

GEOCHEMICAL CHARACTERIZATION OF LAPITA POTTERY VIA INDUCTIVELY COUPLED PLASMA–MASS SPECTROMETRY (ICP–MS)

D. J. KENNETT,¹ A. J. ANDERSON,² M. J. CRUZ,¹ G. R. CLARK²
and G. R. SUMMERHAYES²

¹Department of Anthropology, University of Oregon, Eugene, OR 97403, USA

²Department of Archaeology and Natural History, Research School of Pacific and Asian Studies,
The Australian National University, Canberra ACT 0200, Australia

We have obtained high-resolution elemental data on Lapita ceramics (3200–2700 cal year BP) from Fiji, Tonga and New Ireland using chemistry-based inductively coupled plasma–mass spectrometry (ICP–MS). These data show clear elemental distinctions between Lapita pottery manufactured in Fiji, Tonga and New Ireland, and demonstrate significant elemental variation in Fijian ceramics collected from settlements in close proximity to one another. Therefore, we anticipate that ICP–MS will become an effective technique for tracking the transfer of Lapita pottery within and between different island groups in Oceania.

KEYWORDS: OCEANIA, NEW IRELAND, FIJI, TONGA, LAPITA, GEOCHEMICAL ANALYSIS, MICROWAVE DIGESTION, INDUCTIVELY COUPLED PLASMA–MASS SPECTROMETRY

INTRODUCTION

The Lapita cultural complex is best known for a distinctive dentate-stamped pottery style, found at more than 180 archaeological sites extending across 5000 km² of the Pacific (Anderson *et al.* 2001; Fig. 1). Radiocarbon dates on sites within this range indicate that Lapita ceramics were first manufactured in the Bismarck Archipelago between 3450 and 3200 cal years BP (Specht and Gosden 1997; Kirch 2000; Summerhayes 2001). Its spread in Near Oceania (New Guinea to Solomon Islands) during the next few centuries is considered by some archaeologists to signal the dispersal of Austronesian-speaking peoples into island Melanesia, possibly along the coastlines and offshore islands of South-East Asia (Kirch 1997, 2000; Spriggs 1997; Diamond and Bellwood 2003). The islands of Near Oceania served as a staging area for longer-distance voyaging and the ultimate colonization of Remote Oceania. Frequency distributions of radiocarbon dates from archaeological deposits bearing Lapita pottery in Near Oceania show a 300–500 year lag prior to the colonization of Remote Oceania between 3100 and 2700 cal years BP (Anderson 2001).

Archaeologists working in the Pacific have a deep interest in Lapita pottery as a marker for the dispersal of people into increasingly remote regions. The dentate stamping of Lapita pottery is broadly similar throughout the area, with subtle differences in design motifs forming regional and temporal variants. Yet the striking similarity of these ceramics across such a broad area has stimulated interest in determining whether they were manufactured at a limited number of production loci and distributed through exchange networks, or if the pottery was produced at a large number of locations and other mechanisms account for the transmission of

