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Characterisation and sourcing of archaeological adzes and flakes from Fiji

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Introduction

This chapter focuses on the characterisation and sourcing of lithic artefacts (adzes and flakes) found in excavations conducted in 1996 and 1997 on Beqa Island, Mago Island and Viti Levu. Although the primary focus is on basalt because of accumulated knowledge, other rock types are represented due to the diversity of lithic materials found in Fiji in contrast to oceanic basalts in the island groups of Polynesia. Lithic material found in the Fijian Islands could be from the island on which it was found, from within the archipelago, or imported from another island group, especially from Samoa (Best 1984; Best et al. 1992; Weisler 1993a). Determination of the provenance of raw materials found during excavation of a site can be valuable in providing information on contacts between that location and others. Provenance is defined here as the material's place of origin, i.e. the geological source (see Weisler 1993c:62).

Most studies have focused on basalt, which was the most widely distributed commodity in prehistoric Polynesia to the east of Fiji, and therefore has the potential to contribute most to the understanding of prehistoric trade and social interaction. In addition to Samoa, basalt sourcing studies have been undertaken in several island groups of Polynesia, including the Cook Islands

(Walter 1990; Weisler 1994; Walter and Sheppard 1996; Sheppard et al. 1997), Pitcairn and Mangareva (Weisler 1993b, 1994, 1995, 1996a, 1996b) and Hawaii (Cleghorn et al. 1985; Weisler 1990a, 1990b, 1990c). Determining the source of an object depends on regional geological knowledge, i.e. the macroscopic, petrographic and geochemical attributes of source material. Basalt sources in much of Polynesia have been extensively studied and chemically analysed. This is not the case for Fiji. Fijian lithic sources have not been geochemically characterised except for some analyses conducted by Best (1984). Fiji is more petrologically diverse given its location to the west of the Andesite Line, which separates Samoa and the rest of Polynesia (alkali and tholeiitic oceanic basalts) from the andesite-plutonic rocks of Tonga and Fiji (Dickinson and Shutler 1979; Sinton et al. 1985). The results of a second project investigating the chemical composition of siliceous artefacts are presented in the Appendix.

Geochemical characterisation of adze rocks

Weisler (1993c) has given a summary of references which deal with different types of analysis for basalt sourcing in Polynesia. These include macroscopic descriptions of adzes and polished flakes (R. Green 1974:141; Kirch 1988:192), thin-section analysis (Buist 1969; Emory 1975; Kirch 1975; Best 1984; T. Green 1984; Cleghorn et al. 1985; White 1987; Weisler 1990b; Withrow 1990, 1991), and geochemical analysis of adze material (Best 1984; Walter 1990; Best et al. 1992; Weisler 1989, 1990b, 1993a). Additional references for geochemical analysis include: Walter and Sheppard 1996; Weisler and Kirch 1996; Weisler and Woodhead 1995; Weisler et al. 1994; and several articles in a monograph edited by Weisler (1997a).

Macroscopic observations can at times be useful, but given similar colour, mineralogy and weathering effects of lithic materials, conclusions based on these observations should be approached with caution. Thin-section descriptions have some of the limitations above, but can provide useful data to discriminate sources in certain circumstances (Best 1984; Cleghorn et al. 1985; White 1987). Either of the above techniques should be combined with geochemical techniques to be most effective in discriminating provenance. Weisler (1993c:68) gives the following reasons for the power of geochemical analysis as an analytical tool: (1) its results are reproducible; (2) instrument specifications and operating conditions can be reported in full; (3) identification of chemical components is not subject to human error; (4) elemental abundances can be determined with accuracy and precision parameters noted; (5) use of standards facilitates inter-laboratory comparisons of databases; and (6) the analytical sample taken to analyse bulk chemical constituents more closely represents the whole specimen, in contrast to a two-dimensional thin-section.

Major and minor element compositions of basalts in the Pacific have been found by researchers doing sourcing studies to be similar over wide areas (Weisler and Woodhead 1995; Sinton and Sinoto 1997), making assignment to a specific source difficult. Assignments to sources from petrographic examination can also be problematic because of similarities in mineralogy (Weisler and Kirch 1996). Also, quarried stone weathers over time and at different rates depending on ambient conditions (Best et al. 1992). Weathering not only affects the petrography but also the chemical make-up (the elemental signature) of the stone. However, the combination of elemental analysis and petrological analysis is more likely to identify identical source material.

Ideally, for sourcing of individual artefacts using geochemical data, it is necessary for all potential sources to have been described and analysed (Wilson 1978; Rapp 1985; Weisler and Sinton 1997:177). This ideal probably is never realised and certainly in the case of basalt in the Pacific, many prehistoric quarries have not been characterised (Weisler and Sinton 1997).

However, several sourcing studies have been successful and have demonstrated intra-archipelago as well as inter-archipelago transfer of basalt. Island quarries which have been most studied are those of Hawaii and Samoa.

In this research, 10 major and minor elements were analysed using energy dispersive X-Ray analysis (EDXA). The advantages of this method over, for example, X-Ray Fluorescence (XRF) are the ease of sample preparation and presentation to the instrument and a much smaller sample size. However, EDXA is not as accurate as XRF. Analytical accuracy is about 6% for a 10 wt% concentration of an element, and improves at higher concentrations. The limit of detection is about 0.1 wt% (Williams 1987; Goodhew and Humphreys 1988). Sheppard et al. (1997:Table 6.2) present accuracy and precision information for XRF data. It is possible using XRF to analyse whole specimens, but with less accuracy than prepared samples (Weisler 1993a).

Nineteen trace elements were analysed using inductively coupled plasma-mass spectrometry (ICP-MS). ICP-MS has detection limits of parts per billion for most of the elements in the periodic table and requires only small sample sizes of ca. 100 mg (Jarvis et al. 1992). This is a much smaller detection limit and sample size than required for XRF. Historically, most analytical work for sourcing in the Pacific has been done using XRF with its limitations, but ICP-MS will probably become more popular in the future. XRF performs best analysing certain elements and this characteristic has often defined the element suite used to characterise lithic sources.

Weisler and Sinton (1997:179) indicate the elements least affected by the combination of real, local source variability and analytical uncertainty are Si, Ti, Al, Fe, Mg, Ca, K, V, Sr, Y, Zr and Ba. Best (1984) and Best et al. (1992) indicate the best discriminators of the major/minor elements are SiO_2 , TiO_2 and P_2O_5 and they plotted these values to show relationships between sources. For Weisler and Sinton (1997), the most efficient discriminators are SiO_2 , TiO_2 and K_2O .

Best's (1984) analyses of adzes and rocks from southern Lau were chosen for comparison with Fiji lithics. These samples were chosen because they would be most likely to furnish information on the possible origins of the adzes and flakes analysed in the present project. Best divided the rock types into five main groups: basalts, andesites, tuffs, all other igneous rocks, and sedimentary rocks. He further divided the basalts into six subgroups:

1. Those with a distinctive glassy texture;
2. Those containing celadonite/biotite;
3. Those containing olivine;
4. Limburgite – oceanic basalt;
5. Leucite – feldspathoidal basalt; and
6. All others.

Best found that the preference for, or presence of, various rock types changed considerably through time. Eight of the Lauan adzes and a Taveuni specimen grouped with two Samoan sources. For Best (1984:406), the most interesting aspect of the island's adze material was that so much of it came from so far away.

In addition to Best's samples, a database of basalt analyses from several researchers was compiled. Sample analyses were chosen from this database for comparison with the chemical analyses of excavated flakes and adzes. Sinton and Sinoto (1997) have constructed a database of basalt analyses from Polynesia containing chemical analyses of 280 individual samples from 36 quarries.

Cluster analysis was used to find out which analyses in a data set were similar. Cluster analysis is a method for describing the similarities among objects in a sample (Romesburg 1984). Cluster analysis results in a diagram called a dendrogram that shows the hierarchy of similarities among all pairs of objects. Other methods of analysing the data were tried, such as plotting ratios of elements or oxides (see, for example, Best et al. 1992) and principal components analysis. Results were similar to results from other methods of data analysis, but dendrograms are more clearly visualised, especially when there are many data points. The cophenetic correlation coefficient is an index that tells us how much the clustering method distorts the information in its input in order to produce its output or the dendrogram. Values for the cophenetic correlation of around 0.8 indicate the distortion is not great. Cophenetic correlations were calculated in this study and varied from 0.85 to 0.92.

Some samples from the Fiji excavations were closely linked with Best's (1984) samples. In addition, some of the 25 samples were closely linked with each other through both major oxide and minor element clustering, as well as being similar petrologically. No samples were similar to those from Samoa, but this could be expected given the morphology of the analysed artefacts.

Adze samples: Materials and methods

Various lithic flakes and adze fragments were provided from excavations conducted in 1996 and 1997 in Fiji, on Beqa Island, Viti Levu and Mago Island. Most of the samples were basalt, but other rock types were represented. Although the sample size was limited, 25 artefacts which were obviously flakes and adze fragments were sampled.

After visually inspecting, weighing and measuring the artefacts, small pieces were cut from each piece using a diamond saw. Samples for energy dispersive X-Ray analysis (EDXA) weighed approximately 50 mg and those for inductively coupled plasma spectroscopy-mass spectrometry (ICP-MS) ranged from 250 mg to 400 mg.

The samples for ICP-MS were polished on 240 grit wet emery paper to remove possible contamination from the diamond saw blade. The samples were then washed and put into an ultrasonic bath to remove any adhering particles. Samples were weighed and put into separate micro-centrifuge tubes for posting to the Advanced Analytical Centre at James Cook University for trace-element analysis. Samples were whole pieces and were not pulverised in order to avoid contamination from any grinding apparatus.

The pieces for EDXA were washed and dried. They were then mounted in a jig holding 26 samples, especially made for the mount available for the electron microscope. The samples were epoxied into holes in the jig. This allowed them to be polished flat for analysis. Polishing was done using 240, 400 and 600 grit wet emery cloth, followed by polishing compound (cerium oxide) on glass. The mounted samples were washed in detergent in an ultrasonic bath. The polished samples were viewed with a microscope at 20x magnification.

Samples were dried at 120°C for 17 hours and were weighed before and after heating to give a loss on drying (LOD) expressed as a percentage. Dried samples were then fired in a muffle furnace at 500°C for four hours. The percentage mass loss on ignition (LOI) was determined.

Energy dispersive X-Ray analysis

The SEM-EDXA instrument is located in the Electron Microscopy Laboratory at the Research School of Biological Sciences, ANU. The instrument used was a JEOL JSM-6400 scanning electron microscope (SEM), fitted with an Oxford 138 eV SATW 10 mm² detector. The analysis system was an Oxford ISIS using SEMQUANT. Samples were coated with carbon before analysis. Analyses were done using 15 keV at 1 nA for 200 seconds live time. Most analyses

were done at 150–180x magnification, although this ranged from 150x to 400x depending on the homogeneity of the sample. Lower magnifications were used on non-homogeneous samples to ‘average’ the surface. Results were in element percent and the oxides were calculated stoichiometrically.

