



– ARTICLE –

## Geochemical evidence of cultural continuity in lithic procurement from the Late Pleistocene to recent Holocene at Nombe rockshelter, Highland Papua New Guinea

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### Abstract

Despite the central role of lithic analysis within Highland Papua New Guinean archaeology, geochemical characterisation studies are deeply underutilised in the region, especially where Pleistocene and informally flaked assemblages are concerned. This paper presents the geochemical characterisation of the flaked volcanic assemblage and an edge-ground axe from the stratified Nombe site in the Papua New Guinea highlands (25,500 cal BP – present), establishing continuous exploitation of the same raw material types throughout the entirety of the site's occupation. Similar analysis of an excavated non-local jade (nephrite) artefact demonstrates down-the-line, long distance transport of stone sometime between 5600 and 0 cal BP. The geochemical analyses of the locally acquired igneous artefacts and the non-local jade axe-adze flake technological strategies continued during the region's incorporation into broader social networks during the Holocene.

### To cite this article:

Nutman, E., Richards, M., Leclerc, M., Mountain, M.-J., & Denham, T. 2025. Geochemical evidence of cultural continuity in lithic procurement from the Late Pleistocene to recent Holocene at Nombe rockshelter, Highland Papua New Guinea. *Journal of Pacific Archaeology*, 15(1): Article 10:1-26. DOI: <https://doi.org/10.70460/jpa.v15i1.379>

Submitted: 09/06/2025, Accepted 09/09/2025, First online 23/09/2025



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**Keywords:** Central Highlands; lithic geochemistry; flaked volcanic assemblage; nephrite; stone procurement; pXRF

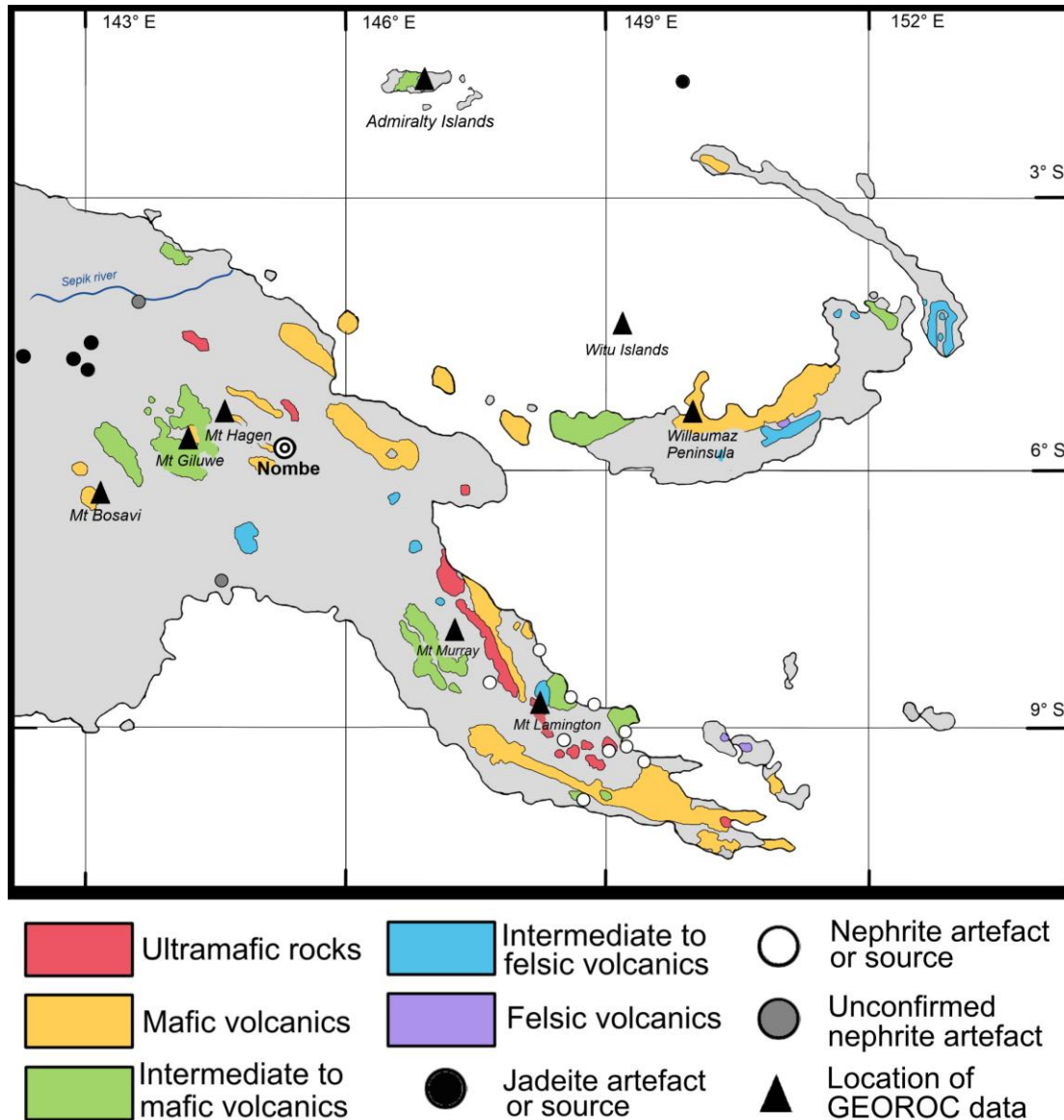
## 1. Introduction

Recognising patterns of cultural continuity versus change is central to understanding the archaeological record of the New Guinea Highlands. Expediently produced chipped stone artefact assemblages from sites in the Highlands have been used to argue for long-term continuity from the Late Pleistocene and into the early-to-mid Holocene. This has largely been achieved through technological and reduction sequence analyses, supplemented by arguments around changing patterns of raw material use (e.g. Evans 2000; Ford 2011; 2017; Gaffney *et al.* 2015a; Huff 2016). These studies have typically relied exclusively upon macroscopic (hand lens) identification to characterise stone artefact rock types, which can be unreliable (see Andrefsky 2009, Boulanger *et al.* 2015; Nash *et al.* 2013, 2016; Tykot 2003). This reflects a wider research gap in the Australia-New Guinea region where geo-scientific characterisation and sourcing techniques are generally underutilized, particularly where expedient technologies and Pleistocene-era assemblages are concerned (Ditchfield *et al.* 2023; although see Glover and Lee 1984; Nutman *et al.* 2025; O’Leary *et al.* 2017). The lack of relevant geochemical reference data in regional databases such as Pofatu and GEOROC makes provenancing non-obsidian volcanic stone artefacts in Papua New Guinea challenging (Hermann *et al.* 2020; Jochum *et al.* 2005; Richards and McAlister *in press*), emphasising the need for more large-scale geochemical studies of stratified sites in the region.

