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Tongan and Samoan volcanic glass: pXRF analysis and implications for constructs of ancestral Polynesian society

David V. Burley[a,*], Peter J. Sheppard[b], Maia Simonin[c]

[a] Dept. of Archaeology, Simon Fraser University, 8888 University Drive, Burnaby, B.C., Canada V5A 1S6
[b] Dept. of Anthropology, University of Auckland, Private Bag 92019, Auckland 1142, New Zealand
[c] University Bordeaux 3 Michel de Montaigne, Maison d'Archéologie – CRPAA, Domaine Universitaire, 33607 Pessac cedex, France

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A B S T R A C T

A provenance study of volcanic glass specimens from 12 archaeological sites in the Kingdom of Tonga is carried out employing pXRF (portable X-ray fluorescence) analysis. To accomplish this, volcanic glass samples from previously identified sources in northern Tonga and the adjacent islands of Samoa are analyzed. Results indicate inter-island voyaging and interaction over a 600 km linear distance along the Tongan island chain from first Lapita settlement ca 2900 BP throughout later prehistory. Tongan volcanic glass, however, is not found in Samoa and, with the exception of one late prehistoric specimen, Samoan volcanic glass is not present in Tonga. This distribution challenges current concepts of an integrated ancestral society and homeland common to Tonga and Samoa from the Lapita period onward.

1. Introduction

First settlement of Polynesia by "Lapita peoples" (after Kirch, 1997) occurred within the adjacent archipelagoes of Tonga and Samoa in the interval 2900–2750 BP. The two island groups are a linear extension of each other, oriented along a southwest to northeast sailing corridor of ca 1000 km. It was here that an ancestral Polynesian society and cultural template developed before renewed eastward expansion populated the remainder of the Polynesian triangle (Fig. 1) (Kirch and Green, 2001). Documenting first settlement and regional integration of the ancestral Polynesian homeland in Tonga has been central to Burley's research interests over the past two decades. This work has led to multiple excavations of Lapita colonizing and later period sites throughout the length of the archipelago, including the recovery of large assemblages of cultural materials. Within these collections are 51 pieces of volcanic glass, a small sample in a numeric sense, but a revealing indicator of inter-island voyaging and interaction for ancestral Polynesian prehistory.

In the following paper we provide a provenance study for the 51 Tongan specimens using portable X-ray fluorescence (pXRF) analysis, and in so doing, examine other aspects of volcanic glass distribution in Tonga and Samoa. Three objectives are set. First, West Polynesian volcanic glass source locales in Tonga and Samoa are identified and clarified allowing for pXRF source signatures based on archaeological and geological samples. Second, data from pXRF analysis of the Tongan archaeological samples are presented and source identifications are securely drawn. Finally, results of the provenance study are examined relative to implications for first settlement and population dynamics in the ancestral Polynesian homeland. As a result, we suggest the ancestral homeland in Tonga is well integrated; the evidence for integration or interaction with Samoa, however, remains equivocal until late in prehistory.

2. pXRF measurement and standards

The development and increasing sophistication of pXRF technology enhances the archaeological tool kit for provenance studies of obsidian and other materials. Limited cost, substantially reduced analysis time, and the non-destructive nature of pXRF measurement are substantial benefits relative to other characterization approaches employed in Oceanic research, including wavelength dispersive X-ray fluorescence (WD-XRF), proton-induced X-ray emission (PIXE), proton-induced gamma ray emission (PIGME), instrumental neutron activation analysis (INAA) and inductively coupled plasma mass spectrometry (ICP-MS) (Sheppard *et al.*, 2011). The trade-off, however, is often lowered sensitivity, and a reduced set of measurable elements.

* Corresponding author. Tel.: +1 778 782 4196; fax: +1 778 782 5666.
E-mail address: burley@sfu.ca (D.V. Burley).

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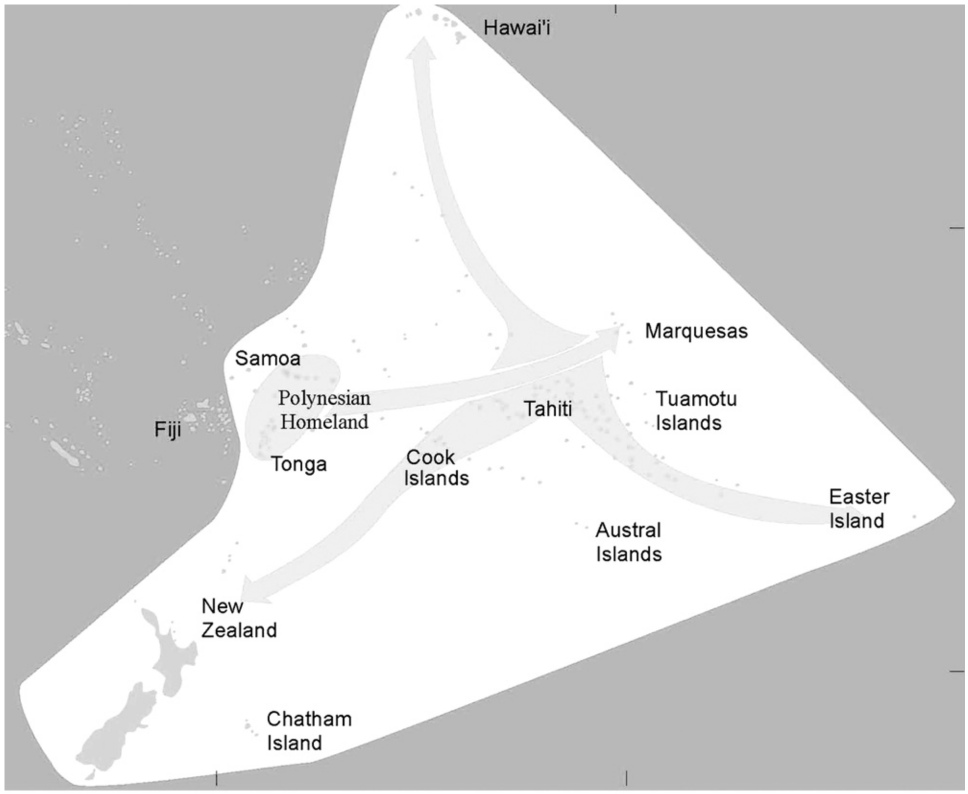