Inductively coupled plasma spectroscopy with mass spectrometry

The sample preparation at James Cook University was done using a method from Jarvis et al. (1992:Chapter 7). The solid samples along with a reference standard (Hawaiian basalt: BHVO-1) were prepared by digesting with a mixture (4:1) of concentrated hydrofluoric acid and concentrated nitric acid, and finally taken up in 2% nitric acid. The ICPMS (Model ‘Ultramass’) was manufactured by Varian Australia. The instrument parameters are given in Table 77. Phosphorus was analysed separately using ICP-atomic emission spectroscopy (ICP-AES).

Table 77. Varian ICP-MS instrument settings for trace-element analysis.

Instrument Parameters		Segmented Scan Mode	
Plasma Flow	15.0 L/min		
Auxiliary Flow	1.50 L/min		
Nebuliser Flow	1.07 L/min		
Sampling Depth	5.0 mm		
Forward Power	1.2 kW		
Sample Pump Rate	25 rpm		
Extraction Lens	-600 V	Reading Space	0.025 AMU
First Lens	-360 V	Points per Peak	3
Second Lens	-13.60 V	Scans Replicate	5
Third Lens	0.60 V	No. of Replicates	5
Fourth Lens	-10 V	Dwell Time	1000 mS
Photon Stop	-15.60 V	Sample Delay	40
Entrance Plate	0 V	Stabilisation Time	15
Exit Plate	0 V	Rinse Time	70

Cluster analysis

The agglomerative hierarchical clustering algorithms available in the statistical system NCSS 6.0.1 were used to build a cluster hierarchy displayed as a tree diagram or dendrogram. The group average (unweighted pair-group) method was used.

Comparison samples

A database of basalt chemical analyses was constructed which incorporated results from several researchers. Analyses were either typed or scanned from journal articles and especially from a monograph edited by Weisler (1997a) which contains values from most basalt sourcing studies. Samples were selected from the database for cluster analysis to provide a comparison with the excavated flakes and adzes.

Adze samples: Results and discussion

Description of samples

The samples analysed in this project and site details are given in Table 78 (see also Table 79). The adzes and flakes listed turned out to be not all basalts. This would be expected for lithics in

Table 78. Description of analysed archaeological samples from Fiji.

Lab No.	Sample Context	Sample Description	Dimensions Length x Width (cm)	Mass (g)	LOD %	LOI %
F1	Beqa Is, Kulu Bay, C10, 90–100 cm	Dark grey, fine-grained adze	5.5 x 2.8	36.72	0.06	0.17
F2	Beqa Is, Kulu Bay, C10, 90–100 cm	Black, fine-grained adze flake	2.4 x 1.5	1.44	0.00	0.10
F3	Beqa Is, Kulu Bay, C10, 90–100 cm	Dark grey, fine-grained adze flake	2.9 x 1.8	2.19	0.59	0.30
F4	Beqa Is, Kulu Bay, C11, 10–20 cm	Grey, fine-grained adze flake	2.3 x 1.0	0.81	0.58	0.88
F5	Beqa Is, Kulu Bay, C10, 30–50 cm	Grey, fine-grained adze flake	5.6 x 4.5	32.37	0.42	0.60
F6	Beqa Is, Kulu Bay, C10, 30–50 cm	Greenish, fine-grained adze flake	4.3 x 4.2	13.99	0.06	0.22
F7	Beqa Is, Kulu Bay, C10, 30–50 cm	Greenish, fine-grained adze flake	2.2 x 1.9	1.70	0.08	0.31
F8	Beqa Is, Ugaga Is, L9: 40 cm	Grey, very fine-grained adze	6.5 x 2.3	31.29	0.38	0.51
F9	Beqa Is, Ugaga Is, D8: 30–40 cm	Grey, fine-grained adze flake	2.7 x 1.3	1.69	0.28	0.09
F10	Natunuku, Trench 3, Level 1: 20–30 cm	Dark grey, fine-grained, adze flake	8.5 x 7.4	232.34	0.04	0.00
F11	Mago Is, Votua TP1: 20–30 cm	Thin, fine-grained, dark grey adze flake	2.8 x 1.2	0.83	0.04	0.24
F12	Natunuku, Trench 3, Level 1: 10–20 cm	Dark grey and brown, fine-grained adze tip. Appears similar to F10	5.0 x 6.1	90.91	0.54	0.28
F13	Natunuku, TP 2-4, Level 1: 10–20 cm	Greenish, fine-grained adze flake	6.4 x 3.8	27.50	0.17	0.27
F14	Natunuku, TP 2, Level 1: 10–20 cm	Grey, fine-grained adze flake	3.4 x 2.1	6.90	0.09	0.24
F15	Natunuku, TP 2, Level 1: 10–20 cm	Grey, fine-grained adze flake	3.3 x 1.7	3.29	0.17	0.21
F16	Natunuku, Trench 3, B5, Layer 2	Greenish-grey, fine-grained adze (?) flake	6.7 x 3.4	49.32	0.14	0.29
F17	Beqa Is, Kulu Bay, C10: 50–70 cm	Black, fine-grained adze flake	4.5 x 2.0	4.89	0.11	0.14
F18	Beqa Is, Kulu Bay, C11: 20–30 cm	Grey, very fine-grained adze flake	3.7 x 1.2	2.11	0.49	0.61
F19	Beqa Is, Kulu Bay, C11: 30–40 cm	Grey, fine-grained core with flake scars	2.0 x 1.9	4.81	0.13	0.10
F20	Beqa Is, Kulu Bay, C11: 30–40 cm	Grey, fine-grained adze flake	2.5 x 1.7	3.45	0.04	0.00
F21	Beqa Is, Kulu Bay, C11: 90–100 cm	Grey, fine-grained adze flake	2.3 x 1.6	1.85	0.08	0.08
F22	Beqa Is, Kulu Bay, C11: 110–120 cm	Grey, fine-grained thin adze flake	2.6 x 1.7	1.46	0.68	0.59
F23	Beqa Is, Kulu Bay, C11: 110–120 cm	Grey, very fine-grained thin adze flake	2.0 x 0.7	0.30	nd	nd
F24	Beqa Is, Ugaga Is, N10: 40 cm	Grey, fine-grained adze flake	5.2 x 2.8	75.74	0.07	0.11
F25	Beqa Is, Kulu Bay, C11: 30–40 cm	Grey, ?adze flake with black and white crystals	2.8 x 1.3	3.07	0.74	0.39

LOD = loss on drying at 120°C; LOI = loss on ignition at 500°C; nd = not determined

Fiji (Best 1984), where several rock types are represented. The samples which visually appeared to be basalt are numbers: F5–F8, F15, and F17–F22. The green and black crystals would likely be olivine and biotite (or iron oxide), respectively. Brown crystals could be weathered biotite or celadonite (Best 1984). Other rock types could not be identified because this is an area for a specialist and no thin-sections were made. Samples which by eye appeared similar and could be from the same sources are groups: F5, F6, F7; F13, F16; F17, F20; F24, F25; and possibly F9, F11.

Some samples appeared quite weathered, especially samples F10, F12, F15, F20 and F25. The greenish appearance of some flakes (Table 78) might be due to weathering. The descriptions presented in Table 79 are more reliable because the samples had a fresh polished surface. Texture and crystals could easily be seen and compared.

The loss on ignition (LOI) values are all less than one (Table 78). Best et al. (1992:53) indicate that if a sample is badly weathered and has an LOI>1%, it plots away from the main group. They therefore omitted such samples from plots of chemical analyses.

Database samples

The publications which provided major/minor element oxide data are given in Table 80. The number of samples incorporated into the database is also given. Most authors have included all of the relevant oxides and this is a consideration in the selection of samples for comparison. The number of samples actually available for comparison is much less than the total number indicated. This is because of the repetition involved when researchers incorporate sample values presented in the literature for their own sourcing comparisons.

Table 79. Description of lithic samples as viewed in mounting plate at 20x magnification.

Lab. No.	Description	Homogeneous?
F1	Black, fine grained	Yes
F2	Black, very fine grained	Yes
F3	Dark grey, some white phenocrysts	Fairly
F4	Brown, fine grained	Yes
F5	Grey, some white and brown inclusions	Yes
F6	Light grey, small black inclusions	Yes
F7	Light grey, light green (olivine?) and black crystals	Fairly
F8	Grey, fine grained	Yes
F9	Dark grey, small black and brown crystals	Fairly
F10	Grey to black, large white and black phenocrysts	No
F11	Black, very fine grained	Yes
F12	Grey, large white crystals	No
F13	Grey, very small black crystals	Yes
F14	Dark grey, small black crystals	Yes
F15	Black, large white crystals	No
F16	Brown, fine grained, appearance of silt stone	Yes
F17	Brown to black, coarse grained, white and brown crystals	Fairly
F18	Grey, fine grained, some small black crystals	Yes
F19	Black, very fine grained	Yes
F20	Black, coarse grained, white crystals, similar to F15	No
F21	Dark grey, fine grained with few very small white crystals	Fairly
F22	Dark grey, fine grained, very small black flecks	Yes
F23	Grey, very fine grained	Yes
F24	Black, very fine grained	Yes
F25	Very weathered, large crystals, similar to F12	No

Table 80. Publications containing lithic source and artefact major/minor element oxide data.

Oxide	This report	Best 1984	Best et al. 1992	Anderson et al. 1997	Weisler 1993a	Ayres et al. 1997	Clark et al. 1997	Sheppard et al. 1997	Allen and Johnson 1997	Rolett et al. 1997	Weisler and Sinton 1997	Sinton and Sinoto 1997
N	25	44	163	10	3	7	37	97	20	20	9	33
SiO ₂												
TiO ₂												
Al ₂ O ₃												
Fe ₂ O ₃												
MnO												
MgO												
CaO												
Na ₂ O												
K ₂ O												
P ₂ O ₅												

N = number of samples. Grey = oxide included in study.

A large number of samples with trace-element analyses was available for incorporation into a database (Table 81). However, there was a problem of incompatibility between analyses performed in different and, at times the same, laboratories. Even though a large suite of elements was analysed in some studies (e.g. the present project; Best et al. 1992; Allen and Johnson 1997), results on several elements could not be used because only those elements common to all samples being considered could be used. For example, the element suite in this study contains 19 elements, but only 11 of these could be used for the clustering analysis.

