– ARTICLE –

Petrography of Temper Sands in 112 Reconstructed Lapita Pottery Vessels from Teouma (Efate): Archaeological implications and relations to other Vanuatu tempers

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ABSTRACT

The recovery of multiple intact and reconstructed Lapita pottery vessels excavated from the Teouma site near the south coast of Efate in Vanuatu has made possible a petrographic temper analysis for which each sherd thin section is known without doubt to derive from a different single pot. Such positive vessel-by-vessel control for the specific provenience of each sherd has not been possible during petrographic study of any other collections of prehistoric potsherds from Pacific Oceania. Our study shows that 100 of 112 Teouma vessels were made using indigenous Efate temper sands of several kinds, but that three of the vessels derive from elsewhere in Vanuatu and nine derive from New Caledonia ~500 km away to the southwest. Petrographic comparison of the Teouma temper sands with tempers in 430 Lapita and post-Lapita sherds from elsewhere in Vanuatu and the geologically related eastern outliers of the Solomon Islands at the northern end of the New Hebrides island arc defines a discrete number of generic temper provinces identified geographically as a guide for future analysis of Vanuatu tempers. Where adequate age control for ceramics is available, no generic distinctions can be drawn between tempers in Lapita and post-Lapita wares from each temper province.

Keywords: Efate, Lapita, New Caledonia, New Hebrides, Teouma, Vanuatu

INTRODUCTION

The Teouma archaeological site (Bedford *et al.* 2006, 2007, 2009, 2010) near the south coast of Efate in south-central Vanuatu is unique for the number of intact or reconstructed Lapita pottery vessels recovered from excavations. Many but not all the vessels were associated with mortuary activity. Initial Lapita occupation of the Teouma site occurred at some time during the interval 3150–3000 BP. Radiocarbon ages from the Lapita horizon calibrate at 2σ to the interval 3070–2755 calBP, although uncertainties in ΔR and the flatness of the calibration curve during the time of interest make the calibrated ages questionable in detail.

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For temper analysis of the Teouma pottery suite, we have studied thin sections of sherds derived from 112 verifiably individual Lapita vessels reconstructed from multiple sherds. The sherds studied petrographically are a substantial sampling (31%) of the entire site collection, which includes at most no more than 366 individual vessels, many of them fragmentary and represented by only one or a few sherds. Frequency percentages of sand grain types in Teouma sherds were determined by areal, ribbon, or crosshair counts (Dickinson 2006: 27–28) of 400 temper grains in each thin section except for sherds containing fewer temper grains (see online supplementary file). With the exception of three thin sections inadvertently prepared from fragments of the same vessel and two thin sections prepared deliberately from another sherd to confirm an unexpected temper composition, each sherd thin section represents a separate pot. Our study is the only temper analysis within Pacific Oceania for which correlation of each sherd with a different vessel can be made with absolute confidence. As a result, we know with certainty that temper statistics, sherd by sherd, represent a temper census of Teouma pottery, vessel by vessel.

From temper analysis, we infer that 93 of 112 Teouma ceramic vessels (83%) were made using fluvial temper sands of volcanic provenance probably collected from Teouma Stream, which flows past the Teouma site into the head of Teouma Bay, and that seven vessels (6%) were made using hybrid beach sands composed of mixed volcanic sand and calcareous reef detritus collected either from the shores of Teouma Bay or elsewhere on the coast of Efate. Twelve other vessels (11%) contain temper sands exotic to Efate. The latter document ceramic transfer to Teouma from elsewhere in central Vanuatu (3%), or possibly from the Bismarck Archipelago, and from Grand Terre in New Caledonia (8%). The relative abundance of New Caledonia wares (one of every dozen Teouma vessels) implies close cultural ties between Vanuatu and New Caledonia during Lapita occupation. Interpretations of Teouma temper origins are reinforced by ancillary petrographic study of 430 non-Teouma sherds from Vanuatu and the eastern Solomon Islands, and 80 sherds from various archaeological sites in New Caledonia. As background for the interpretation of Teouma tempers, we first briefly review Vanuatu and Efate geology as a guide to the nature of source rocks from which temper sand grains were derived.

VANUATU GEOLOGY

The geologic history and tectonic setting of Vanuatu were reviewed by Macfarlane *et al.* (1988) and Greene *et al.* (1988), and the geology of the eastern Solomon Islands at the northern end of the New Hebrides island arc was described in detail by Hughes *et al.* (1981). Vanuatu formed a segment of the ancestral Vitiaz island arc prior to reversal of arc polarity near 10 Ma that initiated eruption of the younger New Hebrides arc assemblage and promoted migration of the ancestral arc structure away from the Vitiaz paleotrench of the northern Melanesian borderland by clockwise rotation accommodated by backarc seafloor spreading (Figure 1). The geotectonic evolution of Vanuatu and the New Hebrides island arc in the context of temper suites has been discussed in detail by Dickinson (2001: 279–283, 2006: 14–20 & 61–67). For sourcing Vanuatu ceramic tempers, the following geologic constraints are paramount (Figure 2A):

1. Thick volcanogenic strata marking the Lower to Middle Miocene trend of the ancestral Vitiaz arc assemblage (Figure 1B) form the bedrock of multiple islands spanning the boundary between the Solomon Islands

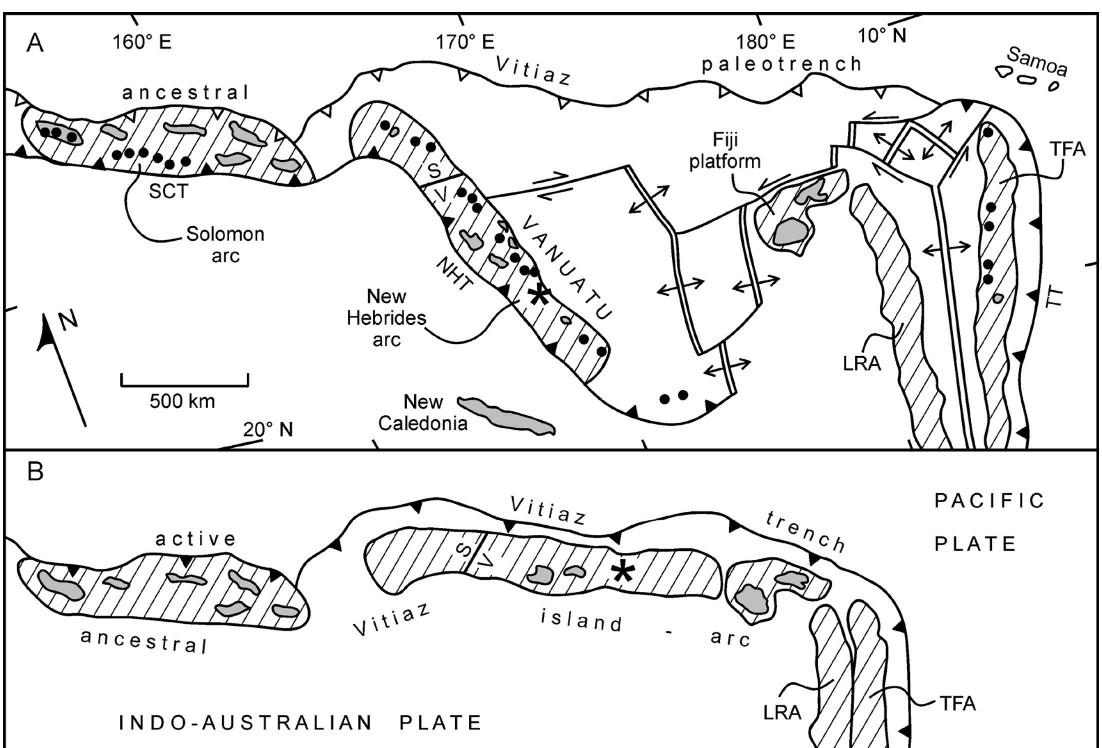

Figure 1. Geotectonic position of Vanuatu in the Melanesian region after Dickinson (2006): (A) today; (B) ~10 Ma (before arc polarity reversal and backarc seafloor spreading). Larger islands are shaded. The S/V line is the political boundary between the Solomon Islands and Vanuatu along the New Hebrides island arc. Barbed lines are trench subduction zones (solid barbs, active; open barbs, dormant): NHT–New Hebrides, SCT–San Cristobal, TT–Tonga. Double lines with opposed arrows are oceanic spreading centers that have dispersed segments (ruled) of the ancestral (pre-10 Ma) Vitiaz island arc (LRA–Lau remnant arc, TFA–Tofua frontal arc). Lines with half-arrows are transform faults (lateral motion). Solid circles in A are selected Quaternary arc volcanoes.

and Vanuatu along the northwestern fringe of the modern New Hebrides island arc, and locally include strata as old as Oligocene in the Torres Islands.

2. Upper Miocene to Lower Pliocene volcanogenic strata erupted along the rear flank of the nascent New Hebrides island arc shortly after arc polarity reversal are exposed sparingly as the bedrock of elongate islands along the eastern flank of the arc edifice in central Vanuatu.
3. Upper Pliocene to Quaternary subaerial and submarine volcanoes of the active New Hebrides island arc (Figure 1A) are spaced at intervals along the arc edifice near its topographic-bathymetric crest, and at least locally on Erromango have cogenetic volcanic underpinnings dating back to near the Miocene–Pliocene time boundary (Bellon *et al.* 1984).
4. Widely spaced backarc islands (Taumako, Mere Lava, Futuna) are associated with elongate rift troughs (Vot Tande on the north, Coriolis on the south) formed by crustal extension along the rear flank of the New Hebrides arc during post-Vitiaz arc migration and rotation, and extensional intra-arc summit basins break the continuity of the active arc assemblage in central Vanuatu where backarc rift troughs are not present.
5. Isolated backarc islands (Tikopia, Anuta) were formed by Quaternary volcanic eruptions within the oceanic

