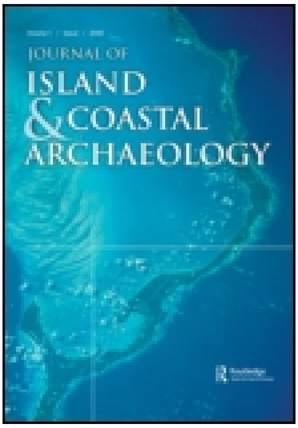

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Obsidian Source Use in Tongan Prehistory: New Results and Implications

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SHORT REPORTS

Obsidian Source Use in Tongan Prehistory: New Results and Implications

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ABSTRACT

The article presents results of an obsidian sourcing study on artifacts from Tonga and Fiji. New LA-ICPMS data on obsidian source locations on Tafahi in northern Tonga are discussed in relation to inter-island mobility during two important phases in the Central Pacific: the late-Lapita phase in Fiji-West Polynesia at 2700–2600 cal. BP and during the time of the rise of Polynesian chiefdoms at ~1000–400 cal. BP. The sourcing results indicate that two sources of obsidian were exploited during Tongan prehistory. It is suggested that different modes of interaction were responsible for obsidian movement during the early and late phases of Tongan prehistory.

Keywords obsidian, provenance studies, colonization, maritime connection of Polynesian chiefdoms

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INTRODUCTION

Geochemical studies of lithic artifacts in the Pacific have been highly effective in tracking the spatial distribution of raw materials and provide unique insight to the social interaction of Oceanic communities (Best 1987; Collerson and Weisler 2007; Reepmeyer et al. 2010). Two chronological periods are associated with long-distance voyaging in the Western Pacific Ocean based on the chemical sourcing of obsidian and basalt artifacts found in archaeological contexts. The most extensive distribution of any prehistoric material occurred during the Lapita colonization of Near and Remote Oceania (∼3200–2700 cal. BP) when obsidian was transported from New Guinea as far east as Fiji and north to Island Southeast Asia, spanning a region some 6500 km (Bellwood and Koon 1989; Best 1987; Specht et al. 1988; Spriggs et al. 2010; Summerhayes 2009). A second episode of expansive voyaging took place in the 2nd millennium AD when basalt tools, particularly those from Samoa, were widely distributed (Best et al. 1992; Clark 2002; Collerson and Weisler 2007; Fankhauser et al. 2010; Weisler 1995; Weisler 1997), and the amount of nonlocal material found in archaeological sites indicates a marked increase in the frequency and extent of prehistoric interaction (Bedford and Spriggs 2008; Clark and Bedford 2008; Green 1996; Kirch and Yen 1982).

The mechanisms responsible for a two-stage sequence of long-distance voyaging in Pacific prehistory are, however, poorly understood. Was early obsidian distribution the result of long-distance migration during a colonization ‘pulse’ (Green 2003; Kirch 1991; Reepmeyer et al. 2010; Sheppard 1993; Specht 2002) followed by the isolation of founding communities (Kirch 1978), or did long-distance interaction continue for several centuries—as suggested by similar changes in the western and eastern Lapita decorative ceramic system (Summerhayes 2000:233)—into the post-Lapita period? Similarly, was the distribution of basalt tools in the last 1,000 years connected to the growth of complex maritime societies like that of Tonga (Clark 2010; Clark et al. 2008), or perhaps similar to the movement of obsidian in Lapita times, the result of a rapid population expansion from West Polynesia that established humans on remote landmasses in East Polynesia (Wilmshurst et al. 2011)?

In this article, we examine the geochemistry of obsidian artifacts found in archaeological sites on Tongatapu Island in the Kingdom of Tonga and Lakeba Island in the Lau Group of east Fiji (Figure 1; Table 1). After colonization, local communities discovered and exploited regional obsidian sources in northern Vanuatu (Reepmeyer et al. 2010), Western Samoa (Sheppard et al. 1989), and Tafahi/Niuatoputapu in northern Tonga (Kirch 1984b). These local obsidian sources appear to have been exploited for relatively long periods and their study has the potential to shed light on different modes of material transport, particularly those associated with the movement of people within and between archipelagos during the Lapita phase (Best 1984; Clark 2000; Reepmeyer 2009) and the role of maritime chiefdoms in the transport of people and goods during the last millennium AD (Barnes and Hunt 2005; Clark 2002).

BACKGROUND GEOLOGY

The geology of Tonga has recently been summarized by Smith and Price (2006) and Dickinson and Burley (2007). The Tongan archipelago is part of the Tonga-Kermadec subduction system, which extends from immediately south of the Samoa archipelago in the North to New Zealand in the South. The Tongan and Kermadec sections of the system are separated by the impinging Louisville Ridge, a seamount chain, at 25.6° S (Smith and Price 2006:316).

The Tongan section of the Island arc can be further subdivided into four separate segments. The northern-most segment includes the island cluster of Niuatoputapu/Tafahi to the north and Fonualai to the north. The central arc segment contains the main surface features of the Tongan archipelago; the Tofua chain consisting of a series of north-south aligned basalt and basaltic andesite islands (Ewart et al. 1977), and the low-lying

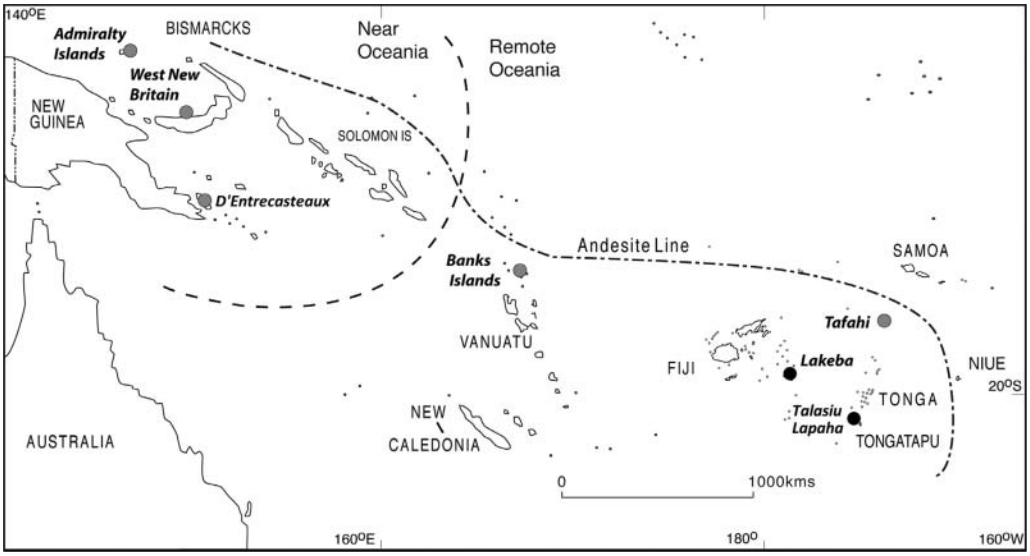

Figure 1. *Map of the area. Location of Lakeba Island in eastern Fiji and Talasiu/Lapaha on Tongatapu (●) and major obsidian sources of the West and Central Pacific (●).*

islands of limestone capped, extinct, submarine volcanoes situated on the Tongan Platform (Bloomer et al. 1994), separated from each other by the Tofua Trough. The two southern segments of the Tongan arc consist of submarine volcanoes as a continuation of the Tofua chain with the exception of the southern island of 'Ata.

The geochemistry of the Tonga-Kermadec arc has been extensively studied (Ewart et al. 1998). Surface exposures of silicate rich volcanic rocks are only present on the Tofua chain. Records of exposed low-silica rhyolitic flows are scarce, but dacite is found on the islands of Tofua, Metis Shoal (although these volcanics derive from recent volcanic eruptions) and Fonualai (Ewart et al. 1977). The distinct elemental composition of the arc consists of an enrichment of large-ion lithophile elements (LILE) in contrast to high-field strength elements (HFSE) and heavy rare earth elements (HREE) that has been discussed by Ewart et al. (1994, 1998:332) and Ewart and Hawkesworth (1987).