Most geochemical and petrographic sourcing work in the Highlands has been conducted on obsidian artefacts, symbolically significant stone bowls, carved pestles and figurines, and edge-ground wealth economy axes (e.g. Burton 1984; Chappell and Strathern 1966; Golson 2000; Pétrequin and Pétrequin 2020; Shaw *et al.* 2020; Swadling and Hide 2005; Torrence 2005; Torrence and Swadling 2008). This has provided insight into extensive social networks connecting the Highlands to the coast during the mid-to-late Holocene. Further geochemical characterisations for the later Holocene include chert and obsidian artefacts (Sutton *et al.* 2015 and Skelly *et al.* 2016 respectively), as well as and Holocene pottery sherds (Skelly *et al.* 2025), which have shed light on Papua New Guinea’s extensive coastal exchange systems, as well as some interactions between the Highlands and coast (Gaffney *et al.* 2015b). However it must be stressed that much less is known about the Pleistocene, and what has been analysed represents a very small and select portion of the available material culture in the Highlands region.

The exchange of prestige items, in particular axe heads made from jade and other rare materials, was likely facilitated by the spread of Lapita culture out of the Bismarcks during the Holocene (Earle and Spriggs 2015; Gaffney *et al.* 2015b; Hayden 1983; Kirch 1997: 254-5; Spriggs 2020, Torrence and Swadling 2008). For instance, a jadeite axe head from the Cyclops Mountains–Lake Sentani region in West New Guinea was found in an early Lapita context on Emirau Island, on the east side of the Bismarck Archipelago (Harlow *et al.* 2012; Lindley and White 2022) (see Fig 1). The existence of Highland-coastal networks in mainland New Guinea has also been linked with wider patterns of cultural change associated with emerging Lapita

influence (Gaffney *et al.* 2015b; Summerhayes 2019). However, a longer sequence of regional exchanges, including coastal-island-Highland interactions, is undeniable (Allen 1984; Allen and White 1989; Bellwood 1984; Gaffney and Denham 2021; Green 1991; Spriggs 1997; Torrence and Swadling 2008; Specht *et al.* 2014). In the Central Highlands, exotic axe heads have been circulating since at least the mid-Holocene. An axe butt from the Waghi valley found at Nombe has been dated to 10,400 – 6300 cal BP, and material from the Kafetu quarry is known at 5745 – 4877 cal BP from Kafavana (Burton 1984; Prideaux *et al.* 2022; White 1972), suggesting a deeper antiquity to these networks.



**Figure 1:** Map of Papua New Guinea and surrounding islands, showing the regional igneous geology (after Bureau of Mineral Resources 1963; Davies 2012). The location of Nombe relative to geological reference data and nephrite and jadeite (jade) axe-adze finds and sources.

Here we present the geochemical results from non-destructive portable X-Ray Fluorescence (pXRF) analysis of the expediently manufactured volcanic stone assemblage from Nombe rockshelter, in the Chuave district. The site provides a unique opportunity for a large-scale diachronic raw material characterisation study since Nombe has the longest occupation sequence in the Highlands (Evans and Mountain 2005). In addition, a complete Pleistocene edge-ground axe (Fig 2), early-to-mid Holocene obsidian and a mid-to-late Holocene jade axe-adze flake have been recovered from Nombe (Mountain 1991a; Prideaux et al. 2022), allowing us to contribute to the discussion around the existence of pre-Lapita social networks in New Guinea.



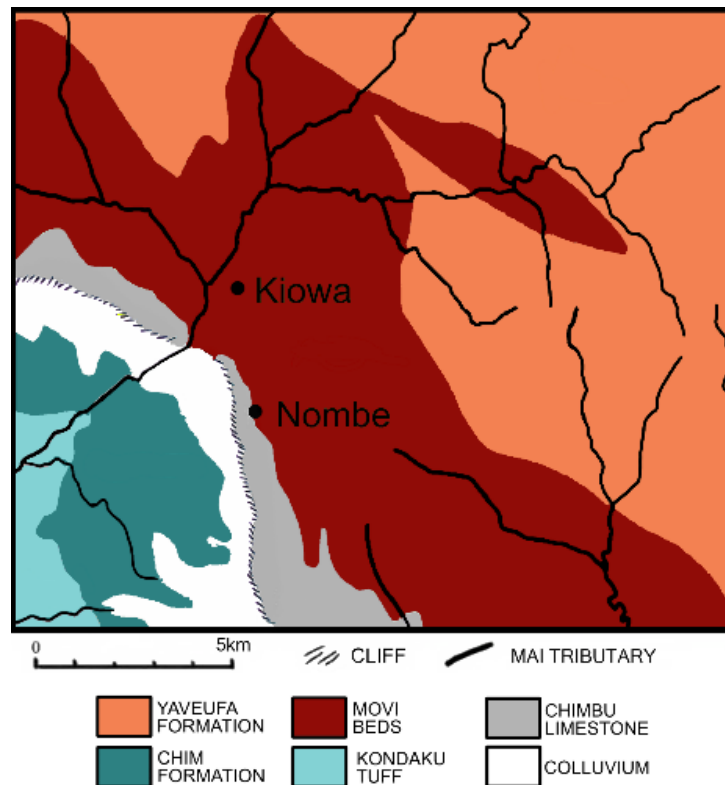
Figure 2: Late Pleistocene edge-ground axe from Nombe, D71 Stratum D (Photo credit: Joshua Willsher)

## 2. Literature review

### 2.1. *Nombe*

Nombe is a limestone rockshelter in the Chuave district of the Chimbu province. It is bordered by the conglomerate Movi beds to the south. The Mai River and its tributaries are present in the north (Mountain

1991a: 2.1) (see Fig 3). It was first drawn into archaeological research in the 1960s when Sue Bulmer (1966) surveyed the wider region and made note of the site before going on to excavate the nearby site of Kiowa (Fig. 1-B). J. Peter White excavated approximately nine square metres at Nombe in 1964, before concluding that the stratigraphy was heavily disturbed and difficult to interpret (Mountain 1991a, 2.10; White 1972, 127). Mary-Jane Mountain undertook a series of excavations between 1971 and 1980 and developed a more comprehensive picture of the site's depositional history (Fig 4; Mountain 1991a).

