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Understanding social connections within the Bismarck Archipelago through petrographic and motif analyses of Mussau Lapita pottery assemblages

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Abstract

Petrographic and motif analyses of Lapita pottery assemblages from the Talepakemalai (ECA), Etakosarai (ECB) and Etapakengaroasa (EHB) Lapita sites of the Mussau Islands help to illuminate the social lives of people living in the Bismarck Archipelago some 3000 years ago. Based on petrographic analysis, these early Mussau Lapita sites acquired pots from many parts of the Bismarck Archipelago, namely the Admiralty Islands, north-east and central north New Britain, northern and south-western New Ireland and the Tabar–Lihir–Tanga–Feni (TLTF) chain. None of our petrographic samples indicate sources from southern New Britain, even though ECA shares a high number of motifs with sites in the Kandrian region of south-western New Britain. There is also no evidence of imports from the northern coast of New Guinea. We suggest that the Mussau Lapita community was linked with at least two possible social networks based on pottery sources, motifs and obsidian distribution patterns.

Introduction

Located on the northern rim of the Bismarck Archipelago, the Lapita communities of the Mussau Islands have long been of particular interest to Pacific archaeologists. Egloff and others initially reported finds of fine dentate-stamped Lapita sherds on Eloaua island (ECA and ECB sites: see below) (Bafmatuk et al. 1980; Egloff 1975), while Allen and Specht, who also surveyed the area, found 16 possible archaeological sites (Allen et al. 1984:8–11, cited in Kirch 2001:58). During the 1985 Lapita Homeland Project and in subsequent field seasons in 1986 and 1988, Kirch and his team extended archaeological survey of this island group, and excavated at the Talepakemalai (ECA), Etakosarai (ECB) and Etapakengaroasa (EHB) Lapita sites (Figure 6.1) on Eloaua and Emananus islands, along with other sites of Lapita and Post-Lapita age (Kirch 1987, 2001, 2021c).

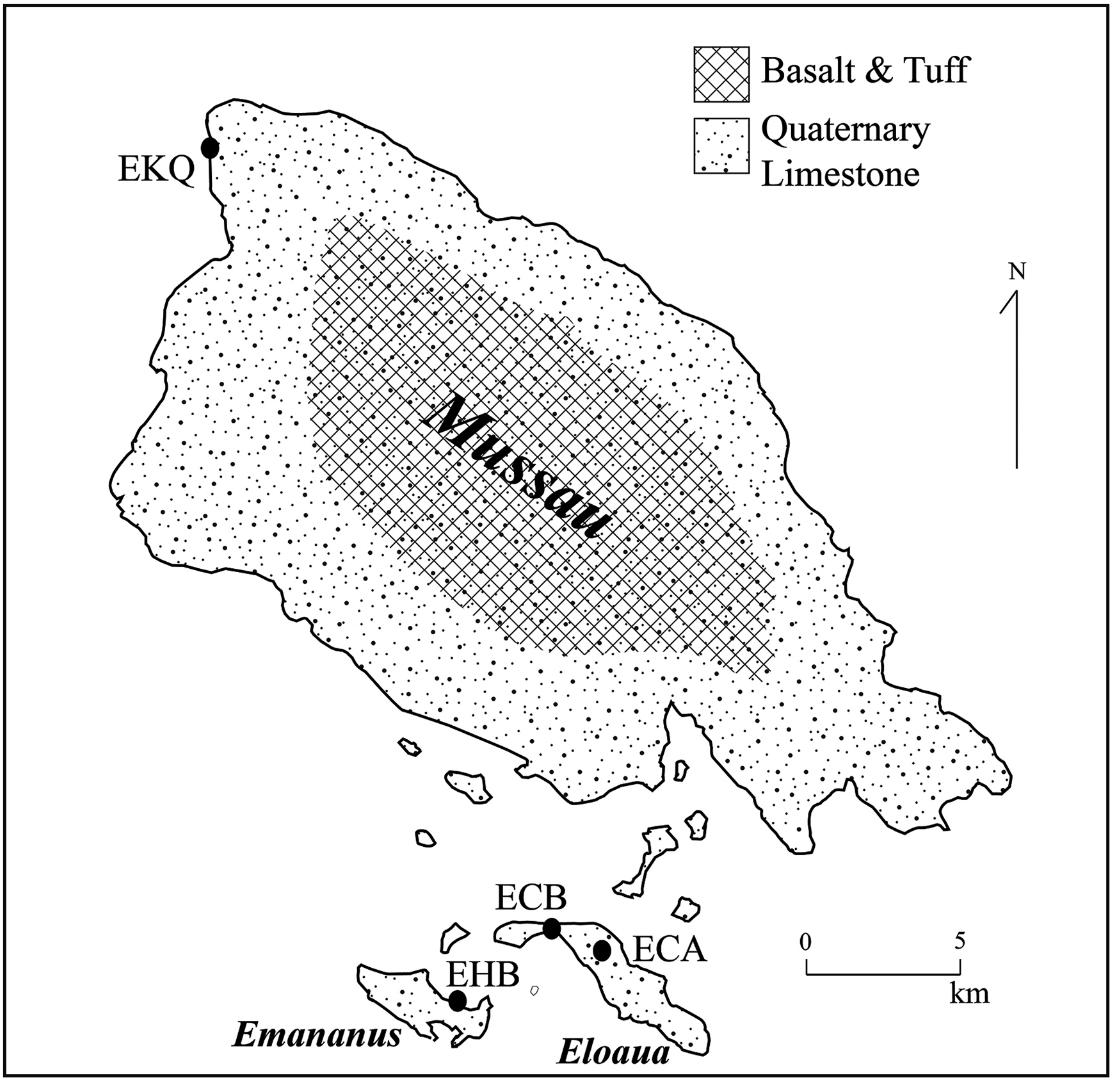


Figure 6.1: Map of the Mussau Islands and nearby isles with locations of Lapita sites discussed in this paper.

Source: Adapted from Kirch (2001:Fig. 3.1, 59), Warin and Jensen (1959:Plate 12).

The extensive Talepakemalai site (ECA) incorporated the remains of numerous stilt houses, including two sides of a stilt house and many posts belonging to other such structures. ECA is estimated to be up to 82,000 m^2 or more in size, thus representing the largest Lapita village site on record (Kirch 1997:167, 173; 2021b:155). In contrast, the smaller ECB (estimated at around 3000 m^2) and EHB (about 1000 m^2) sites are more likely to have been hamlets (Kirch 2021a:519). The Talepakemalai site has a waterlogged, subtidal deposit that preserved wooden stilt house posts, along with large quantities of pottery, obsidian flakes imported from both Lou and Talasea sources, adzes, scrapers, shell fishhooks, shell rings and ornaments. The range of materials associated with the Area B stilt house at Talepakemalai suggest that this was not an ordinary dwelling, but more likely a specialised structure such as a men's house, used for conducting ritual or community-related activities (Kirch et al. 2015:60). Potsherds from the undisturbed parts of the site are quite large, and around 260 vessels have been reconstructed (Kirch et al. 2015; Kirch and Chiu 2021).

Radiocarbon dating of the Mussau sites, previously reported by Kirch (2001), has recently been improved with the accelerator mass spectrometry (AMS) dating of short-lived organic materials such as *Canarium* nuts, coconut endocarp and similar samples, combined with Bayesian modelling and calibration (Kirch 2021c). The earliest Lapita site in Mussau is EHB on Emananus Island, which was estimated to have been established no later than 3350–3325 cal. BP (Kirch 2021a:512). The second earliest is the small ECB site, dated to around 3550–3475 cal. BP with unidentified wood samples, and 3500–3050 cal. BP based on calibrated shell dates. Both sets of dates suggest that ECB may be roughly contemporaneous with the main stilt house occupations at ECA Area B (Kirch 2021b:163). Cultural deposition at site ECA Area A, and the earliest deposits of the southern end of trenches W200 and W250, began at ca 3300–3200 cal. BP. The main stilt house occupation at Area B and B-extension dated to about 3200–2950 cal. BP (Kirch 2021a:512). Zones C_2-C_3 of this area started between 3234–3089 cal. BP and ended between 3155 and 3020 cal. BP, while Zone C_1 started between 3061-2836 cal. BP and ended between 2919-2724 cal. BP. The latest Lapita phase represented by the deposits at Area C and the northern ends of the W200 and W250 transects at ECA likely occurred between 3154 and 2970 cal. BP and ended between 2778 and 2492 cal. BP (Kirch 2021b: Table 5.5, 156).

Petrographic analysis of four sherds from ECA was conducted by Lohu, who reported that two samples (samples 1 and 2) contain high proportions of clinopyroxene having 'a relatively strong colouration (greenish yellow) … The andesite lithic grains also include the same, coloured pyroxenes' (Anson 1983:Appendix II, 290). These samples also contain plagioclase, opaques, volcanic lithics and hornblende, but lack quartz and calcareous sands (Anson 1983:Appendix II, 290). Based on his description, these two samples are likely to have been transported into ECA from the Tabar–Lihir–Tanga–Feni (TLTF) chain of islands, while samples 3 and 4 are from unknown volcanic islands.

