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Exotic ceramics from the Murray Islands, Eastern Torres Strait

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ABSTRACT

The discovery of Lapita-decorated ceramics in the Massim region and southern Papua New Guinea coast, along with finds of pottery on Jiigurru (Lizard Island) in the Great Barrier Reef and in the Torres Strait demonstrates the presence of seaborne movements in the Coral Sea as early as ~ 2900–2500 cal. BP (Ulm et al. 2024). As an introduced Austronesian technology, ceramics are central to archaeological understandings of early maritime routes and cross-cultural relationships between Island Southeast Asians, Papuan peoples, and Indigenous Australians. In the Torres Strait only a small number of pot sherds have been reported. Those found in the western islands were probably made using local materials, while the ceramics from eastern islands have been sourced to southern Papua New Guinea (Carter 2004). In this paper, petrographic examination of sherd tempers recently recovered from the Eastern Torres Strait islands of Dauar and Waier indicate derivation from the Purari River basin in southern New Guinea. A distinct granitic temper sherd dated to ~ 2600 cal. BP differs from known sherd tempers and likely originates from the Western Torres Strait. The provenance of this granitic sherd is consistent with the early movement of ceramic-making groups along the south New Guinea coast and into the Torres Strait, and with the ability of these groups to make long-distance passages in the Arafura and Coral Seas.

1. Introduction

The recent discovery and dating of locally made ceramics on Jiigurru to between 2950–2545 cal. BP and 1970–1815 cal. BP on the Great Barrier Reef (Ulm et al. 2024) adds to growing evidence that the period 3250–2500 cal. BP involved contrasting phases of maritime mobility and cultural contact that influenced a vast area of Australasia and the Pacific.

In Oceania, the remote West Micronesian archipelagos of Palau and the Marianas were colonised by at least 3300–3000 cal. BP (Clark 2005; Fitzpatrick and Jew 2018; Petchey and Clark 2021) along with the Bismarck Archipelago 'homeland' of the Lapita peoples (Denham et al. 2012; Summerhayes 2000). aDNA research reveals that these migrations were made by different pottery-making groups who shared an East Asian ancestry (Liu et al. 2022; Skoglund et al. 2016) and were the first to colonise uninhabited Pacific islands as far east as Tonga and Samoa (Bedford et al. 2023). The initial phase of maritime dispersals is closely linked to Island Southeast Asia suggesting the introduction and rapid employment of a new maritime technology that, in the case of Lapita culture, was used to voyage along the north New Guinea coast (Irwin et al. 2023; Montenegro et al. 2016).

Maritime movements and cultural interaction involving Indigenous

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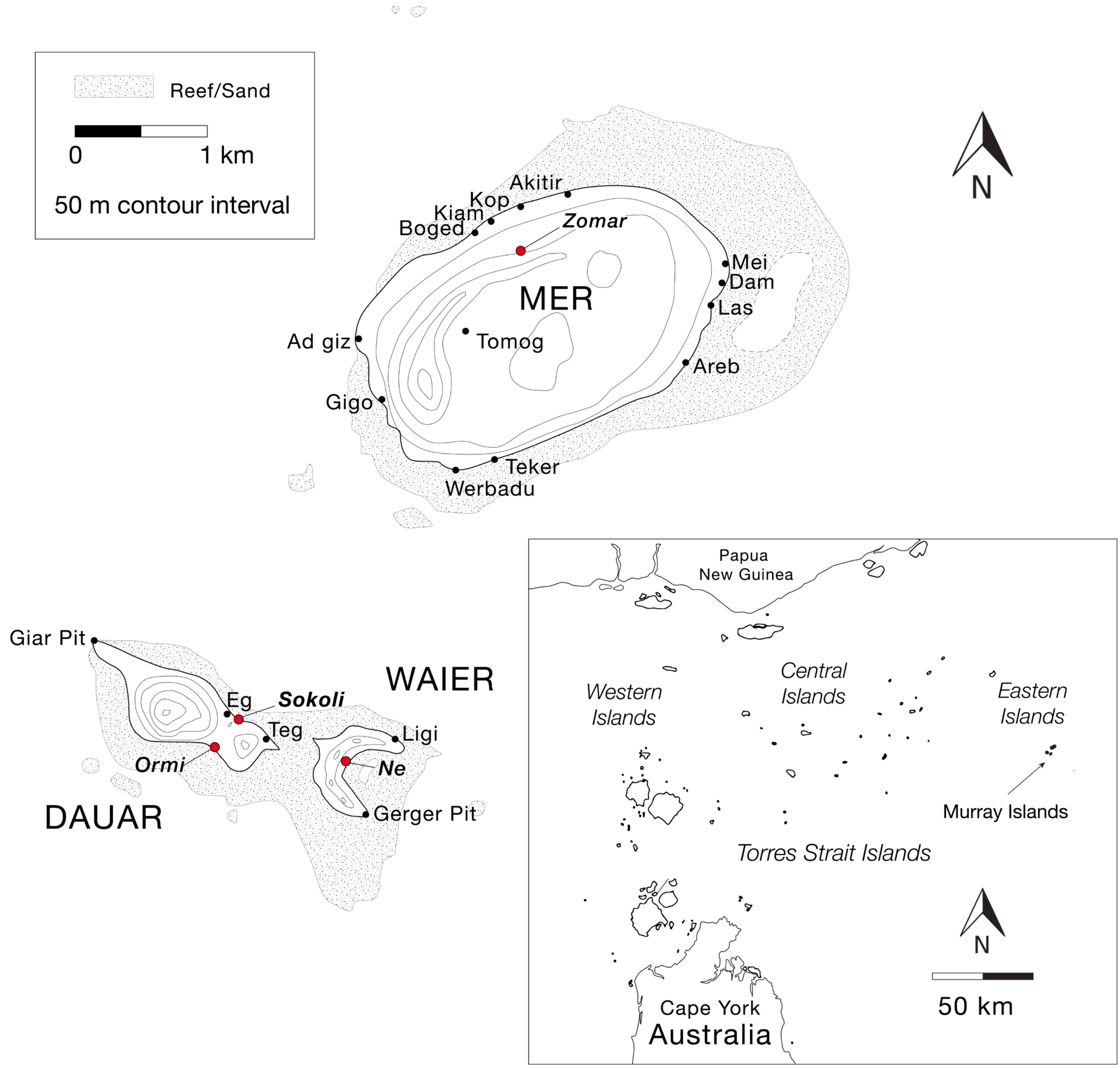

Fig. 1. Murray Islands – Mer, Dauar and Waier – with locations marked in red where ceramics have been found (Dauar Island, Ormi and Sokoli; Waier Island, Ne; Mer Island, Zomar; see Carter 2004). Inset map shows the Western, Central and Eastern Islands of the Torres Strait.

people and migrant Lapita groups are now known to have occurred in the Massim region, Port Moresby region, and along the Gulf of Papua (David et al. 2022; McNiven et al. 2012; Shaw et al. 2022), extending as far west as the Vailala River where late-Lapita style ceramics are dated to ~ 2700–2500 cal. BP (Skelly et al. 2014). Significantly, this second phase of maritime mobility coincides with the migration of Papuan people from island New Guinea into Remote Oceania (Lipson et al. 2018; Posth et al. 2018), a synchronous increase in late-Lapita activity at sites in Caution Bay in south New Guinea that probably involved: "… local non-Lapita populations" (McNiven et al. 2012: 144), and the advent of both locally produced and exotic pottery in the Torres Strait (McNiven et al. 2006; Ulm et al. 2024).

Skelly et al. (2014: 471) suggest that the oldest Torres Strait ceramics point to: "systematic expansion and colonisation westward during terminal Lapita times". A broader set of possibilities is indicated by the attribution of Jiigurru pottery to local Aboriginal manufacture and petrographic results indicating that the Western Torres Strait islands of Mabuiag and Pulu were producing ceramics using local tempers (McNiven et al. 2006; Wright and Dickinson 2009). In addition to receiving late-Lapita influence, the Torres Strait may have been a peripheral region within a "Papuan Gulf pottery trading system" (McNiven et al. 2006: 50). The locally made ceramics could, in part, represent an internal innovation and have been distributed by down-the-line trade among Torres Strait communities, while the oldest pottery, at least in the Eastern Torres Strait, may be associated with Papuan expansion and colonisation (Carter 2004; McNiven et al. 2006; Wright et al. 2022).