Table 1. **Obsidian sources and site locations with tentative provenance of artefacts.**

Island	Outcrop	Site	No. of samples	Proposed source
Tonga-Tafahi	Tefitomaki		4	
	Hala'Uta		1	
Tonga-Tongatapu		Lapaha	1	Central Tonga Arc
		Talasiu	4	Tafahi-Hala'Uta
Lakeba		Qaranipuqa (site 197)	2	Tafahi-Hala'Uta
		Laselase (site 2b)	1	Central Tonga Arc
		Wakea (site 196)	2	Tafahi-Hala'Uta
		Ulunikoro (site 47)	1	Tafahi-Hala'Uta

There is a clear latitudinal geochemical variation along the Tongan arc according to Ewart et al. (1998:344), Element abundances of HFSE (Ti, Yb) and element ratios of Zr/Sm decrease in a northern direction suggesting increasing magma source depletion, whereas element ratios of Sc/Y and Nb/Yb increase in the northern section of the arc. These element ratios will be discussed in relation to two obsidian artifacts which do not appear to be from the Tafahi source in northern Tonga.

BACKGROUND LOCATIONS

Tafahi, Tonga

The Tafahi obsidian source samples examined were collected by G. Rogers (1974; see also Smith et al. 1977), who also found obsidian artifacts on the adjacent island of Niuatoputapu in archaeological sites. According to Dye (1988:287) the source of four obsidian samples analyzed is the Tefitomaka outcrop on Tafahi (Figure 1). The primary deposit is a tuff in which nodules of volcanic glass are embedded. The source description suggests that the deposit originates from a pyroclastic flow rather than a rhyolitic/dacitic dome, which is also supported by the matrix heterogeneity of the material with large amounts of phenocrysts macroscopically visible. The fifth source sample derives from the Hala'Uta outcrop on Tafahi, but no detailed geological description of its setting is available.

The volcanic glass artifacts recovered during survey and excavation of Lapita and Polynesian plainware sites on Niuatoputapu exhibited similarity in hand specimen to material from the extinct island volcano on Tafahi, which is located some seven kilometers from Niuatoputapu. Geochemical analysis of several of the artifacts by Ward (Ward in Rogers 1974:345) using XRF tentatively supported this provenance. In addition, Dye (1988:287) described a tuff outcropping "behind Vaipoa village" on Niuatoputapu that appeared similar to the tuff on Tafahi with embedded obsidian nodules. No source samples from this location were available.

Lakeba, Fiji

The analyzed artifacts comprise six pieces from a set of 19 flakes found at four different sites on Lakeba Island in eastern Fiji (Best 1984, 1987). Best's (1984) marine shell dates were not Conventional Radiocarbon Ages (CRAs) but were reservoir-corrected ages that had been adjusted for an in-house laboratory standard (Fiji marine shell standard; see Petchey et al. 2010). The marine shell and charcoal results reported here were recalculated with reference to the modern oxalic acid standard and are CRAs. Two flakes derive from the deepest layers (Layer T, R-O) of the Qaranipuqa (*site 197*) rock shelter and were previously sourced to Tafahi in northern Tonga (Best 1987). A radiocarbon date from Layer T has an age of 2330–2870 cal. BP (NZ 4596, charcoal, 2540 ± 127 BP), and Best (1984:fig. 6.7) considered that Layer T had an age of 2700 cal. BP, indicating movement between east Fiji and Tonga during the early settlement phase.

One obsidian flake (ANU-9164) was from the Laselase rock shelter (*site 2(b)*) in Layer J3. The overlying J1 layer is dated by a marine shell determination to 950–1140 cal. BP (NZ 5182, *Turbo chrysostomus*, 1495 ± 33 BP). Two flakes from the Wakea coastal flat (*site 196*) and one flake from the upper levels of the Ulunikoro fortification (*site 47*) could not be clearly identified to a source (Best 1984:434). The two flakes from the Wakea coastal flat were found in the early deposit in Layer B dated with charcoal to 2490–3060 cal. BP (NZ 4807, 2698 ± 107) and 2500–2850 cal. BP on marine shell (NZ 4809, *Trochus niloticus*, 2937 ± 63 BP). The larger standard error associated with NZ 4807 suggests that the marine shell result (NZ 4809) with an age of 2650–2790 cal. BP ($p = .98$) is the more accurate of the age determinations. A single obsidian flake was recovered from an excavation on the Ulunikoro fortification (Square 19). The excavation was not described in detail, but the description has Layer A as a topsoil "of a friable granular loam, dark reddish brown, containing cultural material and in the upper 50 to 100 mm a compact root zone" (Best 1984:112), suggesting disturbance of near-surface sediments. The

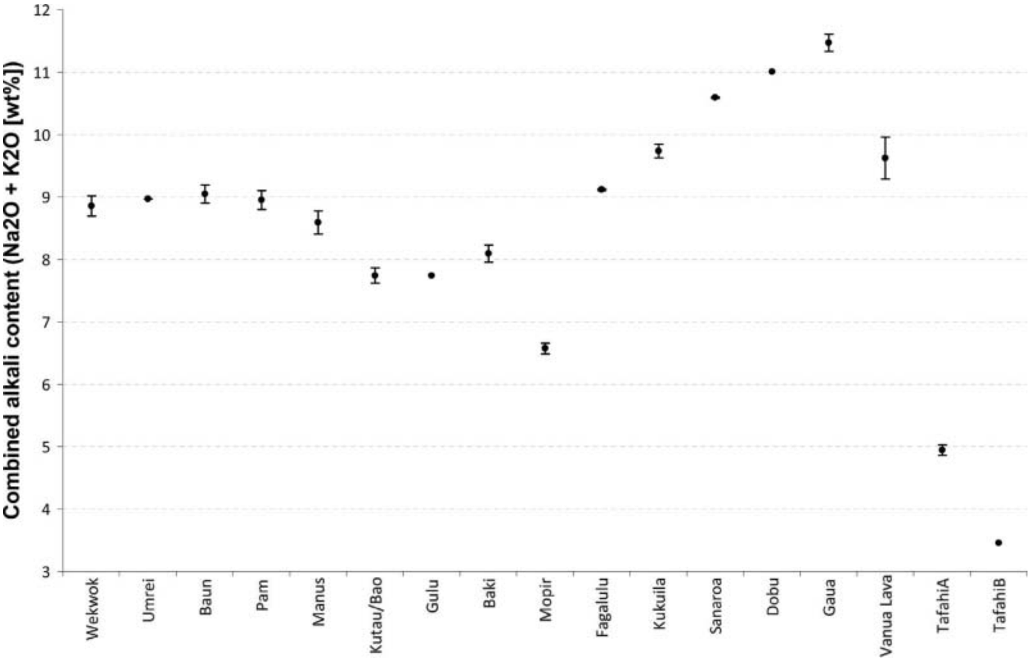

Figure 2. *Alkalinity distribution of selected obsidian sources in the Western Pacific.*

Ulunikoro fortification is dated to 850 cal. BP, with reuse, particularly of the highest parts of the site around 600–400 cal. BP. The remaining 13 obsidian pieces found on Lakeba have been recently discussed by Reepmeyer and Clark (2010) and appear to derive from a source location in west Fiji.

Tongatapu, Tonga

Five artifacts were recovered from excavations at Lapaha and Talasiu. Lapaha is located on the Fanga 'Uta lagoon on Tongatapu and was the central place of the Tongan chiefdom during the height of its influence (Burley 1998; Clark et al. 2008; Clark 2010). Evidence of the complex and highly stratified Polynesian society include massive stone-faced tombs (*langi*) built for the paramount Tu'i Tonga lineage and other paramount chiefs (Kirch 1984a). One artifact ('Lapaha')[1] was found in association with the tomb J20 (*Paepae'otelea*), which dates to 500–300 cal. BP (Clark et al. 2008:996–997). It has three stone tiers of reef limestone and beach rock slabs and was located on reclaimed land west of the old shoreline.

