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Fluctuating Local Mobility from the end of the Pleistocene to the end of the Holocene on the North Coast of New Guinea

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Abstract

The Watinglo rockshelter provides an occupation record from the central north coast of New Guinea from 13 ka to the last few hundred years, with a hiatus in the later Holocene. Examination of the lithic artefacts from this sequence suggests that within a paradigm of technological continuity and local resource procurement, there were notable fluctuations in the use of particular materials and the intensity with which the site was used. This suggests a pattern of small range size and population fragmentation that may have contributed to the unparalleled linguistic diversity of the wider region.

Keywords: Watinglo; lithics; obsidian sourcing; linguistic diversity; Papua New Guinea

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1. Introduction

New Guinea presents considerable challenges for human mobility. The northern and southern halves of the mainland are separated by a mountain chain reaching heights of over 4500 m. Much of the terrain is covered in dense tropical forest, while swathes of the lowland are swamp; and getting to large proportions of the landmass involves sea-crossings to offshore islands. Such impediments to human movement may in part explain the unparalleled language diversity of New Guinea; featuring over 1000 languages grouped into around 36 families together with numerous isolates (Foley 2000).

Agent-based modelling suggests that low levels of residential mobility foster cultural differentiation between neighbouring groups (Premo 2015). Similarly, the capacity for year-round subsistence at a single location has been correlated with high linguistic diversity (Nettle 1998). The high linguistic diversity of New Guinea could thus be linked to the long-term maintenance of human groups in situations of low mobility (Diamond 2013).

However, beginning at the Last Glacial Maximum, species translocations and geochemical sourcing of obsidian demonstrate networks of movement between islands, and from the mainland to the islands in eastern New Guinea (Summerhayes 2009; White 2004). Maritime obsidian networks intensified in the mid-Holocene and took on a radically new scale with the arrival of Austronesian-speaking Lapita peoples in the late Holocene (Summerhayes 2009). Cultural interaction spheres during the middle to late Holocene also featured stone pestles and incorporated the interior of New Guinea including the Highlands (Torrence and Swadling 2008; Shaw et al. 2020). Here, intensive horticultural practices emerged across the early to middle Holocene (Denham 2005) in conjunction with polished axe/adzes, which by the late Holocene were being traded down to the southern coast (Bulmer 2005; Ford and Hiscock 2024). Polished axes were also being produced on Muyua (Woodlark) Island and traded widely throughout the Massim islands and coastal eastern New Guinea in recent centuries (Bickler and Turner 2002). Eastern and southern New Guinea does not conform to a pattern of low inter-group connectivity, but here Austronesian and the Trans-New Guinea families dominate the languages spoken. The deepest linguistic diversity is to be found in the north and west of New Guinea.

On the north coast of central New Guinea, the site of Watinglo features a record of human occupation spanning the terminal Pleistocene to the late Holocene (O'Connor et al. 2011). The durability and abundance of stone artefacts means they provide an unbiased record of resource acquisition ranges. In this study we use the Watinglo stone artefacts to determine patterns of mobility and inter-group connectivity throughout the site's occupation, then assess whether such patterns might relate to the high linguistic diversity of the region.

1.1. Lithics and mobility

Ethnographic evidence from New Guinea indicates easily available and small-clast knapping materials, such as chert, are casually acquired (Sillitoe and Hardy 2003). On the other hand, rare, large clast, high-quality rock sources, such as fine-grained and tough metamorphic rock, often have complex rules of ownership and access (Hampton 1999). Exchange networks move axes made of such valuable materials between groups, with the principal barriers to stone artefact movement in New Guinea being enmity between neighbouring groups (Hampton 1999: 277).

Under conditions of low residential mobility, knappers will tend to encounter a limited number of locally available stone sources; whereas under conditions of high residential mobility, knappers will encounter a greater diversity of materials (Manninen and Knutsson 2014). Exceptions to this pattern can occur in cases where exchange networks allow low mobility groups access to a diversity of materials (Hertell and Tallavaara 2011), as may be the case for cultivators living in permanent villages. Conversely, low diversity can occur where high quality materials (such as obsidian), are targeted through direct procurement by groups making seasonal long-distance migrations (Frahm, Kandel, and Gasparyan 2019).

Concomitant to variation in material types, lithic technological classes vary according to the mobility of their makers. In circumstances of high mobility, flakes are knapped, used, and discarded at ephemeral localities, while cores are preferentially transported and deposited at repeatedly used occupation sites. In low mobility situations, cores are transported to long-term occupation sites and mainly knapped there, leading to many flakes being deposited for each core. The former strategy is characterised as person provisioning and the latter as place provisioning (Kuhn 1992). Similarly, under conditions of high mobility, the proportion of an assemblage which is retouched will tend to be high, because curated tools will need resharpening and/or replaceable inserts with standardized shapes created through retouch are needed to maintain tools while on the move (Kuhn 1992).

A common, but not necessary correlate of mobility is occupation intensity, as measured by the frequency of lithic artefacts (Liu et al. 2020). Sites tend to be used more intensively when mobility is low and more ephemerally when mobility is high (Centi and Zaidner 2022), with rates of retouch inversely correlated with lithic density (Clark and Barton 2017; Frahm, Kandel, and Gasparyan 2019). An exception to this is when a site is a repeatedly used node for a high mobility group, such as a seasonal camp, resulting in frequent lithics alongside high mobility signatures such as high rates of retouch.

Below we report artefact density, technological classes, and material diversity to understand human mobility and connectivity over the course of the Watinglo occupation sequence.

