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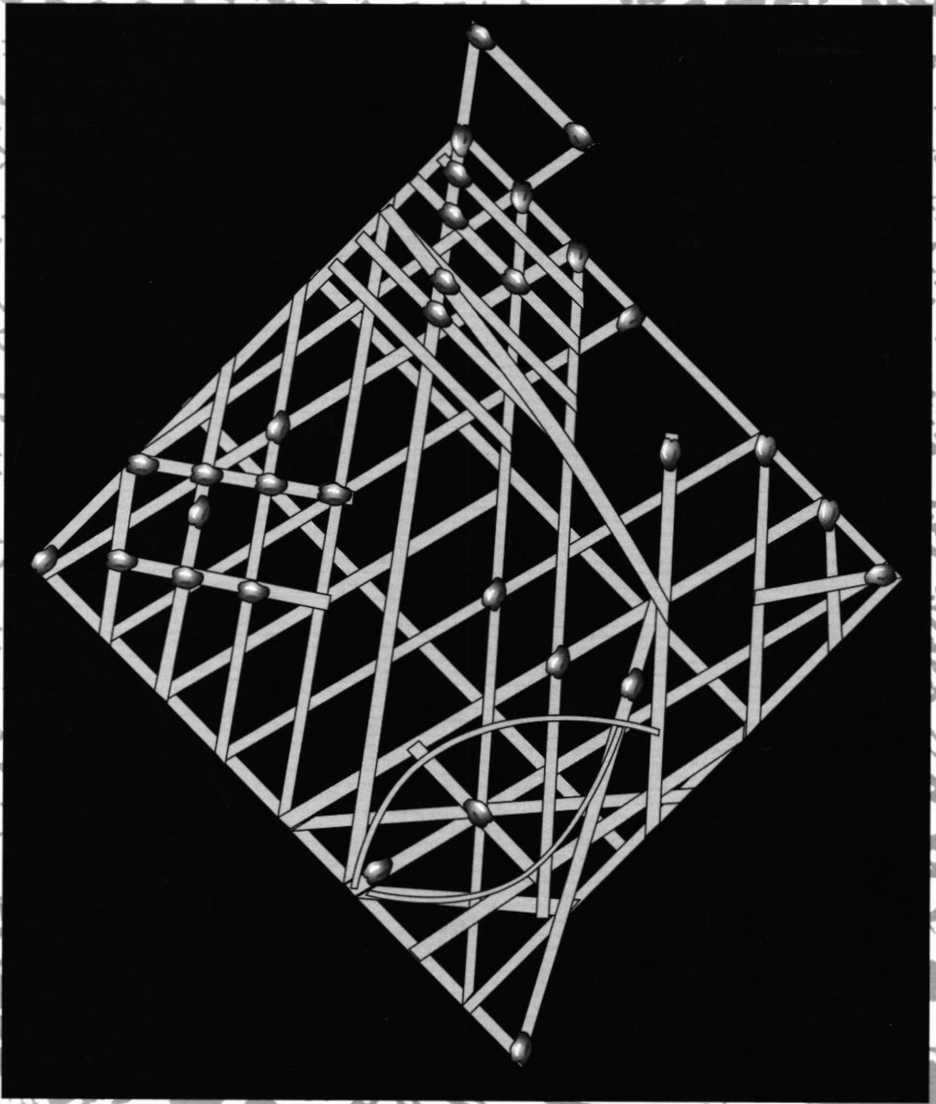

PREHISTORIC LONG-DISTANCE INTERACTION IN OCEANIA: AN INTERDISCIPLINARY APPROACH

Edited by Marshall I. Weisler

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NEW ZEALAND ARCHAEOLOGICAL ASSOCIATION
MONOGRAPH

A GEOCHEMICAL DATABASE FOR POLYNESIAN ADZE STUDIES

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It has long been known that stone tools formed an essential component of Polynesian culture. While the study of stone artefacts has traditionally been made on stylistic characteristics, more recently, the use of chemical data has gained increasing attention among archaeologists as a reliable way to characterise stone materials (see review by Weisler 1993a). The techniques and procedures involved in chemically characterising volcanic materials have been well established in the geological community. In this paper, we report the results of a study using standard geochemical techniques to characterise volcanic rock materials of archaeological importance. The goal of the project was to provide baseline data on geological materials known to be documented or potential sources used by Polynesians. When a comprehensive database of such sources is complete it will be possible to determine the original source for stone artefacts recovered from archaeological sites, which may be far removed from where they were found. Although determining source will not directly answer questions concerning the cultural network involving dispersal, patterns of interaction should emerge once a reliable method for sourcing materials has been established. Hence, the fundamental goal of this project is to provide a sufficient body of data that will allow archaeologists to reliably determine sources of important stone materials found in archaeological sites. In reality a fully comprehensive database should include multiple analyses from every possible quarry site. Clearly we are a long way from achieving this goal, both because all known quarries have not yet been analysed and because only a few of the quarries utilised by Polynesians are presently known. Despite these limitations data are now available for some 36 quarries from throughout Polynesia, and many artefacts can be confidently assigned to source based on geochemical data (e.g., Chapter 7, 8 and 10).

Most previous studies on the geochemistry of Polynesian archaeologic materials were mainly concerned with individual islands or archipelagoes (e.g., Baker 1993; Weisler 1993a, b, 1994). In contrast, the pioneering study by Best *et al.* (1992) provided a wealth of new data and, although primarily concerned with Samoan sources, attempted to provide a means for distinguishing quarry sites from most of Polynesia. Our work builds on this previous effort and significantly expands the geochemical database available for Polynesia.

A GEOCHEMICAL DATABASE FOR ARCHAEOLOGICAL STUDY

In 1991 we began the compilation of geochemical data on reference collections for Polynesian adze studies. The database currently contains data for 280 individual samples. The data include new analyses obtained using the University of Hawaii wavelength-dispersive x-ray fluorescence facility (WDXRF), as well as chemical analyses gleaned from the literature. Additionally, several samples were studied in thin section in order to supplement the geochemical data with petrographic descriptions. Samples included in the database were obtained from the Bishop Museum, collections from the University of Hawaii Department of Geology and Geophysics, samples donated by various archaeological researchers and analyses from the literature.