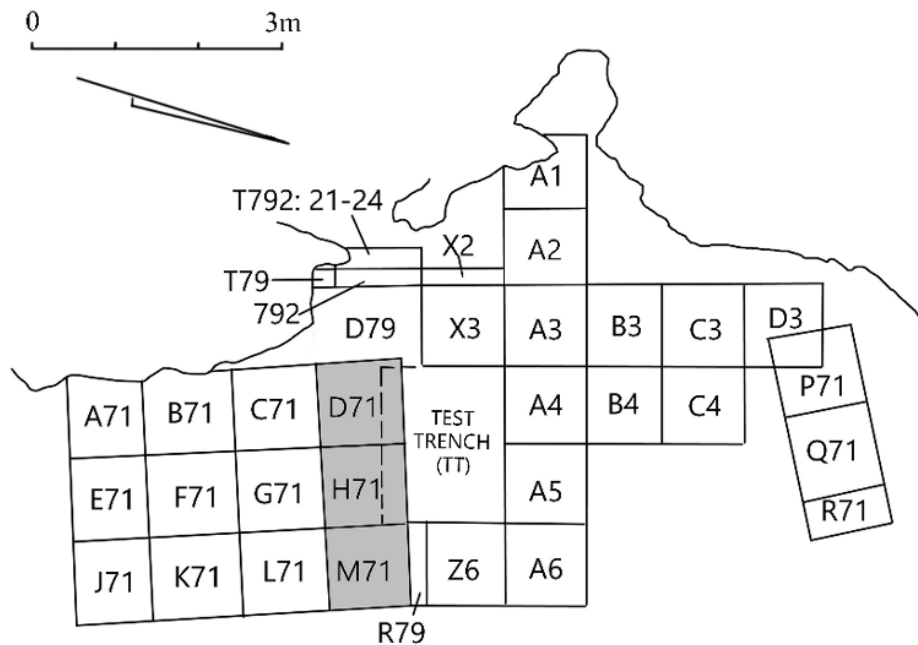


**Figure 3: Geological map of Nombe's surrounds, showing the location of Kiowa and major Mai tributaries (Modified from Mountain, 1991: 2.5; Gaffney et al., 2015a).**

Mountain (1991a; also Denham and Mountain 2016) sub-divided the site's stratigraphy into four major strata, spanning from Stratum A at the top, to Stratum D at the bottom.

A waisted blade and an early edge-ground igneous axe were recovered from these basal clays (Mountain 1991a, 1991b; Prideaux et al. 2022). Stratum D comprises red-brown clays sub-divided into D(1/5) and D(2-4). D(1/5) is dated to between 25,500 – 19,600 cal BP, while D(2-4) was deposited between 32,400 – 29,900 and 38,700 – 34,400 cal BP (Denham and Mountain 2016; Prideaux et al. 2022). Low quantities of artefactual material were present in Stratum D(1/5), suggesting low intensity human activity focused around mobile game hunting during the Late Pleistocene. Several large extinct animal species *Hulitherium tomasettii*,

*Protemnodon tumbuna*, possibly *Nombe nombe* and *Dendrolagus noibano* were recovered in this layer (Prideaux *et al.* 2022, 227).



**Figure 4: Excavation plan of Nombe (after Mountain 1991b; see also Prideaux *et al.* 2022), showing the excavation squares dug by Mountain (1991a) alongside the test trench (TT) dug by White (as detailed in White 1972). Sampled squares are shown in grey.**

People visited the site infrequently between 16,400 – 13,500 cal BP during the deposition of Stratum C (Denham and Mountain 2016; Prideaux *et al.* 2022, 227). A trench was dug into the clays of Stratum D during this period, causing the admixed upcast (Stratum C(X)) to be located immediately underneath Stratum B deposits in some parts of the site.

Stratum B is the most archaeologically rich layer, with good chronostratigraphic integrity (Prideaux *et al.* 2022) and large quantities of burnt bone and stone artefacts revealing people intensively used the site between 10,400 – 6,300 cal BP (Mountain 1991a). Bat (*Aproteles bulmerae* and *Dobsonia magna*, previously referred to as *Dobsonia moluccensis*) and cassowary (*Casuarius bennettii*) bones make up an increasingly large portion of the faunal assemblage at this time, suggesting people's subsistence strategies focused around both trapping evidenced by the bat remains and mobile hunting to obtain cassowary (Evans and Mountain 2005; Mountain 1991a; Sutton *et al.* 2009). Stratum B is the only Stratum from which obsidian artefacts have been recovered (Mountain 1991a).

Stratum A, deposited from 5,600 – 0 cal BP, shows a lower frequency of cultural material, suggesting decreased use of the site (Denham and Mountain 2016; Mountain 1991a; Prideaux *et al.* 2022). The decline

in faunal remains has previously been linked with the mid-to-late Holocene shift towards plant cultivation in the Highlands, resulting in forest disturbance and fewer hunting opportunities (Mountain 1991a). A single jade axe-adze flake was recovered from the lower levels of this Stratum by Mountain (1991a), suggesting that the inhabitants of Nombe participated in the exchange of axe head valuables during the mid-to-late Holocene (see Burton 1984; Chappell and Strathern 1966; Harlow et al. 2011; Lindley and White 2022 etc.)

Evans (2000) analysed the reduction sequences of two visually identified raw material types: an unstipulated igneous raw material Evans termed 'volcanics', and a fine grained, non-igneous 'chert' material. Evans' 'volcanic' category included a diverse range of macroscopically identifiable lithologies, including some with pyroclastic flow banding, obvious phenocrysts, and possible intrusive textures. The 'cherts' were more homogenous, cryptocrystalline, and generally brown to black in colour; they may represent a mixture of true cherts, chalcedonies, jaspers, and/or agate (Gaffney et al. 2015a, 239). Evans (2000) argued that the predominance of volcanics and limited evidence for on-site flaking demonstrated limited local knowledge and infrequent site use by highly mobile people during the Pleistocene. By contrast, the on-site reduction of volcanics and chert during the early Holocene suggests a growing familiarity with and increased occupation of the area, alongside a possible decrease in residential mobility (Evans 2000).

The high rates of pebble cortex in the flaked assemblage suggests that people were collecting local river cobbles, most likely from the stream beds surrounding the site (Evans 2000) (see Fig 3). These local streams crosscut the conglomerate Movi beds (Fig 3), from which this lithic material likely derived. The volcanic material therefore plausibly originates from the Daulo Volcanic member, which forms the major igneous component of the Movi conglomerate (Bain et al. 1975, 49). The Daulo Volcanic member is primarily comprised of basaltic andesite material, with additional mafic basalts, mugearites and basanites present, alongside trachytes and trachyandesite latites. In addition to these extrusive lavas, a high silica welded tuff has also been noted within the Daulo volcanics (Bain et al. 1975, 83-4). These volcanics are chemically reminiscent of the rest of the Highlands igneous geology, which is dominantly mafic-to-intermediate and relatively alkaline in its geochemical signature (see Fig 1). Meanwhile, the siliceous material that Evans (2000) refers to as 'chert' most likely derives from the same secondary source (Bain et al. 1975, 44).