1.2. Regional context

Watinglo is a rockshelter situated ~100 m above sea level and less than 1 km from the coast (Figure 1). Tectonic uplift caused by the collision of the Australian and Pacific plates is estimated to occur at <3m/ka in northern New Guinea (Chappell, Ota, and Berryman 1996; Ota and Chappell 1999), while there is steep drop-off in ocean floor level close to the coast in this part of New Guinea, the New Guinea trench. Therefore the site would never have been far from the sea across the sea-level lows of the Late Pleistocene, but nor would it have been inundated by the middle Holocene high-stand 2-3 m above present levels ~7-6 ka (Woodroffe and Horton 2005). The rockshelter occurs in the uplifted limestone of the Oenake hills, which reach over 1000 m ~4 km south of the site. Dividing this part of the coast and the interior is the Bewani-Torricelli mountain range (Figure 1), rising to 1900 m a further ~50 km inland. Here, igneous rock outcrops in the Torricelli Intrusive Complex and the Bliri arc-type volcanics (Hutchinson and Norvick 1974). The Nemayer river, ~50 km to the east of the site, might transport clasts from these mountains. To the west of the site the coastal Cyclops mountains (Figure 1) provide the nearest outcrops of metamorphic rocks.

Figure 1. The location of Watinglo and other sites mentioned in the text near the north coast of central New Guinea

The pollen record from lake Hordorli in the Cyclops Mountains (Figure 1) shows montane forest grew in the region during the terminal Pleistocene, before lower altitude forest invaded in the early Holocene (~10.5 ka), taking over by the middle Holocene (~7 ka) (Hope and Tulip 1994). Fine charcoal in the lake sediment appears from 10.9 ka, likely due to anthropogenic clearance, with disturbance plant taxa increasing from this time. East of Watinglo, sediment cores from the infilled Sissano lagoon (Figure 1) show increases in charcoal from 6.2-6 ka and from 3-2.6 ka, the latter thought to reflect large scale forest clearance (Golitko et al. 2024). The nearby site of Lachitu shows initial human occupation 40 ka, with sporadic occupation from this time until the middle Holocene 7 ka, when both Lachitu and neighbouring Taora were more repeatedly used (Figure 1) (O'Connor et al. 2011). The site of Paleflatu, close to Watinglo, also shows human occupation from middle Holocene (Beaumont et al. 2019).

The language spoken in the Watinglo area is Wutung, part of the Skou family (Donohue 2002). This family is comprised of about a dozen languages on the north-central coast of New Guinea over a stretch of less than 150 km (Foley 2018b). The family is unusual in New Guinea in being tonal (Donohue 2003), with possible relationships to the Lakes Plain and Kaure families spoken in the interior to the southwest, though there are not enough similarities between these families to reconstruct such relationships with certainty (Foley 2018a).

2. Materials and methods

2.1. *Excavation*

Two 1x1 m trenches were excavated in the central part of the Watinglo shelter in 2005 (Figure 2). Excavations were dug in 2-5 cm spits, with broadly horizontal bedding evident in the layers. The square C excavation was terminated at ~205 cm due to constriction from large boulders, while square A continued to ~270 cm where archaeologically sterile weathered limestone rubble was reached. This study focusses on the more complete sequence from square A, though dates for equivalent layers in square C are also reported. The weight of excavated sediment was recorded in buckets to the nearest half kilogram. All excavated material was wet-sieved through a fine mesh (1 mm) before being sorted in the field into finds categories, with all material (including uncategorised residue) then exported to the Australian National University and sorted again in the lab to obtain the highest possible recovery of archaeological remains.

Ten layers are differentiated in the Watinglo sequence based on sediment composition (Table 1). With the exception of layers 1 and 7, these layers were also traceable across to square C, which is just 1m to the SE (Figure 2). In square A layer 2 there is interdigitation of more and less clast rich horizons, allowing sub-division into 2A (spits 82-71) and 2B (spits 70-62) (Figure 3). In layer 9 there is a horizon of coarser material allowing sub-division into 9A (spits 9-6) and 9B (spits 5-3) (Figure 3). Three broad phases of human occupation are apparent in this stratigraphy (Table 1): a recent phase featuring both ceramics and domestic pig bones (O'Connor et al. 2011); a middle phase with distinct occupation layers and varying quantities of shell; and a lower phase with frequent limestone clasts. A gracile human mandible from layer 2B (Figure 3) shows similarities to that of a 19 ka specimen from Liang Lemdubu in the Aru Islands, suggesting broad regional continuity in human populations (Bulbeck and O’Connor 2011).

Table 1. Layer descriptions for Watinglo Square A

Layer	Spits	Colour	Compaction	Principal inclusions	Phase
10	1-2	Reddish brown	Loose		3
9	3-9	Greyish brown	Compact	Pottery, shell, and bone	3
8	10-14	Orangey brown	Moderate	Frequent shell, occasional limestone	2
7	15-22	Orangey brown	Loose		2
6	23-32	Dark greyish brown	Compact	Occasional shell and bone	2
5	33-44	Pale brownish grey	Loose	Small limestone clasts	2
4	45-51	Pale greyish brown	Loose	Occasional limestone clasts	2
3	52-61	Mid greyish brown	Loose	Frequent small shell fragments, moderate limestone clasts	1
2	62-82	Dark brown	Compact	Frequent limestone clasts	1
1	83-91	Dark greyish brown	Loose	Frequent weathered limestone, moderate shell	1