Database structure

The database structure is in the form of records and fields. Each record represents a single rock sample or analysis; documentation for each sample is in a series of 40 fields. Twenty-eight of these fields are the chemical data for that sample; the other 12 fields document the sample in terms of its physical description and the site from where it was collected. Field designations are as follows: (1) *Sample No.* is the unique number or label that identifies each sample; (2) *Province* is the archipelago from which the sample comes. For Site samples it is the archipelago where the sample was collected; (3) *Island* is the island where the sample was collected; (4) *Site* is the name of the locality where the sample was collected; (5) *Site Description* is a description of the site where the sample was collected; (6) *Site Type* is the designation of the sample locality into one of the three categories: quarry, source or site (see below); (7) *Possible Source* is reserved for *Site* samples where a correlation with a known source can be made with confidence; (8) *Sample Description* a description of the physical sample analysed; (9) *Thin-section Description* is a petrographic description in thin section, where available; (10) *Chemical Data* are listed either as major element oxides in weight % (12 fields) or trace elements in parts-per-million (16 fields); (11) *Method* describes the method of analysis. At this time only wavelength-dispersive x-ray fluorescence data are included in the database; (12) *Lab* is where the data were obtained; and (13) *Ref* contains references for published works related to the individual samples and/or sites.

We have combined these data into a database manager which links files and allows the database to be queried for specific geographic, sample type or compositional ranges. At present we are using Borland's Paradox, in both DOS and Windows versions, which requires a computer with 80386 or higher processor and at least 4 MB of RAM memory. However, the database should be able to be incorporated into any of the database managers that are commercially available for DOS, Windows and MacIntosh operating systems. The database manager allows for a variety of report forms to be generated, such as tables of geochemical data or complete records for individual samples. An example of one of these individual record forms is shown in Figure 11.1.

Site types

A variety of sample types were analysed in this study. We follow Weisler and Sinton (Chapter 10) in dividing the samples into three types, based on knowledge of the site from which the sample was collected. These are described below.

Quarry samples. These samples were collected from locations where previous archaeological study has concluded that the site was actively quarried by Polynesians. In most cases we have confirmed that quarry samples are identical to geologic outcrops from the area. This category represents the most important sources against which artefacts can be compared.

Source samples. In several cases complete documentation of quarries is lacking for important provinces. Also, in some cases, preliminary evidence suggests that particular localities may have been used for stone tools, but archaeological documentation is presently insufficient to designate the specific locality as a quarry. In all cases, source samples can reliably be considered to represent analytical data from actual geological outcrops from specific localities. In general, source samples constitute a class of potential sources for stone tools.

Site samples. This category includes artefacts from archaeological sites. As shown below, some of these artefacts can be reliably sourced using the database compiled in this project.