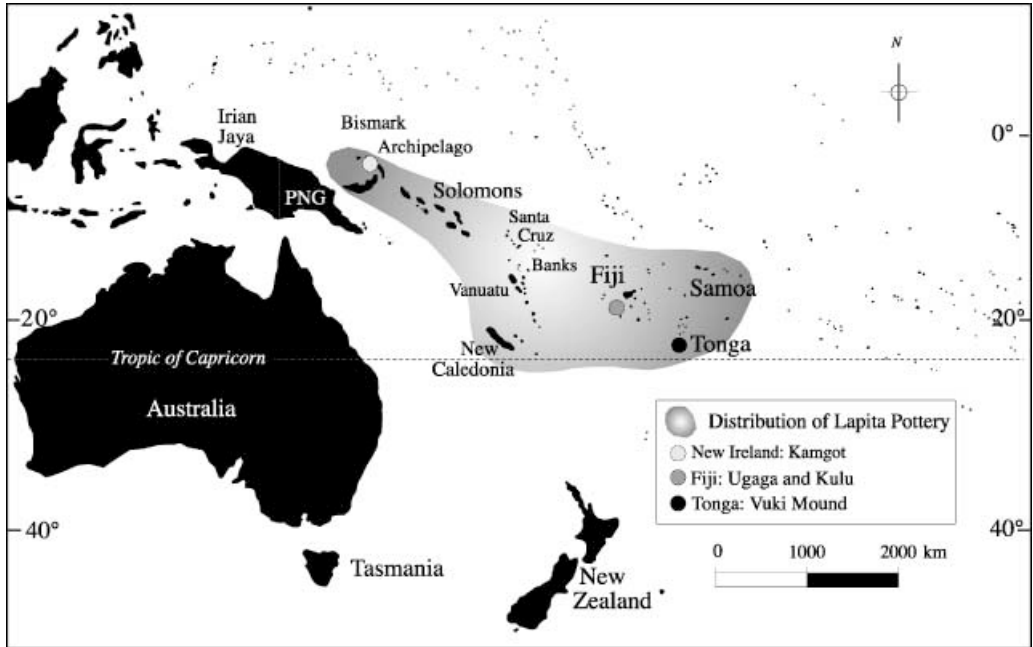


Figure 1 A map of the Pacific, showing the distribution of Lapita pottery and site locations studied.

Lapita design motifs (Green 1974; Dickinson and Shutler 1979, 2000; McCoy and Cleghorn 1988; Hunt 1989; Dickinson *et al.* 1996; Kirch 1997, 2000). Recent analysis of the distribution of Lapita design components suggests that there was continuing transmission after the initial colonization of Remote Oceania, and that the differences between Eastern and Western Lapita design are essentially chronological, Eastern designs being the late component of the Western corpus (Summerhayes 2000a).

Petrographic analysis is currently the most effective and widely used technique for determining the location of Lapita pottery manufacture in Oceania (Dickinson and Shutler 2000; Dickinson 2001). Given the temporally complex and spatially variable geological history of the Pacific islands, artefact provenance studies of this type can provide definitive physical evidence for the movement of pottery or raw materials via exchange or migration (Dickinson *et al.* 1996; Dickinson and Shutler 2000). For a variety of stylistic and technological reasons, potters in Oceania typically added locally available sand to the clay used for manufacturing pottery vessels (Dickinson and Shutler 2000). Sands are derived from local bedrock of a restricted island character and therefore the mineralogy of non-plastic inclusions is often diagnostic to specific island groups (Dickinson and Shutler 2000). Extensive petrographic work on sherd collections representative of the Lapita range demonstrates that most Lapita pottery was manufactured locally to the find-spot, and that long-distance exchange of ceramics was relatively limited (Dickinson and Shutler 2000; Summerhayes 2000a). However, short-distance transfer of ceramics has been documented and there are fabrics whose source remains unknown. In some instances, the source location is ambiguous due to geological similarities between island groups. More recently, stylistic and petrographic studies have shown the first

evidence for the possible transfer of pottery from Near to Remote Oceania (four sherds from the site of Nukuleka [Tongatapu, Tonga], which are similar in composition to material from Nēndo [Reef Santa Cruz Islands]; Burley and Dickinson 2001). This recent study highlights how provenance determinations of a small number of samples can provide insights into the direction of ceramic movement or the origin of founding populations in Remote Oceania.

The use of geochemical techniques for determining the provenance of Lapita pottery has been limited (Anson 1983; Hunt 1989; Kirch 1997; Summerhayes 2000a). This is probably because the costs of using many of these techniques are prohibitive, and that they provide little additional information beyond what can be determined via petrographic analysis. In this paper, we introduce a promising new geochemical technique to the study of Lapita pottery—inductively coupled plasma–mass spectrometry (ICP–MS). Compared to other geochemical techniques, ICP–MS is either faster, more sensitive or has superior detection limits on many elements (Tykot and Young 1996; Gratuze 1999; Kennett *et al.* 2001, 2002; Speakman and Neff 2002; Neff 2003). Although there are many methodological issues that need to be overcome when applying this technique to heterogeneous materials, the sensitivity of the technique may ultimately allow for the ascription of Lapita pottery to specific source settlements within Oceania. This may help to characterize the limited number of ambiguous or unknown source locations of Lapita ceramic manufacture as defined by petrographic analysis.

The immediate goal of this study was to determine whether individual islands and sites can be distinguished geochemically using chemistry-based ICP–MS. To this end, we selected Lapita pottery sherds ($N = 67$) from three different island groups in Oceania that span the full geographical range of the known Lapita distribution (New Ireland, Fiji and Tonga; Fig. 1). Fiji and Tonga are located in the Eastern Lapita region and New Ireland is positioned in the Bismarck Archipelago on the western fringe of the Lapita distribution. The Fijian ceramics come from Kulu Bay ($N = 19$), a Lapita-age settlement on the southwestern side of Bega Island (just south of the large island of Viti Levu), and Ugaga ($N = 24$), a contemporary site on a tiny island off the south-west coast of Bega (Anderson and Clark 1999; Clark 1999). Tongan Lapita sherds ($N = 7$) are from Tongatapu (Vuki Mound, Groube collection) and the ceramics from Anir, New Ireland ($N = 17$), come from Kamgot, a site that is located at the western end of Babase island (Summerhayes 2000b). All the ceramics analysed from these collections had distinctive Lapita design elements, such as dentate stamping, notched collar rims, and paddle or shell impressions.

