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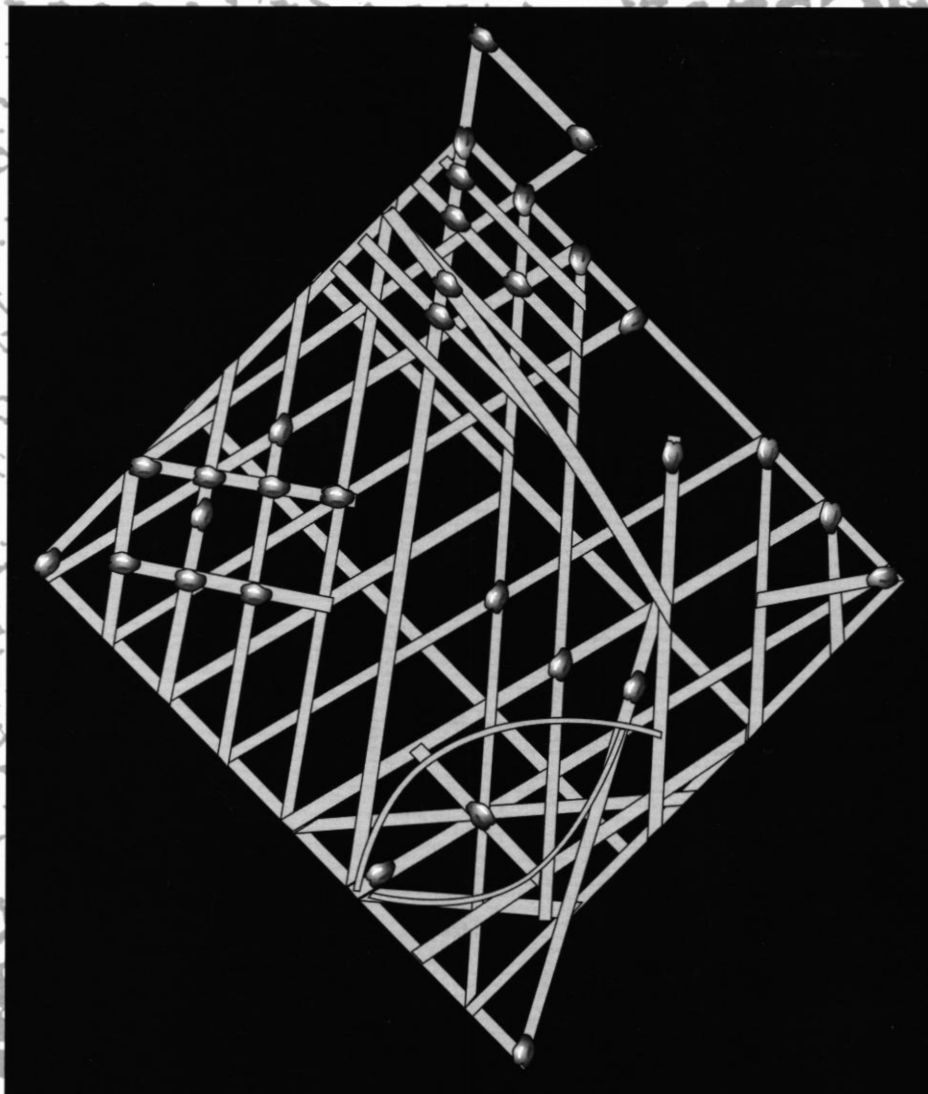

PREHISTORIC LONG-DISTANCE INTERACTION IN OCEANIA: AN INTERDISCIPLINARY APPROACH

Edited by Marshall I. Weisler

21
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BASALT SOURCING AND THE DEVELOPMENT OF COOK ISLAND EXCHANGE SYSTEMS

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The sourcing of lithic and ceramic materials in Oceania plays a very important role in the study of prehistoric inter-island contact. The results of such studies (e.g., Ambrose 1976; Best *et al.* 1992; Cleghorn *et al.* 1985; Dickinson and Shutler 1979; Green 1986; Kirch 1986; Seelenfreund and Bollong 1989; Sheppard 1996; Sheppard *et al.* 1989; Walter and Dickinson 1989; Weisler 1990a, b, 1993a, b; Withrow 1990) have important implications for understanding patterns of movement and colonisation, development of exchange systems, intensification of production and technological change. This paper reports on recent developments in the sourcing of adze stone in the southern Cook Islands.

Assuming unequivocal determination of source, at the simplest level sourcing studies provide one of the strongest lines of evidence for determining the presence and direction of prehistoric contact between two locations. To go beyond the bare fact of contact, in an attempt to measure the degree or intensity of spatial interaction over time requires less direct argument. It is practically possible, in most Oceanic cases, for all the material documented as transported between islands to have been moved in one canoe, possibly during an early colonisation episode. Arguments for repeat contact are generally founded on the total estimated amount of transported material and the chronological extent of archaeological deposits containing exotic material (e.g., Sheppard 1993). Large amounts of material and considerable time depth to associated deposits argues for repeat contacts. However, raw materials and especially finished artefacts can have considerable use histories. Some materials, such as obsidian which is commonly used for the production of expedient tools, may have had brief use histories (although the parent block or core may have had a considerable life); however, other materials and finished artefacts, such as adzes may have existed for decades, and possibly centuries either as treasured heirlooms (Firth 1959) or as increasingly smaller reworked items of exceptionally high quality material. This latter point cautions us to consider use history and stage of reduction when determining the time depth of possible contact periods. Simple quantification of material transported may, assuming all else is equal, inform on relative differences in degree of contact with different sources but absolute figures require a more complex approach.

The study of prehistoric trade or exchange is founded in large measure on the study of the distribution of exotic or non-local materials among archaeological sites. Following from the discussion above, neither trade nor exchange can be directly inferred from the simple evidence of movement (Weisler *et al.* 1994:214). Sourcing studies almost invariably deal with the distribution of materials from raw material source points or areas to sites, rarely do we have evidence of distribution between occupation sites or two-way exchange of artefacts or materials (but see Kirch 1988; see Chapter 9, this volume). Study of a variety of materials will often shed light on a web or network of spatial interactions at various scales (Green 1979; Kirch 1986; Sheppard 1996) and from these it may be possible to construct reasonable hypotheses (e.g., network models) of inter-site or inter-island interaction. Study of variation in the abundance of exotics at sites within such networks could also conceivably serve as a basis for the study of distribution systems and characterisation of the form of such systems although it seems unlikely that simple quantitative 'fall-off' models are capable of differentiating 'types' of exchange (Earle 1982:7).

Intensification is generally defined as the production of more food from the same amount of land or the substitution of labour for land (Brookfield 1984). It is also assumed or postulated that such 'intensification' is linked to change in social organisation especially as it relates to resource management and distribution. In this way intensification can often become short-hand for evolutionary or developmental change. Kirch has suggested (1984:181, 1990:327) that specialised production of items of material culture can be seen as part of intensification strategies which may involve control over raw material resources and artefact distribution (e.g., basalt quarries, adze production and distribution). It is through this link that sourcing studies can contribute to investigations of intensification and sociopolitical transformation (e.g., Friedman 1982). Definition of sources may in some cases rest entirely on the characterisation of archaeological materials and the history of source use or control will in most cases be dependent on chronologies associated with distributed material (e.g., Best *et al.* 1992).

Technological change can be intricately related both to scenarios of specialisation and intensification and to fundamental issues of colonisation and adaptation to new environments, especially as the latter relates to the interplay between available manufacturing techniques and variation in raw material sources (e.g., Allen 1992b for a study of shell fishhooks). In the case of adze manufacture variation in the physical properties of the raw material (Domanksi *et al.* 1994; Leach 1981; Leach and Witter 1987; Sheppard 1996; Turner 1992) can be expected to affect adze morphology and use history. Rock sources can vary in potential blank size and form (e.g., stream cobbles versus jointed bedrock tabular pieces) as well as in basic rock properties such as tensile strength, fracture toughness, homogeneity and hardness. The former may provide fundamental limits on size and influence morphology while the latter may translate into technological properties influencing the application of reduction techniques (e.g., flaking, hammer-dressing, grinding), limiting morphology and affecting use life.

In the following we provide a base-line study of adze material used in the southern Cooks, relate it to known sources or sampled geology and then address the issues which have been briefly reviewed above.

SOURCING IN THE SOUTHERN COOKS

Previous sourcing studies of excavated adzes and adze flakes (Walter 1990, Weisler 1993b; Chapter 9) from the southern Cooks have suggested that some of these are derived from sources in Samoa (Best *et al.* 1992:66). These studies, however, made use of very limited source or geologic data from the southern Cooks. Recent work (Weisler *et al.* 1994) has provided additional data on a Mangaian source, and adze manufacture on the small volcanic island of Moturakau (Allen 1994; Allen and Schubel 1990) located on the outer edge of the Aitutaki lagoon. In neither case do we have evidence of significant quarrying. The Mangaian source was identified from historic records; however, its re-discovery is based on geochemical matches of local rock to Mangaian adzes. No quarry debris was observed on Mangaia. Flaking debris in a small shelter on Moturakau indicates adze manufacture, however the lithic resources of this very small motu are extremely limited and evidence of quarrying is limited to a few negative flake scars on boulders reported by Allen (1992:164). This site was the locus of production of a comparatively small number of adzes from cobbles or boulders during limited occupations which totalled 15 preforms and 137.6 kg of flakes from the excavation of 16, 1 x 1 m units averaging 1.2 m deep (Allen 1992:279, 167, 1994:61). In summary there are no known quarries in the southern Cooks comparable to those found in Samoa (Best *et al.* 1992; Clark and Wright 1994; Leach and Witter 1987; Chapter 5), Hawaii (Cleghorn 1982; Weisler 1990b), Pitcairn (Gathercole 1964; Sinoto 1983; Weisler 1996) or New Zealand (Leach 1990; Turner 1992; see also Leach 1993 for a review of large Pacific adze quarries). It would seem most likely, based on available data, that small scale adze manufacture was carried out in the southern Cooks, at scattered occupation sites or small workshops and not at large quarries.

The specific goals of our study were:

1. To sample a large number of adzes from the southern Cooks in order to estimate the range of rock types used for adze manufacture, and ultimately to determine the number of sources or source areas required to account for this variation;
2. To sample geological sources of potential adze rock from Rarotonga, Aitutaki, Atiu, Mitiaro and Ma'uke (Fig. 6.1) for comparison with the archaeological materials;
3. To intensively sample the phonolite source at Black Rock that may have been a major source for adze material on Rarotonga (Walter 1990:229); and
4. To examine the extent of inter-island contact within the southern Cooks and with other island groups.

METHODOLOGY

A total of 40 provenanced adzes from the Cook Islands Museum and private collections were sampled during field work in December 1992 and January 1993. Data on an additional 18 adzes and adze flakes from the Cook Islands reported in Walter (1990) and Best *et al.* (1992) are also included here in the final analysis of all available data. Appendix 6A provides provenance information for individual adzes.

Selection of adzes for coring was carried out by first sorting all provenanced adzes in the museum (N=116) into groups by island, and then into subgroups using physical characteristics (colour, grain size, phenocrysts). Then,

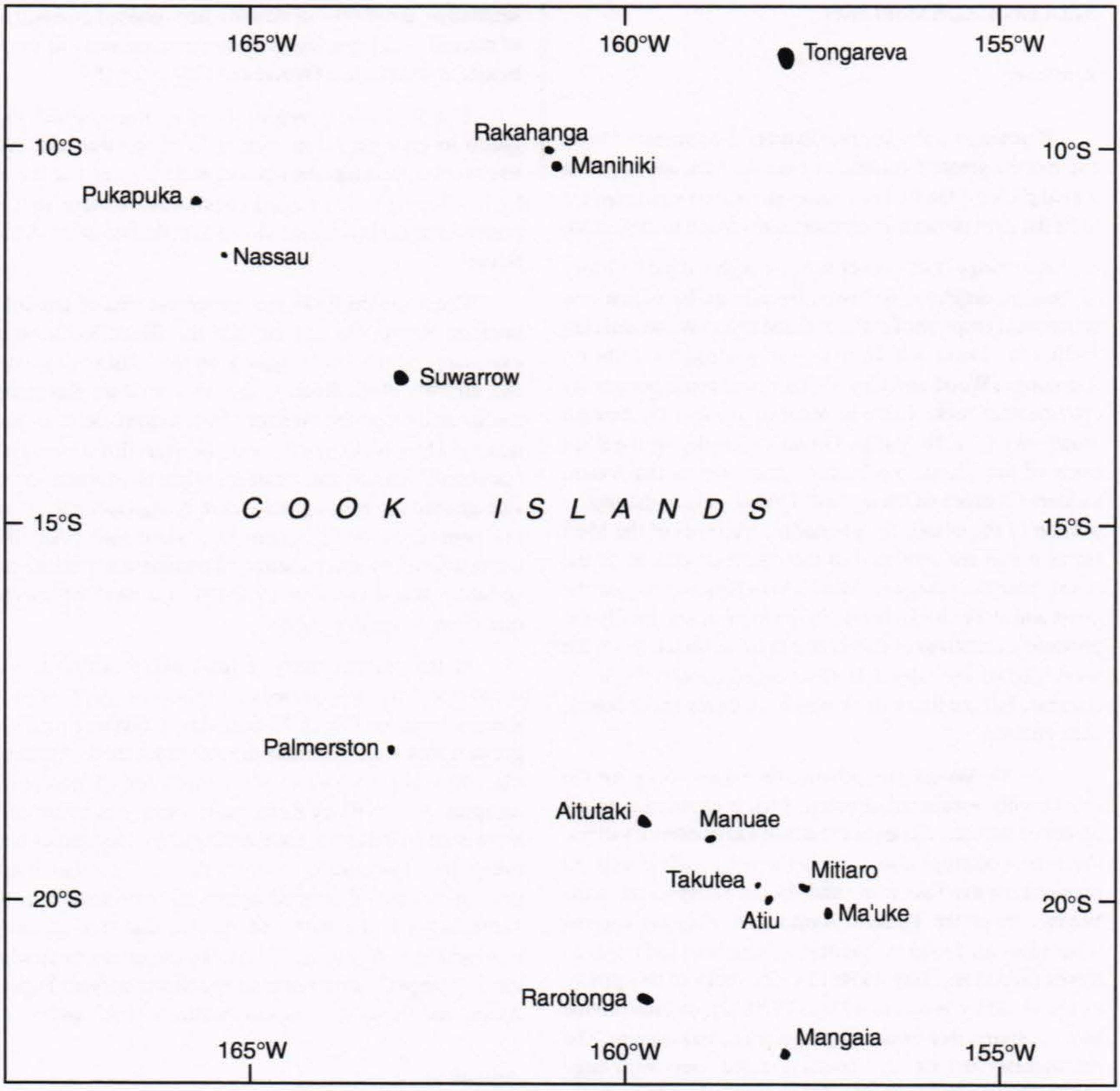

FIGURE 6.1. Map of the Cook Islands.

broken adzes from each of the groups were selected for coring. Weathering and staining of adze surfaces makes it difficult to determine the integrity of these initial categories, however we believe they did serve to provide a broad representative sample of variation in the collection. It was hoped sampling of these groups would allow us to ultimately make statements about the total museum collection.

The high rate of weathering of Cook Islands basalt (Best *et al.* 1992:53) suggested the need to core into the adzes to secure fresh rock for the XRF analysis which requires a sample of greater than three grams. A diamond coring bit of 10 mm diameter, producing an 8 mm core, was used to take samples from broken surfaces of adzes. This operation typically required 10 minutes per adze. The hole was then filled with two part emmerkit epoxy putty that can be tinted and textured to match the adze.

GEOLOGICAL SAMPLING

Rarotonga

Rarotonga is the largest island of the southern Cooks and has the greatest volume of exposed rock and the most varied geology. On first principles Rarotonga would appear to be the most obvious source for adzes found in the Cooks.