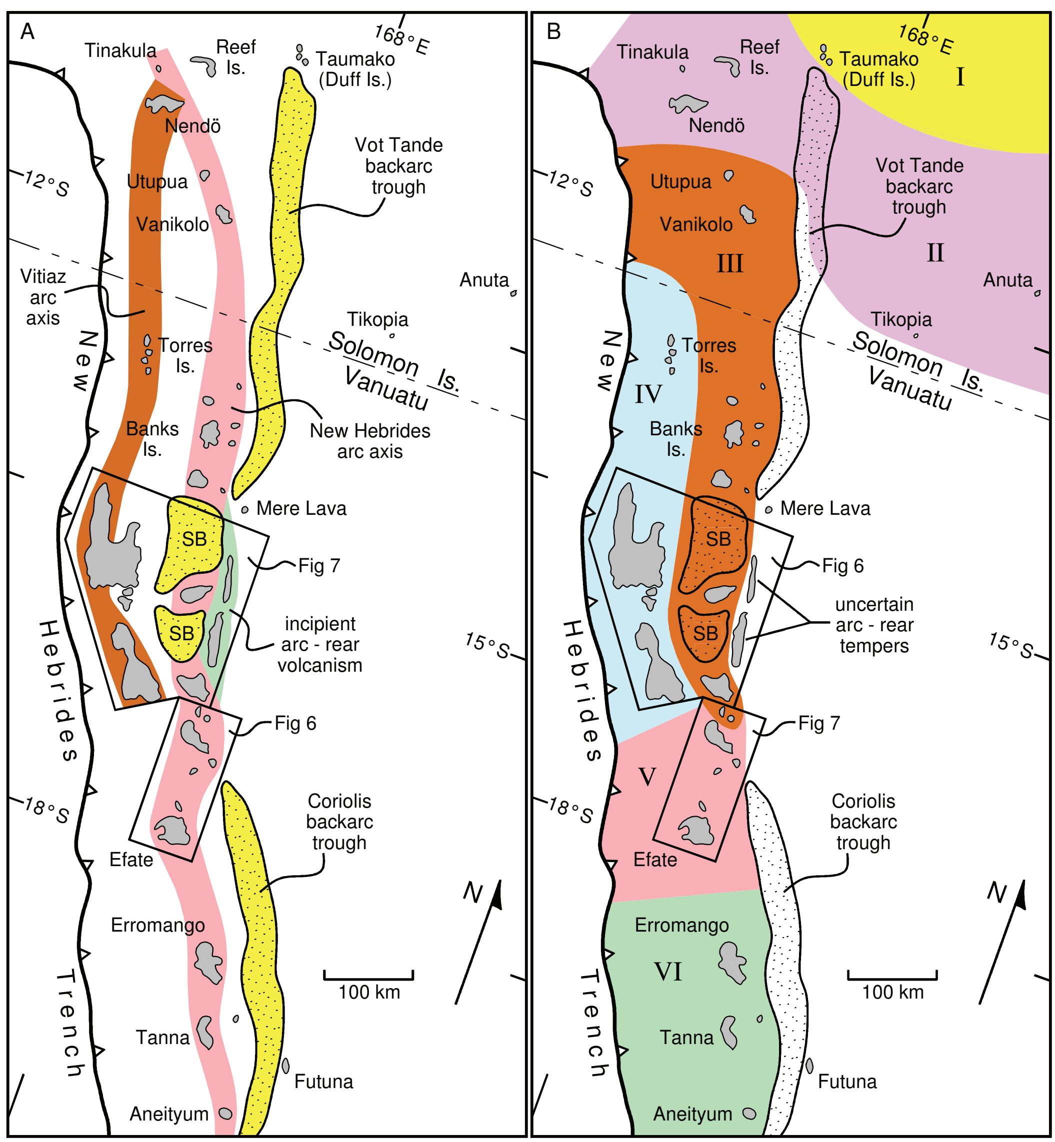

Figure 2. Geologic (A) and temper (B) provinces of the New Hebrides island arc including Vanuatu. The Teouma site is on the south coast of Efate (see Figure 3). Geology (in A) after Mallick (1974), Ash *et al.* (1978), Carney (1986), Macfarlane *et al.* (1988), Greene *et al.* (1988), Dickinson (2001, 2006), and Raos & Crawford (2004). Stipples denote elongate backarc rift troughs and more equant extensional summit basins (SB) along the crest of the central Vanuatu arc edifice. Temper provinces (I-VI in B) are based on patterns of diagnostic grain indices for Vanuatu temper types (Table 6).

region formed by seafloor spreading in the wake of the migratory and rotating New Hebrides island arc.

6. Arc reversal from Vitiaz to New Hebrides polarity was marked by a hiatus in volcanism between the youngest Vitiaz volcanogenic strata (14–13 Ma) and the oldest phase (8–7 Ma) of the New Hebrides eruptive suite, and by volcaniclastic Middle Miocene sedimentation (16–11 Ma) within Vitiaz intra-arc basins where deposition was terminated at a Late Miocene unconformity (11–8 Ma) preceding New Hebrides arc activity.

EFATE GEOLOGY

The island of Efate lies along the trend of the Neogene New Hebrides volcanic arc (Figure 2A).

Its central highlands (Figure 3) are underlain by uplifted early Pleistocene (~1.6 Ma) marine pumice breccias deposited below wave base as proximal turbidites forming massive to graded volcaniclastic beds typically 5–15 m thick and reaching a total exposed stratigraphic thickness of 450 m. The pumiceous density currents were fed by contemporaneous eruption of at least 85 km³ of rhyodacitic magma from nearby submarine vents (Raos & McPhie 2003). Vesicular pumice fragments up to ~5 cm in diameter form >80% of the clasts in the breccias, which also include blocks of obsidian and latite or andesite interpreted as accidental components derived from the subterranean walls of eruptive vents. Analogous eruptions in subaerial settings typically spread outflow blankets of ash-flow tuff (ignimbrite) over wide areas, and lead to caldera collapse. For Efate, two paroxysmal eruption cycles accompanied by caldera collapse are implied by an interval of laminated tuff 10–20 m thick separating lower and upper successions of massive pumice breccia. Reworked pumiceous sediments (≤70 m thick) gradationally overlying pumice breccia contain marine fossils, and form an extensive peripheral apron on southeast Efate, but were either not as extensive or have largely been removed by erosion on southwest Efate (Figure 3).

Efate pumice breccias are exposed to an elevation of

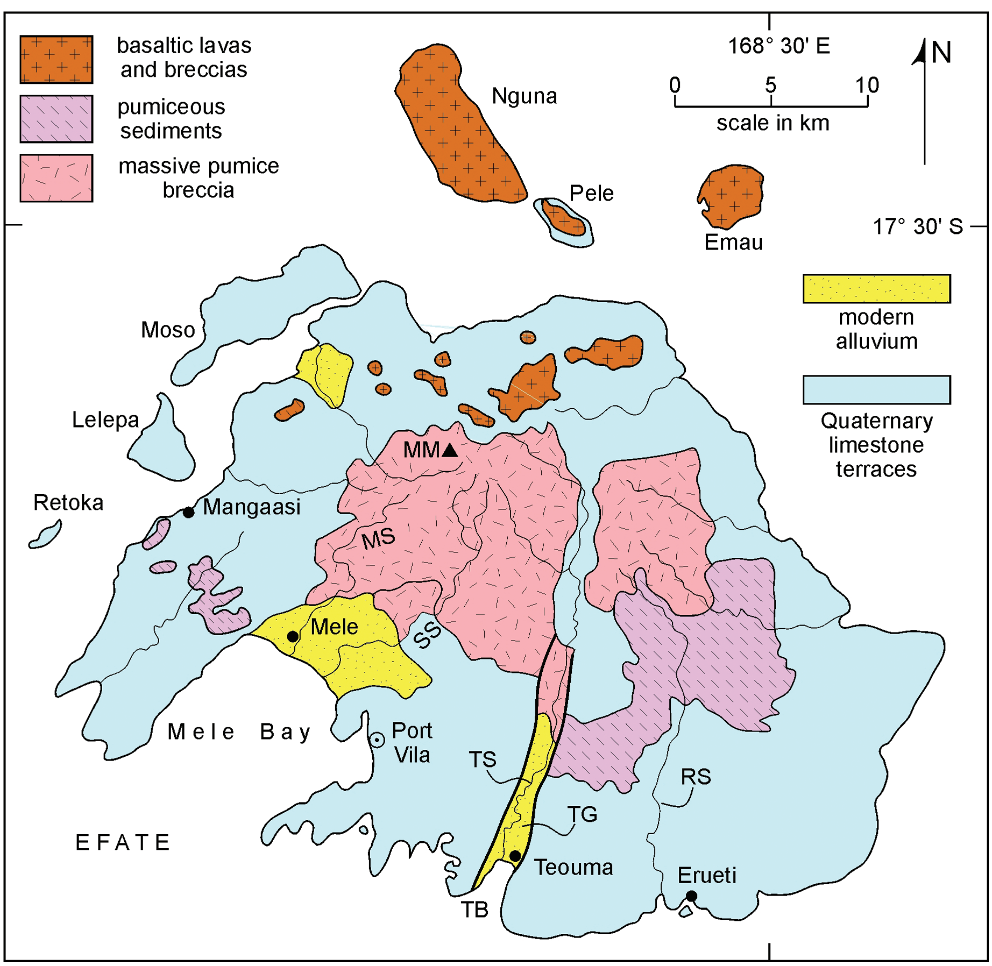

Figure 3. Location of Teouma and other localities on Efate and neighboring islets in relation to geologic source rocks for temper sand and to major drainages. Geology after Ash *et al.* (1978). Selected topographic features: MM–Mount McDonald (647 m), TB–Teouma Bay, TG–Teouma graben (heavy lines are bounding normal faults). Selected south coastal streams: MS–Mele, RS–Rentapao, SS–Sono, TS–Teouma.

647 m at Mount McDonald (Figure 3), which crowns the domical uplift of central Efate, and all streams draining to the south coast of Efate at Teouma and elsewhere rise within central uplands where exposures of pumice breccia are the dominant potential source of terrigenous stream sediment. Largely submarine basaltic lavas and breccias of late Pleistocene age (≤0.7 Ma) form local volcanic edifices capping the buried volcaniclastic apron of pumice breccia on northern Efate (Figure 3). The basalts were erupted from nine local volcanic centers near the north coast of Efate and on offshore islands (Nguna, Pele, Emau), but no basalt is exposed as potential source rock for fluvial sediment in drainages leading to the south coast of Efate (Ash *et al.* 1978, Coulon *et al.* 1979, Raos & Crawford 2004). The central bedrock core of Efate is surrounded on all sides by gently sloping coastal plateaus formed by uplifted flights of marine terraces composed of coralline limestone (Figure 3) dating to as old as the penultimate interglacial at ~200 ka (Bloom *et al.* 1978, Lecolle *et al.* 1990). Holocene uplift of Efate is continuing at a mean rate of 0.8–1.0 mm/yr (Dickinson & Shutler 2009).