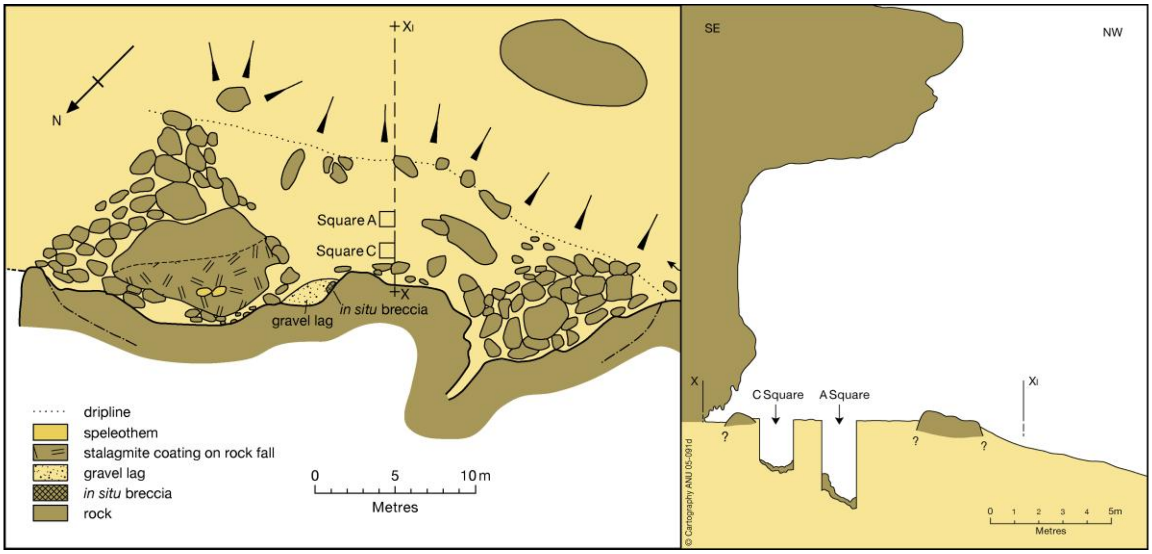

Figure 2. Plan (left) and profile (right) of the Watinglo shelter showing the two excavation trenches.

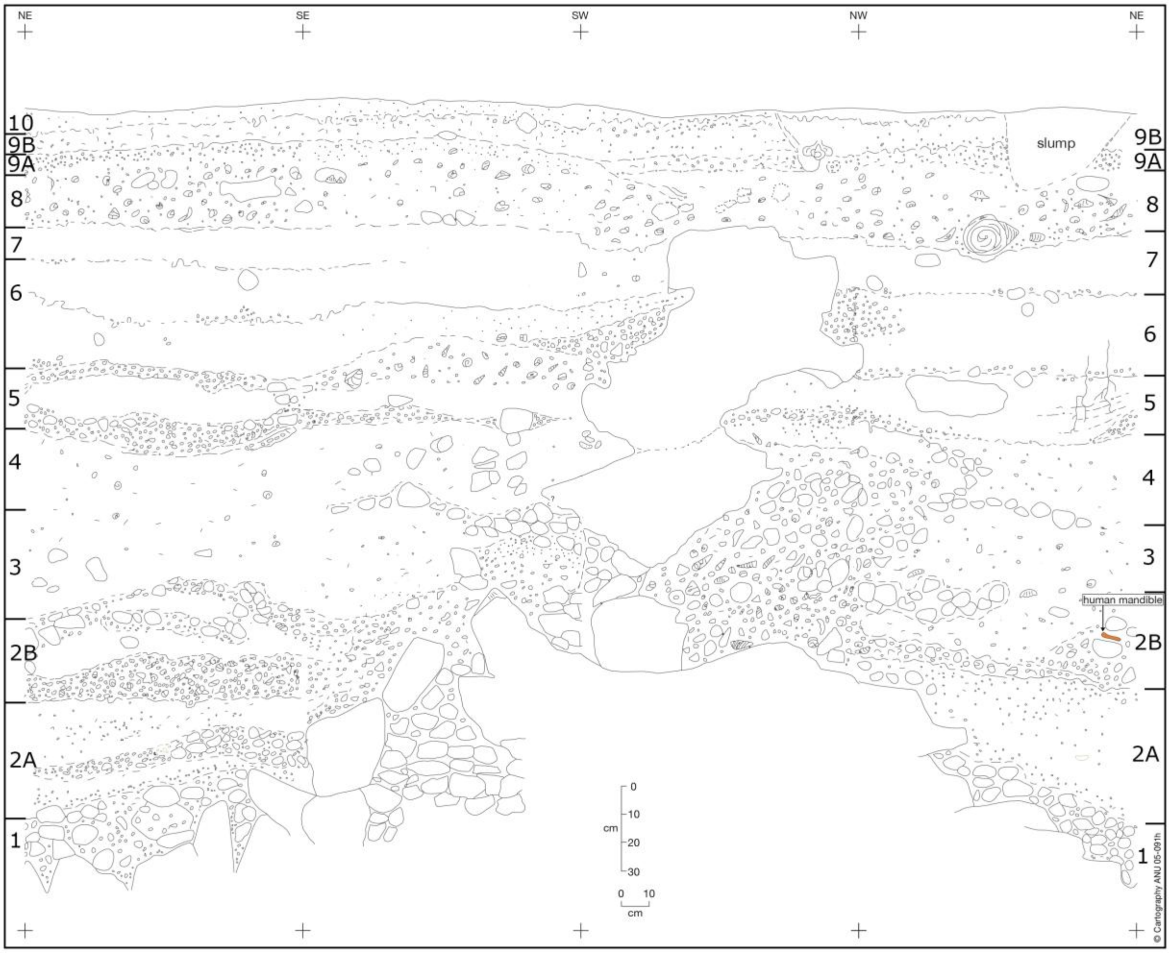

Figure 3. The Watinglo square A profile. Limestone clasts are shown as outlines, shells are shown with infilled patterns.

