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The difficulty of sourcing prehistoric pottery from Bootless Bay, Central Province, Papua New Guinea

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Abstract

Various attempts have been made to characterise and source prehistoric pottery assemblages from the south Papuan coast. Foremost among these is the assemblage from the late prehistoric site on Motupore Island near Port Moresby. Here, a specialised pottery industry produced wares that were traded both locally and over long distances. The earliest attempts to source this pottery were experimental and imprecise but offered important insights into the offshore distribution of Motupore pottery. The problematic nature of this early work is most evident in the inability of subsequent studies to reproduce the earlier results. Overcoming this problem was compounded by the loss of early data samples and results in the Canberra fires of 2003. This paper recounts the history of sourcing studies of Motupore pottery. As part of this history, we began an attempt to reconstruct the lost data, as well as using newer techniques to reinvestigate Motupore pottery production and exchange. Expectations that these newer techniques would succeed in matching the early results were not fulfilled. We consider various explanations for this and think that chemical alterations to the sherd fabrics through time and during burial are a likely cause.

Introduction

Glenn Summerhayes provided the genesis of this paper. His long association with sourcing obsidian and pottery is a central aspect of his wide contribution to Pacific archaeology, beginning 40 years ago (e.g. Summerhayes and Walker 1982; Summerhayes 1987). In particular, Glenn popularised the use of the electron microprobe to analyse pottery (Summerhayes 1996, 2000). This technology enabled the clay component of sherds to be analysed separately from their mineral inclusions, an important advance on the then dominant PIXE analysis that could not separate these components (Summerhayes 1997). Prehistoric pottery sourcing on the Papuan south coast in the last quarter of the twentieth century mirrored these changes. The novel methods developed by Owen Rye, a professional potter and, in the 1970s, a Research Fellow in the Prehistory Department of The Australian National University (ANU), relied on proton-induced X-ray emission (PIXE) for chemical

analyses of pottery from the Motupore site in Bootless Bay near Port Moresby, with analyses carried out at the Australian Atomic Energy Commission Research Establishment at Lucas Heights (AAEC) in Sydney. The PIXE technology is now replaced by more precise and less laborious approaches. Using PIXE to determine the geochemistry of sherds required that the sherd fabric be crushed and formed into pelletised targets. Rye's target pellets were retained as a data source, but, disastrously, most of his pellets and all of his associated data notebooks were lost in the Canberra bushfire of 2003. As described elsewhere (Allen 2017:369–370), a chance conversation with Glenn in 2012 in Dunedin led to him producing a bag of Rye's pellets he had rescued from the AAEC 30 years earlier. Glenn had kept and moved these samples with him, for no apparent reason or use, other than that they were historical data. Only Glenn would have done this.

The existence of the samples led to a fanciful plan to recreate Rye's data and techniques as a basis for further sourcing, a project of false starts and other problems that modified greatly over the following years. The serendipity continued in 2016 when two of us (AF and JA) were working in the National Museum and Art Gallery of Papua New Guinea. Our colleague there, Alu Guise, heard us discussing Rye's work, left the laboratory and returned with the remainder of Rye's original Bootless Bay clay and sand samples. We had assumed that these had been lost in the Canberra fire. With these raw material samples, we could immediately implement new analyses and ask a different range of questions. These included using more modern technology to compare the Bootless Bay clays with each other to see how similar or different they might be and to determine which useful elements they contained. The same could be done for the filler (temper) sands. Overall, these samples provided us with an independent path to analyse and compare sherds made with Bootless Bay raw materials and those made with foreign materials, rather than relying on the crushed pelleted produced by Rye.

This paper reports the work from 2016 onwards. It is appropriate that this research be reported here. If not for Glenn, it would never have happened.

Scope of this paper

Various attempts to source prehistoric pottery from Papuan south coast sites have occurred in the last 50 years, but the most concerted effort involved pottery from the island site of Motupore in Bootless Bay, some 15 km east of Port Moresby CBD. Excavation of this site in the 1970s allowed Owen Rye to undertake a full technological assessment of Motupore pottery (Rye 1976, 1977, 1981; Rye and Allen 1980, 2017; Rye and Duerden 1982; see also Allen and Duerden 1982; Allen and Rye 1982). Rye's specific aims included determining whether pottery recovered from Motupore and other Bootless Bay sites had in fact been manufactured with local materials, and to set up chemical and other technological signatures for Bootless Bay ceramics to allow their identification at other local and distant sites.

Here we offer a brief history of Rye's innovative approach to what was in the 1970s a perplexing question—how to characterise the chemical signature(s) of a pottery assemblage where the ingredients, clay and filler/temper were derived from different geological zones and potentially mixed in differing proportions. We then summarise his principal results. Secondly, we report new geochemical analyses of Motupore pottery using contemporary techniques that offer a firmer scientific characterisation of that assemblage.

Historically there have been difficulties noted with Rye's work. In particular, Frankel et al. (1994) attempted to source pottery from the Gulf sites in the Kerema region by replicating the sourcing study of Allen and Rye (1982), again using PIXE. This study employed reference samples used in the original Bootless Bay analysis and included 40 sherds from Motupore. Essentially it failed to source

any of the sample sherds to the Bootless Bay reference samples, with one of the major difficulties being that multiple analyses of the same samples produced variable results. It was considered that this might reflect analysis of the data using cluster analysis rather than Rye's less precise allocations, although John Chappell (pers. comm. to JA 2015) believed that the AAEC PIXE technology was also unreliable. Thus, fundamental to our new analyses was the question of whether Rye's PIXE results could be duplicated using more modern techniques. Before this we begin by putting Motupore into its historical context.

Motupore Island and the *hiri*

Motupore Island, also known as Motu Hanua, is recognised as an ancestral village of the Western Motu, the coastal population encountered in Port Moresby Harbour in the nineteenth century (Murray 1912). The first systematic excavations occurred there from 1970 until 1975 and were finally reported in Allen (2017). Work began as a field school for students from the University of Papua New Guinea, but the aims of the excavation expanded as the extent and significance of the site was revealed from a total of more than 200 m^2 of excavation. The site's importance concerned both its relatively undisturbed nature and the richness of its artefactual remains; for example, excavations recovered more than half a million medium (>1 cm^2) to large pottery sherds, more than 28,000 of which were diagnostic rim and decorated pieces. The following summary of Motupore history is drawn from Allen's conclusions, based on extensive artefactual analysis and a wide range of other evidence (see Allen 2017 and associated references for details).

Motupore was settled around 1200 AD by ancestral Motu, who, based on earlier pottery studies, likely came from the Boera area, 35 km to the west, a village with whom they maintained social ties. Motupore was abandoned around 1700 AD, probably as a result of local warfare reflecting population pressure on local resources. While its inhabitants likely practised some horticulture, economically they were primarily fishermen and traders. They arrived with pottery-making skills, demonstrated not only by the vast sherdage on the site, but also by pot firing locations and the frequency of firing-damaged sherds. During the site's lifetime, 11 or more satellite hamlets were established in Bootless Bay, together with a further contemporary village-size settlement at Taurama on the Bay's western edge (Figure 10.1). It is assumed that many or most of the women in these other communities were also potters and that the pottery was traded, along with shell artefacts such as strings of small shell beads (*ageva*), both locally and at a distance for food and raw materials.

Historically the Western Motu traded pottery, fish and shell artefacts throughout the year, but annually men from multiple Motu villages mounted a seaborne expedition called the *hiri* that transported thousands of Motu pots to villages in the Papuan Gulf, some 300 km to the west, to be exchanged for sago and canoe logs, and to gain prestige. Much is known about the historical *hiri* (e.g. see papers in Dutton 1982), but archaeology demonstrates that the late prehistoric villages in Bootless Bay, especially Motupore, were part of this history. Motupore pottery shows evolutionary time trajectories from complex to simple in both pottery forms and decoration that by the early twentieth century had evolved to the point where undecorated ovoid cooking pots with restricted necks and everted rims had become the dominant trade ware of the *hiri* (Groves 1960). A century ago, the *hiri* was explained by European observers as a response to wet season starvation in the Port Moresby villages (see Oram 1982 for summary). It is now better understood as part of a complex socio-economic strategy deliberately adopted and developed by the Western Motu and now glossed as subsistence trading (Allen 2017:616–621).