Rarotonga is an extinct volcano with a typical history of basaltic eruptions followed by caldera formation and subsequent eruption of differentiated lavas (Wood and Hay 1970:11). There are four major geological units on Rarotonga (Wood and Hay 1970) which could potentially provide adze rock. These in order of age are: the basaltic eruptives of the Te Manga Group that make up the main mass of the island; the basaltic eruptives of the Avatiu Caldera Complex which are restricted to rocks of the central portion of the island; the phonolitic eruptives of the Muri flows which are restricted to the southeast portion of the island near the village of Muri where they outcrop on the coast and at Taa Koka island in the lagoon; and finally the phonolitic eruptives of the Raemaru flows which lie on the west side of the island in the rugged country between Raemaru hill and Black Rock which is the only major coastal rock outcrop.

The Te Manga group being the oldest rocks are the most highly weathered although rock is exposed in many places on the outer slopes of the island and in interior valleys. Prominent outcrops also occur in the steep cliffs and ridges overlooking the Takuvaine and Avatiu valleys, and in the headwaters of the Tupapa, Avatiu and Akapuao streams where they are found in the rocky stream beds and rarely as dykes (Wood and Hay 1970:11). The rocks of this group, as classified by Wood and Hay (1970:12), include olivine basalt, olivine-free basalt, limburgite and ankaramite. The ankaramites include very coarse-grained rocks with large phenocrysts of titanaugite. The olivine basalts contain phenocrysts of olivine and pink titanaugite within a ground mass of potash-oligoclase and some notable flakes of red-brown biotite. The other basalts lack olivine and often contain labradorite lathes showing pronounced flow banding (Wood and Hay 1970:12).

The Avatiu Caldera Complex of the island centre is composed of much the same basaltic rock as the Te Manga Group and differs little from it in terms of weathering or geochemistry. However its structure is much more complex and it contains numerous basalt dykes of all sizes (Wood and Hay 1970:14). The best exposures of this unit are in stream beds, particularly the Takuvaine and Avatiu streams. The olivine basalts which are dominant in this unit contain phenocrysts of olivine which are often replaced by serpentine, zoned titanaugite and a fine- grained groundmass of microlithic plagioclase with some occasional red-brown biotite and nepheline (Wood and Hay 1970:15).

The Muri flows consist of dense, fine-grained, dark green to grey nepheline-rich soda phonolites and soda trachytes containing abundant agerine augite. These very high silica rocks have good conchoidal fracture and are common on the beach near Muri and in the bed of the Avana River.

The Raemaru flows are the largest area of phonolite lava on Rarotonga and include the Black Rock beach exposure and road metal quarry on the coast road west of the airport. Black Rock is the only area on Rarotonga traditionally reported (Walter 1990) to have been an adze quarry. These rocks like those of the Muri flows have good conchoidal fracture and are dark to light olive green, dense, fine-grained and have a greasy lustre in hand specimen. They are generally very fine grained tracytoid soda phonolites characterised by the presence of abundant nepheline and sodalite (Wood and Hay 1970:19) in a mesh of varying quantities of agerine augite.

In the present study, a total of 76 samples were recovered from stream beds and modern quarries in 24 sample locations (Fig. 6.2). Samples of fine and medium-grained rock were collected from each location; Appendix 6B contains provenance information for all geological samples. As the Black Rock quarry area was believed to have been an important prehistoric quarry 16 samples were taken in a systematic manner. All of the other major geological units discussed above are represented in the sampling scheme with the Avatiu Caldera complex represented by Avatiu and Tukavaine stream locations while the Te Manga Group is sampled by collections from Tupapa, Avana and Papua streams and locations 21, 23 and 6.

Aitutaki

After Rarotonga, Aitutaki (259 km north of Rarotonga) contains the largest accessible quantity of volcanic rock in the Cook Islands. As seen on Figure 6.3 exposed rock is found on the main island of Aitutaki (17 samples) and on the two small volcanic reef islands of Moturakau (eight samples) and Rapota (five samples). The two main types of rock reported by Wood and Hay (1970:37) are nepheline basalts and basaltic pyroclastics, however small pebbles of trachyte and soda phonolite are found in agglomerate on Rapota. Wood (1978) also reports the presence of basanites on the southwest coast of Aitutaki. Exposed rock on Moturakau consists of well-bedded volcanic agglomerate or tuff.

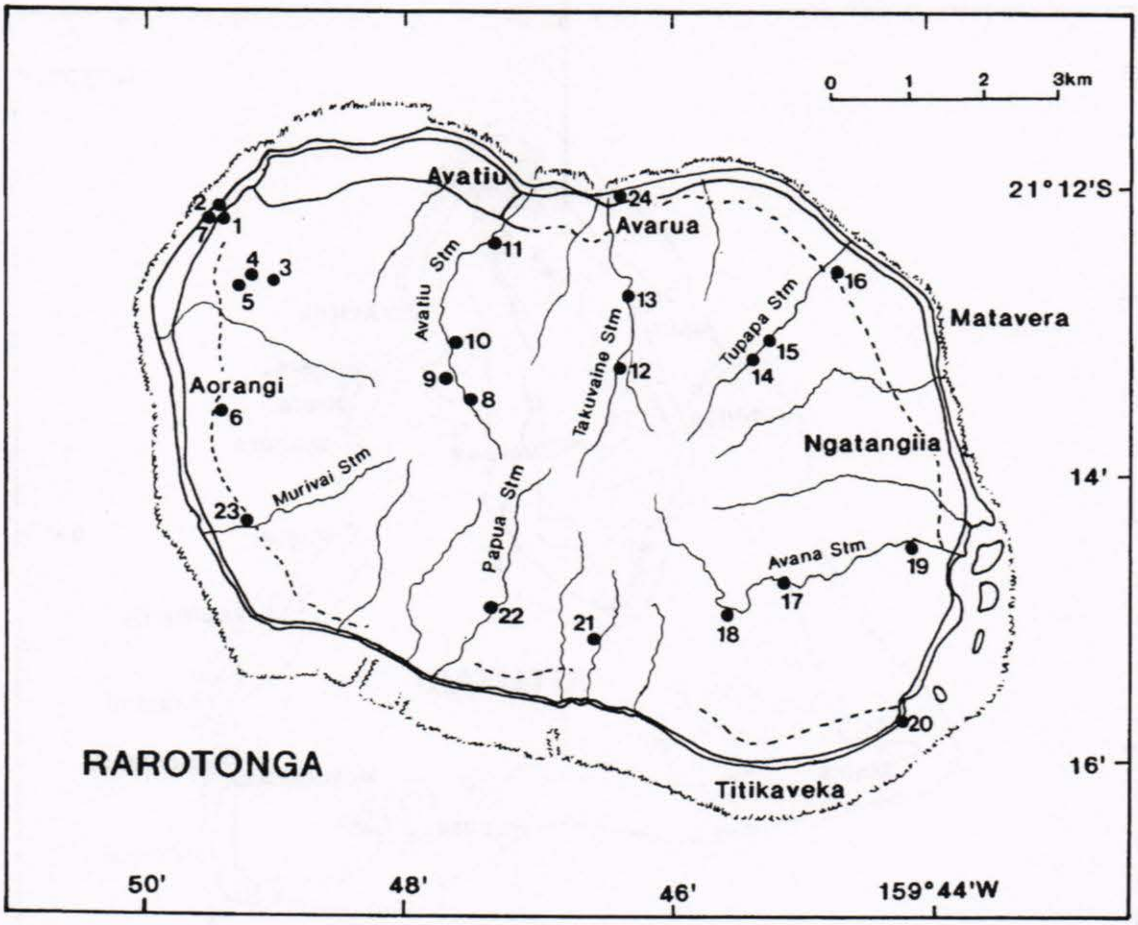

FIGURE 6.2. Map of Rarotonga showing geological sample locations.

Atiu

Atiu is a small (18 km^2) island located 187 km northeast of Rarotonga. Volcanic rock underlies the raised central portion of the island which is surrounded by *makatea*. The rock is deeply weathered to a red clay and the nine sampling locations shown in Figure 6.4 represent the few locations, in the headwaters of the streams which cut the central plateau, where fresh rock can be found. Wood and Hay (1970:33) report the presence of fine-grained augite-olivine-labradorite basalt and olivine nephelinite in the few samples they examined. In a later study, Wood (1978) also reports alkali-olivine basalt, basanitoid and alkali picrite.

Ma'uke

Ma'uke, with an area of 11 km^2, is located 241 km northeast of Rarotonga. Like Atiu, Mitiaro and Mangaia, Ma'uke is a *makatea* island with a central plateau where the volcanic rock has weathered to a red friable soil. Wood and Hay (1970:36) report that no fresh rock can be found, however, Walter, has located a rock source (three samples) on the central ridge of the island (Fig. 6.5).

Mitiaro

Field survey on the small island of Mitiaro (228 km northeast of Rarotonga) over a four day period revealed only highly weathered volcanic rock in some of the interior garden areas as previously reported by Wood and Hay (1970:34). Local inhabitants reported no unweathered igneous rock on the island and that all oven stones are imported.

Mangaia

Mangaia is the second largest (52 km^2) and most southerly of the Cook Islands lying 177 km east-southeast of Rarotonga. The island consists of central highly weathered volcanic hills which are circled by *makatea*. Fresh

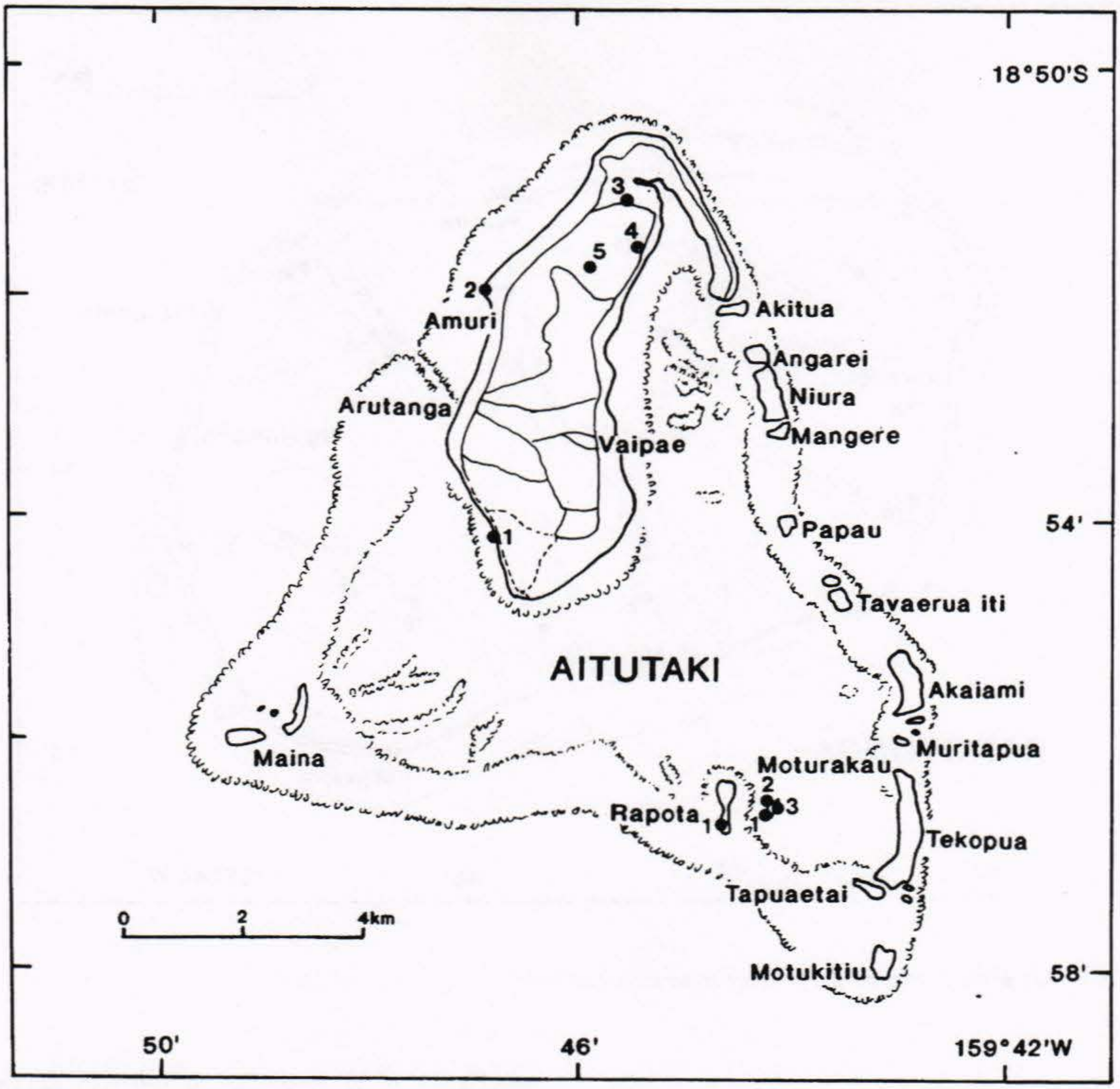

FIGURE 6.3. Map of Aitutaki showing geological sample locations.

rock is found in a limited number of locations in the upper reaches of streams. Wood (1978:769) reports the local volcanics comprise an "undersaturated sodic basalt-basanite suite" similar to that of Atiu. The alkali basalts reported by Wood (1978) have a geochemistry like that of the basalts reported by Weisler *et al.* (1994) from an ethnohistoric rock source located on the Mata'are stream on the western slopes of the island. This island was not sampled as part of this project, however data on the three samples from Mata'are reported by Weisler *et al.* (1994:Table 2) are included in the analysis. Sampling has not yet been carried out on the uninhabited islands of Takutea and Manuae.

GEOLOGICAL SUMMARY

From an adze sourcing perspective the most significant geological characteristics of the southern Cooks are those which allow the discrimination of the different islands. Perhaps the most fundamental is the presence or absence of rock capable of being used for adze manufacture. As noted above, Rarotonga is by far the premier source of adze rock in the Cooks having large volumes of exposed rock of great variety. At the opposite end of the scale is Mitiaro which has no suitable rock and all adzes or adze rock must be imported. After Mitiaro, Ma'uke appears to be the most impoverished geologic environment. Although small amounts of rock are available on Ma'uke, there is only enough to have supplied local needs. Following Ma'uke,

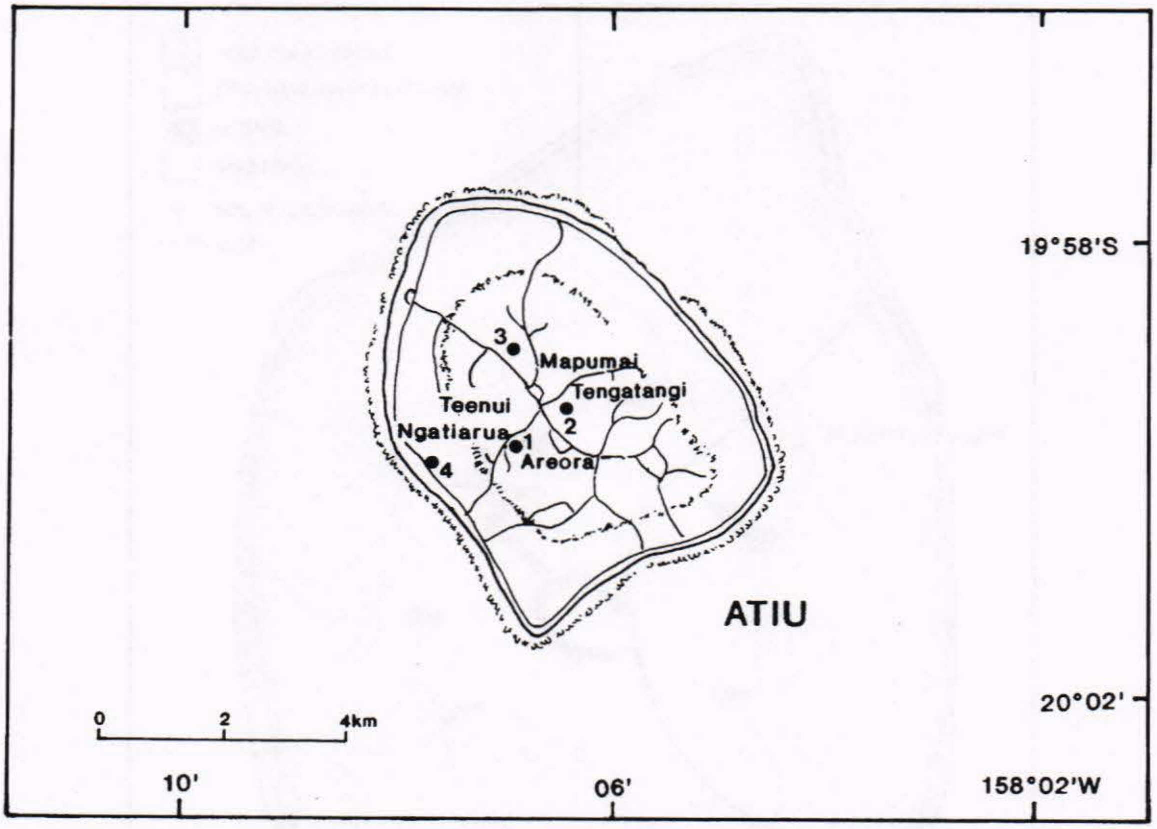

FIGURE 6.4. Map of Atiu showing geological sample locations.