2.2. Dating

A total of 34 samples were radiocarbon dated, 28 of which were previously reported in O'Connor et al. (2011) (Table 2). The samples were of marine shell, charcoal, bone, and *Canarium* shell from the excavations, as well as charcoal from the breccia on the rear wall of the shelter, 30 cm above the floor (Fig. 2). For this study, dates were calibrated using OxCal 4.4.4 (Bronk Ramsey 2021). Since Watinglo is located within the Intertropical Convergence Zone, terrestrial samples were calibrated using a mixed international (IntCal20: Reimer et al. 2020) and southern hemisphere curve (SHCal20: Hogg et al. 2020) with allowance for possible variation in the past (by setting a uniform prior in OxCal between 0 and 50 for SHCal). For marine samples, a ΔR correction for the north coast of New Guinea of 185±30 was applied to samples with a C14 age of 7220-5850 BP (McGregor et al. 2008). Marine shell samples were calibrated with the marine curve (Marine20: Heaton et al. 2020). All dates reported for the site below are in calBP.

Across both excavation squares, dates for the ceramic bearing layer 9 range from 190 to 550 BP (barring a single presumably intrusive date of 6850 from square C spit 7, Table 2). Dates for layer 8 in square A range from 5420 to 7054 BP, with the dates for square C also falling within this timespan. The date for the breccia on the shelter wall falls in between these dates and layer 6, suggesting an erosive phase between the deposition of layers 6 and 8. Dates from layer 6 were 7680 and 7570 BP in squares A and C, respectively. In square A, layer 5 produced a date of 7910 BP and layer 4 8510 BP. Layer 3 yielded dates of 8930 and 10,090 BP in square A, with a date from this layer in square C also falling in this timespan. Layer 2 had dates ranging from 11,090 to 11,450 BP in square A, though there was a date of 9050 BP for this layer from square C. Dates for layer 1 in square A ranged from 11,480 to 12,940 BP, with a sample dating to 11,930 BP for this layer in square C (Table 2).

2.3. Lithic analysis method

Flaked stone artefacts were assigned to a geological type, a technological class (core, flake, retouched), and counted. Additional variables were recorded on cores and retouched pieces.

Cores were assigned a technological type according to their flaking pattern, the number of scars was counted, axial (box) length, width, and thickness were measured according to the main axis of flaking, and the length of the largest complete scar was measured. Using the formula for a rectangular prism, the scar density index (SDI) of reduction intensity was estimated (Clarkson 2013).

For retouched pieces, axial length was measured according to the percussion of the flake with axial width measured orthogonally to this. On tools where retouch had obscured the percussion axis, or irregularly shaped pieces where neither axial percussion length nor width captured the largest dimension of the tool, maximum dimension was measured. The length of the edge that had been retouched was recorded. For notched pieces the width of individual notches was measured.

Cobble manuports were assigned a geological type and complete pieces had their length, mid-width, and mid-thickness measured. Potential mineral pigment pieces >20 mm in maximum dimension were weighed.

Any putative obsidian artefacts were geochemically fingerprinted using a Bruker Tracer 5g portable X-ray fluorescence (pXRF) machine (serial number 900G10419) running at 40 KeV and 30 μA for 30 seconds using a Cu 100μm:Ti 25um:Al 300um filter. Each artefact was analysed three times, repositioning between assays, and the results were averaged to provide a more representative

Table 2. Radiocarbon dates for Watinglo, calibrated using OxCal 4.4.4.

Sample ID	P	**L**	**Square**	**Spit**	**Material**	**C14 Age (-ΔR)**	**+/-**	**Median calibrated age**
KIA-35648	3	9	A	6	Pig bone	265	25	300
S-ANU-9419	3	9	A	6	Charcoal	445	30	500
S-ANU-9418	3	9	A	6	*Turbo* sp.	865	25	330
KIA-35649	3	9	A	8	Pig bone	220	20	190
KIA-35650	3	9	A	10	Pig bone	290	25	380
S-ANU-9421	3	9	C	2	Bivalve	1130	30	550
S-ANU-9425	3	9	C	4	Charcoal	270	25	300
S-ANU-9424	3	9	C	4	*Turbo* sp.	895	35	360
S-ANU-9423	3	9	C	4	*Turbo* sp.	800	35	260
S-ANU-9426	3	9	C	7	*Turbo* sp.	6755 (-185)	40	6850
S-ANU-9427	3	9	C	10	*Turbo* sp.	880	35	350
Wk-17255	2	8	A	10	*Turbo setosus*	5248	51	5420
S-ANU-9430	2	8	C	13	*Turbo* sp.	6810 (-185)	45	6916
S-ANU-9429	2	8	C	13	*Turbo* sp.	6850 (-185)	45	6964
S-ANU-9432	2	8	C	14	*Turbo* sp.	6295 (-185)	40	6341
Wk-17253	2	8	A	14	*Turbo setosus*	6932	65	7054
OZI283	2		Breccia		Charcoal	6350	110	7250
S-ANU-9433	2	6	C	21	*Turbo* sp.	7400	40	7680
NZA-36040	2	6	A	23	*Turbo* sp.	7286	25	7570
NZA-36043	2	5	A	35	*Rochia nilotica*	7086	25	7499
NZA-36041	2	4	A	46	*Turbo* sp.	8213	25	8510
S-ANU-9435	1	3	C	41	Terebralia	8720	50	9200
NZA-36039	1	3	A	53	Terebralia	8509	25	8930
S-ANU-68829	1	3	A	57	*Turbo* sp.	9416	28	10090
S-ANU-9436	1	2	C	48	Terebralia	8590	50	9040
S-ANU-68827	1	2	A	67	*Turbo* sp.	10308	31	11280
Wk-17259	1	2	A	80	Canarium	9892	48	11280
Wk-17260	1	2	A	71	Canarium	9990	51	11450
S-ANU-68826	1	2	A	76	*Turbo* sp.	10282	30	11240
Wk-17257	1	2	A	82	*Turbo* sp.	10143	53	11090
S-ANU-9437	1	1	C	53	*Turbo* sp.	10735	45	11930
S-ANU-9420	1	1	A	86	Terebralia	10445	45	11480
Wk-53005	1	1	A	88	*Turbo* sp.	10948	36	12280
Wk-53002	1	1	A	91	Chiton	11648	38	12970