Five polished axe-adze fragments from Nombe were also examined by Burton (1984) using infrared spectroscopy. Four came from Stratum A (one each from J71 Spit 2, PQR71 Spit 1, A1:2 and A2:2) and one from Stratum B (C 3 Spit 3). Burton (1984: 227) sourced one artefact from Stratum A to the Ganz River quarries in the Jimi Valley, and the rest to the Dom gaima quarries, the major ethnographic source for wealth economy axes on the region around Nombe. This is the oldest dated evidence for the movement of quarried axes in the Highlands and suggests that ethnographically known Highlands' wealth economy axe exchange networks date back to at least the mid-Holocene (see Burton 1984; also Ford and Hiscock 2020).

Here, geochemical analysis undertaken on a sample of volcanic (igneous) stone artefacts ( $n = 716$ ) and the jade axe-adze flake ( $n = 1$ ) from Nombe rockshelter reveal continuities in stone procurement strategies were sustained through shifts in subsistence practices and the emergence of long-distance social networks.

### 3. Materials and methods

An assemblage of unretouched volcanic flakes<sup>1</sup>, debitage<sup>2</sup>, cores and axe-adze fragments were analysed to assess patterns of raw material selection through time. Additionally, characterisation of a jade axe-adze flake from the site provides insight into the circulation of axe head valuables and late Holocene intra-regional connections in the Highlands.

A sample of informally chipped volcanic lithics were drawn from squares M71 and H71 (see Fig 4), alongside the jade axe-adze flake (from H71) and the edge-ground axe (D71). Also included were five igneous edge-ground axe-adze flakes (artefact numbers #47, #48, #171, #239, #662) from spits 3,4, 5 and 7 in Stratums A and B. M71 and H71 were selected as they represent the most flaked stone artefact dense areas excavated by Mountain (1991a) with good chronostratigraphic control and multi-disciplinary datasets (Denham and Mountain 2016; Prideaux *et al.* 2022).

Artefacts were selected based on suitability for analysis. Samples also had to exceed the recommended three millimetre minimum thickness and lithics with minimal visible calcrete (high calcium weathering) were preferentially selected (Davis *et al.* 2011). For spits with less than 30 volcanic artefacts, the relative sample size was increased by including every suitable artefact. With the inclusion of the jade axe-adze flake and edge-ground blade, the sample size comprised 717 artefacts, including just under half (45%) of the total volcanics from squares H71 and M71 (see Table 1 for more information).

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<sup>1</sup> Following Evans (2000: 309-10) flakes are defined as “pieces of stone struck from cores, the primary purpose of which is to provide a sharp edge. They are distinguished from other pieces of flaked stone by having part of the parent core's striking platform identifiable and, usually, a visible bulb of percussion.”

<sup>2</sup> “A category of artefact used to describe artefacts identifiable as neither core nor flake, or any other category of artefact. In general, pieces of debitage lack a striking platform and termination, and the striking axis is frequently indeterminable. All other features of artefacts, such as negative flakes scars and cortex, can usually be identified.” (Evans 2000: 309-10).

**Table 1. Analysed artefact frequencies by spit / excavation unit, square and type.**

<b>H71</b>									
<b>Stratum</b>	<b>Spit / unit</b>	<b>Debitage</b>	<b>Unretouched flakes</b>	<b>Retouched pieces</b>	<b>Redirecting flakes</b>	<b>Cores</b>	<b>Axes / axe-adze fragments</b>	<b>Total volcanic lithics</b>	<b>% sampled</b>
<b>A</b>	1								
	2	6	6					17	70.59
	3	16	16				1	71	46.48
	4	37	57	1		4	1	226	44.25
<b>B</b>	5	48	74	1	1	6	1	249	52.61
	6	19	31		1	1		119	43.70
	7	61	71	1		1		471	28.45
<b>D</b>	8								
	9	3	4					7	100.00
<b>M71</b>									
<b>A</b>	1	2						2	100.00
	2								
	3	3	4				1	13	61.54
	4	15	17				1	57	57.89
<b>B</b>	5	43	45			1		201	44.28
	6	3	9			2		25	56.00
	7	18	54			1	1	152	48.68
<b>D</b>	8	15	12					36	75.00
	9								
<b>D71</b>									
<b>D</b>	8						1		
<b>Stratum Totals</b>									
<b>A</b>		79	100	1	0	4	3	368	50.82
<b>B</b>		192	284	2	2	12	2	1217	40.59
<b>D</b>		18	16	0	0	0	1	43	81.40

### 3.1. *pXRF method*

Portable X-Ray Fluorescence (pXRF) was employed for this analysis due to its cost-effective and non-destructive nature (Richards 2019; Richards and McAlister in press). All analysis was performed using a Bruker Tracer 5g machine (900G10034) at 40keV and 20 $\mu$ A, with the Ti 25 $\mu$ m Al 300 $\mu$ m filter in place to optimise the detection of elements between Ti – Nb in a silicate rock sample (Drake and Shannon 2023). The elements Rb - Nb have been previously demonstrated to be highly reliable in tropically weathered Pleistocene igneous artefacts; Ti (express at TiO<sub>2</sub>) is also relatively reliable, although some degree of Ti enrichment may occur in extreme examples of weathering, although this was not observed in the Nombé assemblage (see Nutman et al. 2025: SOM 7). Each artefact was analysed three times for 60 seconds, with each assay performed in a different location on the artefact surface. The raw spectra were calibrated in EasyCal using 49 CRMs, including the same silicate rock standards as Richards and McAlister (in press).

These produced linear regressions with R<sup>2</sup> values >0.98 for analysed elements (see Appendix A). This silicate rock calibration is appropriate for the igneous rock types, especially basalt-andesite-rhyodacite. The silicate rock calibration is also appropriate for both nephrite [Ca<sub>2</sub>(Mg,Fe)<sub>5</sub>Si<sub>8</sub>O<sub>22</sub>(OH)<sub>2</sub>] and jadeite [NaAlSi<sub>2</sub>O<sub>6</sub>] jade which can be readily distinguished by their chemistry (Harlow *et al.* 2014). The low-z elements (major oxides) are best detected by pXRF without a filter (15keV/20 microA), however this setting was not used in this expedient experiment design. Instead, magnesium oxide (MgO) (R<sup>2</sup> = 0.38) and aluminium oxide (Al<sub>2</sub>O<sub>3</sub>) (R<sup>2</sup> = 0.43) were included in the calibration to identify their presence or absence in the spectra but are not treated as reliable quantifications (see also Richards 2019; Supplementary 1).