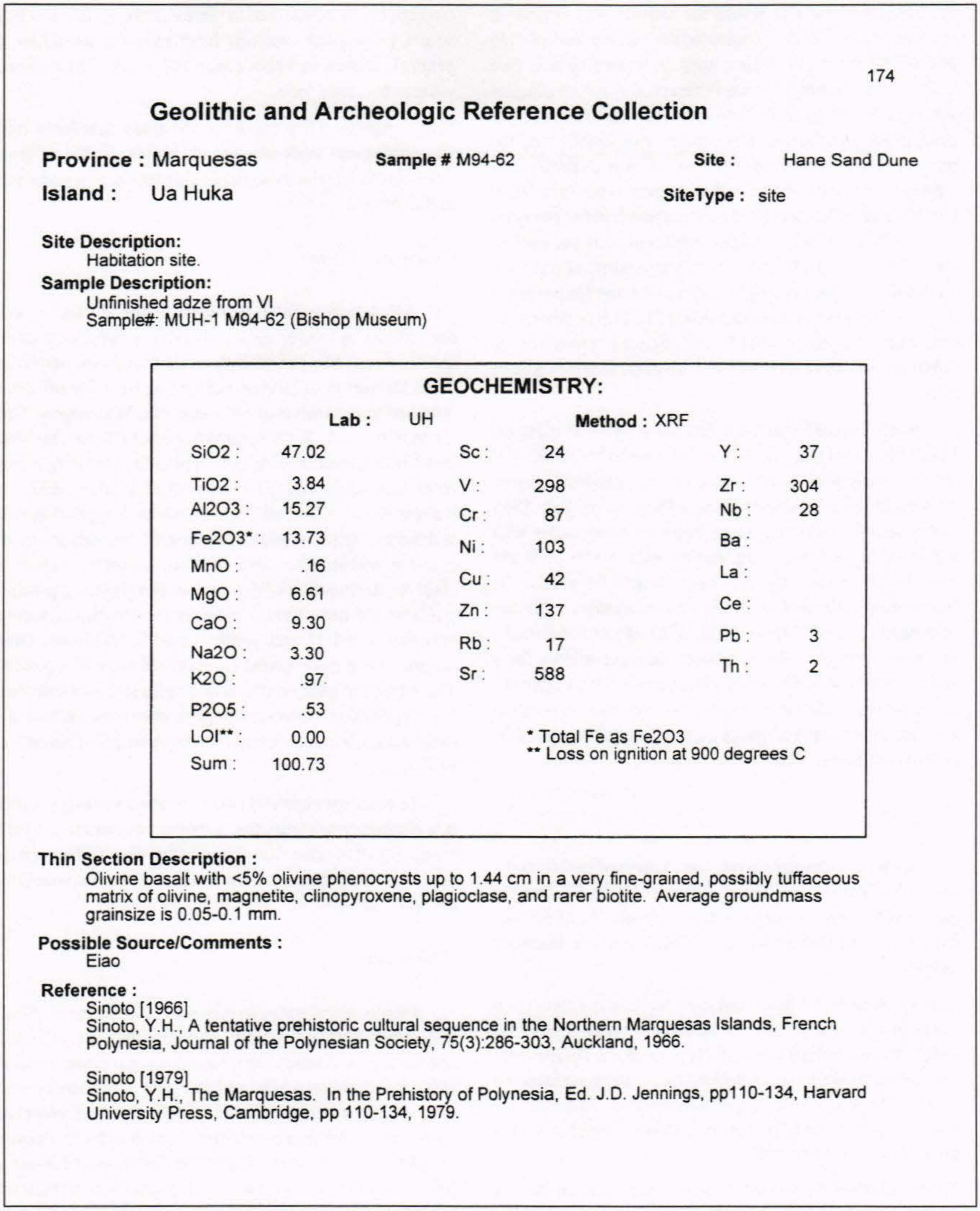
Geochemical data

All data presently included in the database were determined by wavelength-dispersive x-ray fluorescence spectrometry. Most of the data are new analyses performed at the University of Hawaii, but we also have included data obtained at the University of Auckland, Washington State University, the U.S. Geological Survey, Oxford University and North Carolina State University. Chemical data from other techniques could be included at a future date. The highest quality XRF data come from wavelength-dispersive techniques which require reduction of the sample to the finest possible grain size. Hence, sample preparation involves degradation of the sample. For the most precious artefacts we have used a micro-corer which takes cores between 5 and 15 mm (millimetres) in diameter. Other samples have been sawed and crushed to a fine powder. The minimum sample size is that sufficient to yield about 1-2 g (grams) of powder; complete chemical analysis and thin-section fabrication requires degradation of about 10 g of sample.

In order for chemical data to be used to assign source, it is necessary to assess two important parameters. One is the quality of the chemical data, and the other is the chemical variability within a given source locality. These parameters are discussed below.

Data quality

Geochemical data are presented as two types. Major and minor elements (those elements that are relatively abundant in volcanic rocks) have been analysed on fused glass disks, prepared in accordance with procedures similar to those of Norrish and Hutton (1969). These elements are presented as weight per cent (parts-per-hundred). Because oxygen is not analysed, the major elements are listed as oxides assuming electronic neutrality and the most common valence state of the analysed cation. Relative precision for the University of Hawaii system is better than 1% relative for oxides of Si (silicon), Ti (titanium), Al (aluminium), Fe (iron), Mg (magnesium) and Ca (calcium), about 2% relative for Mn (manganese), K (potassium) and P (phosphorous),



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Geolithic and Archeologic Reference Collection

Province : Marquesas **Sample #** M94-62 **Site :** Hane Sand Dune

Island : Ua Huka **SiteType :** site

Site Description:

Habitation site.

Sample Description:

Unfinished adze from VI
Sample#: MUH-1 M94-62 (Bishop Museum)

GEOCHEMISTRY:

Lab : UH **Method :** XRF

SiO2 :	47.02	Sc :	24	Y :	37
TiO2 :	3.84	V :	298	Zr :	304
Al2O3 :	15.27	Cr :	87	Nb :	28
Fe2O3* :	13.73	Ni :	103	Ba :	
MnO :	.16	Cu :	42	La :	
MgO :	6.61	Zn :	137	Ce :	
CaO :	9.30	Rb :	17	Pb :	3
Na2O :	3.30	Sr :	588	Th :	2
K2O :	.97				
P2O5 :	.53				
LOI** :	0.00				
Sum :	100.73				

* Total Fe as Fe2O3
** Loss on ignition at 900 degrees C

Thin Section Description :

Olivine basalt with <5% olivine phenocrysts up to 1.44 cm in a very fine-grained, possibly tuffaceous matrix of olivine, magnetite, clinopyroxene, plagioclase, and rarer biotite. Average groundmass grainsize is 0.05-0.1 mm.

Possible Source/Comments :

Eiao

Reference :

Sinoto [1966]
Sinoto, Y.H., A tentative prehistoric cultural sequence in the Northern Marquesas Islands, French Polynesia, Journal of the Polynesian Society, 75(3):286-303, Auckland, 1966.

Sinoto [1979]
Sinoto, Y.H., The Marquesas. In the Prehistory of Polynesia, Ed. J.D. Jennings, pp110-134, Harvard University Press, Cambridge, pp 110-134, 1979.

FIGURE 11.1. An example of a data sheet from the Geolithic and Archeologic Reference Collection.

and about 5% for Na (sodium). Relative precision means relative to the abundance in that sample. Hence, our estimated absolute reproducibility for SiO_2 (silicon-oxide) in samples with 50 wt % SiO_2 is better than about 0.5 wt %.

Trace elements (those elements present only in trace amounts) were analysed on pressed powder pellets, using procedures similar to those of Chappell (1991). Trace element data are listed in ppm (parts-per-million). Where no analytical data are listed, the elements were not analysed. Values listed as 0 are present in abundances less than the lower limit of detection of our analytical system. Approximate absolute precisions and detection limits for trace elements from the University of Hawaii laboratory are given in Table 11.1.

Element	Detection Limit (ppm)	Absolute Precision (ppm)
Sc	3	2
V	3	3
Cr	3	3
Ni	3	3
Cu	3	3
Zn	3	3
Rb	0.6	1
Sr	1	1
Y	1	1
Zr	1	2
Nb	0.5	1
Ba	8	10
La	8	10
Ce	5	5
Pb	2	1
Th	2	1

TABLE 11.1. University of Hawaii trace element precision and detection limits.

Inter-laboratory comparisons

Several individual samples were analysed in more than one laboratory, but by the same general method (XRF). This allows us to further assess the reliability of data presented in the database. For example, Table 11.2 compares data collected in this project with that reported by Best *et al.* (1992). A comparison between the University of Hawaii lab and that at Washington State University is presented in Table 11.3 (WSU data from Weisler 1990). In this case, 10 presumably identical sample powder splits from the Mo'omomi quarry of West Moloka'i were provided to both labs by Weisler. Data for both major and trace elements are listed as average values of the 10 measurements ± 1s (standard deviation) from the mean. Significant differences in Zr (zirconium), Zn (zinc), Sr (strontium) and Nb (niobium) data from Tataga-matau samples analysed by Washington State University (Weisler 1993b) and Auckland University (Best *et al.* 1992) suggest that there may be analytical biases between these laboratories (Chapter 10).