reading of whole rock chemistry. Calibration was performed in EasyCal (Version 2.4.242.5) using the Missouri University Research Reactor (MURR) obsidian calibration set of Glascock (2020) (see Appendix 1). Readings were then compared to known sources for New Guinea measured with the same machine. In-house obsidian standard ANU9000 was run for drift before and after the analysis of the Watinglo obsidian following the protocol described above, and was run an additional 4 times during the analysis of the reference material (18 assays total). Averaged values and standard deviations are available in Supplementary Data 1.

3. Results

3.1. Occupation intensity

From Watinglo square A, 12,442 knapped stone artefacts were recovered, an average of 3.1 per kg of sediment. Lithic density in number of artefacts per kg of sediment varies markedly through the sequence, with the median density layers 3 and 7 having over 10x the density of lithics as the lowest three density layers (1, 6, and 10), and 0.4x the density of the highest density layer (2B). There are two peaks in lithic density in the sequence: in layers 2-3 and 7-9A (Table 3). Bone weight per kg of sediment has a similar pattern, though the peak in the earlier part of the sequence is lower (Table 3), perhaps due to preservation bias.

Table 3. Lithics and bone by sediment weight in Watinglo square A. Bone data from O'Connor et al. (2011).

Layer	Sediment kg	Bone g/kg	Lithics n	Lithics n/kg	Cores	Retouched
10	84.5	0	23	0.272	-	1 (4.3%)
9B	121.5	0.716	170	1.399	-	-
9A	171	1.38	1155	6.754	2 (0.2%)	1 (0.1%)
8	207	4.527	1434	6.928	2 (0.1%)	4 (0.3%)
7	330	2.161	805	2.439	-	6 (0.8%)
6	411.5	1.064	134	0.326	-	3 (2.2%)
5	513	0.745	388	0.756	4 (1%)	4 (1%)
4	360	0.194	282	0.783	-	2 (0.7%)
3	514.5	0.381	1851	3.598	2 (0.1%)	10 (0.5%)
2B	474	1.635	4316	9.106	11 (0.3%)	17 (0.4%)
2A	420	1.076	1800	4.283	2 (0.1%)	9 (0.5%)
1	327	0.18	85	0.26	-	1 (1.2%)

3.2. Rock types

Nine different materials were used for knapping at Watinglo (Table 4). By far the most common across all layers was chert, comprising 92.4% of all knapped artefacts, but ranging from 97.9% of lithics in layer 4 to 85.1% in layer 6. Red was the dominant colour of chert, but a distinctive green variety was also present in layers 10-9 and 2, and a greyish blue variety in layer 2. The occasional presence of angular cortex on the chert suggests procurement as tabular pieces from primary sources, probably as veins in the local limestone, rather than river cobbles. As in coastal Wallacea (Shipton, O'Connor, and Kealy 2021), post-flaking heat damage was common on these sedimentary lithics.

Quartz was the next most common material, accounting for 3.1% of all lithics, and came in three varieties; milky, crystal, and an unusual aquamarine coloured form - the latter only found in layers 2-3 (Figure 4F). Quartz was largely absent from the upper part of the sequence but constituted 7% of lithics in layer 2B.

Limestone lithics comprised 1.7% of the assemblage, probably representing opportunistic flaking of the rockshelter itself as well as introduced higher quality limestone. Limestone was consistently present in most layers, except 4 and 10. 1.5% of the lithics were milky chalcedony with white cortex (Figure 4A). These were unevenly distributed through the sequence, only occurring in layers 2B, 3, and 7-10, being particularly common in layer 8 where they constituted 5.4% of lithics. There were rare occurrences of quartzite in the assemblage, with nearly all of these in layer 8 – spits 10 and 11 providing 21 of the 25 in total.

Shell flakes only constituted 0.7% of the assemblage, but were found in every layer except 10. High proportions of shell flakes occurred in layers 6 (6%) and 1 (8.2%). Similarly, 0.3% of artefacts were of basalt (Figure 4D), and these were found in low proportions in every layer except 10. Six samples of patinated dark igneous material from layer 2 registered anomalously low Rb concentrations (below detection limits) when screened with the pXRF. There were also 17 (0.1%) flakes of a soft pale green igneous material. A small obsidian flake was found in layer 9A.

Table 4. Knapped materials by layer for Watinglo square A. Note that the table does not include the single small flake of obsidian and the small flake of an unknown translucent material from layer 9A.

