunal assemblages dominated by marine resources have been documented in New Caledonia (Sand 2010a: 195-201, Davidson et al. 2002), Vanuatu (Bedford 2006b; Ono (pers. comm.)), Fiji (Jones 2009, Clark and Szabó 2009, Szabó 2009, Best 2002), Reef/Santa Cruz (Green 1986, Swadling 1986), Tikopia (Kirch and Yen 1982: 286-289), Mussau (Kirch 1987, Kirch et al. 1991), Niuatoputapu (Kirch 1988), and Emirau (Summerhayes et al. 2010). Additionally, Lapita faunal assemblages are often characterised by abundant sea turtle remains (Allen 2007, Dye and Steadman 1990, Burley 1999: 196-197, Hawkins 2015, Kirch 2000: 111). The large amount of sea turtles recovered from some Lapita sites suggest that they represented easy prey, particularly during their annual breeding period when they returned to beaches to lay egg clutches (Kirch 2010: 254-255).

The overwhelming majority of fish remains recovered from sites all across the Lapita distribution are species inhabiting inshore or reef environments (Sand 2010b, Davidson et al. 2002, Burley and Shutler 2007, Butler 1994, Kirch 2000: 111, Bedford 2006b: 231-236, Kirch and Green 2001: 133-134, Green 1986, Summerhayes et al. 2010). Amongst the fish families dominating Lapita contexts are *Scaridae, Lethrinidae, Acanthuridae,* and *Diodontidae*. Occasional specimens of pelagic and offshore carnivorous fish (mostly *Scombridae* and *Sphyraenidae*) are also present in Lapita faunal collections, but inshore and reef fishing was preferentially practiced at the overwhelming majority of Lapita sites (Butler 1994, Kirch 2000: 111, Green 1986). Remains from freshwater species are yet to be recovered from Lapita assemblages but this does not necessarily mean that they were not exploited by Lapita people (Ono pers. comm.). To this day, very few Lapita sites in close proximity to significant sources of freshwater have been excavated, as the vast majority of the sites are located on relatively small islands constituted of uplifted limestone with no rivers or streams. Due to the enormous size of the fish bone assemblage (more than 70 000 fragments: Bouffandeau, pers. comm.) and the presence of the Teouma River and another stream near to the site, the collection of fish remains from the Lapita cemetery at Teouma represents a unique opportunity to investigate the extent to which freshwater resources were exploited by Lapita people.

Despite the recurrence of some fish species dominating the ichtyological assemblages, the diversity of fish species represented in faunal collections suggests that Lapita people used a variety of fishing techniques (Butler 1994). However, the paucity of artifacts related to fishing activities recovered from Lapita sites hardly reflects the importance and diversity of this subsistence practice. Fishing gear recovered from Lapita contexts is limited to several types of fish hooks (for bottom fishing, open-sea trolling, and hand line fishing) and trolling lures (Szabó 2010, 2007, Burley and Shutler 2007, Sand 2010a, Kirch 1997, Szabó and Summerhayes 2002). This situation probably reflects the perishable nature of the equipment employed for other fishing techniques, such as poisoning, nettings or spearing (Kirch and Green 2001: 131-141, Ono 2003).

In addition to the zooarchaeological remains, isotope analysis of human bone collagen from individuals buried at Teouma confirms that marine resources were consumed regularly and represented a significant portion of the diet. Studies indicate that the Teouma population subsisted primarily on a mix of inshore/reef fish resources, marine animals, and terrestrial animal resources (both domesticated and wild) with low-level food production (Bentley et al. 2007, Kinaston, Buckley, et al. 2014, Valentin et al. 2010).

Lastly, linguistic reconstructions also reveal the importance that the sea and its resources had for Lapita people. Reconstruction of the Proto-Oceanic language shows that it included a wide array of words describing a variety of coastal environments, as well as different kinds of fish and fishing techniques. Such linguistic data highlight the detailed and extensive knowledge that Lapita people had in regards to their conception of the ocean and its resources (Kirch 2010: 253, Walter 1989, Kirch and Green 2001: 99-119, Geraghty 1994, Ross et al. 1998).

3.4 Lapita subsistence at the Teouma site and in Vanuatu

When the Teouma cemetery was in use (2940 to 2710 cal BP: Petchey et al. 2015, Petchey et al. 2014), the uplifted karstic reef terrace underlying the site would have been a low promontory extending into the bay, bordered by a river to the north. This environment would have represented an ideal location for the exploitation of pelagic and reef fish species (Bedford et al. 2006: 812-813, Bedford et al. 2010: 143, Hawkins 2015: 45). Neighbouring streams supplying fresh water and the terrestrial ecosystem around the site and inland would have completed the landscape and provided suitable environments for foraging both terrestrial and aquatic resources. The location would also have been adequate for swidden agriculture, even though this practice has still not been demonstrated convincingly for the early occupation stages.