Sample #	MA-Q1-2		Oa-Q1-1		Oa-Q2-1	
Lab	H	A	H	A	H	A
SiO_2	50.99	51.13	52.75	52.54	53.17	52.89
TiO_2	2.02	2.00	2.21	2.16	2.15	2.13
Al_2O_3	17.57	17.46	13.71	13.71	13.99	13.66
Fe_2O_3*	10.57	10.54	11.47	11.25	11.59	11.44
MnO	0.24	0.25	0.15	0.16	0.14	0.16
MgO	2.55	2.46	6.57	6.47	5.96	5.67
CaO	6.25	6.31	9.16	9.16	9.50	9.45
Na_2O	6.48	6.26	2.79	2.59	2.65	2.85
K_2O	2.27	2.25	0.73	0.74	0.35	0.40
P_2O_5	0.85	0.93	0.34	0.36	0.29	0.33
LOI**	0.08	0.20	0.69	0.70	1.03	0.80
Sum	99.86	99.79	100.57	99.84	100.81	99.78

* Total Fe as Fe_2O_3; ** Loss on ignition at 900°C.

TABLE 11.2. Laboratory comparison: Hawaii (H) verses Auckland (A).

Quarry variability

Few quarries have been sampled sufficiently to properly assess the local variability within them. For example, in the absence of combined geological and archaeological mapping of individual quarries, it is generally unknown how many actual geological units were sampled at each quarry. However, the database contains enough analyses from a few quarries so that a preliminary assessment can be made. For example, more than one chemical type (i.e., multiple lava flows or dykes) are present in the data for the Mauna Kea and Keahua quarries of Hawaii, the Tautama quarry of Pitcairn, the Tataga-matau quarry of Samoa and the Tahinu quarry of Tahiti, indicating that various geological units were worked in each of these places. However, in all cases except that for Tahinu, where the data are presently too sparse, it is clear that one chemical type is more common than the others and hence, probably represents the primary material for that quarry.

Another type of quarry variability is the chemical variability within individual geological units. Again, few quarries have been sampled sufficiently to properly assess this variability although a significant body of data exists for the Mauna Kea and Mo'omomi adze quarries of Hawaii, the Tataga-matau quarry of Samoa, the Down Rope and Tautama quarries of Pitcairn and the Eiao quarry in the Marquesas. An assessment of this type of quarry variability is included in Weisler and Sinton (Chapter 10). The results of this assessment indicate that, in most cases, the standard deviations from the means for most elements are greater than those arising from analytical uncertainty. These

	H (n = 10)	W (n = 10)		H (n = 10)	W (n = 10)
SiO_2	44.52 ± 0.15	45.48 ± 0.12	Sc	17 ± 0.8	19 ± 2.6
TiO_2	4.17 ± 0.02	4.10 ± 0.01	V	312 ± 4.3	302 ± 7.7
Al_2O_3	15.75 ± 0.07	15.48 ± 0.04	Cr	14 ± 1.7	5 ± 1.7
Fe_2O_3*	15.95 ± 0.15	15.54 ± 0.20	Ni	86 ± 1.7	68 ± 1.9
MnO	0.18 ± 0.01	0.18 ± 0.01	Cu	32 ± 2.2	12 ± 5.6
MgO	6.31 ± 0.11	6.22 ± 0.08	Zn	149 ± 1.3	133 ± 1.9
CaO	8.45 ± 0.06	8.40 ± 0.03	Rb	13 ± 0.4	14 ± 0.9
Na_2O	3.46 ± 0.07	3.47 ± 0.07	Sr	781 ± 7.6	786 ± 6.6
K_2O	0.91 ± 0.02	0.91 ± 0.02	Y	39 ± 0.4	38 ± 1
P_2O_5	0.64 ± 0.01	0.61 ± 0.01	Zr	298 ± 4.3	273 ± 2.9
Sum	100.34	100.39	Nb	25 ± 0.4	27 ± 1.2
			Ba	236 ± 16	220 ± 21

Data are presented as averages of the 10 analyses, ± 1 sigma.

TABLE 11.3. Laboratory comparison Hawaii (H) verses Washington State University (W) for Mo'omomi quarry samples.

deviations give a preliminary indication of the real geological variability of the outcrops being quarried, although interlaboratory biases also contribute to the variability in some cases (see Chapter 10).

Samples in the database

The database currently contains chemical analyses of 280 individual samples. The sample distribution by province and site type is shown in Table 11.4. Below we review the sample coverage for the individual island provinces. Average chemical data for specific quarries also are presented and discussed. These averages include data from both actual quarry samples and artefacts that are chemically identical (within analytical uncertainty) to the quarry samples. As discussed above, more than one chemical type is present in the data for some quarries. However, in most cases it is possible to identify one of the chemical types as being more important, either because of field evidence documented at the quarry or because one chemical type predominates in the database. Where possible we have reported averages only for those most important chemical types for each quarry; where data are presently insufficient to make this determination, data for the various chemical types are presented.

Province (# Islands)	Quarry Samples (# Quarries)	Source Samples	Site Samples	Total
Hawai'i (8)	58 (12)	13	16	87
Samoa (1)	35 (4)	8	3	46
Cook Is. (2)	7 (4)	7	4	18
Pitcairn (1)	14 (2)	2	14	30
Henderson (1)			5	5
Easter (1)	16 (5)	1	5	22
Marquesas (5)	8 (4)	2	27	37
Society Is. (4)	14 (5)		13	27
Gambiers (7)		5	3	8
Total	152 (36)	38	90	280

TABLE 11.4. Summary of samples in database.

Hawaii. To date we have included 87 rock analyses from the Hawaiian Islands. These include 58 samples from 12 well-documented adze quarries, and various other source and site samples. The total sample coverage is presented in Table 11.5, and average chemical data for the best documented and/or analysed Hawaiian quarries are presented in Table 11.6. Although more than one chemical type is known to be present in the huge quarry complex on Mauna Kea (McCoy 1990), only the main composition from the principal quarry site near the summit is listed in Table 11.6.