Although ceramics are central to archaeological theories about the human history of the Torres Strait, they are rarely recovered in archaeological contexts and are difficult to date. Less than 50 pottery sherds have been found after over 20 years of fieldwork across the Torres

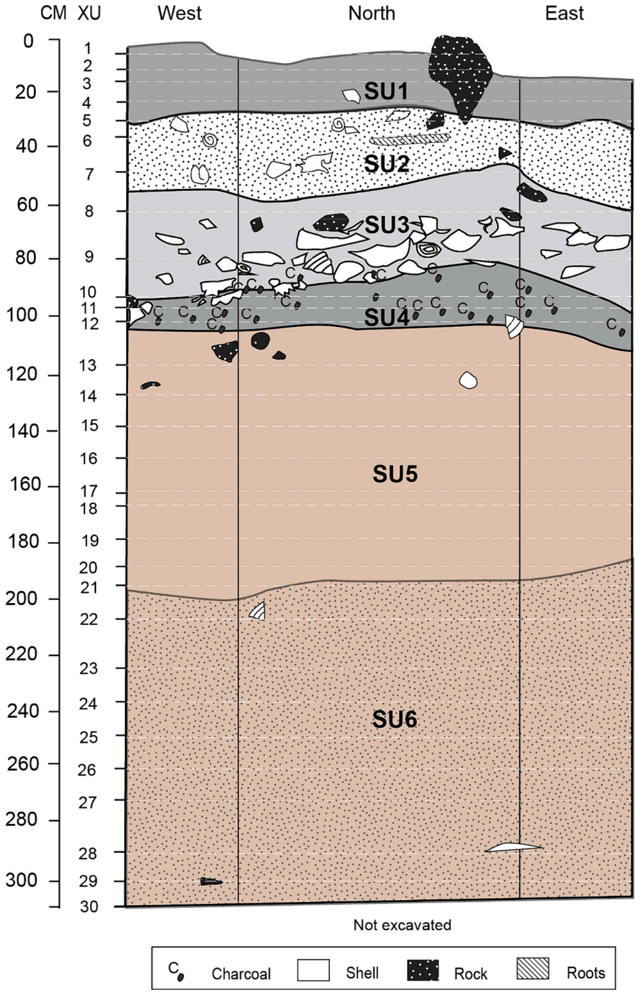

Fig. 2. Stratigraphy of Ormi-3 showing the SUs, XUs and depth to which it was excavated. Descriptions of the SUs given in the text below.

Strait and the age of initial ceramic arrival remains uncertain (Carter 2004: 269; McNiven et al. 2006; Wright and Dickinson 2009). In this paper we report the analysis of four sherds and a fired object recovered from the Eastern Torres Strait. Results show that exotic pottery was brought to the Murray Islands by at least 2600 cal. BP. Petrographic and geochemical analysis indicates that three sherds have mineral tempers from southern Papua New Guinea. The temper of the fourth sherd has been sourced to granite formations located across a 100 km span of the Western Torres Strait. The findings are consistent with the westward spread of pottery-making groups along the south coast of New Guinea and cultural interaction within, and across, the Torres Strait (see Ulm et al. 2024: Fig. 3).

2. Background

2.1. Geological context

The Torres Strait is a geologically diverse region broadly defined by granitic units in the west, with pyroclastic flows and minor rhyolite in the southwest, and basic tuffs and basalts in the east (Cross et al. 2023; Willmott et al. 1969; Willmott et al. 1973). The central islands are primarily uplifted reefs and sand cays that lack stone (Willmott et al. 1969; Willmott et al. 1973).

The western islands are dominated by the carboniferous Badu Supersuite which includes the Badu Granite, the Horn Island Granite and the Torres Strait Volcanics (Cross et al. 2023). The term ‘Badu Granite’ describes three separate lithological groupings: a leucocratic biotite granite, a porphyritic biotite granite, and a hornblende biotite adamellite, granodiorite and tonalite (Willmott et al. 1969: 26). Almost all these subtypes have a high modal proportion of quartz (30–40 %), plagioclase feldspar (20–25 %), and alkali feldspar (40–45 %) which occurs as either orthoclase, or less commonly as microcline, and contain less than 5 % mafic minerals (largely biotite).

Sericite alteration is prevalent within the plagioclase feldspars, and perthite textures are common in the alkali feldspars. Where the alkali feldspar takes the form of orthoclase, quartz-feldspar intergrowths are also common. The Horn Island Granite is mainly plagioclase with a smaller proportion of quartz, microcline alkali feldspar, hornblende, and biotite. The Torres Strait Volcanics are primarily comprised of pyroclastic flows including the Eborac and Endeavour Strait ignimbrites, which are crystalline welded tuffs with quartz, alkali, and plagioclase feldspars (Willmott et al. 1969; Willmott et al. 1973).

The eastern islands, in contrast, are made up of extrusive mafic volcanics, typified in the geology of the Murray Islands. This island group comprises Mer (previously known as Maer), Dauar, and Waier islands. Each island represents a separate Pleistocene-aged volcanic cone of bedded, vitric yellow brown tuff, containing olivine and pyroxene phenocrysts alongside opaque iron oxide minerals, secondary zeolites and fragments of altered limestone, basalt bombs and lapilli. In addition to the tuff, basalt lavas are also noted on the eastern half of Mer Island. The basalts (lavas and the bombs) are dominated by phenocrysts of olivine and pyroxene with the latter often occuring in distinctive crystal aggregates. The groundmass is often glassy and is typically flow banded by small laths of labradorite feldspar. Opaque minerals like magnetite occur frequently and the olivine is sometimes altered to form iddingsite. Due to their similar mineralogy, the tuffs and basalts are often collectively referred to as the Maer Volcanics (Willmott et al. 1969: 41-45; Willmott et al. 1973: 52-53).

Directly north of the Torres Strait lies the Papuan platform, a low-lying region of New Guinea that contains little to no hard stone. The main exception to this is Mabaduan Hill, on the southern coast, where a massif of Badu granite intrudes the sediments of the Papuan platform (Davies 2012; Misztela et al. 2022; Willmott et al. 1969). The mountainous interior of Papua New Guinea and Irian Jaya is geologically diverse. Limestones, shoshonitic lavas, heavily strained metamorphic rocks, granodiorite and granitoid intrusives outcrop throughout the central Kubor range (Bain et al. 1975); while siliciclastic sediments, Oligocene gabbro and Miocene granodiorites dominate the Aure-Moresby region (Davies 2012; Davies and Smith 1971). To the north-east lie the metamorphic, basic and ultramafic rocks of the Owen Stanley Range, and hornblende and biotite bearing granites and granitoids are known from the Suckling-Dayman block (Davies 2012; Österle et al. 2020). These granites are thought to be related to the gneiss domes and mica-bearing granitic outcrops of the D’Entrecasteaux and Muyua (Woodlark Islands) regions, off the eastern coast of Papua New Guinea (Österle et al. 2020; see also Dickinson 2013; Shaw et al. 2016).

To the south, the northernmost tip of Cape York is also dominated by sediments (Willmott et al. 1973). Ironstone is common throughout the region, and granite intrusives and acidic volcanics similar to those of the southern Torres Strait outcrop throughout the region (Rattray 1869; Willmott et al. 1973). A range of metasedimentary rocks are known from the Peninsula Ridge and Yambo Inlier regions, grading from greenschist facies in the northwest, to amphibolite in the southeast (Willmott et al. 1973: 16). The Cape York Batholith, which intrudes the Yambo Inlier, contains a range of granites and granitoids with varying mineral compositions, many of which have been metasomatised and heavily strained to become migmatites (Willmott et al. 1973).