Atiu and Mangaia have rock exposures in the upper reaches of streams cutting the central volcanic mass. Although we have not visited Mangaia, the descriptions of Wood and Hay (1970), Wood (1978) and Weisler *et al.* (1994) and the large area of Mangaia suggests that it has superior resources when compared to the few rocks exposed at the head of streams at the very centre of Atiu. Finally, Aitutaki appears to have the greatest volume of exposed rock after Rarotonga with rock of highly variable grain size and texture exposed at numerous locations along the coast of the main island and on the two small volcanic reef islands.

The presence or absence of different rock types is another significant characteristic of the Cook Islands. Rarotonga has the widest variety of rock types and the most differentiated rocks, such as the high-silica phonolites, are restricted to this island. Some small pebbles of phonolite and trachyte are noted from Rapota, but they are not a significant source of adze rock. Therefore, phonolite adzes would almost certainly be derived from Rarotonga. At the opposite end of the differentiation index, Aitutaki has the greatest quantity of low silica rocks such as the nephelinites which dominate the geology, along with a much smaller quantity of basanite. Therefore, basalt adzes could not be derived from the island although very low silica adzes may well be from that source. Separating Atiu, Mangaia and Ma'uke on rock type may be difficult as they all appear to have a similar basanite-basalt sequence.

The previous geochemical work carried out in the Cook Islands has amassed a good dataset from which we are now able to make some headway towards the identification of the elements and ratios which discriminate between islands (e.g., Palacz and Saunders 1986; Wood 1978a, b). The total sample size is still limited and so we are some way from achieving this end. Nevertheless, the Cook Island sample is a lot better than that which currently exists from a number of archipelagos in the region. As a first step towards pinpointing distinguishing elemental features, Wood (1978a) has suggested that Mangaia and Atiu might be separated using either copper, the sodium/potassium ratio or the potassium/barium ratio. Weisler *et al.* (1994:211) has also suggested that plots of ratios of Zr/SR and Nb/Sr might be useful for distinguishing rocks of the Mata'are source on Mangaia but as indicated in this report, there is evidence for some source overlap using this method. One of the most

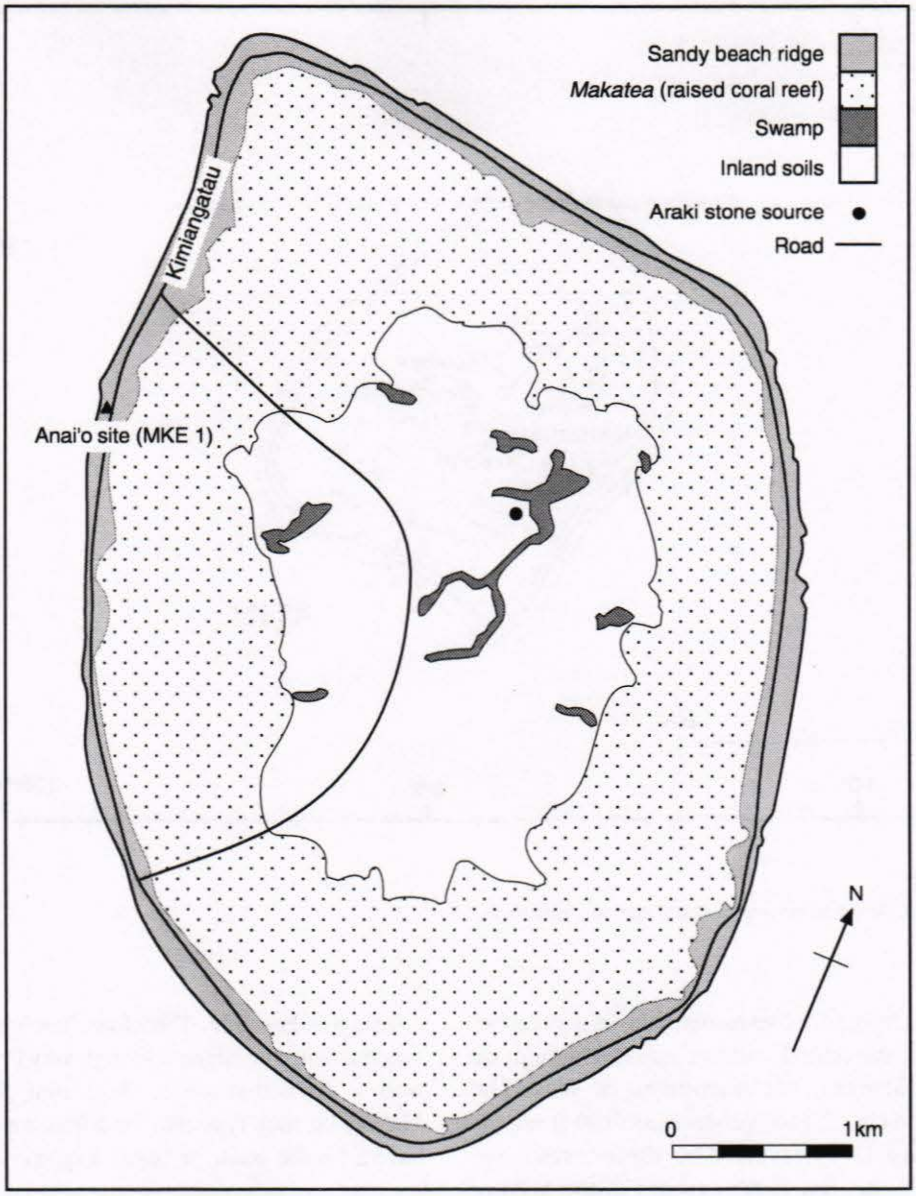

FIGURE 6.5. Map of Ma'uke showing geological sample locations.

positive potential areas may be in the area of Pb isotopes which can unambiguously separate Mangaian sources (Chapter 13).

THIN SECTIONING AND GROUPING

Thin sections were cut from the base of each drilled adze core (those sampled during the December 1992 fieldwork) and examined under the petrographic microscope. Summary notes on the adze petrography are as follows.

In general terms the samples are basaltic with various features pointing to alkali basalts and basanites/phonolites. The mineralogy is dominated by: plagioclase, clinopyroxene, opaque oxides and olivine which is present in 33 of 40 samples. Nepheline appears to be present in eight samples. A total of 29 samples are aphyric to sparsely porphyritic (< 3% phenocrysts) while 11 samples are clearly porphyritic (5-30% phenocrysts). In the porphyritic samples phenocrysts may include one or more of olivine, clinopyroxene, plagioclase, opaques plus occasionally nepheline and orthopyroxene (one sample each). Phenocrysts may be subhedral to euhedral and vary in grain size from 0.3-1.0 mm.

The groundmass varies from fine (0.25-1.0 mm) to very fine (0.05-0.25 mm) to extremely fine grained (<0.05 mm). Typically, the groundmass is composed of prismatic crystallites and irregular granules of pyroxene, granular opaques and lathes and micro-lathes of plagioclase. In olivine-bearing samples the mineral is present in the groundmass as granules, diamonds and prisms. Patches of interstitial felsic material are common, and have a character suggesting alkali feldspar. Some samples are noted for what appears to be groundmass nepheline. Other groundmass phases include patches of biotite and interstitial glassy material. Some samples show good parallel to sub-parallel orientation of plagioclase lathes, while others show only weak or no orientation.

The samples show considerable variation in alteration. Some are relatively fresh, while in others alteration may affect olivine, pyroxene and intersertal groundmass phases. Olivine and sometimes pyroxene, may alter to yellow/green/brown serpentine and occasionally olivine alters to red iddingsite. Patches of serpentine and calcite may be present in the groundmass and in some samples are well developed. Occasionally small amounts of calcite replace olivine and pyroxene crystals.

The samples have been divided into groups based on: (1) the presence or absence of olivine; (2) the presence of a phenocryst rich porphyritic texture; and (3) groundmass grain size. As shown in Table 6.1 over 50% of the samples are non-porphyritic with olivine present and with a very fine to extremely fine groundmass. Such fine-grained samples are generally characteristic of adze rocks, however slightly more than 25% of the samples are porphyritic and thereby exhibit a slightly coarser texture.

The petrographic summary indicates a wide variety of rock sources being used in the southern Cooks for the manufacture of adzes but the most significant conclusion is the absence of phonolites from the Muri or Raemaru flows. These rocks have very distinctive textures and very abundant, easily identified, agerine augite which gives the rock a greenish tint. This result was surprising given the initial assumption that the Black Rock phonolite source would account for a considerable percentage of the adzes in the Cook Islands Museum. Our evidence would indicate that Black Rock is not a major prehistoric adze quarry. It seems probable that the Rarotongan phonolite is in fact too brittle to make durable adzes.

After the petrographic analysis of the adzes, the geological samples were sub-sampled for x-ray fluorescence (XRF) analysis with only fine-grained nephelinite to basalt rocks (determined by thin-section petrography) selected. A total of 40 geological samples out of the original 176 were selected in this manner. Data were also obtained on 12 samples from the Black Rock and Muri phonolites.

X-RAY FLUORESCENCE ANALYSIS

The major and trace element analyses were conducted using an automated Phillips PW1210 XRF spectrometer and multistandard calibration lines. The following international rock standards were used: PR, MRG, JB-1, W-1, AGV-1, JG-1, GH, GA, SY-Z, NIM-S and NIM-L. Major element methods were based on techniques described in Parker (1978). Data reduction was done using a suite of programs similar to those in Parker and Willis (1977). In trace element analysis, corrections were made for background curvature, tube line overlaps, matrix effects and machine drift. Data on analytical accuracy and precision are provided in Table 6.2. Traces and majors were determined for a number of small samples (3 g) by first making pressed powder briquettes, determining trace abundances and then extracting the powder from the briquettes for the manufacture of major element fusion disks.

DATA ANALYSIS

As the goal of the study was to attempt to 'discover' sources rather than discriminate between known sources,

Texture	Dominant grain size (rock or groundmass)	No. of Samples
Porphyritic (olivine present)	very fine	4
Porphyritic (olivine present)	extremely fine	7
Non-Porphyritic (olivine present)	very fine	17
Non-Porphyritic (olivine present)	extremely fine	5
Non-Porphyritic (olivine absent)	very fine	3
Non-Porphyritic (olivine absent)	extremely fine	4

TABLE 6.1. Petrographic summary of adzes studied.

Major Elements	Accuracy %	Precision %	Trace Elements	Accuracy %	Precision %
SiO_2	<0.5	0.52	Nb	4	1.8
TiO_2	2-3	0.9	Zr	8	1.7
Al_2O_3	<1	0.8	Y	8	6.2
Fe_2O_3	<2	0.91	Sr	4	0.5
MnO	<5	10	Rb	4	6.4
MgO	1-3	1.14	Th	10-15	46.5
CaO	<1	0.73	Pb	10-15	23.6
Na_2O	2-3	1.88	As	10-15	na
K_2O	<1	1.03	Zn	10	1.8
P_2O_5	2-3	2.27	Cu	10-15	8.6
			Ni	10	2.6
			Cr	10	3.8
			V	10	3.9
			Ba	5-15	2.8
			La	10-15	10.6

1. Accuracy: estimate of average relative calibration errors in XRF major and trace element analyses of silicate rocks with trace data estimated from calibration errors for standard concentrations >20 ppm. Standard element concentrations are taken from Abbey (1983) and Govindaraju (1984).
2. Precision: Based on runs of Deptartment of Geology, University of Auckland standard MEB (Mount Eden Basalt). Element precision is expressed as a coefficient of variation of 16 analyses of a single fusion disk for major elements and 18 analyses for trace elements.

TABLE 6.2. Accuracy[1] and precision[2] for XRF data.

grouping of cases was performed using cluster analysis. Average linkage cluster analysis (UPGMA) (SAS version 6.01) was carried out on standardised, log 10 transformed data (Bishop and Neff 1989:63), using majors only as trace data were not available for all cases. An additional cluster analysis using Ward's method was also run to confirm that the average linkage result was stable. Only minor variation was observed. The results of the average linkage analysis are presented as Figure 6.6 and Table 6.3. The dendrogram includes only the higher order divisions in the data. The cases in Table 6.3 are ordered according to the results of the cluster analysis. Cluster membership is indicated by a number in the cluster column while an O stands for an outlier from the analysis. The type attribute indicates whether the sample is archaeological (A) or geological (G).

RESULTS

The SAS cluster procedure allows the setting of a limit beyond which extreme outliers are removed from the analysis. This had the effect of trimming six observations from the cluster analysis and these are presented as the first six observations in Table 6.3. As can be seen in Figure 6.7 all of these are rock types which stand out from the mass of samples which are predominately basanites or moderate alkali foidites. Adze R65-371 is a phono-tephrite which has no very close matches in the dataset. This is possibly an import to the region; however, it is a roughout and therefore it seems most probable that it is made from unsampled Rarotongan rock as its closest match is R-20C a geological sample from the Muri Flows. The only samples in the data set which clearly fall into Le Maitre's (1989) phonolite zone are geological samples collected by Roger Green in 1984 from Black Rock (CO-ANT71 and CO-ANT70). Table 6.4 provides summary data for Black Rock phonolite.

Cluster 1 contains two basanite adzes, one from Rarotonga and the other from Ma'uke. Geochemically they are very similar in both majors and traces. Their most distinctive features are very high values for chromium and low values for aluminium. Their geochemistry is most like that of Rarotongan geological samples in cluster 7 (R-5B, R-4B) which come from northwest Rarotonga (Tokerau River) behind the prison. In hand specimen adze R65-338 was vesicular with large brown phenocrysts, while adze RW-1 was very heavily weathered. In thin section these adzes were extremely similar containing 10-15% phenocrysts of euhedral pink clinopyroxene and euhedral olivine. The ground mass is a fine-grained porphyritic interlocking network of unoriented clinopyroxene and plagioclase lathes with some interstitial felsic patches. A Rarotonga source seems probable for both adzes.

Cluster 2 consists of an adze (RW-G) and a core (RW-E) both excavated from the Anai'o site on Ma'uke (Flaking Area 1, Layer 4) and sampled by Walter (1990) and two geological samples from Ma'uke. The very similar major element geochemistry strongly supports a Ma'uke source for the adze rock.

Cluster 3 is a very large and diverse group of adzes and geological samples which together suggest a Rarotongan source(s). However, the variability represented in these data indicates the use of a number of sources or source areas rather than the use of a limited number of large quarry complexes. Finer structure in this group is indicated by the definition of sub-groups A, B, C and D. Based on the plot of alkalis to silica and the abundant olivine in the samples these rocks should all be classified as basanites.

The generalised petrography of the adzes in this cluster is as follows: phenocrysts none to 1% and where present including olivine and clinopyroxene. A very fine groundmass of pink clinopyroxene, plagioclase lathes, olivine altered to iddingsite, granular opaques and felsic interstitial patches. Very fine to fine-grained interlocking granular and unoriented lathy texture. Extensive alteration and development of serpentine and iddingsite.