The terrestrial animal species most represented in the Teouma faunal assemblage are bats, pigs, tortoise, sea turtles and birds (Hawkins 2015). The significant amount of pig remains recovered at the site represents a convincing argument for its introduction, and contrast with the rather sparse zooarchaeological record of this species elsewhere in Remote Oceania (Anderson 2009). Small quantities of pig bones were also reported at the Lapita sites of Vao, Uripiv and Erueti (Bedford 2007, Garanger 1972). Chicken and rat bones (both *Rattus exulans* and *Rattus praetor*) are also abundant at Teouma (Hawkins 2015, Storey et al. 2010).

While published archaeobotanical work in Vanuatu has been relatively limited (Hope and Spriggs 1982, Wirrman et al. 2011, Combettes et al. 2015, Hope et al. 1999), analysis of microfossils from archaeological deposits has yielded some evidence for the introduction of plant species, including banana and taro. Banana (*Musa*) phytoliths have been identified from Lapita deposits at the site of Uripiv (c. 3000-2700 BP)) (Horrocks et al. 2009) as well as in dental calculus from a Late-Lapita individual buried at the site of Vao (2300-2000 cal BP) (Horrocks et al. 2014). Both sites are located on islets off the northeastern coast of Malekula about 225 km to the northwest of Teouma. Other studies have identified starch granules attributed to the Aroid family in Lapita deposits from Uripiv, and possibly from dental calculus of individuals buried at Vao and Uripiv. The species could not be identified but *Cyrtosperma merkusii* (giant swamp taro) is believed to be the most likely candidate (Horrocks et al. 2014, Horrocks and Bedford 2005). Calculus of individuals buried at Teouma also yielded starch granules and phytoliths from a variety of nuts and both introduced and native tree crops species (*Dioscorea esculenta, Cocos nucifera, Barringtonia* spp. nuts, *Inocarpus fagifer* and *Musa sp.* amongst others) (Tromp 2016). Vegetation clearance during Lapita times has also been identified from the palaeoenvironmental records of New Caledonia (Stevenson 1999); Aneityum in Vanuatu (Hope and Spriggs 1982); and Fiji (Anderson et al. 2006).

4. ORGANIC RESIDUE ANALYSIS

4.1 Sampling

Organic residue analysis was conducted on eight dentate-stamped decorated and two plain Lapita rim sherds (Figure 1). Since Lapita decorated vessels always display decoration on their upper section near the rim (Sand and Bedford 2010b), the absence of decorations in this section confirms that they originated from plain vessels. In terms of stratigraphic context, seven samples were recovered from the orange tephra layer associated with Lapita burials and the initial activity at the site (Table 1). Two samples (TC16 and PLAIN1), were recovered from the overlying midden and TCC01 was recovered from a disturbed section with limited stratigraphic control. Nevertheless, it was established based on the reconstruction of these vessels that the decorated sherds TC16 and TCC01 were originally deposited in association with the Lapita burials in Layer 3. It is probable that their presence in the midden was caused by post-depositional disturbance, as suggested by the presence of crab burrows and coconut roots across the site. As for the sample PLAIN1, it represents the only sample clearly associated with the midden. In terms of vessel forms and temper types, an effort was made to select samples with different forms. The only two samples displaying petrographic traits not corresponding to raw materials from Efate (TD03 and TCC03) were manufactured in New Caledonia[iii].