2.2. Site context

2.2.1. Ormi

At Ormi on the south coast of Dauar Island the sea has breached the

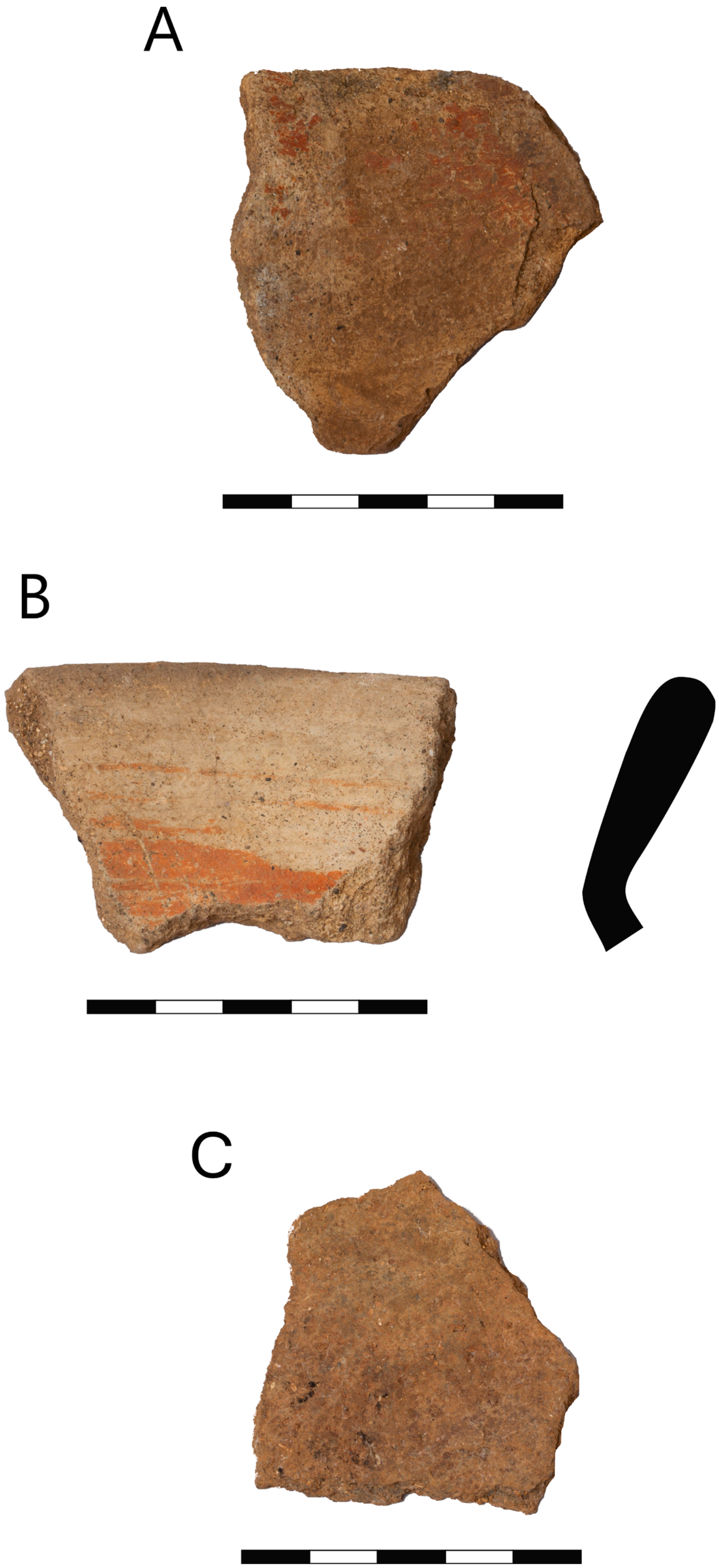

Fig. 3. Ceramic sherds from the Ormi 2022 excavation: (A) Red-slipped body sherd WPP01; (B) Red-slipped rim sherd WPP02 with profile; (C) Excavated sherd WPP03 from XU23.

Table 1
Summary of AMS charcoal and U-Th results for Ormi-3 XUs associated with the granitic-tempered sherd WPP03. See supplementary information (B) for details of the U-Th analysis.

Laboratory Code	**Material**	**Context**	**Conventional Age (BP)**	**^{13}C**	**95.4 % Prob. cal. BP**
S-ANU-73106	Charcoal-not identified	SU6, XU22	2482 ± 21	−24.1	2717–2469
S-ANU-74537	Charcoal-not identified	SU6, XU23	2506 ± 26	−27.4	2725–2492
S-ANU-73107	Charcoal-not identified	SU6, XU24	2519 ± 21	−25.9	2729–2496
U-Th					
Laboratory Code	**Material**	**Context**		**corr. 230Th Age (BP) ± 2 s**	**corr. 230Th Age (ka) ± 2 s**
JLS03-49	*Acropora* spp.	SU6, XU22		2570 ± 7	2643 ± 7

crater rim creating a lower area between the main peak of Au Dauer Giar (185 m) and Kebi Dauer (76 m) where there is a long stretch of beach and access to the sea (Fig. 1). Ormi is a traditional site of the Dauareb community (Haddon 1908). Here an eroding shell midden was recorded in 1998, with a 1 m × 2 m excavation undertaken in 2000 to sample the midden (Carter 2004). More than 15 plain pot sherds were found with most coming from a Horizon IV that dated to ~ 2250–2000 cal. BP. Thin-section and SEM mineral identification of three sherds indicated a source in river systems that drain to the Gulf of Papua (Carter 2004: 294-299). Although no vessel forms could be identified sherd thickness suggested that between 2000 and 1600 cal. BP small and fragile vessels may have been replaced by larger and more robust pottery containers. The possibility that small sherds were displaced downward initially suggested ceramic introduction after 2000 cal. BP (Carter, 2002; Carter 2004: 269; Carter et al. 2004), with the age estimate subsequently revised to 2500–700 cal. BP (Carter 2010).

In 2022, a 0.5 m × 1.0 m excavation called Ormi-3 was made on the upper beach terrace containing dense shell midden west of the original excavation area examined by Carter (2004), that appears to have been substantially disturbed by erosion. The stratigraphy comprised 30 units (XUs) and six stratigraphic units (SUs) and reached a depth of 3.05 m (see Fig. 2). More comprehensive excavation details will be reported elsewhere (Wright et al. In prep), but the main units are comparable with the sediments reported by Carter (2004: 172–175).

Three pieces of ceramic were recovered during the Ormi-3 investigations. Two sherds were surface finds. WPP01 is a red-slipped body sherd (5.7 cm by 5.3 cm) 7.0 mm thick, and WPP02 is a rim sherd from a red-slipped jar with an out-curving rim and rounded lip (5.1 cm by 3.5 cm) that measured 10 mm thick below the rim (Fig. 3). The third ceramic (WPP03) is an undecorated body sherd (~5.0 cm by 7.5 cm) with a thickness of 4.0 mm excavated from XU23 at a depth of 2.25 m in apparently undisturbed SU-6 sediment. A micromorphology sample was taken from Ormi-3 at the transition between SU-1 and SU-2 (~35 cm depth) that contained an inclusion (WPM01) with a burnt circumference that resembled a pot sherd in thin section.

SU1: 0–28 cm: Dark brown (7.5YR 3/3) silty loose topsoil with many rounded calcareous sand grains and frequent black volcanic grains similar to those in modern placer beach deposits in front of the site. Abundant root pieces and fibres with fragments of broken shell, coral, small pieces of eroded tuff and particles of charcoal.

SU2: 28–57 cm: Dark greyish brown (10YR 5/1) medium-grained sand with less silty clay. Rounded calcareous particles and fewer volcanic particles and small pieces of fish bone, broken marine shell, rock and land snail fragments. Less midden shell and fewer roots than in SU1, and charcoal was common in small and large fragments.

SU3: 57–90 cm: Dark greyish brown (10 YR 4/3) medium-grained loose carbonate sand similar to SU2, but with abundant marine shellfish remains including *Tridacna* spp. *Lambis lambis*, *Hippopus hippopus* and *Trochus* spp. Rock from local volcanics occurs in the sediment as pebbles and cobbles with fragments of *Acropora* spp. Coral.

SU4: 90–105 cm: Dark grey (10YR 3/1) medium-grained loose sand. Rounded carbonate grains were common along with dark volcanic rock minerals, fragments of fish bone and numerous flecks and pieces of charcoal. Small amounts of fine silt and some large marine shells at the boundaries between SU5 and SU3.

SU5: 105–200 cm: Brown (7.5YR 4/3) coarse to medium carbonate sand with more silt than SU4 and a sharp transition between SU4 and SU5. The increase in the fine clay fraction indicates a paleosol or increased erosion of sediment from nearby slopes. Small fragments of charcoal and fish bone with dispersed marine shell remains and less midden content than SU4.

SU6: 200–310 cm: Dark yellow brown (10YR 3/4) coarse sand. Similar proportion of rounded calcareous grains to mafic minerals. The upper part of SU6 is similar in texture and content to a sample of modern beach sediment but has a minor component of fine silt in the upper part of the SU which declines with depth. At excavation base the carbonate particle size ranges from coarse to fine gravel with numerous smaller volcanic mineral grains. Few midden remains with rare pieces of fish bone covered in cemented sand and occasional pieces of shellfish and particles of charcoal. SU6 sediments indicate an accumulating beach deposit, probably from Mid-Holocene sea-level fall.