Pitcairn. Quarry samples are from the Tautama (hawaiite) and Down Rope (dacite) quarries. Source rocks from two secondary sources near Tautama have been analysed, in addition to various site samples (artefacts). Several artefacts from Henderson Island can be assigned confidently to sources on Pitcairn (Weisler 1994, 1995; Chapters 9 and 10). Average chemical data for Down Rope and Tautama quarries are listed in Table 11.7.

Samoa. All samples analysed so far are from Tutuila. The Tataga-matau quarry is currently the most analysed quarry in Polynesia, primarily because of the large number of analyses included in Best *et al.* (1992). Table 11.7 includes average chemical data for two other east Tutuila quarries for which new data are included in the database. In addition, analyses are available from Mako Ridge and Fa'ala'aga sources (Weisler 1993b) and Fagasa quarry (see Chapter 5).

Hawaii	Quarry Samples (# Quarries)	Source Samples	Site Samples	Total
Ni'ihau			1	1
Kaua'i	5 (1)		5	10
O'ahu	6 (2)		2	8
Lāna'i	6 (1)		6	12
Kaho'olawe	8 (1)			8
Moloka'i	16 (4)	7		23
Maui	4 (1)		1	5
Hawai'i	13 (2)	6	1	20
Total	58 (12)	13	16	87

TABLE 11.5. Sample coverage for the Hawaiian Islands.

Marquesas. Table 11.8 summarises our analytical effort so far in the Marquesas Islands. Although much work remains to be done for this province, several interesting results are beginning to emerge. For example, of the 37 analysed samples from the Marquesas, 19 of these can be confidently assigned to the major quarry on Eiao (Table 11.7). Also, large flakes of an unusual sodalite-bearing phonolite have turned up in sites on three different Marquesan islands (Ua Huka, Nuku Hiva and Tahuata); although the exact location of the source for this material is unknown, chemically it is most like a phonolite analysis from Motopu on Tahuata (Brousse 1978), although the exact location of the source for this material is unknown, chemically it is most like phonolites present on Ua Pou (e.g., Chapter 8).

Rapa Nui (Easter Island). Five known quarries have been well sampled on Easter Island (Table 11.9). These include rhyolitic obsidian quarries on Rano Kau (two localities), Maunga Orito and Motu Iti. Chemical analyses of samples from Maunga Orito and Te Manavai on Rano Kau (Rano Kau I) are identical within analytical precision (Table 11.10). These two glassy rhyolite structures are aligned along a fissure system and may have formed from the same eruption. In contrast, the obsidian quarry from Rano Kau summit (Rano Kau II) is sited in explosion debris formed during one of the climactic eruptions leading to the formation of the large crater of Rano Kau. Slight distinctions in chemical composition allow differentiation of the Motu Iti and Rano Kau II sites from each other, as well as from the Orito-Te Manavai localities.

The database includes new data on an hawaiite adze quarry near Ovahe. Additionally, source rocks from Orongo and a flake from Vai'atare (both are benmoreites), and hawaiite from Rano Raraku also were sampled and analysed.

Society Islands. Much work remains to be done on Society Islands quarries as several known quarries have not yet been chemically analysed. Sample coverage is presented in Table 11.11, and quarry averages for Society Islands quarries are listed in Table 11.12. A major quarry area near Tahinu in the back of Papeno'o Valley is chemically diverse, suggesting at least two chemical types were quarried there. These are listed as Tahinu I and Tahinu II in Table 11.12. In addition to the well known quarry at Vaiopatapata, uniform chemical composition of several artefacts suggests a second quarry on Ra'iatea, for which the exact location is presently unknown to the authors. It is notable that the identification of a Vaiopatapata source for an artefact recovered from the Cook Islands (Chapter 7) is one of the few exceptional cases where either stone or tools can be shown to have traveled between archipelagoes (see also Weisler 1993c; Weisler and Kirch 1996; Walter and Sheppard 1996; Chapters 6 and 9).

Cook Islands. A total of 36 samples have been analysed from the Cook Islands. Three source rocks from Aitutaki and six sources on Mangaia have been analysed in addition to data from Ma'uke (listed in Best *et al.* 1992; see also Weisler *et al.* 1994). The Aitutaki sources include rocks from the main island, Rapota and Moturakau islets. In addition three samples from sites on Aitutaki have been analysed. These are all different from the sampled sources and probably do not come from Aitutaki; one probably comes from the Vaiopatapata quarry on Ra'iatea (Chapter 7).

Mangareva (Gambiers). Eight source rocks from the Gambier Islands have been analysed. These were all collected by Marshall Weisler from possible sources. No confirmed quarries have been archaeologically documented from the Gambiers despite two field seasons of survey in 1991-1992 (Weisler 1996).

SIGNIFICANT RESULTS

A preliminary database containing chemical analyses of 280 samples of archaeological interest is available for comparison with data on artefacts from archaeological sites. This database will continue to expand as additional data are obtained. However, although still relatively small and incomplete, sufficient data exist to confidently assign a source to many artefacts.

The most important result of this study confirms that virtually all of the major quarries studied throughout Polynesia are chemically unique. This conclusion is particularly true when thin-section descriptions are combined with a full suite of major and trace element analyses. Although geological processes sometimes combine to produce lavas in different areas with grossly similar chemical composition, the combination of mineralogy, rock texture and chemistry can be used to discriminate individual lava flows, even within a particular