TEOUMA TEMPERS

The Teouma site is located at an elevation 8 m above sea level and 800 m inland from the sheltered head of Teouma Bay (Figure 3). At the time of Lapita occupation, before sediment delivered to the bay by Teouma Stream had prograded the shoreline into the bayhead, Teouma stood atop a low promontory on the coast. The site may have risen in elevation by as much as 3 m over the past 3000 years owing to continued uplift of Efate. Teouma Stream flows past the site from interior highlands toward Teouma Bay down the floor of a local fault-bounded graben whose dormant continuation to the north is marked by a narrow belt of downdropped terrace limestone aligned with the graben floor and bounded to either side by exposures of older pumice breccia (Figure 3).

The Teouma ceramic assemblage includes ten vessel types and eight temper types (Table 1), but there is no systematic or statistically meaningful correlation between vessel type and temper type (Table 2). All or nearly all temper types are present in all vessel types represented by more than five pots, and all temper types present in more than five pots occur in all or nearly all vessel types. Comparing tempers in all carinated vessels to tempers in other vessels reveals an excess of PPLT tempers in the former and HSET tempers in the latter, but the numbers of vessels involved in the comparison (eight with PPLT tempers and seven with HSET tempers) are too low to make statistical comparisons convincing. On balance, we conclude that the temper types are randomly distributed among the vessel types. Non-Efate tempers documenting ceramic transfer to Teouma from elsewhere in Vanuatu or from New Caledonia occur in at least one pot for all vessel types represented by five or more pots.

Table 1. *Vessel types and temper types of Teouma Lapita ceramics.*

A. Vessel Types
1. *carinated*:
TC–carinated, TCC–carinated convex, TCI–carinated incurving, TCSI–carinated shell-incised
2. *other*:
TCS–cylinder stand, TD–dish, TGI–globular incurving, TGO–globular outcurving, TI–incised, TO–outcurving
B. Temper Types
1. *Efate sources*:
UPLT–unplacered local volcanic sand, PPLT–partially placered local volcanic sand, HSET–hybrid (mixed terrigenous-calcareous grains) Efate coastal sand, PPET–pyroxenic Efate placer sand, OPET–opaque-rich Efate placer sand
2. *non-Efate sources*:
NEHVT–hornblendic Vanuatu volcanic or hybrid sand temper, NCMHT–New Caledonia metamorphic hybrid temper, NCQHT–New Caledonia quartzose hybrid temper

The five temper types inferred to derive from Efate (Table 1) contain the same array of grain types in differing proportions (see Appendix). The dominant sand grains in unplacered tempers (UPLT) are plagioclase mineral grains and vitric volcanic rock fragments composed of felsic volcanic glass, tan and isotropic in thin section. Many of the glassy grains are microvesicular, as expected for derivation from pumice breccias on Efate. Minor non-vitric volcanic rock fragments of microscopically polycrystalline character are thought to derive from blocks of andesite and latite in the pumice breccias of central Efate, rather than from basaltic rocks of northern Efate (Figure 3). Subordinate grain types include opaque iron oxide grains and clinopyroxene, which is the only ferromagnesian silicate mineral present in Efate pumice breccias. Clinopyroxene and opaque iron oxide grains of higher specific gravity are variably concentrated in related placer tempers (PPLT, PPET, OPET).

The lack of any calcareous grains in UPLT-PPLT-PPET-OPET tempers favors derivation as stream sand, whereas the presence of skeletal and pelletal calcareous grains in the less abundant HSET tempers implies derivation as coastal beach sand at locales where contributions of reef detritus from offshore fringing reefs formed hybrid sand (Zuffa 1979) containing both calcareous and terrigenous grains (so-called 'mixed tempers' of common archaeological parlance). The occurrence of UPLT tempers in 45% of the Teouma vessels (Table 2) is taken to mean that unplacered sands from banks and intrachannel bars of Teouma Stream were the source of that dominant temper type. The placer tempers (PPLT-PPET-OPET) present in an additional 46% of Teouma vessels are interpreted as local placer sands also collected from Teouma Stream. The

Table 2. *Census of temper type by vessel type for Teouma Lapita ceramics.*

Type	UPLT	PPLT	HSET	PEPT	OEPT	NEHVT	NCMHT	NCQHT	Total
TC	26	6	1	8	11	1	0	4	57 (51%)
TCC	2	0	1	1	0	0	1	0	5 (4%)
TCI	2	0	0	0	2	0	0	0	4 (4%)
TCSI	0	1	0	0	0	0	0	0	1 (1%)
subtotal	30 (45%)	7 (10%)	2 (3%)	9 (13%)	13 (19%)	1 (2%)	1 (2%)	4 (6%)	67 (60%)
TCS	4	0	3	1	2	1	2	0	13 (12%)
TD	5	0	1	3	2	0	1	0	12 (11%)
TGI	2	1	0	0	1	0	0	0	4 (4%)
TGO	1	0	0	0	0	0	0	0	1 (1%)
TI	7	0	1	1	3	1	0	1	14 (12%)
TO	1	0	0	0	0	0	0	0	1 (1%)
subtotal	20 (44%)	1 (2%)	5 (11%)	5 (11%)	8 (18%)	2 (4%)	3 (7%)	1 (2%)	45 (40%)
Total	50 (45%)	8 (7%)	7 (6%)	14 (12%)	21 (19%)	3 (3%)	4 (4%)	5 (4%)	112 (100%)

comparable proportions (87%–95%) of vitric grains among the volcanic rock fragments of both placered and unplacered tempers thought to derive from Teouma Stream is compatible with that interpretation (Table 3). Compositions of Teouma Stream tempers do not vary for vessels of different typology (Table 3), implying that the same local temper sources were tapped for all the locally made Teouma ceramics and providing no indication that vessels of different types might have systematically been fabricated in different places.

On ternary compositional diagrams for the Teouma Stream tempers (Figures 4 and 5), the various temper types form coherent arrays that display placering trends in compositional space. On the VRF-plg-FM diagram (Figure 4), placer effects are seen to concentrate ferromagnesian grains of higher specific gravity relative to plagioclase feldspar and largely vitric volcanic rock fragments of lower specific gravity. On the plg-cpx-opa diagram (Figure 5), including only the subpopulation of monocrystalline mineral grains exclusive of vitric and polycrystalline rock fragments, placering is seen to first enhance the content of clinopyroxene grains relative to plagioclase feldspar grains, and then to further concentrate opaque iron oxide grains of even higher specific gravity than clinopyroxene. The sedimentology of stream placering implies that placered and unplacered sands can be deposited in close proximity to one another along the same reaches of a given stream. Analogous variations between unplacered and placered tempers have been observed repeatedly for temper suites from multiple Pacific islands (Dickinson 2006). The slight compositional gap of ≤10% in plg content between UPLT-PPLT and PPET-OPET tempers on the plg-cpx-opa diagram (Figure 5) could be interpreted to mean that the more strongly placered tempers did not derive from Teouma Stream. That interpretation is discounted here, given the overall congruence of grain types in the placered and unplacered tempers (Table 3).

Table 3. *Mean frequency percentages of grain types±standard deviations of variance with respect to multiple individual frequency counts (see Appendix) for terrigenous (non-hybrid) Efate-derived volcanic sand temper types in Teouma Lapita vessels. N=number of vessels in each dataset.*

Grains[1]	UPLT	UPLT	UPLT	PPLT	PEPT	PEPT	PEPT	OEPT	OEPT	OEPT
	total vessels (N=50)	carinated vessels (N=30)	other vessels (N=20)	total vessels (N=8)	total vessels (N=14)	carinated vessels (N=9)	other vessels (N=5)	total vessels (N=21)	carinated vessels (N=13)	Other vessels (N=8)
Plg	46±8	46±8	47±8	52±7	43±5	44±5	41±5	14±9	14±9	14±10
Cpx	3±2	3±2	3±1	8±2	23±5	23±5	23±6	16±7	16±6	16±7
Opa	2±1	2±1	2±1	4±2	11±5	9±5	13±5	60±17	60±17	61±17
VRF	48±9	48±9	48±9	36±7	23±6	23±6	22±5	10±5	10±4	10±6
VVI	95±2	95±2	94±3	95±3	88±9	87±10	90±3	91±7	89±8	93±5

1. Grain types: plg–plagioclase, cpx–clinopyroxene, opa–opaque iron oxides (magnetite-ilmenite), VRF–volcanic rock fragments, VVI (vitric volcanic index): percentage of volcanic rock fragments composed of felsic volcanic glass or its cryptocrystalline alteration products from devitrification

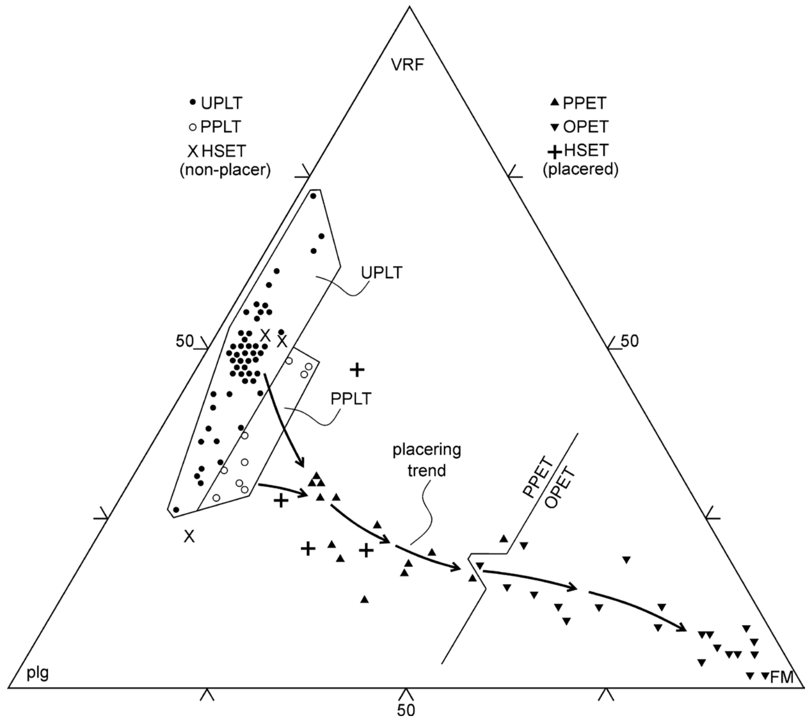

Figure 4. Ternary compositional diagram (all temper grains) for Efate-derived tempers in Teouma Lapita sherds (terrigenous fractions plotted for HSET hybrid tempers are ignored for drawing the placering trend). Poles for frequency percentages are volcanic rock fragments (VRF), plagioclase feldspar (plg), and ferromagnesian (FM) grains (silicates and oxides combined).