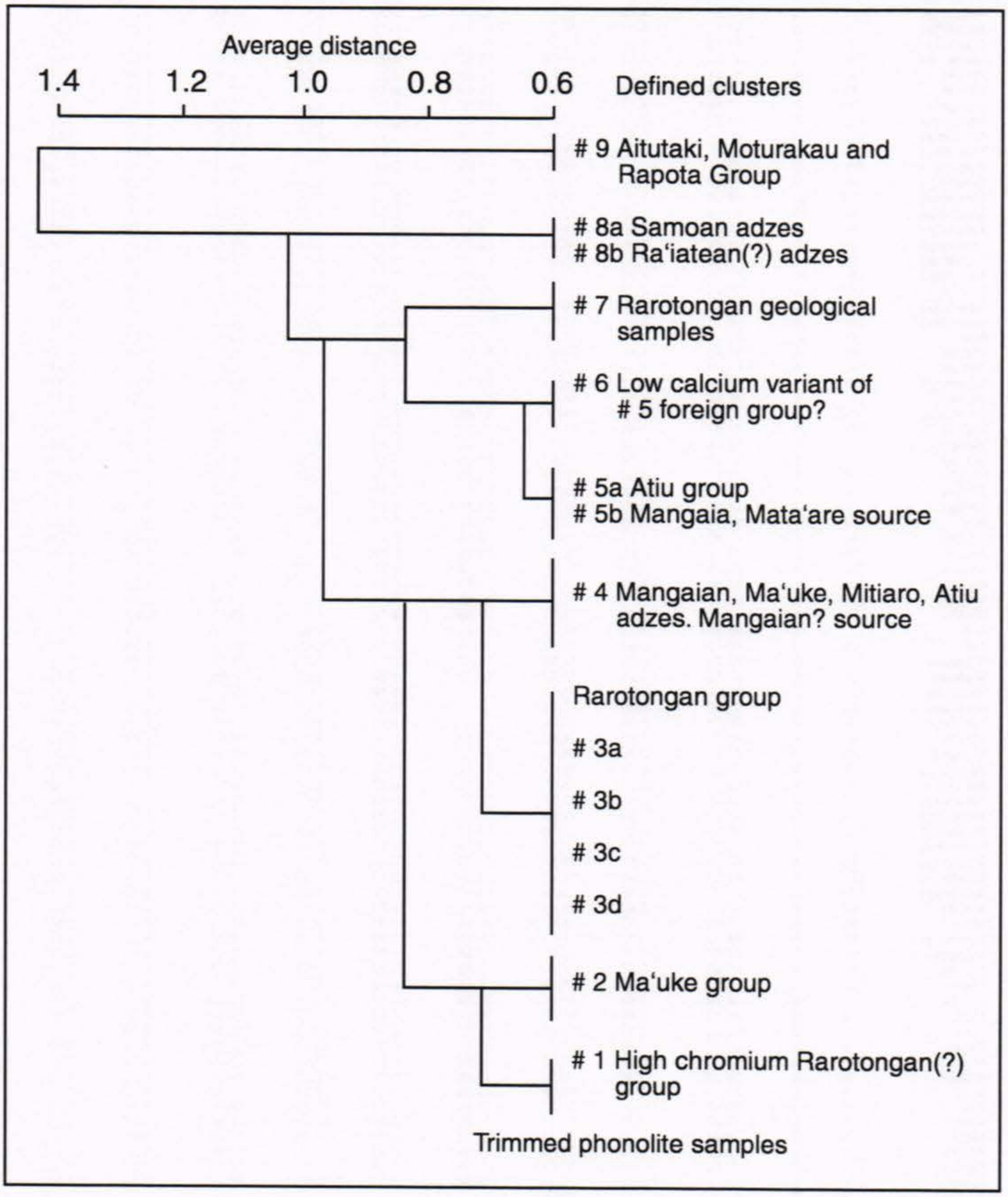

FIGURE 6.6. Dendrogram showing major divisons of the Average Linkage Cluster analysis.

Id	Island	Clus	Type	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	LOI
R65-371	Rarotonga	P	A	49.50	2.29	18.48	8.08	0.28	2.39	6.42	5.19	4.38	0.65	1.20
CO-ANT71	COOKS	P	A	52.50	0.72	21.13	5.24	0.24	0.25	2.96	9.59	5.24	0.16	1.65
CO-ANT70	COOKS	P	A	50.73	1.00	19.98	6.46	0.25	0.85	4.77	8.34	5.42	0.26	2.43
R-20C	Rarotonga	P	G	48.28	1.34	19.24	6.96	0.29	1.59	4.42	10.18	4.62	0.34	2.29
R-14A	Rarotonga	O	G	43.10	2.64	9.53	13.03	0.22	16.57	8.84	1.33	1.15	0.52	2.22
AT-1B	Atiu	O	G	40.16	1.80	9.34	13.15	0.21	14.39	9.21	1.50	0.83	0.26	7.79
R65-338	Rarotonga	1	A	42.47	3.41	12.39	13.61	0.26	9.38	10.79	2.70	1.83	0.65	1.30
RW-1	Ma'uke	1	A	42.05	3.33	14.05	12.70	0.24	8.64	10.76	3.52	2.15	0.74	0.82
MAU-3	Ma'uke	2	G	41.37	4.79	14.21	15.08	0.28	6.48	8.94	4.29	1.70	0.77	1.18
MAU-1	Ma'uke	2	G	41.33	4.82	14.48	14.95	0.26	6.61	9.19	4.42	1.11	0.80	1.36
RW-G	Ma'uke	2	A	41.11	4.23	14.31	17.14	0.27	6.31	8.18	4.30	1.69	1.21	0.75
RW-E	Ma'uke	2	A	41.46	4.24	14.50	16.93	0.26	6.39	8.14	4.76	1.67	1.20	0.29
R-3D	Rarotonga	O	G	42.19	3.91	13.57	15.51	0.23	6.37	10.32	4.79	1.00	1.08	0.90
R72-6	Mangaia	3a	A	42.80	4.09	14.60	13.09	0.22	5.50	10.88	2.85	2.32	0.94	2.39
R-16A	Rarotonga	3a	G	43.74	3.88	15.37	12.83	0.21	5.08	10.49	3.94	2.28	0.88	1.15
RW-L	Rarotonga	3a	A	43.35	3.88	15.11	12.81	0.21	5.24	10.73	2.63	2.73	0.84	1.77
MIT-3	Mitiaro	3a	A	43.18	4.27	15.53	12.67	0.21	5.43	10.42	2.74	2.26	0.68	1.08
R-24A1	Rarotonga	3a	G	43.93	4.35	15.06	13.80	0.21	5.54	11.20	2.77	1.97	0.68	0.82
R63-10	Rarotonga	3a	A	43.15	3.88	14.51	13.05	0.23	5.54	10.73	3.39	1.98	0.71	1.14
R-10B	Rarotonga	3a	G	43.72	3.87	14.76	12.89	0.23	5.21	10.79	3.15	2.19	0.76	1.53
R65-220	Rarotonga	3a	A	44.20	3.81	14.31	13.23	0.23	5.96	10.62	3.31	2.10	0.73	0.66
RW2	Rarotonga	3a	A	42.62	4.46	15.01	13.43	0.23	5.32	11.55	2.27	2.11	0.82	
R62-8	Rarotonga	3a	A	41.37	4.11	14.28	14.37	0.22	5.23	11.90	2.70	1.83	0.79	1.64
R72-5	Pukapuka	3a	A	41.45	3.74	15.45	10.56	0.22	4.60	10.75	3.47	1.64	0.83	5.29
R-17C	Rarotonga	3a	G	42.92	4.32	15.26	13.87	0.22	5.34	11.79	2.34	1.68	0.58	1.61
R65-70	Ma'uke	3a	A	43.56	4.51	15.63	12.30	0.23	5.29	9.95	4.01	2.17	0.93	1.32
MAU-2	Ma'uke	3a	G	41.54	4.75	14.41	15.49	0.23	6.70	9.30	3.72	2.43	0.82	0.74
RW-I	Mangaia	3a	A	42.18	4.57	14.50	14.80	0.24	5.21	9.48	3.55	1.97	0.83	1.77
R86-30	Rarotonga	3a	A	43.97	3.35	14.57	11.94	0.23	6.73	9.55	3.13	2.47	0.80	1.44
R62-17	Rarotonga	3a	A	44.12	3.52	15.86	11.25	0.23	4.27	9.43	4.01	2.65	1.03	2.18
R62-38	Rarotonga	3b	A	42.41	4.25	13.66	13.84	0.18	5.67	11.65	2.87	2.10	0.79	1.15
R-14C	Rarotonga	3b	G	42.52	4.37	15.56	12.84	0.18	5.36	11.22	2.39	2.15	0.71	1.71
R-5A	Rarotonga	3b	G	43.53	4.36	16.04	11.02	0.18	5.24	10.81	2.20	1.90	0.70	2.98
R-14B	Rarotonga	3b	G	44.79	3.80	15.42	12.50	0.16	4.94	10.75	2.59	2.21	0.73	1.82
R-24A2	Rarotonga	3c	G	44.16	3.52	15.11	12.94	0.20	5.84	11.05	2.56	2.09	0.64	1.51
R62-10	Rarotonga?	3c	A	43.82	3.85	14.71	13.42	0.20	5.47	10.48	3.43	2.13	0.75	0.99
R-16B	Rarotonga	3c	G	44.74	3.70	15.04	12.71	0.18	5.39	10.78	2.75	2.14	0.71	1.37
R-15A	Rarotonga	3c	G	44.58	3.63	15.22	12.83	0.19	5.50	9.93	2.54	1.92	0.69	1.76
R65-372	Rarotonga	3c	A	44.05	3.72	15.76	12.46	0.20	4.72	9.78	3.85	2.21	0.73	0.94
RW-N	Aitutaki	3c	A	44.98	3.77	15.65	12.87	0.20	4.74	9.61	3.33	2.39	0.85	0.99
R-10C	Rarotonga	3c	G	45.51	3.69	16.55	12.54	0.19	4.89	9.58	3.81	2.21	0.78	0.56
R62-38B	Rarotonga	3c	A	44.74	3.66	15.90	12.22	0.22	4.77	9.30	3.15	2.23	0.79	1.66
R66-68	Atiu	O	A	42.58	3.44	16.10	12.27	0.19	4.73	10.71	4.07	1.54	0.75	2.54
R65-72	Ma'uke	3d	A	43.33	4.41	15.82	12.06	0.20	4.94	9.92	4.04	2.20	0.95	0.98
R63-21	Aitutaki	3d	A	43.20	4.39	15.57	12.23	0.20	5.00	9.77	3.98	2.22	0.96	0.75
RW-H	Rarotonga	3d	A	43.60	4.51	15.68	12.44	0.18	5.14	10.12	3.74	2.27	0.98	0.73
RW-K	Ma'uke	3d	A	42.74	4.34	14.53	13.63	0.20	5.07	11.14	3.33	2.42	1.12	0.55
R-11B	Rarotonga	O	G	45.81	3.78	15.94	11.78	0.18	4.09	9.13	3.37	2.21	0.97	1.92
R65-62	Ma'uke	O	A	43.92	3.64	16.06	11.71	0.18	3.79	8.80	4.13	1.79	0.72	3.07
R68-6	Mangaia	4	A	45.06	3.08	16.72	10.96	0.20	3.91	8.83	4.63	1.88	0.86	2.66
R65-57	Ma'uke	4	A	43.89	3.14	16.82	11.00	0.22	3.76	8.80	4.13	1.79	0.85	3.49
R65-56	Ma'uke	4	A	43.12	3.04	16.43	11.25	0.25	4.00	9.14	4.49	1.80	0.79	3.88
MIT2	Mitiaro	4	A	44.70	3.48	15.92	11.75	0.24	4.19	8.92	4.62	1.76	0.73	2.60
RW-O	Mangaia	4	A	46.00	3.67	16.31	11.36	0.26	4.61	9.34	3.90	1.79	0.74	1.70
ATIU-1	Atiu	4	A	44.17	3.40	15.78	11.82	0.22	5.13	9.23	3.67	1.60	0.63	2.21
R68-3	Aitutaki	5a	A	42.43	3.27	14.71	14.36	0.22	4.59	10.12	3.63	0.78	0.41	4.48
AT-1C	Atiu	5a	G	42.14	3.05	14.93	11.93	0.25	4.86	10.90	2.48	1.09	0.51	6.63
MIT-1	Mitiaro	5a	A	41.78	3.47	14.85	14.39	0.21	5.66	11.80	3.87	1.15	0.53	1.72
RW-J	Mitiaro	5a	A	43.07	3.78	16.30	12.92	0.21	5.58	10.28	3.43	1.21	0.50	2.28
COOKS-3	Ma'uke	5a	A	43.70	3.70	16.30	13.50	0.21	5.45	10.40	3.98	1.04	0.49	1.16
COOKS-2	Ma'uke	5a	A	44.10	3.69	16.40	13.30	0.22	5.41	10.10	4.02	1.14	0.49	1.16
AT-50B	Atiu		G	43.60	3.31	14.90	12.02	0.20	4.90	11.57	2.70	1.01	0.55	5.31
AT-2D	Atiu	5a	G	43.75	3.03	15.92	12.64	0.19	6.16	11.81	3.55	1.14	0.47	0.89
MAN-88A	Mangaia		G	43.20	3.32	14.80	14.37	0.21	5.60	12.14	3.90	1.13	0.55	0.90
R65-116	Mangaia	5b	A	43.30	3.23	14.82	13.70	0.22	5.97	11.69	3.09	0.85	0.45	1.81
92-32	Mata'are	5b	G	44.87	3.28	14.45		0.19	5.93	12.21	3.01	0.82	0.44	
92-20	Mata'are	5b	G	45.20	3.35	15.21		0.20	5.89	11.66	3.44	0.84	0.44	
92-4	Mata'are	5b	G	45.08	3.34	15.04		0.20	5.87	11.60	3.28	0.82	0.45	
COOKS-4	Ma'uke	5b	A	44.10	3.75	16.60	13.10	0.18	4.91	10.60	3.73	0.86	0.50	1.61
R72-3	Mangaia	O	A	41.34	3.76	14.45	16.47	0.19	6.08	12.18	2.15	0.70	0.43	
R68-1	Rarotonga	6	A	45.86	3.78	15.23	13.22	0.22	6.83	9.20	3.20	0.99	0.51	0.29
COOKS-1	Ma'uke	6	A	46.40	4.51	15.30	14.30	0.22	5.90	8.35	3.43	1.23	0.59	0.31
R-5B	Rarotonga	7	G	42.29	3.43	12.48	13.21	0.19	9.84	11.64	2.92	0.86	0.66	2.45
R-4B	Rarotonga	7	G	42.35	3.50	12.68	13.01	0.20	9.02	11.21	3.16	0.82	0.66	2.34
R-11A	Rarotonga	7	G	43.96	3.30	12.08	13.37	0.17	9.68	11.61	2.27	1.53	0.50	0.82
R-23C	Rarotonga	7	G	43.75	3.10	10.35	12.73	0.20	13.85	10.38	1.37	1.59	0.55	1.44
R63-19	Rarotonga	8a	A	48.17	2.65	16.24	11.96	0.24	4.13	6.86	4.42	1.82	1.00	0.65
RAR-6	Rarotonga	8a	A	47.83	3.04	16.13	13.08	0.21	4.50	7.24	3.95	1.68	0.83	0.89
R92-1	Rarotonga	8a	A	47.21	3.16	15.75	13.07	0.22	4.73	7.19	3.70	1.63	0.78	1.07
RW-M	Ma'uke	8a	A	47.92	3.43	15.53	13.57	0.21	4.77	7.74	3.91	1.54	0.81	0.01
RW-F	Ma'uke	8a	A	49.45	2.73	16.61	11.91	0.20	4.19	7.13	4.55	1.88	1.00	0.05
RAR-10	Rarotonga	8b	A	46.42	3.15	17.49	10.85	0.19	4.00	8.52	4.39	2.37	1.50	
R66-7	Mangaia	8b	A	47.04	3.17	17.23	10.84	0.22	4.25	8.51	4.47	2.48	1.54	
RW-C	Ma'uke	O	A	41.83	3.83	17.20	12.30	0.19	3.58	8.78	4.50	1.85	1.30	2.90
RW-A	Atiu	O	A	47.7	2.48	18.3	9.55	0.18	2.26	7.50	5.72	2.39	0.83	
R86-2	Aitutaki	9	A	38.70	2.43	11.15	12.65	0.23	12.34	11.68	4.78	1.94	1.06	1.53
MOT-3B	Motu	9	G	39.01	2.49	11.58	12.81	0.23	11.78	12.07	4.79	2.01	1.18	1.19
RAP-1E	Rapota	9	G	39.50	2.47	11.36	13.02	0.23	12.78	12.01	5.10	2.22	1.23	0.18
RAP-1C	Rapota	9	G	39.47	2.52	11.62	13.16	0.22	10.37	12.25	5.16	2.30	1.20	0.97
MOT-3C	Motu	9	G	39.51	2.46	11.19	12.56	0.25	11.50	12.45	4.49	2.03	1.13	1.08
AIT-M-1	Aitutaki	9	A	39.27	2.40	11.36	13.26	0.25	12.22	11.95	3.37	1.69	1.13	
MOT-2	Motu	9	G	39.71	2.49	11.36	12.63	0.21	12.27	12.28	4.16	1.76	1.16	1.07
CO-SB1	Aitutaki	9	A	39.61	2.54	11.37	12.68	0.21	12.46	12.16	4.36	1.71	1.15	1.79
MOT-3D	Motu	9	G	39.02	2.45	11.41	12.86	0.21	12.07	12.54	4.37	1.74	1.13	1.09
MOT-1A	Motu	9	G	38.44	2.48	11.26	13.02	0.23	11.86	12.53	3.95	1.43	1.19	2.48
RAP-1B	Rapota	9	G	38.65	2.43	11.63	12.59	0.23	11.56	13.36	3.33	1.33	1.21	3.20
RAP-1A	Rapota	9	G	39.25	2.47	11.44	13.07	0.19	11.98	12.73	4.82	1.84	1.18	1.08
RAP-1D	Rapota	9	G	39.38	2.52	11.59	12.86	0.18	11.88	13.01	4.78	1.90	1.24	0.78
AIT-4A	Aitutaki	9	G	40.92	2.34	12.06								

TABLE 6.3. All geochemical data ordered by the results of the average linkage cluster analysis.

