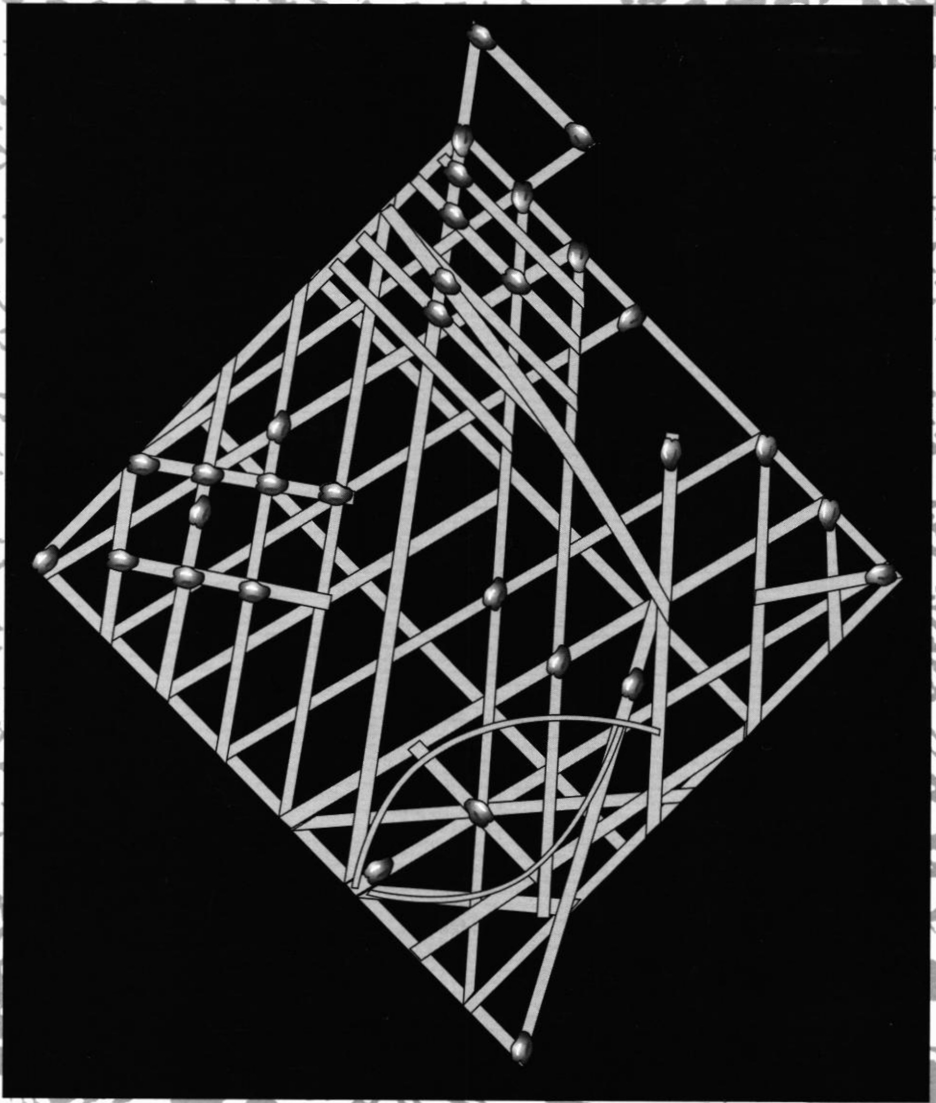
NEW ZEALAND ARCHAEOLOGICAL ASSOCIATION

NEW ZEALAND ARCHAEOLOGICAL ASSOCIATION MONOGRAPH 21:
Marshall I. Weisler (ed.), *Prehistoric Long-Distance Interaction in Oceania: An Interdisciplinary Approach*



PREHISTORIC LONG-DISTANCE INTERACTION IN OCEANIA: AN INTERDISCIPLINARY APPROACH

Edited by Marshall I. Weisler

21
NEW ZEALAND ARCHAEOLOGICAL ASSOCIATION MONOGRAPH

ACCURATE SOURCING OF BASALTIC ARTEFACTS BY RADIOGENIC ISOTOPE ANALYSIS

Jon D. Woodhead and Marshall I. Weisler

Identification of prehistoric interaction networks - so-called trade and exchange - is fundamental to understanding the processes leading to cultural variability and identifying mechanisms fostering change. Early studies of this type linked stylistically similar artefacts as a proxy for demonstrating interaction between geographically separated sites, while more recent investigations have advocated identifying artefacts made from exotic materials, found in habitation sites, as a better foundation for proposing prehistoric contacts.

After colonisation of the widely-spaced archipelagoes of Polynesia, documenting subsequent inter-island contact between the many scattered landfalls presents a formidable archaeological challenge. In the southwestern Pacific, for example, islands are generally larger and closer spaced and, furthermore, exotic, distinctive pottery, obsidian and shell ornaments are all relatively abundant in archaeological sites; this has greatly facilitated interaction studies in the region (reviewed in Chapter 2, this volume). In contrast, however, these artefact classes are rare or absent in Polynesia and, consequently, artefacts produced from basalt and volcanic glass provide the best means of empirically defining patterns of interaction in these eastern Pacific islands (e.g., Best *et al.* 1992; Weisler 1990, 1994; see papers in this volume). This is possible because geological sources for stone-tool quality rock are relatively few, yet manufactured artefacts are found across a wide geographic scale in prehistoric habitation sites occupied for long duration. Consequently, attempts have been made to develop sourcing protocols for volcanic glass, vesicular basalt oven stones and fine-grained basalt fashioned into adzes and other cutting tools that are widespread in the eastern Pacific (reviewed in Weisler 1993a).

We focus here on radiogenic isotope analysis - a highly accurate technique of great utility in regions of Polynesia where source overlap and geochemically-homogeneous regional geology, as identified by standard x-ray fluorescence (XRF) procedures, may cause problems when assigning artefacts potentially obtained from widely spaced archipelagoes such as Hawaii, the Marquesas, Societies and Samoa (see, for example, Chapter 7:Fig. 7.6). The technique also shows much promise on a smaller scale such as in the southern Cook Islands where current XRF techniques have identified geochemical overlap of potential sources (see Chapter 10:Fig. 10.7) and in the many fine-grained basalt quarries on Tutuila, Samoa, where much geochemical overlap exists between known sources on a single island (Chapter 5). Furthermore this method can also be used as a check on source assignments made by other less powerful methods such as the semi-quantitative energy-dispersive x-ray fluorescence (EDXRF) (see Weisler 1993c). Radiogenic isotope analysis requires only 50-100 mg sample material, thus small or valuable museum specimens can be analysed with a minimum of destruction.

After considering the limitations of currently used petrographic and XRF characterisation of basaltic artefacts we demonstrate the efficacy of radiogenic isotope analysis by reference to three examples from Polynesia. Initially, we provide the first evidence for two-way movement of fine-grained basalt in the eastern Pacific (between the Pitcairn group and the Gambiers, the latter group also known as Mangareva). Secondly, we document inter-archipelago interaction with imports from Tutuila, Samoa to Mangaia in the southern Cooks, a distance of more than 1200 km. Finally, to demonstrate the applicability of our technique to sourcing issues on a smaller scale, we identify intra-archipelago prehistoric movement of fine-grained basalt in the Marquesas.