Island	Hawai'i				Maui		Kaho'olawe		Lāna'i		West Moloka'i	
Quarry	Mauna Kea		Pololū		Haleakalā		Pu'umōiwi		Kapōhaku		Ka'a	Ka'eo
n	*8*		*3*		*3*		*7*		*5*		*1*	*1*
SiO_2	47.99	0.57	49.36	0.10	51.00	0.11	52.37	0.34	51.48	0.34	47.11	49.91
TiO_2	3.95	0.14	2.53	0.07	2.02	0.01	2.98	0.04	2.11	0.03	3.70	3.04
Al_2O_3	13.44	0.17	17.11	0.34	17.49	0.06	14.02	0.34	13.96	0.11	15.86	13.72
Fe_2O_3*	15.32	0.17	12.23	0.23	10.57	0.03	13.18	0.13	12.11	0.12	14.03	13.34
MnO	0.21	0.01	0.22	0.01	0.25	0.00	0.17	0.01	0.16	0.00	0.18	0.17
MgO	5.07	0.16	3.50	0.15	2.49	0.04	4.60	0.10	7.10	0.30	4.93	5.57
CaO	9.58	0.24	6.54	0.06	6.27	0.03	8.37	0.18	10.06	0.08	7.51	9.74
Na_2O	3.08	0.18	5.10	0.04	6.25	0.18	3.00	0.06	2.29	0.13	4.28	2.62
K_2O	1.13	0.06	1.85	0.03	2.25	0.01	0.85	0.02	0.52	0.02	1.39	0.63
P_2O_5	0.56	0.03	1.91	0.05	0.88	0.04	0.38	0.04	0.25	0.01	0.90	0.39
LOI**	0.01	0.03	0.08	0.08	0.44	0.43	0.27	0.25	0.34	0.20	0.29	0.63
Sum	100.34		100.43		99.91		100.18		100.62		100.20	99.76
n	*2*		*1*		*2*		*4*		*5*		*1*	*1*
Sc	29	0.01	11		7	0	28	0.01	30	0.01	15	29
V	427	1	48		38	0	345	8	304	9	169	339
Cr			0		6	0.01	59	2	291	25	8	61
Ni	30	1	0		0	3	60	4	118	8	4	77
Cu	35	6	8		8	0	75	11	103	10	9	114
Zn	137	0	116		133	0.01	145	14	106	7	135	163
Rb	30	0	37		55	0	16	1	7	0.01	23	10
Sr	538	2	1678		1105	4	396	3	357	18	1010	453
Y	39	0.01	58		41	0	65	28	64	31	74	162
Zr	314	9	419		412	2	228	0	136	5	411	213
Nb	44	2	63		77	0	17	0	10	0	39	16
Ba	405	1	706		886	7	299	40	97	4	424	153

Island	West Moloka'i				O'ahu				Kaua'i			
Quarry	'Amikopala		Mo'omomi		Waiāhole		Kailua		Keāhua I		Keāhua II	
n	*2*		*12*		*3*		*2*		*3*		*3*	
SiO_2	50.56	0.42	44.45	0.29	52.81	0.25	53.03	0.14	45.64	0.14	46.17	0.33
TiO_2	2.61	0.06	4.16	0.04	2.19	0.02	2.14	0.01	2.43	0.02	3.09	0.03
Al_2O_3	13.81	0.00	15.74	0.07	13.77	0.08	13.82	0.16	14.94	0.12	16.84	0.10
Fe_2O_3*	12.70	0.27	15.97	0.20	11.37	0.09	11.52	0.08	14.21	0.12	12.26	0.11
MnO	0.16	0.01	0.18	0.00	0.15	0.01	0.15	0.01	0.18	0.00	0.22	0.00
MgO	6.09	0.24	6.22	0.25	6.54	0.05	5.81	0.14	7.83	0.02	4.05	0.15
CaO	9.90	0.31	8.41	0.12	9.14	0.03	9.48	0.03	11.18	0.01	7.94	0.27
Na_2O	2.29	0.03	3.42	0.11	2.69	0.08	2.75	0.10	3.02	0.11	5.44	0.15
K_2O	0.52	0.05	0.91	0.02	0.71	0.04	0.38	0.03	0.53	0.02	2.09	0.03
P_2O_5	0.34	0.04	0.64	0.01	0.34	0.01	0.31	0.02	0.31	0.01	1.28	0.17
Loi**	0.58	0.23	0.18	0.54	0.64	0.08	0.91	0.11	0.03	0.04	0.32	0.25
Sum	99.56		100.28		100.36		100.30		100.31		99.70	
n	*1*		*11*		*2*		*1*		*3*		*3*	
Sc	31		17	0.01	26	0.01	23		27	0.01	8	2
V	311		311	5	272	6	267		335	8	141	14
Cr	187		14	2	225	2	148		172	5	11	5
Ni	94		89	11	123	6	93		106	3	11	5
Cu	122		32	2	106	14	127		55	2	16	2
Zn	133		150	3	104	0.01	100		106	4	138	5
Rb	7		13	0	10	0.01	25		12	0	55	0
Sr	383		780	8	445	3	405		506	3	1427	25
Y	127		39	0	25	0	26		23	0.01	39	2
Zr	167		298	4	167	0	157		107	2	342	2
Nb	11		25	0	10	0	10		23	0.01	91	1
Ba	89		236	16	119	5	85		259	4	995	10

n = number of analyses in average; * total Fe as Fe_2O_3; ** loss on ignition at 900°C.

TABLE 11.6. Quarry averages for the Hawaiian Islands.