METHODS

Inductively coupled plasma–mass spectrometry (ICP–MS) is an analytical technique that is becoming increasingly popular for determining the provenance of materials found in archaeological contexts (Tykot and Young 1996; Young *et al.* 1997; Hall *et al.* 1998; Mallory-Greenough *et al.* 1998, 1999; Pingitore *et al.* 1998; Tykot 1998; Bentley 2000; Kennett *et al.* 2001, 2002; Speakman and Neff 2002; Neff 2003). The potential advantages of ICP–MS compared to other techniques include: (1) the ability to analyse small samples, thus making it a less destructive technique (particularly when coupled with laser ablation); (2) more target analytes (~70); (3) lower detection limits (parts per billion) on more elements relative to other techniques; (4) the possibility of measuring the isotopic ratios of some elements; and (5) a lower cost per sample, particularly compared to INAA (see Tykot and Young 1996; Kennett *et al.* 2001, 2002). The application of this technique to archaeological materials is in its infancy, and a great deal of methodological development is needed to effectively contend with contamination

problems associated with measuring small samples and the difficulties in characterizing heterogeneous materials. Dissolution techniques must also be improved to effectively measure certain elements (Tsolakidou *et al.* 2002). However, used cautiously, ICP–MS can be employed to discriminate source-related compositional groups and ultimately help reconstruct prehistoric interaction and trade. The capabilities of ICP–MS are also expanding as sample preparation techniques improve and more sensitive magnetic sector instruments equipped with multicollectors become widely available (Kennett *et al.* 2001; Neff 2003).

In this study, multi-element compositional analyses of Lapita ceramics and laboratory standards were completed with a Hewlett-Packard 4500 quadrupole ICP–MS at California State University, Long Beach. Liquid samples were introduced into an argon plasma that was ignited through RF inductive coupling. The torch (~8000 C) atomizes and ionizes all elements with a conducive ionization potential and sends them towards the quadrupole, where ions of different masses are separated using two sets of oppositely charged rods. Alteration of the voltage allows only certain charged isotope species to pass through to the detector. Rapid scanning of the voltage facilitates the measurement of the entire mass range of elements (lithium to uranium) in an essentially simultaneous manner. We measured the abundance of 37 matrix and rare earth elements (Be, Mg, Al, K, Sc, V, Cr, Mn, Fe, Co, Ni, Cu, Zn, Ga, Rb, Sr, Y, In, Cs, Ba, La, Ce, Pr, Nd, Sm, Eu, Gd, Tb, Dy, Ho, Er, Yb, Lu, Pb, Bi, Th and U). Instrumental precision was 2–3% and detection limits for most elements were in the parts per billion (ppb) range.

Lapita ceramic samples ($N = 67$) were solubilized prior to analysis via ICP–MS using a scientific microwave digestion system (CEM, Mars 5; Kennett *et al.* 2002). The interior and exterior surfaces of all ceramics were abraded with a dremel tool (titanium bur) to remove exterior decoration or adhering soil. These samples were then ground in a synthetic agate mortar that was scoured out with sand between samples and rinsed with deionized water. Powdered ceramic samples (100 mg) were weighed into 50 ml Teflon reaction tubes and combined with a mixture of ultra-pure (optima grade) hydrofluoric acid (HF, 5 ml), nitric acid (HNO₃, 4 ml) and hydrochloric acid (HCl, 1 ml). Eleven samples and one standard (Brick Clay, SRM-679) were digested at 200 C (~180 psi) for 30 min. After the multi-acid digestion, an ultra-pure boric acid solution (25 ml, 4% boric acid) was added to each sample and evaporated down to 1 ml using CEM's patented MicroVap™ system. The boric acid solution was added to reduce the formation of calcium fluorides that are known to precipitate rare earth elements out of solution (Kingston and Haswell 1997; Kennett *et al.* 2002). An additional 25 ml of ultra-pure water was added to each sample and evaporated down to ~1–3 ml, decanted into 50 ml centrifuge tubes and rehydrated with a 2% ultra-pure nitric acid solution (50 ml final volume). A 10× dilution of 1 ml of the sample solution was analysed via ICP–MS (0.2 mg of original sample). Analysis of samples was preceded by a serial dilution of multi-element sample solution (Spex Certiprep, CLMS-1 and CLMS-2, eight dilutions from 0.5 to 1000 ppb) to quantify the measurement of target analytes. Lithium (6), rhodium (102) and platinum (195) were used as internal standards (1 ml of 2500 ng solution) to correct for instrumental drift during each ICP–MS run.