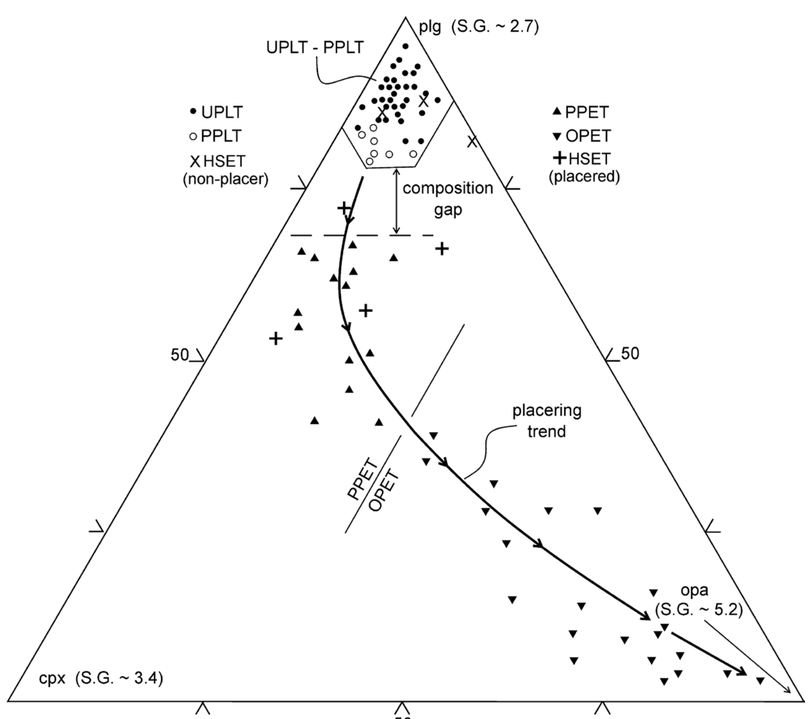

Figure 5. Ternary compositional diagram of mineral grains exclusive of volcanic rock fragments for Efate-derived tempers in Teouma Lapita sherds (terrigenous fractions plotted for HSET hybrid tempers are ignored for drawing the placering trend). Poles for frequency percentages are plagioclase feldspar (plg), clinopyroxene (cpx), and opaque iron oxides (opa).

The terrigenous fractions of hybrid HSET beach tempers are somewhat more variable in composition than the fluvial Teouma Stream tempers (Figures 4 and 5), and the proportions of vitric grains (~42%) among volcanic rock fragments is less than half that of the Teouma Stream tempers (Table 4). The contrast in the nature of volcanic rock fragments could be interpreted to mean that HSET tempers derive from some locale on Efate other than Teouma, but we prefer the interpretation that sluicing on the shoreline preferentially flushed porous vitric grains from sand aggregates, and that the HSET tempers derive from the coast at the head of Teouma Bay. If so, then 89% of the Teouma vessels are indigenous wares made at or near Teouma. Local fabrication of the bulk of Lapita ceramic assemblages is the common experience throughout Pacific Oceania (Dickinson 2006).

The absence of any calcareous grains from all Teouma Stream tempers (see Appendix) is unexpected because tracts of uplifted limestone from which detrital calcareous limeclasts could be derived are exposed along the middle course of Teouma Stream (Figure 3). We infer that erosion of limestone on Efate proceeds dominantly by solution weathering without producing detrital limeclasts.

EXOTIC WARES

Three temper types in selected Teouma vessels cannot be ascribed to derivation from Teouma Stream or Bay, nor to any other locale on Efate. They are inferred to reflect ceramic transfer of pottery by exchange, trade, or even the direct participation in mortuary rituals at Teouma by individuals from islands elsewhere in central Vanuatu (three vessels) and from New Caledonia (nine vessels).

Exotic Vanuatu Wares

The non-Efate Vanuatu tempers in three Teouma vessels are volcanic sands containing hornblende (Table 4), a ferromagnesian mineral unknown from the bedrock of Efate. The most convincing case for an exotic temper origin can be made for a hybrid placer temper, counted twice in two separate thin sections for confirmation of its composition (see Appendix), in which a majority of the terrigenous grains (65% of the total) are ferromagnesian silicates and oxides with a hornblende:pyroxene ratio of 11:1. That level of predominance of hornblende over pyroxene seems impossible for any sand of Efate provenance even if geologic descriptions of the island are incomplete. Hornblende-rich tempers are known in Vanuatu only from Santo and Malekula 150–400 km north of Efate in central Vanuatu (Figure 6), and the anomalous vessel is inferred to derive from that region. The only caveat to that conclusion stems from the presence of minor quartz gains in the hornblende-bearing tempers of the exotic Teouma vessels. Quartz does not occur except in trace amounts in any other known tempers from Vanuatu, but minor quartz-bearing dacite is known as a potential subordinate bedrock source for sand in the ancestral Vitiaz arc assemblage of western Vanuatu (Figure 2A). The calcareous grains in the anomalous temper are reworked limeclasts composed of diagenetic microspar, rather than modern reef detritus, and are inferred to derive from the widespread limestone terraces that overlie Vitiaz arc assemblages on Santo and Malekula (Figure 6).

The other two Teouma vessels containing hornblende-bearing but non-hybrid tempers contain much less hornblende (hornblende:pyroxene ratio of 1:8), but are also inferred to derive from Santo or Malekula. Previous study of 40 prehistoric potsherds from Efate exclusive of Teouma

Table 4. *Mean frequency percentages of terrigenous grain types ± standard deviations of variance with respect to multiple individual frequency counts (see Appendix) for hybrid Efate tempers (HSET) and non-Efate hybrid and non-hybrid tempers (NEHVT) from elsewhere in central Vanuatu. N=number of vessels in each dataset. Calcareous grains tabulated as proportions of total grain populations (calcareous + terrigenous grains).*

Grains types[1]	HSET	HSET	NEHVT	NEHVT
	unplacered tempers (N=3)	placered tempers (N=4)	unplacered non-hybrid tempers (N=2)	placered hybrid temper (N=1)
Quartz	0	0	2 ± 0	6
Plagioclase	49 ± 12	44 ± 10	45 ± 6	16
Clinopyroxene	3 ± 3	17 ± 5	24 ± 6	2
Hornblende	0	0	3 ± 2	23
Opaque iron oxides	5 ± 2	10 ± 6	6 ± 1	28
Volcanic rock fragments	42 ± 14	29 ± 11	21 ± 3	25
Vitric volcanic index (VVI)[1]	42 ± 14	42 ± 21	41 ± 3	56
Calcareous grains	1%–85%	11%–55%	0%	35%

1. VVI=vitric volcanic index (percentage of volcanic rock fragments composed of felsic volcanic glass or its cryptocrystalline alteration products from devitrification

has detected no hornblende at all in any of their temper sands (Dickinson 2001, 2006). The contrast in composition between the non-hybrid (two vessels) and the hybrid (one vessel) hornblendic tempers implies ceramic transfer to Teouma from two different localities or islands other than Efate.

The quartz grains in all three hornblendic tempers (Table 4) of exotic Teouma wares may conceivably imply that the vessels containing hornblendic tempers derive from much farther away than central Vanuatu. It is notable that numerous obsidian flakes from the 'Lapita homeland' of the Bismarck Archipelago east of New Guinea have been recovered from Teouma excavations (Reepmeyer *et al.* 2011). Tempers containing both quartz and hornblende grains occur in tempers of uncertain specific derivation in sherd suites from Mussau and the Admiralty Islands in the northern Bismarck Archipelago (Dickinson, 2000, 2006: Tables 13 & 16). Neither the hybrid nor the non-hybrid tempers in hornblendic Teouma sherds are closely similar either texturally or mineralogically, however, to quartz- and hornblende-bearing tempers in sherds excavated at Mussau (Dickinson 2013). Most Bismarck tempers, like most Vanuatu tempers, lack any quartz, and we are unable with present information to evaluate the likelihood of ceramic transfer over a distance of ~3500 km from the Bismarck Archipelago to Efate..

New Caledonian Wares

Much more quartzose temper sands in nine Teouma vessels are wholly unlike any tempers known from Vanuatu or the Bismarck Archipelago (Dickinson 2001: 285–294, 2006: 61–67), and bear distinctive hallmarks of New Caledonian origin (Dickinson 2002, 2006: 99–101). These Teouma vessels without question document ceramic transfer of 8% of the Teouma ceramic assemblage from Grand Terre, the main island of New Caledonia (Tables 1 and 2). Both the temper types of New Caledonian derivation (NCMHT, NCQHT) contain a third or more monocrystalline quartz grains and nearly half quartzose grains if polycrystalline quartz aggregates (quartzite, vein quartz, chert) are included in the total (Table 5). Similarly high levels of quartz content are unknown for temper sands from any other islands of the southwest Pacific (Dickinson 2006). One of the New Caledonian temper types (NCMHT) contains metavolcanic (amphibolite) and metasedimentary (quartz-mica schist) rock fragments for which no provenance is known in Vanuatu, as well as metamorphic mica flakes and garnet grains unknown from any temper sands of either Melanesia or Polynesia apart from New Caledonia (Grand Terre). Most telling for the New Caledonian origin of the NCMHT temper type is the presence of unusual pyriboles that occur within island Melanesia only in blueschist facies metamorphic rocks of Grand Terre: soda-rich jadeitic clinopyroxene displaying anomalous interference tints, untinted diopsidic augite, iron-poor and colorless magnesian amphiboles (cummingtonite, tremolite), and especially the blue (in thin section) sodic amphibole glaucophane (see Appendix). The latter mineral is diagnostic of an origin for the temper on Grand Terre in New Caledonia even without the other parallel mineralogical indicators.