Talasiu is located to the north of Lapaha where a midden deposit site listed as TO-Mu-2 by Spennemann (1986) extends along 100 m of the old shoreline. The midden deposit contains abundant pottery and marine shell and was excavated by Jack Golson in 1957 (J. Golson, personal communication). In 2008, human remains were seen protruding from a road cut and an excavation of 1.5 m by 1.5 m called TP.1 was made to recover the remains and sample the TO-Mu-2 midden deposit. Four flakes of volcanic glass were recovered from the midden, which is dated by two samples of charred coconut endocarp (Wk-28234, 2473 ± 31 and Wk-28235, 2510 ± 30) that have a pooled age of 2490–2720 cal. BP, consistent with a late Lapita/early Polynesian plainware age.

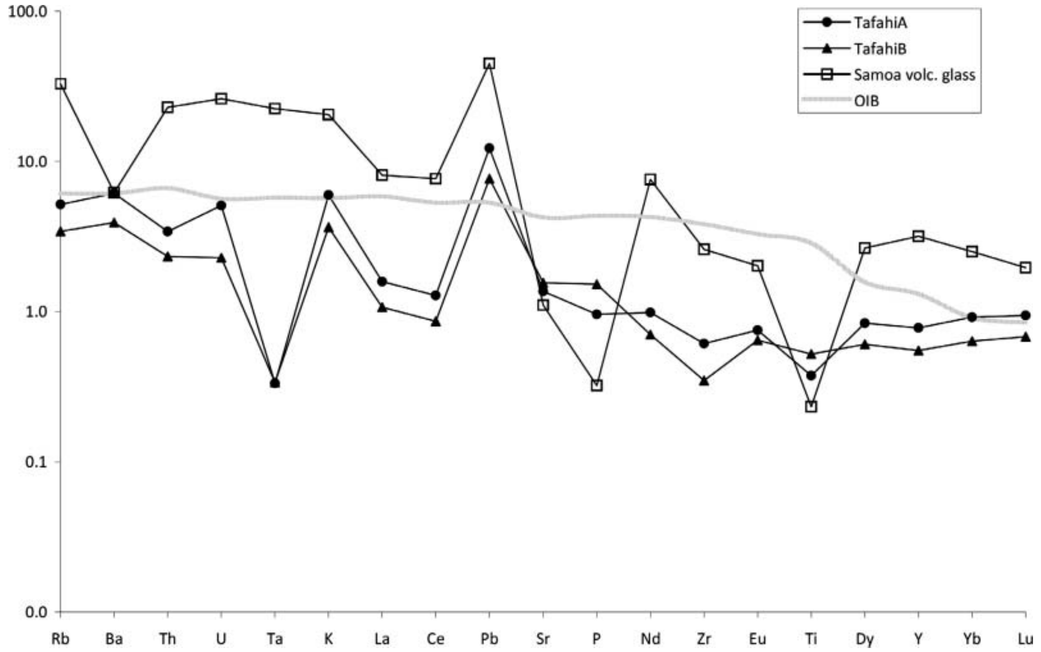

Figure 3. *Primitive mantle normalized trace element diagram of Tafahi outcrops in comparison to volcanic glass sources in Samoa (geochemical data taken from Sheppard et al. 1989) and OIB.*

RESULTS

The obsidian samples (Table 1) were examined with a JEOL JSM6400 SEM equipped with an Oxford ISIS EDXA (Oxford Instruments Link ISIS 3.3 software) for nine major elements (Na, Mg, Al, Si, Ca, K, Ti, Mn and Fe) at the Research School of Biological Sciences, Australian National University (Ambrose et al. 2009; Reepmeyer 2008; Reepmeyer et al. in press). LA-ICPMS analysis was conducted in the Research School of Earth Science at the Australian National University (Falkner et al. 1995; Longerich et al. 1996; for detailed experimental set-up and methods used, Ambrose et al. 2009; Reepmeyer 2008; Reepmeyer et al. in press). Samples were analyzed in an AGILENT 7500S ICPMS combined with a Lambda Physik 193 nm wavelength ArF laser ablation system, with the laser diameter set at 86 μm. Counts for 31 isotopes were determined by calculating the mean counts for each isotope from three analysis runs per sample. For multivariate statistical analysis, the statistics program C2 was employed (Juggins 2005).

Five source samples were analyzed from Tafahi Island and two sub-sources were identified. The most distinctive feature of obsidian from the Tongan arc in comparison with obsidian sources in the Western Pacific (Ambrose et al. 2009; Reepmeyer et al. in press) is the strong depletion in both LILEs and selected HFSEs. Both sources are distinguishable from more Western Pacific obsidian sources by their low alkalinity (Figure 2), especially low K_2O values (<1.5 wt%) (Smith and Price 2006:2325, fig. 3) and high Fe, Ca and Mg content (Table 2). In comparison with the Oceanic volcanic glass sources in Samoa to the north and Polynesian islands to the east there is a higher depletion of all trace elements, which is characteristic of Island Arc obsidian sources, compared to an OIB trace element distribution (Albarède 2003) which is characteristic of the Oceanic

Table 2. **Absolute counts and summary statistics of the EDXA and LA-ICPMS analysis.**

	Tafahi			**Talasiu**		**Lakeba**			**Lapaha1**		**Standards**			
	Tefitomaka		**Hala'Uta**	**Group-Av.**		**Group-Av.**		**Outlier**	**J20 tomb**		**ANU2000**		**ANU9000**	
EDXA (in wt %)	***n* = 4**	***SD***	**ANU9372**	***n* = 4**	***SD***	***n* = 5**	***SD***	**ANU9164**	***n* = 2**	***SD***	***n* = 18**	***SD***	***n* = 20**	***SD***
Na_2O	3.4	0.1	2.5	3.0	0.1	2.8	0.0	2.4	2.3	0.0	4.9	0.1	3.9	0.1
MgO	0.5	0.1	2.6	1.2	0.1	1.1	0.1	2.4	3.1	0.2	0.2	0.0	0.2	0.0
Al_2O_3	11.7	0.1	13.7	12.7	0.1	12.7	0.1	13.0	13.2	0.3	13.5	0.1	12.6	0.1
SiO_2	74.4	0.3	63.0	68.6	0.3	69.2	0.7	61.9	60.5	0.0	73.2	0.3	76.3	0.3
K_2O	1.5	0.0	0.9	1.0	0.2	1.2	0.0	0.7	0.6	0.0	4.0	0.1	3.8	0.1
CaO	3.1	0.1	7.0	5.2	0.2	5.0	0.2	7.4	7.8	0.2	1.1	0.0	1.1	0.0
TiO_2	0.4	0.1	0.6	0.5	0.1	0.5	0.0	0.9	0.8	0.0	0.3	0.1	0.2	0.0
MnO	0.1	0.1	0.3	0.2	0.0	0.2	0.1	0.3	0.2	0.0	0.0	0.0	0.0	0.0
FeO	4.5	0.1	9.2	7.5	0.5	7.1	0.3	10.9	10.4	0.2	2.0	0.1	1.2	0.1
Totals	99.9		100.2	100.2		99.9		100.0	99.1		99.4		99.6	
ICPMS (in ppm)														
P	595.0	14.2	946.9	936.2	161.7	1004.9	23.3	750.6	603.6	148.0	183.6	12.8	138.8	7.4
Sc	17.4	0.1	34.6	30.1	0.9	29.5	1.1	40.4	41.2	1.8	6.5	0.8	6.5	0.8
Ti	2252.1	47.1	3134.5	2853.0	71.9	2816.3	60.3	5841.9	5124.6	184.2	2013.5	55.5	1624.8	43.5
V	19.2	0.6	239.9	58.7	6.0	47.0	17.9	452.2	387.3	12.5	5.6	0.1	5.7	0.1
Mn	907.1	8.5	1426.1	1429.7	18.2	1410.7	18.6	1356.3	1313.3	13.5	452.5	11.4	454.0	13.2
Co	6.0	0.0	21.8	10.9	0.5	9.9	1.3	27.3	27.6	0.3	1.4	0.0	0.6	0.0
Cu	51.8	1.7	90.5	39.5	5.6	41.1	25.7	216.7	206.0	3.0	3.5	0.5	3.1	0.2
Ga	11.2	0.7	13.1	12.3	0.2				14.0	0.3	17.5	0.3	10.7	0.1
As	5.7	0.3	3.5	3.7	0.2	3.5	0.1	5.3	5.1	0.6	2.1	0.2	6.8	0.7
Rb	26.1	0.6	17.3	20.6	0.8	19.6	0.4	8.9	8.5	0.1	148.3	5.3	51.7	1.8
Sr	212.2	22.9	241.8	222.8	7.6	216.1	2.7	158.9	156.1	5.7	58.9	2.7	170.3	7.5
Y	17.2	0.4	12.1	15.4	0.5	15.1	0.4	19.3	18.1	0.8	32.2	1.3	17.8	0.7
Zr	44.8	1.3	25.4	31.5	1.1	31.2	0.8	34.5	32.3	1.6	284.4	11.6	119.2	4.4