Major/minor element oxides

The EDXA results are given in Table 82. The results for F1, F2, F3, F5, F14 and F16 are averages of duplicate analyses. The EDXA spectrum for sample F19 is presented in Figure 161. The phosphorus peak in this spectrum is not discernible by eye. Although P₂O₅ was analysed by EDXA, results from ICP-AES are included in this table because they are more accurate. EDXA values below ca. 1% are not reliable. The P₂O₅ values have been corrected to BHVO-1 standard values. Total iron is presented as Fe₂O₃ although it would be better presented as ferrous iron (FeO) because most of the iron in basalts is in this form (Wright 1971). However, most people doing sourcing research in the Pacific present Fe as Fe₂O₃. SiO₂ values are generally higher and TiO₂ values lower than those for oceanic island basalts (see Weisler and Sinton 1997:Table 10.5). There is a wide range of oxide concentrations and this may represent the diversity of rock types available locally. The sum of analyses varies from 94.78% to 104.70%, with an average of 98.85%. There appear to be no systematic errors in the values except for F19, which has an unusually high TiO₂ value of 7.08% and an MnO value of 1.62%. It appears that the EDXA beam sampled a Ti-rich mineral inclusion. The analysis of solid polished samples gives the most reliable results for EDXA, although non-homogeneous solid samples can present problems because of the small area analysed.

Some samples were powdered and analysed as a comparison to solid samples (Table 83).

Table 81. Publications containing lithic source and artefact trace element data.

Element	This report	Best et al. 1992	Anderson et al. 1997	Weisler 1993a	Ayres et al. 1997	Clark et al. 1997	Sheppard et al. 1997	Allen and Johnson 1997	Weisler and Sinton 1997	Sinton and Sinoto 1997
Number	25	36	10	3	7	31	77	17	8	32
Sc										
V										
Cr										
Ni										
Cu										
Zn										
Rb										
Sr										
Y										
Zr										
Nb										
La										
Ce										
Nd										
Sm										
Eu										
Dy										
Er										
Yb										
Pb										
Th										
U										
Ba										
Ga										
Fr										
Co										
As										
Tb										
Ra										
Lu										
Ta										
Hf										

Grey areas = measured elements.

Table 82. EDXA percentage concentrations for adzes and flakes from Fiji. Note P_2O_5 values determined by ICP-AES.

Location	Lab. No.	SiO ₂	TiO ₂	Al ₂ O ₃	Fe ₂ O ₃	MnO	MgO	CaO	Na ₂ O	K ₂ O	P ₂ O ₅
Kulu Bay	F1	55.07	1.07	17.01	9.38	0.12	3.36	4.61	6.81	1.15	0.077
Kulu Bay	F2	71.37	0.40	15.09	2.90	0.07	0.19	1.69	4.83	4.32	0.087
Kulu Bay	F3	52.47	1.78	15.88	9.69	0.15	4.13	7.35	2.86	0.73	0.111
Kulu Bay	F4	62.98	1.19	12.12	9.87	0.06	2.43	1.30	4.05	1.03	0.185
Kulu Bay	F5	71.69	0.97	13.38	3.05	0.27	0.54	1.22	5.77	2.08	0.143
Kulu Bay	F6	59.15	1.83	12.32	8.15	0.20	1.93	9.42	1.58	0.66	0.121
Kulu Bay	F7	60.87	1.19	15.05	7.44	0.23	2.10	7.61	2.58	0.79	0.154
Ugaga Is	F8	57.32	0.83	14.75	8.34	0.21	2.83	6.36	4.34	0.19	0.090
Ugaga Is	F9	56.60	0.98	15.31	10.24	0.32	4.06	9.39	3.35	0.37	0.197
Natunku	F10	52.78	0.71	17.20	7.98	0.32	8.20	10.48	2.78	0.16	0.154
Votua	F11	65.14	0.67	16.80	4.80	0.13	0.77	4.40	4.95	2.37	0.351
Natunuku	F12	53.93	0.57	19.77	5.82	0.08	4.98	9.12	2.63	1.79	0.372
Natunuku	F13	61.35	1.20	13.69	8.05	0.20	2.86	7.08	2.00	0.69	0.130
Natunuku	F14	55.33	1.50	15.04	9.86	0.19	2.54	8.03	4.37	0.10	0.123
Natunuku	F15	53.76	1.04	15.58	10.14	0.23	4.71	12.29	2.37	0.38	0.134
Natunuku	F16	57.07	0.86	14.77	10.09	0.11	3.08	4.79	2.90	0.98	0.133
Kulu Bay	F17	55.26	1.48	15.78	15.26	0.15	5.17	4.38	6.86	0.24	0.122
Kulu Bay	F18	54.78	0.90	16.56	8.47	0.19	3.28	10.04	5.36	0.52	0.089
Kulu Bay	F19	52.41	7.08	13.44	13.89	1.62	3.95	5.97	3.33	0.96	0.086
Kulu Bay	F20	59.80	0.86	17.08	6.19	0.18	4.07	6.58	6.98	0.03	0.098
Kulu Bay	F21	56.73	0.89	13.83	9.83	0.16	4.73	7.86	4.87	0.40	0.102
Kulu Bay	F22	52.17	0.85	17.99	8.56	0.16	3.19	10.43	4.31	0.37	0.063
Kulu Bay	F23	65.58	0.91	14.05	6.95	0.14	2.51	7.60	2.80	0.46	0.128
Ugaga Is	F24	47.22	0.77	18.08	9.20	0.22	8.57	12.72	1.63	0.32	0.114
Kulu Bay	F25	55.02	0.51	19.56	5.15	0.09	2.32	5.98	4.25	2.70	0.320

Note that these analyses are normalised to 100%; powdered samples have analyses adding up to less than 100% and this can be much less than 100% in the case of porous samples with an uneven surface and charging effects. There is fairly good agreement between results for the two methods of preparation. Both homogeneous (F16 and F24) and non-homogeneous (F10 and F20) samples were picked for comparison (see Table 79). The analytical results for solids and powders have similar differences for homogeneous and non-homogeneous samples. This is most likely due to the care taken during analysis to avoid non-homogeneous areas of polished solids. The results indicate that samples for EDXA can be either solid or powdered. Powdered samples are generally easier to prepare and there would be an advantage to obtaining samples by drilling artefacts where minimum damage is usually desirable. Sample sizes for EDXA would require a depth of only ca. 2 mm for a 2 mm diameter drill. Note that there can be problems with contamination from drills, corers and grinding equipment. This is generally not a problem for major/minor element determinations but must be considered for trace elements.

The dendrogram of analysed Fijian lithics (Figure 162) shows close similarities between

Figure 161. EDXA spectrum of sample F19.

Table 83. Comparison of EDXA results for powdered and solid samples. Results are normalised to 100%.

	Natunuku		Natunuku		Kulu Bay		Ugaga	
	F10-S	F10-P	F16-S	F16-P	F20-S	F20-P	F24-S	F24-P
Oxide	Solid	Powder	Solid	Powder	Solid	Powder	Solid	Powder
SiO ₂	52.40	49.82	60.24	57.36	58.72	57.56	47.81	48.88
TiO ₂	0.70	0.56	0.91	0.81	0.84	0.68	0.78	0.90
Al ₂ O ₃	17.08	17.66	15.59	15.18	16.77	14.20	18.30	17.11
Fe ₂ O ₃	7.92	10.16	10.65	11.32	6.08	7.14	9.32	10.03
MnO	0.32	0.16	0.12	0.30	0.18	0.19	0.22	0.18
MgO	8.14	8.42	3.25	3.87	4.00	7.04	8.68	8.07
CaO	10.40	10.35	5.06	7.41	6.46	7.63	12.88	12.04
Na ₂ O	2.76	2.59	3.06	2.70	6.85	5.45	1.65	2.43
K ₂ O	0.16	0.18	1.03	0.89	0.03	0.05	0.32	0.32
P ₂ O ₅	0.12	0.09	0.09	0.17	0.07	0.05	0.04	0.06

Figure 162. Hierarchical clustering report for oxide analysis of excavated flakes and adzes.

Figure 163. Hierarchical clustering report for samples from Best (1984:A74-A75).

sample numbers: F1, F20; F2, F5; F3, F16; F6, F7, F13, F23; F8, F14, F21; F9, F15; F10, F24; F12, F25; and F18, F22. Results of visual examination of the artefacts (Tables 78 and 79) combined with cluster analysis indicate only groups F6, F7, F13; F12, F25; and F18, F22 are probably from three different sources. Samples F6 and F7 are from the same bag labelled Beqa Is, Kulu Bay, and F13 is from Natunuku VL 1/1. Sample F12 is also from Natunuku, from a depth of 10–20 cm and closely resembles F25 from Beqa Is, Kulu Bay, Sq. 11 at a depth of 30–40 cm. In both cases, this represents inter-island use of stone from the same source. Samples F18 and F22 are from the same square at Beqa Is, Kulu Bay, but at depths of 20–30 cm and 110–120 cm respectively. This could indicate that the same stone source was being used over a long time period, but given the archaeological evidence for deposit mixing at Kulu Bay this cannot be confirmed.

All of Best's analyses (1984) for the Lau Islands and Samoan adzes and rocks are included in Table 84. The four adzes from Samoa are from Roger Green's excavations in Samoa (Green and Davidson 1969). Petrographic descriptions of most of these samples are given in Table 85. The data matrix in Table 84 was cluster analysed.

Results for the clustering analysis of Best's data are shown in Figure 163. As expected, the results are similar to those found by Best (1984) and Best et al. (1992). Best found several Lauan adzes were closely associated with adzes and quarry material from Samoa. Lauan adzes AN16

Table 84. XRF analyses (%) of selected adzes and rocks (from Best 1984). Note that 'AN' numbers are Best's (1984) analysis numbers.