Table 5. *Mean frequency percentages of grain types ± standard deviations of variance with respect to multiple individual frequency counts (see Appendix) for terrigenous fractions of NCQHT and NCMHT hybrid tempers in New Caledonian vessels of the Teouma Lapita ceramic assemblage. N=number of vessels in each dataset. Calcareous grains tabulated as proportions of total grain populations (calcareous + terrigenous grains).*

Grain types	**NCQHT** (N=5)	**NCMHT** (N=4)
monocrystalline quartz mineral grains	33 ± 3	38 ± 3
multicrystalline quartz (quartzite, vein quartz, chalcedonic chert)	15 ± 3	11 ± 4
(**total quartzose grains**)	(**48 ± 1**)	(**49 ± 6**)
monocrystalline plagioclase feldspar mineral grains	25 ± 2	12 ± 3
monocrystalline K-feldspar mineral grains	13 ± 2	3 ± 1
(**total monocrystalline feldspar mineral grains**)	(**38 ± 3**)	(**15 ± 3**)
metamorphic pyribole mineral grains (pyroxene and amphibole)	–	18 ± 4
opaque iron oxide mineral grains (magnetite and ilmenite)	–	2 ± 1
garnet mineral grains (isotropic with high refringence)	–	4 ± 2
biotite (black) and muscovite (white) mica flakes	–	4 ± 2
polycrystalline metavolcanic and metasedimentary rock fragments	–	8 ± 2
unmetamorphosed felsitic volcanic rock fragments	14 ± 1	–
calcareous grains of reef detritus	>50%	0–30%

The Teouma vessels containing two different types of New Caledonian tempers could not have come from the same locale on Grand Terre. NCMHT tempers rich in metamorphic detritus are inferred to derive from the northwest end of the island where the Diahot and Pouébo metamorphic terranes are exposed, whereas NCQMT tempers lacking metamorphic rock fragments but containing both chert and felsite rock fragments probably derive from southern reaches of the southwest coast where the Téremba-Moindou arc-forearc terrane is exposed (Dickinson 2002, Chiu *et al.*, 2011). The NCQHT tempers (Table 5) are so close in composition that counted percentages of grain types overlap at one standard deviation of counting error for the limited number of terrigenous grains (n=48–73) present in five sherd thin sections (see Appendix). The five vessels containing NCQHT tempers may well derive from the same Lapita settlement on Grand Terre, and conceivably could have been made by the same potter. The four NCMHT tempers are not as closely matched (see Appendix), but are similar enough in overall composition (Table 5) to derive from the same second locale on Grand Terre.

Other New Caledonian sherds detected previously in Vanuatu collections include one sherd with spinel-bearing ophiolitic temper (Dickinson 1971, 2001, 2006a: 115) derived from southern reaches of the northeast coast of Grand Terre but recovered from a Lapita site on Malo island off the south coast of Santo (Figure 6), and a reworked and undecorated sherd of Lapita style from the Ifo site on Erromango (Figure 2) containing a quartzose New Caledonian temper of unknown specific origin on Grand Terre (Dickinson 2006b). The multiplicity of New Caledonian temper types in exotic Vanuatu sherds points to widespread cultural contacts between Lapita occupants of the two nearby island groups.

New Caledonian tempers are mineralogically complex because stream and beach sands of New Caledonia

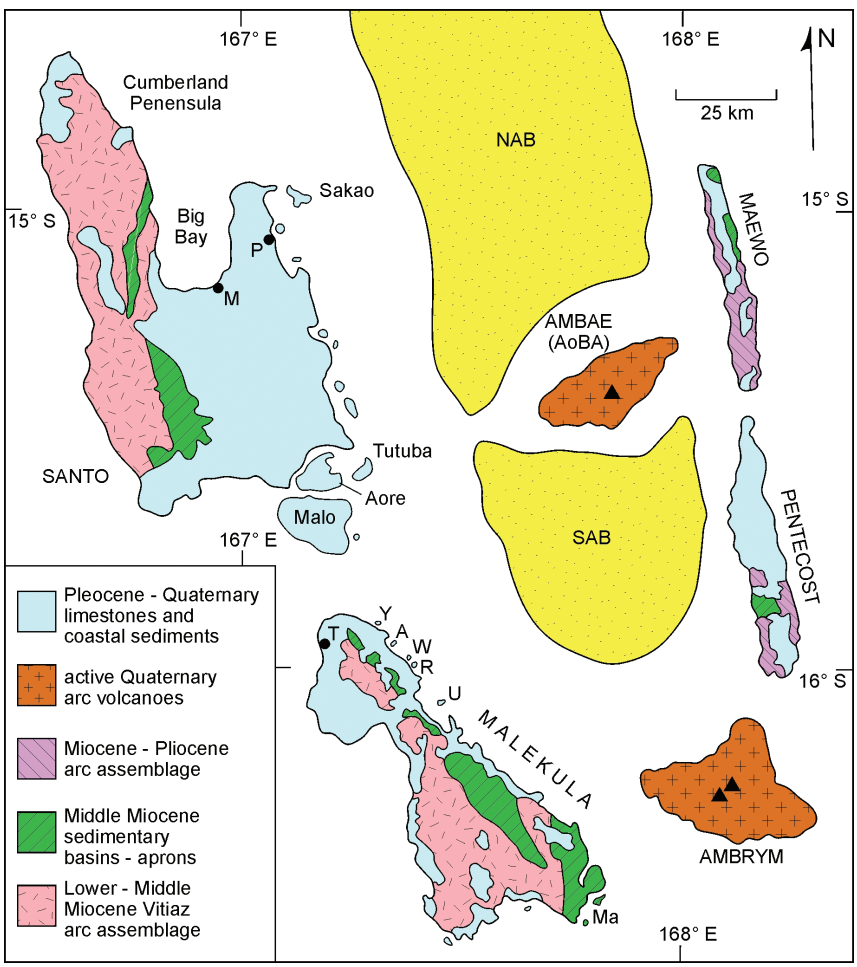

Figure 6. Geologic framework of the six large islands and offshore islets of north-central Vanuatu (see Figure 2 for map area). Floors (stippled) of North (NAB) and South (SAB) Aoba Basins (Fisher *et al.* 1998) delineated by 2000 m bathymetric contour. Solid triangles denote active volcanoes. Islets offshore from Malekula (north to south): V–Vao, A–Atchin, W–Wala, R–Rano, U–Uripiv, M–Maskelyne (multiple tiny islets). Selected localities: M–Matantas, P–Port Olry, T–Tenmaru. Geology adapted (with outcrop patterns simplified) after Robinson (1969), Mitchell (1971), Mallick & Neef (1974), Carney (1986), Carney & Macfarlane (1986), Macfarlane *et al.* (1988), Eggins (1993), Robin *et al.* (1993), Picard *et al.* (1995), and Németh *et al.*(2009).

are derived from multiple bedrock sources forming igneous, metamorphic and sedimentary outcrop belts that are disposed longitudinally along much of the 380 km length of Grand Terre (Dickinson 2002). Temper compositions vary markedly because sandy detritus is derived in variable proportions from the different source rocks (Chiu *et al.* 2011). Tempers of New Caledonian Lapita wares recovered from Teouma and other sites in Vanuatu nevertheless fall well within the compositional spectrum of tempers in Lapita wares studied from New Caledonia, whereas they bear no resemblance to indigenous quartz-bearing Vanuatu tempers in either Lapita or post-Lapita wares (Figure 7).

VANUATU TEMPERS

Generic relationships of the sand tempers present in the Teouma ceramic assemblage are further elucidated by comparison of Teouma tempers to the tempers characteristic of various subregional temper provinces within Vanuatu (Figure 2B). Consistent patterns of temper composition within Vanuatu can be related to inherent geologic variations along the New Hebrides island arc (Figure 2A). From this perspective, Teouma tempers take their rightful compositional place in the overall Vanuatu temper spectrum.

Comparison of sand tempers in the indigenous Teouma ceramic suite with tempers in sherds from other islands in Vanuatu reinforces our interpretation of local origin from Teouma Stream. Distinctions among the temper sands of sherd assemblages from different parts of Vanuatu are challenging to draw because the volcanogenic bedrock assemblages of both the ancestral Vitiaz and the active New Hebrides island chains (Figure 2A) are calcalkalic arc suites of similar petrology (Colley & Warden 1974). The delineation of temper provinces (Figure 2B) within Vanuatu depends for detail on empirical data from tempers in sherds indigenous to each island or island cluster. For regional temper analysis, calcareous grains of hybrid tempers are ignored here as undiagnostic of locality, whether composed of modern reef detritus or reworked

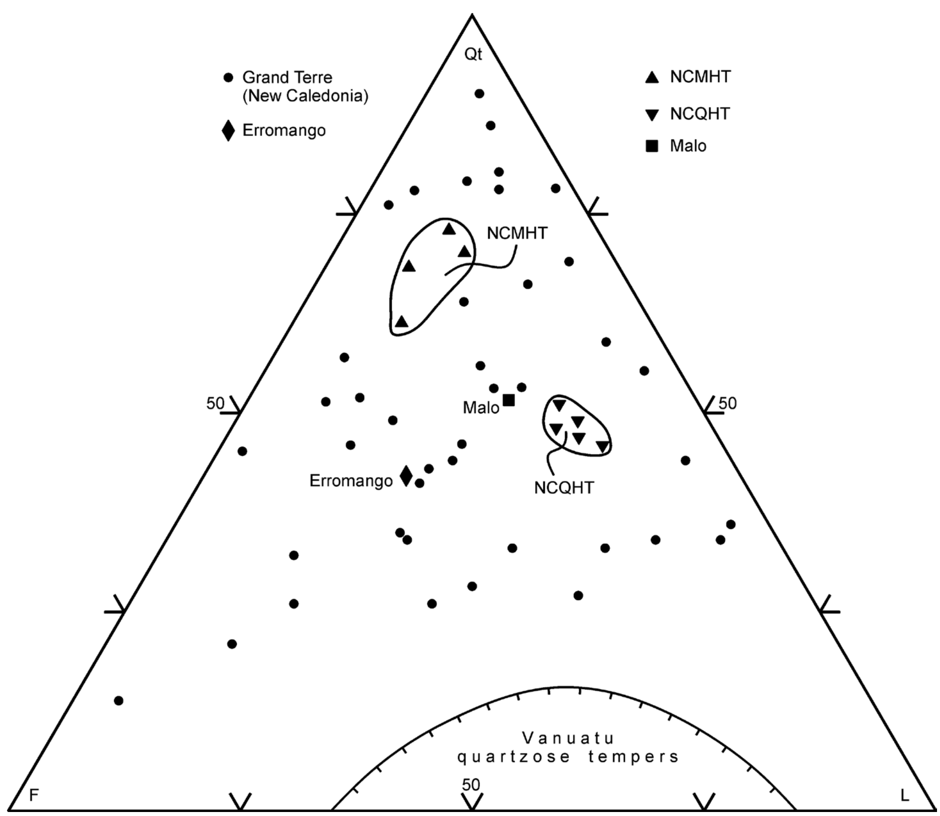

Figure 7. Ternary compositional diagram exclusive of calcareous and ferromagnesian grains for temper sands in (a) excavated Lapita sherds (N=40) from multiple archaeological sites (Goro, Lapita, Nessadiou, Vavouto) on Grand Terre and from the Vatcha site on nearby Île de Pins (Dickinson 2002, Chiu *et al.* 2011), (b) New Caledonia sherds (N=11) recovered from Malo, Erromango, and Efate (Teouma NCMHT and NCQHT temper types) in Vanuatu, and (c) native Vanuatu sherds (N=15) containing minor quartzose grains. Poles for frequency percentages: Qt–total quartzose grains (sum of monocrystalline and polycrystalline quartz grains), F–total feldspar grains (sum of plagioclase and K-feldspar grains), L–labile (<100% quartz) rock fragments (polycrystalline and polymineralic) from varied bedrock source terranes (igneous, sedimentary, metamorphic). Tempers containing >70% combined calcareous and opaque grains are not plotted.

as detrital limeclasts from emergent limestone terraces.