(Continued on next page)

Table 2. **Absolute counts and summary statistics of the EDXA and LA-ICPMS analysis. *(Continued)***

	Tafahi			**Talasiu**		**Lakeba**			**Lapaha1**		**Standards**			
	Tefitomaka		**Hala'Uta**	**Group-Av.**		**Group-Av.**		**Outlier**	**J20 tomb**		**ANU2000**		**ANU9000**	
EDXA (in wt %)	***n* = 4**	***SD***	**ANU9372**	***n* = 4**	***SD***	***n* = 5**	***SD***	**ANU9164**	***n* = 2**	***SD***	***n* = 18**	***SD***	***n* = 20**	***SD***
Nb	5.0	0.1	3.7	3.9	0.0	4.0	0.1	0.4	0.3	0.0	42.5	0.9	2.2	0.0
Mo	2.5	0.1	1.5	1.8	0.1	1.9	0.0	2.0	1.8	0.1	3.5	0.1	3.1	0.1
Sn	0.6	0.0	0.4	0.5	0.1	0.5	0.0	0.5	0.6	0.1	3.2	0.2	0.9	0.2
Cs	0.7	0.0	0.5	0.6	0.0	0.5	0.0	0.5	0.5	0.0	2.0	0.1	1.5	0.1
Ba	350.5	8.7	223.6	247.4	6.1	237.2	5.1	195.1	182.2	5.4	644.4	38.0	466.7	24.5
La	10.0	0.3	6.7	6.7	0.2	6.4	0.2	2.3	2.2	0.1	36.1	1.7	11.3	0.5
Ce	19.3	0.5	13.0	13.4	0.5	12.8	0.3	6.3	6.0	0.3	72.4	3.6	24.4	1.0
Pr	2.3	0.1	1.6	1.7	0.1	1.6	0.0	1.0	1.0	0.0	7.5	0.4	3.0	0.1
Nd	8.9	0.2	6.3	7.0	0.2	6.6	0.1	5.1	4.9	0.2	24.4	1.3	11.4	0.5
Sm	2.4	0.1	1.8	2.1	0.1	2.0	0.1	1.8	1.8	0.0	5.2	0.2	2.7	0.1
Eu	0.7	0.0	0.6	0.7	0.0	0.6	0.0	0.7	0.6	0.0	0.9	0.0	0.6	0.0
Gd	2.7	0.1	2.0	2.4	0.1	2.4	0.1	2.6	2.5	0.1	5.2	0.2	2.7	0.1
Tb	0.4	0.0	0.3	0.4	0.0	0.4	0.0	0.4	0.4	0.0	0.8	0.0	0.4	0.0
Dy	3.0	0.1	2.2	2.7	0.1	2.6	0.0	3.3	3.1	0.1	5.4	0.3	2.8	0.1
Er	2.0	0.1	1.4	1.8	0.1	1.8	0.0	2.3	2.1	0.2	3.5	0.2	2.0	0.1
Tm	0.3	0.0	0.2	0.3	0.0	0.3	0.0	0.3	0.3	0.0	0.5	0.0	0.3	0.0
Yb	2.2	0.1	1.5	1.9	0.1	1.9	0.1	2.5	2.3	0.1	3.8	0.2	2.3	0.1
Lu	0.3	0.0	0.2	0.3	0.0	0.3	0.0	0.4	0.3	0.0	0.6	0.0	0.4	0.0
Ta	0.2	0.0	0.2	0.2	0.0	0.2	0.0	0.0	0.0	0.0	3.1	0.1	0.1	0.0
W	0.9	0.0	0.3	0.4	0.0	0.4	0.0	0.1	0.1	0.0	1.3	0.0	0.4	0.0
^{206}Pb	7.7	0.2	4.9	5.6	0.1	5.5	0.3	3.1	2.8	0.1	6.8	0.3	10.1	0.4
^{207}Pb	6.9	0.2	4.3	5.0	0.1	4.8	0.1	2.8	2.7	0.1	6.2	0.3	9.2	0.4
^{208}Pb	7.4	0.2	4.6	5.3	0.1	5.1	0.1	3.0	2.8	0.0	6.5	0.3	9.5	0.4
Th	2.1	0.1	1.4	1.4	0.0	1.4	0.1	0.2	0.2	0.0	10.7	0.8	2.5	0.2

U	0.9	0.0	0.4	0.5	0.0	0.5	0.0	0.2	0.2	0.0	3.0	0.2	1.6	0.1
REE (in ppm)														
^{139}La	42.2	1.1	28.5	28.3	1.0	27.1	0.7	9.7	9.2	0.5	152.1	7.5	47.7	2.1
^{140}Ce	31.4	0.8	21.2	21.9	0.7	20.9	0.5	10.3	9.9	0.4	117.8	6.0	39.6	1.7
^{141}Pr	24.6	0.6	17.2	18.3	0.6	17.3	0.5	10.7	10.4	0.5	80.2	4.3	32.5	1.6
^{144}Nd	19.5	0.4	13.9	15.4	0.5	14.5	0.3	11.1	10.7	0.5	53.4	2.9	24.9	1.2
^{147}Sm	16.5	0.4	12.0	13.9	0.6	13.3	0.4	12.4	12.2	0.3	34.8	1.6	18.4	0.9
^{153}Eu	12.2	0.5	10.4	11.6	0.3	11.4	0.2	11.8	10.8	0.3	15.6	0.8	10.6	0.5
^{158}Gd	13.3	0.5	9.9	12.1	0.4	11.9	0.3	13.0	12.3	0.4	26.0	1.1	13.5	0.6
^{159}Tb	11.9	0.2	8.9	10.8	0.3	10.3	0.1	12.3	11.8	0.6	22.3	1.1	11.5	0.5
^{162}Dy	12.1	0.2	8.8	11.1	0.3	10.6	0.1	13.4	12.5	0.5	22.0	1.1	11.6	0.5
^{166}Er	12.3	0.5	8.7	11.1	0.3	11.0	0.2	14.2	13.0	0.9	22.1	1.1	12.3	0.5
^{169}Tm	12.4	0.3	8.6	11.0	0.6	10.8	0.3	14.0	13.0	0.7	21.8	0.9	12.5	0.7
^{174}Yb	13.5	0.4	9.4	12.0	0.4	11.9	0.3	15.4	14.2	0.4	23.8	1.2	14.1	0.6
^{175}Lu	13.6	0.4	9.8	12.2	0.5	12.1	0.2	15.2	14.0	0.7	23.6	1.1	14.6	0.7
Ratios														
Th/Yb	0.9		0.9	0.7		0.7		0.1	0.1					
Ta/Yb	0.1		0.1	0.1		0.1		0.0	0.0					
Th/Ta	13.1		8.8	7.4		7.5		8.7	10.0					
Nb/Yb	2.3		2.4	2.0		2.1		0.1	0.1					
Zr/Ba	0.1		0.1	0.1		0.1		0.2	0.2					
Zr/Sm	18.3		14.4	15.3		15.9		18.7	17.8					
Sc/Y	1.0		2.8	2.0		1.9		2.1	2.3					

[1] The Lapaha piece was analyzed twice.

obsidian sources (Figure 3). Situated on the northernmost extension of the Tongan Arc, both Tafahi sources show distinctive trace element ratios of Sc/Y, Zr/Sm and Nb/Yb for volcanic rocks, confirming the geochemical variability of the Tongan Arc.