The Pearce W-F geochemical classification diagram was used to further refine the classification of the volcanic artefacts and compare artefact raw material geochemistry with a) the geochemistry of igneous material from a number of outcrops within the wider tectonic setting of the central Highlands: Mt Lamington (Arculus *et al.* 1983; Zhang *et al.* 2015), Mts Hagen, Giluwe, Murray, and Bosavi (Mackenzie 1976; cited in Pengilley *et al.* 2019); b) petrographic classifications from published geological literature (see Bain *et al.* 1975); and c) geochemical data from interisland sources: New Britain (Woodhead *et al.* 1998), the Witu (Johnson and Arculus 1978) and Admiralty Islands (Johnson *et al.* 1979), and the Willaumez Peninsula (Kurzweil *et al.* 2019).

Multivariate statistical analysis (principal components analysis (PCA) and Ward's hierarchical cluster analysis (HCA)) using the mid-z elements Rb-Nb were employed to further investigate any geochemical connections between the Highlands reference data, the Pleistocene edge-ground axe, and the early to recent Holocene igneous axe-adze fragments. All statistical analysis was performed in JMP 18.2.1 (JMP 2025) (see Appendix B for PCA and HCA code).

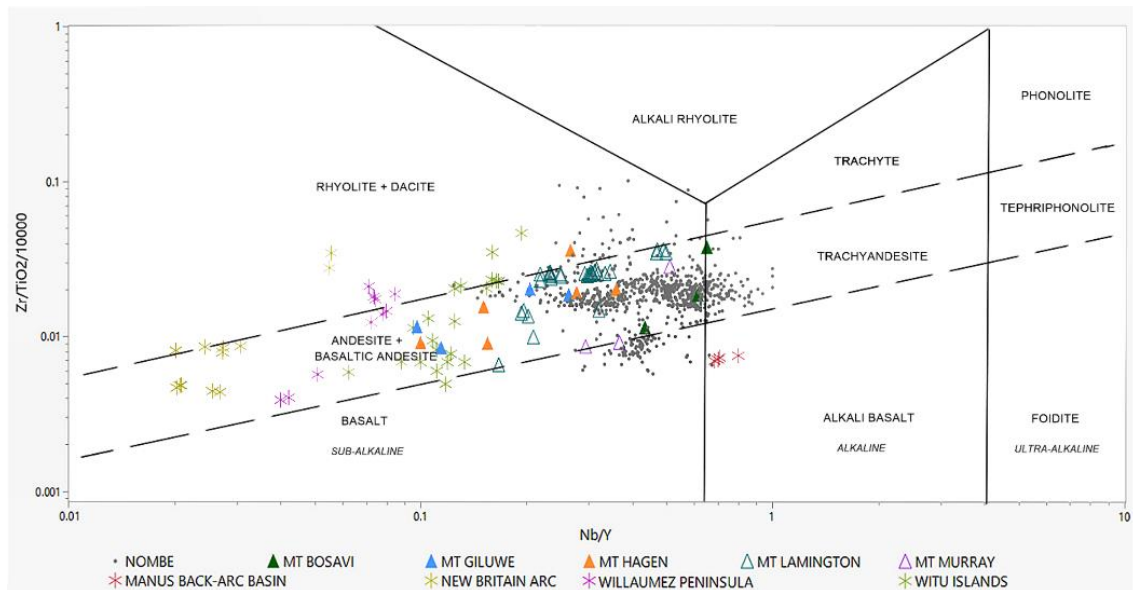
## 4. Results

### 4.1. Volcanics

The Nombe lithic geochemical results (see Supplemental 1), identify the rock types chosen by past people for flaking as basalts, basaltic andesites, andesites, trachyandesites, dacites and rhyodacites. These geochemical signatures are consistent with the tectonic signature of the local Highlands igneous material, and they display very similar geochemical classifications to the Daulo volcanics (as reported by Bain *et al.* 1975), the main contributor of igneous cobbles to the local waterways. As the assemblage is relatively diverse and heterogenous compared to the known igneous material from Mts Hagen, Giluwe, Murray, Bosavi, and Lamington, the data produced is consistent with the hypothesis that the raw material for the Nombe lithics came from loose cobbles retrieved from the local tributaries of the Mai River.

The Nombe samples can be broadly divided into two subgroups on the Pearce W-F: one corresponding to the more andesitic component of the Daulo volcanics and one to the Daulo basalts / basaltic andesites. The basaltic / basaltic andesite artefacts are clustered below  $\leq 0.01$  on the Zr/TiO<sub>2</sub> axis and 0.35 on the Nb/Y axis, demonstrating some overlap with the Mt Murray and Mt Bosavi samples (Fig 5). This is notable as the early complete edge-ground blade from Stratum D plots with this group, alongside one axe-adze flake from

Stratum A and one from Stratum B (see Fig 5, bottom). The other three axe-adze flakes are classified as higher silica andesites, plotting between 0.01 and 0.02 on the Zr/TiO<sub>2</sub> axis and displaying a broadly comparable level of alkalinity (as determined by the Nb/Y proxy).



**Figure 5: Pearce WF plot of the Nombe lithics compared to example igneous data from the Highlands geological province, and from inter-island possible sources.**

No significant changes were observed in the overall Stratum-by-Stratum chemistry of the assemblage (Fig 6). The seemingly greater concentration of basaltic material apparent in Stratum B (Fig 5) is explained by inter-Stratum differences in sample size. Stratum B has the highest density of lithic artefacts and hence represents the largest portion of the analysed assemblage. The relative abundance of rhyolite / dacite, andesite / basaltic andesite and basalt lithics (across all technological types – see Table 1) in each Strata approached (but did not meet) the traditional threshold for statistical significance as determined by a Chi-Square test ( $X^2(6, N = 715) = 11.5, p = 0.07$ ) (see also Table 2).

There was little evidence for differing geochemistry by artefact type (Fig 6). A larger proportion of the edge-ground axe / axe-adze flakes are basaltic compared to the bulk of the volcanic assemblage (50% versus ~10%), this result is unsurprising because it is well established that people favour finer grained basalt for edge-ground artefact manufacture and given the small axe / axe-adze flake sample size ( $n = 6$ ) not statistically significant. The presence of both basaltic and andesitic material in the axe / axe-adze flake assemblage suggests that procurement strategies for the production of edge-ground igneous blades did not significantly differ compared to the other flaked stone artefacts in assemblage. No significant chemical differences were noted between the cores, flakes and lithic debitage and the pieces with retouch; types did not cluster by chemistry. Therefore, we conclude that there is no association between artefact chemistry and technological type. This reinforces the local expedient character of the knapping industry at Nombe explored by Evans (2000; see also Evans and Mountain 2005).