Fig. 1. The ancestral Polynesian homeland and voyaging paths for the settlement of East Polynesia based on Kirch (2000: 131).

Recent research illustrates obsidian is well suited for pXRF analysis relative to other lithic suites typically examined in provenance studies (Craig et al., 2007; Liritzis and Zacharias, 2010). Phillips and Speakman (2009: 1262) succinctly characterize pXRF as an "analytically accurate and precise method" for their study of Kuril Island obsidians from the Russian Far East. Sheppard et al. (2010) similarly demonstrate the efficacy of pXRF specifically for southwest Pacific obsidian studies, successfully differentiating geological samples for West New Britain, Admiralty Islands, Ferguson Island and Banks Islands sources. They further analyze a large number ($n = 966$) of archaeological materials from Reef/Santa Cruz Island sites, replicating earlier PIXE results and refining source region identifications. Shackley (2010: 12) suggests pXRF technology has transformed archaeological science. He also emphasizes, however, that there is critical need for implementation of measurement and calibration protocols if results are to be comparable between instruments and operators.

The pXRF analysis presented here was conducted with an Innov-X (Alpha Series) X-ray tube (Ag or W anode, 10–40 kVm,10–50 μA) system with results downloaded to a PDA. X-rays are detected by a Si PiN diode detector (<300 eV FWHM at 5.95 keV Mn K-alpha line). The system is configured to analyze 18 elements in ppm using the manufacturer's standard package and an additional seven elements using the Light Element Analysis Package (LEAP). There is no vacuum capability, so elements lighter than P cannot be detected. Detection limits for all the elements used in the analysis described below range from 10 to 100 ppm. The instrument is mounted in a stationary test stand in the University of Auckland Anthropology Department laboratory. Clean, flat surfaces of the volcanic glass specimens are placed on the detector window, analyzed for 3 min using the standard analysis package, and 3 min using the LEAP package (average live-time of 115 s). Measurement of the NIST 2709 powdered soil standard at the start of every analysis run monitors measurement consistency. Data on precision of the analysis of the NIST 2709 standard is provided in Table 1 (see also Sheppard et al., 2011). To calibrate results, NIST SRM-278 standard obsidian (powdered obsidian from Clear Lake, Newberry Crater, Oregon) and laboratory specific powdered obsidian standards (MI 9.3, determined by WD-XRF in the Department of Geology, University of Auckland) were also run. Elemental values were calibrated using the method and correction factors reported in Sheppard et al. (2010: Table 1).

3. Regional volcanic glass sources – Tonga and Samoa

The term volcanic glass is employed here in keeping with common usage by Oceanic archaeologists; obsidian typically refers to rhyolitic glass such as that found in the Bismarck archipelago with volcanic glass generally reserved for lower flaking quality opaque material found as nodules within dacitic or basaltic eruptive sequences of northern Vanuatu and western Polynesia (Ambrose et al., 1981). Western Polynesian volcanic glass

Table 1
Precision and accuracy data for analysis of the NIST 2709 standard.

NIST 2709 Standard San Joaquin soil					Certified value	
ppm	*N*	Mean	Std	CV	Mean	Std
Mn	14	566	94	0.13	538	17
Ti	14	4559	412	0.06	3420	240
Fe	14	38,927	3402	0.07	35000	1100
Zn	14	82	2	0.03	106	3
Rb	14	95	2	0.02	96	Recommended
Sr	14	240	3	0.01	231	2
Zr	14	130	3	0.02	160	Recommended
Pb	14	20	2	0.09	19	0.5
K	14	26,418	2266	0.06	20300	600