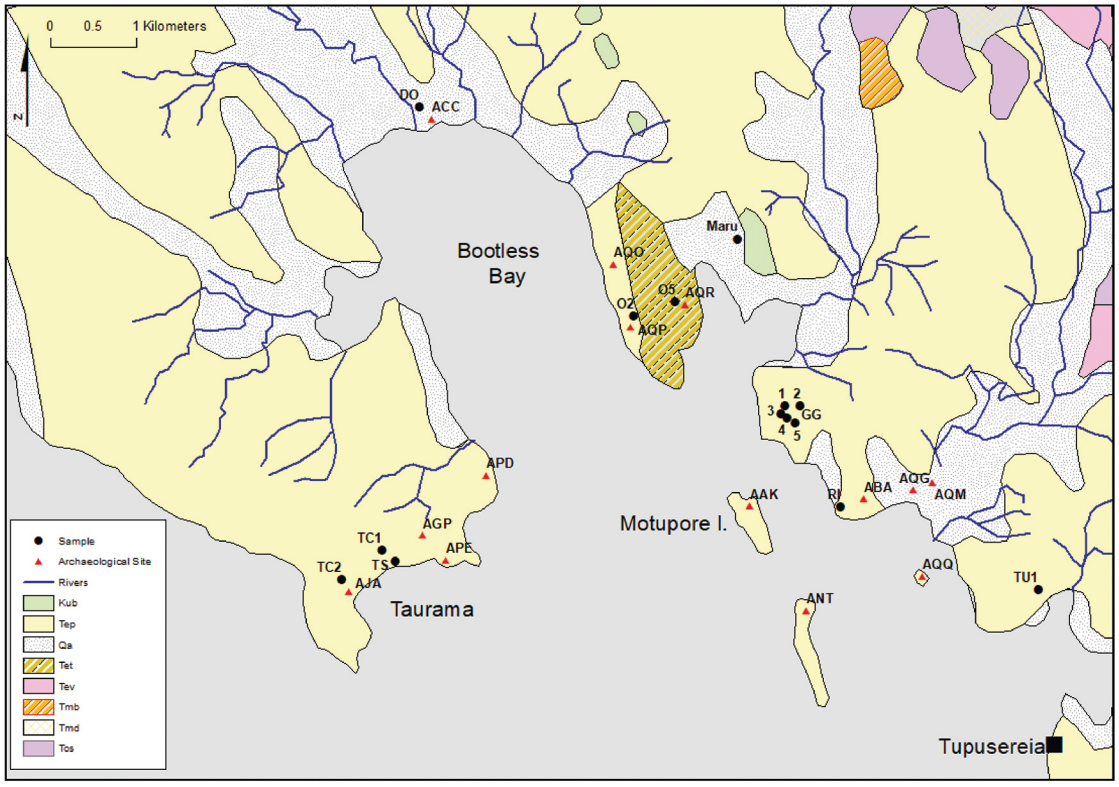


Figure 10.1: Bootless Bay with clay and sand sampling locations by Owen Rye.
Source: From Allen (2017:Fig. 9.1).

Sourcing pottery on the Papuan south coast

Archaeological studies of Papuan (and New Guinean) pottery production and trade grew out of a long tradition of ethnographic observation (e.g. Chalmers 1887; Seligman 1910; Stone 1876), culminating in the remarkable book by May and Tuckson (1982). Because of this connection between pottery and trade, there have been a number of pottery sourcing or characterisation studies completed on the south coast of Papua New Guinea (e.g. Bickler 1997; Frankel et al. 1994; Marsaglia et al. 2016; Rye and Duerden 1982; Summerhayes and Allen 2007; Sutton et al. 2019; Vigalys and Summerhayes 2016; Worthing 1980a, 1980b, 1982; Worthing and Swadling 1980). In particular, multiple sourcing studies have aimed at establishing a link between the Port Moresby region as a pottery-producing area and Gulf Province sites known historically or assumed to have been pottery consumers within the *hiri* trade network, although these studies have varied in terms of both methodology and results.

The sourcing techniques utilised have included petrography (Frankel et al. 1994; Marsaglia et al. 2016; Worthing 1980a, 1980b, 1982; Worthing and Swadling 1980), X-ray fluorescence or XRF (Bickler 1997) and PIXE (Rye and Duerden 1982; see also Allen and Duerden 1982). Different techniques mean that different information has been retrieved from the pottery. For the XRF/PIXE analyses for example, crushed pottery samples were used, which combined both clay and temper materials together into an overall 'signature'. In contrast, petrography involved thin-section analysis of microscope slides that largely removed the clay contribution from the analysis and instead focused on mineral inclusions to source sherds to geological locations.

Previous studies have also varied in terms of their scales of analysis when suggesting source locations for pottery. For example, Bickler's (1997) focus was regional, identifying Papuan Gulf pottery as deriving from either the Port Moresby or Yule Island regions. In contrast, Worthing (1982) suggested more focused source localities, identifying five close to Port Moresby: Eastern Bootless Bay, Motupore/Western Bootless Bay, Port Moresby/Fairfax Harbour, Lea Lea and Boera. Even more localised, Rye distinguished three prehistoric clay-temper combinations that were sourced within Western Bootless Bay itself. The problem with these previous studies is that different approaches have meant that it is difficult to integrate them, even where the same source and recipient site assemblages have been used, such as in the study by Frankel et al. (1994) noted above.

Previous pottery sourcing studies from Bootless Bay

The Rye PIXE study

The earliest pottery sourcing in Bootless Bay by Owen Rye asked simple questions. Were there local materials suitable for making pots and if so which, if any, were used by Motupore potters? Did sources change over time in the Motupore assemblage? Could Motupore pottery be distinguished from pots made in Port Moresby/Fairfax Harbour (Rye and Allen 2017)? And leading from this, might we be able to identify Motupore pottery in Gulf sites thought to reflect an early version of the *hiri* trade?

Rye (1981) surveyed the Bootless Bay inlet and obtained three sand samples and 12 clays from different locations (see Figure 10.1; see Allen (2017:331–335)). Sands from Taurama (labelled TS) and Motupore (MS) beaches were largely identical, but a distinctive mineralised black sand was recorded at two mainland locations. The nearest, c. 1 km from Motupore, was labelled R1. Of the clays, two from near the Taurama site (T1 and T2) and one on the mainland nearest Motupore (GG3) became important in the Rye analysis, but other sources also produced viable clays for making pottery.

Rye used different combinations of these sands and clays to determine the workability of these particular materials. The experiment involved making more than 850 small clay briquettes of known clay/sand compositions, firing them in the laboratory at various controlled temperatures and monitoring their post-firing viability (for example, some disintegrated because of CaO hydration of the calcite present in the shell component of the TS and MS sands). The 'successful' briquettes not only demonstrated the viability of each combination, they also provided proxy sources against which to compare the archaeological sherds.

At that time ANU archaeologists were closely associated with the AAEC at Lucas Heights, carrying out elemental sourcing of obsidian using PIXE. Rye set up experiments with AAEC physicist Peter Duerden to create PIXE characterisations of Motupore ceramics. The results were not perfect, with individual ceramic samples showing variability when measurements were repeated at different positions on the sample. Despite this, it was possible to determine 'an overall pattern of minor and trace element composition which differs from that of another clay' (Duerden et al. 1980:451).

Because of the uneven surfaces on pottery, the procedure required the sample to be crushed into a homogenous powder and compressed into a metal cap approximately 1 cm in diameter, with one smooth, exposed clay surface. These caps, the target pellets, were slow to make but had the advantage that around 150 could be processed in a day when measured in the Lucas Heights 3 MeV Van Der Graaff accelerator. Experimentation suggested that the most useful elements for the project were the major elements Si, Al, K, Ca, Ti and Fe, and the minor elements V, Sr and Rb and together these

were the ones used in the archaeological sourcing project (Rye and Duerden 1982), although Allen and Rye (1982:111) noted the use of the major elements Mg, Al, Si, K, Ca and Ti, with the trace elements of V, Ni, Ga and Sr.

Each measurement of the pottery pellets produced a spectrum that was assessed for similarity with the source pellet spectra. Initially, peak area counts were obtained for the elements; however these could not be normalised to cater for counting conditions between runs (Allen and Rye 1982:110), so peak area ratios were used instead. Sherds were then allocated to source based on how they 'intersected' with a source plot. In the first run, allocations were made at two standard deviations, but for following runs one standard deviation marked the boundary for inclusion (Allen and Duerden 1982:50). This increased the percentage of 'unknowns' fourfold, from 2.5 per cent to 10.8 per cent between runs 1 and 2. While it was possible and probably likely that some unknowns were foreign sherds made from materials different to the target sources in use, it was equally likely that unknowns might be reflecting the variability within individual sherds made from local materials.

The Worthing sherd mineralogy study

In the mid-1970s a small project was set up by Dr Mike Worthing, then of the Geology Department, University of Papua New Guinea, to identify the mineralogy of pottery sherds from the Port Moresby region using standard thin sections and then to identify groupings within the wider set. Rye and Allen supplied Worthing with samples of Bootless Bay clays and sands and 42 sherds excavated from Motupore.

Worthing (1980a, 1980b, 1982) and Worthing and Swadling (1980) report the full project which also included samples from Boera and nearby Lea Lea. For Bootless Bay and Motupore, Worthing determined that the Bootless clays were too similar to relate the Motupore sherds to particular Bootless Bay sources and therefore he chose to focus upon the mineral inclusions in the filler sand. His initial results, however, noted that the Motupore and Taurama sands were likewise mineralogically indistinguishable, but the R1 sand was identifiable because of the presence of pyroxenes and gabbro fragments.

Worthing initially identified three mineralogical groups for the 42 Motupore sherds. The most numerous (~55 per cent) comprised Bootless Bay clays mixed with beach sands, consistent with the Motupore and Taurama sands. A smaller group (~15 per cent) was separated by the presence of R1 sand; Worthing assumed, but could not demonstrate, that this sand had also been mixed with Bootless clays. Unexpectedly, Worthing allocated four of the Motupore sherds to a Boera source suggesting a connection that would grow in importance in Rye's later studies. Worthing considered that a further nine sherds (which he labelled Group F) might reflect sources originating between Boera and Bootless Bay, and for no better reason nominated the intermediate Fairfax Harbour area as a possible location. Further details and implications of this study are reported in Rye and Allen (2017:345–349).

Rye's PIXE results

Three runs were undertaken at Lucas Heights, involving 816 sherds. Some 605 derived from Motupore while the remainder included other Bootless Bay sites, coastal and inland sites nearer to Port Moresby Harbour, sites near Boera, one site named Poukama on the mainland near Yule Island and one Papuan Gulf site called Popo excavated by Jim Rhoads (1980, 1994). The sherds external to Motupore were largely included on the basis of similarities in vessel decoration with Motupore sherds; the exceptions here were the five sherds from Poukama. These carried no stylistic similarities

to Motupore sherds and were included as a negative sample. All five sourced as 'unknown'. Because of the results of the petrographic studies by Worthing, proxy source briquettes now also included representatives from Boera, Fairfax Harbour (Hanuabada village) and Galley Reach to the west (from the Western Motu pottery-making village of Manumanu).