THE LIMITATIONS OF PETROGRAPHIC AND X-RAY FLUORESCENCE ANALYSIS

Macroscopic observations (e.g., Dye 1987) and thin-section petrography (e.g., Best 1987; Lass 1994) have been used in an attempt to track prehistoric exchange of adze materials. Although petrographic techniques date back well into the last century (Grimes 1979), they still remain largely descriptive and should be used in concert with sophisticated equipment for the determination of mineral chemistry, such as the electron microprobe (e.g., Baker 1993; Weisler 1990; Weisler and Clague 1997). Without the aid of such techniques no two petrologists consistently perform the same petrographic analysis of a given rock sample (Weisler 1989). Petrographic study does has some utility in defining rock characteristics - for example, flow-banding, grain size and the presence of phenocrysts - yet petrographic descriptions are difficult to assess with quantitative methods (Chayes and Fairbairn 1951), rendering data standardisation and inter-laboratory comparisons - of paramount importance for regional-level analyses - extremely difficult. Perhaps more fundamental to Polynesian sourcing studies, however, is the fact that oceanic island basalts tend to follow a limited number of magmatic differentiation (partial melting, crystal fractionation, assimilation) paths and thus can be broadly similar in hand-specimen and thin-section appearance. In summary then, petrographic analysis, by itself, does not provide a satisfactory method to accurately distinguish the provenance of basaltic artefacts and differentiate rock sources.

Recognising this shortfall, more recent studies in Polynesia have begun to utilise geochemical analytical techniques, in particular major and trace element determination by XRF, as a means of classifying artefacts (Best *et al.* 1992; Weisler 1993b, c; Weisler *et al.* 1994). There are many advantages to such an approach. These methods produce data with high degrees of analytical accuracy and precision and, in addition, inter-laboratory comparisons are readily achieved by means of widely available standards (the U.S. Geological Survey, for example, produces a broad spectrum of geological reference materials; see Weisler 1993c:173). Finally, such techniques can, in many cases, be non-destructive, especially where a relatively flat surface, free from contamination or secondary products, is available (Weisler 1993c). XRF has certainly been used with success in a number of studies involving comparisons of artefacts with specific sources (e.g., Best *et al.* 1992; Weisler 1993b, papers in this volume). However, as the geographic scale of analysis increases (e.g., individual flow, volcano, island, archipelago, petrologic province; see Chapter 10:Fig. 10.3), problems of source overlap follow as a direct result of the geological processes which produce chemical variation, and we believe that this is an issue which has been largely ignored.

The sourcing strategy often employed is to geochemically characterise a sample of artefacts from a site or region and then determine which element-ratio plots serve to best distinguish the various artefacts sources (Best *et al.* 1992). Oftentimes, geological data are used in addition to geochemical averages for known sources. To illustrate the problems inherent in such an approach, we have superimposed relevant geological data on a typical archaeological 'discriminant diagram'. In Figure 13.1 we reproduce a plot of total alkalies vs. silica (from Weisler 1993a:67), in which data for a number of Polynesian basaltic sources are shown (filled circles). Superimposed on this diagram are typical literature analyses of geological samples, mostly basalts, from Pitcairn island (Woodhead and McCulloch 1989), and the Gambiers (Dupuy *et al.* 1993). Clearly, although the analysis of the Tautama source on Pitcairn falls within the field of Pitcairn island geological data, the latter array extends across a large portion of the entire figure, especially when the more differentiated Pitcairn volcanic glass is considered, to such an extent that it encompasses many other geographic locations. The data for the Gambiers exhibit similar variation. This is, of course, a slightly unfair comparison of known basalt sources with geological samples - of no known archaeological significance - but it serves to illustrate an important point. Incorporation of geochemical data from geological features or events of undemonstrated archaeological significance may prove problematic for sourcing studies but it may be necessary to incorporate such geological data when the archaeologically-confirmed basalt sources are few or unknown in the region of interest (e.g., Society Islands, Australs and the Marquesas). Similar, and in many cases worse, overlaps are noted in trace element ratio plots when geological data, representing the real natural variation for any given island or island group, are superimposed on discriminant plots.

Under favourable circumstances, of course, it may prove possible to assign a given artifact to a known (i.e., analysed) quarry by XRF methods, especially at the scale of a single archipelago, but there is a great deal of compositional variation at the scale of a petrological province (e.g., Polynesia) which involves several archipelagoes and potentially thousands of separate volcanic events (a single volcano may record many hundreds of eruptive events). Thus, in the absence of a complete chemical database for all possible quarry sites within Polynesia, we do not have, at present, the capability to positively source all artefacts by this means.

The reasons for these overlaps are readily understood in terms of the underlying geological processes. In volcanic rocks, particularly those from oceanic regions, variation in the content of major element oxides and trace elements is controlled predominantly by near-surface magma-chamber processes such as fractional crystallisation and crustal assimilation, phenomena which are in turn related to the pressure and temperature during magmatic segregation and ascent (see discussion in Chapter 10). In geological terms

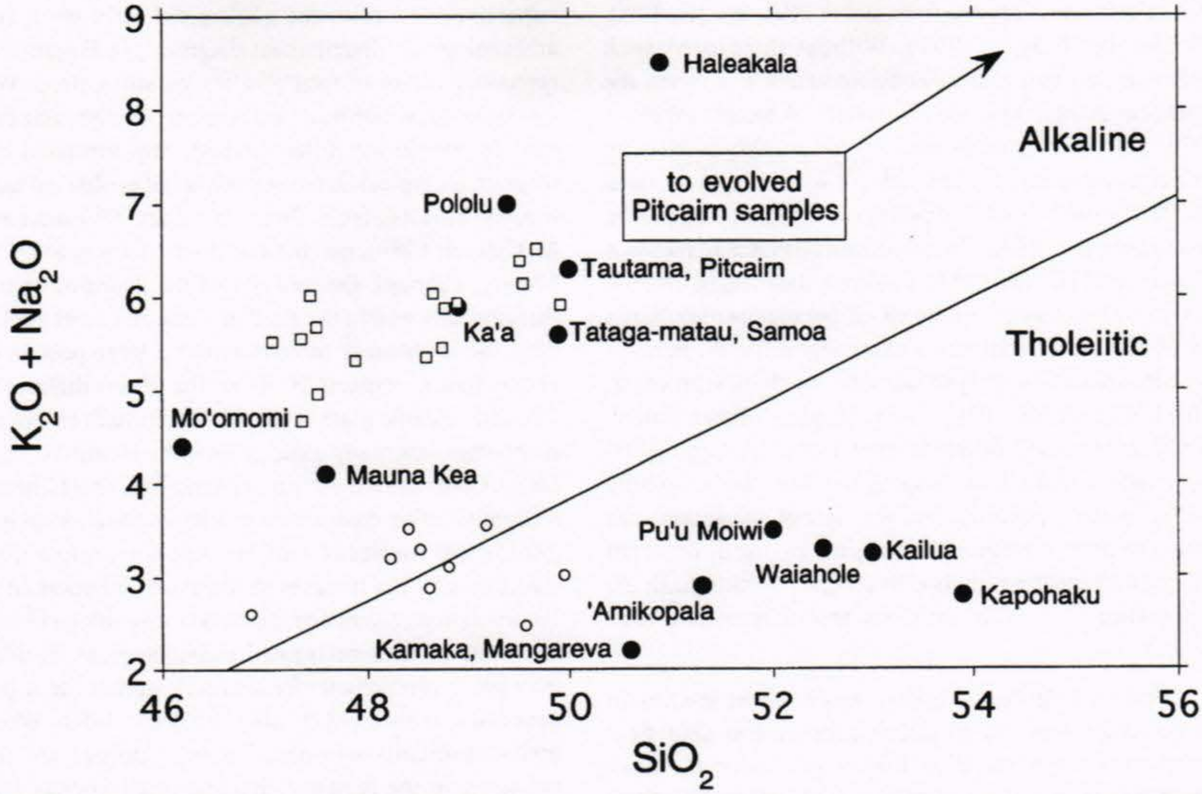


FIGURE 13.1. Plot of total alkalies vs. silica. Filled circles represent analyses of well known quarry sources from throughout Polynesia (Weisler 1993a). Open squares and circles represent analyses of geological materials from Pitcairn island and the Gambiers, respectively (see text for references). Clearly, the incorporation of geological data to aid in determining artefact source requires the use of a more powerful discriminator such as radiogenic isotopes. As the geographical scale increases, the potential problems with overlapping major and trace element fields multiply.

the high volcanic islands of Polynesia (e.g., Hawaii, Marquesas and the Society Islands) are all formed in response to upwelling hot 'mantle plumes' impinging on an oceanic crust of relatively constant thickness. Consequently, in general terms at least, fractionation histories are similar between most oceanic islands and, as a result, major and trace element contents (and even ratios of the latter) can show much overlap.