Id	Island	Clus	Type	Nb	Zr	Y	Sr	Rb	Th	Pb	Zn	Ni	Cr	V	Ba	La
R65-371	Rarotonga	P	A	136	555	45	1636	101	27	18	134	19	35	87	1141	140
CO-ANT71	COOKS	P	A													
CO-ANT70	COOKS	P	A													
R-20C	Rarotonga	P	G	254	1019	46	2285	104	54	37	223	.	.	112	1573	186
R-14A	Rarotonga	O	G	44	231	22	563	26	.	7	130	534	826	241	416	44
AT-1B	Atiu	O	G	30	149	19	548	19	5	4	102	452	553	182	274	25
R65-338	Rarotonga	1	A	61	300	29	818	41	9	10	128	176	378	286	555	57
RW-1	Ma'uke	1	A	64	249	29	899	53	13	13	116	191	228	261	526	61
MAU-3	Ma'uke	2	G	87	330	40	963	30	7	5	108	21	7	251	595	72
MAU-1	Ma'uke	2	G	85	322	36	960	24	9	7	106	20	8	242	592	69
RW-G	Ma'uke	2	A													
RW-E	Ma'uke	2	A													
R-3D	Rarotonga	O	G	101	442	35	1229	104	16	12	155	47	65	262	997	98
R72-6	Mangaia	3a	A	72	350	34	1125	51	12	16	122	55	59	300	801	69
R-16A	Rarotonga	3a	G	73	349	32	1023	51	7	9	129	45	22	293	689	64
RW-L	Rarotonga	3a	A													
MIT-3	Mitiaro	3a	A	62	304	31	963	42	6	7	124	27	33	310	647	60
R-24A1	Rarotonga	3a	G	61	308	31	923	37	11	11	126	65	15	367	663	60
R63-10	Rarotonga	3a	A	66	309	32	944	42	10	16	123	82	96	330	630	56
R-10B	Rarotonga	3a	G	68	326	32	972	44	11	8	131	62	41	309	682	59
R65-220	Rarotonga	3a	A	65	316	30	928	47	7	10	128	79	115	296	629	64
RW2	Rarotonga	3a	A													
R62-8	Rarotonga	3a	A	67	318	34	946	45	8	10	129	63	61	349	652	63
R72-5	Pukapuka	3a	A	75	279	28	2777	38	10	11	127	51	59	296	879	67
R-17C	Rarotonga	3a	G	57	287	30	1045	37	7	6	118	29	.	361	622	46
R65-70	Ma'uke	3a	A	55	325	32	1059	55	11	11	126	55	49	293	652	53
MAU-2	Ma'uke	3a	G	87	336	37	980	59	10	6	106	26	7	234	606	67
RW-I	Mangaia	3a	A													
R86-30	Rarotonga	3a	A	75	348	30	1012	63	12	13	126	103	177	226	802	75
R62-17	Rarotonga	3a	A	92	409	35	1249	60	12	11	132	28	42	210	848	89
R62-38	Rarotonga	3b	A	62	305	32	949	44	12	16	129	94	132	342	606	57
R-14C	Rarotonga	3b	G	72	316	32	1166	53	6	9	118	43	6	373	912	66
R-5A	Rarotonga	3b	G	67	318	32	971	37	10	10	132	26	7	335	758	57
R-14B	Rarotonga	3b	G	68	335	32	993	61	10	10	116	52	17	298	708	64
R-24A2	Rarotonga	3c	G	65	299	29	1099	47	4	10	123	90	59	318	731	57
R62-10	Rarotonga?	3c	A	66	326	32	952	43	7	9	130	77	76	312	676	59
R-16B	Rarotonga	3c	G	66	327	33	920	49	11	10	119	57	32	314	704	58
R-15A	Rarotonga	3c	G	59	299	34	882	61	9	8	126	53	23	297	604	47
R65-372	Rarotonga	3c	A	69	334	33	968	47	11	8	126	53	56	283	717	67
RW-N	Aitutaki	3c	A													
R-10C	Rarotonga	3c	G	78	342	33	1087	50	10	9	121	16	6	254	717	63
R62-38B	Rarotonga	3c	A	78	355	35	1039	52	13	16	131	38	59	247	742	71
R66-68	Atiu	O	A	67	258	31	978	40	8	11	133	69	74	290	505	65
R65-72	Ma'uke	3d	A	60	343	35	1074	55	9	10	122	50	62	281	682	54
R63-21	Aitutaki	3d	A	59	349	35	1108	55	9	8	128	45	57	271	684	55
RW-H	Rarotonga	3d	A													
RW-K	Ma'uke	3d	A													
R-11B	Rarotonga	O	G	67	345	36	1052	47	10	12	135	16	8	241	785	69
R65-62	Ma'uke	O	A	73	302	34	745	53	11	9	130	39	29	266	451	67
R68-6	Mangaia	4	A	86	323	32	877	58	12	12	122	33	49	215	525	95
R65-57	Ma'uke	4	A	87	325	38	844	58	12	8	134	26	33	209	575	87
R65-56	Ma'uke	4	A	85	317	34	894	59	15	14	117	35	59	217	540	82
MIT2	Mitiaro	4	A	70	297	32	759	50	10	9	121	30	24	266	445	69
RW-O	Mangaia	4	A													
ATIU-1	Atiu	4	A	62	265	33	865	49	10	11	107	78	54	263	442	61
R68-3	Aitutaki	5a	A	41	205	29	493	18	5	7	129	46	36	311	232	39
AT-1C	Atiu	5a	G	53	237	27	638	28	9	8	141	59	71	308	375	50
MIT-1	Mitiaro	5a	A	64	256	30	669	27	11	10	129	77	60	327	385	53
RW-J	Mitiaro	5a	A													
COOKS-3	Ma'uke	5a	A	63	239	32	708	17	4	7	116	23	.	272	372	52
COOKS-2	Ma'uke	5a	A	63	241	33	717	20	6	5	110	54	.	248	370	48
AT-50B	Atiu		G	59	231	31	679	26	6	3		61	34		518	47
AT-2D	Atiu	5a	G	51	224	28	678	29	5	9	99	80	51	289	359	44
MAN-88A	Mangaia		G	60	230	30	610	23	6	4		96	1051		361	46
R65-116	Mangaia	5b	A	44	226	30	547	19	.	8	119	77	73	309	257	45
92-32	Mata'are	5b	G	55	215	31	551	19	5	1	113	40	48	315	205	33
92-20	Mata'are	5b	G	59	216	31	548	17	4	3	121	28	26	318	228	38
92-4	Mata'are	5b	G	57	213	30	549	18	4	1	118	27	23	325	216	44
COOKS-4	Ma'uke	5b	A	63	245	34	734	13	.	5	115	39	.	285	372	48
R72-3	Mangaia	O	A													
R68-1	Rarotonga	6	A	27	285	34	587	23	.	7	135	129	121	290	217	24
COOKS-1	Ma'uke	6	A	39	347	42	598	27	.	9	159	54	.	279	264	36
R-5B	Rarotonga	7	G	68	316	30	951	45	10	12	115	172	379	279	826	65
R-4B	Rarotonga	7	G	71	320	29	959	44	8	8	122	144	369	303	885	66
R-11A	Rarotonga	7	G	50	266	29	699	32	5	7	120	214	587	324	537	47
R-23C	Rarotonga	7	G	41	247	30	774	36	10	10	113	422	700	263	662	46
R63-19	Rarotonga	8a	A	60	454	52	906	43	9	11	190	33	65	117	399	56
RAR-6	Rarotonga	8a	A	48	417	50	666	46	6	7	183	15	39	174	354	44
R92-1	Rarotonga	8a	A	47	406	48	648	46	6	10	179	20	35	193	331	43
RW-M	Ma'uke	8a	A													
RW-F	Ma'uke	8a	A													
RAR-10	Rarotonga	8b	A													
R66-7	Mangaia	8b	A													
RW-C	Ma'uke	O	A													
RW-A	Atiu	O	A													
R86-2	Aitutaki	9	A	76	216	30	1137	59	19	12	126	215	254	176	1022	91
MOT-3B	Motu	9	G	93	237	34	967	58	16	12	133	196	239	180	520	102
RAP-1E	Rapota	9	G	61	213	30	948	54	17	11	119	204	261	163	732	81
RAP-1C	Rapota	9	G	95	235	34	1368	61	22	14	137	174	228	166	517	103
MOT-3C	Motu	9	G	82	225	31	1293	53	20	17	123	182	237	185	441	95
AIT-M-1	Aitutaki	9	A													
MOT-2	Motu	9	G	88	234	34	1188	45	20	14	128	191	234	166	1246	101
CO-SB1	Aitutaki	9	A													
MOT-3D	Motu	9	G	82	222	34	1318	49	17	10	120	179	228	173	457	94
MOT-1A	Motu	9	G	83	225	33	1212	40	20	14	129	187	226	169	1040	101
RAP-1B	Rapota	9	G	77	212	34	1738	37	17	13	121	178	189	164	1085	99
RAP-1A	Rapota	9	G	81	236	33	1411	52	19	22	127	195	236	191	1060	96
RAP-1D	Rapota	9	G	76	211	31	1507	44	18	13	126	188	231	172	961	90
AIT-4A	Aitutaki	9	G													

TABLE 6.3 (continued). All geochemical data ordered by the results of the average linkage cluster analysis.

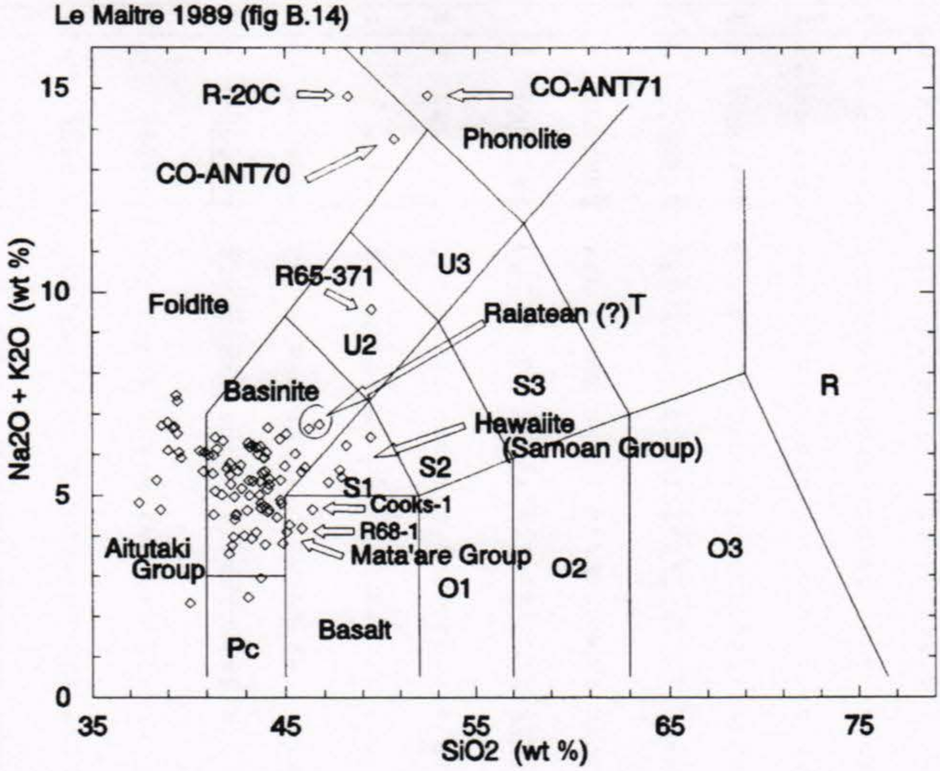

FIGURE 6.7. Plot of silica against alkali (after Le Maitre 1989) for all samples.

Element	N	Minimum	Maximum	Mean	Std dev
SiO_2	12	50.13	52.24	51.35	0.68
TiO_2	12	0.69	0.74	0.71	0.01
Al_2O_3	12	20.4	21.4	20.87	0.38
Fe_2O_3	12	4.77	5.16	4.99	0.12
MnO	12	0.21	0.28	0.24	0.02
MgO	12	0.45	1.13	0.7	0.22
CaO	12	2.61	3.08	2.84	0.15
Na_2O	12	8.63	10.8	9.58	0.65
K_2O	12	4.91	5.5	5.23	0.18
P_2O_5	12	0.11	0.13	0.12	0.01
H_2O	12	0.26	1.17	0.61	0.33
LOI	12	1.77	4.33	2.81	0.96
Nb	12	210	218	214	2.83
Zr	12	1018	1060	1036.75	13.09
Y	12	32	36	33.83	1.11
Sr	12	1579	1796	1697.17	71.54
Rb	12	127	154	146	8.24
Th	12	47	55	51.17	1.9
Pb	12	28	37	33.67	2.42
Zn	12	189	206	195.75	4.92
Ni	4	4	7	5.25	1.26
Cr	4	4	8	5.5	1.73
V	12	45	61	53	6.24
Ba	12	1371	1457	1417.08	27.41
La	12	113	127	121	4.02

TABLE 6.4. Summary data on Black Rock phonolite.

Minor exceptions to this pattern are: R86-30 which contains 25-35% phenocrysts in 'clots' including pink clinopyroxene, sparse orthopyroxene and olivine; a Pukapukan adze R72-5 which has a distinctive poikilitic plagioclase in the groundmass; and R65-372 which contains 5% phenocrysts of plagioclase, clinopyroxene and olivine.

The geochemistry of both majors and traces in this group is remarkably similar. Variation between subgroups occurs primarily in silica, manganese, titanium, sodium and phosphorous. Such variation may be related to various fractionation processes (e.g., Mullen 1983). The Pukapukan adze should possibly not be grouped with the others in this cluster as it has a very high loss on ignition (5.29%) and an extremely high strontium value (2777 ppm). This taken with its distinctive petrography may suggest a source outside Rarotonga.

In total this cluster contains 23 adzes representing all islands of the southern Cooks with 12 adzes coming from Rarotonga. With the exception of one sample from Ma'uke all 12 geological samples are from Rarotonga. The Ma'uke sample is in all respects like the Rarotongan samples with the exception of an elevated iron content and niobium at the high end of the Rarotongan range. Given the preponderance of Rarotongan geological and archaeological samples in the cluster it seems most probable that this group represents Rarotongan sources or source areas.