The detailed results of this sourcing program appear in references already cited and are also summarised at length by Rye and Allen (2017:358–367).

Here we merely list the main results achieved, noting differences between these results and those of Worthing.

1. PIXE could not separate some Bootless clay sources. However, although the two sources close to Taurama (T1, T2) and the mainland source (GG3) were 'almost identical' (Allen and Duerden 1982:48), Rye was satisfied that he could distinguish them, with perhaps a 5 per cent error. These three sources provided the clays for the vast majority of Motupore pottery; however Worthing could not differentiate these Bootless clays using petrography. Rye also recognised the presence of R1 sand in some sherds but did not differentiate these. In his study they grouped within the GG3 clay category.
2. While the GG3 source occurred frequently among the Motupore sherd assemblage, the combined Taurama sources were consistently more frequent.
3. The Boera sourced sherds noted for Motupore by Worthing also occurred regularly throughout the site sequence in Rye's analysis.
4. Only a single sherd from Motupore was sourced to Fairfax Harbour. This suggested that Fairfax Harbour was not the source of Worthing's Group F.
5. For Motupore, no significant associations could be made between particular clay sources and ceramic changes through time, or with ceramic decorations or ceramic morphologies.
6. Analysis of 211 sherds from beyond Motupore showed a frequent presence of the T1, T2 and GG3 clays. In other Bootless Bay sites, these clays comprised ~77 per cent of that sample; at six sites near Boera ~70 per cent; at seven sites on the Port Moresby coast and in the hinterland ~69 per cent and at the Popo site in the Gulf ~65 per cent. (It should be recalled that these ex-Motupore samples were not random but were included because their decorations were similar to Motupore sherd decorations.) Notably the numerical precedence the Taurama clays over GG3 clays continued in these samples.

These results formed the basis for reconstructing spheres of socio-economic influence for the Motupore traders. They helped develop the ideas that:

1. Motupore and Taurama were related and closely interacting sites where the two-way flow of pots and/or pot-making raw materials was a likely proxy for other close social ties, invisible in the archaeological record;
2. That the two-way flow of pottery between Boera and Motupore (and Taurama) from Motupore's first settlement to abandonment was a strong indicator of social connectedness that implied the Boera area was the likely ancestral homeland of the Motupore/Taurama settlers;
3. That a lack of connection with Fairfax Harbour, located between Motupore and Boera, made the connection with Boera more pronounced;
4. That the presence of sherds of Bootless Bay clay in Gulf sites demonstrated that trading pottery from the Western Motu region to the Gulf of Papua was a practice much older than the ethnographic *hiri*.

Also, sherds with GG3 clay and R1 sand posed the question of whether these pots were made on Motupore or a different Bootless Bay site. The distributional data (Rye and Allen 2017:347–348) remains equivocal on this point.

The new project

In 2016, with the Summerhayes' target pellet collection and the Rye clays and sand from Bootless Bay, we undertook three analyses to compare with Rye's conclusions. We report each in turn.

Reanalysing Rye's pellets using pXRF

Among the pellets retained by Summerhayes the only useful ones were those for which we could establish some identification from the remnant documentation. This resulted in a sample of 146 items, including 27 pellets from Rye's original briquettes that represented known clay sources, 97 pellets from archaeological sherds that Rye had attributed to particular sources, and 22 pellets from archaeological sherds that were unidentified by source.

The aims of this analysis were (1) to determine, using portable X-ray fluorescence (pXRF) rather than PIXE, if the sources could be distinguished from each other, as per the original PIXE project; and (2) if the first proved possible, to determine if the archaeological pellets could be attributed to these sources.

We recognised that the latter objective was severely limited because the source sherds only represented three of Rye's original seven Bootless Bay sources: U1 (Tupesereia clay and Motupore sand); U2 (Tupesereia clay and R1 sand); and T2 (Taurama 2 clay and Taurama sand). (Note that Rye variously used U1 or TU1 or U2 or TU2 to refer to the Tupesereia clay. Here we use U1 and U2 to indicate the pellet combinations, and TU1 for the clay source and any clay samples obtained from here.) Two out of Rye's three important sources, T1 and GG3, were missing, with only T2 represented. Rye had eventually eliminated the Tupesereia clay from his analysis (Allen and Duerden 1982:48), deciding that he could not distinguish between Tupesereia clay and GG3 clay. He thus subsumed both clays under the GG3 rubric.

Methods

The pellets were analysed using a Bruker Tracer III-SD pXRF, using two settings (15 kv 23μA with a vacuum; and 40 kv 10.7μA with a 0.001" Ti, 0.012 Al filter (Bruker's yellow filter)), for a 300-second run time on each setting. These settings were chosen to reflect the original elements used in the Motupore pottery sourcing study (Allen and Duerden 1982). Elements were tested to identify which setting provided more accurate results and the following were selected: vacuum (Si, Al, K, Ti) and yellow filter (Ca, Fe, Sr, Rb). A pelletised international standard (NIST679—Brick Clay) was also analysed to understand the accuracy of the instrument before each run and after 15 samples during a run. The results of this analysis are presented in Table 10.1.

Calibration to parts per million for the pellets was completed in S1CalProcess using Bruker's Mudrock Major calibration for the vacuum setting and Bruker's Mudrock Trace calibration for the yellow filter setting.

Table 10.1: Results (weight %) of NIST 679 Brick Clay Standard shot using University of Otago.

	Al	Si	K	Ca	Ti	Fe	Rb	Sr
Univ. of Otago average (*n* = 15)	10.15	22.94	2.29	0.97	0.62	8.53	0.016	0.005
SD	0.23	0.54	0.02	0.06	0.01	0.15	0.0005	0.0001
RSD (%)	2.31	2.36	0.98	5.87	2.37	1.27	2.99	3.03
NIST values	11.01	24.34	2.43	0.16	0.58	9.05	–	0.007

Notes: SD = standard deviation; RSD = relative standard deviation.

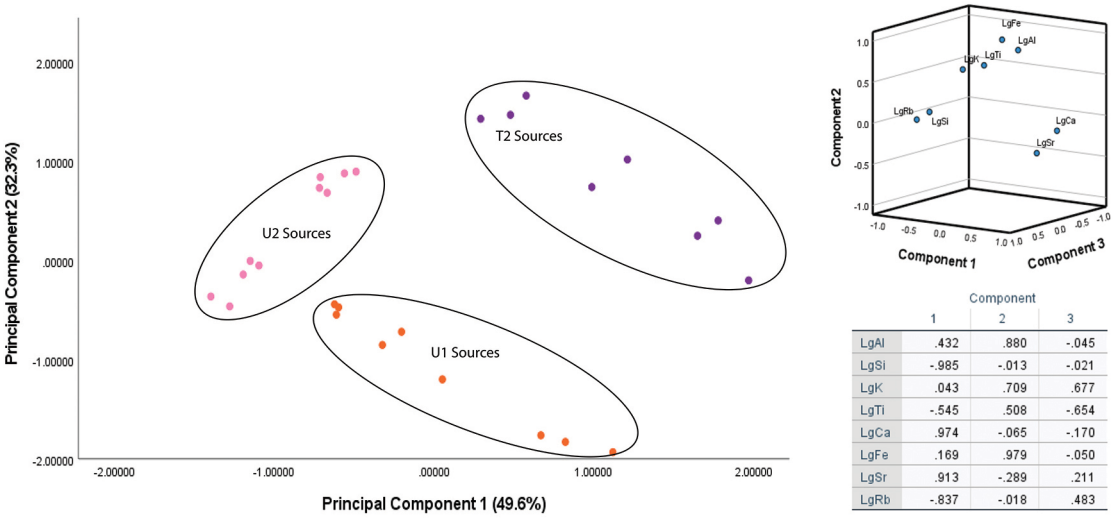
Source: Authors' summary of results.

To determine if there were any groupings within the pXRF data, Principal Component Analysis (PCA) and Hierarchical Cluster Analysis (HCA) were performed, using SPSS Version 25. Prior to statistical analysis, all elemental values were logarithm base-10 transformed. As part of the PCA, the Kaiser-Meyer-Olkin measure of sampling adequacy (value >0.5) and Bartlett's test of sphericity ($\alpha = \leq 0.05$) were also applied to determine if the data was suitable for PCA. No rotation of the data was applied. For the HCA, Ward's method was used.

Results

As noted, Rye found that the U1, U2 and GG3 clays were largely indistinguishable from each other, but in our first PCA (Figure 10.2) U1 and U2 quite clearly separate out from each other, as does T2. Elements that are important to creating separation, as can be seen from the loadings in Figure 10.2, include Si versus Ca/Sr. Ca and Sr are usually linked elements and likely relate to the amounts of shell in the pelletised sample, whereas Si relates to the amount of quartz or chert in the beach sand temper.