Anson carried out X-ray fluorescence (XRF) and electron microprobe analysis on 16 ECA samples excavated by Egloff (1975). He concluded that they might have been transported from two or more distinctive clay sources. In a more extensive analysis of 172 sherds excavated by Kirch at ECA and other Mussau sites, Hunt compared the chemical compositions of one local Mussau clay and two clay samples from the Manus islands with the archaeological samples using a scanning electron microscope in conjunction with an X-ray analyser (Hunt 1989:121, 171; Kirch et al. 1991:158). Hunt identified 16 chemical composition groups in the archaeological samples, among which one is indistinguishable from a local Mussau clay, some are clustered with Hus (Ahus) and M'Buke clays of the Admiralty Islands, while others are from unknown sources exotic to Mussau (Hunt 1989:191). Pots made with clays from M'Buke Island off the south of Manus were found in ECA Area A, as well as in the ECB and EKQ (Epakapaka, a rockshelter Late Lapita site on the Mussau Island) samples, while Hus (off the north of Manus) clay was found at the much later post-Lapita Sinakasai (EKU) site (Figure 6.3) (Hunt 1989:121:195, Table 7.1, 203). Hunt concluded that ECB, ECA Area B and EHB had 12, 11 and 9 different compositional groups respectively (Hunt 1989:206). A small number of samples from ECB (12 per cent) and EKQ (9 per cent) with high amounts of calcareous sands clustered with local Mussau clay, while the rest of the samples were interpreted as exotic to the region (Kirch et al. 1991:159).

Dickinson (2000a) initially examined thin sections of 12 sherds excavated by Kirch at ECA, indicating that at least two sources exotic to Mussau were evidenced. Kirch subsequently invited Dickinson to sample a wider array of sherds from the ECA and EHB sites. Together, Dickinson and Kirch selected 49 sherds, basing their sampling on both macroscopic indications of temper variation and on stylistic traits of the pottery. Petrographic analysis of the combined sample of 61 sherds by Dickinson (2021b) resulted in the definition of 10 different calcareous, hybrid and volcanic temper

groups, nearly all of which are exotic to the Mussau Islands. These samples had been sourced to the Admiralty Islands (Manus and nearby islands), Lavongai (and adjacent parts of New Ireland) and the TLTF alkalic chain (Dickinson 2021b:388); none of them resembles what Dickinson had examined from other archaeological assemblages within the Bismarcks (Dickinson 2021b:376). Our own petrographic analysis builds upon this pioneering research by the late professor Dickinson.

Simplified geology of the Bismarck Archipelago

Mussau Island, the largest island in the St Matthias Group located in the north of the Bismarck Archipelago, is comprised of basic volcanic and sub-volcanic rocks such as basalt and mafic andesite, surrounded by an apron of uplifted limestones of coral reef origin. At the central hilly part of the island, Mt Eunainaun rises c. 645 m above sea level, where basalts and tuffs (Warin and Jensen 1959:15) and epidotised porphyry have been reported (Thilenius 1927:440, cited from Kirch 2001:55). Evidence for metamorphism or faulting is not reported for this island. Rock samples collected by Kirch in 1985 near the Ekasi river on the eastern side of Mussau Island include both 'plutonic (intrusive) diorite-gabbro' and 'fine-grained igneous rocks of probably volcanic and hypabyssal origin' (Kirch 2001:33). The plutonic rocks were identified by Dickinson as 'highly porphyritic plutonics (gabbro)' (Kirch et al. 1991:146). The island's volcanic core is deeply weathered, with exposures of fine-grained workable clay (Hunt 1989:80–81, Fig. 5.1). Eloaua and Emananus islands to the south-west of Mussau Island are composed entirely of coral reefs surrounding upraised limestone (fossil reefs) (Dickinson 2006, 2021b), and thus lack clay sources or exposed volcaniclastic rocks.

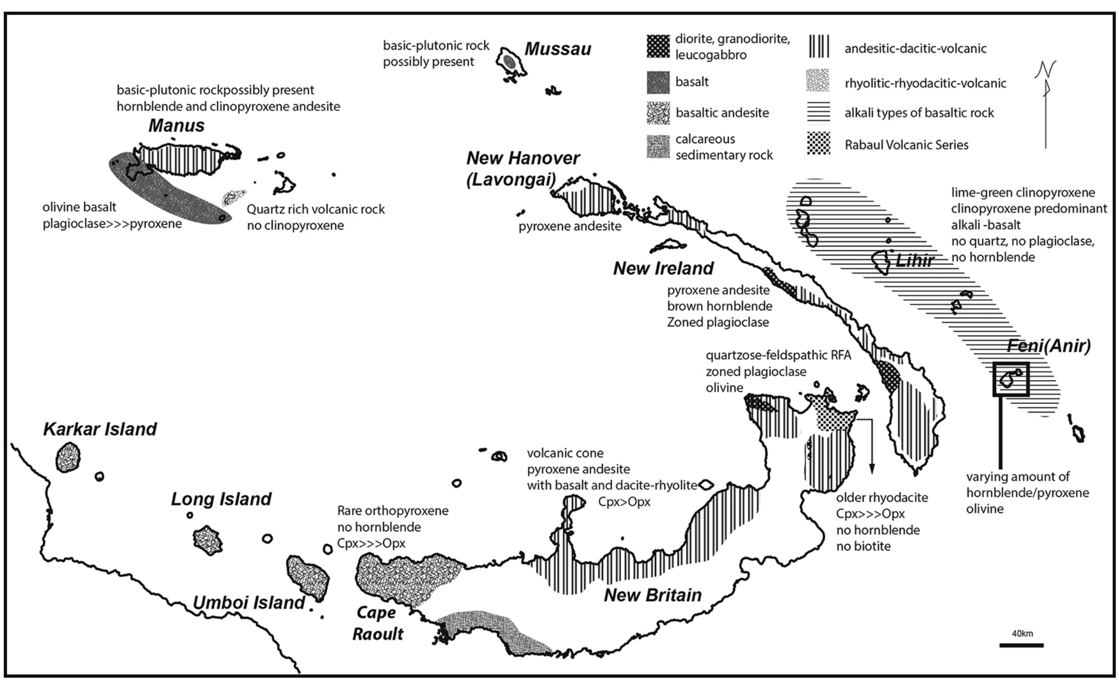


Figure 6.2: Map showing the simplified geological zones within the Bismarck Archipelago region.

Note: The map includes notes summarised from Dickinson's reports and geological references related to our own observations from available thin sections (after Blake and Miezitis 1967; Dickinson 2000a, 2021b; Jaques 1980; Page and Ryburn 1977; Rogerson 1989; Stewart and Sandy 1988).

Source: Authors' illustration; see also references cited.

The Bismarck Archipelago is a geologically complex region (Figure 6.2), with 'intersecting subduction zones, spreading centers, and transform faults' (Dickinson 2006:50) caused by various geological events that have transformed these island landscapes over the last four million years (Martinez and Taylor 1996:204).

In general, Paleogene volcanogenic assemblages of the ancestral Vitiaz Island arc 'contain both hornblende and clinopyroxene in widely varying proportions, but generally lack orthopyroxene or olivine in any appreciable amount'; these can be found in all the major islands (Dickinson 2006:52). During the Miocene, sequences of limestone accumulated across much of this region and beyond, forming thick layers of limestone on top of the Paleogene volcanic rock. New volcanoes then intruded into these limestone layers, forming volcanic landscapes mainly on New Britain and Bougainville during and after the Pliocene (Sheppard and Cranfield 2012:27). In addition, many islands are fringed by raised Pleistocene–Holocene coral reefs (Lindley 2006:404).

Dickinson (2021b) pointed out the difficulty in discriminating among different temper sources within the Bismarck Archipelago, given that most terrigenous sands are derived from similar volcanic parent rocks. Three out of five geotectonic temper classes defined by Dickinson (2006:11-14) are found within the Bismarck Archipelago: (1) andesitic arc tempers, (2) backarc/postarc tempers (lacking grains from plutonic or metamorphic rocks) and (3) dissected orogen tempers containing plutonic rocks (Dickinson 2006:Table 1, 13). Distinguishing one source from another largely depends on subtle variations in volcanic petrology and temper grain types, mostly based on the observation of archaeological ceramics and occasional sand and rock samples of this region (Dickinson 2021b).

Based on available geological reports, we have developed a simplified geological map of the region (Blake and Miezitis 1967; Dickinson 2000a, 2000b, 2021b; Hohnen 1978; Jaques 1980; Page and Ryburn 1977; Rogerson 1989; Stewart and Sandy 1988) (see Figure 6.2). We have also listed regional differences expected from local terrestrial sand tempers, data which we then use to differentiate temper sources. More detailed descriptions of these geological settings will be provided in another paper (Chiu et al. in prep.). It should be emphasised that the geology of the Bismarck Archipelago and eastern Papua New Guinea is still poorly known, and that detailed geological maps are not available for many parts of this region.

Petrographic analysis

In his effort to establish a generic classification system for all Oceanic temper types, Dickinson (2006) not only provided summary descriptions of what major sand grain types can be expected from each of the five geotectonic temper classes of the Pacific, he also employed various parameters to calculate ratios of certain rocks and minerals in order to further differentiate among various temper types within each geotectonic region (Dickinson 2006:Table 6, 29). Yet in doing so, he sometimes omitted the more geologically specific but rare index minerals or rocks in his temper summary tables, although these are usually described in the more general description of these regions. One such case is 'the greenish cast and faint yellowish pleochroism typical of aegirine-augite, a sodic variety of augite characteristic of alkalic volcanic suites' (Dickinson 2006:76) that only appears in ceramic samples made from the TLTF islands. This mineral had been described and was used by Dickinson to allocate samples to this particular island chain, however it was not listed in the point count tables when he reported analytical results of either the Kamgot (Dickinson 2000b) or Mussau (Dickinson 2021a) Lapita ceramic samples.

Therefore, we first reanalysed 59 of the samples from the ECA, ECB and EHB sites that Dickinson had previously analysed, in order to familiarise ourselves with the methods and classification principles that he used to identify possible sources (Dickinson 1996, 1997, 2021b). We started with a detailed description of the texture, size and weathering degree of tempers, types of minerals and rocks included. Based on our observations, we merged Dickinson's original temper Types A, B and H into two larger Groups 1 and 2; merged Types E and F into one (Group 5); and relocated one sample each from his Types C and G to our Group 8, while the rest of his original temper types remain the same (see Appendix, Table 6.S1).