Sample	Label	SiO ₂	TiO ₂	Al ₂ O ₃	Fe ₂ O ₃	MnO	MgO	CaO	Na ₂ O	K ₂ O	P ₂ O ₅
Samoa Adze	AN7	47.287	4.228	13.536	13.695	0.171	8.034	8.939	3.181	1.134	0.624
Samoa Adze	AN8	45.306	4.576	15.331	14.464	0.188	5.672	8.093	3.674	1.218	0.686
Samoa Adze	AN9	48.901	3.103	15.697	13.321	0.179	4.556	7.208	4.382	1.599	0.966
Samoa Adze	AN28	49.635	3.215	15.469	13.334	0.178	4.508	7.51	4.013	1.719	0.896
Lakeba Adze	AN27	63.957	0.802	15.117	7.345	0.173	1.410	4.269	4.396	2.425	0.378
Lakeba Adze	AN10	46.066	3.162	14.527	13.014	0.191	4.539	7.177	3.833	1.399	0.984
Lakeba Adze	AN11	47.200	4.675	13.700	13.794	0.197	6.815	8.723	3.147	0.985	0.578
Lakeba Adze	AN12	46.897	4.600	13.938	13.406	0.164	6.413	8.505	3.285	1.015	0.606
Lakeba Adze	AN13	44.514	2.120	14.914	11.821	0.181	9.514	9.959	2.547	1.360	0.668
Namuka Adze	AN14	47.852	3.374	15.390	13.833	0.175	4.633	7.517	4.067	1.446	0.889
Kabara Adze	AN15	47.731	3.318	15.436	13.558	0.173	4.758	7.436	3.990	1.496	0.878
Vanuabalavu Adze	AN16	48.751	3.051	16.011	13.059	0.182	4.666	7.082	4.270	1.625	0.939
Taveuni Adze	AN17	46.414	4.794	15.724	14.632	0.127	5.944	8.380	3.530	1.214	0.661
Moce Adze	AN18	48.613	3.363	15.519	13.895	0.157	4.789	7.488	4.045	1.485	0.872
Fulaqa Adze	AN19	46.421	4.824	15.654	14.939	0.213	5.700	8.511	3.523	1.259	0.673
Kabara Rock	AN22	45.421	2.190	15.302	12.217	0.153	8.598	10.537	3.238	0.810	0.600
Lakeba Rock	AN23	44.106	1.363	13.767	11.840	0.168	3.775	7.805	2.834	0.764	0.292
Lakeba Rock	AN24	52.808	1.393	15.585	12.251	0.141	3.174	7.084	3.627	1.019	0.311
Samoa Leone Q.	AN40	48.580	3.340	15.490	14.080	0.190	4.790	7.550	3.680	1.600	0.880
Samoa Leone Q.	AN41	45.860	4.780	15.530	14.770	0.170	5.640	8.480	3.140	1.240	0.670
Henderson Rock	AN48	50.930	2.350	16.310	11.250	0.200	2.870	6.740	4.970	2.420	1.170

Table 85. Petrographic descriptions of samples in Table 84 (from Best 1984:A70-A72).

Petrology No.	Sample	Label	Petrographic Description
1	Lakeba Adze	AN27	Glassy basalt, with small pyroxene needles and iron-oxide in volcanic glass
7	Vanuabalavu Adze	AN16	Basalt, celadonite, some small plagioclase phenocrysts, microphenocrysts of olivine
9	Lakeba Adze	AN10	Olivine basalt, celadonite replacing olivine phenocrysts, plagioclase phenocrysts
10	Lakeba Adze	AN11	Olivine basalt, similar to AN10
12	Lakeba Adze	AN12	Olivine basalt, similar to AN10
17	Namuka Adze	AN14	Basalt, similar to AN16
20	Kabara Adze	AN15	Olivine basalt, feldspathic, with celadonite
22	Moce Adze	AN18	Olivine basalt, similar to AN15
23	Fulaqa Adze	AN19	Olivine basalt, similar to AN15
26	Lakeba Adze	AN13	Alkaline olivine basalt, with titaniferous augite
94	Lakeba Rock	AN23	Fine-grained feldspathic basalt
96	Lakeba Rock	AN24	Fine-grained feldspathic basalt with celadonite-filled cavities
101	Kabara Rock	AN22	Olivine basalt, olivine phenocrysts, microphenocrysts of plagioclase, iron oxide
105	Samoa Adze	AN7	Olivine basalt (olivine phenocrysts); groundmass with augite and ores
106	Samoa Adze	AN8	Olivine feldspar basalt; contains green and brown celadonite in cavities
107	Samoa Adze	AN9	Feldspathic basalt; contains brown biotite (celadonite)

and AN10 were thought to be from Tutuila and are grouped as such, with AN10 being an outlier. The Samoan adze (AN28, AN9, AN8) and quarry (AN40, AN41) samples form a large cluster with several Lauan adzes (Lakeba AN10, Moce AN18, Kabara AN15, Namuka AN14, Vanuabalavu AN16 and Fulaga AN19). The larger cluster can be divided into two smaller clusters, which was also noted by Best (1984:403). One Samoan adze sample forms a cluster with Lakeba adzes AN11 and AN12. It can be seen in Figure 163 that some Lauan adzes are closely linked with Samoan adzes and quarry samples. Best concluded the adzes were sourced to Samoa and specifically to Tutuila. According to Best (1984:403), AN23 and AN24 are rock samples from the two mineralogically nearest sources. They are linked, but not closely. Lakeba adze AN13 and an andesitic-basalt from Delaioloi (Kabara, AN22) are similar.

The dendrogram in Figure 164 has the results of a cluster analysis for the analyses from Best (Table 84) and excavated Fiji flakes and adze fragments (Table 82; also compare Figures 162 and 163). Interestingly, there are few closely associated artefacts among Best's samples and those of the current project. None of the excavated samples is closely associated with the Samoan material. This could be expected given that no adzes resembling those of a Samoan origin were available for analysis. In addition, flakes would be unlikely to have a Samoan origin given that Samoan adzes would have been imported in finished form and the only possibility of finding flakes sourced to Samoa would be flakes from retouching adzes.

However, there are a few linked samples. These include AN27, F11; AN24, F3, F16; and less so with AN23, connected to a group of samples from the present project. Best found that Lakeba rock (AN23 and AN24) clustered by itself in a ternary diagram. This most likely indicates a local source of rock for associated samples in this project. Although the analysis of a

Figure 164. Hierarchical clustering report for excavated samples and Best (1984:A74-A75).

Lakeba adze (AN27) appears in Best (1984:A70, A74) it ‘disappears’ from further consideration there and in Best et al. (1992). Note that it is an outlier in Figure 163 but is clustered here with F11 and F5 (Figure 164). However, its petrographic description (Tables 78 and 79) does not resemble those of the latter samples, and it most likely is not from the same source.

Additional selected samples from the database will now be considered (see Table 86). Several samples were obtained from sites on American Samoa and some were sourced to Samoa (e.g. RW-M and RW-F labelled Ma’uke in Best et al. 1992), with other Cook Island samples likely to be from Samoa (Sheppard et al. 1997:101–103).

Results of cluster analysis for all samples with major/minor elemental analyses considered in this report are presented in Figure 165. Note that the dendrogram is split into two sections. A large cluster is formed, with AN23 and AN24 linked closely with Alega 1 and F3 and less so for several other excavated (F) samples. Another large cluster contains mostly Samoan samples, with closely associated Lauan adzes and samples from other island groups having artefacts possibly sourced to Samoa. Some Hawaiian samples form a group which includes AN23 and AN13 (previously found to be off by themselves in Best’s ternary diagram), but there is unlikely to be

Table 86. Additional basalt reference samples (oxides in %).

Reference	Archipelago	Information	Label	SiO ₂	TiO ₂	Al ₂ O ₃	Fe ₂ O ₃	MnO	MgO	CaO	Na ₂ O	K ₂ O	P ₂ O ₅
Clark et al. 1997:75	A. Samoa	Weisler	Taputapu	49.56	3.38	15.35	13.72	0.17	4.55	7.56	3.96	1.54	0.79
Clark et al. 1997:75	A. Samoa	TUT-II.2	Asiapa	50.24	2.94	16.01	12.87	0.18	4.11	7.26	3.99	1.77	1.25
Clark et al. 1997:75	A. Samoa	TUT-II.3	Le'aeno	47.80	3.71	16.09	12.74	0.18	4.84	7.71	3.65	1.61	0.76
Clark et al. 1997:76	A. Samoa	H1	Fagasa	48.90	3.19	15.90	13.24	0.19	4.45	7.21	3.71	1.70	0.84
Clark et al. 1997:76	A. Samoa	TUT-II.7	Alega 1	49.80	3.16	15.50	12.09	0.18	4.07	7.39	3.56	1.61	0.08
Clark et al. 1997:76	A. Samoa	TUT-II.4	Lau'agae	47.95	3.82	15.96	13.91	0.16	4.89	7.71	3.63	1.51	0.73
Clark et al. 1997:76	A. Samoa	TUT-11.10	Nu'u'uli	52.80	2.03	16.30	9.25	0.17	3.23	6.10	4.20	2.20	1.25
Weisler and Sinton 1997:179	A. Samoa		Tataga- mataua	48.52	3.42	15.51	13.66	0.18	4.79	7.54	3.76	1.55	0.78
Allen and Johnson 1997:121	Cook Islands	5	Aitutaki	49.58	3.13	15.90	13.39	0.17	4.53	7.54	3.54	1.64	0.90
Sheppard et al. 1997:96	Cook Islands	R63-19	Rarotonga	48.17	2.65	16.24	11.96	0.24	4.13	6.86	4.42	1.82	1.00
Sheppard et al. 1997:96	Cook Islands	RAR-6	Rarotonga	47.83	3.04	16.13	13.08	0.21	4.50	7.24	3.95	1.68	0.83
Sheppard et al. 1997:96	Cook Islands	R92-1	Rarotonga	47.21	3.16	15.75	13.07	0.22	4.73	7.19	3.70	1.63	0.78
Sheppard et al. 1997:96	Cook Islands	RW-M	Ma'uke	47.92	3.43	15.53	13.57	0.21	4.77	7.74	3.91	1.54	0.81
Sheppard et al. 1997:96	Cook Islands	RW-F	Ma'uke	49.45	2.73	16.61	11.91	0.20	4.19	7.13	4.55	1.88	1.00
Weisler and Sinton 1997:179	Pitcairn		Tautama	49.93	2.68	15.57	13.45	0.22	3.49	7.09	4.55	1.99	1.25
Weisler and Sinton 1997:179	Marquesas		Eiao	46.95	3.90	15.23	13.53	0.16	6.47	9.32	3.18	1.00	0.54
Weisler and Sinton 1997:181	Hawaii	Kaho'olawe	Pu'umaiwi	52.37	2.98	14.02	13.18	0.17	4.60	8.37	3.00	0.85	0.88
Sinton and Sinoto 1997:200	Hawaii	Hawai'i	Mauna Kea	47.99	3.95	13.44	15.32	0.21	5.07	9.58	3.08	1.13	0.56
Sinton and Sinoto 1997:200	Hawaii	Maui	Haleakala	51.00	2.02	17.49	10.57	0.25	2.49	6.27	6.25	2.25	0.88
Sinton and Sinoto 1997:200	Hawaii	Lana'i	Kapohaku	51.48	2.11	13.96	12.11	0.16	7.10	10.06	2.29	0.52	0.25
Sinton and Sinoto 1997:200	Hawaii	Ovahu	Waiahole	52.81	2.19	13.77	11.37	0.15	6.54	9.14	2.69	0.71	0.34
Sinton and Sinoto 1997:202	Easter Island		Ova he	51.28	2.46	14.69	13.96	0.22	3.29	7.16	3.91	1.32	0.82
Sinton and Sinoto 1997:203	Society Islands	Ra'iatea	Ra'iatea II	42.37	4.54	15.07	13.83	0.18	5.16	10.69	3.72	1.82	0.64
Sinton and Sinoto 1997:203	Society Islands	Tahiti	Tahinu II	42.73	3.93	15.15	13.83	0.19	5.01	10.45	3.65	1.98	0.67

Figure 165. Hierarchical clustering report for excavated and all reference samples.

any relationship between samples from Hawaii and Fiji. What is clear here is that several Lauan adzes have their origin in Samoa and are most likely from Leone (Tutuila). The sample from Alega is out of place here. According to Clark et al. (1997:76), Alega samples cluster tightly with the bulk of the Fagasa samples. Alega 1 cannot be associated with source rock from Lakeba.