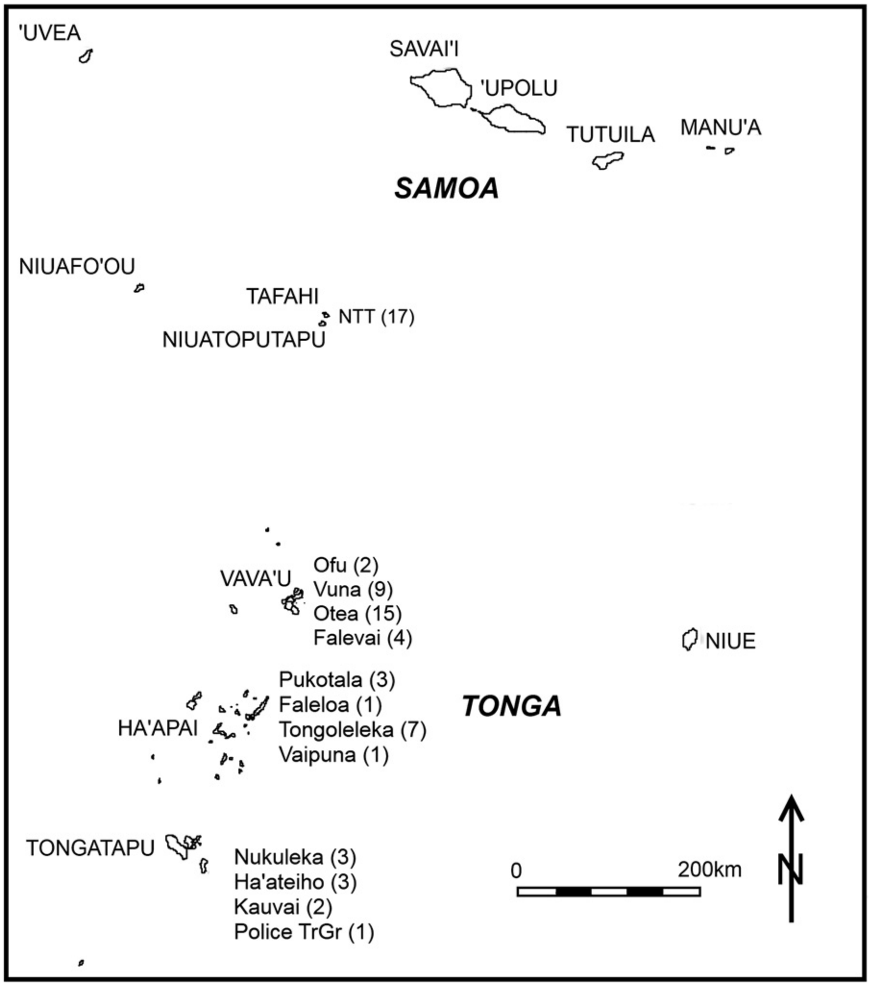

Fig. 2. Archaeological sites from which analyzed volcanic glass samples were recovered. Number of specimens is included in parenthesis. Also see Tables 4 and 5.

specimens have long been documented in the archaeological records of Samoa and Tonga, and geochemical characterization studies undertaken (Ward, 1974a, b; Sheppard et al., 1989; Clark and Wright, 1995). Distinctive geochemical signatures exist for materials from each of the two archipelagoes, but respective source identifications are less certain.

Volcanic glass samples from Samoan sites are well summarized in other publications (Sheppard et al., 1989; Clark and Wright, 1995). Ward (1974a) undertook initial XRF analysis on several specimens recovered by Green and Davidson (1974) from sites on 'Upolu, Western Samoa. He had no geological samples for Samoa, but inferred a Samoan source based on sample homogeneity and geochemical differentiation from volcanic glass of the northern Tongan islands of Niuatoputapu and Tafahi (Fig. 2). Sheppard et al. (1989) similarly examined a large sample of volcanic glass from six sites on 'Upolu employing INAA and XRF. Duplicating Ward's conclusions, the study also incorporated geological samples of basaltic glass from Goat Island, Tutuila, American Samoa. In both geochemistry and petrography, Goat Island is proved not to be the source. More recent excavations at 'Aoa, Tutuila, American Samoa by Clark and Wright (1995) recovered a sizeable number ($n = 276$) of volcanic glass flakes and cores. Fourteen of the samples were analyzed for major elements using a scanning electron microscope EDAX (energy-dispersive X-ray) attachment. The samples proved consistent in character but varied significantly from six geological samples of "glassy material" from dykes around Tutuila, including one from Goat Island. Clark and Wright found the 'Aoa and 'Upolu volcanic glass samples similar in composition, with major elements closely aligning to Tutuila lavas. The source locale, in their (1995: 256) view, "is almost certainly Tutuila and not 'Upolu or any other known Pacific source".

Early archaeological study of Niuatoputapu by Rogers (1974) recovered a small assemblage of volcanic glass flakes from the surface of several sites. He also acquired[1] volcanic glass geological samples from Tefitomaka, a locale on the volcanic island of Tafahi, 7 km to the north of Niuatoputapu. XRF trace element analysis of the two groups led Ward (1974b: 345) to conclude, "it is highly likely that the natural volcanic glass from the Lapita sites at Niuatoputapu derives from the Tafahi source". A later survey of Oceanic volcanic glass sources by Smith et al. (1977) restates this identification. In 1976 Kirch (1988) undertook an extensive archaeological study of Niuatoputapu, carrying out island-wide survey and excavating several sites spanning full human occupation of the island. From 11 sites he recovered 11,457 volcanic glass specimens, including 8778 from Nt 90, a site including first Lapita settlement through later prehistoric occupations. Kirch (1988: 215) also

[1] New Zealand Anthropologist Wendy Pond collected the samples, and gave them to Rogers. She was recording place names on Tafahi at the time. In her words, she was "keen to find a source of quarriable obsidian, but the Tafahi people I asked did not know of an outcrop" (correspondence to Burley 1 June 2010).