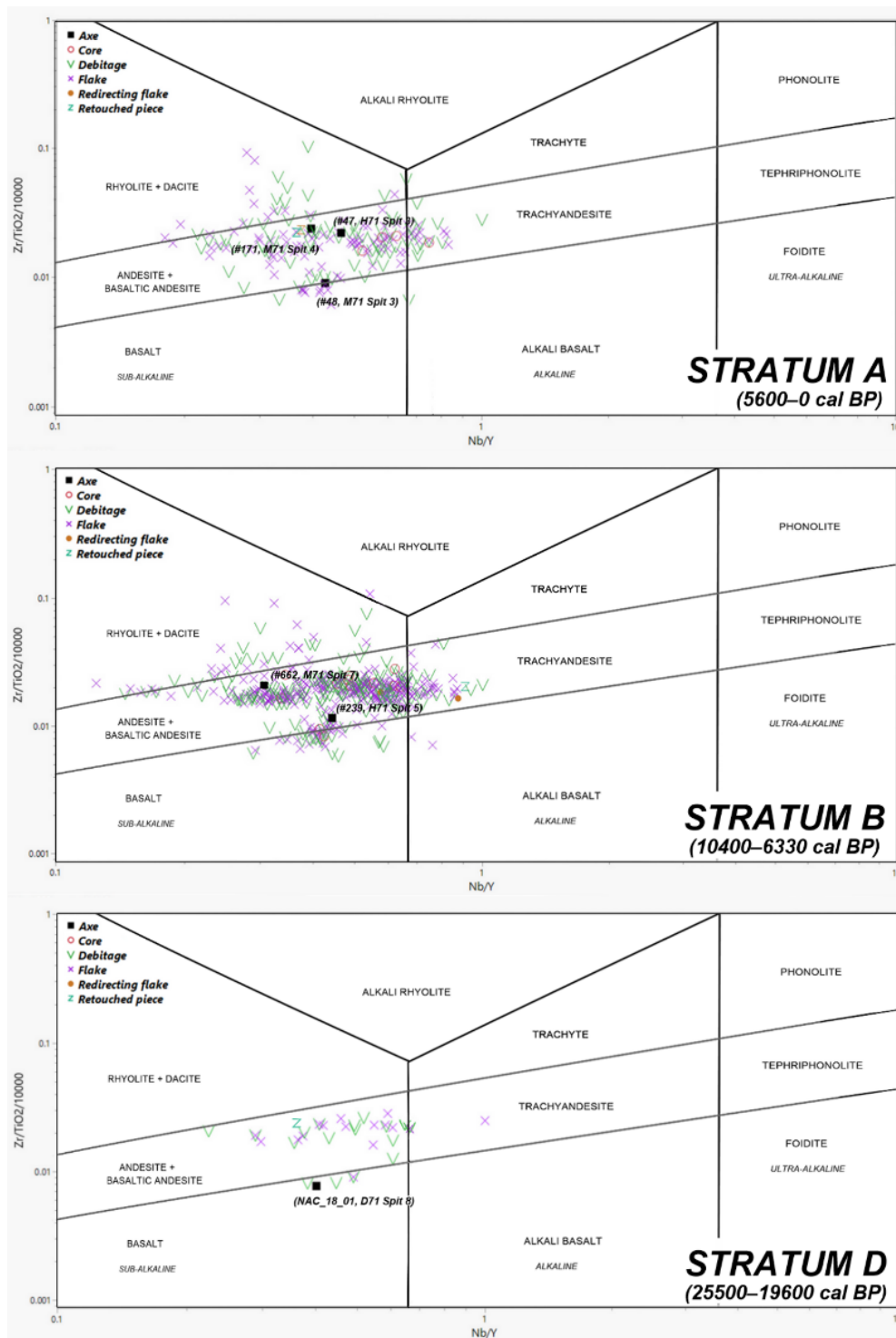


Figure 6: Artefacts by Stratum (panels), with symbology depicting artefacts by artefact type. No pattern changes are apparent through time and no patterning or clustering in chemistry is evident by artefact type, suggesting that the same procurement strategies applied for all igneous lithics through time, regardless of the intended artefact use. Note the cropping (changed scale on the X axis).