Sampling strategy

According to Dickinson, the first group of 12 sherds were selected primarily to study the non-calcareous terrigenous tempers of the ECA assemblage, while the second group of 49 sherds were selected to represent the full range of variation in the Eloaua and Emananus temper types. All diagnostic sherds from Area B-extension and Area C were first examined macroscopically by Dickinson; nine calcareous dominate samples from Area B were selected to represent that particular temper type, and the other 40 were selected to represent the non-calcareous dominate temper types (Dickinson 2021b:375–376).

New samples

In 2017–19 Chiu thin-sectioned 182 additional samples from the Mussau assemblages curated in Kirch's laboratory. These new samples were selected from a subset of the entire assemblage due to constraints on time and funding. This subset includes many of the 266 reconstructed vessels, plus 95 sherds belonging to particular vessel or motif groups from the ECA, ECB and EHB sites, as well as sherds from 10 controlled excavation units of ECA Area B (units A14, A31, A32, A35, A36 (A14), A39, A40), and Area B-extension (units A66, A67, A68, A69). A total of 1216 sherds were first examined under a binocular microscope at 4-10×. Nine different mineral or rock fragments (based on colour and texture of the non-plastic inclusions) and their abundances were estimated and recorded in order to establish the range of variability in different temper groups present. Based on the observed ratio of minerals/rock fragments, we generated 260 preliminary temper groups.

Grouping was further refined based on the presence of different types of minerals or rock fragments, regardless of their relative ratios. This follows from Dickinson's warning that 'no reliable distinctions can be drawn between different temper types from megascopic estimates of relative proportions of light and heavy mineral grains and volcanic lithic fragments', due to the highly variable degree of placering in this region (Dickinson 2006:52). This led Chiu to condense the 260 preliminary groups to 30 temper groups. The next step was to measure sherd weight, as only 842 sherds heavier than 8 g (the minimum amount required for thin sectioning) were identified for further analysis. For each temper group, if the number of sherds was lower than 10, all were selected for further analysis. If the number of sherds was greater than 10, 20 per cent of the sherds were selected.

Analytical results

Combined with Dickinson's earlier analysis, a total of 241 thin sections from Mussau sherds were analysed at the Institute of History and Philology, Academia Sinica, Taipei, and at the School of Anthropology, University of Arizona. Based on observed inclusions, we clustered these samples into nine different temper groups, with two isolates (see Table 6.S1 in Appendix; two samples from

the Post-Lapita EKQ site are omitted from the following discussion, thus the total number is 239 for this paper). Detailed petrographic descriptions will be published in a future paper (Chiu et al. in prep.); here we provide a summary of our results.

The ratio of various minerals and rocks, degree of weathering, appearance and the frequency of geologically specific index minerals that we observed in a given thin section sample all provide useful information for determining possible sources, by comparing them to the available geological maps and published and unpublished reports (Davies 2012; Dickinson 2000a, 2006, 2021b; Hohnen 1978; Summerhayes 2000; Warin and Jensen 1959) (Figure 6.2). As most samples contain large amounts of either reef detritus, opaque or only volcanic lithics, at this stage we can at best tentatively assign sherds to known volcanic regions within the Bismarck Archipelago, thus covering a rather large geological zone, or even to multiple possible sources. While the geology of this region is not yet mapped in sufficient detail to allow for more precise attributions—particularly on the north-east coast of New Guinea and in the Schouten Arc—it is nonetheless possible to suggest some source attributions (see Table 6.1).

Table 6.1: Summary of temper groups and subgroups identified.

Temper group and subgroups	The feature of geological area	Possible source	Number of samples
G1 Reef detritus-predominant fabric			**70**
1 Typical coral reef detritus, limeclast, with trace of volcanic lithics		unknown	28
2 Homogeneity reddish clay			11
3 Probable clay bulks			12
4 Weathered volcanic lithic			12
5 Yellowish-grey clay mineral			7
G2 Reef detritus-predominant hybrid fabric			**82**
1 Volcanic cone related	acid, intermediate and basic volcanic (no sub-volcanic, no dioritic, no plutonic)	volcanic zone along the north coast of New Britain	6
2 Heavy mineral	coral reef detritus and basic/ intermediate volcanic	Mussau or basaltic Manus, Manus or Lavongai (or adjacent parts of New Ireland)	14
3 Quartz-feldspar	coral reef detritus and intermediate-acid/acid volcanic lithic	Lou island and the nearby rhyolitic islands	34
4 Slightly metamorphism	weathered intermediate plutonic/sub-volcanic area or sedimentary area	Manus or Lavongai (or adjacent parts of New Ireland), or Northern New Britain near Watom, or plutonic parts of New Ireland	28
G3 Coral reef detritus–opaque fabric			**23**
1 Coral reef detritus	coral reef detritus:placer sand (7:3). Basic volcanic area/ pyroxene bearing intermediate volcanic	Mussau or basaltic Manus	7
2 Sub-volcanic & sediment	intermediate volcanic/ sedimentary area with placer sand	Manus or Lavongai (or adjacent parts of New Ireland)	11

Temper group and subgroups	The feature of geological area	Possible source	Number of samples
3 Opaque	coral reef detritus:placer sand (3:7). Basic volcanic area/ pyroxene bearing intermediate volcanic	Mussau or basaltic Manus	5
G4 Opaque-dominant fabric	intermediate volcanic area with placer sand	Manus or Lavongai (or adjacent parts of New Ireland)	**8**
G5 Amphibole-feldspar fabric			**20**
1 Metavolcanics absent	basic or intermediate volcanic area	unknown basic or intermediate volcanic area	8
2 Epidote-bearing metavolcanics	weathered intermediate plutonic/sub-volcanic area or sedimentary area	Manus or Lavongai (or adjacent parts of New Ireland), or Northern New Britain near Watom, or plutonic parts of New Ireland	7
3 Prehnite-bearing metavolcanics	weathered intermediate plutonic/sub-volcanic area or sedimentary area	Manus or Lavongai (or adjacent parts of New Ireland), or Northern New Britain near Watom, or plutonic parts of New Ireland	5
G6 Pyroxene volcanic fabric			**15**
1 Basic volcanic with red iron oxide	basic volcanic area	unknown basic volcanic area	4
2 Alkali basalt, no lime-green clinopyroxene	alkali-rich basic volcanic area	TLTF alkalic chain(?)	1
3 Intermediate volcanic	intermediate volcanic	unknown intermediate volcanic	10
G7 Quartz-feldspar fabric			**9**
1 Quartz-feldspar fabric with silty clay	basic/intermediate/acid sub-volcanic/plutonic area	Northern New Britain near Watom, or plutonic parts of New Ireland	4
2 Quartz-feldspar fabric with dark matrix	basic/ intermediate/acid sub-volcanic/plutonic area	Northern New Britain near Watom, or plutonic parts of New Ireland	5
G8 Lime-green clinopyroxene	alkali-rich basic volcanic area	TLTF alkalic chain	**6**
G9 Two different pastes	mixed tempers	unknown	**4**
ECA69-05-004	no identifiable inclusion	unknown	**1**
ECA34-05-062	basic volcanic area	from unknown basic volcanic area	**1**
Total			**239**

Source: Authors' data.

Identified temper groups and subgroups, number of samples within each group, the feature of geological area they reflect and the possible source(s) are provided in Table 6.1. The reef detritus-predominant fabric group (G1) has 70 samples, all of which contain more than 30 per cent clay with more than 50 per cent reef detritus and limeclasts[1] and very few heavily weathered unidentifiable terrestrial fragments as tempers. Eighty-two samples that do contain a few identifiable rock fragments with roughly the same proportions of clay and reef detritus and limeclasts form the reef detritus-predominant hybrid fabric group (G2). Twenty-three samples that contain 30–50 per cent reef

1 Limeclasts are formed from terrestrial limestones, and have distinctive microstructures from those of coral.

detritus but without any limeclast, 25–70 per cent opaque minerals and very few other terrestrial grains, are classified as the coral reef detritus/opaque fabric group (G3). The opaque-dominant fabric group (G4) has eight samples, all of which contain more than 60 per cent opaque minerals (mostly iron and iron/titanium oxides) and roughly 15–20 per cent silicate minerals and rock fragments, indicating an intermediate volcanic origin with a high amount of placer sand sorting. Twenty samples in the amphibole-feldspar fabric group (G5) contain roughly more than 30–50 per cent feldspar, 10–20 per cent opaque minerals and less than 5 per cent pyroxenes. The 16 samples in the pyroxene volcanic fabric group (G6) are defined by roughly 15–25 per cent volcanic lithics, 10–20 per cent feldspar and more than 10 per cent pyroxene grains. Nine samples containing more than 50 per cent feldspar and quartz, and roughly 5–10 per cent heavy minerals with silty or dark clays are classified into the quartz-feldspar fabric group (G7). We have also classified eight samples that contain about 30 per cent clinopyroxene, especially the lime-green clinopyroxene (probably aegirine-augite (Dickinson 2004:1; Dickinson 2021b:382)), into the lime-green clinopyroxene fabric group (G8). Samples of this group likely derive from an alkali-rich basic volcanic region, as with the TLTF chain (Dickinson 2006).

Four samples with clays of contrasting colour but similar types of calcareous temper (two samples from ECB), or with similar clay but different suites of tempers (two ECA samples), are clustered under the two different pastes group (G9) (for more discussion about clay mixing, see Ho and Quinn 2021). Two samples cannot be classified with any other samples we examined. ECA69-05-004 consists of lumps of laterites with no identifiable temper, thus no origin can be identified. ECA34-05-062 contains extremely high amounts of heavily weathered, devitrified basic volcanic lithics in its matrix, unlike all other samples that also include basaltic or andesitic volcanic lithics that we have examined.