Table 2
Source samples for Samoan ('Upolu and Tutuila) and Tongan volcanic glass.

Site	Island	Source	Period	*N*
Su Sa 3	'Upolu	Archaeological	Samoan Plain	12
Su Va 4	'Upolu	Archaeological	Samoan Plain	25
Su Lo 1	'Upolu	Archaeological	Late?	1
As-21-S (Aoa)	Tutuila	Archaeological	Samoan Plain – Late?	10
Nt 90	Niuatoputapu	Archaeological	Lapita – Late?	75
Tefitomaka	Tafahi	Geological		7

reports an outcrop of volcanic glass on the island's central volcanic ridge. This source is described specifically by Dye (1988: 287) as a tuff outcrop yielding glassy nodules behind Vaipoa village, a location in close proximity to Nt 90. The potential Niuatoputapu source notwithstanding, Kirch's (1988: 255) conclusions continue to give primacy to Tafahi, asserting, "*Tafahi obsidian* will prove [ultimately] to have been fairly widely distributed throughout the region" (emphasis added). Tafahi, thus, became the default source locale for northern Tongan volcanic glass in regional literature.

The island of Tafahi is a stratovolcano with difficult access, limited resources for human settlement and a thinly developed archaeological record without evidence for early Lapita settlement (Dye, 1988). It is an unlikely quarry for volcanic glass export in light of an alternative at Vaipoa on Niuatoputapu. The large volcanic glass assemblage recovered by Kirch from Nt 90 near Vaipoa is also characteristic of exploitation from a nearby source rather than off-island import. It lacks finished tools, largely incorporating bipolar shatter fragments and cores, cortex flakes, and flakes with hinge or step fractures lacking distinctive bulbs of percussion (Kirch, 1988: 214–215). It represents, we believe, primary nodule reduction expected of a quarry locale. Seventy-five volcanic glass specimens from a single excavation unit at Nt 90 (Unit G-37 I/IV, Kirch, 1988: Fig. 51) were acquired for pXRF analysis here. The specimens were drawn systematically as a grab sample across Kirch's excavation levels; we assume, therefore, representation over different periods of time. The sample consists of 19 cores or core fragments, 12 flakes and 44 shatter fragments with a cumulative weight of 276.8 g.

Three source locales for volcanic glass extraction are identifiable within the ancestral Polynesian homeland as described above. Archaeological collections from Samoa suggest a single source, the specific locale unknown, but thought to lay on Tutuila in American Samoa. In Tonga, two sources are reported, Tefitomaka on Tafahi and Vaipoa on Niuatoputapu, both tuff deposits in which volcanic glass nodules occur. To provide geochemical source signatures for comparison to the 51 archaeological specimens from elsewhere in Tonga, we carried out pXRF analysis on 38 samples from three archaeological sites on 'Upolu, Samoa, ten archaeological samples from the 'Aoa site on Tutuila, American Samoa, seven geological samples from Tefitomaka on Tafahi, Tonga as well as the 75 samples from Nt 90 taken to represent the Vaipoa source on Niuatoputapu, Tonga (Table 2). Element concentrations (ppm) for K, Fe, Ti, Mn, Zn, Rb, Sr, Zr, Co and Pb were acquired for each specimen employing the protocols described above. Table 3 gives summary data for each of the four groups, and Fig. 3 provides a bivariate plot of rubidium (Rb) and strontium (Sr), two elements that clearly differentiate source locales. Based on these data, we reaffirm that the Samoan and American Samoan archaeological materials are very close in composition and probably derive from a single source. The northern Tongan sources of Vaipoa and Tefitomaka, however, cannot be distinguished. Some degree of variation occurs in specific elements, but a distinctive signature for each seems absent. The relative proximity of Tafahi and Niuatoputapu, the tuff imbedded nodules from both locales, and the possibilities of a single volcanic centre, potentially explain this situation. The Samoan and Tongan composite source groups are significantly divergent in geochemical composition to provide regional differentiation for the analysis at hand (Table 3, Fig. 3).

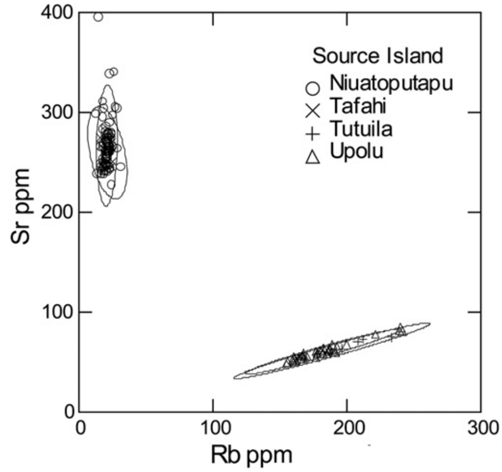

Fig. 3. Bivariate plot of strontium and rubidium for volcanic glass source samples from northern Tonga (Niuatoputapu, Tafahi) and Samoa (Tutuila, 'Upolu). Density elipses are drawn at 95% confidence intervals for each of the source island samples. Also see Table 3.