Compositional groups of Lapita ceramics were established using a series of bivariate and multivariate statistical techniques. Samples with similar elemental profiles were first aggregated into provisional groups using bivariate plots of individual elements and hierarchical cluster analysis (Ward's method). Independently, a principal components analysis (PCA) was conducted (correlation matrix) to reduce the dimensionality of the data and to account for the maximum amount of variation with the smallest number of components. A bivariate plot of components shows the samples with similar elemental compositions as clouds of points. In this way, the groups defined with bivariate plots and hierarchical cluster analysis can be

compared with the PCA results. Mahalanobis distances from the centroids of defined groups were used to determine group membership and are shown as 90% confidence ellipses on the bivariate plots of the first two principal components.

RESULTS

The bivariate plots indicate clear differences between Lapita ceramics from New Ireland, Fiji and Tonga. The elemental compositions of samples from New Ireland and Fiji are distinct, with overlap or partial overlap occurring only in 11 of 37 elements (Be, K, Co, Zn, Ga, Sr, Y, Er, Pb, Th and U). The Fijian material is also distinctive from the Tongan material on most elements, only overlapping in the composition of five elements (K, Er, Lu, Pb and Th) and partially overlapping in eight others (Be, Zn, Y, Eu, Gd, Tb, Dy and Yb). Interestingly, the elemental compositions of ceramics from New Ireland and Tonga overlap significantly and are only slightly distinguishable in six elements (Mn, Eu, Gd, Tb, Dy and Ho). Of these, Mn and Ho are the most distinctive and the three compositional groups, corresponding to each island, are most visible in the bivariate plots of these elements (Fig. 2). Lapita ceramics from the two Fijian sites are also distinguishable in bivariate plots (Fig. 3). As expected, significant overlap in composition exists, but the ceramics from Ugaga and Kulu have distinctive Ba, Be, Zn and Ga concentrations, and only partial overlap occurs in Co, Ni, Cu, In, Er, Yb, Lu and Bi.

Hierarchical cluster analysis verifies the groupings visible in the bivariate projections of the data. The four-cluster solution groups the ceramics by island and by site, with the pottery from the two Fijian locations (Ugaga and Kulu) forming two distinctive clusters. The five-cluster solution tells much the same story, but shows some additional structure in the data from the Fijian site of Kulu, where four sherds form a fifth cluster. The three-cluster solution separates the two Fijian sites, but combines the ceramics from New Ireland and Tonga, thus reflecting the similarities in the ceramics from these two islands visible in the bivariate data plots.

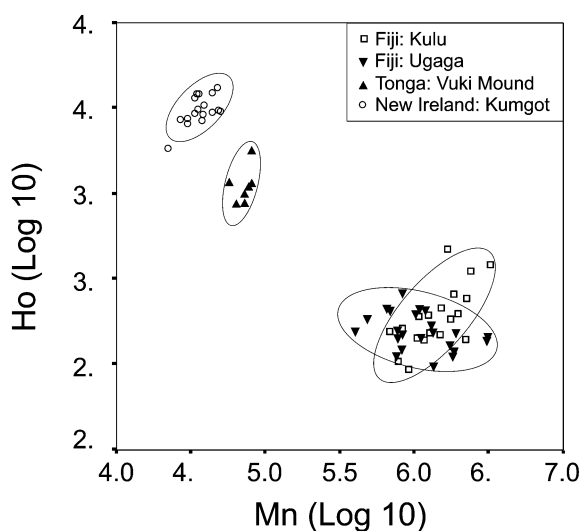


Figure 2 A bivariate projection of manganese (Mn) and holmium (Ho) log base 10 concentrations, showing the separation between Lapita pottery from New Ireland, Tonga and Fiji. The symbols differentiate the location of each sample and the ellipses represent 90% confidence of group membership.