Plotting known Vanuatu tempers in VRF-plg-FM ternary space (Figure 8), the same display used for Efate-derived Teouma tempers (Figure 4), reveals wide and intricate overlap of the compositional fields for temper sands in sherd assemblages from various islands. Placering effects to concentrate ferromagnesian grains are evident for ~75% of the temper suites, but this sedimentological process confuses rather than clarifies relations of derivative temper sands to island bedrock sources. Rather than relying on bulk temper compositions to make generic distinctions between volcanic sand tempers of Oceanian islands, attention is more fruitfully focused instead on the nature of the ferromagnesian silicate mineral grains in the temper suites (Dickinson 2007). Ferromagnesian silicate sand grains are derived from phenocrysts of sand size or larger in volcanic bedrock, their occurrences tend to be both consistent and distinctive in volcanic source rocks, and their relative proportions do not vary markedly from placering. Vanuatu temper provinces can accordingly be successfully delineated (Figure 2B) based on differences in the relative contents of the ferromagnesian mineral grains olivine, pyroxene (predominantly clinopyroxene), and hornblende in temper sands (Table 6).

Vanuatu sherd assemblages can be subdivided into older Lapita suites and younger post-Lapita suites of varied incised, fingernail impressed, and applied relief styles (Bedford & Clark 2001, Spriggs 2003, Bedford 2003 & 2007, Bedford 2006: 157–192, Bedford & Spriggs 2008, Bedford & Galipaud 2010). Tempers in Lapita and post-Lapita sherds from the same sites or islands in Vanuatu do not differ substantially in composition (Table 6), arguing that it is the geologic provenance of sands available locally for temper and not changes in collecting habits that governed the nature of Vanuatu temper sands over time. It should be noted, however, that only the earliest Lapita sites in Vanuatu have yielded any exotic sherds. Otherwise, general congruence of tempers in Lapita and post-Lapita sherds has now been documented for sherd collections from Taumako (Leach & Davidson 2008, Dickinson 2008), Nendö

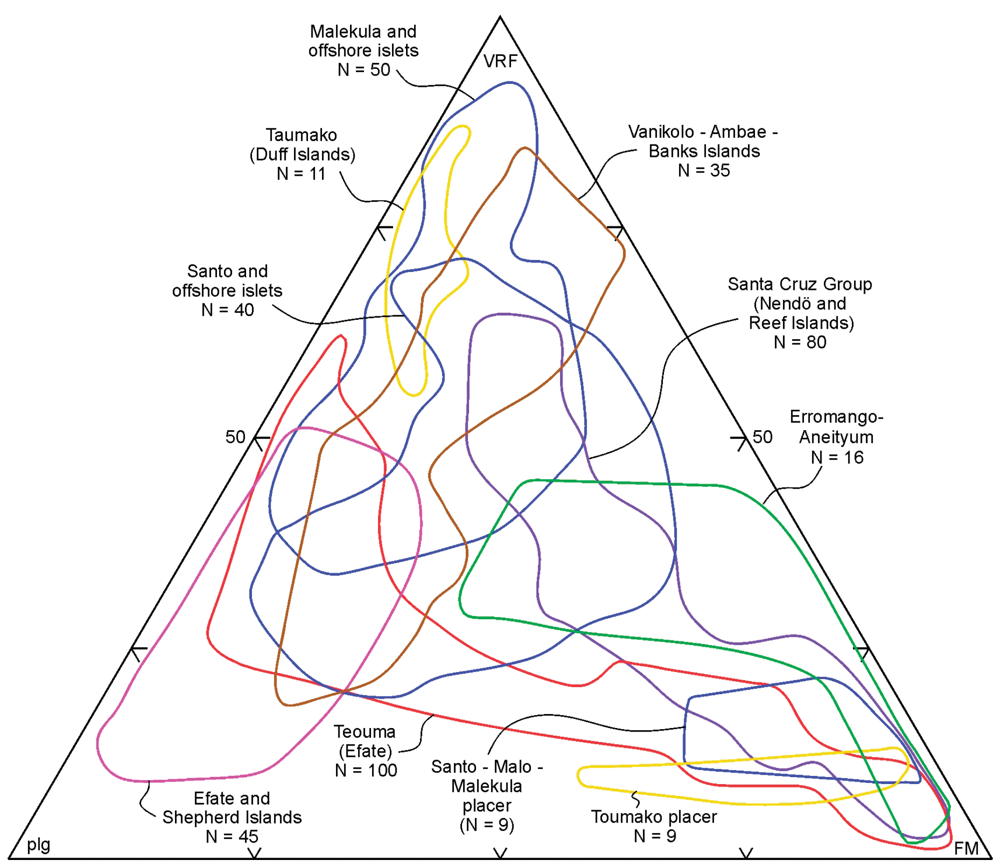

Figure 8. Compositional fields for variably placered Vanuatu temper sands in prehistoric sherds from different islands or island clusters in VRF–plg–FM space (poles same as Figure 4). Teouma field after Figure 4. Other fields adapted from Dickinson (2006: 64–65) using unpublished data (n~95 sherds) for Ambae, Aneityum, the Banks Islands, Epi, Malekula, Santo, and the Santa Cruz Group (Nendö and the Reef Islands). Proportions of terrigenous grain types in hybrid tempers are recalculated to 100% exclusive of undiagnostic calcareous grains, and outlier temper compositions are omitted for clarity. Color bands bounding temper fields are coded by temper province (Figure 2).

Table 6. *Diagnostic grain indices (Dickinson 2006:29) for Vanuatu tempers (means ± standard deviations) calculated from frequency percentages (for n sherds) of temper grain types (see Figure 2B for temper provinces). Pottery styles: L–Lapita, pL–post-Lapita).*

Province	island or island cluster	n	style	OLi[1]	PYi[2]	VVi[3]
I	Taumako indigenous pottery[4]	11	L-pL	0	100	24 ± 6
	Taumako indigenous pottery (placer temper)	9	pL	0	99 ± 1	nd
II	west Nendö (multi-sites) indigenous pottery	12	L-pL	2 ± 2	98 ± 2	18 ± 8
	east Nendö (Nanggu) indigenous pottery	6	L	8 ± 4	98 ± 2	32 ± 16
	Reef Islands Lapita pottery from Nendö	12	L	8 ± 3	99 ± 1	43 ± 12
	Reef Islands post-Lapita pottery from Nendö	18	pL	9 ± 2	99 ± 1	42 ± 14
	Tikopia indigenous pottery (Kiki phase)	5	L	53 ± 10	100	nd
III	Vanikolo indigenous pottery	8	L-pL	0	100	58 ± 11
	Tikopia pottery (Sinapupu) from Vanikolo	10	pL	0	99 ± 1	~50
	Banks Islands indigenous pottery	10	pL	0	92 ± 6	47 ± 14
	Ambae (Aoba) indigenous pottery[4]	4	pL	0	100	20 ± 12
IV	Vanikolo pottery from Santo	2	pL	0	67 ± 3	26 ± 18
	Torres Islands pottery from Santo	5	pL	0	81 ± 2	10 ± 6
	Santo indigenous pottery (SW mainland)	12	pL	0	73 ± 8	25 ± 16
	Santo indigenous pottery (NE mainland)	10	L	0	94 ± 3	22 ± 6
	Malo Island pottery from Santo	14	L	0	82 ± 9	14 ± 4
	Malekula (Tenmiel) pottery from Santo	1	pL	0	93	20
	Teouma pottery[5] from Santo (?)	2	L	0	88 ± 9	41 ± 3
	Malekula (+offshore islands) pottery	28	pL	0	75 ± 17	18 ± 5
	Vao Island pottery from Malekula	22	L	0	76 ± 19	16 ± 9
	Ambae pottery from Malekula	5	pL	0	40 ± 4	15 ± 8
	Teouma pottery[6] from Malekula (?)	1	L	0	8	59
V	anomalous Santo sherd from Kuwae (?)	1	L	0	100	100
	anomalous Vao sherd from Kuwae (?)	1	L	0	100	95
	anomalous Malekula sherd from Kuwae (?)	1	pL	0	100	95
	Epi Island indigenous pottery	4	pL	0	100	0-100
	Shepherd Islands[7] indigenous pottery	3	pL	0	100	98 ± 2
	Teouma (Efate) indigenous pottery	85	L	0	100	94 ± 4
	non-Teouma Efate[8] and offshore islets[9]	40	pL	0	100	98 ± 2
VI	Erromango indigenous pottery	10	L-pL	2 ± 2	100	41 ± 20
	Aneityum indigenous pottery	6	L-pL	3 ± 2	99 ± 0.5	52 ± 14

1. Olivine index: 100 × (olivine mineral grains/total ferromagnesian silicate mineral grains)
2. Pyribole index: 100 × [pyroxene/(pyroxene+hornblende)] calculated for tempers containing >5% pyribole grains
3. Vitric volcanic index: 100 × (vitric volcanic rock fragments/total volcanic rock fragments) calculated for tempers containing >12% volcanic rock fragments (nd = not determined)
4. Taumako and Ambae temper sands respectively contain 2 ± 1% and 7 ± 4% chalcedonic silica grains derived from amygdules (filled vesicles) in mafic lavas
5. Also contains 6% quartz mineral grains (anomalous for other Santo tempers)
6. Also contain 2% quartz mineral grains (anomalous for other Malekula tempers)
7. Surface sherds from Tongoa and Emae
8. Mangaasi-Arapus, Mele, and Erueti sites
9. Surface sherds from Leleppa and Retoka

and the Reef Islands (Green *et al.* 2008, Doherty 2009), Vanikolo or Vanikoro (Kirch 1982, 1983), Santo (Bedford & Spriggs 2008:103), Malekula and offshore Vao islet (Bedford 2001 & 2003, Bedford & Spriggs 2008:103, Bedford & Galipaud 2010), Erromango (Spriggs & Wickler 1989, Bedford 1999, 2006:85–103), the Mangaasi-Arapus site on Efate (Bedford 2000, Bedford & Spriggs 2000, Spriggs & Bedford 2001, Bedford 2006:105–132, Bedford, 2009), and Aneityum (this paper). The consistent similarity of sand tempers in Lapita and post-Lapita wares from given sites in Pacific Oceania is supported by detailed studies of ceramic assemblages from outside Vanuatu at Watom in the

Bismarck Archipelago, on Buka at the northern end of the Solomon Islands, at Sigatoka on Viti Levu in Fiji, and in the Ha'apai Group of central Tonga (Dickinson 2006a).