Trace elements

Table 87 gives the ICP-MS results for trace-element analysis of the excavated flakes and adzes. Nineteen elements were included in the analyses. The limit of detection was 1 part per million (1 µg/g) for Nb, Ni, Pb and Th, and 5 ppm for As. Values below this limit are indicated by a < sign. Note that these limits of detection are to some extent laboratory dependent and the actual limit of detection with ICP-MS for these elements is <1 part per billion (Rubinson 1987:227–228). Literature and determined values for BHVO-1 are presented. In addition to some being

Table 87. ICP-MS analysis results (ppm) for excavated adzes and adze flakes from Fiji.

Sample	Analysis Ref.	As	Ba	Ce	Cr	Cu	Ga	La	Mb	Nd	Ni	Pb	Rb	Sc	Sr	Th	V	Y	Zn	Zr
F1	AAC Ref:2430-01	<5	135.1	7.5	16.3	85.3	16.3	2.6	3.2	6.5	9.3	3.5	16.9	35.8	171.6	2.2	314.4	17.6	67.0	33.7
F2	AAC Ref:2430-02	<5	1114.3	37.9	3.7	27.7	15.8	16.5	10.6	21.5	<1	4.5	79.6	11.6	126.2	4.3	5.8	36.7	88.5	240.5
F3	AAC Ref:2430-03	<5	1194.4	8.3	13.4	126.2	18.0	2.8	2.8	7.9	9.2	2.4	9.6	36.6	216.8	1.5	339.3	26.1	121.5	63.1
F4	AAC Ref:2430-04	54.5	479.8	11.4	7.7	52.7	15.5	5.2	6.4	11.2	6.0	2.8	10.2	30.1	203.8	1.9	138.5	34.6	168.3	87.5
F5	AAC Ref:2430-05	<5	411.3	16.8	3.4	10.3	16.9	6.3	3.7	15.8	3.7	1.8	16.9	19.7	127.8	1.2	31.3	56.7	133.9	126.1
F6	AAC Ref:2430-06	39.5	176.6	9.1	7.5	60.2	16.1	3.1	3.8	8.5	6.2	1.4	8.0	33.0	467.3	1.0	184.2	29.7	106.5	74.3
F7	AAC Ref:2430-07	17.4	267.4	9.5	8.4	35.5	16.6	3.6	4.7	9.7	8.2	1.3	20.1	31.5	451.1	1.1	155.4	33.5	400.0	66.1
F8	AAC Ref:2430-08	<5	101.7	5.7	10.4	6.5	12.3	2.9	1.8	7.1	12.0	1.0	38	34.0	227.8	1.0	194.2	24.9	70.2	73.4
F9	AAC Ref:2430-09	142.5	323.1	9.3	17.8	9.3	17.2	3.8	6.4	9.4	11.3	6.4	17.9	29.4	300.0	1.9	249.8	25.9	94.4	50.1
F10	AAC Ref:2430-10	<5	72.2	11.7	271.4	44.4	152	4.5	<1	86	106.8	2.0	1.6	29.1	186.5	<1	268.4	16.6	81.2	51.1
F11	AAC Ref:2430-11	<5	784.0	32.6	28	29.5	16.9	13.6	6.6	22.1	<1	2.9	42.0	18.6	251.1	2.5	32.0	37.6	111.0	161.7
F12	AAC Ref:2430-12	166.1	558.7	18.3	8.2	95.0	17.4	9.1	5.5	13.1	10.5	2.6	58.6	28.2	743.8	1.8	265.3	20.7	91.7	58.0
F13	AAC Ref:2430-13	<5	512.7	11.7	12.9	64.2	16.4	3.8	35.5	11.3	8.8	1.1	11.4	28.8	373.8	<1	200.0	39.5	129.4	68.8
F14	AAC Ref:2430-14	<5	279.4	10.1	10.0	89.3	17.5	3.1	4.6	8.9	7.2	1.0	1.4	33.5	420.9	<1	276.6	29.0	112.5	75.4
F15	AAC Ref:2430-15	<5	43.3	2.8	15.6	9.9	15.9	1.1	30.2	2.8	17.8	1.1	7.0	39.0	167.6	<1	257.3	15.6	73.4	45.0
F16	AAC Ref:2430-16	<5	502.4	10.7	10.8	67.7	17.6	7.0	30.2	15.3	11.8	1.1	19.9	32.4	309.5	<1	201.4	55.9	125.2	54.9
F17	AAC Ref:2430-17	<5	3052	6.6	13.8	643.6	20.9	2.5	4.6	6.7	13.1	1.0	3.5	39.9	140.1	<1	561.2	26.1	74.0	50.7
F18	AAC Ref:2430-18	<5	1187	4.0	9.8	148.2	16.6	1.9	2.7	4.9	17.4	<1	22.8	42.2	298.7	<1	234.5	25.3	99.0	87.8
F19	AAC Ref:2430-19	130.4	175.1	6.0	11.4	213.3	17.3	2.4	1.2	5.8	14.0	4.7	22.2	40.3	106.2	<1	348.0	19.8	93.2	34.5
F20	AAC Ref:2430-20	<5	29.0	1.6	16.5	17.0	15.3	<1	23.1	1.9	14.6	<1	1.6	28.5	93.1	<1	305.1	17.6	106.3	30.1
F21	AAC Ref:2430-21	<5	53.4	3.8	15.1	28.3	14.9	2.0	<1	3.7	13.0	<1	9.3	40.5	102.2	<1	340.8	20.8	50.1	47.5
F22	AAC Ref:2430-22	<5	147.9	2.2	26.8	48.3	12.0	<1	2.0	1.5	18.7	<1	5.6	28.4	230.6	<1	201.1	10.3	93.6	60.0
F23	AAC Ref:2430-23	<5	333.1	7.2	6.5	46.3	14.0	2.4	1.5	6.6	7.5	<1	7.2	27.7	223.4	<1	153.7	26.5	89.1	51.8
F24	AAC Ref:2430-24	<5	86.8	5.3	389.3	46.0	16.1	1.8	<1	4.9	123.2	<1	2.7	33.7	111.4	<1	268.0	13.1	76.4	34.3
F25	AAC Ref:2430-25	<5	337.4	23.0	58.7	145.9	18.7	11.1	3.1	17.0	24.9	2.6	33.5	32.6	535.1	<1	272.7	24.9	93.0	89.5
BHVO-1	Determined	<5	129.8	36.4	257.4	136.0	22.0	16.2	19.3	21.6	115.1	2.0	13.7	32.1	318.9	1.0	310.3	25.5	116.4	182.5
BHVO-1	Lit. Value	0.4	139.0	39.0	289.0	136.0	21.0	15.8	19.0	25.2	121.0	2.6	11.0	31.8	4030	1.1	317.0	27.6	105.0	179.0

below the level of detection, values for Th and Pb were low and too similar to be of use and were removed from the data set. Because arsenic (As) results appear useful for discrimination, values <5 were set to 1. Other elements with values <1 were set to 0.1. The element values were further corrected to reflect the standard BHVO-1.

Cluster analysis for the trace-element analysis of Fijian excavated material is given in Figure 166. NCSS has divided the results into four clusters with six outliers. Cluster 1 contains F10, F24; Cluster 2: F13, F16; Cluster 3: F2, F11; and Cluster 4: F1, F21, F18, F8, F23, F22, F4, F6, F14, F15, F20, F9, F19. Closely linked (similar) samples include F1, F21, (F18); F8, F23, (F22); F6, F14, (F4); F15, F20; F13, F16; and F10, F24. Note that samples not as closely linked are indicated within parentheses. Other samples which are linked include F2, F11; F12, F25; F9, F19. Note that the clustering analysis of trace elements for Fiji where all elements are used is similar to clustering with a reduced number of elements. The exception is that F9 and F19 are linked with the full data set.

Linkages common to dendrograms for major/minor and trace elements (Figures 162 and 166) are: F12, F25 (and similar petrology); F10, F24 (petrology different); F8, F22, F23 (similar petrology); and F6, F14 (similar petrology). These commonly linked samples should be considered as coming from the same sources. Samples F10 and F24 do not appear the same petrologically but differential weathering may be involved and they may be from the same source.

Ideally, the same samples which were used to form Table 86 for the oxides should have been considered for trace elements. The trace-element database unfortunately does not contain any samples of possible Fijian origin for comparison with the excavated material. Best (1984) and Best et al. (1992) have results only for oxides (Table 84) of Fijian lithics. The table of reference

Figure 166. Hierarchical clustering report for trace-element analysis of Fiji excavated flakes and adze fragments.

samples contains analyses of flakes either directly or indirectly sourced to American Samoa and other lithic material from Polynesia (see Table 88). Several of these references are unlikely to have a connection with the excavated artefacts, but they were included to see how they would cluster.

Trace-element analyses for excavated adzes and flakes, along with selected reference samples, are shown in Table 89. The samples in this table have only 11 analysed elements in common, although the original analyses contained more. The data matrix was cluster analysed.

Results of the cluster analysis are given in Figure 167. Most of the excavated samples cluster together and away from the reference samples. This would be expected because there are no likely source rocks in the reference database to link with the Fijian artefacts. It can be seen that samples from Samoa are closely linked and form a cluster, although Tautama and Ovahe are in the cluster but not closely linked. Sample AN41 is linked with F7, but it should be in the Samoan cluster and this appears to be a faulty chemical analysis. Some of the linkages indicate the similarities in trace-element make-up of certain basalts from widely separated sources. At this time, it appears that major-element analyses were of more use than trace elements because of the availability of reference samples.

Table 88. Trace-element analyses (ppm) for basalt references.