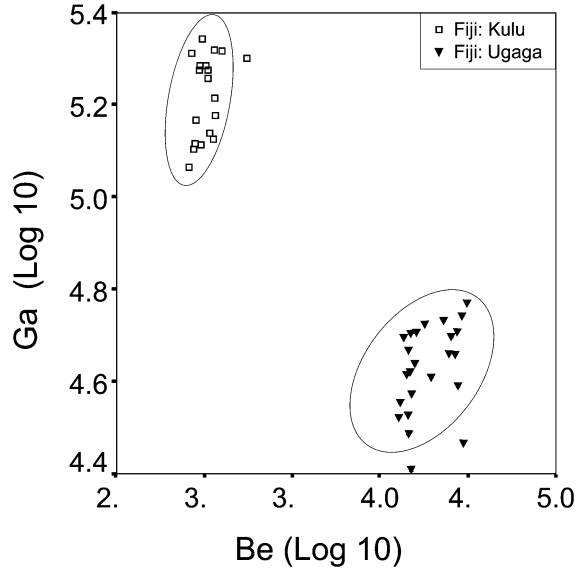


Figure 3 A bivariate plot of beryllium (Be) and gallium (Ga) log base 10 concentrations, showing the separation between Lapita pottery from the Fijian sites of Kulu and Ugaga. The symbols differentiate the location of each sample and the ellipses represent 90% confidence of group membership.

Table 1 The first four factors extracted during principal components analysis (correlation matrix)

Principal component	% variance	Cumulative % variance	Eigenvalue
1	71.736	71.736	26.542
2	11.157	82.893	4.128
3	6.035	88.929	2.233
4	2.76	91.688	1.021

Principal components analysis (PCA) indicates that the first three or four components account for the majority of the total variance in the data set (Table 1; 88.92% and 91.68%, respectively). This suggests that the proximity of each sample in three or four dimensions reflects the structure of the data in 37 dimensions. Based on the Kaiser criterion for defining the number of principal components (eigenvalues greater than 1), four components explain their proportional share of the data. However, the Kaiser criterion often overestimates the number of components, so a Scree test was also conducted. This more visual method for determining the number of principal components often underestimates the number of factors, and in this case suggests three components. Therefore, between three and four components exist in the data set, highlighting the similarity between the compositions of pottery from New Ireland and Tonga.

A scatterplot of the first two principal components shows clouds of points that correspond closely to the provisional compositional groups defined with bivariate projections of the data and hierarchical cluster analysis (Fig. 4). In this figure, symbols indicate group membership as

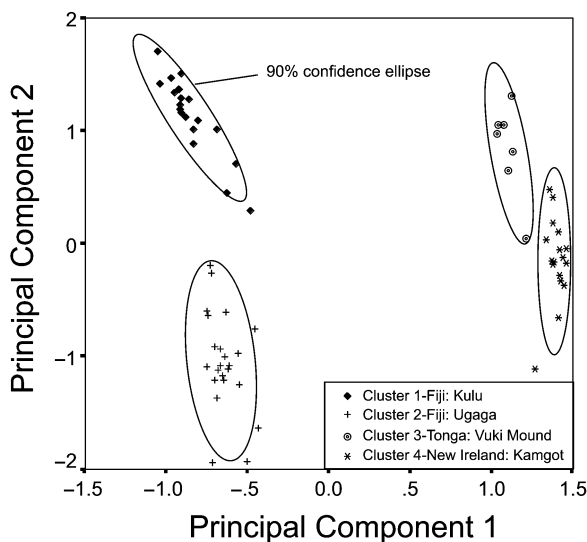


Figure 4 A plot of principal components 1 and 2 for all Lapita ceramics analysed ($N = 67$). The symbols differentiate the compositional groups determined with hierarchical cluster analysis and the ellipses represent 90% confidence of group membership.

defined by cluster analysis and bivariate normal density ellipses identify outlying samples at the 90% confidence level. These same samples also had high Mahalanobis distance scores and were not assigned group designations. These samples include LBS-221 (KB-118), LBS-484 (UGA-2594), LBS-486 (UGA-2671), LBS-704 (UGA-1352), LBS-709 (KULU-27) and LBS-718 (UGA-906), and were excluded from the summary statistics presented in Table 2 for each group.

Clear elemental distinctions between pottery samples collected from sites in New Ireland, Fiji and Tonga indicate that ICP-MS has great potential for documenting the transfer of Lapita ceramics in Oceania via colonization or exchange. The inter-element correlation between groups is visible in the loadings of the first two principal components (Fig. 5). High negative and positive loadings (–1, 1) for the majority of the elements in principal component 1 differentiate the Fijian material from that from the other two islands (Tonga and New Ireland). The high loadings on Be, Zn and Ga in principal component 2 separate the pottery from the two Fijian sites, and Co and Er contribute to the subtle differences between the pottery from New Ireland and Tonga. High negative and positive loadings on Mn and Ho in principal component 1 are primarily responsible for separating the compositional groups that correspond to each island group.