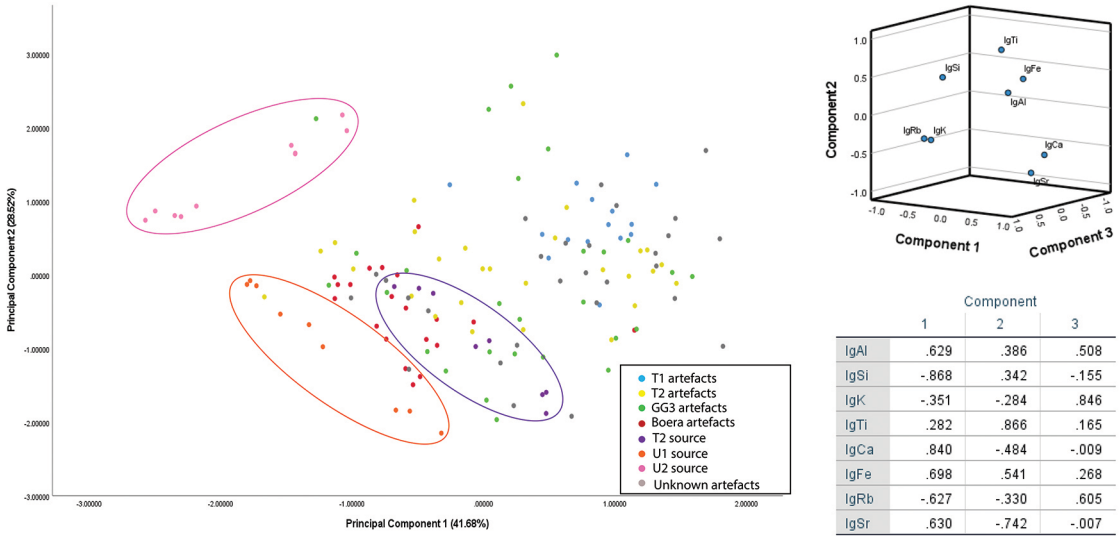
A second PCA was run incorporating 119 pellets made from Motupore pottery that were mostly attributed to sources during the original PIXE project. Not all of the pellets included source information. Of the pellets sourced by the original PIXE project, 15 were attributed to T1, 29 to T2, 30 to GG3, and 23 to Boera. Figure 10.3 includes these original sourcing locations, and compares these to Rye's source pellets, which shows little correlation, particularly with U1 and U2 sources.



	Component		
	1	2	3
LgAl	.432	.880	-.045
LgSi	-.985	-.013	-.021
LgK	.043	.709	.677
LgTi	-.545	.508	-.654
LgCa	.974	-.065	-.170
LgFe	.169	.979	-.050
LgSr	.913	-.289	.211
LgRb	-.837	-.018	.483

Figure 10.2: PCA of Rye source pellets, using pXRF.

Source: Authors.



	Component		
	1	2	3
lgAl	.629	.386	.508
lgSi	-.868	.342	-.155
lgK	-.351	-.284	.846
lgTi	.282	.866	.165
lgCa	.840	-.484	-.009
lgFe	.698	.541	.268
lgRb	-.627	-.330	.605
lgSr	.630	-.742	-.007

Figure 10.3: PCA of Rye source and Motupore pottery pellets, using pXRF.
Source: Authors.

For the T2 source, there is overlap with the archaeological pottery, some of which was originally attributed to this source, but which also includes numbers of sherds previously attributed to Boera and GG3 sources. Removing the sources, there is some clustering of the pottery into two larger groups: one which includes predominantly Boera and T2-attributed artefacts, and the second which consists of T1 and T2-attributed artefacts. GG3-attributed artefacts are spread across the PCA.

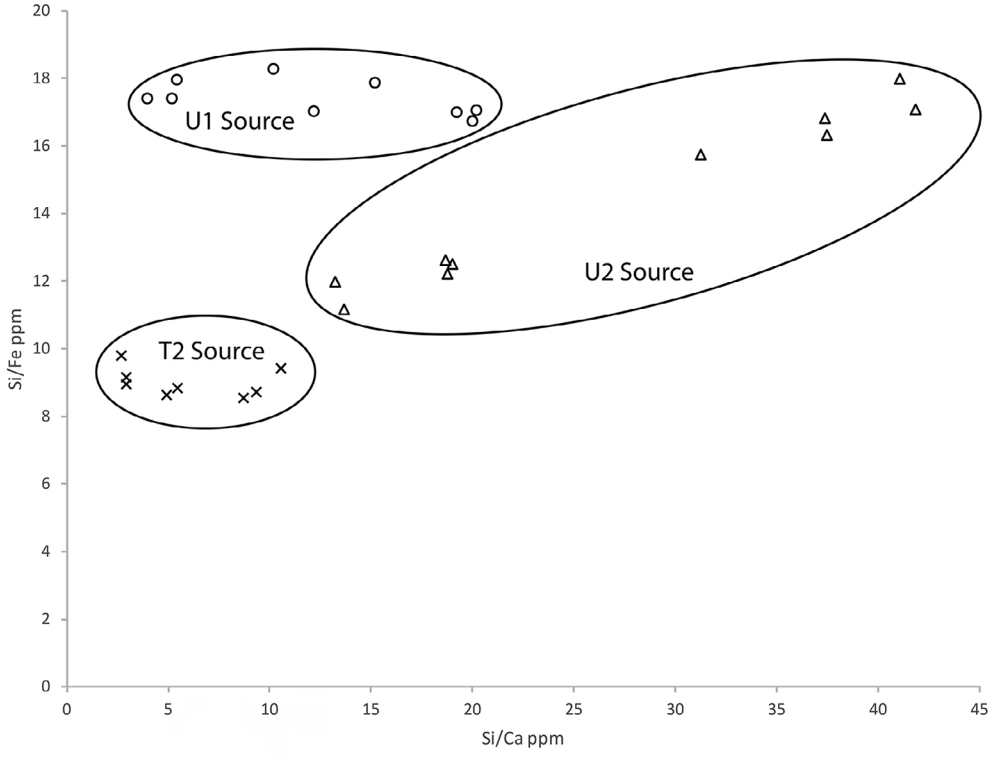


Figure 10.4: Bivariate analysis of Rye source pellets, using pXRF.
Source: Authors.

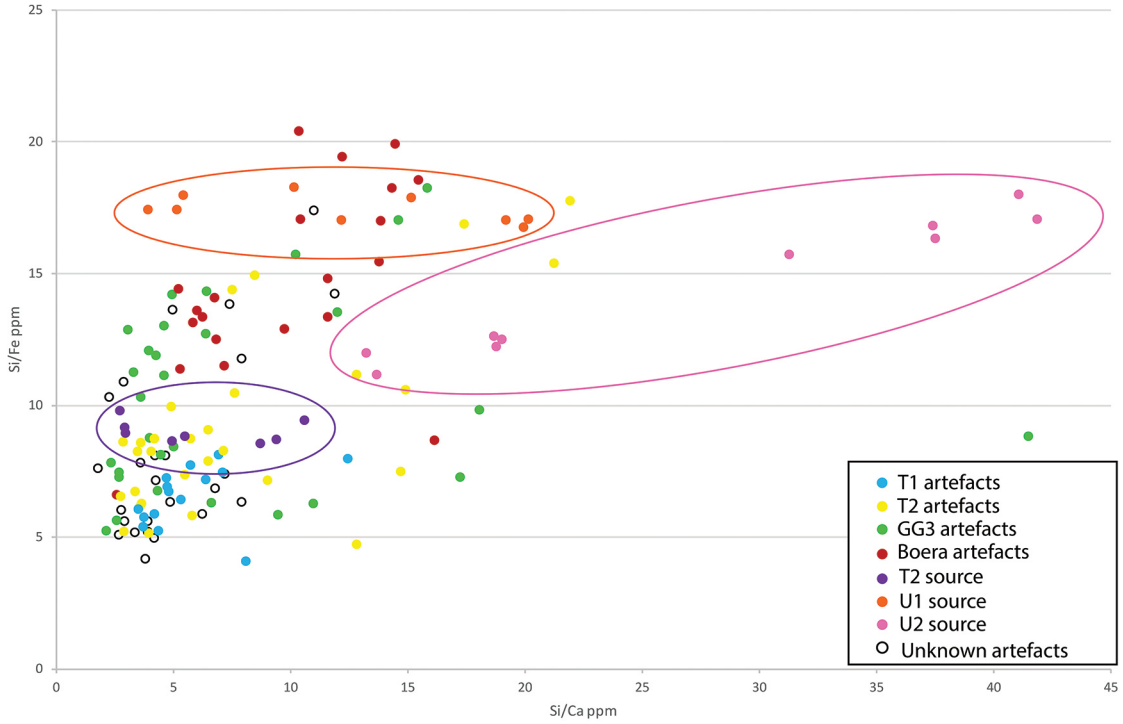


Figure 10.5: Bivariate analysis of Rye source and Motupore pottery pellets, using pXRF.
Source: Authors.

To test whether the lack of clarity of the archaeological pottery reflected minor fluctuations in pXRF counts caused by the level of precision and accuracy of the machine, a second analysis was completed where ratios of elements were used, rather than parts per million for each element. A similar analysis was undertaken in the original PIXE studies, although which specific peak ratios were used was not reported (Allen and Duerden 1982). Figure 10.4 demonstrates that this type of analysis, where ratios of the major elements are involved in the loadings of the PCA, successfully distinguishes between Rye's sources. Similar to the PCA results, the bivariate analysis shows that the source pellets are spread across a range of values, largely driven by the proportions of clay/temper used in making them. For example, the U1 and T2 sources decrease in Ca levels as the amount of temper is decreased, which likely reflects decrease in shell in the temper.

While some studies (e.g. Buhring et al. 2015) have suggested that different temper proportions do not prevent the identification of different clay sources in bulk sample analysis, other studies have noted that there can be a considerable effect on overall geochemical composition (Bentley 2000; Chiu 2003:222; Chiu et al. 2020). This appears to be particularly exacerbated for shell/coral tempers because of the degradation of Ca and Sr (Ambrose 1982; Cogswell et al. 1998), to the point where studies using crushed bulk samples with these types of tempers have used statistical methods to try and cater for this 'dilution' effect (Chiu et al. 2020; Cogswell et al. 1998) or have removed Ca/Sr from their geochemical compositions altogether (Shaw et al. 2016).