Reference	Archipelago	Information	Label	V	Cr	Ni	Cu	Zn	Rb	Sr	Y	Zr	Mb	Ba
Best et al. 1992:85	Cook Islands	Ma'uke	Cooks1	279	0	54	42	159	27	598	42	347	39	264
Best et al. 1992:85	Cook Islands	Ma'uke	Cooks2	248	0	19	34	110	20	717	33	241	63	370
Best et al. 1992:85	A. Samoa	Flake, Area 1	15 (TTM-A1)	221	0	0	7	195	44	710	50	406	44	297
Best et al. 1992:85	A. Samoa	Flake, Area 1	17 (TTM-A1)	214	0	0	8	191	38	720	50	406	42	330
Best et al. 1992:85	A. Samoa	Flake, Area 3	23 (TTM-A3)	209	0	6	15	190	41	721	50	407	44	314
Best et al. 1992:85	A. Samoa	Flake, Leone	AN40	197	0	0	0	197	50	742	51	424	44	326
Best et al. 1992:85	A. Samoa	Flake, Leone	AN41	305	0	41	26	549	28	622	43	350	40	271
Best et al. 1992:85	A. Samoa	Il.2	Asia pa	153	0	17	23	193	41	755	55	451	48	426
Sinton and Sinoto 1997:201	A. Samoa	Tutuila	Maupua	198	1	36	30	150	342	107	50	473	60	317
Sinton and Sinoto 1997:201	A. Samoa	TUT-II.3	Le'aeno	247	0	23	25	181	39	764	43	391	47	303
Sinton and Sinoto 1997:201	A. Samoa	Tutuila	Tataga-matau	210	1	0	5	182	42	708	49	383	49	305
Sinton and Sinoto 1997:201	Pitcairn		Tautama	109	8	1	15	171	39	589	48	417	89	458
Sinton and Sinoto 1997:201	Marquesas		Eiao	297	87	100	47	130	18	591	37	306	28	187
Sinton and Sinoto 1997:200	Hawaii	Kaho'olawe	Pu'umoiwi	345	59	60	75	145	16	396	65	228	17	299
Sinton and Sinoto 1997:200	Hawaii	Hawai'i	Mauna Kea	427	0	30	35	137	30	538	39	314	44	405
Sinton and Sinoto 1997:200	Hawaii	Maui	Haleakala	38	6	0	8	133	55	1105	41	412	77	886
Sinton and Sinoto 1997:200	Hawaii	Lana'i	Kapohaku	304	291	118	103	106	7	357	64	136	10	97
Sinton and Sinoto 1997:200	Hawaii	O'ahu	Waiahole	272	225	123	106	104	10	445	25	167	10	119
Sinton and Sinoto 1997:202	Easter Island		Ovahe	162	1	7	5	154	28	299	74	459	53	260
Sinton and Sinoto 1997:203	Society Islands	Ra'iatea	Ra'iatea II	158	8	3	12	118	63	1882	42	433	74	864
Sinton and Sinoto 1997:203	Society Islands	Tahiti	Tahinu II	381	1	53	110	114	53	740	34	311	60	587

Table 89. Trace-element analyses (ppm) for excavated and selected reference samples.

Sample	Label	V	Cr	Ni	Cu	Zn	Rb	Sr	Y	Zr	Nb	Ba
Kulu Bay	F1	321.1	18.3	9.8	85.3	60.4	13.6	216.8	19.1	33.1	3.1	144.7
Kulu Bay	F2	5.9	4.1	0.1	27.7	79.8	64.2	159.5	39.7	235.9	10.4	1193.5
Kulu Bay	F3	346.5	15.0	9.7	126.2	109.6	7.8	274.0	28.3	61.9	2.8	1279.3
Kulu Bay	F4	141.5	8.6	6.3	52.7	151.8	8.2	257.6	37.5	85.8	6.3	513.9
Kulu Bay	F5	32.0	3.8	3.9	10.3	120.8	13.6	161.5	61.4	123.7	3.6	440.5
Kulu Bay	F6	188.2	8.4	6.5	60.2	96.1	6.4	590.6	32.2	72.9	3.7	189.2
Kulu Bay	F7	158.8	9.4	8.6	35.5	360.8	16.2	570.1	36.3	64.8	4.7	286.4
Ugaga Is.	F8	198.4	11.7	12.6	6.5	63.3	3.0	287.9	27.0	72.0	1.8	108.9
Ugaga Is.	F9	255.2	19.9	11.8	9.3	85.2	14.4	379.1	28.1	49.1	6.3	346.0
Natunuku	F10	274.2	304.7	112.2	44.4	73.3	1.3	235.6	18.0	50.1	0.1	77.3
Votua	F11	32.7	3.1	0.1	29.5	100.1	33.9	317.3	40.7	158.6	6.5	839.8
Natunuku	F12	271.0	9.2	11.0	95.0	82.8	47.3	940.0	22.5	56.9	5.4	598.4
Natunuku	F13	204.3	14.5	9.3	64.2	116.7	9.2	472.4	42.8	67.5	34.9	549.1
Natunuku	F14	282.5	11.3	7.5	89.3	101.5	1.1	532.0	31.4	73.9	4.5	299.2
Natunuku	F15	262.8	17.6	18.7	9.9	66.2	5.7	211.8	16.9	44.2	29.7	46.3
Natunuku	F16	205.8	12.2	12.4	67.7	112.9	16.0	391.1	60.6	53.9	29.7	538.1
Kulu Bay	F17	573.2	15.5	13.8	643.6	66.8	2.8	177.1	28.2	49.7	4.5	326.9
Kulu Bay	F18	239.5	11.0	18.3	148.2	89.3	18.4	377.4	27.5	86.1	2.7	127.1
Kulu Bay	F19	355.5	12.8	14.7	213.3	84.1	17.9	134.2	21.4	33.8	1.2	187.6
Kulu Bay	F20	311.6	18.6	15.3	17.0	95.9	1.3	117.6	19.1	29.5	22.7	31.1
Kulu Bay	F21	348.1	16.9	13.7	28.3	45.2	7.5	129.2	22.5	46.6	0.1	57.2
Kulu Bay	F22	205.4	30.1	19.7	48.3	84.4	4.5	291.4	11.1	58.8	1.9	158.4
Kulu Bay	F23	157.0	7.3	7.8	46.3	80.4	5.8	282.3	28.7	50.8	1.5	356.7
Ugaga Is.	F24	273.8	437.0	129.5	46.0	68.9	2.2	140.8	14.2	33.6	0.1	92.9
Kulu Bay	F25	278.6	65.9	26.2	145.9	83.9	27.0	676.3	26.9	87.7	3.1	361.4
Ma'uke	Cooks1	279	0	54	42	159	27	598	42	347	39	264
Ma'uke	Cooks2	248	0	19	34	110	20	717	33	241	63	370
Flake, Area 1	15 (TTM-A1)	221	0	0	7	195	44	710	50	406	44	297
Flake, Area 1	17 (TTM-A1)	214	0	0	8	191	38	720	50	406	42	330
Flake, Area 3	23 (TTM-A3)	209	0	6	15	190	41	721	50	407	44	314
Flake, Leone	AN40	197	0	0	0	197	50	742	51	424	44	326
Flake, Leone	AN41	305	0	41	26	549	28	622	43	350	40	271
II.2	Asiapa	153	0	17	23	193	41	755	55	451	48	426
Tutuila	Maupua	198	1	36	30	150	342	107	50	473	60	317
TUT-II.3	Le'aeno	247	0	23	25	181	39	764	43	391	47	303
Tutuila	Tataga-matau	210	1	0	5	182	42	708	49	383	49	305
Pitcairn	Tautama	109	8	1	15	171	39	589	48	417	89	458
Marquesas	Eiao	297	87	100	47	130	18	591	37	306	28	187
Kaho'olawe	Pu'umoiwi	345	59	60	75	145	16	396	65	228	17	299
Hawai'i	Mauna Kea	427	0	30	35	137	30	538	39	314	44	405
Maui	Haleakala	38	6	0	8	133	55	1105	41	412	77	886
Lana'i	Kapohaku	304	291	118	103	106	7	357	64	136	10	97
O'ahu	Waiahole	272	225	123	106	104	10	445	25	167	10	119
Easter Island	Ovahe	162	1	7	5	154	28	299	74	459	53	260
Ra'iatea	Ra'iatea II	158	8	3	12	118	63	1882	42	433	74	864
Tahiti	Tahinu II	381	1	53	110	114	53	740	34	311	60	587

Figure 167. Hierarchical clustering report for trace element analysis of Fiji excavated samples and reference samples.

Adze samples: Conclusion

Among the small sub samples cut from 25 excavated flakes and adzes, some showed a high degree of weathering which would influence the petrography and chemical make-up. The pieces were successfully analysed for major/minor element oxides using EDXA and for 17 trace elements by ICP-MS. In addition, phosphorus was determined by ICP-AES.

EDXA works best on polished flat specimens, which was the reason for preparing such samples in this project. A comparison of solid versus powdered samples indicates that powdered samples may be successfully analysed and the results normalised to 100%. This method of sample preparation is preferred when minimal damage to an artefact is necessary – for example, in museum specimens, where a sample can be obtained by drilling. Contamination of samples during the sampling and pulverising process is not a great concern for major/minor element oxide determinations. However, trace-element concentrations can be affected by sampling and pulverising processes.

ICP-MS is an excellent method for the determination of trace-element concentrations because of its sensitivity and small sample size requirements. Most analytical determinations for sourcing studies in the Pacific have been done using XRF. This has limited the number of chemical elements which have been determined and various researchers have selected different element suites, further restricting comparisons. A non-destructive EDXRF method used by Weisler is probably the ideal for museum specimens, but the lack of instrumentation and reduced sample output restricts this technique.

The analyses reveal that some of the samples from the Fiji excavations are closely linked with Best's (1984) samples. A Lakeba adze (AN27) is closely linked with sample F11, but they do not resemble one another petrologically. Lakeba rock (AN24) is closely linked with F3 and F16 and they could be from the same source. Lakeba rock (AN23) is linked to a cluster of excavated samples and some of these may be from the same source, samples that also include AN24.

None of the excavated samples are closely associated with Samoan reference samples. However, no adzes resembling those of known Samoan morphology were found. All of the flakes which were analysed are most likely from local sources.

Closely linked samples which should be considered as coming from three separate sources are F12, F25; F8, F22, F23; and F6, F14. Another pair, F10, F24, with differing petrology, may be from the same source. These closely linked samples indicate inter- and intra-island usage of rock from the same sources. Also, there may be a considerable time depth to this usage.

Trace-element analyses characterised the excavated samples but there were no relevant reference samples from local quarries to carry out sourcing. It is clear from the clustering analyses that none of the artefacts was from Samoa.

Best (1984) and Best et al. (1992) analysed archaeological lithic samples from Fiji and Samoa as well as the wider Pacific. Their interest, after the discovery that basalt adzes could be sourced to the island of Tutuila, has centred on basalt and Samoa to the detriment of Fijian lithics. Other rock types are to be found to the west of the Andesite Line, making sourcing of rocks found in archaeological sites in Fiji more complex. There is little data available except for some initial work by the above authors.