Ryburn reports that the coastal region of south-western New Britain starting from the Arawe Islands to the islands and hills east of Kandrian consists of raised coral reefs and terraces, backed by a raised marine platform that extends as much as 25 km inland (Ryburn 1976:6, Fig. 1, 5; Page and Ryburn 1977:Plate 1). Thus, any pottery made from this region is expected to contain large amount of limeclasts mixed with coral reef fragments, calcareous mudstone, siltstone, sandstone and conglomerate, except where terrestrial grains have been brought by rivers tapping into other geological zones located in interior highlands of western or central New Britain (namely the Pulie, Palicks and Andru Rivers) (Ryburn 1976:Fig. 1, 5). According to Ryburn (1976), there is probably a small inlier of volcanic breccia and tuff (indicative of the presence of basaltic and andesitic lavas) along the Anu River which runs close to the Kreslo site. Dickinson had also reported the local Kreslo tempers, which contain 'presence of appreciable hornblende, as well as pyroxene', that may be from such an intrusion (Dickinson 1998:2). Summerhayes has collected river sands (alluvial deposits) from four river mouths located on the south-western coast of New Britain (namely the Adi, Pulie, Anu and Alimbit Rivers) and analysed them with an electron microprobe (Summerhayes 2000:168; Fig. 11.1, 169). The same set of river sand samples plus 150 ceramic samples from six Arawe sites were later analysed by Wu with SEM-EDS (Wu 2016:Table 9.2, 302). The Arawe pottery samples were sourced to the above four river mouths according to the texture and composition of their inclusions (Summerhayes 2000:168; Wu 2016:303–306).[2] Yet none of these samples contains only calcareous sands.

2 Both authors reported what types of minerals can be found in the river sand and pottery samples, but no rock types specified. As they were using different methods to analyse their samples, we cannot compare our results directly to theirs.

Although samples of our Group 1 also contain only reef detritus and limeclasts that match the main characteristics of the above region, these calcareous grains alone are not diagnostic of any particular geological region (Dickinson 2006:4). At this stage we can only assign our G1 samples to unknown sources, since previous petrographic results of Kreslo and Arawe samples all contain volcanic and/or plutonic terrestrial grains with or without calcareous inclusions (Dickinson 1998, 2006:89).

Our results do not differ greatly from those previously obtained by Dickinson (2021b). After examining 180 new archaeological samples from well-controlled layers from Area B and Area B-extension of ECA, ECB and EHB, we have been able to add north-eastern and central northern New Britain and Mussau Island to the original list of possible sources identified by Dickinson (2021b:388) (Figure 6.2). The majority of samples contain mostly reef detritus with or without identifiable terrestrial grains. Only samples from the alkali-rich basaltic area with the distinctive lime-green clinopyroxene can be assigned to the TLTF chain, and those with excessive amounts of quartz and feldspar and rarely anything else can be assigned to rhyolitic volcanic islands such as Lou in the Admiralties. All other temper groups can be found in various parts of many islands in this region. The bottom line is that this is a challenging region for ceramic petrography. To pin things down more precisely would require a huge effort to sample many more localised potential clay and temper sources (for example, see Leclerc 2020).

Chronological changes in possible sources

Table 6.2 illustrates samples selected from ECA Area B and Area B-extension, where well-controlled stratigraphic layers and radiocarbon dates are available. Out of 190 samples selected from this excavation area, 63 contain almost entirely calcareous sands and therefore cannot be assigned to any known geological source. Another 11 are from unknown basic or intermediate volcanic areas. The remaining 116 samples could derive from five rather large geological zones within the Bismarcks. The first is Mussau itself, or the basaltic part of south-western Manus. The second is rhyolitic Lou and nearby islands in the Admiralties. The third is from the main island of Manus, New Hanover (Lavongai) Island, or adjacent parts of New Ireland with andesitic-dacitic volcanic temper.

Pots made on the Gazelle Peninsula in north-eastern New Britain or plutonic parts of central and south New Ireland, as well as pots made in Manus – New Ireland – New Britain arc all appear fairly early on in the Mussau sequence, quite consistently from the beginning of the chronological sequence at ECA Area B, Zone C_3. Pots made in the volcanic zone along the northern coast of New Britain and on the Willaumez Peninsula were imported into ECA at Zone C_2, only slightly later than those from other areas. However, pots imported from the alkali-rich volcanic TLTF chain seem to occur at Zone C_1 at ECA, which may be as much as 200 years later than Zones C_3 and C_2, although a shorter interval is not ruled out (Kirch 2021b:155–156).

Table 6.2: Possible source(s) for samples excavated from ECA Area B and B-extension areas with well-controlled stratigraphic information.

ECA Area B and B-extension	Possible source(s)										Total
	Mussau or basaltic Manus	Lou island and the nearby rhyolitic islands	Manus or Lavongai (or adjacent parts of New Ireland)	Northern New Britain near Watom, or plutonic parts of New Ireland	Manus or Lavongai (or adjacent parts of New Ireland), Northern New Britain near Watom, or plutonic parts of New Ireland	The volcanic zone along the north coast of New Britain	TLTF alkalic chain	Unknown basic volcanic area	Unknown intermediate volcanic	Unknown	
A	–	4	–	1	1	–	–	–	1	1	8
B1	–	4	7	1	7	2	1	2	1	14	39
B2	–	7	2	–	5	2	1		1	18	36
C1	–	7	3	1	3	1	3	1	1	14	34
C2	7	3	3	2	19	1	–	1	3	7	46
C3	1	6	2	2	7	–	–	–	–	9	27
Total	8	31	17	7	42	6	5	4	7	63	190

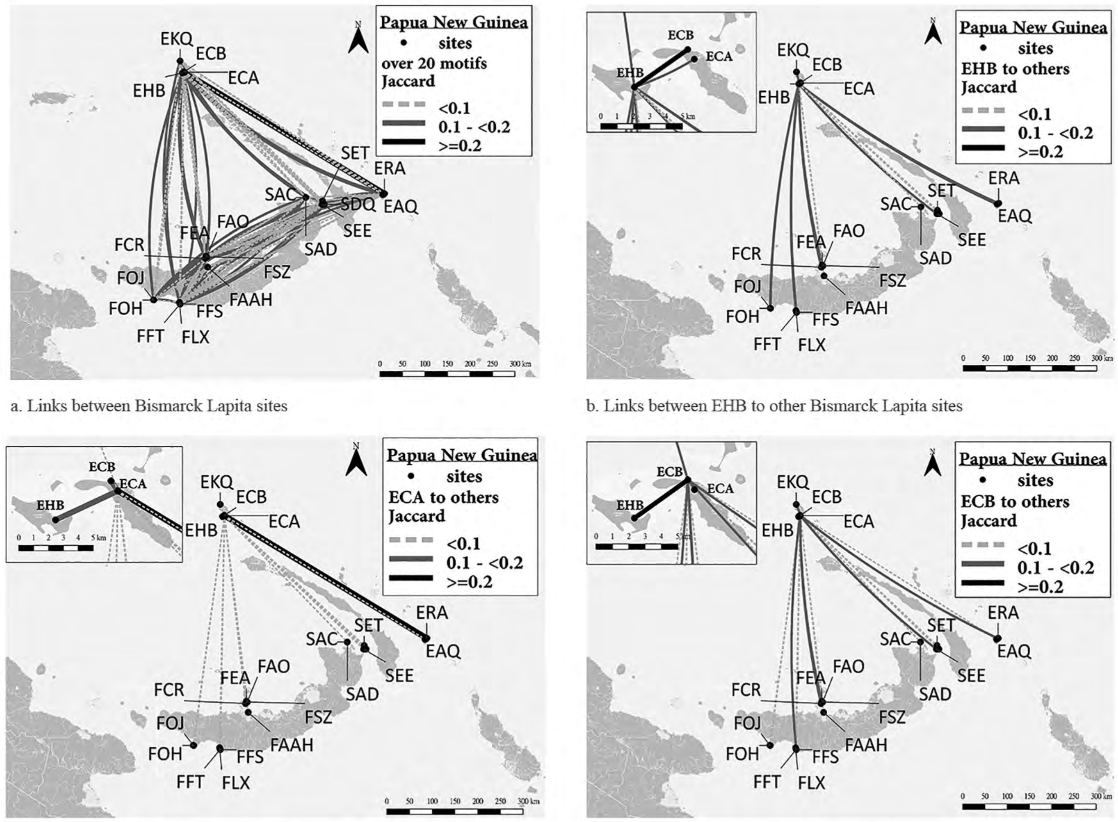
Source: Authors' data.

Motif analysis

Sampling strategy

Since 2011, Kirch and Chiu have reconstructed motifs and vessel forms occurring in the Mussau assemblages, and Chiu has studied other Lapita sites through collaborations with numerous scholars. Motifs included in the Lapita Pottery Online Database (LPOD, lapita.ihp.sinica.edu.tw) have been recorded in Excel tables, allowing specific motifs and their frequency in a given site to be extracted from the dataset. A total of 8502 decorated sherds that exhibit 1834 different motifs from 71 Lapita sites of the Bismarck Archipelago have been recorded in the LPOD. Fifty sites contain less than 20 different motifs and we have omitted them from the following analysis. Motifs that are too fragmented to recognise the original pattern, called TFGs, have been omitted as well. Therefore, 8313 decorated sherds with 1803 different motifs from 21 Bismarck Lapita sites are employed in this study.