	Pitcairn				Samoa						Marquesas		
Island	Pitcairn				Tutuila						Eiao		Nuku Hiva
Quarry	Down Rope		Tautama		Tataga- matau		Le'aeno		Maupua		Eiao		Ha'aupa'upa
n	*7*		*21*		*30*		*4*		*2*		*19*		*11*
SiO_2	62.65	0.24	49.93	0.36	48.52	0.56	47.91	0.09	46.53	0.06	46.95	0.21	48.40
TiO_2	0.58	0.01	2.68	0.04	3.42	0.07	3.71	0.02	4.21	0.05	3.90	0.11	2.93
Al_2O_3	16.27	0.13	15.57	0.21	15.51	0.19	16.03	0.04	15.54	0.10	15.23	0.14	13.31
Fe_2O_3*	6.46	0.01	13.45	0.13	13.66	0.24	14.06	0.06	14.32	0.38	13.53	0.10	12.16
MnO	0.18	0.01	0.22	0.02	0.18	0.01	0.17	0.01	0.16	0.01	0.16	0.01	0.15
MgO	0.32	0.04	3.49	0.11	4.79	0.14	4.93	0.05	5.14	0.27	6.47	0.13	8.40
CaO	1.87	0.02	7.09	0.10	7.54	0.08	7.73	0.03	7.71	0.26	9.32	0.05	10.68
Na_2O	5.86	0.12	4.55	0.20	3.76	0.17	3.43	0.13	3.20	0.13	3.18	0.11	2.06
K_2O	4.97	0.04	1.99	0.05	1.55	0.04	1.52	0.06	1.38	0.04	1.00	0.03	0.67
P_2O_5	0.12	0.00	1.25	0.07	0.78	0.02	0.73	0.02	0.68	0.02	0.54	0.04	0.31
LOI**	0.12	0.06	-0.11	0.25	-0.10	0.24	-0.18	0.14	0.84	0.84	-0.12	0.15	0.67
Sum	99.47		100.11		99.61		100.03		99.69		100.16		99.74
n	*5*		*6*		*17*		*3*		*1*		*3*		
Sc	12	1	14	1	19	3	19	0	21		24	1	
V	2	5	109	2	210	8	247	3	198		297	8	
Cr	3	1	8	1	1	2	0	0	<4		87	5	
Ni	4	1	1	2	0	1	23	0	36		100	3	
Cu	4	1	15	2	5	5	25	2	30		47	5	
Zn	159	7	171	5	182	11	181	1	150		130	6	
Rb	85	1	39	2	42	3	39	1	342		18	2	
Sr	58	1	589	1	708	7	764	1	107		591	2	
Y	64	0	48	1	49	2	43	0	50		37	0	
Zr	772	31	417	2	383	26	391	1	473		306	1	
Nb	114	10	89	16	49	6	47	0	60		28	0	
Ba	1979	34	458	9	305	17	303	1	317		187	5	

Quarry averages ± 1 s; n = number of analyses in average; * total Fe as Fe_2O_3; ** loss on ignition at 900°C

TABLE 11.7. Quarry averages for Pitcairn, Samoa and the Marquesas.

volcano. However, casual users of the database are advised to work closely with geochemists familiar with volcanic petrology in order to properly evaluate whether or not a particular artefact can confidently be assigned to a specific source.

Another result is that data for some quarry localities indicate that more than one lava flow or dyke was worked in the fabrication of tools by Polynesians. For example, more than one chemical type is present in the Mauna Kea, Keāhua, Tautama (Weisler 1993c:219, 223) and Tahinu quarry areas. Complete geological characterisation of the local variability within individual quarries will be required in future studies of this type.

It is worth citing a few examples of successful sourcing exercises. Several artefacts from Henderson Island are identical to quarry samples from Pitcairn; in the Hawaiian Islands, a Ni'ihau site sample comes from the Keāhua quarry on Kaua'i, one adze flake from a site on Kaua'i clearly can be assigned to the Pu'umōiwi quarry on Kaho'olawe; two adzes found under water in Honolulu Harbor and offshore Kaua'i, respectively, both come from Pu'upāpa'i on east Moloka'i. An example of an interesting negative result is that none of the artefacts collected from Aitutaki even remotely resemble analysed source rocks from that island.

Marquesas	Quarry Samples (# Quarry)	Source Samples	Site Samples	Total
Eiao	5 (1)			5
Tahuata			1	1
Ua Huka			10	10
Hiva Oa			1	1
Nuku Hiva	3 (3)	2	15	20
Total	8 (4)	2	27	37

TABLE 11.8. Marquesas Islands samples.

Quarry or Site	# of Samples
Orito Quarry	4
Rano Kau -Te Manavai Quarry	3
Rano Kau - Summit Quarry	5
Motu Iti Quarry	2
Ovahe Quarry	2
Rano Raraku Quarry	4
Orongo Source	1
Vai'atare Site	1
Total	22

TABLE 11.9. Easter Island samples.

Quarry	Orito		Motu Iti		Rano Kau I		Rano Kau II		Ovahe	
n	*4*		*2*		*3*		*5*		*2*	
SiO_2	72.20	0.29	72.24	0.02	72.30	0.09	73.34	0.20	51.28	0.14
TiO_2	0.21	0.01	0.00	0.00	0.21	0.01	0.09	0.08	2.46	0.02
Al_2O_3	12.81	0.09	13.15	0.01	12.74	0.04	12.28	0.04	14.69	0.04
Fe_2O_3*	3.18	0.02	3.33	0.01	3.15	0.02	2.86	0.01	13.96	0.15
MnO	0.07	0.00	0.09	0.00	0.07	0.00	0.06	0.00	0.22	0.00
MgO	0.00	0.01	0.01	0.00	0.00	0.00	0.01	0.01	3.29	0.08
CaO	0.61	0.01	0.81	0.00	0.59	0.00	0.42	0.01	7.16	0.05
Na_2O	5.43	0.11	5.67	0.00	5.39	0.10	5.23	0.14	3.91	0.05
K_2O	3.80	0.02	3.69	0.00	3.81	0.02	4.04	0.01	1.32	0.05
P_2O_5	0.01	0.00	0.02	0.00	0.01	0.01	0.01	0.01	0.82	0.00
LOI**	0.72	0.22	0.41	0.00	0.56	0.15	0.82	0.08	0.94	0.24
Sum	99.05		99.40		98.83		99.16		100.05	
n	*4*		*2*		*3*		*5*		*2*	
Sc	<4		<4		<4		<4		28	1
V	<4		<4		<4		<4		162	3
Cr	<4		<4		<4		<4		<4	
Ni	12	3	11	0	14	3	11	0	7	1
Cu	5	3	3	0	3	2	2	2	5	1
Zn	227	5	214	1	222	3	229	3	154	4
Rb	78	3	74	0	80	2	85	1	28	1
Sr	25	1	43	1	24	0	9	0	299	2
Y	159	2	149	1	159	2	166	3	74	4
Zr	1002	7	836	11	1011	10	926	4	459	2
Nb	177	30	137	2	147	15	134	9	53	1
Ba	458	12	446	2	451	11	393	3	260	10

Quarry averages ± 1 s. n = number of analyses in average; * total Fe as Fe_2O_3; ** loss on ignition at 900° C.