Once the archaeological pottery is added, a clear link between the pottery and a source is difficult to discern (Figure 10.5; compare Figure 10.2). This result indicates that while there appears to be some grouping of the pottery into 'sources' attributed by the original PIXE work, particularly with the Boera and T1-attributed artefacts, T2 and GG3-attributed artefacts are spread across a range of values. Another difference from the PCA results is that some of the Boera-attributed sherds align with the U1 source, however, examination of other elements, particularly Al, indicate that this is

unlikely to be a true match. The importance of this result, where Boera trends into the T2 source in the PCA but to U1 in the bivariate, is that it indicates that the choice of elements used to attribute sherds to a 'source' may directly impact which 'source' is assigned, making this potentially a result of the statistical analysis employed, rather than a real difference in the archaeological pottery itself.

A geochemical analysis of Bootless Bay clays using the scanning electron microscope (SEM)

Here we reanalysed the Museum clay samples obtained by Rye from Bootless Bay. The purpose of this analysis was to determine if we could distinguish the clay samples geochemically using a scanning electron microscope (SEM). The clay samples were Taurama 1 (TC1), Taurama 2 (TC2), O5, Guma's Garden 3 (GG3), Guma's Garden 5 (GG5), Maru and Tupesereia 1 (U1) (see Figure 10.1).

Geologically, all of these clays derive from a similar geological zone (Figure 10.1): the Eocene-aged Paga chert (Tep) which is described as 'partly calcareous, siliceous argillite and shale, calcilutite, chert, and minor calcarenite and dolomite' (Pieters 1978:39). The exception is O5, which originates in a similar aged geological zone known as Tatana calcarenite (Tet), which is calcarenite, minor calcirudite and glauconite.

Methods

The raw clay samples were made into small briquettes suitable for analysis. They were first ground with a mortar and pestle to create a homogenous powdered material. Distilled water was then added to the clay and balls were formed with the wet material averaging 2 cm in diameter. The balls were then left in a drying room for three days at a temperature of 20 °C. Two batches of the seven clay samples were then fired at different temperatures: 500 °C and 800 °C. These temperatures were chosen to reflect possible open firing conditions that were likely utilised at Motupore (Rye and Allen 2017:342–343) and to identify what effects firing might have on the geochemical signature of the clays, as previous studies have noted some effects above 700 °C (Rye and Duerden 1982). To fire the clay samples, the balls were placed in a furnace which was set to the required temperature for an hour, then the heat source was turned off and the samples were left in the furnace until they were cool enough to be removed. These clay samples were then turned into plugs, using HillQuist epoxy, and polished to one micron. Prior to SEM analysis, the plugs were carbon-coated.

Quantitative geochemical analysis of the clay matrix was then completed on a Hitachi Tabletop Scanning Electron Microscope (SEM), using a Bruker QUANTAX energy dispersive X-ray spectrometer (EDS) and ESPRIT Compact acquisition and processing software. Before each analysis session, the EDS was calibrated with a pure copper standard. Additionally, a spot point analysis on a NMNH 115900 Plagioclase standard was recorded to track the stability of machine conditions. For clay analysis, five areas of each sample were examined. The clay matrix areas were carefully chosen after observation at 100×, 1000× and 2000× magnification. After capturing a 1024 × 960 pixel electron micrograph at 50,000× magnification, a spot analysis was then undertaken to collect elemental data. Each spot point measurement was acquired for 60 seconds.

For the statistical analysis, methods were the same as described for the pXRF data.

Results

Of the seven Rye clays shot for analysis, all of these included samples fired to 800 °C, with two additional samples of TC1 and GG5 fired to 500 °C. Elements included in the PCA analysis included Na, Mg, Al, Si, K, Ca, Ti and Fe. As noted above, each clay sample was analysed five times and all shots were then plotted individually within the PCA (Figure 10.6).

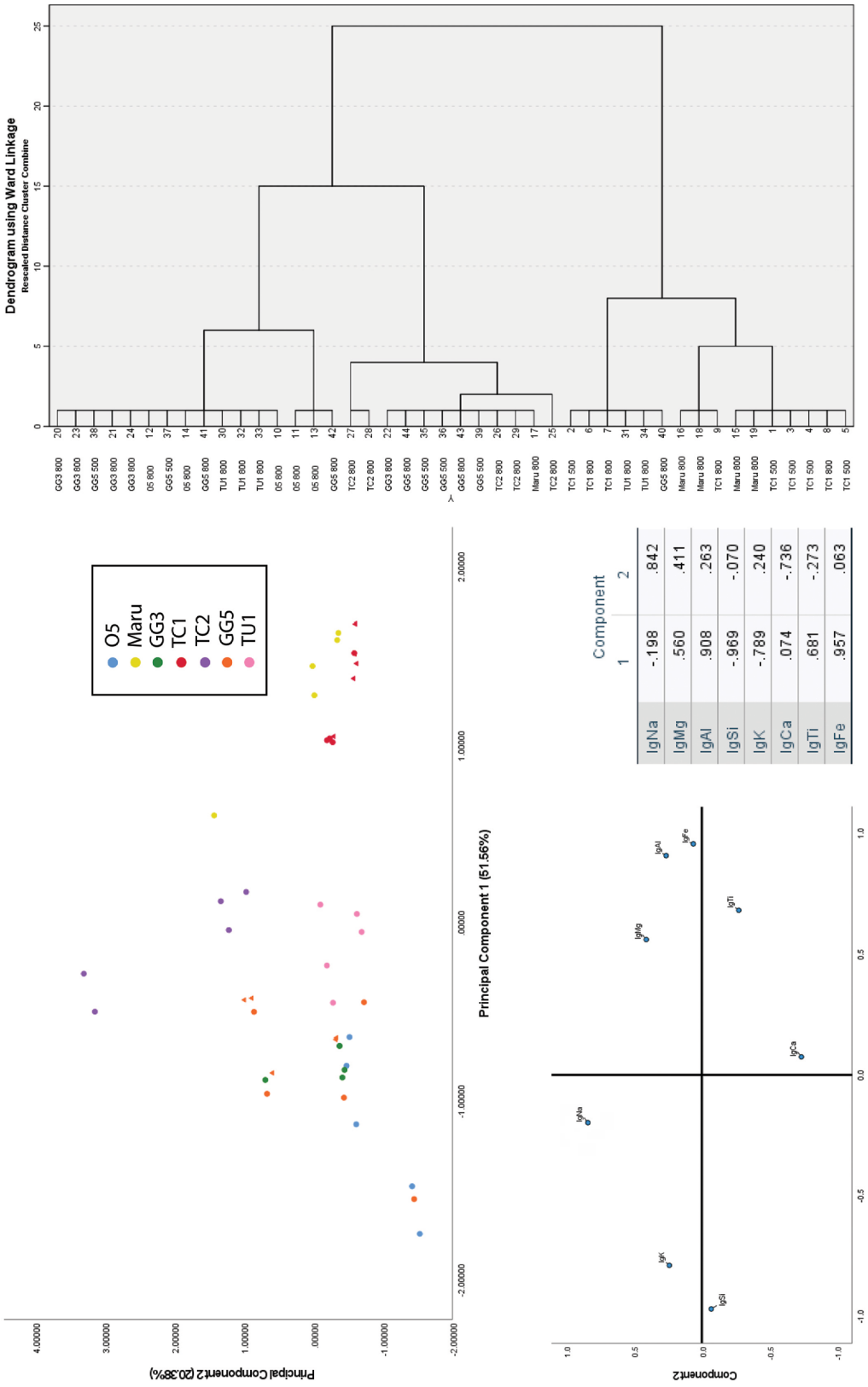


Figure 10.6: PCA and HCA of Rye clays, using SEM. Triangles represented clays fired to 500 °C, circles represent clays fired to 800 °C.
Source: Authors.

The PCA indicates fairly good source separation; in particular, there appears to be little change in signature according to firing temperature utilised (see GG5 and TC1). There is some overlap between sources, for example GG3, GG5 and O5, which likely reflects the geographic proximity of these sources (Figure 10.1). TC1 tends to cluster well, associated with Maru. TC2 and TU1 also tend to exist by themselves, although TU1 is closer to O5 and GG3/GG5. Distinction between the clay sources is largely driven by Al, Si and Fe in Principal Component 1 and Na and Ca in Principal Component 2.

The groupings of the clays were further tested using the HCA. Again, it is noted here that the TC1 and GG5 clays cluster together regardless of firing temperature. Similar results to the PCA are also demonstrated, with TC1 and Maru clustering at one end, with the GG3/GG5, plus O5 at the other. TC2 is largely with the GG cluster, although there is one outlier, and TU1 splits across both clusters. The results of both the PCA and HCA would therefore indicate real differences between at least the GG3/GG5/O5 cluster and the TC1/Maru cluster, with TU1 and TC2 being intermediary between the two. The close relationship between all these clays likely reflects their common geological origin.

Comparing Bootless Bay clays and Motupore sherds using the SEM

Given that some geochemical separation could be made between the Bootless Bay clays, we then tried to match archaeological sherds from Motupore with these clay sources. This comparison used 120 sherds from Motupore and 10 sherds from the Boera/Davage site complex. From Motupore, sherds were selected to provide 20 sherds from each of the six stratigraphic/analytical phases (1–6) (Allen 2017:129–131). Each of the six groups contained a mixture of forms (ovoid pots and restricted/unrestricted bowls) and decorated/undecorated items. In particular, a deliberate inclusion in each unit (where possible) was both painted and unpainted pottery since Rye and Allen (2017:356) suggest that painting is associated with a lighter coloured fabric that in turn is associated with lower amounts of shell temper than the unpainted sherds. The 10 sherds from Boera/Davage were part of a surface sample selected at random but which included both painted and unpainted pottery. While undated, this sample was 'prehistoric' on the basis of forms and decorations and considered to be a representative sample of Boera fabric sufficient for comparison.