RADIOGENIC ISOTOPE ANALYSIS

To circumvent the potential problems encountered in inter-archipelago scale sourcing studies in Polynesia, we have investigated the use of radiogenic isotope variations in basaltic artefacts and source rocks as a means of accurately determining artefact provenance (Weisler and Woodhead 1995). A consideration of geological processes once more provides the rationale behind this approach. In contrast to trace elements, radiogenic isotope variations in basaltic rocks from the ocean basins are a function of both parent/daughter elemental ratios in the mantle source (i.e., trace element composition) and the age of this source. Although most of the islands of Polynesia are geologically relatively young (a few tens of million years at most), it is believed that the Earth's mantle, melting to produce these islands, is considerably older (of the order of 1-2 billion years). The combination of these factors has resulted in a diversity of isotopic compositions in the islands of Polynesia - thus isotope ratios can potentially be used with far more confidence as provenance indicators.

Sr (strontium), Nd (neodymium) and Pb (lead) isotopes are most frequently determined by Earth scientists, and thus a considerable database exists in these elements for most oceanic islands and, indeed, igneous provinces in general. Of these the Pb isotope system is perhaps the most sensitive consisting, effectively, of three individual decay schemes: the daughter products of the radioactive parent isotopes of U (uranium) and Th (thorium) (namely ^{238}U, ^{235}U and ^{232}Th) are, respectively, ^{206}Pb, ^{207}Pb and ^{208}Pb. Abundances of the latter are conventionally quoted as ratios relative to the stable isotope ^{204}Pb: thus $^{206}Pb/^{204}Pb$, $^{207}Pb/^{204}Pb$ and $^{208}Pb/^{204}Pb$. Later, we also consider the use of Sr and Nd isotopic analysis in provenance studies; in this case the ratios of interest are $^{87}Sr/^{86}Sr$ and $^{143}Nd/^{144}Nd$ (^{87}Sr and ^{143}Nd being the products of radioactive decay from ^{87}Rb [rubidium] and ^{147}Sm [samarium] respectively).

There is considerable interest in the use of Pb isotope determinations for assigning geographic provenance to metallic artefacts, particularly in the eastern Mediterranean (e.g., Gale 1989). Although Pb isotopic analysis of basaltic material is analytically more challenging, due to inherently lower Pb contents (most Polynesian basalts average 2-3ppm [parts-per-million] Pb), it does not suffer many of the uncertainties associated with these studies as we describe in a later section.

On an analytical note, the chemical separation of Pb is well documented in the literature (e.g., Manhes 1978), but the analytical precision and accuracy of Pb isotope determinations has always been limited by an inability to make a suitable correction for mass fractionation effects encountered during thermal ionisation mass spectrometry. A rigorous correction is, however, possible by spiking a second sample aliquot with an artificial solution, highly enriched in two isotopes - the so-called 'double spike' technique. This method, detailed in Woodhead *et al.* (1995), provides considerable improvement in analytical precision and accuracy over 'conventional' Pb isotope analyses, by at least a factor of three, and is strongly recommended for studies of this type where extremely accurate and precise Pb isotope data are required. Realistic external precision on the determinations quoted below is ±0.003, 0.003, and 0.01 (2 x SD) on $^{206}Pb/^{204}Pb$, $^{207}Pb/^{204}Pb$ and $^{208}Pb/^{204}Pb$.

CASE STUDIES

We have chosen to illustrate the utility of radiogenic isotope techniques with reference to three examples from Polynesia. The archaeological setting is briefly presented for each case and the efficacy of the technique is demonstrated.

Two-way interaction in southeast Polynesia

Identifcation of two-way interaction in Polynesia has relied mostly on ethnographic descriptions projected back into prehistory; for example, the historically recorded interaction sphere of Fiji-Tonga-Samoa is well attested (Hjarnø 1979/80; Kaeppler 1978) and it undoubtedly had its genesis in prehistory (Davidson 1977, 1978; Kirch 1984). The reciprocal movement of obsidian has also been suggested between New Zealand and the Kermadecs (Anderson and McFadgen 1990). Yet, the archaeological documentation of the two-way movement of commodities is quite rare considering the amount of long-distance voyaging thought to have taken place during prehistory (Irwin 1992; Chapter 3).

Previous investigations have delineated the duration, complexity and geographic scale of the southeast Polynesian interaction sphere, defined here as the Gambier Islands and the Pitcairn group (Weisler 1993b, 1994, 1995, 1996a; Chapter 9). In this study, we initially wished to confirm source assignment of imported artefacts made by the semi-quantitative ED (energy-dispersive) and fully-quantitative WD (wavelength-dispersive) XRF techniques as well as to add to the current database for the region. We also saw an opportunity to analyse very small artefacts that could not be processed by standard XRF techniques.

The first specimens analysed were recovered from an archaeological survey of Henderson Island in the Pitcairn group, where 28 sites were recorded, mostly rockshelter and cave habitations. Of the sites on Henderson, 16 were excavated and 31 radiocarbon age determinations document an occupation span of around 600 years beginning at least by A.D. 1000 (Weisler 1994, 1995). The artefact sequence reveals imported materials such as volcanic adzes and oven stones (Henderson itself does not have naturally occurring volcanic rock outcrop) and pearl-shell (*Pinctada margaritifera*), the latter probably brought from the Gambiers. Bearing this in mind, two artefacts were also studied from Temoe atoll (about 40 km from the main Gambiers) and one fine-grained basalt artefact from Aukena in the Gambier islands (Weisler 1996b). Our goal then was to determine where the artefacts originated (initial results published in Weisler and Woodhead 1995).

In addition to these artefacts from Henderson and the Gambiers, we also analysed a larger number of geological samples from Pitcairn and the Gambiers (the nearest sources of volcanic rock) and from documented fine-grained basalt sources throughout Polynesia. These analyses were then combined with Pb isotope data from the geological literature in an attempt to produce an isotopic template for determining the provenance of our artefacts (Fig. 13.2).