The data presented also strongly suggest that pottery produced at individual Lapita settlements can be distinguished with this technique. This is most visible in the data from Ugaga and Kulu, two Lapita settlements situated close to each other in Fiji. At these Fijian sites, along with Kamgot (New Ireland) and the Vuki Mound (Tonga), the elemental variation (%CV, Table 2) within groups is in the 20–30% range. Technologically advanced and homogeneous ceramic traditions may display elemental groupings in the 4–9% range (Harbottle 1976), but compositional groups more frequently have elemental variation in the 10–20% range (Neff *et al.* 1996). Intra-group variation can be caused by: (1) analytical and procedural error (for the errors associated with this technique, see Kennett *et al.* 2002); (2) different combinations of temper and clay (Neff *et al.* 1988, 1989); (3) varied paste preparation by individual potters

Table 2 Descriptive statistics of ICP-MS data for four groups of Lapita ceramics identified in this study

Element	Mass	Cluster 1 (New Ireland, N = 16)			Cluster 2 (Tonga, N = 7)			Cluster 3 (Fiji; Ugaga, N = 20)			Cluster 4 (Fiji; Kulu, N = 18)		
		Mean (ppm)	Std dev. (ppm)	%CV	Mean (ppm)	Std dev. (ppm)	%CV	Mean (ppm)	Std dev. (ppm)	%CV	Mean (ppm)	Std dev. (ppm)	%CV
Be	9	23.55	1.84	7.82	23.95	3.11	12.97	19.35	6.18	31.95	1.05	0.20	19.51
Mg	24	15 071.19	5 730.62	38.02	23 184.29	8 920.30	38.48	18 832.50	6 347.11	33.70	19 040.33	13 832.56	72.65
Al	27	63 968.13	6 397.27	10.00	58 344.29	14 229.09	24.39	162 555.00	20 439.86	12.57	156 238.89	19 628.29	12.56
K	39	3 434.81	1 424.58	41.47	5 544.71	4 386.69	79.11	11 037.55	5 349.43	48.47	13 854.56	4 162.92	30.05
Sc	45	38.25	7.09	18.54	73.35	9.05	12.34	51.25	10.43	20.36	89.05	19.47	21.86
V	51	565.25	315.38	55.80	314.16	81.35	25.90	507.08	153.12	30.20	626.23	162.13	25.89
Cr	52	106.27	107.94	101.57	202.30	53.10	26.25	142.05	54.43	38.32	356.69	590.76	165.62
Mn	55	1 191.48	492.84	41.36	1 133.51	231.17	20.39	1 339.94	743.06	55.46	1 538.05	689.63	44.84
Fe	57	115 668.13	54 943.26	47.50	92 244.29	9 316.60	10.10	125 518.00	29 824.46	23.76	142 333.33	40 487.94	28.45
Co	59	45.35	20.82	45.92	48.31	3.52	7.28	20.95	8.67	41.39	43.87	19.88	45.32
Ni	60	84.41	21.24	25.16	91.79	17.23	18.77	23.41	5.59	23.90	70.32	56.69	80.61
Cu	65	177.89	48.83	27.45	105.29	41.66	39.57	74.21	29.39	39.60	247.03	76.76	31.07
Zn	66	192.46	65.17	33.86	150.64	15.09	10.02	80.78	29.65	36.70	313.99	73.81	23.51
Ga	69	39.32	7.27	18.50	31.91	7.38	23.13	45.73	7.50	16.40	171.49	34.15	19.92
Rb	85	11.33	3.68	32.46	9.58	4.93	51.46	16.88	9.85	58.36	23.89	5.51	23.06
Sr	88	607.09	319.98	52.71	383.99	83.80	21.82	544.38	185.53	34.08	757.89	222.11	29.31
Y	89	21.03	6.87	32.66	11.60	4.01	34.60	13.98	4.21	30.09	8.98	3.69	41.11
In	115	0.35	0.06	16.19	0.38	0.07	17.48	0.36	0.07	19.56	0.12	0.05	39.55
Cs	133	1.54	0.50	32.27	0.61	0.14	22.61	0.73	0.18	24.56	2.11	0.76	36.01
Ba	137	189.99	49.45	26.03	203.44	39.69	19.51	369.28	86.16	23.33	1 109.66	261.94	23.61
La	139	22.87	4.40	19.25	2.91	1.06	36.57	7.46	4.03	54.06	10.03	3.87	38.55
Ce	140	48.67	5.81	11.93	6.83	2.33	34.13	17.50	7.90	45.16	23.07	6.61	28.63
Pr	141	8.22	1.60	19.49	1.43	0.50	35.18	2.32	1.08	46.61	3.16	0.81	25.63
Nd	146	36.53	6.88	18.84	7.25	2.47	34.09	9.52	4.09	42.99	12.81	3.01	23.47
Sm	147	10.23	1.59	15.53	3.56	0.97	27.29	3.00	0.90	30.14	3.14	0.73	23.26
Eu	153	3.46	0.47	13.49	1.30	0.38	29.19	0.90	0.27	30.16	1.24	0.23	18.39
Gd	157	10.78	1.43	13.22	4.67	1.30	27.95	2.80	0.73	26.15	3.25	0.85	26.16
Tb	159	1.57	0.23	14.81	0.84	0.24	28.85	0.43	0.10	23.17	0.59	0.19	32.76
Dy	163	8.73	1.66	18.99	5.23	1.58	30.22	2.17	0.53	24.47	2.84	1.00	35.27
Ho	165	1.75	0.41	23.69	1.16	0.35	30.36	0.47	0.11	22.41	0.61	0.25	40.72
Er	166	2.15	0.75	34.87	1.37	0.40	29.25	2.24	0.55	24.33	1.19	0.51	43.27
Yb	172	2.00	0.88	44.12	1.44	0.44	30.71	2.54	0.55	21.74	1.06	0.48	45.94
Lu	175	0.29	0.14	47.92	0.21	0.07	32.33	0.45	0.09	18.72	0.20	0.10	48.42
Pb	208	12.48	2.37	18.97	3.53	0.85	24.13	11.88	14.96	125.88	5.41	1.68	31.08
Bi	209	0.22	0.10	47.43	0.13	0.05	38.46	0.10	0.35	29.00	0.15	0.07	46.75
Th	232	2.52	0.51	20.15	0.31	0.10	31.94	1.82	0.81	44.33	1.53	0.65	42.63
U	238	3.45	0.77	22.46	2.42	1.58	65.11	0.85	0.36	42.59	0.77	0.53	69.39