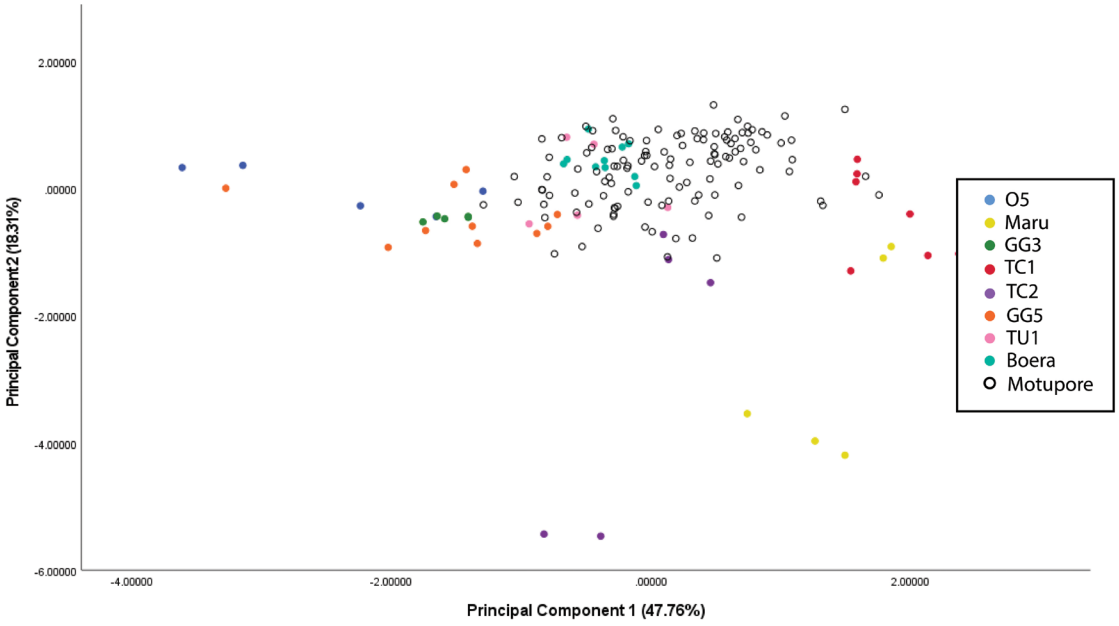
Methods

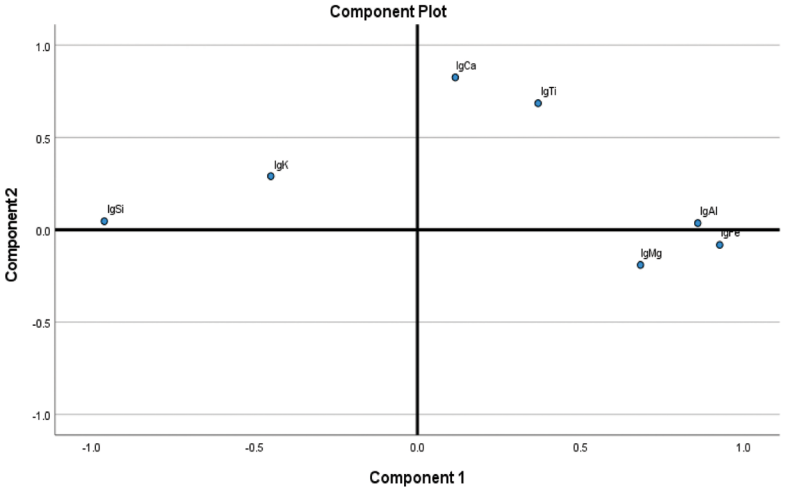
The sherds were cut, cleaned and turned into plugs, following the same methodology as outlined above for Rye's clays. The benefit of using a cut sample of pottery versus a crushed sample is that the clay matrix and the mineral inclusions can be distinguished. Two different types of analysis were therefore conducted: the first was a clay matrix analysis, following the same procedures for the Rye clay analysis already described. However, for this analysis Na was excluded because it is likely that seawater was used to produce the archaeological pottery samples, whereas distilled water was used for the clay briquettes. The second analysis was a temper analysis: for this, micrograph images were captured at a high resolution, 2000 × 1875 pixels. One or two temper abundant areas per sample were selected at 100× magnification to examine the mineral inclusions, following the procedure below:

1. Map-scanning analysis was firstly conducted to obtain data from the entire view, in order to identify the main mineral groups. With the assistance of phase maps and mixed maps of the nominated elements: Na, Mg, Al, Si, K, Ca, Ti and Fe, it is possible to distinguish different minerals or inclusions visually. While a 32µs dwell time per pixel was set for map imaging, all the qualitative data were captured with a 128µs dwell time per pixel, which makes an acquisition time of approximately 8 minutes.

2. After each type of mineral or inclusion was grouped using the map scan, a follow-up spot point analysis was then completed to further define the chemical composition of each mineral group. Minerals or inclusions were then identified based on their geochemical signature. Finally, minerals/inclusions were quantified as to their abundance, borrowing the idea of point counting from sedimentary petrology, that is to count the grain types/clay matrix falling beneath the intersection points of a rectilinear grid on the printed out 2000 × 1875 pixels SEM maps, resulting in a 100-point count for each SEM map. While frequency counting has been used most commonly in the Pacific (Dickinson 2006), the two other studies to have employed petrographic analysis of temper on the south coast of Papua New Guinea (Marsaglia et al. 2016; Worthing 1980a, 1980b, 1982) both employed point counting.

Results 1. Clay matrix





	Component	
	1	2
lgMg	.684	-.190
lgAl	.860	.036
lgSi	-.960	.047
lgK	-.449	.290
lgCa	.116	.825
lgTi	.370	.685
lgFe	.927	-.082

Figure 10.7: PCA of Motupore and Boera/Davage pottery, compared to Rye clays, using SEM.
Source: Authors.

Figure 10.7 represents the PCA which compares the Motupore pottery to pottery from Boera/Davage and to the Bootless Bay clays. Following the previous analysis, the clays largely fall out into the same clusters. However, there is little overlap with the archaeological pottery from either Motupore or Boera/Davage, with most of the archaeological pottery forming its own group independent of the clays. Boera/Davage appears to cluster quite tightly, but this cluster overlaps with the Motupore pottery; if the source of this pottery was not known it would be lost within the Motupore pottery. Since it is unlikely that the Boera/Davage sherds originated in Bootless Bay, it is probable that the source clays of Boera/Davage and Motupore are too similar to distinguish through geochemistry. As analysis using the SEM mainly identifies major elements, incorporating trace or rare earth elements might assist with providing distinctions between the two localities.

Results 2. Temper

The vast majority of the sherds from Motupore and Boera share a very similar suite of mineral inclusions that reflects the local geology. These include shell fragments, indicating the use of beach sands as temper, as well as minerals dominated by quartz and plagioclase feldspar. Accessory minerals in these sherds include K-feldspar, hornblende, pyroxenes, epidote and mica. Some rocks and opaques are also present but these are in smaller amounts.

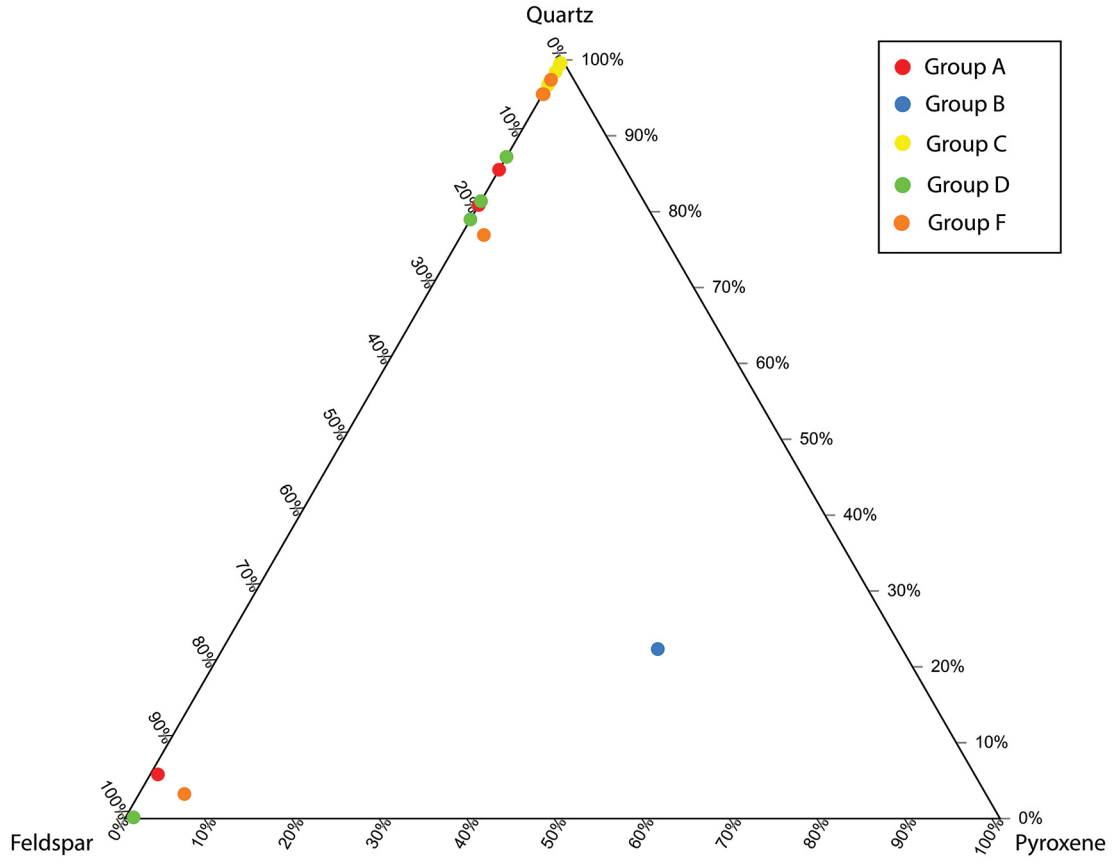


Figure 10.8: Ternary plot diagram of clays and sands.
Source: Authors' interpretation of data from Worthing (1982).