Northeastern Temper Provinces

Province II (Nendö-Tikopia) is distinguished from Province I (Taumako) and Province III (Vanikolo-Banks-Ambae) by the presence of significant olivine in temper sands (Table 6), but the temper suites in all three of those northern provinces (Figure 2B) were otherwise derived from dominantly mafic (basalt and basaltic andesite) source rocks of similar character though varying age (Figure 2A). Vitric volcanic rock fragments are composed of mafic sideromelane of brownish to reddish hues rather than being the colorless (in thin section) to pale tan felsic glass fragments prominent in Efate-derived Teouma tempers. Olivine-rich tempers at Tikopia within a backarc oceanic basin are readily explicable as representative of a mafic variant of the postarc-backarc temper class (Dickinson 2006: 13), but the reason for the dominance of olivine-bearing temper sands on Nendö in the Santa Cruz Group is not readily apparent from extant geologic descriptions. Olivine is mentioned as a phenocrystic mineral in Nendö lavas (Hughes *et al.* 1981) of Province II, but in general not more prominently than for lavas of Vanikolo (Hughes *et al.* 1981), the Banks Islands (Mallick & Ash 1975, Ash *et al.* 1980, Robin *et al.* 1995), and Ambae (Warden 1970, Eggins 1993) in Province III. Tempers in sherds from east Nendö are notably more olivine-rich than tempers in sherds from west Nendö (Table 6), implying that the Nendö wares taken ~50 km to the nearby Reef Islands (Dickinson 2001, 2006: 62–63) were derived from the Nanggu site or near it on easternmost Nendö. The Lapitoid Kiki phase of indigenous pottery containing olivine-rich temper on Tikopia was succeeded (Kirch & Yen 1982) by the post-Lapita Sinapupu phase of pottery containing olivine-poor temper inferred to reflect ceramic transfer from Vanikolo >200 km to the west in Province III (Table 6). Known Province III tempers from Vanikolo, the Banks Islands, and Ambae lack any placered variants comparable to Taumako (Province I) or Nendö (Province II) placer tempers (Figure 8), but that contrast in the temper suites is perhaps sedimentological accident rather than generic distinction.

Available sherds from the Duff Islands forming Province I derive from the small island of Lakao (~20 km²) located ~10 km northwest of Taumako (Leach & Davidson 2008: 301–302). Given the association of Neogene eruptions that produced the volcanoes and volcano remnants of the Duff Islands (Figure 2AB) with the propagating northern end of the backarc Vot Tande rift trough, any sands available for temper on Mere Lava (Barsdell 1988) or Futuna (Carney and Macfarlane 1979, Marcelot *et al.* 1983) in analogous backarc positions farther south (Figure 2AB) may resemble Taumako tempers of Province I, although no sherds are available to test that supposition. There is currently also no ceramic control for temper sands that might be collected on Pentecost (Mallick & Neef 1974) or Maewo (Carney 1986) along the rear flank of the central New Hebrides arc edifice (Figure 6). Province III is extended southward here to include the large volcanic island of Ambrym (Figure 6), analogous in its tectonic setting to Ambae (Figure 2AB), and the smaller islands of Paama and Lopevi off its south coast, because of their basaltic geology (Robin *et al.* 1993, Picard *et al.* 1995, Németh *et al.* 2006 & 2009, Handley *et al.* 2008), but no sherd collections have yet been studied petrographically from those three related islands.

Santo-Malekula Tempers

Tempers from Province IV lying to the west of Province III (Figure 2B) and exposing the Vitiaz arc assemblage of central Vanuatu (Figure 2A) contain abundant hornblende that is rare or wholly absent in Province I-II-III temper sands (Table 6). The temper contrast reflects the greater abundance of andesitic volcanic rocks in the bedrock assemblages of Santo (Robinson 1969, Mallick and Greenbaum 1977, Carney and Macfarlane 1986), Malekula (Mitchell 1966, 1971), and the Torres Islands (Greenbaum *et al.* 1979) than in island clusters farther to the east and north where basaltic rocks are dominant. Bedrock exposures beneath uplifted limestone cover are severely limited in the Torres Islands (Greenbaum *et* al. 1985), where the pottery that has been recovered (Galipaud 1998) contains terrigenous temper sands that probably reflect ceramic transfer from Santo (Table 6). Subordinate sherds containing hornblendic temper sands recovered on Vanikolo in Province III are also interpreted to reflect ceramic transfer from Santo (Table 6).

Temper sands in sherds from Santo, Malekula, and nearby offshore islets of Province IV overlap broadly in bulk composition (Figure 8), as the similar geology of the two islands would predict (Figure 6). Eastern Santo, coastal fringes of Malekula, and islets offshore from the east coasts of both islands are underlain entirely by emergent reef limestones, implying that terrigenous temper sands and the terrigenous fractions of hybrid temper sands in sherds recovered from those locales derive from the areas of bedrock exposure on western Santo and in the interior of Malekula. The terrigenous nature (only ~5% reef detritus) of beach gravel collected at Matantas on the shoreline of Big Bay on eastern Santo (Figure 6) indicates, however, that terrigenous detritus from interior bedrock exposures of Santo and Malekula can be delivered by streams to limestone coasts of the islands. That dictum cannot apply, however, to long reaches of the east coast of Santo where all local streams head in limestone plateaus of eastern Santo. Along the east coast of Malekula (Figure 6), the extent to which terrigenous sands delivered to the coast by streams can be dispersed by shoalwater currents to nearby offshore islets is unclear, but terrigenous temper sands in sherds from the offshore islets probably reflect either ceramic transfer from mainland Malekula or transport of temper from the mainland to the islets. The frequent recovery of clay wasters from Lapita sites on the small offshore islets is indicative of substantial transport of ceramic raw materials from the Malekula mainland to islets offshore. At Vao Island (Figure 6), the predominance of stream sand tempers, which are present instead of beach sands in 75% of the local sherd assemblage, implies ceramic transfer from the mainland rather than sedimentary transport of terrigenous sand to islet beaches. Similarly, sherds with terrigenous tempers from Port Olry (Figure 6) on northeast Santo probably reflect ceramic transfer from a locale or locales farther west on Santo, but information about areal variations in temper compositions is not detailed enough to support a systematic analysis of ceramic transfer within the Santo or Malekula realms of Province IV.

The Santo temper suite includes somewhat more feldspathic and ferromagnesian variants than the Malekula temper suite, but placer variants of both temper suites overlap closely in composition (Figure 8). Ratios of pyroxene to hornblende also overlap for Santo and Malekula tempers (Table 6), although there is a tendency for a slightly higher ratio in Santo tempers than in Malekula tempers. On a strictly empirical basis from temper analysis, without any support from geologic descriptions of the bedrock assemblages exposed on the two islands, the internal textures of the volcanic rock fragments in Santo and Malekula temper sands differ in character (Dickinson 2001, 2006a: 63–66, 2006b: 312–315). Volcanic rock fragments of Malekula tempers in sherds from both the mainland and the islets offshore from eastern Malekula (Figure 6) are characteristically felsitic, composed of microcrystalline quartz-feldspar mosaics, whereas volcanic rock fragments of Santo tempers are characteristically microlitic, composed of plagioclase microlites set in volcanic glass (hyalopitic texture) or packed tightly together (pilotaxitic texture). Occurrences of the two kinds of andesitic rock fragments are not mutually exclusive in tempers from the two islands, but the ratio of felsitic to microlitic rock fragments is 0.5–50 in Malekula temper suites but <0.25 in Santo temper suites. One sherd recovered from Tenmaru on northern Malekula (Figure 6) is inferred to derive from nearby Santo (Table 6) based on the absence of any felsitic volcanic rock fragments in its temper, which contains only microlitic volcanic rock fragments (Dickinson 2006b: 316–317). That sherd is to date the only robust indication from temper analysis for prehistoric ceramic transfer between Santo and Malekula.

The presence of Lapita sherds with terrigenous sand tempers on Malo (Hedrick 1971), a limestone island located between Santo and Malekula (Figure 6), is ascribed to ceramic transfer from nearby Santo based on the predominance of microlitic volcanic rock fragments in their temper sands, for which the ratio of pyroxene to hornblende is undiagnostic (Table 6). Lapita sherds from the adjacent limestone island of Aore (Galipaud & Kelly 2007, Galipaud 2010) have not yet been studied in thin section. By contrast with Malo pottery, sherds recovered on Ambae (Figure 6) containing anomalous Province IV rather than indigenous Province III tempers (Table 6) contain three to five times as many felsitic as microlitic rock fragments (Dickinson, 2006b), and are accordingly inferred to document ceramic transfer from Malekula rather than Santo, even though the latter island lies closer to Ambae (Figure 6). Ceramic transfer to Ambae from Malekula is further implied by high contents of hornblende with respect to pyroxene in the tempers of the exotic Ambae sherds as opposed to sherds thought to be indigenous to Ambae (Table 6). A Malekula–Ambae temper connection is backed up by both linguistic and traditional exchange ties between northeast Malekula and southwest Ambae (Huffman 1996, Tryon 1996).