2.2.2. *Ne*

Ne is a large eastern embayment forming the inner lagoon of Waier Island (Fig. 1). The volcanic island was a sacred place associated with initiation and funerary rites of the Waiet cult (Wright et al. 2019, Wright et al. 2022). In 2014, three 1 m × 1 m squares designated A, B and C were excavated, each targeting a different part of a linear rock shelter formed by wave-erosion in the southeast of the main embayment (see Wright et al. (2019) for details). A single sherd (Waier01) was recovered from Square A, 15–17 cm below the surface. The plain sherd is small (1 cm by 1 cm) and has a thickness of 5.0 mm. Initial SEM analysis indicated the sherd might derive from Papua New Guinea, but potentially also mainland Australia or the Western Torres Strait (Wright et al. 2019: 127).

3. Methods

3.1. *Radiocarbon and U-Th dating*

To determine the age of the WPP03 sherd, unidentified charcoal from XU23, and two charcoal samples from XU22 and XU24 bracketing the sherd were analysed with AMS at the Australian National University. A sample of *Acropora* coral from XU22 was submitted for U-Th dating at the Radiogenic Isotope Facility in the University of Queensland. Charcoal samples were cleaned using a standard acid-base-acid protocol to remove exogenous carbonates, humic acids and degraded charcoal and radiocarbon determinations were obtained with an NEC Single Stage AMS (Fallon et al. 2010; Wood et al. 2023). Radiocarbon ages were calibrated using the Oxcal Program (Bronk Ramsey 2009) and the Intcal20 calibration curve (Reimer et al. 2020) as used in a recent chronological study of Torres Strait archaeological sites (Linnenlucke 2022). The *Acropora* sample had sharp corallite structures on its surface suggesting minimal bioerosion, and it was analysed with MC-ICP-MS, using protocols described in Zhou et al. (2011) and Clark et al. (2014).

3.2. *Ceramic analysis*

The analysis focused on mineralogical inclusions within added

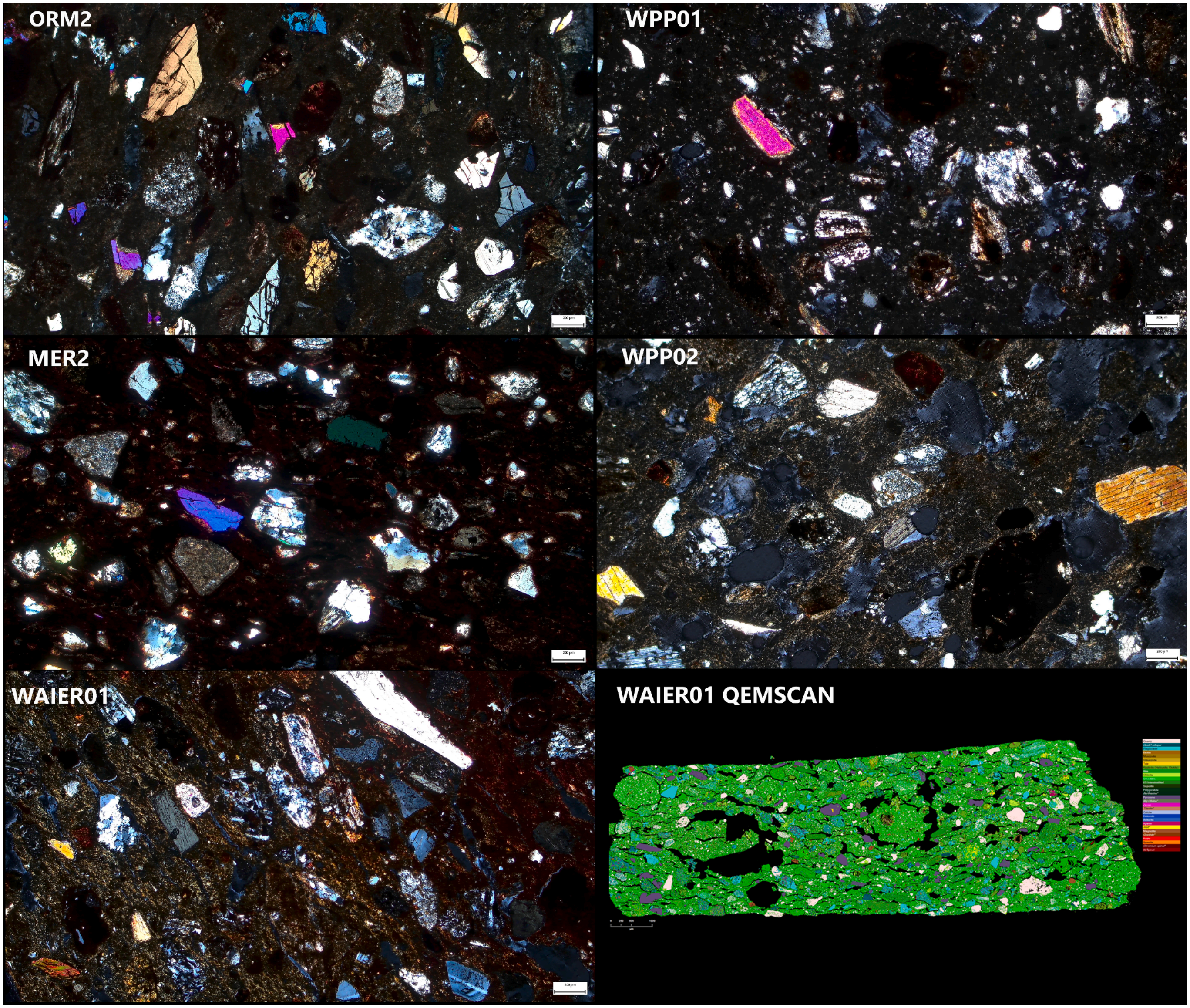

Fig. 4. Photomicrographs of ORM2, MER2, WPP01, WPP02 and Waier01 ceramic fabrics. All have similar temper inclusions and derive from the south New Guinea coast. Mineralogical QEMSCAN map of Waier01 showing the coarseness and sorting of inclusions. All petrographic photomicrographs taken in cross-polarised light (XPL) with the scale bar at 200 μm.

tempers as these can reliably be associated with geological features as opposed to the clay matrix (Leclerc 2020). Petrographic analysis was performed on thin-sectioned samples WPP01, WPP02, WPP03, WPM01, and Waier01 using a Zeiss Axiolab 5 microscope set up for transmitted light polarisation. The ORM1, ORM2, ORM3 and MER2 thin sections of Carter (2004) were also re-examined with the same microscope. Both plane polarised and cross polarised light were used to determine the optical characteristics and mineralogy of the samples. For confirmation of mineral identification and examination of micrometric features, we performed a second SEM analysis of the Waier sherd with a Hitachi S-4300SE/N field emission scanning electron microscope (FE-SEM) operating at 15 kV and ~ 0.6 nA. A mineralogical map for documentation of clast and grain varieties of the Waier sherd was then produced by a QEMSCAN system using an FEI Quanta FE-SEM equipped with dual Bruker 30 mm^2 energy dispersive spectrometers (EDS). Acquisition was conducted with iDiscover using beam conditions of 15 kV and 10 nA and 5 μm resolution. Mineral identification and mapping was conducted using a bespoke recipe in the Nanomin software.

Portable X-ray fluorescence (pXRF) analysis was used to chemically characterise the Ormi-3 and Waier01 ceramics and the portion of WPM01 still embedded in the micromorphology block. The south New Guinea sherds of Carter (2004) were included for comparison with WPP01, WPP02 and Waier01. Four samples of local tuff were analysed to determine whether WPM01 chemically grouped with the local Dauar Island geology. To investigate the possibility that the granitic sherd (WPP03) had a source in the Western Torres Strait, two samples of Badu Granite (referred to as 'red granite') and four samples of Hammond Island granite, were analysed as well. All samples were thicker than 3 mm and were large enough to cover the 8 mm collimator. No sample preparation was performed beyond brushing off obvious debris, however all surfaces selected for analysis were planar and relatively clean.