Firstly, note that the data for each island or archipelago generally fall into distinct fields on these diagrams and, in the case where some overlap is noted in one figure, the two fields are generally separated in the other (this arises from the fact that one plot is influenced by long term variations in U/Pb ratio and the other by both U/Pb and Th/Pb evolution). In addition, even though Pitcairn and the Gambiers are both products of melting above the same mantle plume (i.e., are geologically related) they are distinct

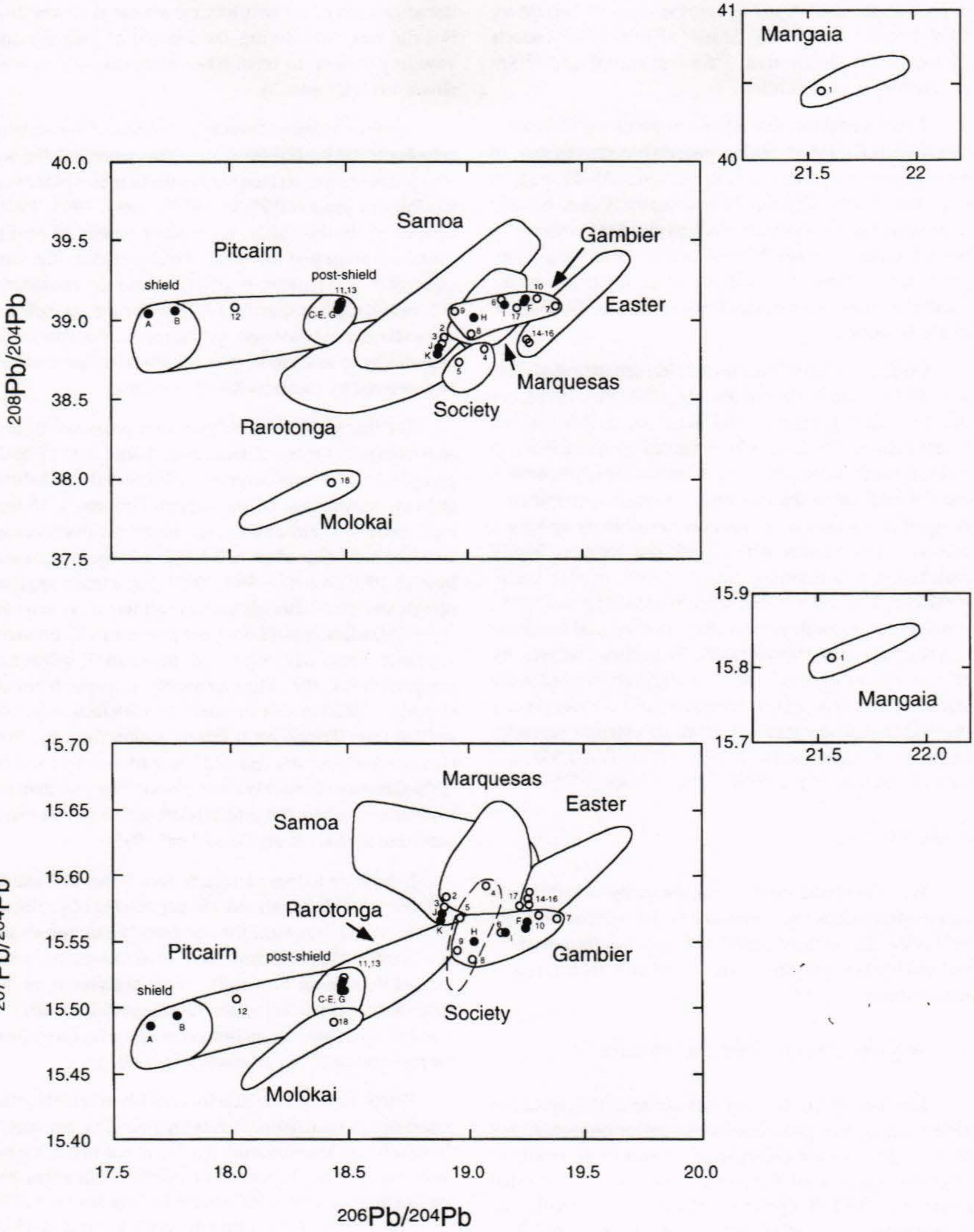


FIGURE 13.2. Pb isotope plots modified after Weisler and Woodhead (1995). Samples 1 to 18 (open circles) represent analyses of quarry and geological samples and, in each case, fall within the appropriate fields defined from literature data. Filled circles represent analyses of the following artefacts: A to F, Henderson Island; G to I, Gambier Islands, J and K, Mangaia (southern Cooks). See text for interpretation.

in Pb isotope space - a feature related to mixing of plume and lithospheric melts (e.g., Dupuy *et al.* 1993; Woodhead and Devey 1993). These relationships become even clearer when all three ratios are viewed concurrently by using three dimensional plotting programmes (MacSpin™ software was used for a rigorous examination of the data in this case).

Rock samples were analysed from quarry sources on Mangaia (Cook Islands), Samoa, Tahiti (Society Islands), Moloka'i (Hawaii), Nuku Hiva (Marquesas), Easter Island and Pitcairn island in addition to geological samples from the Gambiers and Pitcairn. These samples, denoted by open circles, in all cases fall within the appropriate fields established from the literature analyses of these islands, providing a check on data quality.

The Pb isotope analyses of the artefacts were then compared to the fields of *geological* data to allow discrimination of their provenance. In summary, five of the six Henderson artefacts (filled circles) clearly originated from the nearest basalt source, Pitcairn island - their isotopic signatures are incompatible with any other island (the high $^{208}Pb/^{204}Pb$ and low $^{206}Pb/^{204}Pb$ composition of Pitcairn lavas is unique within the region). However, one oven stone does not originate from Pitcairn and appears to have been procured from the Gambiers some 400 km to the west. Note once more that although on individual plots this sample overlaps with other island fields (e.g., Easter on $^{207}Pb/^{204}Pb$ vs. $^{206}Pb/^{204}Pb$), in three-dimensional isotopic space there is no overlap. Our analysis of the artefacts from the Gambiers indicates a similar story - two samples were quarried locally (plotting within the Gambier fields on both diagrams) but one sample was transported from Pitcairn island. This then provides the first documented archaeological evidence for prehistoric exchange within the region.

Isotopic methods of this type have all the advantages of major/trace element analysis for assigning artefacts to known sources; for example, many of the artefacts analysed in our study are almost identical in composition to the Tautama quarry source on Pitcairn and thus can be assumed to have been obtained from this site with a high degree of confidence. However, in contrast to these methods, the reliability of the technique is totally *independent* of prior identification and analysis of prehistoric quarry sites on Pitcairn and the Gambiers (since it relies solely on geological data), and thus can be used with confidence when artefact sources are wholly unknown.

Within the existing geological data it is often also possible to distinguish between the various units on a given island, for example, the detailed stratigraphic/geochemical analysis of Pitcairn island (Woodhead and McCulloch 1989) allows distinction between shield-building lavas and post-shield formations, the Tautama source belonging to the latter. As more detailed isotopic surveys of individual geological provinces become available, the utility of isotopic techniques is thus sure to increase.

Inter-archipelago interaction between Samoa and the Cook Islands

Current debates on the timing and direction of prehistoric settlement of East Polynesia have focussed on the Cook Islands. Situated at the threshold between West Polynesia and the eastern Pacific, they retain a pivotal geographical role in understanding the colonisation of Polynesia. One important question requires understanding the frequency and scale of contact between the Cooks and neighbouring archipelagoes. The continuing use of geochemical techniques to identify exotic artefacts imported to the Cooks has been of major interest (Best *et al.* 1992; Walter and Sheppard 1996; Weisler 1993b; Weisler and Kirch 1996; Chapters 6 and 7). We describe here the application of our isotopic technique to: (1) identify inter-archipelago transport of artefacts from Tutuila, Samoa to Mangaia, southern Cook Islands - a distance of approximately 1200 km - between A.D. 1000 to 1500; and (2) confirm these artefact assignments previously made by the semi-quantitative EDXRF method (Weisler 1993a, c; Weisler and Kirch 1996).