**Table 2. Rough proportion of different igneous chemistries by Stratum.**

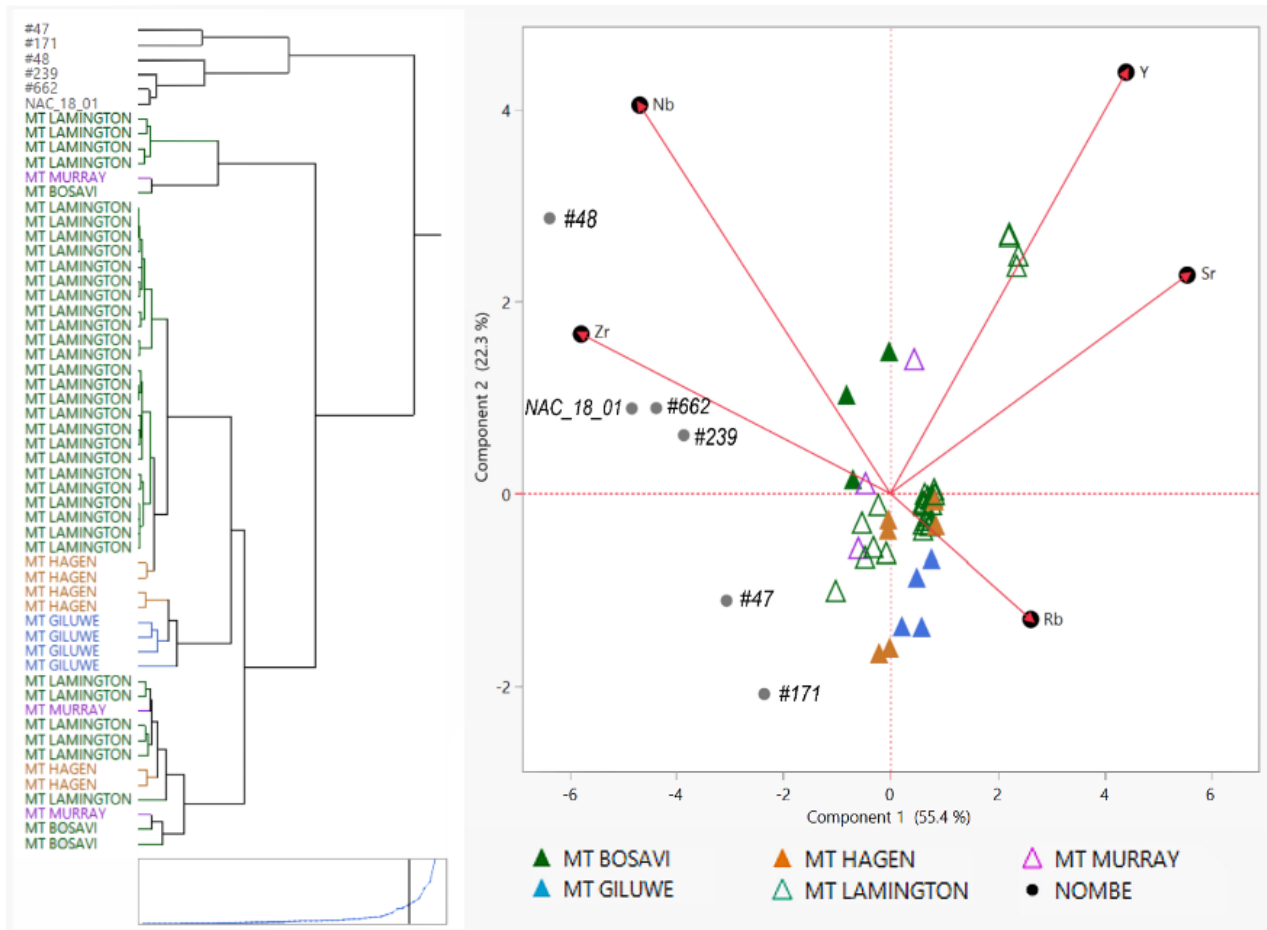
	<b>Basalt</b>	<b>Basaltic Andesite + Andesite</b>	<b>Rhyolite + Dacite</b>	<b>Trachyandesite + Trachyte</b>
<b>Stratum A</b>	6%	72%	11%	11%
<b>Stratum B</b>	6%	80%	7%	7%
<b>Stratum D</b>	14%	85%	0%	1%

Principal Components Analysis (PCA) and Hierarchical Cluster Analysis (HCA) (Fig 7) of the axes / axe-adze fragments supports the results of the Pearce W-F diagram. The three basaltic to basaltic andesite axes / axe-adze fragments (#48, #239 and NAC\_18\_01) do not group with the Mt Murray and Mt Bosavi samples on the PCA (Fig 7 – right). All the axes / axe-adze fragments group separately from the Highlands reference data on the hierarchical cluster analysis (Fig 7 – left), demonstrating they cannot be linked to any of these sources.

#### 4.2. *Jade*

Chemical pXRF analysis of the jade axe-adze flake from Nombe reveals heightened levels of major elements, calcium oxide (CaO = 24.15 wt. %) and iron oxide ( $\text{Fe}_2\text{O}_3\text{T} = 3.03$ ). Similarly, magnesium oxide (MgO) and aluminium oxide ( $\text{Al}_2\text{O}_3$ ) (although less reliably quantified by pXRF) are expected to exist in significant concentrations based on the chemical results (MgO = 100 wt. %;  $\text{Al}_2\text{O}_3 = 29.96$  wt. %). The presence of detectable levels of CaO and  $\text{Fe}_2\text{O}_3\text{T}$  within the axe-adze flake from Nombe is more consistent with nephrite ( $\text{Ca}_2(\text{Mg, Fe})_5\text{Si}_8\text{O}_{22}(\text{OH})_2$ ) as opposed to jadeite ( $\text{NaAlSi}_2\text{O}_6$ ) (see Harlow et al. 2014). Although Fe concentrations similar to what was measured in the Nombe jade axe-adze flake have previously been reported in some jadeite jade artefacts from Papua New Guinea (see Harlow et al. 2012), the heightened high Ca signature is distinctive of nephrite and has not been observed in jadeite examples (Harlow et al. 2014; Harlow and Sorenson 2005; Lindley and White 2022). The heightened levels of MgO are also suggestive of nephrite, as MgO is present at high concentrations at the tremolite end of the actinolite-tremolite series ( $\text{Ca}_2(\text{Mg}_{4.5-2.5}\text{Fe}_{0.5-2.5})\text{Si}_8\text{O}_{22}(\text{OH})_2 - \text{Ca}_2\text{Mg}_5(\text{Si}_8\text{O}_{22})(\text{OH})_2$ ) of nephrite but absent from the more sodic jadeite (see Harlow and Sorenson 2005).

Throughout New Guinea's central fold belt, jadeite is the dominant jade species, with nephrite axes typically being produced on the Papuan peninsula east of Mount Lamington, mainly in the southern coastal regions around Cloud Bay and Collingwood Bay (Fig 1). Unconfirmed (macroscopic) identification of a single nephrite axe head has been reported from the Sepik basin by Swadling (1983), however this is comparatively tenuous, and the source of this material is unknown. Although ~200 km closer, this would still suggest a journey of several hundred kilometres to reach the Chuave district, emphasising the scale of the social networks necessary to acquire such material.



**Figure 7: Hierarchical cluster analysis (HCA; left) and principal components analysis (PCA; right) of the Nombe axe / axe-adze fragments compared to the Highlands reference data of MacKenzie (1976) using the mid-Z elements Rb, Sr, Y, Zr, Nb. PCA variance is 43.4 on the X axis and 31.7 on the Y axis.**

### 5. Discussion

The volcanic assemblage at Nombe demonstrates long term continuity, with sustained exploitation of the same igneous raw material sources from the Late Pleistocene to the recent past. Although shifting patterns of subsistence and occupation intensity have been inferred at Nombe, the igneous axe-adze flakes and the expediently knapped volcanics remain geochemically consistent throughout the entirety of occupation, demonstrating long-term exploitation of the same raw material sources. Additionally, no single raw material type was favoured for the edge-ground axes, with basaltic and andesitic lithologies both employed for tool production. The chemical similarity between the complete edge-ground axe, axe-adze flakes, and the expediently flaked material at Nombe suggests that similar procurement strategies were employed for both formal and expedient tools from the Late Pleistocene to the recent past. This is particularly significant as the complete edge-ground axe from Nombe’s Stratum D represents the oldest

example of this technology in the Highlands (Ford and Hiscock 2020). This suggests that the widespread availability of high-quality volcanic stone was the deciding factor for technological organisation at Nombe, and that tool type and intended usage were secondary considerations (Andrefesky 1994; see also Sillitoe 2024).