The analysis was performed under laboratory conditions using a Bruker Tracer 5 g (serial no. 900G10419) equipped with an 8 mm collimator, in air, using a "green" (Cu 75 μm: Ti 25 μm: Al200μm) filter. Analyses were conducted at 40 kV and 30 μA with each analysis running for 60 seconds to target reliably detected mid-z elements (Rb – Nb) (Hunt and Speakman 2015). Five assays were conducted at random spots on each sherd and geological sample, repositioning between

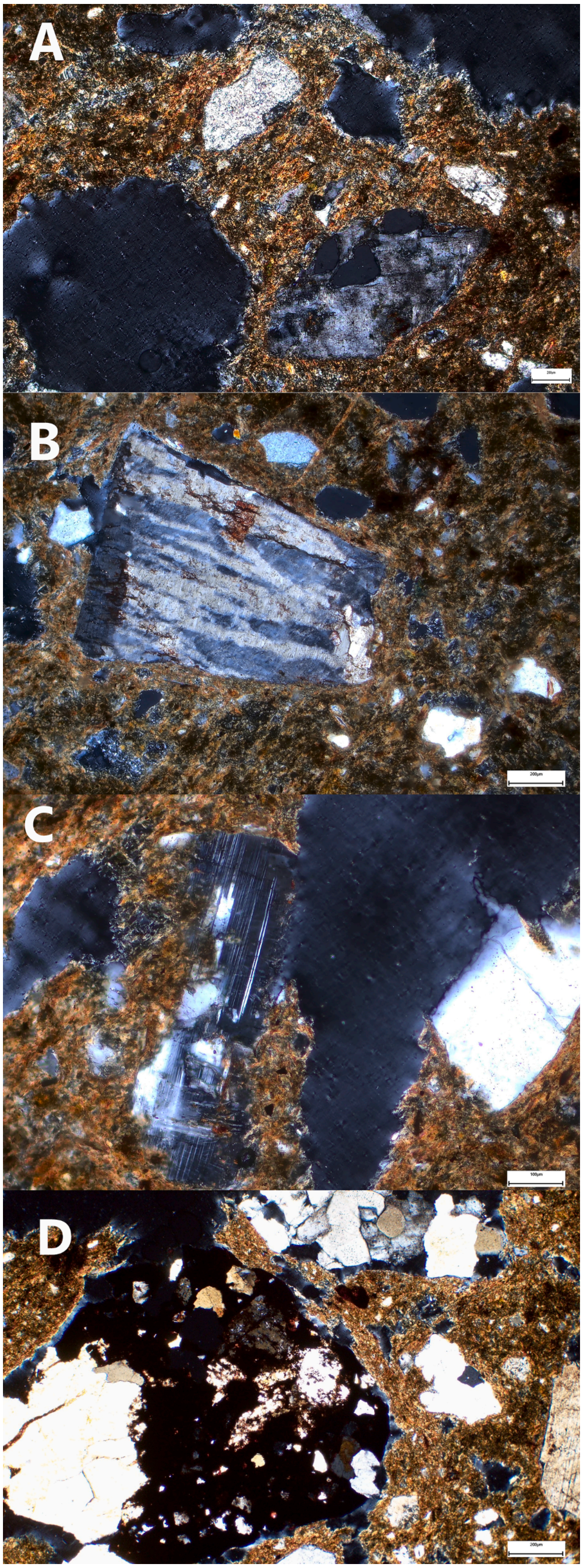

Fig. 5. Photomicrographs of the ceramic fabric of the granitic WPP03 sherd: (A) View of fabric and different temper grains with 200 μm scale bar; (B) Microcline micro-perthite grain with 200 μm scale bar; (C) Microcline feldspar showing distinctive twinning with 100 μm scale bar; (D) Pyroclastic volcanic grain with quartz inclusions with 200 μm scale bar. Photomicrographs taken in cross-polarised light (XPL).

assays. All five assays for each sample were then averaged to give a more representative reading of whole sample chemistry. Analytical precision was validated with the certified reference materials (CRMs) JA-2, JB-1b, and JR-1.

An empirical calibration was created in-house with Bruker EasyCal software (Version 2.4.242.5), using 29 CRMs with values following Jochum et al. (2005) and 19 in-house standards (see supplementary information (A) for full details of calibration). Although this calibration had been initially designed for the analysis of stone (especially basalts from eastern Torres Strait), it was deemed appropriate for this study as the many of the ceramic tempers contained significant quantities of igneous material. Creation of a matrix matched ceramics calibration was not possible due to a lack of time and available CRMs. The calibration used was additionally well suited to the study as it was optimised for analysis of mid-z elements which are reliable elements for the pXRF provenancing of archaeological ceramics (Hunt and Speakman 2015).

The calibrated chemical results were interpreted using principal components analysis (PCA) performed with JMP software version 15.2.0 (JMP, 2023) to determine which samples showed the most chemical affinity to each other (see supplementary information (A) for code).

4. Results

4.1. Age results

4.1.1. Ormi 3

Charcoal ages from XU-22 to XU24 (Table 1) are consistent, indicating deposition of the granitic WPP03 sherd at 2729–2469 cal. BP. The ^{14}C ages fall on a flat section of the calibration curve known as the Hallstatt plateau that cause CRAs ~ 2500–2400 BP to always calibrate to ~ 2800–2400 cal. BP (Rose et al. 2022). A Bayesian analysis in Oxcal (Sequence and Phase) did not reduce the age span which will require additional AMS and U-Th results to refine. The 620 BCE U-Th age from XU22 supports the calibrated charcoal results and indicates sherd deposition on Dauar Island by 2600 years ago.

4.1.2. Ne

AMS dating of marine shell in the upper shelter sediments of Square A could indicate sherd deposition at 1520–1125 cal. BP (Wright et al. 2019: 129). However, sherd age is uncertain due to evidence for several kinds of disturbance in the sandy deposits of the rock shelter (human burials, tree roots, turtle nesting and goanna burrows).

4.2. Ceramics: Compositional analysis

4.2.1. Ormi: WPP01 and WPP02

The two surface finds are highly similar and possess coarse, sub-angular to sub-rounded inclusions, with igneous, metamorphic, and minor sedimentary detritus present, but no calcareous grains (Fig. 4). Rounding of the mineral temper is suggestive of water transport indicating likely derivation from a fluvial source.

Orthopyroxene and clinopyroxene are common in both sherds with clinopyroxene being more common in WPP02 than orthopyroxene. In addition to pyroxenes, the presence of brown and green hornblende, as well as opaque inclusions, is consistent with a terrigenous magmatic origin for most of the temper. Lithic fragments include extrusive igneous grains with elongated plagioclase feldspar crystals as the dominant mineral. Quartz is common, often in the form of composite (polycrystalline) grains with minor edge recrystallisation. Other lithic fragments possess a schistose or foliated texture indicative of a metamorphic origin (Fig. 4).

4.2.2. Ormi: WPP03

WPP03 clearly derives from a different source as ferromagnesian minerals are rare-to-absent in thin section and iron oxide opaques are sparse, small, and rounded. Calcareous inclusions are rare, and quartz