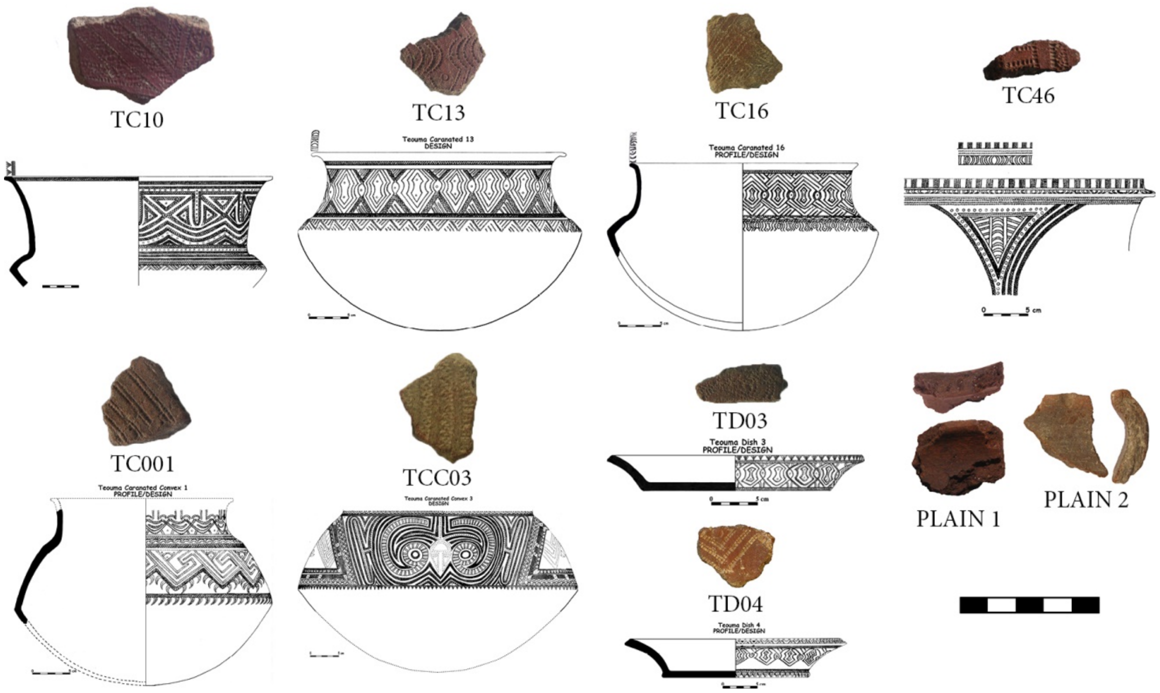

Figure 1 (double column fitting)│Ceramic pieces from Teouma that have been analysed for the biomolecular and isotopic characterization of their absorbed organic residues. The shape of the vessels from which they originate is also illustrated. TCC03 and TD03 were manufactured in New Caledonia, the others were local to the Teouma area.

Pot	# catalog	Area	Square	Layer	Temper type, provenance[a]
TC 10	8.2481	3A	3.2	Lapita orange tephra (3)	Unplacered, local
TC 13	5.3897	2	G1	Lapita orange tephra (3)	Opaque-rich, Efate
TC 16	5.3195	2	B1	Midden (2)	Unplacered, local
TC 46	6.1067A	3B	2.3	Lapita orange tephra (3)	Opaque-rich, Efate
TD 03	4.2477	3A	0.3	Lapita orange tephra (3)	Metamorphic hybrid, New Caledonia
TD 04		3	7.3	Lapita orange tephra (3)	Pyroxenic, Efate
TCC 01	4.2233	deep cut		Undetermined	Unplacered, local
TCC 03	6.670	3B	1.8	Lapita orange tephra (3)	Metamorphic hybrid, New Caledonia
PLAIN1	10.571	B ext	I17	Midden (2)	Undetermined (local)
PLAIN2	10.2841	B ext	F14	Lapita orange tephra (3)	Opaque-rich, Efate

[a] From Dickinson et al. (2013)

Table 1 │ Contextual details for the ceramic samples involved in this study.

4.2 Presentation of analytical techniques

Ceramic samples (≈1-2 g drilled from the potsherd interior surface) were weighed and lipids were extracted and methylated according to established protocol (e.g. Craig et al. 2013) by direct acid-catalysed transesterification to maximise recovery. Methanol (4 mL) was added and homogenised with the ceramic powder, the mixture was ultrasonicated for 15 min and then acidified with concentrated sulphuric acid (800 μL). The acidified suspension was heated in sealed tubes for four hours at 70◦C and then cooled, and lipids were extracted with n-hexane (3×2 mL) and dried down under a gentle N_2 flow. The extracts were transferred to autosampler vials and 10 µg of internal standard (hexatriacontane) was added.

Lipids extracted from ceramic matrices were first analysed by GCMS, a technique that allows the separation of complex mixtures and the identification of plant- and animal-derived lipids (e.g. sterols, *n*-alkanoic acids). Lipid extracts analysed by GCMS can be tentatively associated with food sources using two major techniques: the biomarker and the relative abundance approaches. Through the identification of chemical compounds that are unique to a certain resource or class of resources, the biomarker approach allows us to link directly and with confidence a residue with a specific resource, or at the very least with a group of resources. The relative abundance approach employs the ratios of various common compounds to propose, albeit with high degree of uncertainty[iv], the general overall composition of a residue (e.g. plant vs animal). While we favor a methodology that combines both approaches, no biomarker has been identified in this study.