As part of a larger inter-disciplinary project investigating the archaeology and paleoecology of Mangaia (Kirch *et al.* 1995) the large stratified rockshelter known as Tangatatau was excavated revealing 19 well-dated stratigraphic zones containing a diverse assemblage of stone tools and faunal and floral materials spanning at least 600 years beginning about A.D. 1000. Sixty-nine artefacts including adzes, preforms, polished basalt flakes and unmodified flakes were selected from most stratigraphic zones and analysed by non-destructive XRF (Weisler 1993b). The source of most artefacts was the Mata'are fine-grained basalt source on Mangaia (Weisler *et al.* 1994) but, surprisingly, four polished basalt flakes were assigned to one or more sources on Tutuila, Samoa (details of the Tutuila sources are provided in Chapter 5). In this case we sought to use isotopic techniques primarily to check these results.

Unfortunately, although the island of Mangaia in the Cooks is entirely unique in its Pb isotopic composition (Woodhead 1996) there is, in this case, some overlap between the Pb isotopic compositions of the remaining Cook Islands (Rarotonga, Aitutaki, Mauke etc.) and those of the Samoan Islands (this may be in part a result of poor quality Pb isotope data in the literature but at this stage this possibility cannot be quantitatively assessed). We therefore chose other isotopic systems in this case, since these islands are readily distinguishable in terms of their Sr and Nd isotopic composition. Figure 13.3 shows a simple Sr-Nd isotopic plot widely used by geochemists in the interpretation of the petrogenesis of basaltic rocks, with literature data for the Cook Islands and Samoa (see references in figure caption). Also shown are the results of our analysis of two polished basalt flakes from the Tangatatau rockshelter on Mangaia (filled circles). Comparison of Pb isotopic signatures (Fig. 13.2) of the flakes with data from geological samples from Mangaia immediately demonstrates that the flakes could not have originated on Mangaia. Furthermore, Figure 13.3 reveals that the flakes are incompatible with any other geological material from the remaining Cook or (closely associated) Austral Islands. The high $^{87}Sr/^{86}Sr$ ratios observed in these flakes are in fact a characteristic shared only by Samoa and the Society Islands (see, for example, White and Hofmann 1982) and these two archipelagoes are themselves then readily distinguished by Pb isotopes. In this case the two flakes undoubtedly derive from Samoa, confirming the EDXRF result. Thus, with these five variables (three Pb plus Sr and Nd isotope ratios), and in many cases just three (see case 1 above) it is nearly always possible to uniquely identify Polynesian basaltic artefact sources.

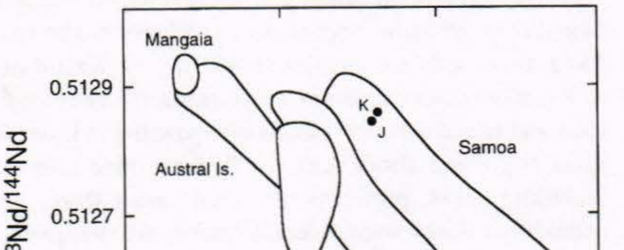


FIGURE 13.3. Sr-Nd isotope plot showing data from Australs (Chauvel *et al.* 1992), southern Cook Islands (Nakamura and Tatsumoto 1988), Mangaia (Nakamura and Tatsumoto 1988; Woodhead 1995), Samoa (Wright and White 1987) and the Societies (Hémond *et al.* 1994). The two samples from the rockshelter on Mangaia (J and K) fall clearly within the Samoan field, indicating their true provenance.

Intra-archipelago Interaction: Marquesas Islands

Extreme isolation characterises the highly-weathered Marquesas Islands situated some 1400 km from the nearest volcanic landfalls (see Chapter 8). It is perhaps ironic that the earliest known settlement of East Polynesia - dating to perhaps 2000 BP - has been identified here (Rolett 1993; Rolett and Conte 1995). Consisting of 10 islands, early habitations are found at coastal dunes fronting stream valleys. Fine-grained basaltic resources include the largest known source at Eiao (Candelot 1980) and a stratum of tool-quality basalt exposed on the coast at Ha'a'upa'upa, Nuku Hiva (Suggs 1961:67). Quite different from these basaltic rocks, phonolite from an unidentified but geologically distinctive source was also widely exploited during Marquesan prehistory (Chapter 8). Flake tools of this material are known from several archaeological sites in the central and southern Marquesas. Local coarse-grained rock was commonly fashioned into expedient tools, while fine-grained rock, large quantities of which were transported between islands, was apparently reserved primarily for adzes (Chapter 8).

Our study focuses on five basaltic artefacts recovered from the stratified coastal dune site fronting Hanamiai Valley on Tahuata. Here, eight well-defined cultural layers reveal a 750 year continuous occupation sequence beginning about A.D. 1100 (Rolett 1992). One flake was also analysed from a site on Nuku Hiva.

To demonstrate the potential for studies at the geographic scale of archipelago, in Figure 13.4 we show data collected recently for geological samples from a number of islands in the Marquesas (Woodhead *et al.* in prep). Unfortunately, there are currently no published Pb isotope data from the archaeologically important island of Eiao but this is one of our goals for the near future. With the exception of Hiva Oa, each island possesses a unique Pb isotopic composition thus providing an excellent opportunity to evaluate prehistoric interaction between islands over relatively short distances. Here, once more, it is possible that the use of other isotopic systems (Sr and Nd) in conjunction with Pb will be the best method for identifying all possible sources with confidence, since Woodhead (1992) demonstrated that shield-building and post-erosional sources on the Marquesan islands of Ua Pou, Nuku Hiva and most importantly, Hiva Oa are all distinct in plots of Sr and Nd isotopes. The combination of all the three isotope systems therefore shows great promise for distinguishing between all potential Marquesan island sources.

Our results are at this stage preliminary, due mainly to a lack of appropriate isotopic data in the literature for key islands such as Eiao, but do demonstrate a clear distinction