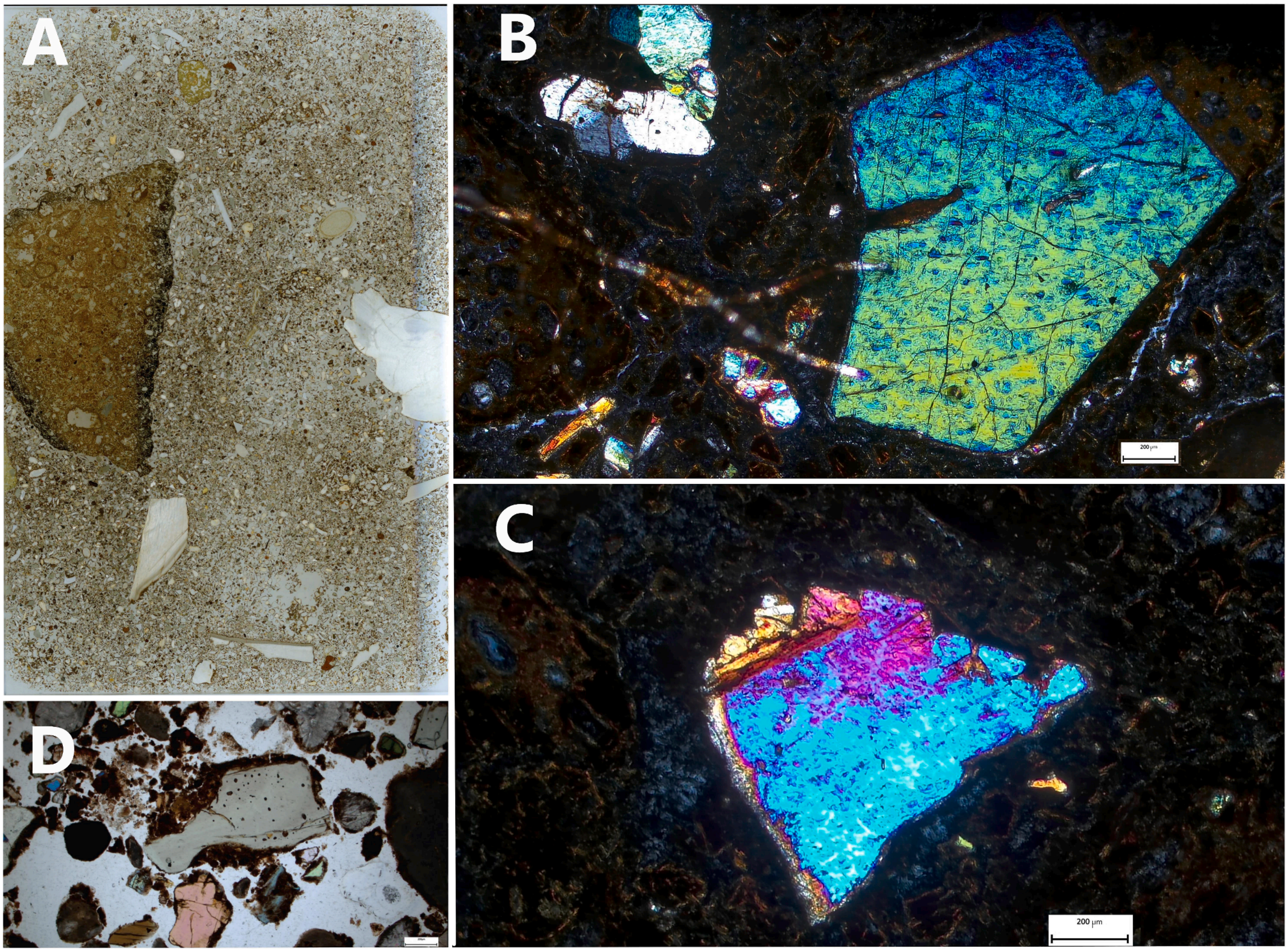

Fig. 6. Petrography of WPM01: (A) Photograph of the micromorphology thin section taken from the SU-1 and SU-2 transition showing the burnt inclusion; (B) Grains within WPM01 showing co-existence of large olivine crystal (blue) and smaller quartz (light grey) with 200 µm scale bar; (C) Iddingsite alteration (reddish staining at one margin) of olivine with 200 µm scale bar; (D) Surrounding sediment grains from the micromorphology thin section, showing olivine, opaques and calcareous inclusions with 200 µm scale bar.

and feldspars are the dominant inclusions. The feldspars are diverse with plagioclase typically altered to sericite. Plagioclase is secondary to alkali feldspar, which mainly occurs in the form of microcline micro-perthite (see Fig. 5A and 5B). A large subrounded object has an opaque groundmass and numerous quartz inclusions. This is likely an inclusion of welded tuff or ignimbrite as the presence of numerous quartz inclusions and a glassy matrix is associated with high-silica pyroclastic volcanism (O'Brien, 1963).

4.2.3. *Ormi: WPM01*

The inclusions in WPM01 are coarse, poorly sorted, sub-angular, and occur at a lower abundance than in the Ormi sherds (Fig. 6). The dominant grains are clinopyroxenes – which are often twinned – while orthopyroxenes are rare. Olivine is common and is sometimes altered to iddingsite. This matches descriptions of the local geology, with iddingsite alteration noted as being particularly prevalent in the Murray Islands (see Willmott et al. 1969: 44), and with the mineralogy of the surrounding sediment monolith. Additionally, the unaltered olivine is relatively fresh, indicating that the source rocks were located relatively close to the site. No extrusive igneous or schistose lithic fragments are noted in WPM01, although rare quartz and biotite mica are apparent. As quartz and olivine cannot normally crystalise within the same melt (see Nicholls and Ringwood 1972), it is likely that WPM01 represents a piece of burnt soil or loam rather than a fragment of tuff or low-fired ceramic. Nonetheless, the petrographic description of WPM01 is important as it provides a description of the likely temper constituents in pottery manufactured in the Eastern Torres Strait.

4.2.4. *Ne: Waier01*

4.2.4.1. *SEM.* The dominant mineral grains identified by QEMSCAN in Waier01 are quartz, pyroxene, plagioclase and lesser alkali feldspar (Fig. 4). Minor olivine, mica, iron oxides and chrome-spinel are present along with a single grain of apatite. QEMSCAN analysis also identified shoshonitic melt inclusions within the pyroxene grains, while the matrix of other volcanic grains showed the potassic nature of the melt.

4.2.4.2. *Petrography.* The petrographic analysis identified a significant proportion of metasedimentary grains and composite quartz inclusions that are consistent with observations of WPP01 and WPP02. Compared to WPP01 and WPP02, the Waier01 sherd displays a higher ratio of orthopyroxene relative to clinopyroxene, green hornblende is rare-to-absent with a small number of lithic chert fragments (Fig. 4). The clay matrix is darker and the temper additions are more frequent and poorly sorted. A single grain of antiperthite was noted in Waier01, but was not observed in the WPP01 or WPP02 thin sections.

Table 2
Calibrated pXRF values for Rb, Sr, Y, Zr, and Nb for all samples included in analysis, error margins included.

Sample	Material	Rb (PPM)	Sr (PPM)	Y (PPM)	Zr (PPM)	Nb (PPM)
WPS05	Tuff	71 ± 3	1164 ± 11	40 ± 3	168 ± 6	68 ± 4
WPS07	Tuff	73 ± 3	1059 ± 10	35 ± 2	178 ± 6	69 ± 3
WPS08	Tuff	52 ± 3	1426 ± 12	33 ± 2	145 ± 6	63 ± 3
WPM01	Burnt loam	78 ± 4	1616 ± 14	41 ± 3	212 ± 7	80 ± 4
ORM1	Pottery	42 ± 2	325 ± 6	38 ± 2	418 ± 6	75 ± 3
ORM2	Pottery	44 ± 2	348 ± 6	32 ± 2	224 ± 5	44 ± 3
ORM3	Pottery	56 ± 3	282 ± 5	45 ± 2	254 ± 5	47 ± 3
MER2	Pottery	75 ± 3	181 ± 4	37 ± 2	168 ± 4	40 ± 3
WPP01	Pottery	37 ± 2	356 ± 6	32 ± 2	314 ± 6	39 ± 3
WPP02	Pottery	41 ± 2	331 ± 5	29 ± 2	170 ± 4	38 ± 3
WPP03	Pottery	178 ± 4	336 ± 5	46 ± 3	168 ± 4	48 ± 3
WAIER01	Pottery	51 ± 4	232 ± 15	33 ± 2	209 ± 7	36 ± 3
LAS2023-3	Badu granite	354 ± 5	31 ± 1	64 ± 3	92 ± 3	47 ± 2
LAS-DAM	Badu granite	359 ± 6	61 ± 2	40 ± 3	68 ± 3	37 ± 2
HAM1-W	Hammond granite	203 ± 4	164 ± 4	34 ± 2	192 ± 4	45 ± 3
HAM1	Hammond granite	167 ± 4	186 ± 5	49 ± 3	210 ± 4	46 ± 3
HAM3	Hammond granite	170 ± 4	264 ± 5	57 ± 3	212 ± 4	47 ± 3
HAM4	Hammond granite	144 ± 4	142 ± 4	51 ± 3	199 ± 4	45 ± 3

4.2.5. *Re-examination: ORM1, ORM2, ORM3 and MER2*

The petrography of these sherds was consistent with the findings of Carter (2004), with ORM2 and MER2 being distinct from ORM1 and ORM3 based on the presence of volcanic lithic fragments, pyroxenes and composite quartz grains (Fig. 4).