GCMS analysis was performed using an Agilent 7890A Series gas chromatograph connected to an Agilent 5975 C Inert XL mass-selective detector with a quadrupole mass analyzer (Agilent Technologies, Cheadle, Cheshire, UK). The splitless injector and interface were maintained at 300°C and 280°C respectively. Helium was the carrier gas at constant inlet pressure, and the GC column was inserted directly into the ion source of the mass spectrometer. The ionization energy was 70 eV and spectra were obtained by scanning between m/z 50 and 800. All samples were analyzed using a DB5-ms (5%-phenyl)-methylpolysiloxane column (30 m x 0.32 mm x 0.25 µm; J&W Scientific, Folsom, CA, USA). The temperature program was 2 min at 50°C, 10°C min^{-1} to 325°C and 15 min at 325°C.

To better characterize the lipids extracted from Lapita pottery, the most abundant fatty acids preserved in ceramics, i.e., octadecanoic ($C_{18:0}$) and hexadecanoic ($C_{16:0}$), were then classified by their isotopic composition using GC-c-IRMS. By comparing such single isotope values with corresponding values from reference fats and oils, further information about lipid sources can be obtained. For example, it has been shown that fats from marine organisms are consistently enriched in ^{13}C compared to those of freshwater and terrestrial organisms. Additionally, $C_{18:0}$ acids in ruminant animals are generally depleted in ^{13}C by 1-7‰ compared to $C_{16:0}$ acids (Copley et al. 2003). The carbon isotopic composition of fats from non-ruminant animals and freshwater fish, however, exhibit a broad range of values and are more difficult to discriminate from one another without an exhaustive reference collection of modern fats from the study area. Moreover, to this date, very few reference data exist for the composition of oils originating from plant resources, with the exception of acorns (Lucquin et al. 2016).

GC-c-IRMS analysis of the samples was conducted in order to estimate the $^{13}C/^{12}C$ ratio in the two most abundant $C_{18:0}$ and $C_{16:0}$ fatty acids. This analysis provides further information for distinguishing different substances. The samples were analyzed using an Agilent 78908 GC (Agilent Technologies. Santa Clara. CA. USA) instrument coupled to an Agilent 5975C MSD and an Isoprime 100 IRMS (Isoprime, Cheadle, UK) with an Isoprime GC5 interface (lsoprime, Cheadle, UK). All samples were diluted with hexane and subsequently 1 µl of each sample was injected into a DB-5MS (30 m x 0.25 mm x 0.25 µm) fused-silica column. The temperature was set for 0.5 min at 50°C, and raised by 10°C min^{-1} until 300°C was reached, and held for 10 min. The carrier gas was ultra-high purity grade helium with a flow rate of 3 mL min^{-1}.The gases eluting from the chromatographic column were split into two streams. One of these was directed into an Agilent 5975C inert mass spectrometer detector (MSD), for sample identification and quantification, while the other was directed through the GC5 furnace held at 850°C to oxidize all carbon species to CO_2. A clear resolution and baseline separation of the analyzed peaks was achieved in both systems. Eluted products were ionized in the mass spectrometer by electron impact. Ion intensities of m/z 44, 45, and 46 were monitored in order automatically to compute the $^{13}C/^{12}C$ ratio of each peak in the extracts. Computations were made with IonVantage and IonOS Softwares (Isoprime, Cheadle, UK) and were based on comparisons with a standard reference gas (CO_2) of known isotopic composition that was repeatedly measured. The results from the analysis are reported in parts per mille (‰) relative to an international standard (V-PDB). The accuracy and precision of the instrument was determined on n-alkanoic acid ester standards of known isotopic composition (Indiana standard F8-3). The mean ± S.D. values of these were -29.82 ± 0.16‰ and -23.28 ± 0.19‰ for the methyl ester of $C_{16:0}$ (reported mean value vs. VPDB -29.90 ± 0.03‰) and $C_{18:0}$ (reported mean value vs. VPDB - 23.24 ± 0.01‰) respectively. Each sample was measured in replicate (mean of S.D. 0.11‰ for $C_{16:0}$ and 0.10‰ for $C_{18:0}$). Values were also corrected subsequent to analysis to account for the methylation of the carboxyl group that occurs during extraction. Corrections were based on comparisons with a standard mixture of $C_{16:0}$ and $C_{18:0}$ fatty acids of known isotopic composition processed in each batch under identical conditions.

4.3 Results

The amount of lipid yielded from the two plain rim sherds are considered too low to interpret reliably (Evershed 2008b). In contrast, the eight decorated samples yielded higher concentrations of lipids (Table 2) and are therefore most likely derived from the use of these vessels. Whilst long-term exposure to the burial environment leads to progressive loss of lipid molecules, it seems unlikely that this process has affected only the plain samples since they were deposited in the same conditions as the decorated sherds. Second, the lipid profiles, as discussed below, are typical of degraded oily foodstuffs rather than as might be expected from soils and sediments. Overall, the difference in the amount of lipids between decorated and plain vessels is difficult to interpret at this stage but it will be interesting to see if this pattern persists on a larger sample.