Table 3
Summary elemental pXRF data for northern Tonga and Samoan volcanic glass source samples. Also see Fig. 3.

ppm	Island											
	Tonga						Samoa					
	Niuatoputapu			Tafahi			Tutuila			Upolu		
	N	Mean	Std	*N*	Mean	Std	*N*	Mean	Std	*N*	Mean	Std
Fe	75	71750	5357	7	59722	19957	10	16177	721	38	22003	5869
Ti	75	4124	287	7	3359	435	10	405	277	38	4402	4945
K	75	14105	1382	7	16801	1441	10	55356	3016	38	57211	8863
Zr	75	38	3	7	44	10	10	205	22	38	200	20
Sr	75	267	24	7	259	12	10	61	9	38	60	9
Rb	75	20	3	7	21	4	10	189	23	38	182	22
Mn	75	4930	743	7	3317	956	10	2222	161	38	2646	380
Zn	75	140	13	7	105	13	10	273	43	38	279	51
Co	73	355	62	7	375	100	8	124	30	5	109	24
Pb	75	nd		7	nd		10	15	4	38	16	4
Ni	1	80		0	nd		1	43		6	61	17

4. Tongan archaeological site volcanic glass and source identification

The Kingdom of Tonga has 169 islands spread over a linear distance of 700 km. From south to north, the archipelago incorporates three island groups, Tongatapu, Ha'apai and Vava'u, with Niuatoputapu forming a far northern outlier. First Lapita settlement occurred in the south, on the Tongatapu lagoon ca 2850–2900 BP, with northward exploration and dispersal taking place immediately thereafter (Burley et al., 2010). Decorated Lapita ceramic vessels disappear from the Tongan archaeological record within a two-century time span for reasons undetermined. A sequent undecorated ceramic phase, referred to as Polynesian Plainware, persisted until ca 1600 BP (Burley and Connaughton, 2007). Kirch and Green (2001) associate this Plainware period with the emergence and development of ancestral Polynesian society. Ceramics disappear altogether from Tongan material culture thereafter. At ca 900 BP, first indication of a complex maritime chiefdom is marked on the Tongan landscape by burial tumuli and other forms of monumental architecture (Burley, 1998; Clark et al., 2008). Burley has carried out surveys and multiple site excavations over the past two decades, attempting to track initial Lapita settlement throughout Tonga, and to characterize its transition into ancestral Polynesian society. This has resulted in recovery of the 51 volcanic glass specimens from 12 sites on Vava'u, Ha'apai and Tongatapu (Fig. 2).

The Tongan archaeological volcanic glass assemblage consists of small flakes, flake fragments or shatter. All but two of the samples come from excavations with defined stratigraphic context and provenience, the exceptions being surface collected from excavated sites. Most samples are assigned securely to a Lapita, Polynesian Plainware, or a-ceramic chronological phase (Table 4). A disturbed context was identified where intrusive features or surface disturbances made it impossible to determine primary context. The continuous use of volcanic glass from initial Lapita colonizing sites through to later prehistory in each of the island groups is illustrated in Table 4. Site assemblage spatial distributions also imply a degree of association with the northern sources, as there appears to be down-the-line fall-off in specimen numbers from the Niuatoputapu/Samoa composite sources to Vava'u ($n = 30$), Ha'apai ($n = 12$) and Tongatapu ($n = 9$).

The archaeological specimens were analyzed using the previously defined pXRF protocols and elements. We further added 17 specimens recovered by Rogers (1974) from the surface of archaeological sites on Niuatoputapu, including Nt 90. This provides full coverage of archaeological sites throughout Tonga. Analysis results are provided in Table 5, and a bivariate plot of Rb with Sr is given in Fig. 4. Of the 68 samples, all but one confidently associate with the northern Tongan source. The exception is a close match to the Samoan/American Samoan composite source. It comes from an upper a-ceramic stratum from the Vuna site, Pangaimotu Island, Vava'u. The stratigraphic context indicates a post 600 BP date for deposition, a period in which the Tongan chiefdom was actively engaged in well-documented trade with Samoa and Fiji (Kaeppler, 1978).

Table 4
Volcanic glass data recovered from Tongan archaeological sites as used for pXRF analysis. Temporal/contextual associations are LAP = Lapita, PW = Polynesian Plainware, ACER = a-ceramic and DIST = Disturbed. NTT refers to samples surface collected from several sites on Niuatoputapu by Rogers (1974). Also see Fig. 2.