4.3. *pXRF*

The pXRF results indicate that WPM01 is more similar to the local Dauar tuff than to any of the ceramics (Table 2). This supports the view that WPM01 is not a fragment of pottery, but rather a piece of burnt loam or other locally derived sedimentary material. The PCA plot (Fig. 7) shows that WPP01, WPP02 and the Waier01 sherd are most similar to the ORM2, ORM3 and MER2 sherds of Carter (2004). All the sherds previously described by Carter (2004), the Waier sherd, and the Ormi-3 surface finds are broadly similar when compared to the granitic samples (WPP03, Hammond Island and 'red' Badu Granites). However, WPP03 groups more closely with the Western Torres Strait granitic geological samples than with the other Murray Islands sherds (Fig. 7). It differs significantly from the other samples in its Rb content. This is likely due to the higher concentration of alkali feldspar within WPP03, as Rb preferentially partitions into highly potassic material (El Bouseily and El Sokkary 1975: 214; Heier and Adams 1964: 335; Shaw 1968). The sherd is not as strongly enriched in Rb as the Badu Granite samples, being similar to the Hammond Island granite, but this may be the result of element dilution due to the addition of granitic temper grains to the pot clay or taphonomy.

5. Discussion

The WPP01 and WPP02 mineral temper additions have significant petrographic resemblance to ORM2 and MER2. A local source for these inclusions can be discounted based on the presence of metasedimentary grains and deformed polycrystalline quartz grains in these sherds. These grains appear to be consistent with the strained metasediments of the Kubor range, a mountainous region of Papua New Guinea which is drained by the Purari River system (Bain et al. 1975: 12). Further, the only metamorphism noted on the Murray Islands is of limestone fragments associated with tuffs (Willmott et al. 1969: 45) that is incompatible with these inclusions. Geochemical analysis also demonstrates that WPP01 and WPP02 do not group with the local tuffaceous samples from Dauer Island and instead are more similar to the Ormi sherds with temper sands derived from southern New Guinea (Carter 2004).

The two SEM mineral analyses of the Waier01 sherd are valuable but gave ambiguous results. The highly potassic nature of some of the temper inclusions within the sherd is suggestive of both shoshonites within the Papua New Guinea highlands (Bain et al. 1975) as well as the local Maer Volcanics (Willmott et al. 1973: 135–136). As such, both the Eastern Torres Strait and southern New Guinea are potential sources based on the QEMSCAN results. The petrography is more definitive as the composite quartz grains and high frequency of metasedimentary lithic fragments within the temper suggests to a south New Guinea origin. In addition, the presence of antiperthite points to a plutonic component that is incompatible with the geology of the Murray Islands, but consistent with the Purari River Basin. The location is supported by the discovery of a wide distribution of pottery manufacture on mainland Papua New Guinea, particularly the presence of ceramic-making communities in river valleys located between the highlands and the coast (Gaffney et al. 2015).

Despite their overall similarity it is worth noting that the mineral assemblages in the sherd tempers of WPP01, WPP02, Waier01, ORM2 and MER2 are not identical (Fig. 4). Green hornblende is relatively common in WPP01 and WPP02 but is absent from the sherds reported by Carter (2004). Fewer clinopyroxene, sedimentary and vitric igneous grains are found in WPP01 and WPP02 when compared to ORM2, which also contains less quartz, mica, and metasedimentary detritus than MER2. The Waier01 sherd is more orthopyroxene dominant than WPP01 and WPP02, which have less temper grains and are more poorly sorted. Although all these sherds are likely to source from within the Purari River system, WPP01, WPP02 and the Waier01 sherd may derive from separate sub-sources within it. Temper variability is also suggested also by the geochemical results (Fig. 7).

The excavated WPP03 sherd (dated to ~ 2600 cal. BP) has granitic temper that is different from previously reported granitic sherds. The sherds from Pulu and Mabuiag in the Western Torres Strait do not contain perthite and possess orthoclase rather than microcline alkali feldspar (McNiven et al. 2006; Wright and Dickinson 2009). The Jiigurru sherds recently reported by Ulm et al. (2024) contain alkali feldspar and quartz indicating a granitic origin. However, the dominance of perthite (as opposed to quartz-feldspar intergrowths), the low frequency of calcareous grains, the complete absence of muscovite mica, and the more angular nature of the inclusions distinguishes WWP03 from Jiigurru sherds (see Ulm et al. (2024) for description of the mineral grain assemblage). The lack of other ferromagnesian grains similarly excludes D'Entrecasteaux and Muyua (Woodlark Islands), where sherds containing granitic fragments were previously found by Shaw et al. (2016; see also Dickinson 2013).

The presence of microcline micro-perthite in the temper can be linked to granites in the Western Torres Strait; Mabaduan Hill (southern Papua New Guinea coast adjacent to Torres Strait), the nearby island of Dauan, and the eastern part of Mua Island in the central western Torres Strait. Microcline micro-perthite is also known from East Strait Island, a small islet approximately 15 km west of Wednesday Island in southwest Torres Strait. The pyroclastic lithic fragment in WPP03 also excludes the

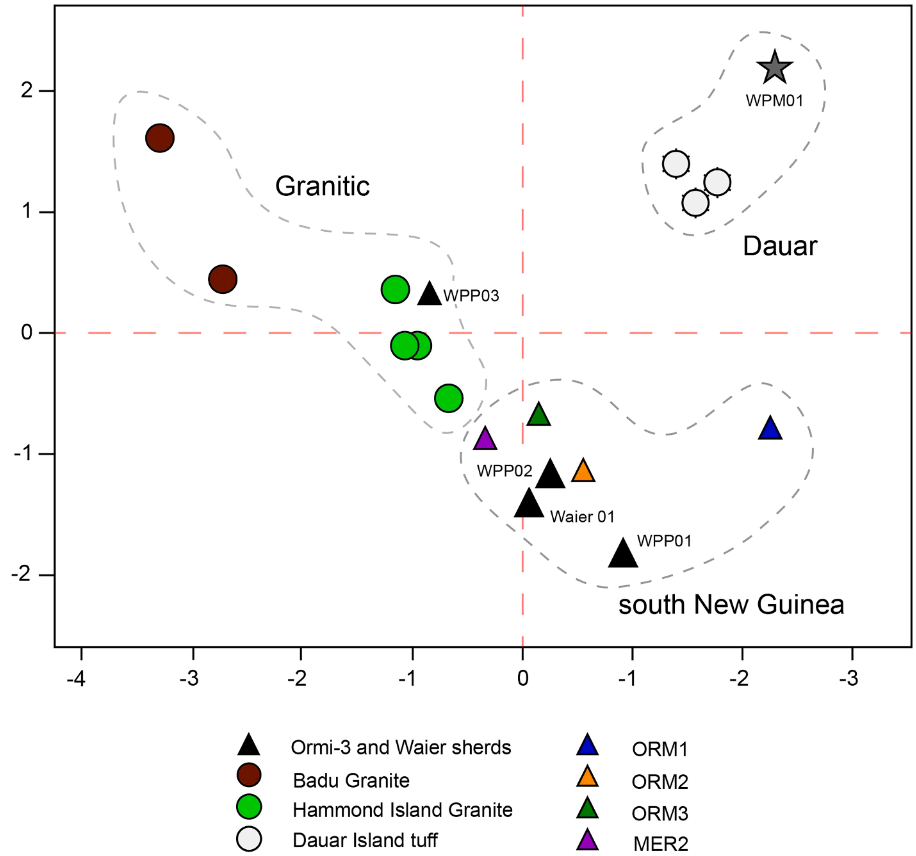

Fig. 7. Principal components analysis plot obtained from pXRF analysis of archaeological and reference material, including six ceramic sherds from Dauar, one each from Mer and Waier, the burnt sediment from Ormi-3, three samples of tuff from Dauar, and six samples of Western Torres Strait granite. Grey dashed lines correspond with mineralogical groupings. PCA variance is 49.3 % X axis (PC 1) and 27.0 % on Y axis (PC 2).

perthite bearing formations of Cape York, as the nearest suitable pyroclastic formations occur several kilometres away from the Cape York perthite bearing rocks (Willmott et al., 1973). Instead, it points towards derivation from Mua – Dauan – Mabaduan, where glassy, quartz-bearing pyroclastics occur closer to the Badu granite, as evidenced by the presence of contact metamorphism (Willmott et al. 1969: 19-20).

Although WPP03 is chemically similar to the granites from Hammond Island these rocks are unlikely to be the source of the temper minerals. The Hammond Island granites are described as being either granodiorites or tonalites, indicating they are heavily dominated by plagioclase and biotite (Willmott et al., 1969), which is incompatible with the highly alkaline mineral assemblage of WPP03. Similarly, the dominance of microcline-micro perthite and the lack of hornblende and biotite in WPP03 precludes deviation from the granites / granitoids of mainland Papua New Guinea (see Bain et al. 1975: 61-2; Österle et al. 2020).