TABLE 11.10. Quarry averages for Easter Island.

The implication is that these artefacts presumably all were quarried elsewhere and transported to Aitutaki.

Finally, a nearly perfect chemical and petrographic match occurs between two adzes purportedly from Eiao in the Marquesas Islands and the Pu'umōiwi quarry samples from Kaho'olawe in the Hawaiian Islands. At face value this result is truly remarkable because it implies transport of lithic material thousands of kilometres between archipelagoes. The chemistry is unlike any other Marquesan rock and hence the chemical match is compelling. However, on further inspection it turns out that both the Eiao samples and several samples from Pu'umōiwi were collected by a yachtsman and donated to the Bishop Museum. Hence the provenance of the 'Eiao' adzes is suspect; the most probable interpretation is that the collections were mixed prior to donation and that the mislabled 'Eiao' adzes were actually collected from Kaho'olawe. Excluding this dubious result, there is only one clearly documented case where stone materials can be confirmed to have traveled between archipelagoes. However, transport within archipelagoes is common.

Society Islands	Quarry Samples (# Quarries)	Source Samples	Site Samples	Total
Tahiti	10 (4)		2	12
Huahine			5	5
Ra'iatea	4 (2)		4	8
Maupiti			2	2
Total	14 (6)		13	27

TABLE 11.11. Society Islands samples.

CONCLUSIONS

The database compiled in this project must be considered only a first step. The total number of analyses is still far too few to be comprehensive. There undoubtedly are many potential sources yet to be found (see Chapter 5), and several known quarries have not yet been analysed, particularly for provinces in French Polynesia. Furthermore, few artefacts have yet been analysed, so the real value of the existing database will come with the analysis of archaeological materials from well-documented sites. We hope that the creation of this database will encourage chemical studies of lithic artefacts wherever they are found throughout Polynesia.

Island	Ra'iatea						Tahiti				
Quarry	Vaiopatapata		Ra'iatea II		Tahinu I		Tahinu II		Papeno'o		Orofero
n	*5*		*2*		*3*		*5*		*2*		*1*
SiO_2	43.95	0.55	46.08	0.04	42.37	0.11	42.73	0.28	44.66	0.02	47.16
TiO_2	4.25	0.07	3.19	0.02	4.54	0.02	3.93	0.09	3.80	0.11	4.26
Al_2O_3	14.36	0.27	17.18	0.29	15.07	0.03	15.15	0.21	14.68	0.03	14.53
Fe_2O_3*	13.17	0.19	10.74	0.09	13.83	0.05	13.83	0.26	14.08	0.24	12.18
MnO	0.16	0.00	0.16	0.01	0.18	0.00	0.19	0.01	0.19	0.00	0.16
MgO	5.50	0.23	4.10	0.02	5.16	0.07	5.01	0.10	5.03	0.13	5.22
CaO	11.00	0.21	8.86	0.26	10.69	0.03	10.45	0.16	11.15	0.12	9.35
Na_2O	2.72	0.12	4.19	0.39	3.72	0.01	3.65	0.20	3.28	0.16	2.25
K_2O	1.61	0.05	2.50	0.01	1.82	0.10	1.98	0.09	1.59	0.03	2.85
P_2O_5	0.67	0.04	1.53	0.00	0.64	0.02	0.67	0.03	0.72	0.02	0.68
LOI**	2.00	0.70	1.50	0.51	2.77	0.14	2.67	0.29	1.09	0.02	1.83
Sum	99.39		100.47		100.80		100.25		100.27		100.47
n	*1*		*2*		*3*		5		*2*		*1*
Sc	22		8	1	19	1	18	1	19	1	23
V	352		158	7	379	11	381	12	340	3	300
Cr	46		8	3	13	13	1	3	0	0	<4
Ni	77		3	1	58	5	53	2	53	3	68
Cu	89		12	1	114	3	110	3	110	2	72
Zn	122		118	4	109	2	114	6	132	1	123
Rb	38		63	1	42	1	53	8	40	2	50
Sr	778		1882	38	734	12	740	30	784	11	720
Y	34		42	0	33	1	34	1	36	1	32
Zr	334		433	0	305	8	311	5	352	8	512
Nb	51		74	0	59	4	60	4	62	2	54
Ba	433		864	2	609	25	587	36	603	17	541

Quarry averages ± 1 s; n = number of analyses in average; * total Fe as Fe_2O_3; ** loss on ignition at 900°C

TABLE 11.12. Quarry averages for the Society Islands.

There are three areas of continued work that should be strongly considered in future studies of this type. One is to continue to analyse quarry materials as they become available. The present database contains data on only 36 well-documented quarries from all of Polynesia, and almost half of these are from Hawaii. There likely are hundreds of other quarries or sources present that await discovery and/or description. We are aware of several other known quarries that were not analysed in this preliminary effort, either because material was not readily available to us, or the resources were not sufficient to complete the analyses. Development of a comprehensive database containing complete characterisation of individual quarries remains of utmost importance.

A second important type of study concerns a detailed sampling of individual quarry areas, in order to better appraise the local variability within large quarry complexes (e.g., Weisler 1993a:76). Unfortunately the geology of each quarry is likely to be somewhat unique and so the results of local variability studies of individual quarry complexes cannot be extended to all others. Nevertheless, it would be very important to attempt to assess local variability within a few, particularly important quarry complexes. This work should be a collaborative effort involving volcanic geologists and local expert archaeologists. It requires field work and extensive sampling and analysis. Due to the variability of the quarries concerned, no single template for how the work should be done is possible. Each complex must be evaluated for its geological and archaeological variability and then sampled and analysed accordingly.

Finally, this database is now ready, even in its preliminary form, to be used for the purpose for which it is intended, i.e., sourcing artefacts. The chemical analysis of lithic materials from archaeological sites should be encouraged. Only when a sufficient body of such data exists, can patterns of cultural interaction begin to emerge.

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