The number of shared motifs among all sites is calculated with the Jaccard index of similarity (Real and Vargas 1996); QGIS 3.16 is used to plot the links representing weak to strong connections among these Early Lapita sites. Jaccard similarity indices between any two sites can be calculated by the number of motifs shared by these sites divided by the sum of the number of shared motifs plus the number of motifs that only appear at one site. We grouped those with a score higher than or equal to 0.2, less than 0.2 to 0.1, and less than 0.1 to form three clusters, in order to better illustrate their connections with other sites (Table 6.3 and Figure 6.3).



a. Links between Bismarck Lapita sites

b. Links between EHB to other Bismarck Lapita sites

c. Links betweem ECA to other Bismarck Lapita sites

d. Links between ECB to other Bismarck Lapita sites

Figure 6.3: Jaccard similarity measures of shared motifs between ECA, ECB and EHB and other Bismarck Archipelago Lapita sites that have more than 20 different motifs recorded in the LPOD.

Source: Authors' illustration.

Table 6.3: Jaccard similarity measures from EHB, ECA and ECB to other Bismarck Lapita pottery assemblages recorded in the LPOD.

Jaccard site	Jaccard similarity score to EHB	Jaccard similarity score to ECB	Jaccard similarity score to ECA	Jaccard similarity score to ERA	Region
EHB	x	**0.214**	0.105	0.118	Mussau
ECB	**0.214**	x	0.143	0.154	Mussau
EKQ	0.191	0.137	0.051	0.065	Mussau
FFS	0.171	0.141	0.062	0.077	Kandrian
FEA	0.170	0.144	0.080	0.091	CN New Britain
SEE	0.160	0.144	0.080	0.105	Duke of Yorks
FSZ	0.137	0.082	0.036	0.039	CN New Britain
FFT	0.136	0.084	0.038	0.040	Kandrian
FCR	0.130	0.116	0.058	0.073	CN New Britain
EAQ	0.126	0.100	0.046	0.050	TLTF
FOH	0.124	0.097	0.039	0.049	Arawe
FLX	0.119	0.073	0.024	0.029	Kandrian
ERA	0.118	0.154	**0.219**	x	TLTF
FOJ	0.109	0.099	0.032	0.043	Arawe

Jaccard site	Jaccard similarity score to EHB	Jaccard similarity score to ECB	Jaccard similarity score to ECA	Jaccard similarity score to ERA	Region
ECA	0.105	0.143	x	**0.219**	Mussau
SAC	0.094	0.064	0.024	0.033	Watom
SAD	0.075	0.063	0.026	0.032	Watom
SET	0.071	0.050	0.017	0.019	Duke of Yorks
SDQ	0.064	0.050	0.013	0.019	Duke of Yorks
FAAH	0.057	0.046	0.015	0.015	CN New Britain
FAO	0.050	0.029	0.015	0.012	CN New Britain

Note: Jaccard similarity measures from EHB, ECA and ECB to other Bismarck Lapita pottery assemblages that have more than 20 different motifs recorded in the LPOD, sorted from highest to lowest based on the weight to EHB. The highest scores of each site are marked by bold font, those higher than 0.1 marked by italicised font. 'CN' should be read as 'Central North', and 'TLTF' as 'the Tabar–Lihir–Tanga–Feni chain'. Red highlight indicates first level of signficance

Source: Authors' data.

Because only a few assemblages in the Bismarck Archipelago have been fully recorded in the LPOD at this stage, we lack detailed information from sites located on Manus, New Ireland or the Arawe Islands. We also lack records from nearby Emirau Island where Lapita site Tamuarawai (EQS) has been reported (Summerhayes et al. 2010). This no doubt restricts our ability to fully understand the nature of exchange patterns among these islands with the Mussau sites. Future collaborations with archaeologists working on those assemblages are planned.

Analytical results

In contrast with what we observed from the petrographic analysis, in which only four ECA petrographic samples, from Zones C_1 (ECA-67-05-007 and ECA-67-05-011), B_2 (ECA69-01-004), and B_1 (ECA39-02-005) of ECA Area B and B-extension, have been provisionally sourced to the Feni (Anir) Islands, ECA shares the greatest number of motifs and degree of motif similarity with the contemporary Kamgot (ERA) Lapita site (Summerhayes 2007:146) (Table 6.3 and Figure 6.3). Anson had observed a similar pattern from his motif analysis, in which ECA was closely related to Ambitle (Site Malekolon (EAQ)). A second set of Ambitle samples was clustered with those from Talasea, indicating that communities in the TLTF chain shared motifs with Mussau and north New Britain communities (Anson 1986:Fig. 3, 16). ECA also has stronger links to both ECB and EHB, not surprisingly, as these sites were surely part of a single community that persisted over several centuries. However, unlike EHB and ECB, ECA shares a much lower degree of motif similarity with all other Lapita sites located in the Bismarck Archipelago (Table 6.3).

EHB shares the highest degree of motif similarity with ECB and EKQ in the Mussau islands, followed by sites located in the Kandrian region of southern New Britain, central north New Britain, the Duke of Yorks, the TLTF chain, the Arawe Islands and then ECA of Mussau (Table 6.3). It shares a lesser degree of motif similarity (less than 0.1) with SAC and SAD of Watom Island off eastern New Britain, SET and SDQ of the Duke of Yorks, and FAAH and FAO of central north New Britain. This indicates a wide and relatively strong connection between EHB and other Bismarck Lapita sites. ECB shows an almost identical pattern, sharing the strongest similarity with EHB and well connected to other sites, although not so much with ECA. ERA, on the other hand, shares an identical pattern to that of ECA, with the highest similarity with ECA, followed by ECB and EHB of the Mussau Islands, SEE of the Duke of Yorks, and not very much with all other Lapita sites in this region.

The motif similarity pattern analysis demonstrates a connection between Lapita sites located in the Mussau islands, northern coastal and north-eastern New Britain, the Duke of York islands, the southern TLTF chain, south-western New Britain and the Arawe Islands. The first four regions are also consistent with the results of our petrographic analysis. However, the relatively high degree of motif similarity shared between Mussau sites and south-western New Britain and the nearby Arawe Islands is unexpected, since petrographically no thin section samples of Mussau Lapita sites have been sourced to this region.

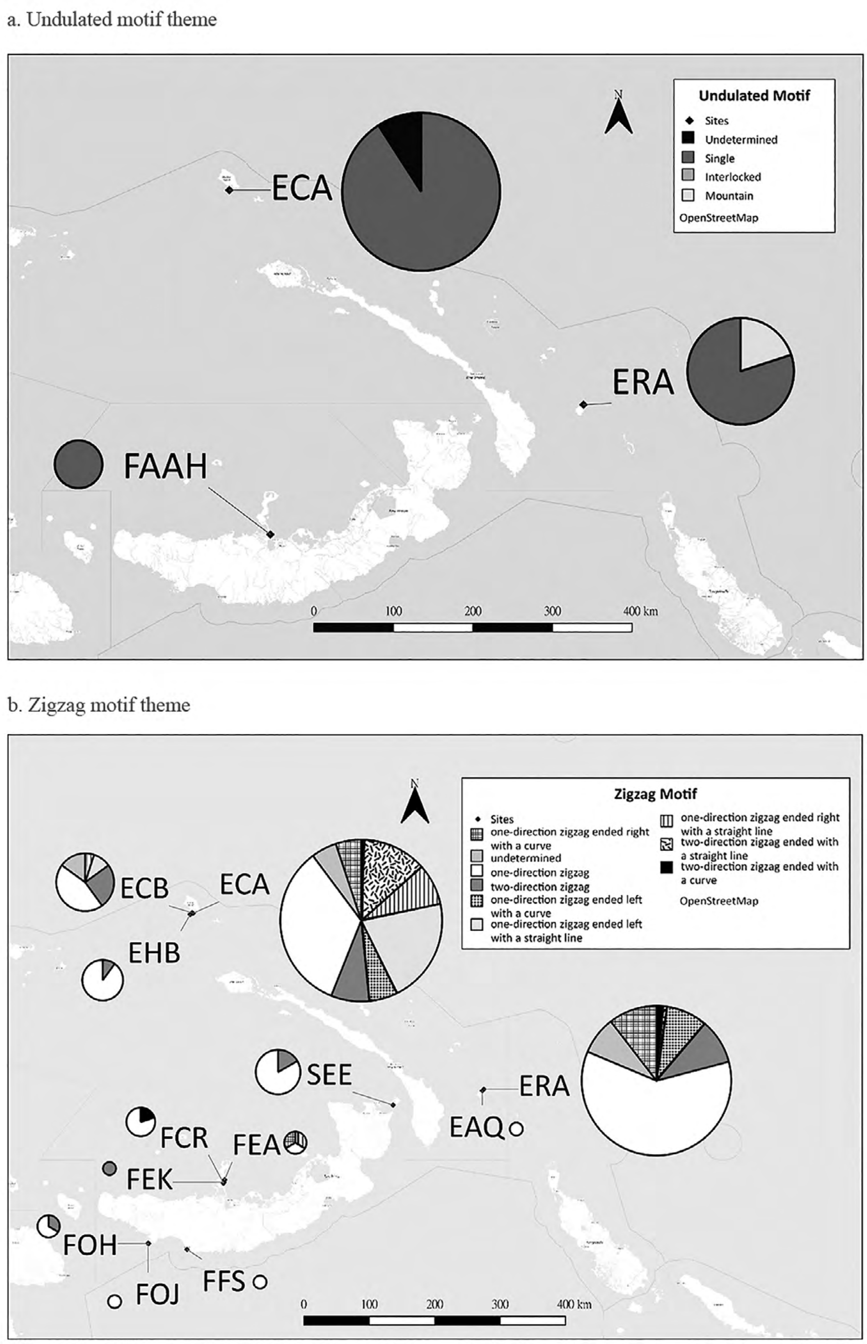


Figure 6.4: Distribution of undulated (a) and zigzag (b) motif themes among Bismarck Lapita sites.

Source: Authors' illustration.

Table 6.4: Distribution of different subcategories of both undulated and zigzag motif themes among Bismarck Lapita sites.