We conclude, therefore, that WPP03 is likely to represent an undocumented ceramic temper source near Mabaduan Hill, and/or on the islands of Dauan or Mua (Fig. 8).

6. Conclusion

The analysis of the small Ormi-3 pottery collection contributes to an emerging view that during the third millennium BP long-distance maritime movements connected south New Guinea with the islands of the Torres Strait and northern Australia (McNiven 2021; Ulm et al. 2024). Petrography demonstrates the arrival on Dauar of pottery with a mineral temper indicating manufacture in the Purari River Basin. Significantly, the late-Lapita style pottery from Hopo reported by Skelly et al. (2014) and marked with dentate and circle stamping and fingernail/tool impression is around 40 km from the Purari Basin (Fig. 8). We do not know the age of the surface-collected Purari River sherds WPP01 and WPP02 and they may represent post-Lapita ceramics similar to Jiigurru where ceramics are dated to between 2950–2545 cal. BP and 1970–1815 cal. BP (Ulm et al. 2024). However, the possibility that exotic pottery from southern Papua New Guinea was reaching the Eastern Torres Strait in late-Lapita times is suggested by two conjoining sherds (MER1 and MER2) found on Mer. Although Carter's (2004) initial petrographic analyses of MER2 identified its southern Papuan origin (a finding reaffirmed by the current analysis), what has been often overlooked is that MER1, while eroded, is reportedly marked with: "… distinctive but weathered dentate decoration…" (see Carter 2004: Figure 8.3, Plate 9.1, 288), representing the westernmost occurrence of probable late-Lapita style pottery.

The movement of early pottery-making groups into the Coral Sea and westward along the Papua New Guinea south coast is further highlighted by the sourcing of the mineral temper in WPP03 to granites located in the narrowest part of the Torres Strait at ~ 2600 cal. BP, some 350 km from the Vailala River (Skelly et al. 2014). Narratives about maritime mobility in Melanesia can downplay the role played by communities south of present-day Papua New Guinea, and we acknowledge that the extension of pottery-making in the Mua-Dauan-Mabaduan area might represent a late-Lapita outpost (after Skelly et al. 2014: 485). Nonetheless, the significant vessel and temper variation reported from Jiigurru, the south New Guinea coast and Torres Strait suggests that Indigenous Australian, Papuan, and Austronesian groups were probably involved in pottery production at this time (McNiven et al. 2006; Ulm et al. 2024). The raw materials used to make and temper the pottery derive from a variety of environments – fluvial/riverine, terrestrial, and coastal. Therefore, determining points of both ceramic material

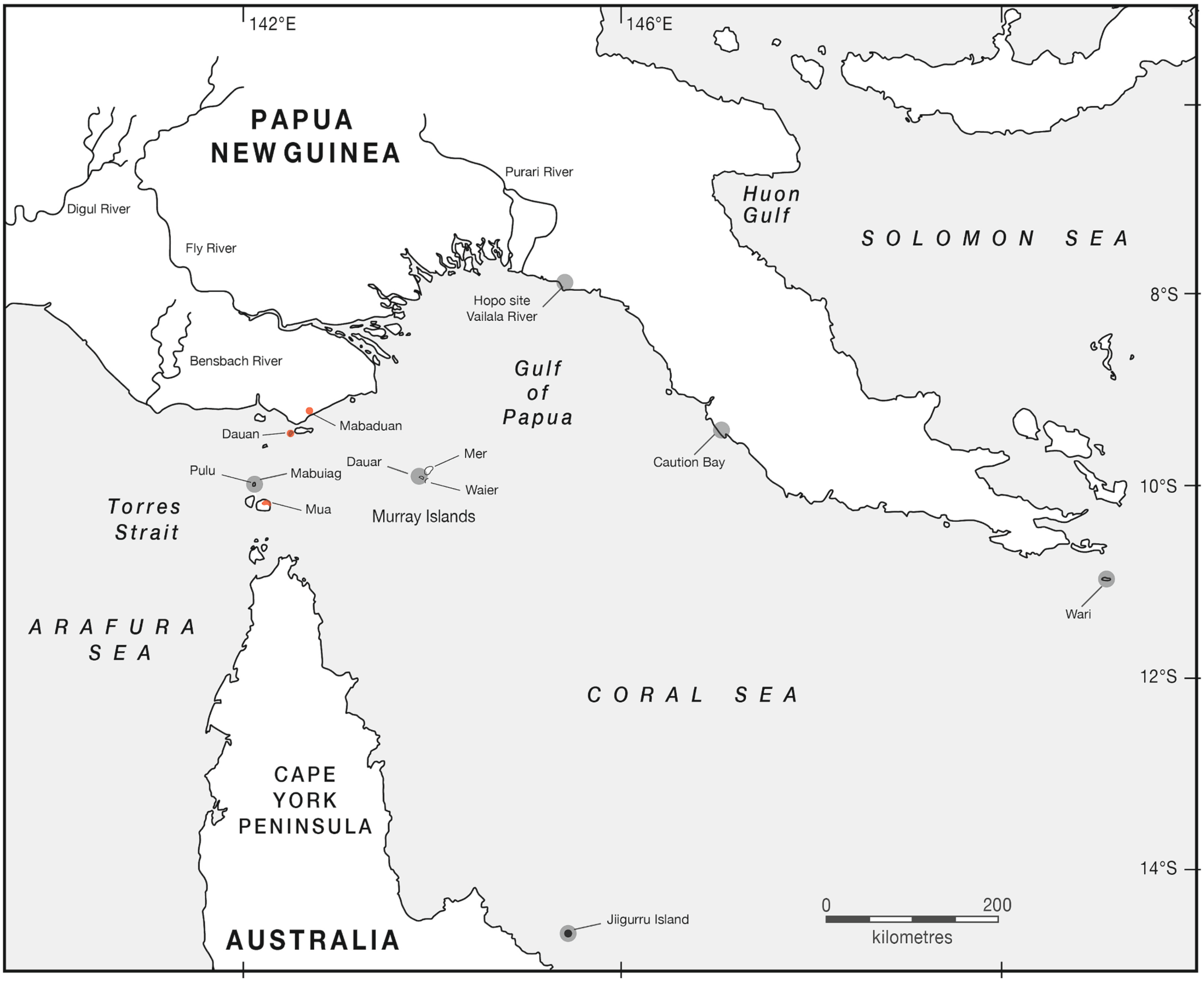

Fig. 8. Map of the Torres Strait showing locations mentioned in text. Grey circles mark locations in Torres Strait, Great Barrier Reef and southern New Guinea where ceramics have been dated to 2900–2500 cal. BP. Red shading identifies locations with granites containing microcline micro-perthite.

extraction and use is key to identifying mobility and interaction in the north Australian-Papuan region during the Late Holocene (e.g. Souilmi et al. 2024).

While maritime expansion was likely based on the spread of elements of Lapita canoe technology (dugouts with raised planks and outriggers carrying a fore-and-aft sail, see Irwin et al. 2024) it is probable that Austronesian maritime and ceramic technologies diffused widely and were used by some Indigenous Australian and Papuan groups in the Coral Sea. An uptake of Lapita-era maritime and ceramic systems is indicated by Papuan post-Lapita migration into the Pacific and Torres Strait (Lipson et al. 2018; Purnomo et al. 2021), and by the presence of pottery production on Jiigurru some 600 km from the Torres Strait and Papua New Guinea (Ulm et al. 2024). At the regional level, the granitic sherd brought to Dauar in the Eastern Torres Strait suggests the existence of a pottery-making settlement, and significant culture-contact, in the Western Torres Strait.

CRediT authorship contribution statement

Emily Nutman: Writing – original draft, Visualization, Investigation. **Geoffrey Clark:** Writing – original draft, Visualization, Supervision, Investigation, Funding acquisition. **Mathieu Leclerc:** Writing – review & editing, Investigation. **Michael Anenburg:** Writing – review & editing, Investigation. **Joshua Willsher:** Writing – review & editing, Investigation. **Elisa Scorsini:** Visualization, Resources, Investigation. **Dylan Gaffney:** Writing – review & editing, Investigation. **Glenn Summerhayes:** Investigation. **Melissa Gibbs:** Writing – review & editing, Resources. **Jillian Huntley:** Writing – review & editing, Investigation, Funding acquisition. **Sabu Wailu:** Resources, Investigation. **James Zaro:** Investigation. **Duncan Wright:** Writing – original draft, Supervision, Investigation, Funding acquisition.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

All data produced by the research described is available in the article or in Supplementary files.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jasrep.2024.104727.

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