Five of the geological samples come from the Tupapa valley, two from the Tukavaine valley, and one each from Tokerau, Avatiu and Avana valleys. The closest geological sample to an adze in the cluster analysis was sample R-10B from Avatiu stream and adze R63-10 which have very similar majors and traces. This evidence suggests further searches for quarries might focus on the central north half of Rarotonga, although the fact that the adzes and geological samples are intermingled within the cluster might suggest prehistoric use of a wide variety of minor sources rather than a focus on dominant quarries.

Cluster 4 contains six adzes all moderate to high silica basanites with nearly identical trace element abundances. Examination of the petrographic data revealed near identical mineralogy and texture. Phenocrysts are either absent or present as 1-2% with only Atiu-1 having phenocrysts at 5-8% of the mass. Phenocrysts are sub to anhedral crystals of plagioclase with Atiu-1 also containing some clinopyroxene. The groundmass is a very fine-grained mix of plagioclase, pale pink clinopyroxene, diamonds and 'fishtails' of olivine (absent in R65-57 and R65-56), occasional felsic intersitial patches and patches of calcite. The most distinctive characteristic of this group of samples is that they all exhibit a strong trachytic texture of oriented plagioclase. These are the only samples in the entire petrographic dataset to have this texture. Taken together the geochemical and petrographic data strongly suggest that these adzes are all, with the possible exception of Atiu-1 with its numerous phenocrysts, derived from one very distinctive source. Unfortunately we have no geological data which matches with this cluster. This grouping is also remarkable for the absence of adzes from Rarotonga, three adzes are from Ma'uke, two from Mangaia and one each from Mitiaro and Atiu. The absence of adzes from Rarotonga suggests that island is not a likely source, although Wood and Hay (1970:12) report samples of basalt from the Te Manga group that lack olivine or have it as micro-phenocrysts and have pronounced trachytic texture "formed by flow oriented microlithic labradorite and granules of colourless clinopyroxene". The majority of their samples come from the upper portion of the Tupapa valley. If, however, we rule out Rarotonga and Mitiaro - the latter having no unweathered rock - we are left with three possibilities. We have already defined one Ma'uke group and it seems unlikely that the limited rock resources of Ma'uke would provide two distinctive sources. The trace element abundances of cluster 4 also differ systematically from the Ma'uke group (cluster 2). It seems most probable that the comparatively more abundant rock resource of Mangaia might provide the source for this cluster. However, as we will discuss below, this is not the Mata'are source reported by Weisler *et al.* (1994) as it forms a distinctive grouping of its own. If Mangaia is the source then this rock might be from the 'Ruapetau' source mentioned in Gill (1876:117) but which Weisler *et al.* (1994) report being unable to find. All adzes for which data are available are typical Cook Island 3A forms.

Cluster 5 is a large group of adzes which are accompanied by two geological samples from Atiu and three samples from the Mata'are source on Mangaia. Like cluster 3 this has been subdivided to indicate finer structure in the dendrogram. Cluster 5A splits from 5B between Atiu geological sample AT-2D and Mangaian adze R65-116. Cluster 5A contains adzes from the geographically close islands of Aitutaki (1), Mitiaro (2), and Ma'uke (3), and two geological samples from Atiu. All of these samples are classified as low silica basanites. The petrographic section for adze R68-3 contains only occasional fragments of feldspar phenocrysts in a very fine groundmass of suboriented plagioclase lathes, clinopyroxene needles, opaques and irregular patches of calcite. The petrography of adze MIT-1 differs from R68-3 having less than 1% clinopyroxene phenocrysts and orthopyroxene (?) and olivine in the groundmass. It seems probable on both geochemical and ethnohistoric (Walter 1990:267) grounds that the source of these adzes is in fact Atiu although a number of areas may be indicated as discussed below.

Cluster 5B is made up of two adzes from Mangaia, another from Ma'uke and three geological samples from the Mata'are quarry (Weisler *et al.* 1994) on Mangaia. This group of samples sits across the geochemical border between basanites and basalts. Figure 6.8 is the trace element plot used by Weisler *et al.* (1994) to discriminate the Mata'are source from other source regions. This figure contains geological samples only and demonstrates the effectiveness of these elemental ratios in discriminating between the islands, although Atiu, Ma'uke and the Mangaian source may form a continuum along a geochemical trend. Figure 6.9 is the same plot with all geological and adze samples for which trace data are available plotted by cluster. Using this plot the Pukapukan adze (R72-5), which has been considered an outlier in cluster 3, clearly falls outside the Cook Island grouping. The plot also shows some discrimination between clusters 5A and 5B, however the majority of the adzes fall to the left of the Mata'are source material although the members of cluster 4, which we have suggested may be an additional Mangaian group, fall very close to the Mata'are source.

Figure 6.10 provides a more detailed plot of the relationship between the Atiu, Ma'uke and Mata'are

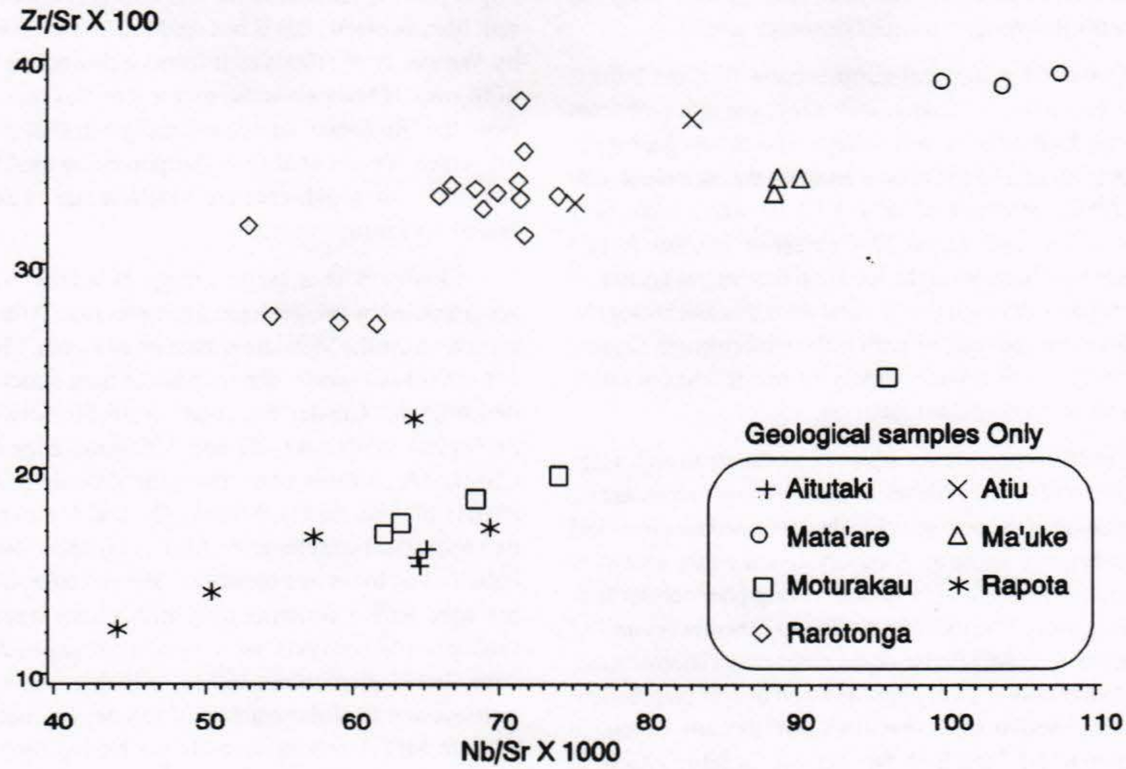

FIGURE 6.8. Plot of Zr/Sr and Nb/Sr of geological samples only.

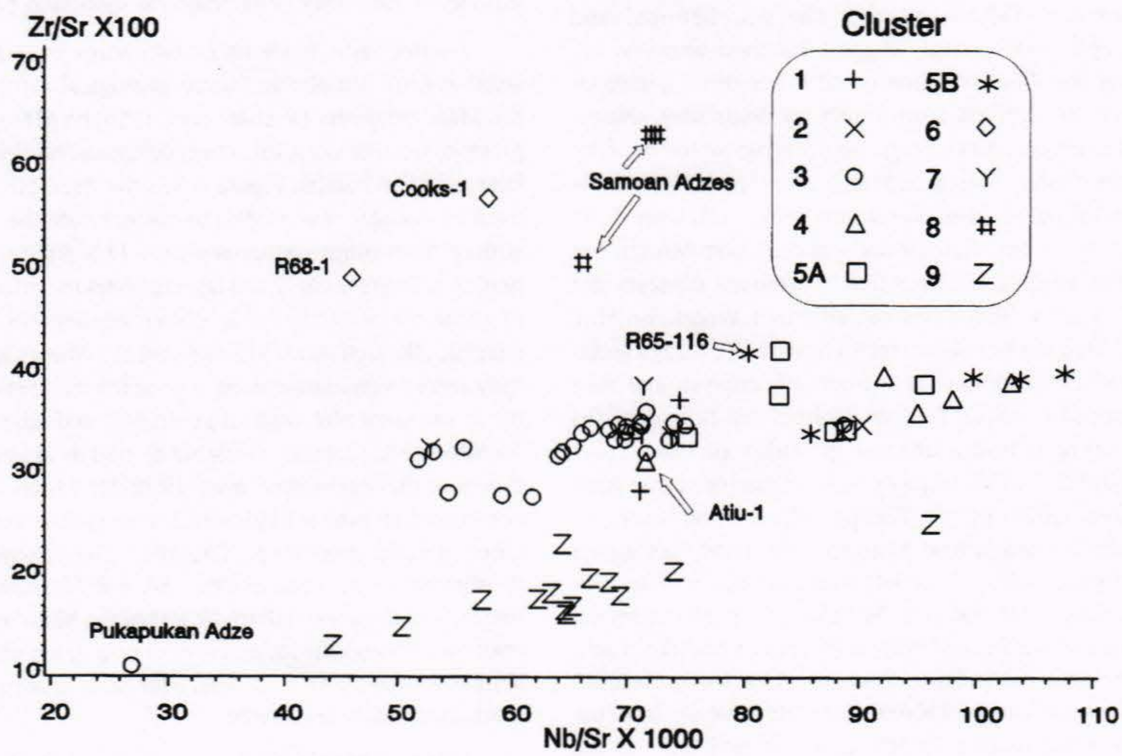

FIGURE 6.9. Plot of Zr/Sr and Nb/Sr for all samples (geological and archaeological).

geological material and clusters 4, 5A and 5B. One very interesting observation is the close clustering of samples Cooks-2, Cooks-3 and Cooks-4 (all adze flakes from the Anai'o site Area B Layer 4) with the three geological samples from Ma'uke (MAU-1, MAU-2, MAU-3). Despite considerable variation in majors and other traces (although the incompatible elements tend to covary in the same direction) this strongly suggests the Ma'uke samples in clusters 5A and 5B could be sourced to Ma'uke. Similarly the one Atiu adze (Atiu-1) falls closest to the Atiu geological samples, although as can be seen in Figure 6.9 this overlaps with the Rarotongan group. It is possible that the dispersion in this plot relates to petrogenetic processes (e.g., partial melting and fractionation) that have common or intersecting trends in these islands creating convergence of ratios of incompatible and compatible (assuming Sr is compatible in these plagioclase rich rocks) elements like those plotted in Figures 6.5 to 6.7. This taken with the prehistoric selection of similar fine grained high silica rocks (e.g., the Zr/Sr (zirconium/strontium) ratio has a very strong positive linear correlation with SiO_2 (silicon-oxide) in this dataset) may complicate sourcing when only a few ratios are used rather than a suite of elemental abundances. However, if this is not the case then the assignment of source to members of cluster 5B, and to some extent cluster 4, is in doubt. Further work on methods of discriminating among these islands is clearly required. The addition of data from Palacz and Saunders (1986) for Atiu (AT-55C) and Mangaia (MAN-88A) to Figure 6.10 shows how further data might increase the overlap among Atiu, Ma'uke and Mangaia.

Cluster 6 is a low calcium variant of cluster 5B, however it has low niobium which also removes it from the Cook Island grouping in Figure 6.9 and suggests these basalt adzes form a distinctive and possibly exotic group. In thin section the basalt adze R68-1 has 1% olivine phenocrysts and an extremely fine-grained groundmass of plagioclase, clinopyroxene, opaques, olivine and occasional patches of biotite.

Cluster 7 is a group of Rarotongan geological samples left in the analysis for comparative purposes.

Cluster 8 is a very distinctive group of adzes which are clearly not from the southern Cooks. These high silica rocks are all classified as hawaiite and are unlike any geological samples reported from the Cooks. Cluster 8 is subdivided into two groups 8a and 8b. In cluster 8a Adzes RW-M and RW-F have previously been sourced to Samoa (Best *et al.* 1992) and further cluster analysis of all the Cook

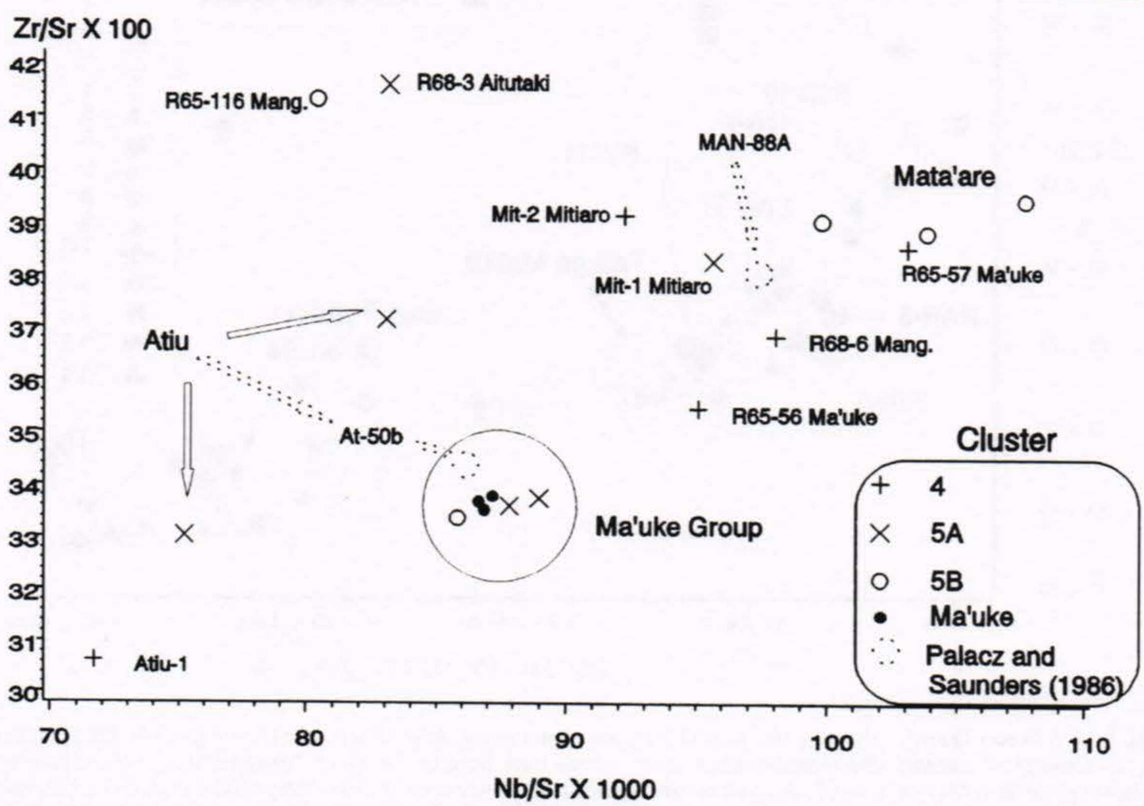

FIGURE 6.10. Plot of Zr/Sr and Nb/Sr for clusters 4 and 5, including all Ma'uke geological samples.

Island data reported here with the Pacific dataset from Best *et al.* (1992) has shown that the samples in cluster 8a group away from a well defined Cook Island group and with the Samoan adzes and geological samples. Adzes RW-M, RAR-6, and R92-1 group most closely with Tataga-matau (Tutuila) geological sample No. 39 which is from Tataga-matau Area 1, while the higher silica and phosphorous adzes R63-19 and RW-F form a separate group most closely related to the East Tutuila Asiapa quarry. Figure 6.11 is a discrimination plot used in Best *et al.* (1992:Fig. 8) with the additional Cook Island samples plotted. The new samples plot with the older samples to the left of the diagram near the low titanium cluster attributed (Best *et al.* 1992:59) to the base of Tataga-matau. In addition the trace element data for these samples compare very closely to that reported for Tataga-matau (c.f. Best *et al.* 1992:Table 2, Fig. 10). We realise, however, that assigning adzes to *specific* sources on Tutuila may be premature (Chapter 5).