(A) Distribution of the undulated motif theme.			
undulated sub	**ECA**	**ERA**	**FAAH**
undetermined	1	–	–
single	10	4	1
interlocked	–	–	–
mountain	–	1	–
Total	11	5	1

(B) Distribution of the zigzag motif theme.												
zigzag sub	**EHB**	**ECA**	**ECB**	**ERA**	**EAQ**	**FEA**	**FFS**	**FEK**	**FOH**	**FOJ**	**FCR**	**SEE**
undetermined	–	8	3	11	–	–	–	–	–	–	–	–
one-direction zigzag ended right with a curve	–	8	–	14	–	1	–	–	–	–	–	–
one-direction zigzag	9	53	9	81	1	1	1	–	2	1	4	10
two-direction zigzag	1	12	5	13	–	–	–	1	1	–	–	2
one-direction zigzag ended left with a curve	–	9	–	12	–	–	–	–	–	–	–	–
one-direction zigzag ended left with a straight line	–	33	2	–	–	–	–	–	–	–	–	–
one-direction zigzag ended right with a straight line	–	13	1	–	–	1	–	–	–	–	–	–
two-direction zigzag ended with a straight line	–	20	–	1	–	–	–	–	–	–	–	–
two-direction zigzag ended with a curve	–	1	–	2	–	–	–	–	–	–	1	–
Total	10	157	20	134	1	3	1	1	3	1	5	12

Source: Authors' data.

In terms of major motif themes that are usually executed on the main surface of a vessel or ceramic object such as a pedestal stand, ECA and ERA have the highest number of undulated and zigzag motifs among all 70 Lapita sites in the Bismarck Archipelago recorded so far in the LPOD. This clearly sets both of them apart from other Bismarck Lapita sites (Table 6.4 and Figure 6.4). A previous motif distribution pattern analysis shows that only the single undulated category of the undulated motif theme is widely shared among Lapita sites in Papua New Guinea, the Solomon Islands, Vanuatu and New Caledonia. It does not appear in the Fiji–Tonga–Samoa region (Chiu 2019:324, Table 15.10). Single undulated motifs appear exclusively in ECA (Mussau), ERA (Anir) and FAAH (Talasea, New Britain) assemblages in the entire Bismarck Archipelago, while a subcategory of the undulated motif theme ('mountain') appears only at ERA (Anir) (Table 6.4A). Furthermore, ECA and ERA have the highest number and diversity of zigzag motifs among Bismarck Lapita sites (Table 6.4B), while only the simplest one-directional zigzag subtype occurs in most other Lapita assemblages throughout the whole Lapita realm (Chiu 2019:322, Table 15.8). What we see in the undulated and zigzag motif themes may be an indicator of a set of firmly controlled motif categories that were never widely shared beyond ECA and ERA.

Due to the high variation in the size of individual Lapita pottery assemblages recorded in the LPOD, sites with only a small number of motifs may get a much higher Jaccard similarity score as most of them share sets of the more geometric motifs, or the so-called zone markers that are commonly

found on fragmented sherds. Finding the more complex 'index motifs' such as the zigzag and the undulated major motif themes may be a further way to investigate social relationships through motif analysis, as these motif themes are more likely to be used as group symbols with restricted usage among different social groups. Additional petrographic studies will surely enhance our current understanding of the Lapita exchange network.

Discussion

We have tried to assess the social connectedness of geographically dispersed communities during the Lapita period based on the assumption that people who produced and used pots decorated with the same motifs or their alloforms had a higher degree of social connectedness than those who do not share many motifs, and by assuming that people tend to acquire more pots and other materials from those with whom they have frequent exchanges or visits. As Lapita people also exchanged obsidian tools and raw materials rather extensively, comparing distributions of obsidian and pots may also help us better understand the dynamics of Lapita social networks.

As Summerhayes and others have previously noted, sites located in Mussau, New Britain, the Arawes, the Duke of Yorks, Anir and Nissan Islands during the early Lapita era all imported obsidian mainly from the Kutau/Bao source close to the Talasea region of West New Britain. In contrast, only Mussau and Kamgot in the Anir Islands acquired 20–50 per cent of their obsidian from the Lou source that was previously exclusively used by the Manus community in the pre-Lapita era (Allen 1996; Ambrose 2002; Fredericksen 1997a, b; Summerhayes 2009:116, Fig. 12; Summerhayes et al. 2014; Torrence et al. 2009:141). Lou obsidian was very rare in sites located on New Britain and the Duke of Yorks (Summerhayes 2003a:137) during this period. Over time, Mussau communities imported more obsidian from the nearby Lou source while importing less obsidian from New Britain. Kamgot went through a similar temporal shift in terms of obsidian exchange (Summerhayes 2009:116, Fig. 12-14), as did the Nissan Islands sites located further south of Anir (Spriggs 1991:241). On the south-west coast of New Britain, only a few pieces of Lou obsidian were found in Late or Post-Lapita times at the site of Apalo (FOH) on the Arawe Islands (Henderson 2017:62). Our petrographic results likewise suggest a large number of pots were likely imported into ECA from Lou Island and/or the nearby rhyolitic islands, beginning around 3234–3089 cal. BP and associated with the earliest Zone C_3 at ECA Area B and Area B-extension (Table 6.2). Pots imported from the northern part of New Britain where the Kutau/Bao obsidian source is located are found in slightly later stratigraphic contexts associated with Zone C_2 at ECA Area B and Area B-extension and are not as numerous as those acquired from Lou Island and/or the nearby rhyolitic islands. This pattern of ceramic exchange fits with the frequency patterns identified from the obsidian sources mentioned above.

Kirch has suggested that Lou obsidian might have reached the southern TLTF chain Lapita sites via Mussau (Kirch et al. 1991:158). Therefore, the high frequency of motifs shared by Mussau and Kamgot correlates with the fact that both acquired the majority of their obsidian from the Lou Island source in the Admiralties. As pots made from the TLTF chain only appear in Mussau assemblages in Zone C_1 of Area B and B-extension at ECA, these may represent stronger social networks between these two sites postdating 3000–2800 BP. Interestingly, this corresponds to an increased usage of Admiralty Islands obsidian at Kamgot (ERA) (Summerhayes 2009:116, Fig. 12-13). Therefore, at least in the Mussau and the TLTF chain regions, we find strong convergence in pottery and obsidian exchange patterns, suggesting that Lapita social networks, at certain times and places, involved multiple forms of material culture.

Motifs shared among Mussau assemblages that are similar to the ones located in central north New Britain—near Talasea and in the Arawe Islands—do not correlate with obsidian distribution patterns. Although pots made in central north New Britain did reach the Mussau islands, none from the Arawe and the Kandrian areas have been identified, despite the fact that the region's FOH and FOJ sites are said to be contemporary with ECB and ECA in Mussau (Summerhayes 2007:145) and the fact that sites located in this region also share motifs with Mussau sites (Figure 6.4). As Arawe and Kandrian consistently used Kutau/Bao obsidian without importing Admiralty obsidian before, during and after the entire Lapita sequence, the social and economic factors that led these two regions to network with Mussau communities are still unknown.

Petrographic analysis of 10 EHB and eight ECB samples provide little information on their possible sources. Only one ECB sample can be sourced to Mussau or basaltic Manus; one EHB sample to Lou and nearby rhyolitic islands. Another EHB sample can be sourced to basic and intermediate volcanic areas that include Mussau, basaltic Manus and Lavongai (or adjacent parts of New Ireland). Two sherds from each site can only be sourced to weathered intermediate plutonic/sub-volcanic areas or sedimentary areas, a vast region covering Manus, Lavongai (or adjacent parts of New Ireland), northern New Britain near Watom Island and plutonic parts of New Ireland. The rest of the samples cannot be sourced (see Appendix: Table 6.S1). Dickinson had reported that six Lapita sherds sent to him by Summerhayes from Kamgot were all locally made on the Anir Island of the TLTF chain (Dickinson 2000b). What we see here is that EHB and ECB share a higher degree of motif similarity with many sites located on New Britain, Duke of Yorks and the TLTF chain, yet there is little petrographic evidence that inhabitants of these two sites imported pots from all these areas. ECA has many exotic pots sourced to various regions, while ERA does not have any, yet these two sites are paired with one another in term of motifs, and do not share as many motifs with all other sites in the Bismarck Archipelago.

Summerhayes (2000) has proposed that Lapita communities shared not just pots, but more importantly, the concepts of how to make and decorate pots. He also demonstrated that Lapita pots were rarely transported between sites located on the north and south coasts of New Britain, and that early Lapita potters of south-western New Britain probably used locally available clays, tempered with grains collected from various river systems along the south coast of New Britain to Arawe region, to produce similarly shaped and decorated pots (Summerhayes 2003b:140). Samples from our two pastes group (G9), however rare, also show a similar pattern of a vessel using either different clays mixed with similar tempers, or similar clay with different tempers. Lapita potters used locally available raw materials to produce pots carrying similar motifs that were shared over extensive regions encompassing several island groups. Although direct material evidence through imported pottery for shared motifs is extremely rare, similar motifs with subtle differences can be traced throughout the Lapita realm (Chiu 2019). Further comparison among the Bismarck Lapita sites is needed before we can explore issues such as chronological or spatial patterns of preferred motifs or motif themes across this region. Yet, from data we have gathered so far, it is clear that inhabitants of the Mussau islands maintained close relationships with communities surrounding their island group for both obsidian and pottery, especially with Manus to the west and sites located on northern and north-eastern New Britain. Links to various parts of New Ireland were established quite early on as well, yet the connection to the TLTF chain was perhaps, based on our current data, a few decades later.