Site	Island	LAP	PW	ACER	DIST	Total
Nukuleka	Tongatapu	1			2	3
Ha'ateiho	Tongatapu	1	1	1		3
Kauvai 2	Tongatapu	1	1			2
Police TrGr	Tongatapu	1				1
Tongoleleka	Lifuka (Ha)		6	1		7
Vaipuna	Uiha (Ha)		1			1
Pukotala	Ha'ano (Ha)	2			1	3
Faleloa	Foa (Ha)	1				1
Ofu	Ofu (Vav)	1			1	2
Vuna	Pangaimotu (Vav)	4		4	1	9
Otea	Kapa (Vav)	10	1	3	1	15
Falevai	Kapa (Vav)		1	3		4
NTT	Niuatoputapu					17
Total		22	11	12	6	68

5. Implications for archaeological interpretation of the ancestral Polynesian homeland

Ancestral Polynesian society and the homeland in which it developed are topics of debate in Oceanic archaeology (Kirch and Green, 2001; Smith, 2002). West Polynesia, including Tonga, Samoa and the outliers of Futuna and 'Uvea, was first settled by Lapita peoples between 2900 and 2750 years ago as stated. Extension of this settlement to East Polynesia did not occur until 1900 years later, the exact length of this pause being constantly refined (Wilmshurst et al., 2010). With no definitive archaeological or linguistic evidence for population discontinuity in West Polynesia, the long held assumption has been *in situ* transition of cultural, linguistic and biological traits from Lapita to ancestral/proto-Polynesian peoples. Founder effect, remoteness, small island adaptations, and shared innovations are contributory processes to a Polynesian template that, ultimately, spread eastward (Kirch and Green, 2001). A high degree of integration and inter-island interaction within the ancestral homeland is expected for such a scenario to play out. Volcanic glass from Tonga and Samoa provide one set of data to examine this expectation.

Our pXRF analysis definitively illustrates a wide distribution of Niuatoputapu volcanic glass throughout the length of the Tongan archipelago. First settlement of Tonga occurs at Nukuleka on the southern island of Tongatapu; shortly thereafter exploration/colonization extended northward to Niuatoputapu and Samoa (Burley, 2007). Discovery of the Vaipoa source must have been contemporaneous with first Lapita landfalls at Nt 90, given its abundance in the early deposits at that site (Kirch, 1988). The presence of volcanic glass, in fact, may have been a factor for the Nt 90 site location, if not the rationale for Lapita settlement of Niuatoputapu *per se*. The occurrence of what is most likely Vaipoa volcanic glass in eight different Lapita site contexts throughout the archipelago within a two hundred year time slot speaks strongly to rapid population dispersal with return voyaging to the south. The eastern Lapita ceramic assemblage, not surprisingly, is homogeneously configured in decorative applications and vessel form production (Burley et al., 2002). The persistence of Niuatoputapu volcanic glass within Polynesian Plainware period assemblages speaks also to integration and inter-island relationships in at least the initial phases of ancestral Polynesian ethnogenesis in Tonga. Again strong parallels mark this in ceramic change throughout the length of the archipelago.

The Samoan archaeological sequence, as characterized by Green (1979) and also by Clark (1996) is similar to Tonga in its initial Lapita phase occupation followed by a Samoan variant of the Polynesian Plainware ceramic phase. The largest majority of Samoan specimens employed in our analysis are attributed to Polynesian Plainware ceramic period sites on 'Upolu or the 'Aoa site, Tutuila (Table 2). The absence of Samoan volcanic glass in Polynesian Plainware sites of Tonga, thus, contradicts expectations of an integrated ancestral homeland inclusive of both archipelagoes. This is emphasized by the lack of northern Tongan volcanic glass in any of the Samoan Plainware sites, despite 'Upolu being as close to Niuatoputapu (295 km) as the latter is to Vava'u (293 km). The volcanic glass distribution pattern of Tonga and Samoa, at least

Table 5
Elemental pXRF data for Tongan volcanic glass samples. Also see Table 4 and Fig. 4.