Although the geochemical data strongly suggest a Tutuila source for these adzes the argument is also supported by the petrographic data as the thin sections compare very closely with the descriptions for Tataga-matau rocks (Best *et al.* 1992). For example the Tataga-matau, Leafu Stream sample with low titanium is described as follows: basalt-probably alkaline. Thin section shows phenocrysts (<0.5 mm long) of plagioclase feldspar with minor small anhedral olivine crystals and patches of brown biotite. The rock has an intergranular groundmass of feldspar microlites with granules of pale brown augite, iron oxides and occasional small olivines with interstitial glass. (Best *et al.* 1992:51).

Cooks adze RAR-6 has the following description. Phenocrysts 10-15% (0.2-05 mm in size) of alkali(?) feldspar, plagioclase, equant diamond shaped olivine (heavily fractured and altered to serpentine) and opaques. An extremely fine-grained groundmass of granular opaques (iron oxides), clinopyroxenes (likely augite) and microlites of plagioclase exhibiting some orientation with the plagioclase phenocrysts. The other two thin section descriptions in Best *et al.* (1992:51) note the presence of an oriented (subtrachytic) texture and both contain patches of

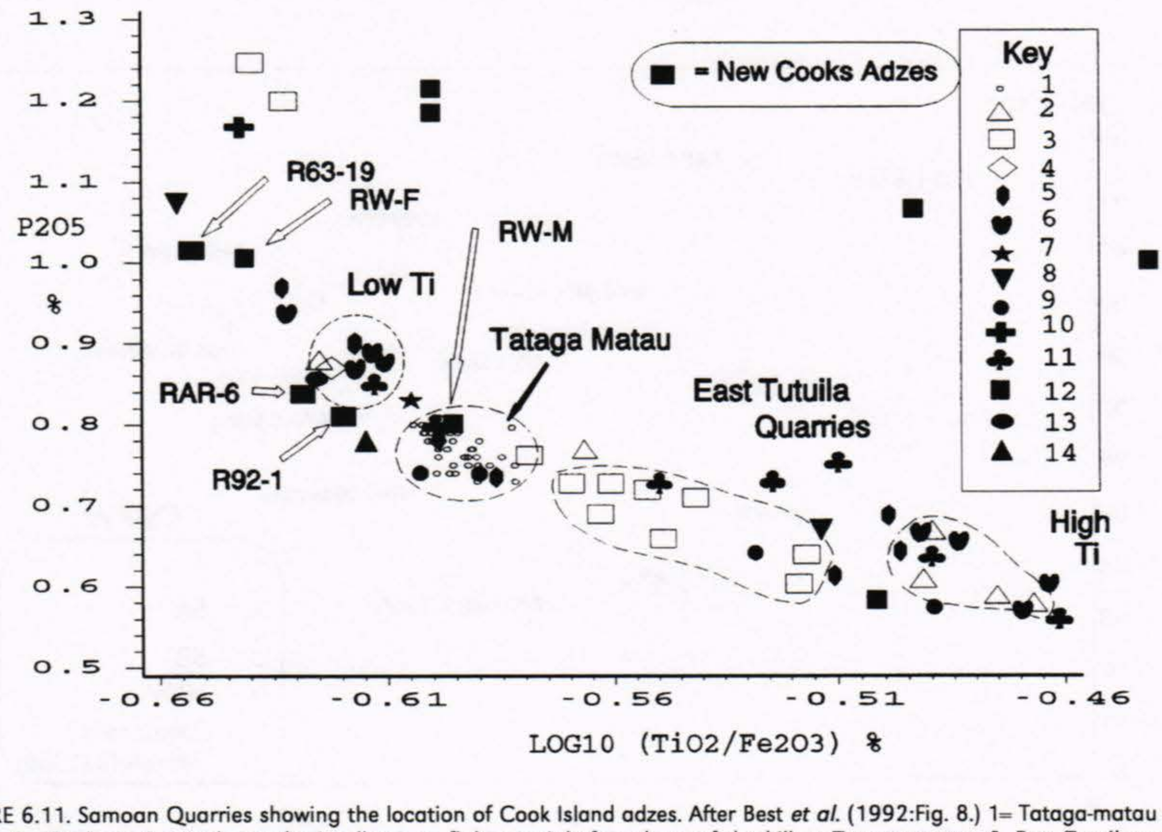

FIGURE 6.11. Samoan Quarries showing the location of Cook Island adzes. After Best *et al.* (1992:Fig. 8.) 1= Tataga-matau quarry flakes, 2= Geological samples and miscellaneous flakes mainly from base of the hill at Tataga-matau, 3=East Tutuila quarries, 4=Archaeological flake Manua Island, 5=Adzes from Western Samoa, 6=Adzes Fiji, 7=Adze Tonga (TO-6 Horizon 1), 8=Archaeological flakes Tuvalu (Temei site), 9=Adzes Taumako, Kahula and Kongo, 10=Adze Reef Islands, Nupani (RE-51), 11=Adzes Tokelau, 12= Adzes and flakes southern Cook Islands, 13= San Cristobal adze, 14= Pukapuka adze.

biotite and interstitial felsic material. In the present sample adze R63-19 has a subtrachytic texture while interstitial felsic material is reported from two thin sections. Biotite is present in all the sections available (R63-19, RAR-6, R92-1) for the cluster 8a adzes. With the exception of sample R68-1 from cluster 6 these are the only samples in the analysis to contain biotite. Flakes of red-brown biotite are reported from rocks on Rarotonga (Wood and Hay, 1970:12,15), however, their petrography appears to differ on many other mineralogical points.

Another significant feature of this group is the fact that a number of the adzes are either early or not typical of the Cook Islands. Adze R92-1 is a quadrangular form while R63-19 has a reversed triangular cross section and is from the Rarotongan Ngati Tiare cache of six adzes all of the same form (Walter and Sheppard 1996). The cache is attributed to a site excavated by Bellwood (1979:348) and dated between 500 and 700 B.P. Sample RAR-6 is a bevel fragment while RW-M and RW-F are flake fragments from quadrangular adzes.

Cluster 8b consists of two geochemically similar adzes and two outliers which join the cluster at a relatively high level. Of the former, one is a quadrangular adze (R66-7) recovered from Mangaia and the other (RAR-10) an undiagnostic butt fragment from Rarotonga. The outliers are RW-A (from Atiu) and RW-C (from Ma'uke). These samples are geochemically unlike any others from the Cooks database and are clearly from outside the region. They group most closely with the Samoan adzes, however their extremely high phosphorous values (>1.5% for RAR-10 and R66-7), high calcium and low iron put them outside the known Samoan geochemistry. In thin section they also lack the biotite seen in cluster 8a samples. A survey of the geological literature for Samoa and the Societies (Hémond *et al.* 1 1994) failed to find any geochemical analyses with such high phosphorous values. However, RAR-10 and R66-7 appear very similar geochemically to two Ra'iatean adze samples (TR-93 and TR-350) housed in the Bishop Museum which also show unusually high phosphorous values (Kevin Johnson pers. comm.). These adze samples do not cluster with any known Ra'iatean source but since Ra'iatea is not yet well sampled it is not possible to rule out a source in that general area.

The final group, cluster 9, consists of two adzes from Aitutaki, one from Moturakau, one from Palmerston (R65-6) and a large number of geological samples from the main island of Aitutaki and the two volcanic motu, Moturakau and Rapota. All of these rocks are very distinctive low silica foidites (using Le Maitre 1989) and most probably olivine nephelinites (Wood 1978b:763) based on the thin section for adze R86-2. The adzes from Aitutaki and Moturakau appear to be made of rock from Moturakau or Rapota with Moturakau the more likely candidate. The Palmerston adze has the distinctive geochemical composition of a foidite but it is not exactly matched by any of the Cooks geological or adze samples. At present it is only tentatively assigned to an Aitutaki source.

SUMMARY

The data reviewed above suggest that all of the islands of the southern Cooks which have any rock at all, have had some adzes made from local sources. In the islands of Ma'uke, Atiu and Aitutaki these sources may, as a consequence of limited rock exposure, have been very restricted with material possibly coming from only one source. Mangaia may have had adzes produced at two distinct quarries although we only have geological data for the Mata'are source. The abundance and variety of rock on Rarotonga appears to have supported the manufacture of adzes from numerous small sources, possibly from suitable stone selected from a number of drainages cutting the Te Manga Group. Phonolite, and especially the Black Rock phonolite, was not used to manufacture utilitarian adzes possibly because it was too brittle.

Table 6.5 lists the adze find spots by source in an effort to examine patterns of interaction within the southern Cooks. Although the numbers in this table are somewhat skewed by the comparatively high numbers of adzes sampled from Ma'uke it can be used to examine general trends. Rarotonga is obviously, by virtue of its geological wealth and position, providing adzes to all the islands of the southern Cooks. Aitutaki with rather poor quality low silica nephelinite as the dominant rock type is not providing adzes to other islands. Atiu with its rather limited range of basanites and basalts may, if we accept the assignment of cluster 5B adzes to Atiu, be contributing adzes to most of its near neighbours and this could relate to the documented Ngaputoru confederacy of Atiu, Ma'uke and Mitiaro (Walter 1990:267) which involved considerable interaction between these islands in the early 19th century. Ma'uke with its rather limited supply of rock appears to have only made adzes for local use with none moving beyond the island. Mangaia, which is the second largest and most southerly of the islands appears to have had some contact with the islands of the Ngaputoru confederacy, and Allen and Johnson (Chapter 7) have also identified a Mangaian source on Aitutaki.

The pattern of stone movement summarised above is illustrated in Figure 6.12 without reference to chronology. A possible interpretation of this figure is that a lineal chain of communication involving only short open sea crossings existed from Ngaputoru through Manuae and Takutea to

	Adze Find Spot					
Source	Rarotonga	Aitutaki	Atiu	Mitiaro	Ma'uke	Mangaia
Rarotonga	13	3	1	1	4	2
Aitutaki		3				
Atiu		1	1(2)	2	3(1)	
Ma'uke					2(5)	
Mangaia			1(0)	1	4(3)	4
Ra'iatea(?)	1					1
Samoa	3				2	

TABLE 6.5. Summary of adze find spot by source of adze rock.

Aitutaki. This may have served as the backbone to the Cook Island exchange system with both Rarotonga and Mangaia feeding into the system at less regular intervals. This model is based solely on basalt sourcing but is reinforced by the evidence for pearl-shell exchange in the archipelago. Black-lipped pearl-shell, *Pinctada margaritifera*, was an important industrial material throughout East Polynesia where it was the material of choice for fishhook manufacture wherever it was available. It has a very uneven natural distribution in the Cook Islands, more so even than basalt, but was widely traded throughout the group in early prehistory. It is found in large quantities in sites in Aitutaki, Ngaputoru and Mangaia and to a lesser extent in Rarotonga (Allen 1992; Kirch *et al*. 1992; Walter 1990) but declines rapidly from the archaeological record of all these islands from the early 1500s (Allen 1992; Kirch *et al*. 1995; Walter 1990; Walter and Campbell 1996). There is some debate over whether the pearl-shell originated in Aitutaki (Allen 1992) or whether it came from the Northern Cook Islands or regions east, but in either scenario it would have followed a similar pattern of movement to the basalt, and sourcing studies directed at this material should be rewarding. One possible source for the pearl-shell is Palmerston Island. This island lies at the opposite end of the Aitutaki-Ngaputoru chain to Mangaia, and at about a similar distance from the nearest neighbour (see Fig. 6.12). Like the Mangaian basalt, Palmerston Island may have been intermittently feeding pearl-shell into the main exchange system of the Southern Cook Islands.

It is very difficult to discuss the chronology of interaction in the southern Cooks using the present dataset as most of the adzes are surface finds. The adzes from Samoa are very likely all early as the Ngati Tiare cache dates between 500 and 700 B.P. while the adzes from the Anai'o site (RW-F, RW-M) date between A.D. 1300 and 1400. After this early period of interaction we have no evidence of outside contact to the west. However, the tentative grouping of RAR-10 and R66-7 with two adzes from Ra'iatea is suggestive of contacts to the east. The two Cook Island samples are almost certainly exotic and while a third, hitherto unidentified, origin for all four samples is possible it is more likely to lie east of the Cooks than to the west. R66-7 is a quadrangular adze from Mangaia and probably a relatively early form, RAR-10 is undiagnostic and we have no data on the two Ra'iatean types.

After the early period of widespread interaction we have very little chronological control. The data from the Anai'o site indicate early use of stone resources on Ma'uke and we can assume a similar pattern of local use developed in all the other islands. The development of patterns of interaction with Rarotonga may have some chronological depth but the study of dated adzes is required to examine this issue. The interaction between Atiu and the other islands of the Ngaputoru confederacy was clearly continuing at contact but its time depth is unknown. This is also a question which could be investigated through the sourcing of dated adze material and the improvement of our ability to distinguish rock from Atiu, Ma'uke and Mangaia. The latter

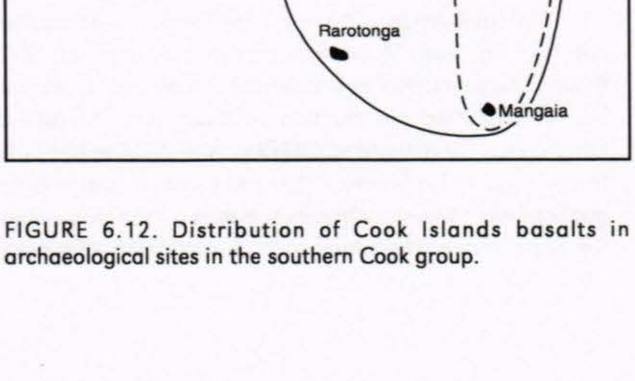

FIGURE 6.12. Distribution of Cook Islands basalts in archaeological sites in the southern Cook group.

will require analysis of more samples from these islands in order to examine geochemical and petrographic trends. Palacz and Saunders (1986) have demonstrated considerable isotopic difference between Atiu and Mangaia and such analysis may be required to achieve accurate sourcing.

DISCUSSION

The results of this study have fairly conclusively determined that adzes or adze material has been transported into the southern Cooks from outside the region. The majority of this material is closest in geochemistry and petrography to known sources in Samoa (Tutuila), 1200 km upwind to the northwest. Geochemical information on the Societies and Australs (Hémond *et al.* 1994) suggests that it is unlikely that either could have provided basalt comparable to that from the Samoan quarries but the importation of stone from an eastern source also exploited by Ra'iatean adze makers is a possibility. However, more characterisation research is needed on adze quarries in all island groups before the full picture can be pieced together.

The chronology of movement is based on data from a small number of excavated samples. On Ma'uke, Samoan adzes are dated to A.D. 1300-1400 (Walter 1990) while the Ngati Tiare cache at Avarua on Rarotonga is also dated indirectly by presumed association with Layer 3 of the Ngati Tiare site (Bellwood 1978:79) which has two radiocarbon dates of A.D. 1297 ± 73 and A.D. 1470 ± 70 (Bellwood 1978:72). Allen (1990:300, 1994b) reports flakes and two broken adzes (Duff Type 2c) from strata on Moturakau dated to late 13th to mid-15th century A.D. Kirch *et al.* also report Samoan adze material from the Tangatatau rockshelter on Mangaia (1995:54; Weisler and Kirch 1996). The Tangatatau rockshelter samples date from the lower end of the deposit, between 1000-1500 A.D. Thus evidence for contact with Samoa is restricted to the period prior to the 15th century although maximum and minimum dates of contact remain uncertain.