In total, 11 obsidian flakes (six from Lakeba and five from Tongatapu) were included in the multi-element analysis. The geochemical composition of the artifacts was compared with chemical results from 13 obsidian sources in New Guinea and two sources in Vanuatu (Figure 1). The obsidian source samples are from the Obsidian Collection in the Department of Archaeology and Natural History in the Australian National University (Ambrose et al. 2009; Reepmeyer et al. in press). Obsidian sources from New Zealand were excluded from the comparison as they show distinctive higher values in Rb and Zr, and significant lower values in La and Th (Leach 1996).

Element concentrations of 31 isotopes measured with SEM-EDXA and LA-ICP-MS were statistically tested for their ability to separate the different obsidian sources from one another. Principal Component Regression on the first and second score gave potassium oxide (K_2O) and the elements of Rb, Cs, W, Pb, Th and U the highest source discrimination. These oxides and elements were examined with the method of Principal Component Analysis (PCA). The PCA showed a clear separation of all obsidian sources from each other, with the first eigenvector representing 69.5% of the variance and the second 16.9% (Figure 4). Five obsidian artifacts from Lakeba and four artifacts from Talasiu (group-averages are given in Table 2) could be sourced to the Hala'Uta outcrop on Tafahi in northern Tonga. There is a clear distinction between the two source outcrops on Tafahi, suggesting that only one of these outcrops was utilized in prehistory.

Ward's (Ward in Rogers 1974:345) previous XRF study of a sample set from the 11,000 volcanic glass artifacts found at Lapita sites on Niuatoputapu (Kirch 1984b) indicated that they originate from the Tefitomaka outcrop on Tafahi. Comparing the early XRF results (Table 3) with the new LA-ICP-MS results, particularly Rb and Zr values, it seems likely that the Tefitomaka outcrop was not the main obsidian source. Rather, it was the Hala'Uta outcrop, which has source samples that plot with artifacts from Lapita/late Lapita sites on Lakeba and Tongatapu (no elemental data available for the volcanic glass source on Niuatoputapu).

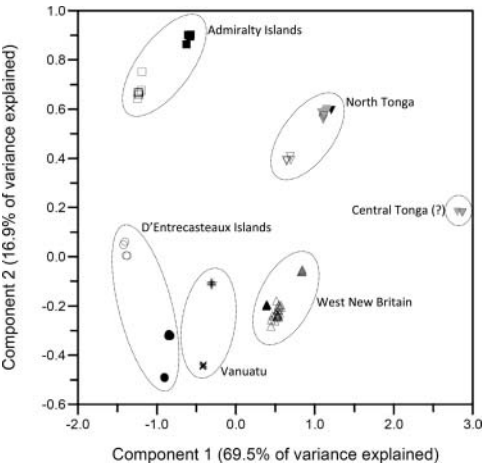

Figure 4. *Principal Component Analysis of obsidian artifacts in comparison with 13 obsidian sources in the Western Pacific. Principal components analysis of selected elements and element ratios for source samples from the Kutau/Bao (△); Baki (▲); Mopir (▲); Lou (☐); Manus (■); West Fergusson (○); East Fergusson (●); Vanua Lava (+), Gaua (×); Tafahi – Tefitomaka (▽) Tafahi – Hala'Uta (●) obsidian sources and Lakeba (●) and Tongatapu – Lapaha and Talasiu – artifacts (▼).*

The two obsidian artifacts from sites dating to the 2nd millennium AD plot away from all artifacts and obsidian sources in the PCA. There is a strong correlation between the geochemical composition of these two artifacts found on Lakeba and Lapaha (Figure 5). Both artifacts show low K_2O values (<0.8 wt%) typical for the Tongan Arc, but could not be sourced to the Tefitomaka or Hala'Uta outcrops on Tafahi.

Distinctive trace element ratios of Nb/Yb, Zr/Sm and Sc/Y suggest that the

Table 3. **Absolute counts and summary statistics of XRF analysis (data taken from Ward and Rogers 1974).**

	Mn	Rb	Sr	Zr	Zr/Mn	Rb/Sr
Niuatoputapu sites mean	1876.9	15.8	194.8	27.1	0.014	0.081
SD	180.9	7.3	28.5	14.6		
$p = .05$	112.1	4.5	17.7	9.0		
Tafahi source mean	1353.5	26.1	233.7	58.0	0.043	0.112
SD	154.2	3.5	12.2	14.3		
$p = .05$	95.6	2.2	7.6	8.9		

source of the artifacts is not located in the northern section of the Tongan Arc. This is supported by additional trace element ratios of Th/Yb, Zr/Ba and Nb/Yb which show a more southern alignment consistent with a possible source in the central part of the Tongan Arc. In relation to Ewart et al.'s (1998:345, fig. 5) latitudinal distribution of trace element ratios on the Tonga-Kermadec Arc, a source location in the volcanic islands (Hunga Ha'apai, Hunga Tonga, Fonuafo'ou, Tofua, Kao, Late) south of 18.5° South and north of 21.5° South is assumed.

DISCUSSION AND CONCLUSION

The study has shown a potential change in the use of obsidian sources over time, with raw material from Tafahi/Niuatoputapu

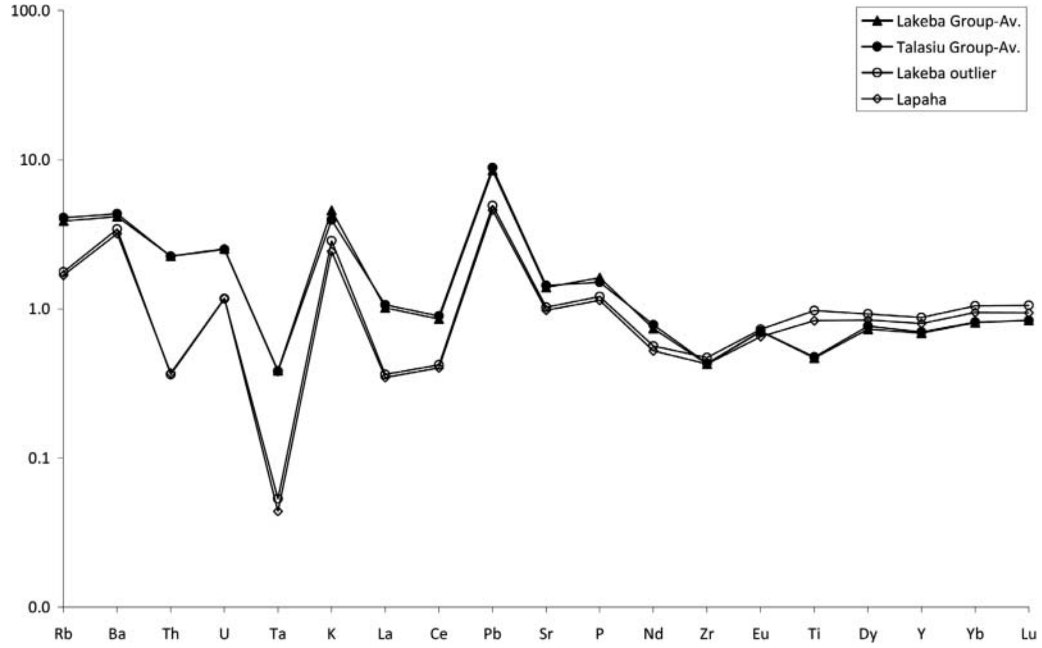

Figure 5. *Primitive Mantle normalized trace diagram of analyzed artifacts showing two distinctive source locations.*