Sample ID	Lipid analysis		GC-c-IRMS	
	Lipid conc.(ug g-1)	Compounds detected	$C_{16:0}$ $\delta^{13}C$ (‰)	$C_{18:0}$ $\delta^{13}C$ (‰)
10.576	<5			
10.2841	<5			
TC-10	13.08	FA($C_{14:0-16:0,18:0}$ $C_{18:1}$), AL(C_{17-21})	-28.64	-29.22
TC-11	17.25	FA($C_{14:0-16:0,18:0,20:0,24:0-26:0}$ $C_{18:1}$)	-27.36	-26.61
TC-13	10.12	FA($C_{14:0-16:0,18:0}$ $C_{16:1,18:1}$)	-29.22	-29.8
TC-16	6.89	FA($C_{14:0-16:0,18:0}$ $C_{18:1}$)	-28.67	-29.89
TCC-01	10.87	FA($C_{14:0-16:0,18:0}$ $C_{18:1}$)	-27.73	-28.9
TCC-03	6.66	FA($C_{14:0-18:0}$ $C_{16:1,18:1}$)	-28.41	-29.44
TD-03	10.2	FA($C_{14:0-18:0,20:0}$ $C_{18:1}$)	-29.48	-29.5
TD-04	17.83	FA($C_{14:0-18:0,20:0,23:0,24:0}$ $C_{16:1,18:1}$)	-27.25	-27.46

Table 2 │ Biomolecular and isotopic characterisation of absorbed residues from Teouma, Vanuatu
FA (Cx:y)=fatty acids with carbon length x and number of unsaturations y, ALx=alkanes with carbon length x. Lipid concentrations are expressed in µg g^{-1} (concentrations below 5 µg g^{-1} cannot be reliably interpreted (Evershed 2008a).

There is a high degree of homogeneity in the fatty acid profiles associated with the eight decorated Lapita sherds, suggesting that the residues were composed of similar resources (Figure 2). Notable in the absorbed residues from Teouma are the high abundance of unsaturated fatty acids, namely $C_{16:1}$ and $C_{18:1}$, which are more common in plant and fish sources than in meat (Table 3). Palmitic acid ($C_{16:0}$), which also tends to be more abundant in plant and fish than in mammalian fats is slightly more abundant in the lipid profiles in five of the eight analyzed residues. However, an absence of lipids associated with aquatic animals (e.g. isoprenoid or alkylphenyl fatty acids (Evershed et al. 2008)) in all the samples suggests that plant or meat, rather than aquatic resources, contributed to these residues, although this interpretation needs to be confirmed by increasing the sample size. Indeed, it has been shown elsewhere that an absence of aquatic biomarker does not necessarily mean that no aquatic resources were processed in the pots (Taché and Craig 2015). A ratio of $C_{16:0}/C_{18:0}$ slightly below one characterises the three remaining samples (TC10, TC11 and TD03), which tend to indicate an animal source. However, without corroboration from other diagnostic compounds (e.g. cholesterol, triacylglycerides), and given the abundance of unsaturated fatty acids in these samples as well, meat cannot be definitively identified as the primary components of these residues. Similar chemical profile can be derived from plant resources containing relatively high abundance of stearic acid ($C_{18:0}$), or with a mixture of terrestrial plant and animal resources. Fatty acid ratios may also change during exposure to the burial environment, particularly as shorter chain molecules are more soluble and therefore more easily loss through dissolution.

Results from single-compound analysis also show a high degree of consistency between samples and are not consistent with marine or ruminant animals in all the samples (Table 2 and Figure 3). While these data are in line with the preliminary interpretations outlined above, they do not allow us to identify plants, non-ruminant animals and/or freshwater resources as the main components of the residues.