Conclusion

Comparing connection maps generated by the results of our petrographic and motif analysis of the Mussau sites, it is clear that the communities of the Bismarck Archipelago were highly connected. While the idea of how to make pots and of what motifs to be employed might be shared widely, even spreading beyond the Bismarck Archipelago and well into Remote Oceania, the physical sources of pots used at ECA were limited to Manus, New Ireland, the TLTF chain and north-eastern and central north of New Britain. Paired with the results from the obsidian sources and distribution ranges, we propose that there might have been at least two social networks existing in the Bismarck Archipelago. The first realm includes the Admiralties, the Mussau islands, the Duke of Yorks, the TLTF chain and possibly also parts of northern New Ireland and northern New Britain. Some sites (ECA and ERA in particular) of this first network share a high degree of motif similarity to many early Lapita sites outside of the Bismarcks. The second realm perhaps encompasses central north and southern New Britain including the Arawe Islands, although there is currently no evidence for the transport of pottery from the south coast of New Britain to the Mussau Islands.

Acknowledgements

We are delighted to offer this paper to Glenn Summerhayes as a sign of our respect and admiration for his contributions to Pacific archaeology, especially in the Bismarck Archipelago and New Guinea Highlands where he has helped to transform our understanding of the regional history. For each of us, in different ways, he has been a teacher, mentor, field companion and co-author on many projects, but most importantly we thank Glenn for his collegial friendship and ability to bring humour and common sense appropriate to every occasion. May our friendships continue for many more years.

We thank the Bishop Museum for lending us Papua New Guinean petrographic thin sections first worked on by the late William Dickinson. We also thank the School of Anthropology, University of Arizona, and the Archaeological Research Facility, University of California at Berkeley, for providing access to their laboratories. We want to thank Si-ru Chen and Jia-Zun Chang and the team members of Lapita Pottery Online Database for working on vessel and motif analyses over the years. We thank also Hsiung-Ming Liao for teaching Chiu and her assistants how to use QGIS, and Jennifer Kahn and Nick Hogg for commenting and proofreading drafts of this paper.

Finally, we would also like to thank the Ministry of Science and Technology (MOST-106-2410-H-001-023-MY2) and Academia Sinica (AS-TP-107-L18-2) for funding this project under Chiu's directorship. The Lapita Pottery Online Database has been funded by Academia Sinica through awards to Chiu since 2005.

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Appendix: Supplementary table

Table 6.S1: Summary of petrographic results. Dickinson's original grouping and inferred sources are included for comparison.

					Probable resource		
Thin section ID	**New group**	**Subgroup**	**Dickinson's group**	**Sources inferred by Dickinson**	**Sources inferred by us**	**The feature of geological area**	**sample ID**
ECA002	G1 Reef detritus-predominant fabric	Sub1 Typical modern reef debris			unknown	modern reef debris & limeclast & volcanic lithic	ECA31-04-004
ECA008							ECA31-07-037
ECA023							ECA32-07-037
ECA035							ECA36-15-008
ECA067							ECA50-05-053+50-06-005
ECA070							ECA52-02-018
ECA073							ECA53-03-038
ECA097							ECA68-01-029
ECA104							ECA68-09-007
ECA105							ECA68-09-008
ECA113							ECA93-04-006-Pot
EHB001							EHB08-07-003
ECA121							ECA-V-030
ECA124							ECA-V-049
ECA128							ECA-V-062
ECA137							ECA-V-130
ECA140							ECA-V-143
ECA148							ECA-V-235
ECA151							ECA-V-239
ECA155							ECA-V-243
ECA161							ECA47-07-026
ECA164							ECA42-09-030
ECB008							ECB07-07-020

					Probable resource		
Thin section ID	New group	Subgroup	Dickinson's group	Sources inferred by Dickinson	Sources inferred by us	The feature of geological area	sample ID
EHB02-03-008			A	unknown			EHB02-03-008
ECA88-04-012			A				ECA88-04-012
ECA87-05-006			B	Admiralty bimodal zone—rhyolitic to rhyodacitic			ECA87-05-006
ECA69-05-007			B				ECA69-05-007
ECA66-08-024			B				ECA66-08-024
ECA007		Sub2 Homogenous reddish clay			unknown	modern reef debris & limeclast	ECA31-07-033
ECA045							ECA39-08-005+39-09-004
ECA069							ECA52-02-013
ECA106							ECA69-02-003
ECA130							ECA-V-089
ECA141							ECA-V-173
ECA149							ECA-V-237
ECA160							ECA40-10-007
ECB007							ECB07-03-008
EHB01-09-006			B	Admiralty bimodal zone—rhyolitic to rhyodacitic			EHB01-09-006
ECA66-03-007			B				ECA66-03-007
ECA006		Sub3 Probable clay bulks			unknown	modern reef debris, less grains	ECA31-07-028
ECA011							ECA31-08-016
ECA077							ECA54-02-051
ECA078							ECA54-02-055
ECA091							ECA67-03-017
ECA093							ECA67-04-011
ECA107							ECA69-02-007
ECA110							ECA69-05-001+002+009
ECA115							ECA-V-031
ECA143							ECA-V-196
ECA69-06-001			A	Admiralty bimodal zone—rhyolitic to rhyodacitic			ECA69-06-001
ECA88-04-007			A	unknown			ECA88-04-007

					Probable resource		
Thin section ID	**New group**	**Subgroup**	**Dickinson's group**	**Sources inferred by Dickinson**	**Sources inferred by us**	**The feature of geological area**	**sample ID**
ECA005		Sub4 Weathered volcanic lithic			unknown	modern reef debris & heavily weathered volcanic lithic	ECA31-07-021
ECA013							ECA31-10-020
ECA020							ECA32-05-004
ECA031							ECA35-12-024
ECA063							ECA50-03-024
ECA064							ECA50-04-020_046
ECA068							ECA52-02-011
ECA071							ECA52-03-026+53-02-032
ECA079							ECA54-02-056
ECA147							ECA-V-234
ECA154							ECA-V-242
ECA88-07-004			A	unknown			ECA88-07-004
ECA018		Sub5 Yellowish-grey clay mineral			unknown	modern reef debris with pale yellow matrix	ECA32-04-003
ECA081							ECA54-06-014
ECA134							ECA-V-105
EHB01-05-012			A	unknown			EHB01-05-012
ECA88-04-004			B	Admiralty bimodal zone—rhyolitic to rhyodacitic			ECA88-04-004
ECA66-08-015			A				ECA66-08-015
EHB01-04-019			B				EHB01-04-019
ECA072	G2 Reef detritus—predominant hybrid fabric	Sub1 Volcanic cone related			Volcanic zone along the north coast of New Britain	acid, intermediate and basic volcanic	ECA53-03-009-Pot
ECA085							ECA66-03-019
ECA090							ECA67-02-023
ECA100							ECA68-06-009
ECA116							ECA-V-001
ECA019							ECA32-05-003

					Probable resource		
Thin section ID	New group	Subgroup	Dickinson's group	Sources inferred by Dickinson	Sources inferred by us	The feature of geological area	sample ID
ECA022		Sub2 Heavy mineral			Mussau or basaltic Manus, Manus or Lavongai (or adjacent parts of New Ireland)	modern reef debris & basic volcanic & intermediate volcanic area	ECA32-07-022
ECA034							ECA36-14-024+029
ECA051							ECA40-06-008
ECA092							ECA67-04-010
ECA098							ECA68-03-011
ECA132							ECA-V-095
ECA133							ECA-V-107
ECA138							ECA-V-132
ECA159							ECA38-08-033
ECA166							ECA53-02-035
EHB003							EHB-V-003
ECA90-02-001			H	Manus, and Lavongai (and adjacent parts of New Ireland), andesitic-dacitic volcanic rocks, associated in some instances with cogenetic subvolcanic hypabyssal intrusions			ECA90-02-001
ECA66-03-016A			H				ECA66-03-016A
ECA004		Sub3 Quartz-feldspar			Lou island and the nearby rhyolitic islands	modern reef debris & intermediate-acid/acid volcanic lithic	ECA31-07-009+016+026+0xx
ECA009							ECA31-07-041
ECA010							ECA31-08-015+017
ECA014							ECA32-01-005
ECA016							ECA32-03-009
ECA017							ECA32-04-002
ECA021							ECA32-06-003
ECA024							ECA32-07-051+053
ECA026							ECA32-09-056

					Probable resource		
Thin section ID	New group	Subgroup	Dickinson's group	Sources inferred by Dickinson	Sources inferred by us	The feature of geological area	sample ID
ECA028							ECA33-05-053+058_51-03-029+034
ECA030							ECA34-01-012+34-02-013
ECA032							ECA36-14-004
ECA036							ECA36-18-016+37-07-022
ECA041							ECA37-06-016
ECA042							ECA37-06-033+058
ECA043							ECA37-06-040
ECA050							ECA40-06-005
ECA056							ECA40-11-023
ECA082							ECA54-06-024
ECA083							ECA54-06-027
ECA117							ECA-V-002
ECA118							ECA-V-003
ECA120							ECA-V-026
ECA125							ECA-V-051
ECA152							ECA-V-240
ECA156							ECA14-03-002
ECA162							ECA47-07-027
EHB004							EHB01-04-008
ECA68-03-005			B	Admiralty bimodal zone—rhyolitic to rhyodacitic			ECA68-03-005
ECA67-05-005			B				ECA67-05-005
ECA68-01-024			B				ECA68-01-024
ECA67-06-023			B				ECA67-06-023
ECA66-03-16B			B				ECA66-03-16B
ECA66-07-003			B				ECA66-07-003