Site	Sample	Ti	Fe	Mn	K	Zn	Rb	Sr	Zr	Co	Pb
Ha'ateiho	to5.1	4,110	69,200	4,300	15,840	171	25	255	38	298	nd
Ha'ateiho	to5.114	4,010	73,410	4,530	14,860	149	22	262	36	492	nd
Ha'ateiho	to5.116	4,070	69,830	4,340	15,280	123	23	263	38	377	nd
Kauvai 2	kau2.44	3,780	72,110	4,400	15,340	127	19	252	37	440	nd
Kauvai 2	kau2.73	4,030	68,660	4,200	14,680	137	18	242	41	249	nd
Nukuleka	to2.6	4,220	69,730	4,520	15,270	279	24	276	45	346	nd
Nukuleka	to2.50	4,480	80,190	5,190	16,660	150	19	262	36	340	nd
Nukuleka	to2.95	4,570	78,090	4,830	15,630	130	17	254	38	372	nd
Police TrGr	to10.9	3,630	68,240	4,210	14,750	126	21	254	38	385	nd
Faleloa	fol117	4,270	79,300	5,190	18,620	137	22	255	36	410	nd
Pukotala	hal234	4,320	77,050	4,910	18,010	488	22	255	39	315	nd
Pukotala	hal.233	4,760	79,310	5,140	18,730	136	22	255	43	283	nd
Pukotala	hal232	4,410	75,530	4,920	17,760	136	20	245	38	449	nd
Tongoleleka	li7.17	3,920	69,060	4,380	16,600	123	20	248	37	450	nd
Tongoleleka	li7.18	4,450	75,740	4,840	17,240	161	25	290	47	433	nd
Tongoleleka	li7.19	3,650	65,000	4,210	15,840	111	17	216	29	252	nd
Tongoleleka	li7.20	3,940	68,520	4,430	16,990	140	21	261	44	466	nd
Tongoleleka	li7.21	4,150	72,900	4,800	15,900	126	21	251	37	458	nd
Tongoleleka	li7.5	4,370	73,150	4,790	16,380	133	20	243	36	389	nd
Tongoleleka	li7.78	5,000	89,730	5,780	20,480	139	23	256	35	267	nd
Vaipuna	vi4.233	4,000	84,820	4,460	16,170	128	20	291	34	415	nd
Falevai	ka2.03.17	3,970	70,380	4,450	14,930	139	19	250	36	285	nd
Falevai	ka2.03.27	4,500	82,800	5,020	15,890	117	15	240	37	315	nd
Falevai	ka2.03.44	4,800	76,390	4,240	12,740	153	20	268	40	235	nd
Falevai	ka2.03.56	4,790	83,680	4,490	13,420	143	18	246	38	262	nd
Vuna	pa1.04.183	nd	16,090	2,160	52,730	279	167	65	196	nd	14
Vuna	pa1.04.134	4,130	74,250	4,630	21,860	152	23	300	49	221	nd
Vuna	pa1.04.16	4,310	89,480	4,300	14,810	128	18	286	33	395	nd
Vuna	pa1.04.162	3,660	65,870	4,340	16,026	140	27	265	42	267	nd
Vuna	pa1.04.241	3,930	67,620	4,190	15,160	134	24	271	42	440	nd
Vuna	pa1.04.245	3,920	69,660	4,430	15,910	134	22	257	39	357	nd
Vuna	pa1.04.248	3,790	71,830	4,310	14,410	171	20	254	37	393	nd
Vuna	pa1.04.286	3,590	69,250	4,370	15,560	130	19	247	41	280	nd
Vuna	pa1.04.97	3,780	67,100	4,330	15,080	145	18	248	40	352	nd
Ofu	of1.03	3,930	70,970	4,280	14,540	131	20	248	40	318	nd
Ofu	of1.210	5,440	82,990	6,260	15,820	166	20	250	40	261	nd
Otea	ka1.03.109	4,070	71,720	4,480	15,080	134	21	251	37	385	nd
Otea	ka1.03.11	4,000	70,960	4,290	15,030	134	21	256	42	289	6
Otea	ka1.03.110	3,770	67,910	4,180	14,700	120	17	241	36	235	nd
Otea	ka1.03.127	4,140	72,560	4,440	16,690	127	23	244	34	383	nd
Otea	ka1.03.128	4,210	74,530	4,000	13,590	134	23	260	36	395	nd
Otea	ka1.03.147	4,320	74,230	4,550	15,230	134	19	266	37	533	nd
Otea	ka1.03.148	4,130	72,240	4,440	17,040	139	25	265	40	328	nd
Otea	ka1.03.15	4,120	71,770	4,290	16,120	130	18	250	37	464	6
Otea	ka1.03.159	3,940	68,820	4,220	16,230	134	22	257	37	413	6
Otea	ka1.03.17	3,910	70,690	4,090	14,290	127	19	248	36	302	nd
Otea	ka1.03.20	4,100	72,830	4,230	15,780	134	18	257	37	310	nd
Otea	ka1.03.48	3,870	69,460	4,390	15,170	126	21	253	39	341	nd
Otea	ka1.03.63	3,750	68,210	4,070	13,920	131	23	248	36	326	nd
Otea	ka1.03.75	4,370	75,440	4,450	14,120	130	20	268	40	413	nd
Otea	ka1.03.8	3,860	67,510	4,120	15,080	131	22	243	37	274	nd
Niuatoputapu	ntt 110	3,890	67,300	4,300	14,560	121	21	241	38	272	nd
Niuatoputapu	ntt 111	3,080	44,530	2,500	15,730	89	23	243	50	216	nd
Niuatoputapu	ntt 112	3,820	65,510	4,360	13,500	152	24	278	37	363	nd
Niuatoputapu	ntt 113	3,840	69,930	4,440	14,800	149	21	263	36	239	nd
Niuatoputapu	ntt 115	3,980	69,910	5,490	15,080	136	23	263	36	344	nd
Niuatoputapu	ntt 116	4,260	72,700	4,270	13,740	130	18	266	40	394	nd
Niuatoputapu	ntt 117	2,820	43,510	3,110	15,960	107	25	266	53	180	nd
Niuatoputapu	ntt 118	3,850	64,930	5,290	46,340	159	27	305	41	363	nd
Niuatoputapu	ntt 119	4,810	78,580	5,210	13,200	143	28	304	40	270	6
Niuatoputapu	ntt 120	4,290	69,980	3,670	11,230	123	23	339	36	250	6
Niuatoputapu	ntt 121	4,000	69,680	4,560	14,920	134	22	259	39	323	nd
Niuatoputapu	ntt 125	3,970	69,800	5,220	15,100	128	21	253	36	365	nd
Niuatoputapu	ntt 126	3,180	77,120	4,250	12,660	123	16	245	31	539	nd
Niuatoputapu	ntt 127	3,950	67,940	4,930	14,360	153	28	264	39	313	nd
Niuatoputapu	ntt 129	3,140	43,510	3,130	13,990	110	24	228	49	234	nd
Niuatoputapu	ntt 130	3,200	49,000	4,020	13,160	133	31	246	44	170	nd
Niuatoputapu	ntt unk	4,110	72,900	4,530	14,860	134	22	247	39	260	nd

superficially, implies regionally distinct populations with limited interaction early in west Polynesian prehistory. Early Samoan prehistory, however, is poorly understood and contested. Rieth et al. (2008) and also Addison et al. (2008) for example report the virtual absence of archaeological deposits (and presumably people) predating 2500 years ago, with the Samoan settlement landscape in-filled only by 2300 years ago. Addison and Matisoo-Smith (2010) additionally claim a discontinuous archaeological record for Samoa.