Appendix: Chemical characterisation of chert artefacts from Fiji

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Introduction

Flake tools made in siliceous rock have been found in numerous archaeological sites in Fiji and such materials might represent prehistoric movement and interaction in the Central Pacific (Green 1996). Crypto-crystalline rocks fracture conchoidally and were commonly used to make expedient sharp-edged artefacts. Primarily composed of silica (SiO_2), with minor oxides of Al, Fe, Ca, Mn, Na, K and Mg, chert develops in different environments often over long periods and varies in its colour, texture and composition. In geology, 'chert' is a term that includes flint, chalcedony, jasper, silicified coral and other crypto-crystalline material. The different colours of chert often reflect the amount and form of minor elements, particularly Fe, which in red 'jasper' is in the form of hematite (Fe_2O_3), while in yellow chert Fe is in the form of lepidocrocite ($\text{FeO}(\text{OH})$). White chert, whether partially or completely translucent, often indicates a low concentration of minor elements. Accidental and purposeful heating as well as weathering can affect the colour, hardness and flaking characteristics of chert (Hatch and Miller 1996).

Ward and Smith (1974) used X-Ray Fluorescence (XRF) to compare the chemical signatures of cherts from the Solomon Islands with those from Australia, New Zealand and New Guinea, and, from a comparison of trace elements, demonstrated the likely transfer of chert from Ulawa to the Reef Santa Cruz Islands. In an important paper, Sheppard (1996:101) summarised the distribution of chert, obsidian and basalt in Near and Remote Oceania and noted that chert had a wide areal extent but a low regional frequency, and was usually not abundant at an individual source. Chert could be divided using petrology into different types based on quartz mineralogy and micro-fossil content and structure, with the possibility that chert from Futuna was taken to Tikopia around ca. 1500 AD. Geochemical analyses appeared to reflect the major depositional environment, suggesting that cherts that were formed in comparable geological settings and conditions might have similar chemical signatures.

The diverse geology of the Fiji Islands indicates the existence of numerous chert sources (see Chapter 14), with two sources of jasper and two sources of silicified coral reported from Vanuabalavu in the Lau Group. Best (1984:415–416) identified a silicified coral source on Vanuabalavu as the likely source of flakes from an early site on Lakeba, which demonstrated the transfer of silicious stone within the Lau Group. A pilot project to examine the chemical composition of chert tools recovered in the EPF excavations was instigated as no geochemical analyses of Fijian chert had been made, and the presence of silicious tools in sites could represent the widespread transfer of crypto-crystalline material in prehistory.

Materials and methods

Twenty chert tools recovered from EPF excavations were selected for analysis: Votua (n=12), Kulu Bay (n=4), Natunuku (n=3), Ugaga Island (n=1) and Yacata Island (n=2, see Clark and Hope 2001). A jasper outcrop was sampled at Tiotio on Vanuabalavu (n=1). Additional chert tools were obtained from existing archaeological collections in Fiji (Sigatoka n=5, Natunuku n=3, Cikobia n=2, Lakeba n=6, Totoya n=4), making a total of 43 samples (Table 90). Chert artefacts from Votua and Sigatoka date to the late-Lapita era, but the dating of chert samples from other sites is uncertain, as at Kulu Bay and Ugaga, where Lapita and post-Lapita artefacts were mixed together, and at Totoya and Yacata, where chert flakes were surface collected.

Table 90. Chert samples submitted for chemical analysis. FJ09 was not analysed.

Lab. No.	Location	Type	Description
FJ01	Mago, Votua, Area 1: 0–10 cm	core	Red banded fine-grained material, pitted with thin veins of grey-blue and brown.
FJ02	Mago, Votua, Area 1: surface	core	White fine-grained with pale yellow areas and grey veined.
FJ03	Mago, Votua, Area 1: surface	core	Red banded fine-grained and pitted with grey-blue and brown vacuoles.
FJ04	Mago, Votua, Area 1: 0–10 cm	flake	Yellow-brown banded and fine-grained.
FJ05	Mago, Votua, Area 1: 20–30 cm	flake	Dark red fine-grained homogeneous material.
FJ06	Mago, Votua, Area 2: 0–10 cm	flake	Red with micro-layering, fine-grained with a thin lens of brick red material in section.
FJ07	Mago, Votua, Area 2: 30–40 cm	flake	Dark red fine-grained surrounding a light orange-red area 4 mm ² . Cortex in cross section has a thin white covering.
FJ08	Mago, Votua, Area 2: 0–30 cm	flake	Yellow-brown fine-grained with diffuse patches of grey-black, possible cortex on one face.
FJ09	Mago, Votua, Area 2: 30–40 cm	flake	Brown fine-grained material with small vacuoles.
FJ10	Mago, Votua, Area 2: 30–40 cm	flake	Dark red fine-grained with patches of mottled pink and a few small vacuoles.
FJ11	Mago, Votua, Area 2: 0–10 cm	flake	Brown with thin branches of red-brown and diffuse patches of quartz.
FJ12	Mago, Votua, Area 2: 10–20 cm	flake	Mottled yellow brown and a vein of red penetrating 3 mm from cortex.
FJ13	Viti Levu, Sigatoka, 45A, Y/2/2	flake	Pale white with diffuse inclusions of dark red. White cortex on one face.
FJ14	Viti Levu, Sigatoka, 45A, Y/2/4	flake	Yellow with red patches near cortex. Small crystals on thin cortex layer.
FJ15	Viti Levu, Sigatoka, 45A, S	flake	White fine-grained material with an area of yellow and red on one edge. Numerous small grey vacuoles.
FJ16	Viti Levu, Sigatoka, 45A, Y/2/4	flake	Yellow-white coarse-grained and veins of grey-green.
FJ17	Viti Levu, Sigatoka, 45A, Z/2/1	flake	White fine-banded material with stained patches of yellow.
FJ18	Cikobia, CIK-06B: 130–140 cm	flake/core	Brown fine-grained and banded material with veins of quartz and small grey vacuoles.
FJ19	Cikobia, CIK-06D: 80–90 cm	flake	Dense dark red material with small pinkish pits near cortex and a few interior grey-blue vacuoles.
FJ20	Viti Levu, Natunuku, Tr. 3: Layer 2A	flake	White mottled with grey-to-yellow quartz. No visible banding or vacuoles.
FJ21	Viti Levu, Natunuku, Tr. 3: 30–40 cm	flake	Red glassy material with a coarse-grained inclusion of ?red-black glass. Near the edge the material is coarse-grained with particles of white, red and ?black.
FJ22	Viti Levu, Natunuku, surface. FJM	flake	White fine-grained and banded material stained with pale yellow-brown. Sample had a small oyster growing on surface.
FJ23	Viti Levu, Natunuku, surface. FJM	flake	Pink-red quartz coarse material with a plate-like structure.
FJ24	Viti Levu, Natunuku, Tr. 3: 50–60 cm	flake	Dark red dense material with veins of purple-red and numerous grey-blue vacuoles.
FJ25	Viti Levu, Natunuku, surface. FJM	flake	Orange-brown cortex. Interior has blocky grey-white inclusions with coarse and irregular banding.
FJ26	Beqa, Kulu, C10: 30–50 cm	flake	White coarse-grained material with very small patches of black and yellow-brown. No banding present.
FJ27	Beqa, Kulu, C10: 30–50 cm	flake	White-grey material with diffuse white patches and inclusions. Pale yellow towards edge.
FJ28	Beqa, Kulu, C11: 30–40 cm	flake	Pink-white material with round inclusions of red-orange and angular white particles. Vacuoles and possible micro-fossils.
FJ29	Beqa, Kulu, C10: 0–30 cm	flake	White homogeneous material lacking vacuoles or coloured inclusions.
FJ30	Beqa, Ugaga, P9: 30–40 cm	flake	Interior has angular fragments of quartz surrounded by irregular areas of yellow and red.
FJ31	Lakeba, 196-12-B-1(1)	flake/drill bit	White homogeneous fine-grained material.
FJ32	Lakeba, 101/7/47(16A)	flake	Irregular coarse areas of pinkish-red and brown.
FJ33	Lakeba, 196-B-B-3(2)	flake	White coarse-grained quartz.
FJ34	Lakeba, 196-16-B-1(1)	flake	Mottled coarse white and grey-brown with possible micro-fossils.
FJ35	Lakeba, 196-16-B-3(8)	flake	Dark red fine-grained and homogeneous material.
FJ36	Lakeba, 196-23-B14	flake	Dark red fine-grained with micro-vacuoles and mottled with brick red.
FJ37	Yacata, Natuiwaqa, TP1: 0–30 cm	flake	Dark brown fine-grained material.
FJ38	Yacata, 200m southeast of village	flake	Brick-red interior intruded by crystal-filled vacuoles and dark brown patches.
FJ39	Vanuabalavu, Tiotio	cobble	Dark red, fine-grained homogeneous material with very small vacuoles.
FJ42	Totoya, Jigojigo, T031/43/32	flake	Dark red, fine-grained homogeneous material with very small vacuoles. Thin veins of blue ?quartz.
FJ43	Totoya, Keteira 1, T031/46	flake	Interior crystal-filled vacuoles surrounded by irregular and coarse patches of pink and red material.
FJ44	Totoya, Waroka 3	flake	Dark red fine-grained material with irregular pink and white streaks.
FJ45	Totoya, Udu, T031/1/2	flake	Mottled grey-yellow coarse material with small black grains and partially absorbed lathe structures.

Chert samples were cut with a hydraulic diamond wire saw with the wire-cut surface analysed with proton and gamma induced X-Ray emissions (PIXIE/PIGME) at the ANSTO 3 MV van de Graff accelerator at Lucas Heights. Elements measured in ppm were F, Na, Al, Si, K, Ca, Ti, Cr, Mn, Fe, Zn, Rb, Sr, Y, Zr, Nb and Pb (Table 91). Sample FJ09 from Votua was too small to examine, leaving 42 analysed samples. Following the geochemical study, chert sections were scanned at 4800 dpi to facilitate the description of colour and texture (Table 90), and to check whether the area sampled by the proton beam – visible in most sample scans as a grey or brown circle – included any voids or anomalies that might affect element concentrations. Element values were log₁₀ transformed, with individual element values checked against sample colour to identify elements that were highly correlated with Fe. Associated with ‘red’ iron-rich chert samples were Pb, Zn, Ti, Rb, F, Ca, Cr and Mn, while Al, Na, K, Sr, Y, Nb and Zr were not strongly correlated with Fe. SPSS Version 13 software was used to perform two hierarchical cluster analyses (between-groups linkage, squared Euclidean distance).