transported during the Lapita era to Talasiu on Tongatapu (600 km) and Lakeba Island in east Fiji (600 km). Both of the early sites with Tafahi/Niuatoputapu obsidian are radiocarbon dated to ~2850–2650 cal. BP, and have ceramic assemblages with small amounts of dentate-stamped Lapita pottery, indicating obsidian transport after initial colonization (Clark and Anderson 2009a). Obsidian movement during the early colonization phase has been connected to the importance of social interaction between small founding communities in thinly populated island groups (Anderson 2003). In these situations obsidian has been postulated as a social object whose movement helps to connect isolated communities (Green 2003; Kirch 1991; Reepmeyer et al. 2010; Sheppard 1993; Specht 2002). This interpretation of obsidian transport is supported by the use of local obsidian sources that were exploited after Lapita colonization, but which have a limited distribution compared to the Kutau-Bao source in island New Guinea. Intensive exploitation and utilization of Tongan obsidian occurred only close to the source, as seen in the large number of flaked artifacts found on Niuatoputapu in ceramic and post-ceramic sites (Kirch 1984b) and their limited presence in ceramic deposits on Vava'u, the Ha'apai Group (Dye 1988) and Tongatapu. On islets off Vava'u, Burley (2007b:195) recorded volcanic glass, currently unsourced, but assumed to be from Tafahi/Niuatoputapu, in all Polynesian plainware sites (~2650–1550 BP) while at the Falevai site on Kapa Island, Connaughton (2007:209) reports four obsidian flakes from upper Polynesian plainware levels, but none in Lapita or early Polynesian plainware levels. At the early Nukuleka site (~2900–2650 cal. BP) on Tongatapu two obsidan flakes from Tafahi/Niuatoputapu have been identified (Burley et al. 2010).

Combining the distributional and chronological data suggests there was a rapid and not necessarily linear movement of Lapita groups in east Fiji and Tonga. Interaction apparently extended further, as indicated by pot tempers and stone adzes from west Fiji in Lapita deposits on Lakeba Island and a pot sherd from the Mulifanua Lapita site in Samoa with a quartz temper indicating an origin in west Fiji (Clark 2000). While the earliest Lapita sites in west Fiji (3050–2950 cal. BP) have obsidian from the Kutao-Bao source in island New Guinea (Best 1987; Nunn 2007:170), it is apparent that the oldest sites in east Fiji and Tonga date slightly later (~2900–2800 cal. BP) and have volcanic glass from northern Tonga in deposits that date to the initial and later stages of Lapita colonization. This suggests that there was ongoing and relatively high rates of mobility between east Fiji and southern and northern Tonga during the Lapita phase. As the voyaging distances between Tafahi/Niuatoputapu and east Fiji/Tongatapu (600 km) are greater than the sailing distances to Samoa (300 km) and 'Uvea (400 km) it is likely that voyaging to these islands also took place.

A parsimonious explanation of Lapita voyaging patterns in Fiji–West Polynesia based on exotic pottery (e.g., Burley and Dickinson 2010) posits the arrival of multiple groups in the large landmasses of west Fiji and possibly Tonga over several centuries, suggesting the likelihood of some return voyaging to New Caledonia, Vanuatu, and the Reef/Santa Cruz Islands (Summerhayes 2000). The eastward expansion of these early groups and their descendents appears to have a strongly nodal character, based on the size/number of Lapita sites on Lakeba in the Lau Group, Tongatapu in southern Tonga, and Niuatoputapu in northern Tonga, and absence of West New Britain obsidian in West Polynesia. A series of staging locations has several advantages for a dispersed and mobile colonizing population spread across several archipelagos, including the efficient transmission of geographic information, the opportunity for group recruitment and exchange, opportunity for reverse migration, and the performance of integrative events such as those relating to birth, death, marriage, and the socio-cultural belief system. We hypothesize that a low population density in east Fiji-Tonga-Samoa (and potentially 'Uvea and Futuna-Alofi) during the first centuries of colonization (see also Burley 2007a) encouraged greater amounts of long-distance travel relative to Lapita groups in Vanuatu, New Caledonia and West Fiji, which resulted in material culture and socio-linguistic similarities, and to a lesser extent the physical transportation of obsidian, over a broad area of the Central Pacific. Whether interaction continued in the Polynesian plainware phase is less clear. The contraction of transport networks evidenced by an absence of obsidian from northern Tonga in the post-Lapita deposits of Fiji might be associated with a decrease in inter-archipelago voyaging. If an increasing population density is related to a decline in inter-archipelago mobility in the post-colonization era then it should also be manifested by the stylistic divergence of Tongan ceramics from the pottery assemblages of east Fiji and Samoa. The restriction of volcanic glass from northern Tonga to east Fiji-Tonga may be related to the formation of the Tokalau Fijian-Polynesian language branch of Proto-Central Pacific that developed in northeast Vanua Levu, the Lau Group and Tonga (Geraghty 1983; Pawley n.d.). The close correlation between the geographic patterning in the linguistic data and the distribution of Tongan obsidian indicated that geochemical sourcing studies are a powerful tool for tracking regional and sub-regional changes in Lapita and post-Lapita interaction and migration behavior.

Recent research on the source of obsidian in Lapita sites in the Reef-Santa Cruz Islands (RSC) off the main Solomon Islands and Lapita sites in Vanuatu indicates an initial colonization pulse from island New Guinea to the RSC Islands that carried with it obsidian from West New Britain (WNB). An early emphasis on West New Britain obsidian was followed by the dominance of obsidian from the Admiralty Islands in late-Lapita sites in the Bismarck Archipelago (Summerhayes 2004, 2009). Admiralty Islands obsidian is minimal/absent, however, in the RSC Lapita sites (Green 1987; Sheppard 1992; Sheppard and Walter 2006) and there is a dramatic decline in the number and size of WNB obsidian artifacts in the oldest Lapita sites in Vanuatu, New Caledonia and Fiji Archipelago (Reepmeyer 2009; Reepmeyer et al. 2010). This suggests that after leaving the RSC, Lapita groups in Vanuatu and island groups to its south and east ceased to have major interactions with Lapita communities in the Bismarcks region, and Lapita migration from the Bismarcks to the RSC may have been minimal/absent during the period of Admiralty Island obsidian use.

The similarity between the process of cultural diversification in historical linguistics (above) and in the obsidian data suggests that disruption to long-distance interaction networks among founding Lapita communities occurred relatively soon after archipelago colonization. Change to the size of prehistoric interaction zones and to contact intensities can similarly be tracked using the distribution of obsidian sources in the Admiralty Islands, southern New Guinea, northern Vanuatu, northern Tonga and Samoa to illuminate the dynamics of Lapita colonization behavior in different parts of the West and Central Pacific.

Evidence for the resumption of inter-archipelago interaction in the Central Pacific from the sourcing of basalt artifacts dates to ~1000 BP may be related to increased oceanic seafaring during the colonization of East Polynesia coupled with the rise of complex chiefdoms that supported extensive maritime activity. This study indicates that in the late prehistoric period there was a change in raw material use with an unknown source most likely close to the Tongan chiefdom transported to Lapaha on Tongatapu and Lakeba (*site 2(b)*) in east Fiji, and Tafahi/Niuatoputapu obsidian taken to Lakeba (*site 47*; ANU-9166). The re-emergence of inter-archipelago voyaging is likely to have had significant cultural impacts, as site 47 (Ulunikoro) is currently the oldest and largest securely dated fortification structure in Fiji-West Polynesia (Clark and Anderson 2009b). The early age and size of Ulunikoro are anomalous in the Fiji Group, and Best (1984) suggested a Tongan origin for the defensive site followed by later use by a Fijian chief as reported in Fijian oral history, while a Tongan legend refers to a group of Tongan carpenters who built a massive fortification in east Fiji (Gifford 1924:201). In addition to indigenous traditions, there is also architectural evidence for a Tongan presence at Ulunikoro, as Best (1984:111) identified graves outlined with beach-rock slabs, which are structures that in other parts of east Fiji are associated with Tongan burials. Best (1984) also analyzed three olivine basalts artifacts from Ulunikoro, identifying a Samoan origin for all three, and Samoan stone tools are common at Lapaha on Tongatapu (Clark unpublished data), indicating the resumption of an east-Fiji-Tonga-Samoa interaction sphere in the last millennium AD.