The amount of material geochemically sourced to Samoa is very small, however the fact that it appears at three early sites excavated on different islands suggests that a considerable amount of material was transported, especially if colonisation is pushed back prior to A.D. 900 (Allen 1994a) or earlier (Kirch and Ellison 1994) giving a very long potential contact period. As noted above, however, calculating the chronological extent of contact is made difficult by potential curation effects. Best *et al.* (1992:66) have indicated that Pacific wide sourcing work suggests adzes did not move out of Samoa prior to 900 years ago. This would appear to create a maximum contact time depth of *ca* A.D. 1000 after which time there appears to be a period of movement out of Samoa into neighbouring island groups of East and West Polynesia and Fiji (Best *et al.* 1992:69). Whether the episode of contact between the southern Cooks and Samoa documented in the stone sourcing represents colonisation or post-colonisation interaction is unclear at present. Either option is possible and there are strong and conflicting points of view about which is the most likely (Kirch *et al.* 1991; Spriggs and Anderson 1993). Independent evidence will have to be invoked to determine which alternative is ultimately correct but whatever the answer, the implications in terms of Cook Islands and eastern Polynesian culture history are profound.

Development of exchange systems

Exchange, as a fundamental social glue, was pervasive within prehistoric Cook Island societies. Of theoretical significance are the scale and pattern of exchanges as a measure of socio-political integration or specialised production. Gill (1876:117) reporting the sermons of the native Mangaian pastor Mamae illustrates perhaps the simplest level of exchange associated with adze manufacture. Speaking of Mangaia Mamae stated that: "The best basaltic stones for making axes are found at the head of the valley Mataare, or else at Rupetau. If a man wanted some axes made he would go to one of these places, and with his ironwood spade dig out the best stones he could find, and then carry them to the artisan who had agreed to make a set of axes. Payment was rendered in food and cloth." It seems probable, based on our evidence of the use of many small dispersed sources that most adze production in the southern Cooks was carried out in the manner reported above. Specialised production such as that suggested by Leach (1993:36) for the large debris-rich quarries of Samoa, Hawaii and New Zealand does not seem to have been a feature of the southern Cooks. Even on Mangaia which may, based on its silica content, have produced the 'best quality' adze material, production was carried out by 'specialists' (*taunga*, Gill 1876:117) as a very limited transaction at some location away from the quarry.

The presence of inter-island interaction throughout the southern Cooks has been documented by our work, however investigation of hypotheses of the pattern and scale of exchange and their relation to intensification or changing land use (Walter 1990; 1993) will have to await further excavation and careful analysis, sourcing and dating of materials. Results to date are not inconsistent with recorded patterns of socio-political integration or geographical proximity such as the Ngaputoru confederacy of Atiu, Ma'uke and Mitiaro or the proposed decline in inter-island interaction over time (Bellwood 1978: 202-203; Walter

1990). A much richer analysis (Sheppard 1996) will depend on the integration of evidence from adzes (including roughouts and flakes), pearl-shell, oven stones and possibly chert which occurs on Mangaia.

Technological change

Adze morphology and manufacturing techniques can be influenced by the type of raw material available. Some adze parameters such as maximum size can be determined by size, homogeneity and strength of available raw material and this may explain the size of adzes manufactured at some quarries. Other parameters may be constrained by differing degrees of ease of manufacture or adze use life. Studies of adze technology in the southern Cooks are in their infancy and as yet the physical properties (e.g., fracture toughness, hardness etc.) of adze rock or the results of replication experiments have not been carried out or reported. The unexpected discovery that phonolite was not used for adze manufacture has been tentatively explained above by suggesting that the material is too brittle. This has yet to be substantiated. One property of southern Cooks adze rock which can be estimated before testing is hardness, which relates directly to ease of grinding. The adze rocks of the Cooks are distinctive in the quantity of comparatively soft felsic material which they contain. It may be that the abundance of small fully ground 3a adzes in this island group is related to the ease of grinding and hammer dressing and comparative difficulty of flaking. Investigation of the physical properties of Cooks adze rock is currently underway.

CONCLUSION

The results of this study have demonstrated that it is possible to source adze rock in the southern Cooks to Rarotonga or the Aitutaki group with comparative ease, however discriminating among the other islands is slightly more problematic. Our data have indicated that all islands with igneous rock produced adzes from local stone and in the case of Ma'uke we can document this from the earliest occupation. On the island of Rarotonga adzes were manufactured from a variety of basanite rocks suggesting the use of many small sources located in the northern and central portions of the island. None of the 51 adzes or adze flakes studied in this sample were made from true phonolite, although one Rarotongan roughout (R65-372) was made from phono-tephrite. Our data demonstrate that phonolites such as those found at Black Rock were not used in the manufacture of adzes, therefore Black Rock should no longer be considered a source. The island of Mangaia appears to have produced the highest silica basalt in the region and this may account for the indicated presence of two quarries on the island and the distribution of adzes from this most southerly island to the geologically impoverished islands north of Rarotonga.

Considerable interaction within and between island groups is indicated by the sourcing data. Contact with Samoa is indicated by a series of adzes which source to Tatagamatau and other east Tutuila quarries. All of these adzes are chronologically early based on morphology and radiocarbon dating. These data strongly support some settlement of the southern Cooks from Samoa. A number of other adzes may be foreign to the Cooks (three), and although we may not yet be able to accurately source them, some potential candidates are beginning to emerge.

Considerable interaction within the Cooks is shown in the data; however, as most of the samples are surface finds we are unable to examine the chronology of interaction. The presence in the analysis of at least one cluster of adzes, which did not contain a sample from the large group of adzes found on Rarotonga, suggests that restricted patterns of interaction may have occurred in the past, although adzes from outside Rarotonga may be hard to find in the large mass of Rarotongan adzes made in Rarotonga. Investigation of known political entities such as the Ngaputoru confederacy of Atiu, Mitiaro and Ma'uke will require further efforts at discriminating these islands.

One of the interesting results of this study is the documentation of the use of a wide variety of low silica, probably poor flaking, rocks for the manufacture of adzes in the southern Cooks. Many of these rocks were likely cobbles collected from stream channels and not obtained from large quarries producing large angular blank forms. The implications of this type of material procurement strategy for adze morphology is an area of future research which will integrate both adze sourcing and the technological study of adze manufacture and use.

Finally this study has demonstrated the difficulty of 'finding' sources as opposed to discriminating between known sources. Even in the presence of considerable geochemical and petrographic data it is difficult to assign a source island when a series of islands have very similar geologies. The possibilities of independent convergence on a similar petrography or geochemical composition remains a large unknown when these factors are controlled or influenced by petrogenetic processes producing broad trends in the geochemistry, or prehistoric selection processes which may preferentially select certain petrographies (e.g., trachytic texture in high silica rocks). It seems theoretically probable that assignment of rocks to volcanoes, which may on occasion be equivalent with islands, could be carried out using ratios of incompatible elements as this ratio might be characteristic of a volcano throughout its life; however, assignment of rocks to lava flows within a volcanic sequence will require the use of abundances. Such cases call for either more analysis in an effort to understand, or at least evaluate local geological variation, or the use of more powerful sourcing techniques such as isotopic studies (Weisler and Woodhead 1995; Chapter 13). Further work in the southern Cooks is called for before we can confidently investigate some of the more interesting questions of prehistoric interaction within the area.

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Id	Island	Comment	Type	Group[1]
R68.13	Aitutaki	Medium to fine grained greyish yellow 2.5Y6/2	3a	Ait-2
R66.7	Mangaia	Fine grained light grey N7	quad	Man-2
Cowan-1	Atiu	Mapumai, George Cowan's collection	triangular reverse	
Ait-M-1	Moturakau	Aitutaki Adze #1, heavily weathered Fine grained, numerous phenocrysts of augite? Munsell 10BG5/1		
RW-2	Rarotonga	Ruatonga, weathered	3a frag.	
RAR-10	Rarotonga	Fine - medium grained. Grey, possibly phonolite, no phenocrysts	butt frag	RAR-1
R72.3	Mangaia	Fine grained light grey N7	quad	Man-2
R65.6	Palmerston	Medium grained slightly vesicular, weathers to Munsell 5Y7/10	traingular reverse	
R65.371	Rarotonga	Dark grey, fine grained. No phenocrysts. Munsell 7.5Y5/1	roughout	RAR-1
R65.338	Rarotonga	Medium coarse. Vesicular with small number rectangular phenocrysts up to 2mm. Munsell 7.5Y6/1.	butt frag	RAR-2
RW-1	Ma'uke	Ngatiarua Carr Residence, light grey/white highly vesicular weathered	rev. triangular roughout	
RW-G	Ma'uke	Anai'o Layer 4 Flaking Area 1. Core. Walter (1990)		
RW-E	Ma'uke	Anai'o Layer 4 Flaking Area 1. Adze. Walter (1990)		
R72.6	Mangaia	Medium to fine grained greyish yellow 2.5Y6/2	3a	MAN-1
RW-L	Rarotonga	Arai-te-Tonga, surface adze Walter (1990)		
R65.70	Ma'uke	Prob. Anaio, fine grained dark grey-black	quad	Mau-1
Mit-3	Mitiaro	Takaue Section, Medium coarse grained. Munsell 10Y6/1	mid-section	
R63.10	Rarotonga	Medium fine grained. Small number of small black phenocrysts Munsell 2.5Y5/1.	butt frag	RAR-1
R65.220	Rarotonga	Fine grained, no phenocrysts, Munsell 2.5Y6/1	frag	RAR-1
R86.30	Rarotonga	Poor sample, weathered, Coarse grained, many black-brown phenocrysts up to 4mm. Looks like the TeManga range Munsell 10Y7/1	3a	Rar-2
R62.8	Rarotonga	Medium - coarse brown-grey. Few large phenocrysts Munsell 5Y6/1.	butt frag	RAR-2
R72.5	Pukapuka	Medium grained weathers to 2.5Y6/2	3a	
R62.38	Rarotonga	Medium grained, no phenocrysts. Munsell 7.5Y5/1	butt frag	RAR-1
R62.10	Rarotonga?	No record	quad	
R65.372	Rarotonga	Medium coarse grained. Phenocrysts of brown- black, up to 2mm in size, most smaller. Munsell 2.5Y6/2	butt frag	RAR-2
RW-N	Aitutaki	Vaipae, surface adze Walter (1990)		
R65.62	Ma'uke	Fine grained dark grey black	3a	Mau-1
R65.72	Ma'uke	Prob. Anaio, Fine grained dark grey black	quad	MAU-1
R63.21	Aitutaki	Very fine grained black 2.5Y2/1	oval	Ait-3
RW-H	Rarotonga	Arai-Te-Tonga, surface adze Walter (1990)		
RW-K	Ma'uke	Araki, surface adze. Walter (1990)		
R62.17	Rarotonga	Dark grey, fine grained. No phenocrysts. Munsell 7.5Y5/1	frags	RAR-1
R68.6	Mangaia	Medium to fine grained greyish yellow Munsell 2.5Y6/2	3a	Ait-1
R65.57	Ma'uke	Fine grained dark grey black	3a	MAU-1
R65.56	Ma'uke	Fine grained dark grey-black	3a	Mau-1
Mit-2	Mitiaro	Adze # 2 Fine grained, no phenocrysts. Munsell 2.5Y6/2	3a	
RW-O	Mangaia	Surface adze Walter (1990)		
Atiu-1	Atiu	Tumai Beach surface adze, Medium grained, black phenocrysts Munsell 5Y5/1	qaud	
RW-C	Ma'uke	Makatea, surface adze. Walter (1990)		
R68.3	Aitutaki	Medium to fine grained greyish yellow about Munsell 2.5Y6/2	3a	AIT-2
Mit-1	Mitiaro	Takaue Section Adze #1, Fine-medium grained, brown grey One or two small phenocrysts. Munsell 5Y4/1	3a	
RW-D	Ma'uke	Areora, surface adze Walter (1990)		
RW-J	Mitiaro	Walter (1990)		
R65.116	Mangaia	Very fine grained dark black Munsell 5Y2/1	3a	MAN-3
R68.1	Rarotonga	Dark grey, fine grained, no phenocrysts. Munsell 7.5Y6/1	3a	RAR-3
R63.19	Rarotonga	Ngati Tiare, fine grained dark black weathers to Munsell N3	triang	RAR-3
RAR-6	Rarotonga	Dark grey, very fine grained. No phenocrysts. Munsell 10GY5/1	bevel frag	RAR-3
R92.1	Rarotonga	Muri Beach	quad	
RW-M	Ma'uke	Anaio, layer 4 Area B. excavated adze. Walter (1990)		
RW-F	Ma'uke	Anaio, layer 4, flaking area 5. excavated adze. Walter (1990)		
RW-A	Atiu	Areora, surface adze Walter (1990)		
R86.2	Aitutaki	Tapuaeta'i, Fine- medium grained, vesicular with no visible phenocrysts. Munsell N6	roughout	AIT-1
CO-SB1	Aitutaki	Best *et al.* (1992)		
RW-L	Rarotonga	Arai-te-Tonga, surface adze Walter (1990)		
R66.68	Atiu	Fine grained like Rarotonga Group 1	3a	

[1] As first sorted at the museum.

APPENDIX 6A. Provenance of all adze samples.

ID	Provenance
AT-1b	Atiu, Ukaveu Valley, top of valley from boulder eroding out of the red soils.
R-20C	Rarotonga, a flow of phonolite extends into the sea in a narrow reef, *ca* 300 m south of Paringaru Stream.
R-14A	Rarotonga, Tupapa Valley, *ca* 2 km upstream of last house, river bed.
R-3D	Rarotonga, Tokerau Stream. From rubble on new quarry floor.
MAU-3	Ma'uke.
MAU-1	Ma'uke.
R-16A	Rarotonga, Tupapa Valley, under the bridge on the Ara Metua.
R-24a	Rarotonga, Takuvaine stream about 200 m up from the coast road.
R-10B	Rarotonga, Avatiu Stream at E.P.S From river bed.
R-17C	Rarotonga, Avana River, 3.2 km inland from Ara Metua.
MAU-2	Ma'uke.
R-14C	Rarotonga, Tupapa Valley, *ca* 2 km upstream of last house, river bed.
R-5A	Rarotonga, Tokerau Stream, 700 m downstream from the new quarry, from river bed.
R-14B	Rarotonga, Tupapa Valley, *ca* 2 km upstream of last house, river bed.
R-16B	Rarotonga, Tupapa Valley. Under the bridge on the Ara Metua.
R-15A	Rarotonga, Tupapa Valley, *ca* 150 m downstream of 14.
R-10C	Rarotonga, Avatiu Stream at E.P. S. From river bed.
R-11B	Rarotonga, Avatiu Stream *ca* 1 km below E.P.S. river bed.
AT-1C	Atiu, Ukaveu Valley, top of valley. From cobbles on valley floor.
AT-54B	Atiu, Data from Palacz and Saunders (1986). *Ca* 0.5 km northwest of Areora Village.
AT-2d	Atiu, Vairakaia valley, below Tengatangi village from a boulder eroding from the side of the valley.
MAN-88A	Mangaia, data from Palacz and Saunders (1986). 1 km west of Karanga Village.
R-5B	Rarotonga, Tokerau River, 700 m downstream of the new quarry, the river bed.
R-4B	Rarotonga, Tokerau River From the river bed *ca* 300 m downstream of the new quarry.
R-11A	Rarotonga, Avatiu Stream *ca* 1 km below E.P.S. river bed.
R-23c	Rarotonga, Murivai Stream under the bridge on the Ara Metua.
MOT-3 b	Moturakau, boulders on north side towards back of beach.
RAP-1E	Rapota, beach boulders west side.
RAP-1c	Rapota, beach boulders west side.
MOT-3 c	Moturakau, boulders on north side towards back of beach.
MOT-2 a	Moturakau shelter flake.
MOT-3 d	Moturakau, boulders on north side towards back of beach.
MOT-1 a	Moturakau southwest point.
MOT-1 b	Moturakau southwest point.
RAP-1b	Rapota, beach boulders west side.
RAP-1a	Rapota, beach boulders west side.
RAP-1d	Rapota, beach boulders west side.
AIT-4a	Aitutaki, second quarry on Vaipae road.
AIT-4c	Aitutaki, second quarry on Vaipae road.
AIT-4b	Aitutaki, second quarry on Vaipae road.
AIT-2b	Aitutaki, beach boulders 100 m north of the Rapae Hotel.
AIT-1B	Aitutaki, Nikaupara intertidal zone boulders.

APPENDIX 6B. Provenance of geological samples.