Layer	Chert	Quartz	Limestone	Chalcedony	Shell	Basalt	Low Rb igneous	Green volcanic	Quartzite
10	22 (95.7%)	-	-	1 (4.3%)	-	-	-	-	-
9B	154 (90.6%)	-	1 (0.6%)	11 (6.5%)	2 (1.2%)	2 (1.2%)	-	-	-
9A	1095 (94.8%)	-	5 (0.4%)	41 (3.6%)	5 (0.4%)	4 (0.3%)	-	2 (0.2%)	-
8	1302 (90.8%)	1 (0.1%)	25 (1.7%)	77 (5.4%)	6 (0.4%)	1 (0.1%)	-	-	22 (1.5%)
7	739 (91.8%)	-	9 (1.1%)	27 (3.5%)	27 (3.4%)	2 (0.3%)	-	1 (0.1%)	-
6	114 (85.1%)	3 (2.2%)	7 (5.2%)	-	8 (6%)	2 (1.5%)	-	-	-
5	367 (94.6%)	3 (1%)	8 (2.1%)	-	5 (1.3%)	1 (0.3%)	-	4 (1%)	-
4	276 (97.8%)	1 (0.4%)	-	-	1 (0.4%)	2 (0.7%)	-	2 (0.7%)	-
3	1768 (95.5%)	27 (1.5%)	29 (1.6%)	7 (0.4%)	9 (0.5%)	3 (0.2%)	-	7 (0.4%)	1 (0.1%)
2B	3918 (90.8%)	298 (7%)	61 (1.4%)	17 (0.4%)	8 (0.2%)	7 (0.2%)	5 (0.1%)	1 (>0.1%)	1 (>0.1%)
2A	1677 (93.2%)	45 (2.5%)	62 (3.4%)	-	5 (0.3%)	8 (0.4%)	1 (0.1%)	-	1 (0.1%)
1	73 (85.9%)	2 (2.4%)	2 (2.4%)	-	7 (8.2%)	1 (1.2%)	-	-	-
Total	11505 (92.4%)	380 (3.1.%)	209 (1.7%)	181 (1.5%)	83 (0.7%)	39 (0.3%)	6 (>0.1%)	17 (0.1%)	25 (0.2%)

Figure 4. Medium-sized artefacts from Watinglo. A is a chalcedony notch from layer 9A (double-ended arrows denote notches); B is an ochre-covered piece of micaceous slate from layer 2B; C is an operculum notch from layer 1 (double-ended arrows denote notches); D is a polished basalt axe flake from layer 6 (the arrow denotes the platform in profile), note the polishing on the distal part of the flake and the platform; E is an ochre covered chert Janus flake from layer 2B (the arrow denotes the percussion axis of the original flake from which this flake was struck); F is a flake of the aquamarine quartz; G is a flake of micaceous slate with ochre on it and rounding on the dorsal surface from layer 1. Scale is 1 cm long.

3.3. Knapping technology

A total of 24 cores were identified in the assemblage, 15 of which were chert, 5 limestone, and 4 quartz. Limestone was the least reduced material with a median SDI on cores of 0.476, chert intermediate with 0.784, while quartz was the most reduced with a median SDI of 4.164. Cores were most common in layers 2B and 5 (Table 3). A similar range of informal reduction strategies are evident throughout the sequence with discoidal and bipolar cores from both the upper and lower parts of the sequence; the only change is a shift from multifacial cores to unifacial cores from layers 2 to 3 which may just reflect lower levels of reduction (Table 5). Bipolar seems to have been used as a late stage reduction strategy with a median SDI of 7.157 on bipolar cores, well above the assemblage median as a whole of <1. Platform faceting on chert flakes was a knapping strategy evident in both the upper and lower parts of the sequence with examples of facetted platforms noted in layers 2-3 and 8 (Figure 5B).

Table 5. Core types by layer.

Layer	Assayed	Unifacial	Multifacial	Discoidal	Bipolar
9	1	-	-	-	1
8	-	1	-	1	-
5	1	2	-	1	-
4	-	-	-	1	-
3	-	2	-	-	-
2B	2	-	2	2	5
2A	-	-	2	-	-
Total	4	5	4	5	6

The rare basalt flakes often had low platform angles, with examples of grinding or polishing on the dorsal surface and/or platform on flakes from layers 9A-5, and 2B (Figures 4D & 5D). The scarcity of basalt flakes and their repeated occurrence with ground surfaces suggests reworking, but not manufacture, of groundstone axes. Low platform angles (Figures 4D & 5C) are indicative of bifacial axes, with no examples of basalt flakes with high-angled and multi-scarred platforms that might be suggestive of the quadrangular adzes associated with Austronesian peoples in the Pacific (Shipton, O'Connor, Kealy, et al. 2020; Clarkson, Shipton, and Weisler 2015). (As opposed to New Guinea planilateral adzes where the rectangular section is created through grinding (Ford and Hiscock 2024)).

Shell flakes were typically from opercula using the flat side as a platform to create steep-edged tools, as has been documented in eastern Wallacea (Szabó, Brumm, and Bellwood 2007; Shipton, O'Connor, Reepmeyer, et al. 2020). In layer 1 a multiple notch was created on a large operculum (Figure 4C). There were also flakes from layers 2-3 and 9A of giant clam shell, with three flakes from layer 9A and one from layer 2A showing grinding on the dorsal surface. A complete example of a giant clam shell adze, albeit with a weathered surface, was found in layer 2A (Figure 6B).

Across all materials, flakes were predominantly <20 mm in length. The largest complete flake scar on cores provides a measure of the point at which cores were considered unproductive and often corresponds to the average size of flakes in an assemblage (Shipton et al. 2019; Shipton et al. 2021).