For the current study, the chert versus quartz/feldspar ratios used by Worthing (1982) to distinguish between source areas could not be measured as the geochemistry of quartz and chert is too similar under the SEM to be able to distinguish between them. However, ternary plots of Worthing's geological samples of clay and temper (drawn from Worthing 1982:Table 1), show distinctions between Group A (Boera) and Group C (Western Bootless Bay/Motupore) based on quartz/feldspar ratios, with a second distinction able to be made with Group B (Eastern Bootless Bay—R1 Sand) based on pyroxene levels (Figure 10.8). Using these ratios, Group D (Lea Lea) overlaps with Boera and Group F (putatively 'Port Moresby Harbour') overlaps with Western Bootless Bay, reflecting their respective locations.

Temper comparisons between Boera and Motupore are more interesting. Figure 10.9 shows that pottery from Boera is likely to have a higher feldspar content than a large proportion of pottery from Motupore. The second point is that pottery sherds from Motupore with mica present are also more likely to have a higher feldspar content, and tend to overlap with Boera pottery. Worthing (1982) noted that mica is a distinguishing mineral of pottery from Boera/Lea Lea, and suggests that Motupore sherds with mica inclusions were originally manufactured in Boera.

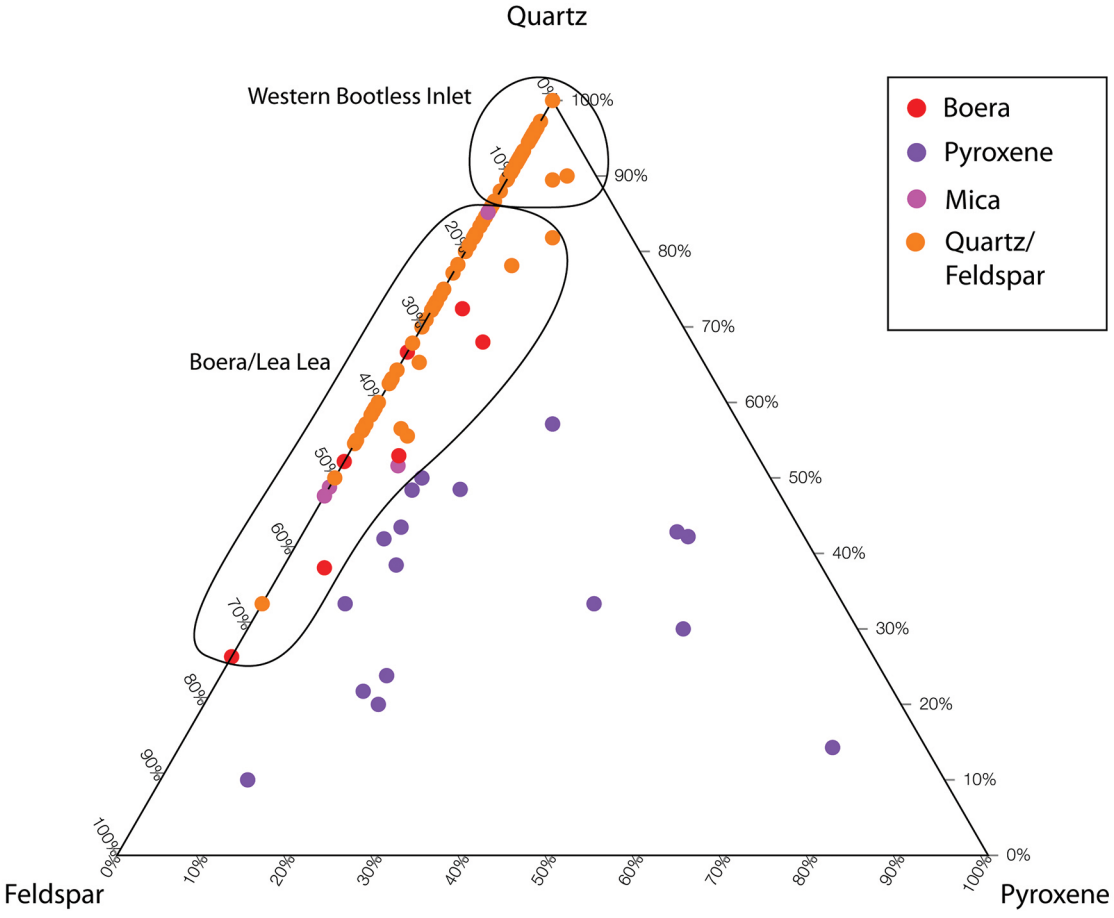


Figure 10.9: Ternary plot diagram of Motupore and Boera pottery: quartz, feldspar, pyroxene.
Source: Authors.

A third point is that some pottery from Motupore contains high levels of pyroxenes, which also tend to have a higher feldspar content than other Motupore pottery. While these sherds may overlap with the feldspar content of Boera sherds, they are distinguishable from Boera sherds on higher pyroxene counts that match Worthing's Group B (R1 sand) pottery, attributed by Rye to the GG3 clay source.

The distinctions noted between Worthing's Groups A, B and C were difficult to apply to the archaeological pottery as the quartz/feldspar ratios show an array of values. In Figure 10.9 a distinction has been made between these groups, largely based on the presence of mica and the values of the Boera pottery, as well as reference to Figure 10.8 which shows the Worthing results. A second ternary diagram (Figure 10.10) was plotted to test the 'realness' of these groups but this time replacing pyroxene with shell, and again, this shows that the pyroxene (or Group B) related pottery largely clumps together with no shell present (although there are some outliers here), and the Boera/mica pottery also clusters together within the centre of the plot, indicating middle ranges of shell, and consistent quartz/feldspar values.

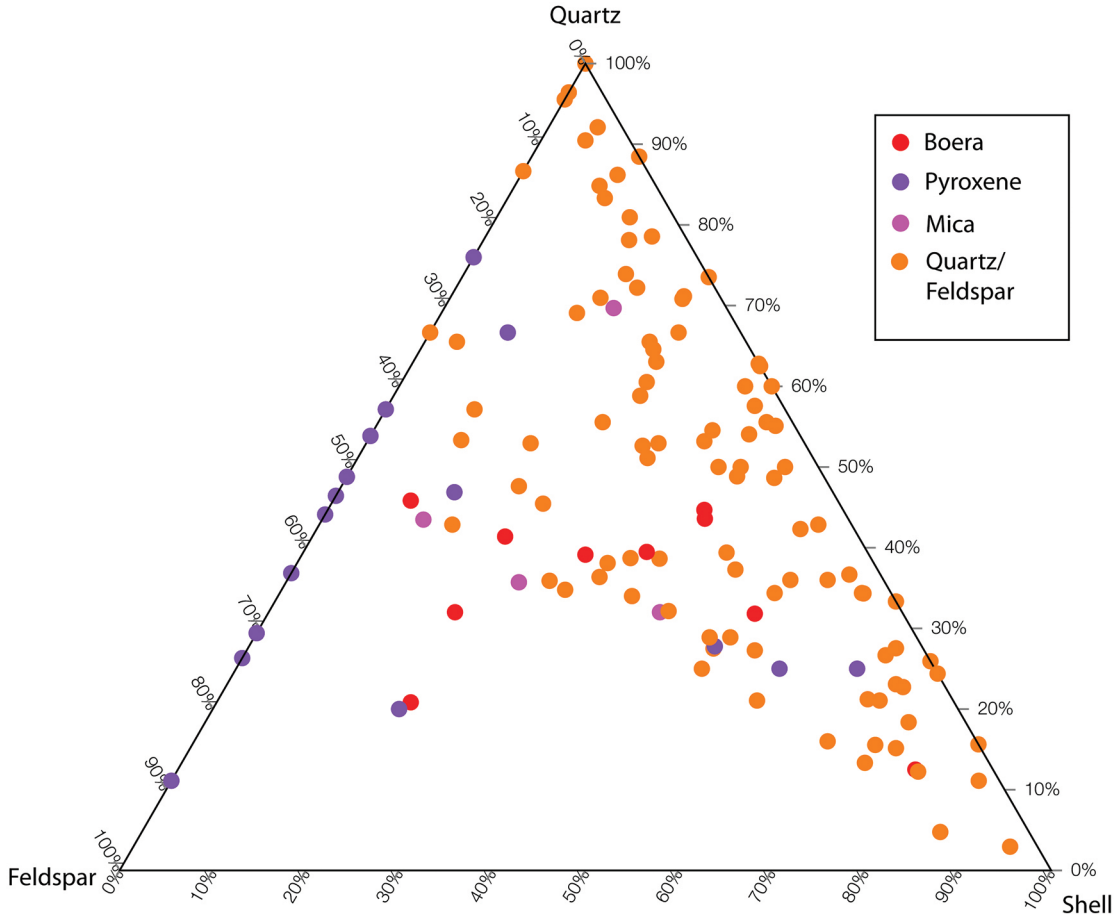


Figure 10.10: Ternary plot diagram of Motupore and Boera pottery: quartz, feldspar, shell.
Source: Authors.