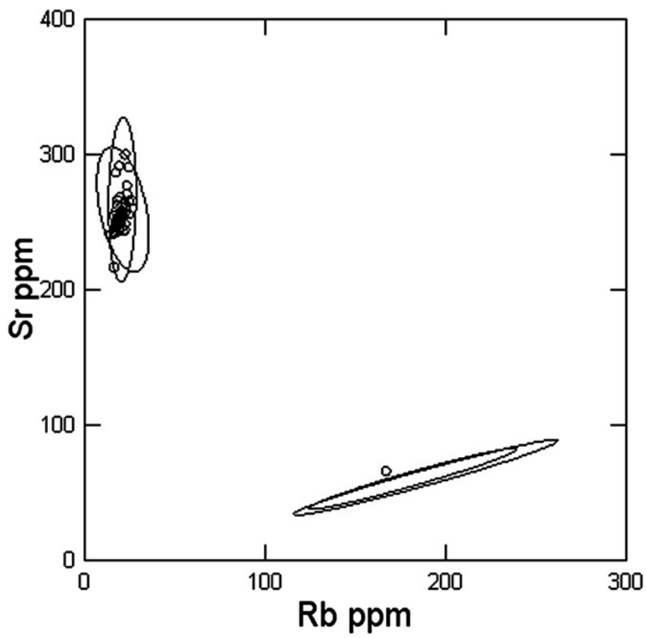

Fig. 4. Bivariate plot of strontium and rubidium for Tongan archaeological samples. The density ellipses are plotted from Fig. 3 for Tongan and Samoan source samples. The only Samoan related source is sample pa1.04.183 from the Vuna site, Pangaimotu Island, Vava'u. Also see Table 5.

They propose a later in-migration from beyond Polynesia, suggesting the Polynesian cultural template was accordingly altered. They challenge openly the Lapita to Plainware model for ancestral Polynesian society. We are in no position to offer insight on either interpretation for Samoan prehistory, nor can we assess related implications for volcanic glass patterns in West Polynesia. We can only say that all current linguistic reconstructions identify a common proto-Polynesian ancestor for Tonga and Samoa (Pawley, 1996; Marck, 1999). In this, the Tongan data support a hypothesized pattern for integration from the Lapita period onward within an ancestral Polynesian homeland; the inclusion of Samoa remains equivocal in the first several centuries of its development.

Finally, based on PIXE/PIGME analysis, Best (1984: 434) reports northern Tongan volcanic glass in Lapita deposits at the Qaranipuqa site, a rock shelter on Lakeba in the Lau islands of Fiji. Reepmeyer and Clark (2010: 5) reconfirm this identification employing LA-ICP-MS, further suggesting the presence of "two different obsidian outcrops". A Lapita context for Tongan volcanic glass in Lau is significant; it illustrates inter-island voyaging and interaction between the two archipelagoes in the earliest stage of West Polynesian prehistory. The almost identical ceramic record of Lau with Tonga over its first 1000 years of prehistory (Best, 1984; Burley, 2005) confirms this relationship, and presages the inclusion of Lau into an ancestral Polynesian homeland. Geraghty's (1983) incorporation of Tongan and Lauan languages within proto-Tokalau Fijian, a common ancestor to east Fijian and proto-Polynesian language groups, fully concurs.

6. Conclusion

The pXRF analysis of 51 volcanic flakes from the Kingdom of Tonga seems a very small basis upon which to infer inter-archipelago relations, population dynamics and historical reconstruction of an ancestral society to all Polynesian peoples. This analysis, however, has required re-examination and clarification of Samoan volcanic glass geochemistry as well as Tongan source data for Tafahi and Niuatoputapu. We illustrate, as a result, distinct geochemical signatures to infer transfer of volcanic glass throughout West Polynesia. Consequential source identification for all but one of the 51 archaeological specimens identifies a northern Tongan origin. This transfer occurs on an archipelago-wide basis, a linear distance in excess of 600 km. It anticipates regional integration of an ancestral Tongan if not Polynesian homeland from first Lapita settlement through the Polynesian Plainware phase. Northern Tongan volcanic glass in Lau, Fiji, alludes to an expansion of this region, an implication supported by other data. What is most surprising in the analysis is the total absence of Tongan volcanic glass in earlier Samoan archaeological sites, and Samoan volcanic glass in Tongan archaeological sites, save for a single late prehistoric context. We cannot rule out sampling error as an explanation. The volcanic glass distribution, nevertheless, strongly implies regional isolation of the two archipelagoes from at least 2500 years into later prehistory. We hope that future research into the earlier phases of Samoan prehistory provides insight and resolution.

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