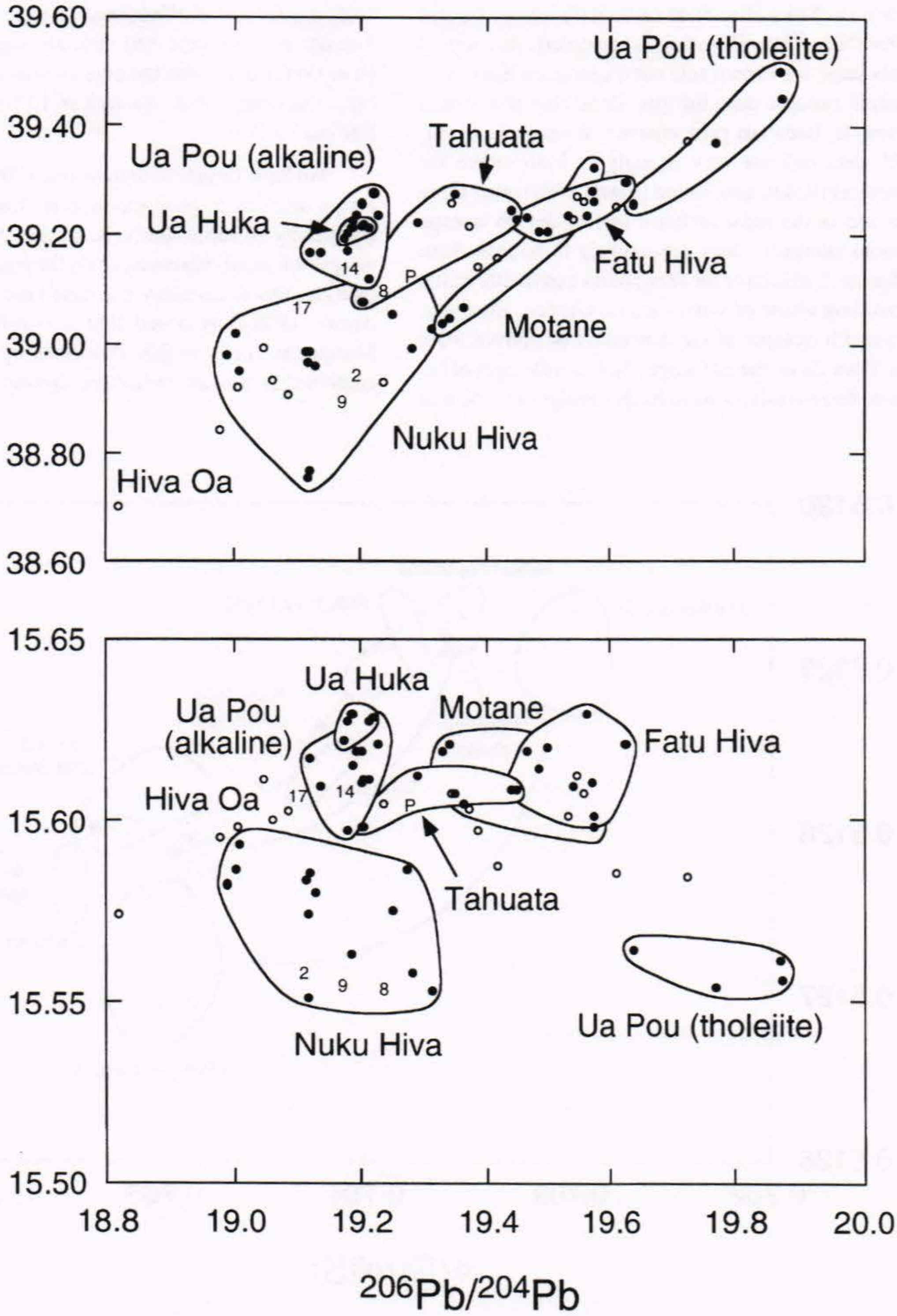


FIGURE 13.4. High precision Pb isotope analyses of geological samples from the Marquesan archipelago (Woodhead *et al.* in prep.) showing the potential for distinguishing between individual island sources. Filled circles represent islands which can be readily distinguished on these plots (or via the 3-D plot combining all three Pb isotope ratios). Open circles are analyses from Hiva Oa which, although spanning a large range of Pb-isotope compositions, do appear distinct in terms of Sr and Nd isotopic composition (see Fig. 13.5). Unfortunately, published data for the island of Eiao are currently not available. Artefact analyses in this case are indicated by numbers alone: see text for full discussion.

of the artefacts into two groups. Three of the six artefacts plot within the Nuku Hiva field on both Pb isotope figures (the $^{207}Pb/^{204}Pb$ - $^{206}Pb/^{204}Pb$ field is particularly distinctive) but at this stage we cannot rule out a source on Eiao since unpublished isotopic data for this island also plot within this region (H. Barsczus pers. comm.). We note, however, that XRF data indicate very strongly an Eiao source for these artefacts (Rolett and Sinton in prep.). The other three artefacts are in the most difficult part of the Pb isotope diagrams to interpret - they are unlikely to be from Fatu Hiva, Motane, Ua Huka or the very poorly exposed tholeiitic shield-building phase of volcanism on Ua Pou. However, based upon Pb isotopes alone they could be derived from Tahuata, Hiva Oa or the late stage alkaline volcanics of Ua Pou. These three artefacts were further analysed for Sr and Nd isotopic composition and these data are shown in Figure 13.5, modified after Woodhead (1992). This plot rules out Tahuata as the source and strongly suggests a source on Hiva Oa (in particular the post erosional lava formations) but, at this stage, due to a lack of further data, we cannot rule out Ua Pou.

We have therefore demonstrated that it is possible to assign artefacts to geologic sources within the Marquesas Islands by isotopic analysis. Earlier we noted that, as geographic scale increases, so do the possibilities of source overlap; this is certainly the case here and Sinton (pers. comm. 1995) has stated that it is difficult to separate Marquesan rocks within Polynesia by XRF alone. The combined Sr, Nd and Pb isotopic signature of the Marquesas