Different transport mechanisms appear to underlie the prehistoric distribution of Tongan obsidian. During Lapita times, obsidian from northern Tonga was a component of the early cultural assemblage that was taken by colonists and moved between settlements marking the cultural differentiation of east Fiji–West Polynesia from west Fiji. In contrast, the late prehistoric distribution of Tongan obsidian appears to be connected with the emergence of stratified societies that engaged in extensive maritime activity, the production of specialized goods, trade-exchange, warfare and colonial activities including colony emplacement and the integration of non-local groups by powerful chiefdoms.

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END NOTE

1. This artefact was measured twice to assure accuracy of the results.

REFERENCES

Albarède, F. 2003. *Geochemistry: An Introduction*. Cambridge: Cambridge University Press.

Ambrose, W. R., C. Allen, S. O'Connor, M. Spriggs, N. V. Oliveira, and C. Reepmeyer. 2009. Possible obsidian sources for artefacts from Timor: Narrowing the options using chemical data. *Journal of Archaeological Science* 36, 607-615.

Anderson, A. 2003. Entering uncharted waters: Models of initial colonization in Polynesia. In *Colonization of Unfamiliar Landscape: The Archaeology of Adaptation* (M. Rockman and J. Steele, eds.):169–189. London: Routledge.

Barnes, S. S., and T. L. Hunt. 2005. Samoa's pre-contact connections in West Polynesia and beyond. *The Journal of the Polynesian Society* 114:227–266.

Bedford, S. and M. Spriggs. 2008. Northern Vanuatu as a Pacific crossroads. The archaeology of discovery, interaction, and the emergence of the ethnographic present. *Asian Perspectives* 47:95–120.

Bellwood, P. and P. Koon. 1989. Lapita colonists leave boats unburned! The questions of Lapita links with Island South East Asia. *Antiquity* 63:613–622.

Best, S. 1984. *Lakeba: The Prehistory of a Fijian Island*. Auckland: University of Auckland.

Best, S. 1987. Long-distance obsidian travel and possible implications for the settlement of Fiji. *Archaeology in Oceania* 22:31–32.

Best, S., P. J. Sheppard, R. C. Green, and R. Parker. 1992. Necromancing the stone: Archaeologists and adzes in Samoa. *Journal of the Polynesian Society* 101:45–85.

Bloomer, S. H., A. Ewart, J. M. Hergt, W. B. Bryan. 1994. Geochemistry and origin of igneous rocks from the outer Tonga forearc (Site 841). In *Proceedings of the Ocean Drilling Program. Scientific Results, College Station, TX* (Ocean Drilling Program), (J. W. Hawkins, L. Parson, J. Allan, et al., eds.):625–646.

Burley, D. 1998. Tongan archaeology and Tongan past, 2850–150 B.P. *Journal of World Prehistory* 12:337–392.

Burley, D. 2007a. Archaeological demography and population growth in the Kingdom of Tonga—950 BC to the historic era. In *Long Term Demographic History in the Pacific Islands* (P. V. Kirch and J. Rallu, eds.):177–202. Honolulu: University of Hawaii Press.

Burley, D. 2007b. In search of Lapita and Polynesian Plainware settlements in Vava'u, Kingdom of Tonga. In *Oceanic Explorations: Lapita and Western Pacific Settlement, Terra Australis* (S. Bedford, C. Sand, and S. P. Connaughton, eds.):187–198. Canberra: ANU E Press.

Burley, D., A. Barton, W. R. Dickinson, S. P. Connaughton, and K. Taché. 2010. Nukuleka as a founder colony for West Polynesian settlement: New insights from recent excavations. *Journal of Pacific Archaeology* 1:128–144.

Burley, D. and W. R. Dickinson. 2010. Among Polynesia's first pots. *Journal of Archaeological Science* 37:1020–1026.

Clark, G. R. 2000. *Post-Lapita Fiji: Cultural Transformation in the Mid-Sequence*. Unpublished PhD Thesis. Canberra: Australian National University.

Clark, G. R. 2002. Adzes of interaction: Samoan basalt artefacts in Fiji. In *Fifty Years in the Field: Essays in Honour and Celebration of Richard Shutler Jr's Archaeological Career* (S. Bedford, C. Sand, and D. Burley, eds.):227–238. Auckland: New Zealand Archaeological Association Monograph.

Clark, G. R. 2010. The sea in the land: Maritime connections in the chiefly landscape of Tonga. In *The Global Origins and Development of Seafaring* (A. Anderson, K. Boyle, and J. H. Barrett, eds.):229–237. Cambridge: McDonald Institute for Archaeological Research.

Clark, G. R. and A. Anderson. 2009a. Colonisation and culture change in the early prehistory of Fiji. In *The Early Prehistory of Fiji, Terra Australis (31)* (G. R. Clark and A. Anderson, eds.):407–437. Canberra: ANU E Press.

Clark, G. R. and A. Anderson. 2009b. Site chronology and a review of radiocarbon dates from Fiji. In *The Early Prehistory of Fiji, Terra Australis (31)* (G. R. Clark and A. Anderson, eds.):153–182. Canberra: ANU E Press.

Clark, G. R. and S. Bedford. 2008. Friction zones in Lapita colonisation. In *Islands of Inquiry: Colonisation, Seafaring and the Archaeology of Maritime Landscapes, Terra Australis (29)* (G. R. Clark, B. F. Leach and S. O'Connor, eds.):59–74. Canberra: ANU E Press.

Clark, G.R., D. Burley, T. Murray. 2008. Monumentality in the development of the Tongan maritime chiefdom. *Antiquity* 82:994–1008.

Collerson, K. D. and M. I. Weisler. 2007. Stone Adze compositions and the extent of Ancient Polynesian voyaging and trade. *Science* 317:1907.

Connaughton, S. P. 2007. Can we dig it? Archaeology of Ancestral Polynesian Society in Tonga: A first look from Falevai. In *Oceanic Explorations: Lapita and Western Pacific Settlement, Terra Australis* (S. Bedford, C. Sand, and S. P. Connaughton, eds.):199–212. Canberra: ANU E Press.

Dickinson, W. R. and D. V. Burley. 2007. Geoarchaeology of Tonga: Geotectonic and geomorphic controls. *Geoarchaeology: An International Journal* 22:229–259.

Dye, T. S. 1988. Appendix C, archaeological investigations on Tafahi Island. In *Niuatoputapu: The Prehistory of a Polynesian Chiefdom* (P. V. Kirch, ed.):278–287. Seattle: Thomas Burke Memorial Washington State Museum Monograph No. 5.

Ewart, A., R. N. Brothers, and A. Mateen. 1977. An outline of the geology and geochemistry, and the possible petrogenetic evolution of the volcanic rocks of the Tonga-Kermadec-New Zealand Island Arc. *Journal of Volcanology and Geothermal Research* 2:205–250.

Ewart, A., W. B. Bryan, B. W. Chappell and R. L. Rudnick. 1994. Regional geochemistry of the Lau-Tonga arc and back-arc systems, Proceedings of the Ocean Drilling Program. *Scientific Results* 135:385–425.

Ewart, A., K. D. Collerson, M. Regelous, J. I. Wendt, and Y. Niu. 1998. Geochemical evolution within the Tonga-Kermadec-Lau Arc-Back-arc systems: The role of varying mantle wedge composition in space and time. *Journal of Petrology* 39:331–368.

Ewart, A. and C. J. Hawkesworth. 1987. The Pleistocene-Recent Tonga-Kermadec Arc Lavas: Interpretation of new isotopic and rare earth data in terms of a depleted mantle source model. *Journal of Petrology* 28: 495–530.

Falkner, K. K., G. P. Klinkhammer, C. A. Ungerer, and D. M. Christie. 1995. Inductively coupled plasma mass spectrometry in geochemistry. *Annual Reviews Earth Planetary Science* 23:409–449.

Fankhauser, B. L., G. R. Clark, and A. Anderson. 2010. Characterisation and sourcing of archaeological adzes and flakes from Fiji. In *The Early Prehistory of Fiji, Terra Australis* (G. R. Clark, and A. Anderson, eds.):373–405. Canberra: ANU E Press.