Thin section ID	New group	Subgroup	Dickinson's group	Sources inferred by Dickinson	Probable resource		sample ID
					Sources inferred by us	The feature of geological area	
ECA029		Sub4 Slight metamorphism			Manus or Lavongai (or adjacent parts of New Ireland), Northern New Britain near Watom, or plutonic parts of New Ireland, near coastline	weathered intermediate plutonic/ sub-volcanic area or sedimentary area	ECA33-08-100
ECA037							ECA36-19-004
ECA046							ECA39-12-012
ECA049							ECA40-06-004
ECA052							ECA40-07-012+015
ECA053							ECA40-11-012
ECA058							ECA40-11-031
ECA062							ECA50-02-019_020_021
ECA075							ECA53-06-067+082
ECA076							ECA53-06-073
ECA086							ECA66-04-001
ECA087							ECA66-07-026
ECA089							ECA66-08-025
ECA099							ECA68-03-014
ECA103							ECA68-08-008
ECA108							ECA69-03-003
ECA109							ECA69-04-003
ECA112							ECA69-06-015
ECA123							ECA-V-045
ECA126							ECA-V-060
ECA129							ECA-V-082
ECA131							ECA-V-094
ECA142							ECA-V-179
ECA150							ECA-V-238
ECA153							ECA-V-241
ECA163							ECA53-02-029
ECA167							ECA54-01-020
ECA168							ECA17-06-037
EHB002							EHB-V-002

					Probable resource		
Thin section ID	**New group**	**Subgroup**	**Dickinson's group**	**Sources inferred by Dickinson**	**Sources inferred by us**	**The feature of geological area**	**sample ID**
ECA057	G3 Coral reef detritus–opaque fabric	Sub1 Coral reef detritus			Mussau or basaltic Manus	modern reef debris & placer sand (70%:30%) & basic volcanic area/ pyroxene bearing intermediate volcanic	ECA40-11-030
ECA095							ECA67-06-014
ECB001							ECB10-02-015_021
ECA16-08-017			C	Quartz-bearing felsitic tempers derived from Lou			ECA16-08-017
ECA67-06-012			C				ECA67-06-012
ECA66-08-009			C				ECA66-08-009
ECA66-07-016			C				ECA66-07-016
ECA025		Sub2 Sub-volcanic & sediment			Manus or Lavongai (or adjacent parts of New Ireland), Northern New Britain near Watom, or plutonic parts of New Ireland, near coastline	intermediate volcanic/ sedimentary area with placer sand	ECA32-08-008
ECA038							ECA36-19-005
ECA047							ECA39-13-007
ECA048							ECA39-13-012
ECA065							ECA50-05-011
ECA080							ECA54-05-004
ECA088							ECA66-08-010
ECA096							ECA67-07-011
ECB002							ECB11-02-013
ECA122							ECA-V-037
ECB009							ECB14-02-014
ECA17-06-020		Sub3 Opaque	C	Quartz-bearing felsitic tempers derived from Lou	Mussau or basaltic Manus	modern reef debris & placer sand (30%:70%) & basic volcanic area/ pyroxene bearing intermediate volcanic	ECA17-06-020
ECA66-07-019			C				ECA66-07-019
ECA68-07-006			C				ECA68-07-006
ECA17-06-030			C				ECA17-06-030
ECA68-07-027			C				ECA68-07-027
ECA054	G4 Opaque-dominant fabric				Manus or Lavongai (or adjacent parts of New Ireland)	placer sand & intermediate volcanic area with placer sand	ECA40-11-016
ECA139							ECA-V-015
ECA144							ECA-V-138
ECA145							ECA-V-228
ECA119							ECA67-02-010
ECA19-01-029			D	Quartz-bearing felsitic tempers derived from Lou			ECA19-01-029
ECA67-02-014			D				ECA67-02-014
ECA67-02-010			D				ECA67-02-010

					Probable resource		
Thin section ID	New group	Subgroup	Dickinson's group	Sources inferred by Dickinson	Sources inferred by us	The feature of geological area	sample ID
ECA012	G5 Amphibole-feldspar fabric	Sub1 Metavolcanics absent			unknown basic or intermediate volcanic area	unknown basic or intermediate volcanic area	ECA31-09-040
ECA084							ECA66-02-016+018
ECA127							ECA-V-061
ECA135							ECA-V-125
ECA146							ECA67-02-017
ECA157							ECA33-03-004
ECB004							ECB-V-011
ECA13-01-003			F	Manus, and Lavongai (and adjacent parts of New Ireland), andesitic-dacitic volcanic rocks, associated in some instances with cogenetic subvolcanic hypabyssal intrusions			ECA13-01-003
ECA015		Sub2 Epidote-bearing metavolcanics			Manus or Lavongai (or adjacent parts of New Ireland), Northern New Britain near Watom, or plutonic parts of New Ireland	weathered intermediate plutonic/sub-volcanic area or sedimentary area	ECA32-03-005
ECA074							ECA53-06-027-Pot
ECA027							ECA32-10-008+009
ECA66-07-021			F	Manus, and Lavongai (and adjacent parts of New Ireland), andesitic-dacitic volcanic rocks, associated in some instances with cogenetic subvolcanic hypabyssal intrusions			ECA66-07-021
ECA67-02-017			F				ECA67-02-017
ECA68-07-010			F				ECA68-07-010
EHB1-03-015			F				EHB1-03-015
ECA16-07-015		Sub3 Prehnite-bearing metavolcanics	F		Manus or Lavongai (or adjacent parts of New Ireland), Northern New Britain near Watom, or plutonic parts of New Ireland	weathered intermediate plutonic/sub-volcanic area or sedimentary area	ECA16-07-015
ECA13-02-001			E				ECA13-02-001
ECA18-01-008			E				ECA18-01-008
ECA16-05-003			E				ECA16-05-003
ECA68-03-003			E				ECA68-03-003

					Probable resource		
Thin section ID	New group	Subgroup	Dickinson's group	Sources inferred by Dickinson	Sources inferred by us	The feature of geological area	sample ID
ECA039	G6 Pyroxene volcanic fabric	Sub1 Basic volcanic with red iron oxide			unknown basic volcanic area	unknown basic volcanic area	ECA37-02-006+007
ECA066							ECA50-05-020+023
ECB003							ECB13-02-004
ECA69-02-006			G	Manus, and Lavongai (and adjacent parts of New Ireland), andesitic-dacitic volcanic rocks, associated in some instances with cogenetic subvolcanic hypabyssal intrusions			ECA69-02-006
ECA033		Sub2 Alkali basalt, no lime-green clinopyroxene			TLTF alkalic chain(?)	alkali-rich basic volcanic area	ECA36-14-018
ECA003		Sub3 Intermediate volcanic			unknown intermediate volcanic	unknown intermediate volcanic	ECA31-06-009
ECA114							ECA-V-016
ECA136							ECA-V-127
ECA69-07-027			G	Manus, and Lavongai (and adjacent parts of New Ireland), andesitic-dacitic volcanic rocks, associated in some instances with cogenetic subvolcanic hypabyssal intrusions			ECA69-07-027
ECA69-07-019			G				ECA69-07-019
ECA16-06-017			G				ECA16-06-017
EHB01-06-005			G				EHB01-06-005
ECA87-06-001			G				ECA87-06-001
ECA68-01-042			G				ECA68-01-042
ECA67-06-029			G				ECA67-06-029

					Probable resource		
Thin section ID	**New group**	**Subgroup**	**Dickinson's group**	**Sources inferred by Dickinson**	**Sources inferred by us**	**The feature of geological area**	**sample ID**
ECA060	G7 Quartz-feldspar fabric	Sub1 Quartz-feldspar fabric with silty clay			Northern New Britain near Watom, or plutonic parts of New Ireland	basic/ intermediate/ acid sub-volcanic/ plutonic area	ECA42-09-050+051
ECA061							ECA47-07-031
ECA90-04-009			J1	Manus, and Lavongai (and adjacent parts of New Ireland), andesitic-dacitic volcanic rocks, associated in some instances with cogenetic subvolcanic hypabyssal intrusions			ECA90-04-009
ECA92-03-003			J2				ECA92-03-003
ECA001		Sub2 Quartz-feldspar fabric with dark matrix			Northern New Britain near Watom, or plutonic parts of New Ireland	basic/ intermediate/ acid sub-volcanic/ plutonic area	ECA14-01-004
ECA040							ECA37-02-009
ECA101							ECA68-07-016
ECA102							ECA68-07-026
ECA165							ECA47-05-010
ECA044	G8 Lime-green clinopyroxene fabric				TLTF alkalic chain	alkali-rich basic volcanic area	ECA39-02-005
ECA17-07-043			K	TLTF alkalic chain			ECA17-07-043
ECA17-05-006			K				ECA17-05-006
ECA67-05-011			K				ECA67-05-011
ECA69-01-004			C	Quartz-bearing felsitic tempers derived from Lou			ECA69-01-004
ECA67-05-007			G	Manus, and Lavongai (and adjacent parts of New Ireland), andesitic-dacitic volcanic rocks, associated in some instances with cogenetic subvolcanic hypabyssal intrusions			ECA67-05-007

					Probable resource		
Thin section ID	**New group**	**Subgroup**	**Dickinson's group**	**Sources inferred by Dickinson**	**Sources inferred by us**	**The feature of geological area**	**sample ID**
ECA059	G9 Two different pastes				unknown	mixed tempers	ECA40-11-045
ECA094							ECA67-05-020
ECB005							ECB-V-017
ECB006							ECB-V-018
ECA111	Loner A				unknown	no identifiable inclusion	ECA69-05-004
ECA158	Loner B				unknown basic volcanic area	unknown basic volcanic area	ECA34-05-062

Note: Dickinson samples marked in blue.

Source: Authors' data and Dickinson (2021b).

This text is taken from *Forty Years in the South Seas: Archaeological Perspectives on the Human History of Papua New Guinea and the Western Pacific Region*, edited by Anne Ford, Ben Shaw and Dylan Gaffney, published 2024 by ANU Press, The Australian National University, Canberra, Australia.

doi.org/10.22459/TA57.2024.06