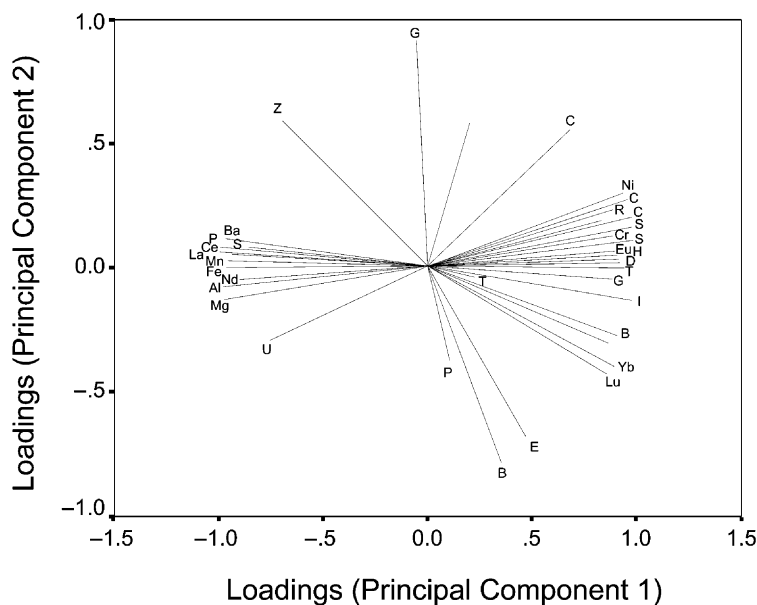


Figure 5 Biplots obtained from principal components analysis (PCA) of the correlation matrices for 67 Lapita ceramics analysed by ICP-MS. PCA loadings are defined with element labels. The angle between two vectors represents the size of the correlation between the two elements: a small angle indicates a high positive correlation; a near-180 angle indicates a high negative correlation; and a right angle indicates little or no correlation (Neff 1994).