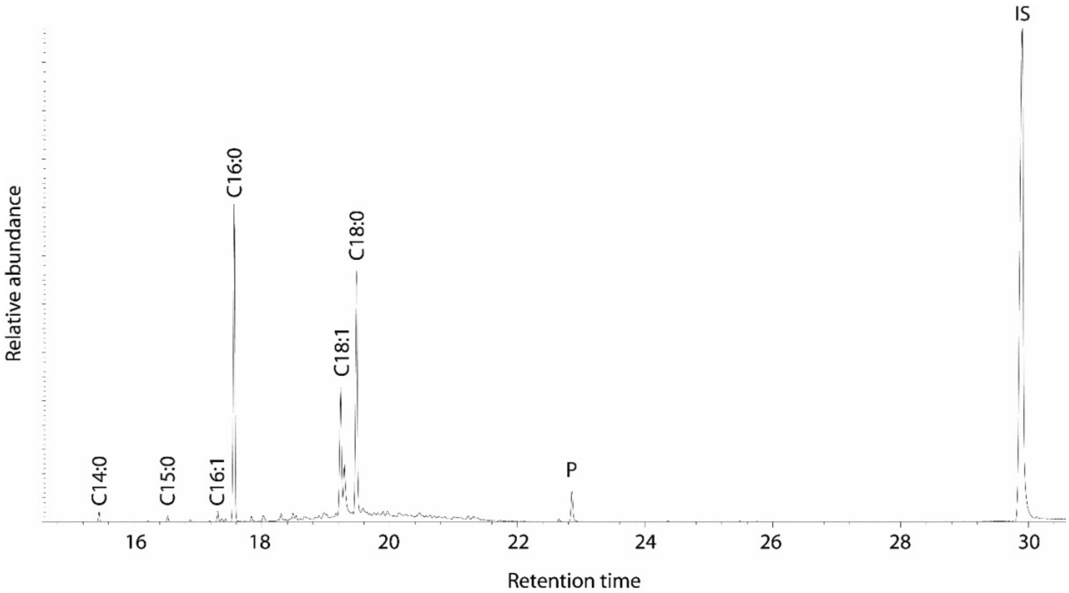

Figure 2 (1.5 column fitting)│Typical partial gas chromatogram of lipid extract from a Lapita dentate-stamped potsherd from Teouma (TC16), Vanuatu. Cn:x are fatty acids with carbon length n and number of unsaturations x; P is a plasticizer contaminant; IS is the internal standard (*n*-hexatriacontane).

Compounds	**TC10**	**TC11**	**TC13**	**TC16**	**TCC01**	**TCC03**	**TD03**	**TD04**
$C_{14:0}$	3.2	2.5	2	1.8	3.3	1.5	1.3	4
$C_{15:0}$	5.1	2.6	2.9	1.1	2	1.8	1.4	1.1
$C_{16:1}$	14.1	3.5	12.7	1.9		7.9		2.5
$C_{16:0}$	31.1	23.6	30.2	37.5	40.3	36.5	39.4	38.9
$C_{17:0}$		3.7					1.8	1.5
$C_{18:1}$	9.6	22.5	23.1	27.5	18.7	20.9	12.4	13.2
$C_{18:0}$	36.9	30.2	29	30.2	35.6	31.5	43.3	35.4
$C_{20:0}$		4.8					0.3	2.1
$C_{23:0}$								0.4
$C_{24:0}$		3.7						0.8
$C_{25:0}$		1.4						
$C_{26:0}$		1.5						

Table 3 │Relative amounts of fatty acids expressed as a percentage of total fatty acids for each compound in each absorbed residue.