Geraghty, P. 1983. *The History of the Fijian Languages*. Oceanic Linguistics Special Publication 19. Honolulu: University of Hawaii Press.

Gifford, E. W. 1924. *Tongan Myths and Tales*. Bernice P. Bishop Museum Bulletin 8. Honolulu: Bayard Dominick Expedition Publication.

Green, R. C. 1987. Obsidian results from the Lapita sites of the Reef/Santa Cruz Islands. In *Archaeometry: Further Australasian Studies, Occasional Papers in Prehistory* (W. R. Ambrose and J. M. J. Mummery eds.):239–249. Canberra: RSPAS and ANU.

Green, R. C. 1996. Prehistoric Transfers of Portable Items during the Lapita Horizon in Remote Oceania: A Review. *Indo-Pacific Prehistory Association Bulletin* 15:119–130.

Green, R. C. 2003. The Lapita horizon and traditions—Signature for one set of oceanic migrations. In *Pacific Archaeology: Assessments and Prospects. Proceedings of the International Conference for the 50th Anniversary of the first Lapita Excavation, Koné-Nouméa 2002, Le Cahiers de l'Archéologie en Nouvelle-*

Calédonie (C. Sand, ed.):95–120. Noumea: Museum of New Caledonia.

Juggins, S. 2005. *C2 data analysis,* 1.4.2 ed. Newcastle: University of Newcastle.

Kirch, P. V. 1978. The Lapitoid Period in West Polynesia excavations and survey in Niuatoputapu, Tonga. *Journal of Field Archaeology* 5:1–13.

Kirch, P. V. 1984a. *The Evolution of Polynesian Chiefdoms*. Cambridge: Cambridge University Press.

Kirch, P. V. 1984b. *Niuatoputapu: The Prehistory of a Polynesian Chiefdom*. Seattle: Thomas Burke Memorial Washington State Museum Monograph 5.

Kirch, P. V. 1991. Prehistoric exchange in western Melanesia. *Annual Review of Anthropology* 20:141–165.

Kirch, P. V. and D. E. Yen. 1982. *Tikopia: The Prehistory and Ecology of a Polynesian Outlier*. Bernice P. Bishop Museum Bulletin. Honolulu: Bishop Museum Press.

Leach, B. F. 1996. New Zealand and Oceanic obsidians: An archaeological perspective using neutron activation analysis. *Journal of the Royal Society of New Zealand* 26:79–105.

Longerich, H. P., S. E. Jackson, and D. Günther. 1996. Laser ablation inductively coupled plasma mass spectrometric transient signal data acquisition and analyte concentration calculation. *Journal of Analytical Atomic Spectrometry* 11:899–904.

Nunn, P. D. 2007. *Climate, Environment and Society in the Pacific during the Last Millennium, Developments in Earth & Environmental Sciences*. Amsterdam: Elsevier.

Pawley, A. n.d. *Polynesian paradoxes: Subgroups, wave models and the dialect geography of Proto Polynesian*. Paper presented at the Eleventh International Conference of Austronesian Linguistics (11 ical), Aussois, France, 22–26 June 2009.

Petchey, F., D. J. Addison, and A. McAlister. 2010. Re-interpreting old dates: Radiocarbon determinations from the Tokelau Islands (South Pacific). *Journal of Pacific Archaeology* 1:161–167.

Reepmeyer, C. 2008. Characterising volcanic glass sources in the Banks Islands, Vanuatu. *Archaeology in Oceania* 43:120–127.

Reepmeyer, C. 2009. *Obsidian Sources and Distribution Systems Emanating from Gaua and Vanua Lava on the Banks Islands of Vanuatu*. Unpublished PhD Thesis. Canberra: Australian National University.

Reepmeyer, C., W. R. Ambrose, and G. R. Clark. in press. Obsidian sourcing in the Pacific: New results using LA-ICPMS. In: *Recent Advances in Laser Ablation ICP-MS for Archaeology* (B. Gratuze, M. Golitko, and L. Dussubieux, eds.). New York: Springer.

Reepmeyer, C. and G. R. Clark. 2010. Post-colonization interaction between Vanuatu and Fiji reconsidered: The reanalysis of obsidian from Lakeba Island, Fiji. *Archaeometry* 52:1–18.

Reepmeyer, C., M. Spriggs, S. Bedford, and W. R. Ambrose. 2010. Provenance and technology of lithic artefacts from the Teouma Lapita Site, Vanuatu. *Asian Perspectives* 49: 205–225.

Rogers, G. A. 1974. Archaeological discoveries on Niuatoputapu Island, Tonga. *Journal of the Polynesian Society* 83:308–348.

Sheppard, P. J. 1992. A report on the flaked lithic assemblages from three Southeast Solomons Lapita sites (SE-SZ-8, SE-RF-2, SE-RF-6). In *Poterie Lapita et Peuplement* (J.-C. Galipaud, ed.):145–153. Nouméa: ORSTROM.

Sheppard, P. J. 1993. Lapita lithics: Trade/exchange and technology. A view from the Reefs/Santa Cruz. *Archaeology in Oceania* 28:121–137.

Sheppard, P. J., R. G. V. Hancock, L. A. Pavlish, and R. Parker. 1989. Samoan Volcanic Glass. *Archaeology in Oceania* 24:70–74.

Sheppard, P. J. and R., Walter, 2006. A revised model of Solomon Islands culture history. *Journal of the Polynesian Society* 115: 47–76.

Smith, I. E. M., R. C. Price. 2006. The Tonga-Kermadec arc and Havre-Lau back-arc system: Their role in the development of tectonic and magmatic models for the western Pacific. *Journal of Volcanology and Geothermal Research* 156:315–331.

Smith, I. E. M., G. K. Ward, and W. R. Ambrose. 1977. Geographic distribution and the characterization of volcanic glasses in Oceania. *Archaeology in Oceania* 12: 173–201.

Specht, J. 2002. Obsidian, colonising and exchange. In *Fifty Years in the Field: Essays in Honour and Celebration of Richard Shutler Jr's Archaeological Career* (S. Bedford, C. Sand, and D. Burley, eds.):37–49. Auckland: New Zealand Archaeological Association Monograph.

Specht, J., R. Fullagar, R. Torrence, and N. Baker. 1988. Prehistoric obsidian exchange in Melanesia: A perspective from the Talasea sources. *Australian Archaeology* 27:3–16.

Spennemann, D. H. R. 1986. *Archaeological Fieldwork in Tonga 1985–1986*. Preliminary report on the archaeological activities during the 1985/86 field season of the Tongan Dark Ages Research Programme, Tongan Dark Ages Research Programme, Department of Prehistory, The Australian National University, Canberra.

Spriggs, M., J. R. Bird, and W. R. Ambrose. 2010. A reanalysis of the Tikopia obsidians. *Archaeology in Oceania* 45:31–38.

Summerhayes, G. R. 2000. *Lapita Interaction, Terra Australis.* Canberra: ANH and CAR.

Summerhayes, G. R. 2004. The nature of Prehistoric obsidian importation to Anir and the development of a 3,000 year old regional picture of obsidian exchange within the Bismarck Archipelago, Papua New Guinea. *Records of the Australian Museum* Supplement 29:145–156.

Summerhayes, G. R. 2009. Obsidian network patterns in Melanesia—Sources, characterisation and distribution. *Indo-Pacific Prehistory Association Bulletin* 29:109–124.

Weisler, M. I. 1997. *Prehistoric Long-Distance Interaction in Oceania: An Interdisciplinary Approach*. Auckland: New Zealand Archaeological Association Monograph.

Weisler, M. J. 1995. Basalt Pb isotope analysis and the prehistoric settlement of Polynesia. *Proceedings of the National Academy of Science USA* 92:1881–1885.

Wilmshurst, J. M., T. L. Hunt, C. P. Lipo, A. Anderson. 2011. High-precision radiocarbon dating shows recent and rapid initial human colonization of East Polynesia. *Proceedings of the National Academy of Science USA* 108:1815–1820.