The mean and standard deviation of largest complete scar length on all Watinglo square A cores was 14.13±4.88 mm, comparable to miniaturized assemblages from eastern Wallacea.

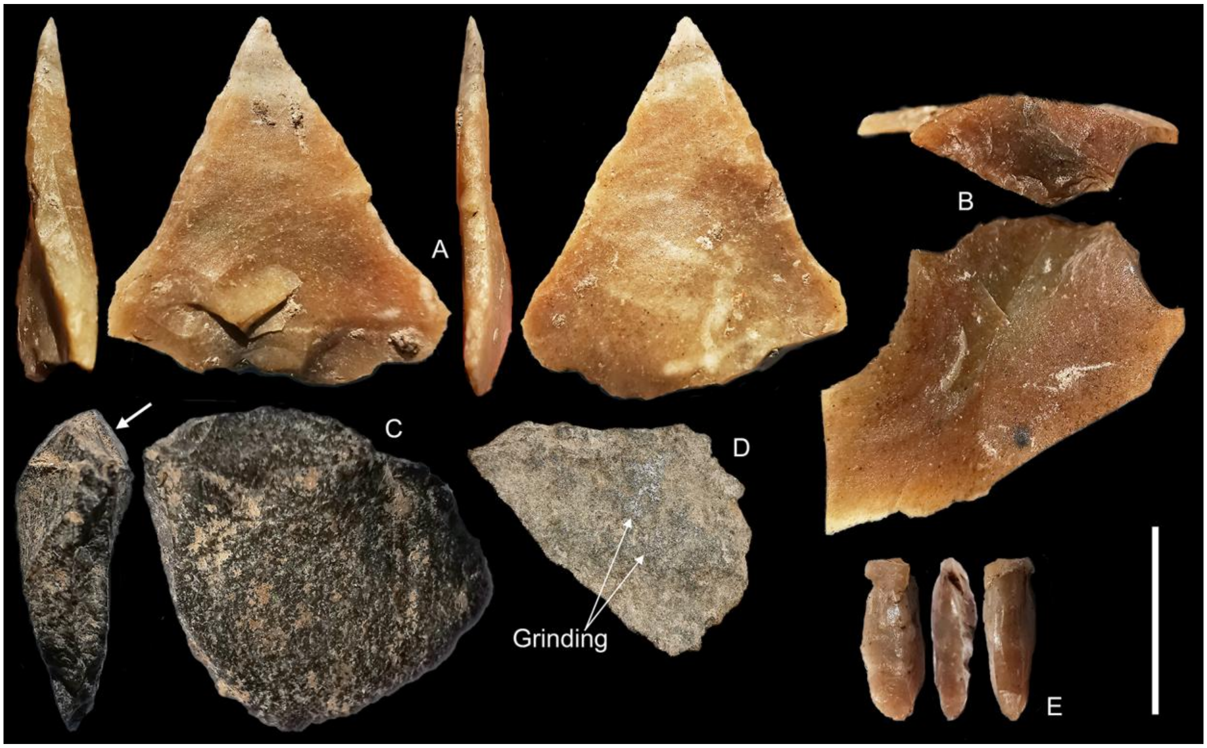

Figure 5. Small artefacts from Watinglo. A is a chert marginally retouched bifacial point from layer 2A; B is a facetted platform chert flake from layer 2A; C is a basalt flake with a low platform angle from layer 9B (the arrow denotes the platform in profile); D is a ground basalt flake from layer 2B; E is a chert bipolar core from layer 9A. Note the proximal scars on the dorsal surface of A. Scale is 1 cm long.

Retouch rates were low, just 0.5% of the assemblage in total. The 58 retouched tools from Watinglo were significantly larger than the largest flake scars on cores, with a mean length of 38.6±17.5 mm. A t-test showed this difference to be significant at the $p<0.0001$ level ($t=6.668$). The majority of retouched artefacts were chert (n=47, 81%), but compared to the total lithic population a disproportionate number were chalcedony (n=6, 10%), limestone (n=4, 7%), and shell (n=1, 2%). A chi-square test with Yates' correction on chert and chalcedony showed the difference in proportion of retouched pieces to be significant at the $p<0.0001$ level ($\chi=27.214$). Chalcedony artefacts tended to be large and included the largest knapped lithic, a retouched flake 114.75 mm long. The retouch preference for both this fine-grained material and coarser-grained limestone suggests large clasts rather than sharpness or durability was the priority. 15 retouched tools, averaging 42.98 mm long, were made on pieces whose ventral surfaces were unclear or on broken flakes, again indicating size rather than the original form of the flake was the important factor when selecting flakes for retouch. The preference for large retouched lithics suggests a relatively heavy-duty function in comparison to the rest of the flake population.

A single retouched piece occurred in the low sample size layer 1. Retouched artefacts were scarce in layers 2-3 but more common above, reaching a notably high proportion in layer 6 (Table 3). 79% (n=46) of retouched tools were notches, with multiple notches on individual pieces common (Figure 4A&C). Notches were present in every layer with retouched artefacts, with a mean notch width of 7.66±4.11 mm (n=97). Other retouched types included scrapers from layers 2, 8, and 10 (n=5), ventrally retouched pieces (n=2) from layer 3, and retouch which did not alter the angle of the edge (resharpening, n=4). The most unusual retouched piece was a chert point from layer 11, with marginal bifacial retouch on both edges (Figure 5A). Scars on the proximal end may have been removed (either before or after the flake itself) to create a thin butt on the opposite surface to the bulb and make the piece easier to haft at this end.