The nature of the volcanic rock fragments in a temper sand is not, however, an infallible guide to alternate origins on Santo or Malekula, and must be treated with caution as a criterion for sourcing Santo and Malekula tempers. For example, the tempers in four of five sherds from the Maskelyne Islands off the southeast tip of Malekula (Figure 6) contain predominantly microlitic rather than felsitic volcanic rock fagments (felsitic:microlitic ratio ≤0.25), but there is little likelihood that Maskelyne pottery derived from Santo rather than being made locally or derived from nearby Malekula (Dickinson 2006b). With that caveat in mind, the three Teouma vessels containing tempers (NE-HVT of Table 4) with probable origins in central Vanuatu may, on the basis of the volcanic rock fragments in their temper sands (see Appendix), derive from both Santo and Malekula (Table 6). In the placered hybrid temper, the high ratio (10:1) of felsitic to microlitic volcanic rock fragments suggests derivation from Malekula whereas the much lower ratio (0.07–0.67) in the unplacered non-hybrid tempers suggests derivation from Santo. The presence of quartz mineral grains and the high proportions of vitric volcanic rock fragments in the exotic Teouma sherds are atypical of either Santo or Malekula tempers (Table 6), and leave open the possibility that the exotic Teouma sherds derive from the Bismarck Archipelago rather than from central Vanuatu.

Efate-Shepherd Tempers

Islands extending northward from Efate for 75–100 km through the Shepherd Islands to Epi are associated with an elongate array of Quaternary calderas (Figure 9), of which the youngest (Kuwae) collapsed in AD 1452 (Monzier *et al.* 1994, Robin *et al.* 1994a, Witter & Self 2007). The southernmost caldera, just north of Efate, is inferred here to be the volcanic center from which the proximal pumice breccias of Efate were derived. Volcanic suites of the Shepherd Islands are bimodal (Warden 1967, Barsdell & Berry 1990), forming both mafic and felsic islets. Islets disposed

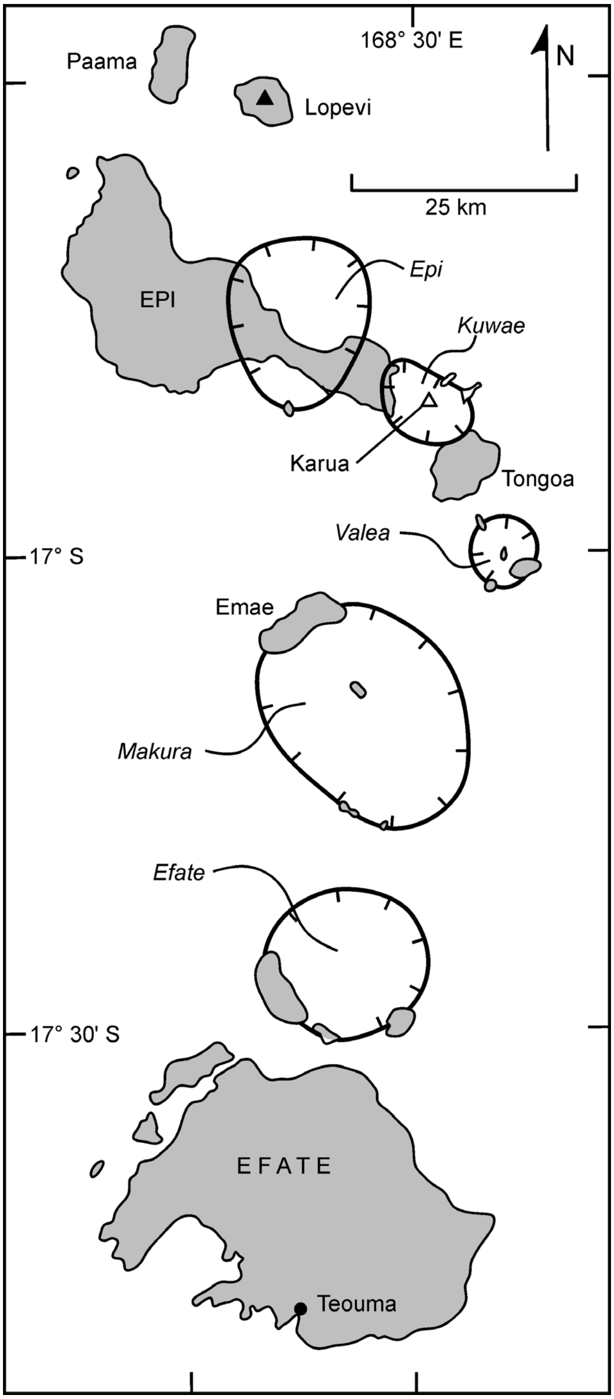

Figure 9. Geographic relations of Efate (Figure 3) and islands to the north in south-central Vanuatu to prominent Quaternary calderas (see Figure 2 for map area) delineated by heavy hachured lines after Warden (1967), Crawford *et al.* (1988), Barsdell & Berry (1990), Monzier *et al.* (1994), Robin *et al.* (1994), Witter & Self (2007), and Handley *et al.* (2008). Islands shaded. Active volcanoes include subaerial Lopevi (solid triangle) and submarine Karua (open triangle). Caldera names are taken from previous designations (Epi, Kuwae) or adopted here from their effusive volcanic debris (Efate) or their central intracaldera volcanic islands (Makura, Valea).

around caldera rims are largely post-collapse basaltic edifices erupted from the ring fracture systems of the calderas, although some extracaldera remnants of pre-collapse volcano flanks are present locally. Renewed post-collapse volcanism has also formed small intracaldera basaltic islets. Most islands are mantled, however, by dacitic-rhyodacitic ash and breccia, petrologically akin to the bedrock of Efate and erupted from vanished islands that once stood above the sites of calderas. Temper Province V (Figure 2B) is coextensive with the array of caldera-related islands including Efate, and has yielded sherds consistently containing vitroclastic tempers rich in vitric volcanic rock fragments (Table 6). There is broad overlap between the compositions of unplacered variants of Teouma temper and other Efate-Shepherd tempers (Figure 8), including the tempers in sherds from Mangaasi-Arapus and Mele on southwest Efate (Figure 3) that were also derived from erosion of the pumice breccias of central Efate (Dickinson 1972, Dickinson *et al.* 1999, Dickinson 2006b: 311)

Two Lapita sherds, one from Vao off Malekula and one from Matantas on Santo, and a third non-Lapita sherd from Vilavi on Malekula, contain distinctive temper sands atypical for either Malekula or Santo but composed dominantly of subequal proportions of dark brown mafic and pale tan felsic volcanic glass fragments. The AD 1452 Kuwae eruption is known to have incorporated both mafic and felsic glass into the pyroclastic debris spread as basaltic andesite hydroclastite (mafic) and pumiceous dacite ignimbrite (felsic) across the surfaces of Epi and neighboring Shepherd Islands during caldera collapse (Robin *et al* 1994b). We speculate here that the three anomalous sherds may represent pottery made on ancestral Kuwae Island (Table 6), which stood at the site of the Kuwae caldera before the paroxysmal eruptions that triggered caldera collapse and cataclysmic destruction of the island (Clark, 1996).

Southern Vanuatu Tempers

Province VI of southern Vanuatu (Figure 2B) has yielded sherds with olivine-bearing mafic temper sands on Erromango (Dickinson 2006b: 305–311) that are broadly similar generically to the tempers in sherds from Nendö (Province II) near the northern end of the New Hebrides island arc. The tempers in Erromango sherds are hybrid sands containing variable minor proportions of calcareous grains (mean content <5%) in the form of detrital limeclasts reworked as grains of diagenetic microspar from the extensive limestone terraces fringing the coasts of Erromango (Colley 1971). Lapita sherds recently recovered (unpublished data) from the Mission Station site on Aneityum are hybrid sands compositionally similar to Erromango tempers (Table 6; Figure 8), but are coastal sands of beach derivation in which the calcareous grains are skeletal and micritic (pelletal) grains derived from modern offshore fringing reefs. The wholly terrigenous temper in a surface sherd of probable local origin found on Aneityum is similar to the terrigenous fraction of the hybrid tempers in five Lapita sherds from Mission Station. Both Erromango and Aneityum are composed of coalesced basaltic volcanoes, and Province VI is inferred here to also embrace Tanna (Shutler & Shutler 1968, Spriggs 1982, Shutler *et al.* 2002) exposing eruptive suites of similar petrology (Colley 1971, Carney and Macfarlane 1979, Robin *et al.* 1993). The olivine content of Province VI tempers from Erromango and Aneityum overlaps with the olivine content of Province II tempers from the Nendö (Table 6), but that partial congruence is not taken here to imply any ceramic transfer between the two temper provinces, which are located ~1000 km apart geographically (Figure 2B).

PRINCIPAL CONCLUSIONS

Petrographic temper analysis of sherds derived individually from 112 Lapita vessels excavated from the Teouma site on Efate documents that 100 were made using apparently local temper sands collected mainly from nearby Teouma Stream (N=93) but also from beach deposits at the head of nearby Teouma Bay (N=7). Regional temper analysis indicates in any case that tempers in the 100 Teouma vessels representing the bulk of the Teouma collection are sands indigenous to Efate. By contrast, temper sands in 12 Teouma Lapita vessels are exotic to Efate, and record ceramic transfer in Lapita times from locales farther north in central Vanautu or the Bismarck Archipelago, and from two separate locales on Grand Terre in New Caledonia to the southwest of Vanuatu. The nine vessels from New Caledonia are inferred to derive from the northwestern end of the northeast coast (N=4) and the southeastern end of the southwest coast (N=5) of Grand Terre. Our data confirms the mobile and interconnected nature of Lapita colonizers, as noted elsewhere across the distribution of Lapita settlements (Summerhayes, 2000). Study of Teouma temper petrography coupled with additional petrographic study of tempers in sherds from elsewhere in Vanuatu and the contiguous eastern Solomon Islands along the New Hebrides island arc allows recognition of six discrete temper provinces as a guide to future temper analysis of Vanuatu ceramic suites. Indigenous Teouma temper sands generically resemble the vitroclastic tempers in other sherds from the caldera-related volcanic province extending northward from Efate to Epi, but are wholly unlike the tempers in sherds from other islands in Vanuatu.

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