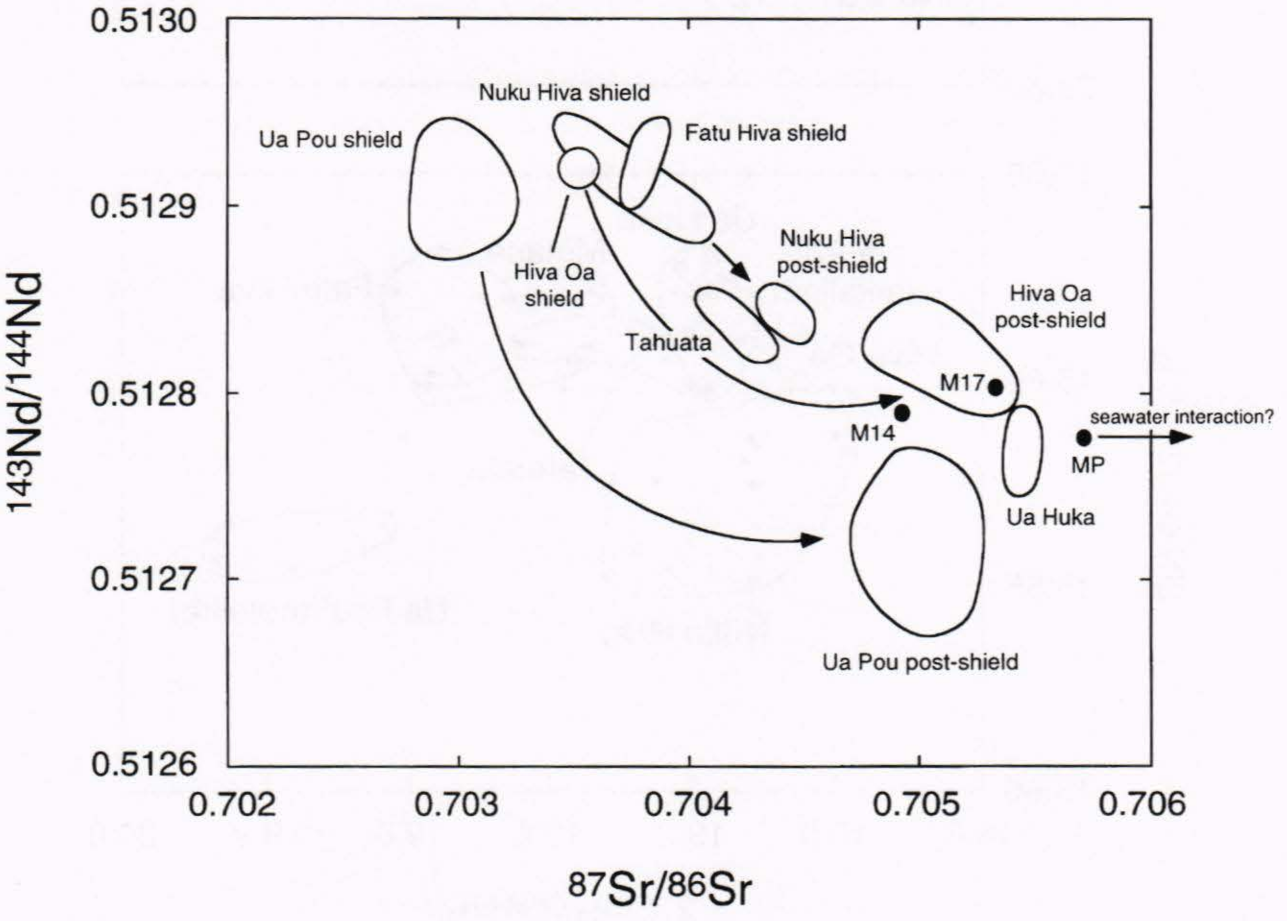


FIGURE 13.5. Sr-Nd isotope plot for Marquesan islands, modified from Woodhead (1992) with additional data fields and analyses of three artefacts (M14, M17, MP) from Figure 13.4. Note the distinction between many of the Marquesan islands on this plot and, in addition, change in composition between shield-building and post-shield volcanic formations on many of these islands (arrows indicate this shift). The data for Tahuata and Ua Huka are not constrained in terms of their stratigraphic position and thus are not shown with reference to this phenomenon. Combination of this and the previous diagram suggest these three artefacts probably originate from Hiva Oa, although a source in the post-shield formations of Ua Pou is possible (more data are required to further define these island fields and thus fully evaluate this hypothesis). The high $^{87}Sr/^{86}Sr$ of sample MP is probably a result of interaction with seawater during magmagenesis or as a late stage alteration process.

is, however, unique once more highlighting the importance of isotopic techniques for interaction studies in Polynesia on a larger, inter-archipelago scale.

CONCLUSIONS

We have highlighted a very specific use of isotopic studies - namely that of sourcing basaltic artefact material within Polynesia. Basaltic adzes, oven stones and volcanic glass are conducive to isotope analysis because it is well known that radiogenic isotope ratios are not fractionated during natural melting and crystallisation processes.

We noted earlier the extensive use of Pb isotopes in tracing metallic artefacts particularly within the Mediterranean region. These studies have been very successful but do encounter potential problems due to mixing of ores and/or metals during metallurgical processing. Magmatic systems are analogous in that they represent complex mixtures of components of variable ages and isotopic compositions and yet, since these processes invariably occur *prior* to cooling and emplacement at the Earth's surface, they actually work in our favour - producing igneous flows, dykes and sills with unique isotopic identities, yet compositionally homogeneous throughout their extent. It is this fact which makes isotopic analysis of volcanic materials such a powerful sourcing technique.

Additionally, we speculate that such methods might find application in the continental regime and possibly as an adjunct to existing XRF techniques which have been used in determining the provenance of other geological materials such as jasper (Warashina 1992) and even millstones (e.g., Williams-Thorpe and Thrope 1993). We note also that tracking the natural and cultural occurrence of black-lipped pearl-shell in Polynesia might in future prove useful for defining interaction spheres (Weisler 1993b) and that chemical/isotopic analyses of this taxon may identify regional variability which could provide new insights for interaction studies. For example, pearl-shell from lagoons surrounded by volcanic islands (e.g., Mangareva) may possess distinctive elemental/isotopic compositions to molluscs from lagoons of coral atolls (e.g., Marshall Islands or northern Cooks). Analysis of these possibilities will provide considerable scope for future studies.

The radiogenic isotope method has obvious advantages over conventional XRF and petrographic techniques. In addition to providing a far more specific tracer, it is highly precise and accurate and inter-laboratory comparisons can easily be made. Isotopic analysis is also relatively non-destructive, requiring of the order of 50-100 mg of sample per analysis. The only disadvantage is the requirement for specialised equipment (clean laboratory facilities and mass spectrometers) and hence cost. However, the recent advent of multiple sample multicollector mass spectrometers has produced not only a dramatic increase in data quality but has also cut analysis time, providing a rapid and efficient means of obtaining high quality isotope analyses. We envisage isotopic methods of sourcing basalt and other volcanic rock artefacts to become far more widespread in the near future. Its particular applicability in the eastern Pacific may be essential for understanding long distance (i.e., inter-archipelago) interaction in Polynesia.

ACKNOWLEDGEMENTS

The continuing cooperation of our colleagues in supplying source samples and artefacts has facilitated the research reported here; we thank Jeffrey Clark, David Herdrich, Patrick Kirch and Barry Rolett. Maeva Navarro, Director, Départment Archéologie du Centre Polynésien des Sciences Humanines (French Polynesia) granted permission to Weisler for collecting geologic samples in Mangareva.

REFERENCES

Anderson, A. and B. McFadgen. 1990. Prehistoric two-way voyaging between New Zealand and East Polynesia: Mayor Island obsidian on Raoul Island, and possible Raoul Island obsidian in New Zealand. *Archaeology in Oceania* 25:37-42.

Baker, P.E. 1993. Archaeological stone of Easter Island. *Geoarchaeology* 8:127-139.

Baker, P.E., F. Buckley and J.G. Holland. 1974. Petrology and geochemistry of Easter island. *Contributions to Mineralogy and Petrology* 44:85-100.

Best, S. 1987. Long distance obsidian travel and possible implications for the settlement of Fiji. *Archaeology in Oceania* 22:31-32.

Best, S., P. Sheppard, R. Green and R. Parker. 1992. Necromancing the stone: archaeologists and adzes in Samoa. *Journal of the Polynesian Society* 101:45-85.

Budd, P., D. Gale, A.M. Pollard, R.G. Thomas and P.A. Williams. 1993. Evaluating Pb isotope data: further observations. *Archaeometry* 35:241-247

Candelot, J-L. 1980. Contribution à la prospection archéologique des îles Marquises: l'île d'Eiao. *Journal de la Société des Océanistes* 36:105-121.

Chauvel, C., A.W. Hofmann and P. Vidal. 1992. HIMU-EM: the French Polynesian connection. *Earth and Planetary Science Letters* 110:99-119.

Chayes, F. H. and H. Fairbairn. 1951. A test of the precision of thin-section analysis by point counter. *American Mineralogist* 36:704-712.

Davidson, J. 1977. Western Polynesia and Fiji: prehistoric contact, diffusion and differentiation in adjacent archipelagoes. *World Archaeology* 9:82-94.

Davidson, J. 1978. Western Polynesia and Fiji: the archaeological evidence. *Mankind* 11:383-390.

Duncan, R.A., M.R. Fisk, W.M. White and R.L. Nielsen. 1994. Tahiti: geochemical evolution of a French Polynesian volcano. *Journal of Geophysical Research* 99:24,341-24,357.

Dupuy, C., P. Vidal, R.C. Maury and G. Guille. 1993. Basalts from Mururoa, Fantataufa and Gambier Islands (French Polynesia): geochemical dependence on the age of the lithosphere. *Earth and Planetary Science Letters* 117:89-100.

Dye, T. 1987. Social and Cultural Change in the Prehistory of the Ancestral Polynesian Homeland. Ph.D. thesis, Yale University, New Haven.

Gale, N.H. 1989. Lead isotope analyses applied to provenance studies—a brief review. In Y. Maniatis (ed.), *Archaeometry. Proceedings of the 25th International Symposium*, pp.496-502. Amsterdam, Elsevier.

Grimes, W. 1979. The history of implement petrology in Britain. In T. Clough and W. Cummins (eds), Stone Axe Studies, pp. 1-4. Council for British Archaeology, *Research Report* 23.

Hémond, C., C. Devey and C. Chauvel. 1994. Source compositions and melting processes in the Society and Austral plumes (south Pacific Ocean): elemental and isotope (Sr, Nd, Pb, Th) geochemistry. *Chemical Geology* 115:7-45.

Hjarnø, J. 1979-80. Social reproduction: towards an understanding of aboriginal Samoa. *Folk* 21-22:73-123.

Hughes, R.E. 1994. Intrasource chemical variability of artifact-quality obsidians from the Casa Diablo area, California. *Journal of Archaeological Science* 21:263-271.