The first HCA used nine iron-correlated elements in the red chert samples (Fe, Pb, Zn, Ti, Rb, F, Ca, Cr, Mn), as colour is a common criterion that is used to group archaeological chert artefacts, and similar-coloured chert tools at different sites could result from the exploitation of a particular source. For red ‘jasper’ artefacts found in the Lau Group this was especially plausible as there were two known sources of jasper on Vanuabalavu, and artefacts made in red chert were found at the Votua Lapita site on nearby Mago Island. A second HCA was run with remaining elements that were not correlated with Fe. This was to investigate the geochemical variability in samples once the elements largely responsible for sample colour had been removed.

Analysis results

All samples were composed of a high proportion of Si (75.7%–99.9%), with variable amounts of Fe, ranging from 0.01% to 23.4%, reflecting colour variation between red, white and variegated cherts. Trace elements were extremely low for Sr, Y, Zr and Nb and slightly higher for F, Ca, K and Cr (Table 91).

The HCA dendrogram of the Fe-correlated elements contains two main clusters (Figure 168). The top cluster contains the majority of chert from archaeological sites in west Fiji, such as Sigatoka, Natunuku and Kulu, with a few samples from east Fiji (Totoya, Votua, Lakeba). These samples are low in Fe, as indicated by their white-to-yellow colour, although two artefacts of reddish chert from Natunuku (FJ21, FJ24) were also placed in the cluster. Most of the white-yellow samples in the upper cluster were fine-grained and relatively homogeneous, in contrast to six samples forming a separate sub-branch of the lower cluster (FJ16, FJ25, FJ28, FJ30, FJ26, FJ43). These cherts were coarse-grained and heterogeneous with diffuse coloured areas, often with veining and vacuoles. The lower branch of the base cluster was dominated by red chert from the Lau Group and Cikobia Island, north of Udu Point on Vanua Levu, including a sample from the Tiotio outcrop on Vanuabalavu. Individual Votua artefacts were found to be similar to those from Totoya (FJ01 with FJ42), Lakeba (FJ06 with FJ36), and Yacata (FJ11 with FJ37). The Tiotio chert (FJ39) grouped with two artefacts from Lakeba and Votua (FJ10 and FJ35). These samples were similar to one another and were dark red and fine-grained and had only a few small vacuoles.

The second HCA examined elements Al, Na, K, Sr, Y, Nb and Zr that were not strongly correlated with sample colour (Figure 169). Such elements might represent the origin of a chert with greater reliability than elements responsible for sample colour, particularly if the same source of crypto-crystalline material contained chert of different colours. There is greater variation in

Table 91. Fijian chert element analysis (ppm).

Sample	Location	F	Na	Al	Si	K	Ca	Ti	Cr	Mn	Fe	Zn	Rb	Sr	Y	Zr	Nb	Pb
FJ01	Votua	5.6	272.4	155.3	585084	131	102	151	549	0	43956	2	2	2	0	2	1	40
FJ02	Votua	4	79.1	—	573976	185	102	0	41	0	123	4	0	1	1	1	2	0
FJ03	Votua	6.6	90.2	—	580546	149	183	230	104	139	68942	16	2	0	0	2	2	86
FJ04	Votua	7.3	217	—	556984	461	302	216	894	467	69134	22	4	0	0	0	2	97
FJ05	Votua	292.6	219.9	—	515240	167	12265	423	1778	268	133434	28	26	8	0	0	4	130
FJ06	Votua	8.2	241	—	569991	179	365	309	1165	0	97621	18	0	0	0	2	0	60
FJ07	Votua	60.5	276.1	136.9	511404	79	2586	480	1760	255	158406	107	7	3	0	5	3	150
FJ08	Votua	6.2	503.9	532	547908	690	394	89	465	1068	37072	8	0	5	0	1	1	12
FJ10	Votua	29.2	268.9	—	523852	81	2006	292	17	99	105730	11	6	5	0	4	1	77
FJ11	Votua	3.1	300.5	—	564198	495	123	25	67	209	11213	4	0	1	1	1	1	2
FJ12	Votua	3.3	183.9	—	553315	308	109	0	82	30	4530	3	1	1	1	1	1	2
FJ13	Sigatoka	3.5	146.4	135.6	561059	152	249	0	120	32	112	1	0	1	0	0	1	0
FJ14	Sigatoka	2.6	182	172.2	568646	116	157	0	92	0	268	0	0	2	0	0	1	0
FJ15	Sigatoka	2.6	955.8	577.1	560531	346	63	0	9	6	337	0	0	1	0	1	0	1
FJ16	Sigatoka	10.5	725.4	3277.1	569699	735	957	171	65	22	2454	5	0	7	2	2	1	0
FJ17	Sigatoka	2.6	376.5	518.4	582253	376	143	0	76	5	81	0	1	1	1	1	1	2
FJ18	Cikobia	5.7	125.5	248	541222	216	18265	182	458	504	53409	7	5	4	0	1	0	43
FJ19	Cikobia	4.5	101	—	574904	142	235	90	433	249	30400	6	2	2	0	2	0	20
FJ20	Natunuku	3.2	106.8	204.5	581342	102	141	0	0	3	224	1	1	2	0	1	1	1
FJ21	Natunuku	4.8	24.8	—	599117	126	20684	0	127	4	663	2	0	12	0	1	1	1
FJ22	Natunuku	2.6	1203.7	320.8	574729	314	0	0	34	0	61	2	1	0	0	2	3	0
FJ23	Natunuku	2.8	332.7	343.8	562690	335	97	0	107	8	330	2	1	1	1	2	2	0
FJ24	Natunuku	4.3	230.6	—	565118	240	0	0	354	50	25036		1	0	0	0	3	17
FJ25	Natunuku	43.2	1558.3	3677.3	556349	1152	1334	188	122	11	682	1	0	13	2	6	0	1
FJ26	Kulu	11.4	15.9	204.2	571314	16	106	1574	9	1	148	2	1	2	1	97	1	5
FJ27	Kulu	4.4	112.5	—	566835	49	67	0	80	0	188	0	0	5	3	4	4	0
FJ28	Kulu	3.6	186.5	188	564416	139	226	3351	161	6	296	1	2	3	1	4	3	4
FJ29	Kulu	1.5	167.5	357.5	575126	214	261	9	44	12	156	4	1	3	0	2	2	1
FJ30	Ugaga	4.1	40.6	132.7	566088	224	107	6322	120	0	4003	2	0	2	2	10	3	6
FJ31	Lakeba	3.3	192.7	322.3	599963	210	464	20	158	8	356	7	1	2	1	2	2	7
FJ32	Lakeba	5.3	150.5	246.6	564536	528	212	149	247	572	30726	10	2	3	0	0	1	18
FJ33	Lakeba	1.8	79.3	—	568402	141	128	0	216	4	186	2	2	2	1	1	2	1
FJ34	Lakeba	12.3	104.4	—	570234	90	133	13	86	12	230	0	1	2	2	0	1	2
FJ35	Lakeba	6.2	237.1	221.1	547460	187	1027	402	100	43	50980	8	0	5	4	2	3	13
FJ36	Lakeba	7.3	125.3	223.3	573053	128	110	321	1181	0	109461	7	1	0	0	6	5	188
FJ37	Yacata	2.3	38	—	561106	505	345	28	208	731	15833	4	2	3	2	1	0	4
FJ38	Yacata	50.4	571.2	3790.1	541650	3142	261	1051	1433	119	106580	11	18	3	0	11	3	130
FJ39	Tiotio	8.8	261.5	3772.6	545718	1392	583	298	58	5	22287	1	3	8	3	8	3	17
FJ42	Totoya	6.1	60.6	43.5	557957	10	157	129	588	0	45740	2	2	0	0	12	1	15
FJ43	Totoya	5.9	32.6	58.8	547170	91	233	4769	0	28	3831	3	0	2	2	16	2	5
FJ44	Totoya	5	216.9	—	563570	265	138	0	149	28	5258	2	0	2	2	0	2	0
FJ45	Totoya	9.7	141.4	177.2	586752	174	154	9712	553	0	66733	6	0	26	0	44	1	44

Figure 168. Hierarchical clustering report for chert samples using Fe-correlated elements.

the distribution of samples in the HCA, with Totua artefacts in the major clusters. The ability to discriminate chert with the seven minor and trace elements does not appear great, as the Tiotio source (FJ39) did not group with any of the Totua artefacts, despite Vanuabalavu being the closest known source of red chert to Mago Island. However, the majority of cherts from Sigatoka were in the top cluster, while three artefacts from Totoya were grouped together in a subcluster (FJ42, FJ43, FJ45), indicating that the artefact groupings are not entirely arbitrary.

Conclusions

Chert is a heterogeneous material compared with some basalts, and particularly obsidians, which form by the rapid cooling of a relatively homogeneous magma fluid (Lyons et al. 2003). Attribution of an artefact to a particular source is further complicated by the number of potential sources in the Central Pacific, as chert can be formed by diagenesis in limestone environments as nodules, or be deposited in thin or thick beds, especially in geosynclinal deposits that have been uplifted. Potential sources of chert have been recorded on Viti Levu (Hunt 1979), Vanua

Chemical analysis of chert artefacts revealed a group of elements strongly correlated with Fe, which in different forms is the main contributor to chert colour. As expected, these elements in a HCA grouped samples by colour, but the analysis also correctly sorted the majority of samples by texture. The similar visual and textural properties of chert were reinforced by the chemical results that placed chert from an outcrop on Vanuabalavu with artefacts from the Votua Lapita site. Results also indicated that a white-yellow chert found at Natunuku and Sigatoka may be from the same source (probably Viti Levu), and chert from this source might also have been taken to Beqa Island and Lakeba. Red and yellow chert artefacts from Votua, Lakeba, Yacata and Totoya are likely to originate from a source in the Lau Group and may have been taken as far afield as Cikobia, while the red chert appears to be from a different source. It is

interesting that a red chert (presumed to be local) circulates mainly in the Lau Group and outer islands, while on Viti Levu, a white chert-chalcedony may have been distributed as far as the Suva area in late prehistory, as Hunt (1979:38) reports that flakes from a ring-ditch overlooking the Samabula River were of the same material as flakes found at Sigatoka. A number of early sites contain chert artefacts, but the temporal association of crypto-crystalline tools with Lapita pottery is unclear due to site disturbance, except at Votua where chert artefacts are numerous. On Lakeba, silicified materials were certainly present in Lapita-age deposits and are common at the Ulunikoro (Site 47) fortification, dating to about AD 1100 (Best 1984:492–493).

Minor and trace elements for chert artefacts did not produce coherent geographic clusters, and several trace elements were present at low concentrations, meaning that they have a limited capacity to confidently differentiate prehistoric artefacts. Chert was almost certainly transported through the Fiji Islands in prehistory and future work should concentrate on establishing the chemical and petrological variation in the known chert sources so that archaeological artefacts can be identified to a source with greater confidence.

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