While accurately provenancing the raw material for these igneous artefacts remains difficult due to the lack of local reference material, their geochemistry stands in agreement with the geological classifications of the Mai River volcanic cobbles (see Bain *et al.* 1975), supporting Evans' (2000) assessment that the bulk of the Nombe lithic assemblage consists of locally procured igneous material. Some similarities are apparent between the basaltic material at Nombe (including the complete edge ground axe) and the geological data from Mt Murray (see Fig 4), yet derivation from Mt Murray cannot be proven, as petrologically similar calcic olivine basalts are present in both the Mt Murray lavas and the Daulo volcanic member (see Hamilton *et al.* 1983, 452 for Mt Murray and Bosavi; Bain *et al.* 1975, 84 for the Daulo volcanics). Additionally, statistical analysis of the axes / axe-adze fragments from Nombe found poor agreement between the artefacts within this basalt / basaltic andesite cluster and the Mt Murray and Mt Bosavi samples. The relatively consistent proportion of this material through time suggests that past people did not differentiate between it and the more common trachyandesite material in the assemblage, which would be more consistent with local procurement than exchange or derivation from a preferred distant source. Ultimately, these results support the hypothesis that local raw materials were rapidly adopted as part of a flexible procurement strategy in the Highlands (see Gaffney *et al.* 2015a; Ford 2011) and are consistent with what is known from the ethnographic present (Sillitoe and Hardy 2003).

Conversely, exotic procurement can be demonstrated by the nephrite (jade) axe-adze flake within the late Holocene (5600 – 0 cal BP) assemblage. The exact age of this axe-adze flake is unclear. Due to considerable mixing within each stratum, yet limited admixture between different strata, the only chronological control available is the 5600 – 0 cal BP bracketing dates for Stratum A (Mountain 1991a; Denham & Mountain 2016; Prideaux *et al.* 2022). Added to this, the age of ethnographically known axe exchange systems in the region is unclear (see Ford and Hiscock 2020).

Nephrite is not known from within the Central Highlands, where jadeite is the dominant jade species. Significantly, the manufacture of nephrite exchange axes has currently only been established on the Papuan Peninsula near Cloudy Bay and Collingwood Bay (see Fig 1). Although nephrite has been reported from the Sepik region and the Gulf of Papua, this is based on unconfirmed identifications of surface collected objects and is comparatively tenuous (Swadling 1983; Lindley and White 2022). By contrast, specific gravity testing has confirmed the identification of numerous nephrite artefacts from the Papuan Peninsula and linked them to known nephrite quarry sites in the foothills of the Maneáo Range and in the vicinity of the Suckling-Dayman Massif (see Jack 1892; Lindley and White 2022, 2023). Due to a lack of suitable reference material in databases such as Pofatu, GEOROC and Mindat, the exact source of this nephrite artefact is uncertain, but chemical characterisation of this material provides an important step towards building a regional geochemical reference set for jade artefacts.

The presence of jade at Nombe is suggestive of a series of down-the-line social exchanges (of unknown antiquity) that enabled the transfer of valuables over long distances (Hughes 1977), something which is further supported by the obsidian recovered from 10400 – 6300 cal BP Stratum B deposits at Nombe. Although the source of this material is currently unknown, Shaw *et al.* (2020) have previously linked mid-Holocene obsidian from the Jimi Valley to the Kutau-Bao source in West New Britain, demonstrating pre-Lapita interisland transport of material. As jade axes were also used as maritime trade articles (see Harlow *et al.* 2012; Lindley and White 2022), the existence of a mid-Holocene exchange network connecting Nombe to the coasts may have facilitated the movement of other goods (such as obsidian) from interisland sources.

The incorporation of people living at Nombe into Holocene-era social exchange networks demonstrates that everyday raw material procurement and technological strategies for other artefacts (including the much more common ground edge volcanic axes-adzes) was not impacted by the development of agriculture or prestige economies in the region (Denham and Muke 2024). This highlights how lithic raw material procurement and technological organisation at Nombe remained constant despite clear social and ecological changes occurring in the region since the Late Pleistocene, establishing a pattern of enduring cultural continuity over the *longue durée*.

## 6. Conclusion

The pXRF analyses undertaken here represent a major step forward in the geochemical analysis of lithic assemblages at archaeological sites in the interior of Papua New Guinea. It represents the first in-depth geochemical study undertaken on a large sample of lithic material Highland New Guinea examining changes in raw material through time. The chemical results of the nephrite axe-adze flake both contrast and complement those of the much larger expediently produced volcanic assemblage. The volcanics demonstrate how past occupants of Nombe adapted technological strategies focused on the expedient use of immediately available raw materials, while the nephrite axe-adze fragment demonstrates the concurrent existence of likely down-the-line, cumulatively long distance, exchange networks, suggesting that external influences had limited impact on everyday lithic procurement, production and use at the site. The combination of technological flexibility and social interconnectedness enabled the first inhabitants of the region to establish and maintain occupation in the Central Highlands for over 20,000 years.

## Supplementary Materials

The supporting information can be downloaded at <https://doi.org/10.70460/jpa.v15i1.379>

S1: All calibrated data from the Nombe assemblage; S2: Reference data.

## Funding

Lead author has been the recipient of an Australian Government Research Training Program (AGRTP) scholarship. This research received no other external funding.

### Data Availability Statement

All data used and produced by this article is available within the supplementary material.

### Partnerships

This research did not use any primary data from Indigenous contexts.

### Conflicts of Interest

The authors declare no conflicts of interest.

### Author Contributions

Conceptualization, EN, M-JM, ML and TD; methodology, EN, M-JM, ML and MR.; software, EN and MR; validation, EN and MR; formal analysis, EN; investigation, EN; resources, EN, M-JM; data curation, EN; writing—original draft preparation, EN, M-JM, ML, MR, TD; writing—review and editing, EN, MR and TD; visualization, EN; supervision, ML, MR; project administration, EN; funding acquisition, EN. All authors have read and agreed to the published version of the manuscript.

### Acknowledgements

Archaeological excavations by MJM at Nombe in the 1980s were conducted with a permit from the Papua New Guinea National Museum and Art Gallery. The authors thank two anonymous reviewers for constructive feedback on the initial draft. Their comments have greatly improved the manuscript Joshua Willsher is thanked for photography of the Pleistocene edge-ground axe, and Maggie Otto and Charlotte Forbes are thanked for assistance with collections. This paper benefited from constructive discussions with Jean Kennedy, Geoffrey Clark and Susan O'Connor. We are grateful for the continuing support of the Australian National University.

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