Irwin, G. 1992. *The Prehistoric Exploration and Colonisation of the Pacific.* Cambridge, Cambridge University Press.

Kaeppler, A. 1978. Exchange patterns in goods and spouses: Fiji, Tonga and Samoa. *Mankind* 11:246-252.

Kirch, P.V. 1984. *The Evolution of the Polynesian Chiefdoms.* Cambridge, Cambridge University Press.

Kirch, P.V., D.W.Steadman, V.L. Butler, J. Hather and M.I. Weisler. 1995. Prehistory and human ecology in Eastern Polynesia: excavations at Tangatatau rockshelter, Mangaia, Cook Islands. *Archaeology in Oceania* 30:47-65.

Lass, B. 1994. Hawaiian Adze Production and Distribution: Implications for the Development of Chiefdoms. *Institute of Archaeology, University of California,* Monograph 37. Los Angeles.

Liotard, J.M., H.G. Barsczus, C. Dupuy and J. Dostal. 1986. Geochemistry and origin of basaltic lavas from the Marquesas archipelago, French Polynesia. *Contributions to Mineralogy and Petrology* 92:260-268.

Manhes, J., F. Minster and C.J. Allègre. 1978. Comparative uranium-thorium-lead and rubidium-strontium of St. Severin amphoterite: consequences for early solar system chronology. *Earth and Planetary Science Letters* 81:151-162.

Nakamura, Y. and M. Tatsumoto. 1988. Pb, Nd, and Sr isotopic evidence for a multicomponent source for rocks of Cook-Austral islands and heterogeneities of mantle plumes. *Geochimica et Cosmochimica Acta* 52:2909-2924.

Pernicka, E. 1993. Comments.....III on P. Budd, D. Gale, A. M. Pollard, R. G. Thomas and P.A. Williams, 'Evaluating lead isotope data: further observations', 1993. *Archaeometry* 35:259-262.

Rolett, B.V. 1992. Faunal extinctions and depletions linked with prehistory and environmental change in the Marquesas Islands (French Polynesia). *Journal of the Polynesian Society* 101:86-94.

Rolett, B.V. 1993. Marquesan prehistory and the origins of East Polynesian culture. *Journal de la Société des Océanistes* 96:29-47.

Rolett, B.V. and E. Conte. 1995. Renewed investigation of the Ha'atuatua Dune (Nukuhiva, Marquesas Islands): a key site in Polynesian prehistory. *Journal of the Polynesian Society* 104:195-228.

Suggs, R. 1961. The Archaeology of Nukuhiva, Marquesas Islands, French Polynesia. *Anthropological Papers of the American Museum of Natural History* 49.

Walter, R. and P.J. Sheppard. 1996. The Ngati Tiare adze cache: further evidence of prehistoric contact between West Polynesia and the Southern Cook Islands. *Archaeology in Oceania* 31:33-39.

Warashina, T. 1992. Allocation of jasper archaeological implements by means of ESR and XRF. *Journal of Archaeological Science* 19:357-373.

Weisler, M.I. 1989. Towards Documenting Exchange in a Complex Chiefdom: an Essay in Method. Paper presented at the 54th Annual Meeting of the Society for American Archaeology, Atlanta, Georgia.

Weisler, M.I. 1990. Sources and sourcing of volcanic glass in Hawai'i: implications for exchange studies. *Archaeology in Oceania* 25:16-23.

Weisler, M.I. 1993a. Provenance studies of Polynesian basalt adze material: a review and suggestions for improving regional data bases. *Asian Perspectives* 32:61-83.

Weisler, M.I. 1993b. Long-distance Interaction in Prehistoric Polynesia: Three Case Studies. Ph.D. thesis, University of California, Berkeley.

Weisler, M.I. 1993c. Chemical characterization and provenance of Manu'a adz material using a non-destructive x-ray fluorescence technique. In P.V. Kirch and T.L. Hunt (eds), The To'aga Site: Three Millennia of Polynesian Occupation in the Manu'a Islands, American Samoa, pp. 167-187. *Contributions of the University of California Archaeological Research Facility,* Contribution 51. Berkeley.

Weisler, M.I. 1994. The settlement of marginal Polynesia: new evidence from Henderson Island. *Journal of Field Archaeology* 21:83-102.

Weisler, M.I. 1995. Henderson Island prehistory: colonization and extinction on a remote Polynesian island. *Biological Journal of the Linnean Society* 56:377-404.

Weisler, M.I. 1996a. Taking the mystery out of the Polynesian 'mystery' islands: a case study from Mangareva and the Pitcairn Group. In J. Davidson, G. Irwin, F. Leach, A. Pawley and D. Brown (eds), Pacific Culture History: Essays in Honour of Roger Green, pp.615-629. *New Zealand Journal of Archaeology Special Publication.* Dunedin.

Weisler, M.I. 1996b. An archaeological survey of Mangareva: implications for regional settlement models and interaction studies. *Man and Culture in Oceania* 12:61-85.

Weisler, M.I. and D.A Clague. 1997. Characterization of archaeological volcanic glass from Oceania: the utility of three techniques. In M.S. Shackley (ed.), Archaeological Obsidian Studies. *Advances in Archaeological and Museum Sciences* 3. New York, Plenum Press.

Weisler, M.I. and Kirch, P.V. 1996. Interisland and interarchipelago transfer of stone tools in prehistoric Polynesia. *Proceedings of the National Academy of Sciences, U.S.A.* 93:1381-1385.

Weisler, M.I., P.V. Kirch and J.M. Endicott. 1994. The Mata'are basalt source: implications for prehistoric interaction studies in the Cook Islands. *Journal of the Polynesian Society* 103:203-216.

Weisler, M.I. and J.D. Woodhead. 1995. Basalt Pb isotope analysis and the prehistoric settlement of Polynesia. *Proceedings of the National Academy of Sciences, U.S.A.* 92:1881-1885.

Williams-Thorpe, O. and R.S. Thorpe. 1993. Geochemistry and trade of eastern Mediterranean millstones from the Neolithic to Roman periods. *Journal of Archaeological Science* 20:263-320.

White, W.M. and A.W. Hofmann. 1982. Sr and Nd isotope geochemistry of oceanic basalts and mantle evolution. *Nature* 296:821-825.

Woodhead, J.D. 1982. Temporal evolution in oceanic intra-plate volcanics: a case study from the Marquesas (French Polynesia) and comparison with other hotspots. *Contributions to Mineralogy and Petrology* 111:458-467.

Woodhead, J.D. 1996. Extreme HIMU in an oceanic setting: the geochemistry of Mangaia Island (Polynesia), and temporal evolution of the Cook-Austral hotspot. *Journal of Volcanology and Geothermal Research* 72:1-19.

Woodhead, J.D. and M.T. McCulloch. 1989. Ancient seafloor signals in Pitcairn island lavas and evidence for large amplitude, small length-scale mantle heterogeneities. *Earth and Planetary Science Letters* 94:257-273.

Woodhead, J.D. and C.W. Devey. 1993. Geochemistry of the Pitcairn seamounts I: source composition and temporal trends. *Earth and Planetary Science Letters* 116:81-99.

Woodhead, J.D., F. Volker and M.T. McCulloch. 1995. Routine Pb isotope determinations using a ^{207}Pb-^{204}Pb double spike: a long-term assessment of analytical precision and accuracy. *The Analyst* 120:35-39.

Wright, E. and W.M. White. 1987. The origin of Samoa: new evidence from Sr, Nd, and Pb isotopes. *Earth and Planetary Science Letters* 81:151-162.