Summary

The present project has reviewed a number of geochemical techniques to assess the ability to distinguish between geological sources of clay and temper sands and to associate these raw materials with archaeological pottery. Particularly significant in this study is the proximity of the raw material sources to each other, with effectively all of the clay and temper sands deriving from the same geological unit of the Paga chert. While using crushed samples or clay matrix alone did not allow for connection to specific geological locales, unlike that originally specified by the original PIXE work (see Rye and Allen 2017), mineralogical analysis of the temper sands using SEM did provide some important distinctions between specific sources. Because of the relatedness of the geology, these distinctions are largely identified as proportions of the same minerals or components (shell) which makes them particularly sensitive to issues such as the percentage of the sherd assemblage actually analysed. Improvements to this methodology may allow for further distinctions to be made.

Discussion

Given the accumulated physical, chemical, and archaeological evidence previously amassed for Bootless Bay, we do not doubt that prehistoric potters there made pots using Bootless Bay raw materials. Indeed, a case might be made that it was the availability of these materials that underwrote the settlement and expansion of the Taurama and Motupore sites and wider settlement in Bootless Bay over five centuries. That we cannot provide a coherent demonstration of such usage in this study or those that preceded us emphasises the complexities of sourcing a composite material such as pottery, especially when compared, for example, to the precise and separate chemical compositions of different obsidians.

Given that we began this study with the original Rye clays from Bootless Bay we expected that our new approach might confirm Rye's central conclusions. This expectation rose when we were able to chemically separate the Bootless Bay clays from each other, but this merely exacerbated our disappointment when we failed to relate the Motupore sherd sample in any meaningful way to these clay 'sources'. At the same time, we were able to take instructive lessons from these experiments. Here we summarise the more important of these.

pXRF analysis of the Rye pellets

Both PCA and HCA indicated our methodology could distinguish between Rye's three sets of available source pellets but pXRF analysis was unable to match the archaeological pellets to these sources, apart for a partial, perhaps coincidental, overlap with the T2 source. Beyond this, this test was of little value because two sets of source pellets employed clay from eastern Bootless Bay excluded by Rye as unlikely to have been preferred to nearer sources. Our results, with virtually no overlap between the archaeological pellets and the eastern sources, appeared to support this. But while lack of overlap might be explained by the physical distance between the eastern sources and the archaeological sample, lack of overlap with the nearer T2 source suggested a different explanation. While Rye's source briquettes were subjected to manufacturing and firing conditions that mimicked the archaeological pottery, these samples could not recreate the effects that use or burial of the pottery might have in creating functional or post-depositional effects on the pottery constituents. This was most clearly seen during SEM analysis in the amount of shell present in the archaeological pottery, which was visibly eroded in some, but not all, archaeological samples (Figure 10.11). The erosion of shell affected Ca/Sr values that are a clear driver in grouping the archaeological samples. We carried this idea forward into the SEM analyses.

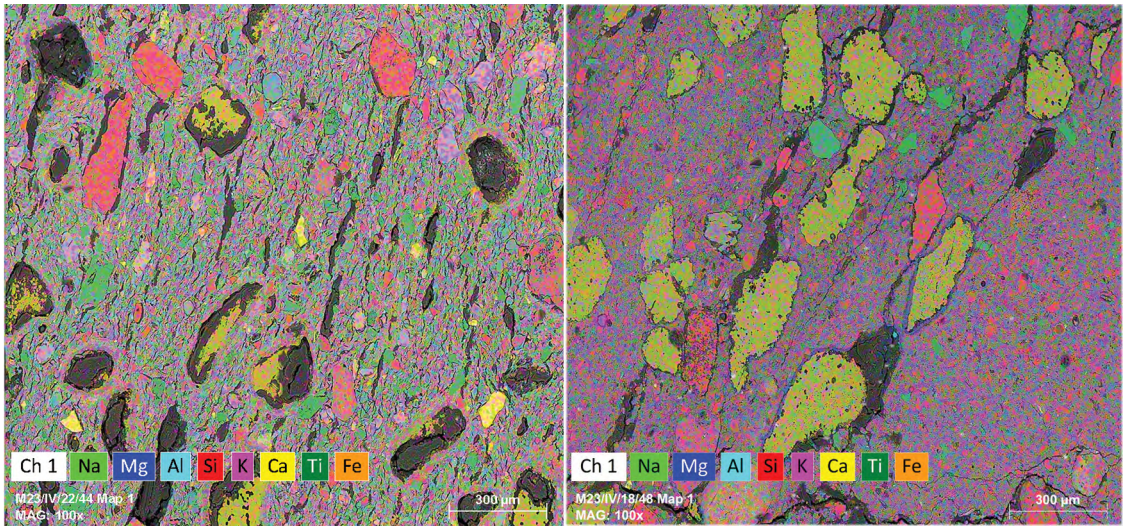


Figure 10.11: SEM micrographs of Motupore pottery.

Notes: (Left) pottery with erosion of shell creating voids; (Right) pottery with more intact shell.

Source: Authors.

SEM analyses of Bootless Bay clays and archaeological sherds

The SEM analyses to some extent mirrored the pXRF analyses in that while we could differentiate between the Bootless Bay clays, especially distinguishing between the T1, T2 and GG3 sources that formed Rye's three major groups, it was difficult to relate the Motupore sherds to any of the clays (see Figure 10.7).

In searching for reasons to explain this difficulty, the noted erosion of shell in the archaeological samples opened up the question of whether the addition or leaching of other elements might explain the differences between the archaeological pottery and the clays (see Schneider 2016 for a comprehensive overview of these types of issues). For the current study, we note three possible areas that might provide explanations: (1) that our source briquettes differed in some significant chemical way from the archaeological samples; (2) that the uses the pottery was put to may have occasioned chemical changes; or (3) that post-depositional burial might have altered the clay geochemistry. The loss of shell temper in the fabric of buried sherds is an example of the latter. Figure 10.11 indicates that this occurred at different rates for Motupore sherds. A study by Golitko et al. (2012) noted the post-depositional leaching of barium that affected pottery geochemical composition sufficiently to make samples appear to derive from different 'sources', while Ambrose (1982) and Bearat et al. (1992) also record change in particular elements due to the nature of the burial contexts of the pottery.

In terms of briquette differences, while our briquettes were made using distilled water, Motu potters used seawater (Groves 1960:15) and Motupore potters likely did as well, as its use in preference to fresh water increased the range of successful firings (Rye and Allen 2017:337–338); and additionally, Motupore has no surface fresh water source. Using salt water may be chemically significant in enriching the pottery samples in Na and Cl (Ambrose 1982). Ethnographically, some newly fired Motu pots were coated with mangrove dye and water pots vigorously rubbed with leaves to make them watertight (Groves 1960:17). The difficulty here is understanding what exact affect each stage of a pot's life can have on its geochemistry and being able to separate these effects to create

an 'unbiased' source identity. While many studies simply exclude possibly affected elements, this may be a different way of introducing bias into the results as some excluded elements may reflect genuine differences in source location. Pottery from more distinct geologies might withstand these exclusions but this research suggests that for pottery from closely related geologies this could become an insurmountable obstacle.

Characterisation of Motupore sherds

As Figure 10.7 demonstrates, while the intersection of the archaeological sherds with the clay sources is poor, the sherds themselves cluster quite well, with relatively few outliers. This suggests that their characterisation, either chemically or mineralogically, might provide groups that stand as the equivalent of a Motupore or Bootless Bay source for external comparisons, even though these groups do not align closely with the clay sources. However, it is also worth noting here that the Boera sherds fit within this cluster as well, therefore perhaps this should be considered to reflect a more general coastal Port Moresby regional signature, similar to that identified by Bickler (1997), rather than solely Bootless Bay.

The types of inclusions in the archaeological pottery are also similar, making it difficult to distinguish between them qualitatively, but as Worthing (1982) showed, the proportions of these can reflect different temper suites. Five of Worthing's six groups were largely based on chert versus quartz/feldspar ratios, with Group B, the R1 sand, recognised as having little shell and the presence of pyroxenes and gabbro fragments.

A limitation of our study was our inability to distinguish chert, a clear marker of Worthing's results. However, the SEM analysis improved upon other parts of Worthing's analysis, as the geochemical approach provides the ability to distinguish more easily between quartz and feldspar, as well as between pyroxenes and amphiboles (see Marsaglia et al. 2016 who note difficulty with this). Petrography of thin sections, in addition to SEM analysis, would therefore be a way forward for improving this type of analysis. A second improvement would be additional map scanning using the SEM. Since our analysis included a large number of sherds, only one map scan was completed for each sherd. However, for a small sample, an additional map scan was completed to compare the results. While this analysis showed that there was not a large difference in quartz/feldspar ratios, it did become important for the identification of important accessory minerals such as mica. Therefore, it is possible that mica is under-represented in the current analysis.

Going forward

While our current analyses indicate the difficulties of relating Bootless Bay archaeological sherd fabrics to local geological sources, they have opened up a different approach to characterising these assemblages for comparison with other local and distant assemblages. Common archaeological practice at present is to point to comparisons between decoration techniques and motifs and vessel morphology, to which we envisage the addition of associated defining chemical tests.

It is assumed that continued research will expand and refine defining characteristics, but for the moment we can begin by identifying that archaeological pottery from Bootless Bay may be differentiated into 'source' groups based on a number of factors, including:

1. Chert versus quartz/feldspar ratios, similar to that proposed by Worthing (1982).
2. Distinctions between quartz and feldspar abundance, which may distinguish between Motupore, Boera and R1 (see Figure 10.9), in conjunction with the identification of associated minerals such as mica and pyroxene (see next two points).
3. The presence of mica that, in turn, indicates a Boera source.
4. The presence of pyroxenes that indicate use of the R1 sand.

This work continues.

Acknowledgements

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