(Arnold 1992); (4) differential firing conditions that result in the transformation of chemical composition (Kilikoglou *et al.* 1988); and (5) post-depositional alteration or contamination of the chemical composition of pottery (Garrigós 1999). The enrichment of barium is known to occur in certain depositional environments, as is the leaching or loss of calcium (Picon 1987; Neff *et al.* 2003). In fact, we cannot completely rule out the possibility that the groups formed in this study were not created by the differing depositional environments on each island. For instance, the barium values for samples from Kulu are enriched relative to those from all other sites and could be the product of diagenetic alteration (Table 2). Post-depositional alteration of barium is well known in other contexts (Picon 1987). However, other elemental differences exist between these groups and these are less likely to be related to diagenetic alteration. Regardless, the within-cluster variation in this study is high relative to INAA studies, but is reasonable given the simple technology used to produce Lapita earthenware and the variation introduced into the sample from a variety of potential sources.

Samples that fell outside the 90% confidence interval for each group were not assigned a designation (six samples excluded from Table 2) and are thought to be ceramics that were fabricated elsewhere or by different potters at the same location. For instance, the sample from the site of Kulu (LBS-709, Kulu-27) that fell outside the 90% confidence interval was the only specimen in this collection that had a collar rim with shell impressions. This could represent multiple potters within this settlement or a vessel obtained through exchange with a more distant village. Alternatively, the difference could have resulted from the same potter using a mixture of local clays and tempers to obtain a specific functional or stylistic effect. Additional compositional structure within the data from each site will become more apparent with larger sample sizes.

This, coupled with the characterization of ceramics from sites within island groups, will help to determine the source of intra-site variability in the geochemical composition of the pottery.

One of the surprising results of this study was the strong geochemical similarity between the ceramics collected from Kamgot (Anir, New Ireland) and the Vuki Mound site (Tonga). Although both Tonga and New Ireland are undissected island arcs composed of andesites and basalts (Dickinson and Shutler 2000), greater differences in geochemical make-up were expected, given the distance between these two island groups and the likelihood of regional differences in pottery manufacture. Burley and Dickinson (2001) recently discovered Lapita pottery from the settlement of Nukuleka (Tonga) that was possibly manufactured in the Reef Santa Cruz Islands. This presents the possibility that the material from the Vuki Mound has its origin somewhere in Near Oceania. On stylistic grounds, the Vuki Mound pottery looks relatively late in the Lapita sequence. It is unlike the Nukuleka material that displayed Western Lapita design motifs thought to date earlier in time. Based on our stylistic and temporal assessment, we suspect that the geochemical similarities between the pottery from Kamgot and the Vuki Mound are a coincidence and do not represent the importation of pottery from Near Oceania. However, in the absence of a comprehensive raw material survey and larger sample sizes, these two possibilities remain alternative hypotheses.

Similarities in the geochemical compositions of Lapita ceramics from Fiji were expected, given that Kulu and Ugaga are on islands (Bega and Ugaga, respectively) composed of volcanic and volcanoclastic rocks that formed during the Pliocene (5.5–2.5 million years ago; Band 1968; Dickinson 2001). However, the geochemical differences (based primarily on Be, Zn and Ga) are striking, particularly because these Lapita sites are only separated by a 3 km stretch of sheltered water. The site of Kulu is situated in a unique geological setting composed of an atypical feldspar-rich shoshonitic rock that forms an intrusive plug in the area (Dickinson 2001). Feldspar temper, presumably from this source, is present in the pottery from Kulu and Ugaga, suggesting that pots were manufactured at Kulu and occasionally transported to Ugaga (Clark 1999). So perhaps the geochemical differences between the pottery stem from the movement of temper, rather than finished pots, to Ugaga. Alternatively, the distinct pottery at Ugaga resulted from the transport of pottery from nearby Yanuca Island or the larger island of Viti Levu, where feldspar sands are also present. Further work to characterize the sources of sand and clay in this area will be required to resolve this question.

The results of this study indicate that chemistry-based ICP–MS provides additional physical data that can be used to complement stylistic and petrographic analyses of Lapita pottery. Although petrographic analysis indicate that most Lapita pottery was manufactured locally, the small percentage of ‘exotic’ material in the collections from each site can provide great insight into the inter- and intraregional connections between Lapita settlements. Realistically, much more work is required to sort out these subtle patterns of ceramic transfer resulting from migration or exchange. Compositional analyses of pottery from other sites in Tonga, Fiji and New Ireland will provide additional interpretative insights into the findings presented here, as will the coupling of petrographic analysis and geochemical characterization of pottery from other island groups. A regional database of this type will facilitate the study of new collections discovered in the Pacific during the years to come.

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