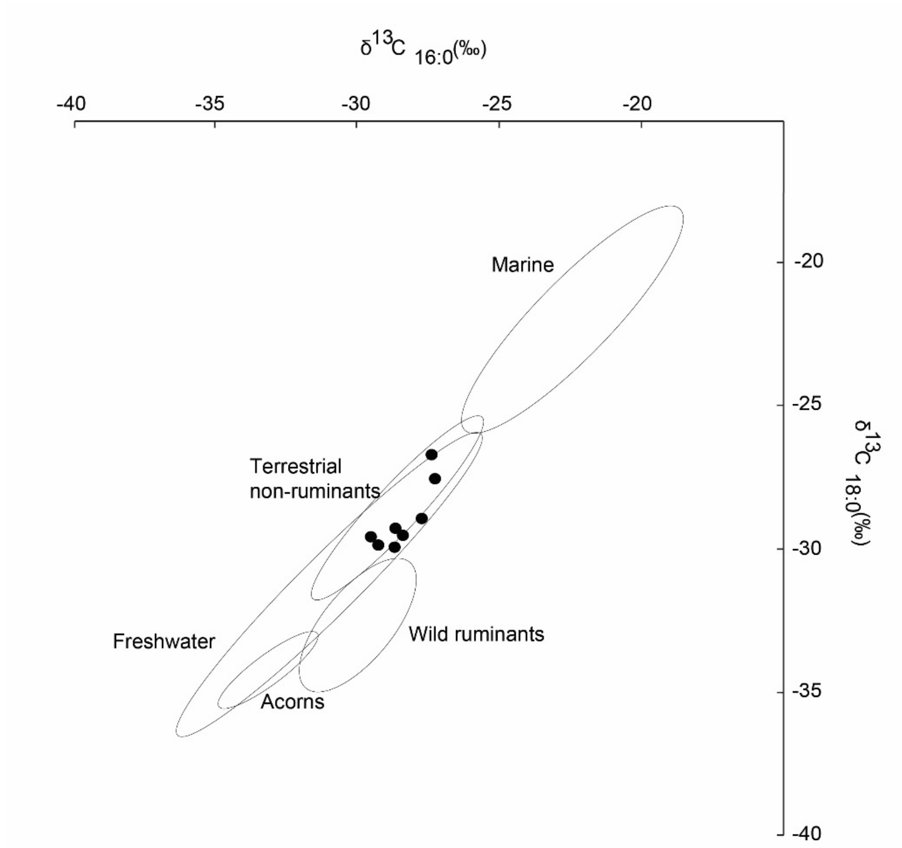

Figure 3 (double column fitting) | Plot of the δ13C values of $C_{16:0}$ and $C_{18:0}$ fatty acids extracted from Lapita dentate-stamped decorated pottery vessels from the Teouma site. These are compared with reference fats from acorns, wild ruminant, terrestrial non-ruminant, freshwater and marine organisms (Taché and Craig 2015, Lucquin et al. 2016) plotted as confidence ellipses (1σ; Stastica v.7).

5. DISCUSSION

Three main conclusions can be reached based on the data obtained from this preliminary organic residue analysis.

i) The biomolecular and isotopic characterisation of the decorated potsherds from Teouma yielded homogenous lipid profiles and carbon isotopic values indicating that similar food types or mixtures of food types were placed in these vessels, whether manufactured locally or from New Caledonia. This suggests a high degree of consistency in the use of Lapita decorated pots, irrespective of the morphological and stylistic variation of these vessels. Indeed, results show that the content of the vessels was not differentiated based on the various forms and/or decorative motifs of the containers. The sampling included three types of vessel forms (carinated, carinated convex and flat dish) and every one of the eight decorated samples analysed displayed distinctive decorative patterns. It is thus argued that the use of Lapita pottery at Teouma was uniform, and possibly culturally regulated, rather than haphazard and opportunistic. While this is aligned with previous interpretations of decorated Lapita vessels having special significance and being employed in non-secular contexts, the context of use and social significance of Lapita pottery still eludes us and will require additional analyses combining molecular and archaeological data.

ii) The amount of lipids detected in the decorated samples strongly suggests that food has been placed in these vessels. It is difficult from the preliminary data obtained so far, however, to identify the content of the vessels at this stage and three broad categories of resources cannot be excluded: terrestrial animals (excluding ruminants), plants, and freshwater resources. Importantly, $\delta^{13}C$ values of fatty acids extracted from the vessels are not consistent with marine species as the dominant food source, as these would be expected to have more ^{13}C enriched fatty acids. Although no comparable measurements of fatty acids from authentic marine organisms from this region are available, collagen and bulk tissue samples of modern Vanuatu marine plants, shellfish, reef fish and deep water fish are clearly enriched in ^{13}C over terrestrial species (Kinaston, Buckley, et al. 2014) supporting our interpretation. The lack of marine foods in pottery is highly unexpected based on what is known of the faunal assemblage recovered from Teouma and Lapita sites in general. Indeed, and as previously mentioned, multiple lines of evidence suggest that marine resources composed a significant portion of the Lapita diet:

- Extensive assemblages of fish and shellfish (and sea turtle to a lesser extent) have been recovered from a majority of Lapita sites all across the Lapita distribution (including Teouma), confirming that marine resources were consumed in significant quantity by Lapita populations.
- Isotopic analysis of human bone collagen from individuals buried at Teouma revealed that their diet was composed of a mix of marine and terrestrial resources.
- Linguistic reconstruction of Proto-Oceanic indicates that Lapita seafarers had an extended vocabulary to describe marine related concepts, including words describing various kinds of fish and fishing techniques. This indicates that fishing and navigating was an important part of their life and thus that marine resources were likely ubiquitous.
- Elements of the Lapita material culture, such as fishhooks and trolling lures, confirm that fishing was practiced, most commonly in inshore or reef environments.

Not only were marine resources commonly exploited, but other characteristics of Lapita sites also suggest that marine resources were abundant and accessible:

- It is generally accepted that Lapita sites were preferentially located on beaches and in at least some cases composed of stilt houses. Given the proximity of the ocean from their habitations, one can assume that marine resources were relatively easy to exploit. Moreover, many Lapita sites are also situated in close proximity to reef passes where fish are found in extremely high density.
- The size of some of the fish and shellfish assemblages recovered from Lapita sites is impressive, to the point where they originally raised the question as to whether Lapita occupants were eating primarily marine resources. This reveals the importance of maritime subsistence activities amongst Lapita people (Bedford 2006b, Davidson et al. 2002, Kirch 1997: 197-203, Szabo 2001) and indicates that such resources were ubiquitous at the time of occupation.

- The assemblages of fish remains from Lapita sites are composed primarily of fish species inhabiting inshore or reef environments. Offshore species are scarcely represented. This indicates that Lapita people preferred easily accessible marine resources that were located in close proximity to the shore.
- Considering that Teouma probably represents a colonising site (Bedford et al. 2010, Bentley et al. 2007), it is argued that pristine fish stocks existed during the earliest stages of occupation as they had never been exploited before by human communities. Consequently, the marine biomass available for exploitation was significant.

Overall, the absence of such commonly consumed, ubiquitous and easily accessible resources in Lapita vessels suggests that these pots were not manufactured to be used for ordinary occasions and day-to-day food consumption. This is consistent with the view that dentate-stamped pottery held a particular status in Lapita societies, and that its use was reserved for exceptional occasions, possibly ceremonial/ritual activities.

iii) Preliminary results presented in this article are extremely promising and have already provided valuable insights regarding dentate-stamped Lapita pottery. This represents the first step of an ongoing project involving additional organic residue analysis that will bring further clarification on the numerous questions raised here. To provide known food residues for isotopic and biomolecular comparisons, reference samples have been obtained from the study region and carbonised experimentally on unglazed ceramic matrices. Animal bones from the site of Teouma in Vanuatu have also been obtained. Lipids will be extracted from these reference samples and submitted to the same analytical techniques described in this article in order to refine our identification of the food resources that were preferentially placed in Lapita vessels. Additionally, a larger number of dentate-stamped and plain potsherds will be analysed to get a more representative portrait of what was placed in these vessels. To account for variability in usage patterns, potsherds will be selected from a variety of domestic and funerary contexts.

6. CONCLUSION

In summary, the biomolecular and isotopic characterisation of residues absorbed in Lapita pottery at the site of Teouma yielded very homogeneous results, suggesting that these vessels were used consistently to process or hold a specific type or mixture of food, rather than opportunistically to process or hold a variety of resources available in the environment. By providing direct chemical evidence, these results support the long-held idea based on contextual inferences, that Lapita dentate-stamped vessels were used for specialised functions rather than mundane cooking activities. Results also show that marine resources, even though they were consumed in large quantity by Lapita dwellers and despite their ubiquitous presence around Lapita sites, were unlikely to have been placed in the ceramic vessels that were analysed. At this point however, data do not allow us to discriminate between freshwater aquatic, terrestrial animal and/or plant resources as the main components of the residues analysed. Ongoing analyses conducted on archaeological ceramics and modern samples of fats and oils will help resolve this issue.

As this preliminary study clearly demonstrates, organic residue analysis of Lapita vessels has the potential to contribute a markedly improved methodology for reconstructing the actual use of ancient ceramics in the south Pacific, while laying the groundwork for more informed theories on the origin, dispersal, function, and eventual replacement of Lapita pottery across Remote Oceania. This can only be verified through the widespread application, across the Lapita distribution, of a combination of techniques in organic residue analysis of archaeological ceramics (e.g., lipid, bulk and single compound isotope, and microfossil analyses). The outcomes of this study not only represent a breakthrough in terms of future research avenues but also provide additional data on the context within which the Lapita vessels were used and on the ways foods were consumed by these colonising groups.

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FOOTNOTES

[i] Many similar albeit not equating terms figure in the literature to define the type of food often consumed on special occasions: 'high status', 'luxury', 'prestige' and 'elite' food (Curet and Pestle 2010, Szabo 2001, Hayden 2003, van der Veen 2003). Each of these denominations carries a specific meaning regarding the social context in which they are consumed and their implications in terms of social and political power structure (Twiss 2012). Because it is premature at this stage to address the significance of our results in terms of the social stratification of Lapita groups, we decided to use the encompassing term 'highly valued' foods, to qualify the content of the presumably prestigious dentate-stamped Lapita vessels.

[ii] It must be noted that factors other than human predation, such as climate change for example, could also have contributed to impacting ecological conditions (Nagaoka 2012, Wirrman et al. 2011, Seeto et al. 2011).

[iii] There is thus a possibility that any residues in these two vessels relate to their use in New Caledonia before transport to Vanuatu. As will be detailed in the discussion however, there is nothing different in the way they were used that might confirm this.

[iv] This uncertainty is due in large part to the fact that fatty acids and other compounds degrade (through, oxidation and/or microbial breakdown) or leach out of pots at different rates in different environments.