Figure 6. Large artefacts from Watinglo. A is limestone pounder from layer 2B (note the pitting and flake scars on the narrow ends of the piece); B is a giant clam adze from layer 2A. Scale is 1 cm long.

3.4. Obsidian sourcing

The single obsidian flake from layer 9A showed a clear match to the Lou source in the Admiralties in both its yttrium vs. niobium and rubidium vs. strontium biplots (Figure 7). Individual values as well as manganese, iron, zinc, gallium, zirconium, and thorium are available in Supplementary Data 1.

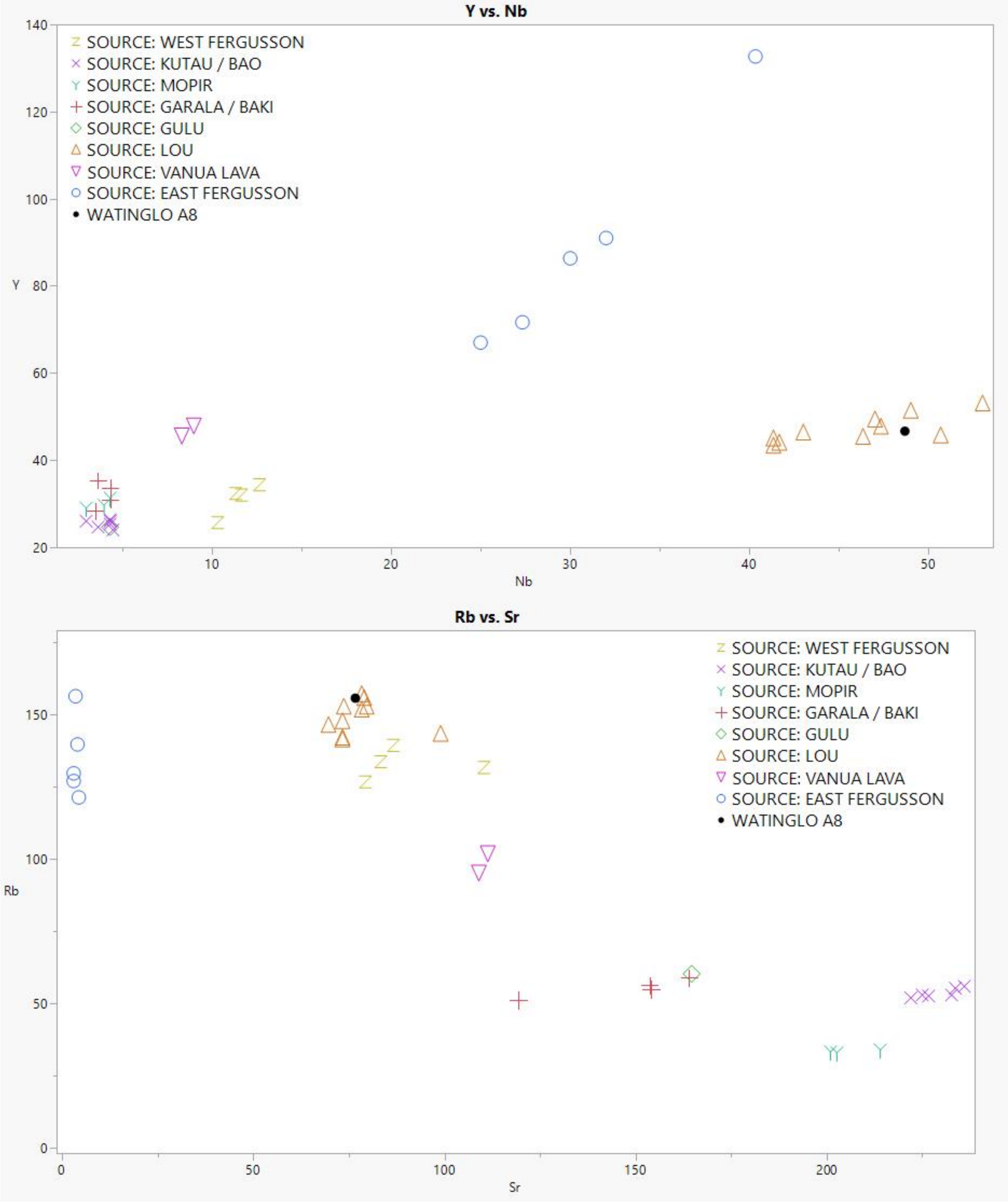

Figure 7. Biplots of yttrium vs. niobium (above) and rubidium vs. strontium (below). Note that in both cases the Watinglo sample (black dot) clusters with Lou (orange triangles).

3.5. Pulverising stones

Grinding stones included rounded cobble fragments of basalt (n=4), the pale green igneous stone (n=4), and limestone (n=10), and were found in layers 2-3, 5, and 7, with a particularly large (84.4x111x19.35 mm) cobble flake from a unique metamorphic stone from layer 2A. The only complete pulverising stones were elongate pieces often with battering at the distal ends (Figure 6A), found in layers 2, 5, 7, and 10. These were mostly of limestone, but the piece from layer 10 was the pale green igneous stone. These pounding stones weighed 344.9±190.3 g and were 118.44±22.7 mm long on average (n=6). A mean width to thickness ratio of 1.41 (n=7, including a piece broken at one end) describes the generally rounded form of these artefacts. The artefact shown in figure 6A appears to have been used as both a pestle, with battering at the ends, and as a muller, with smoothed sides. On the proximal end the brightly coloured ochre is probably a recent accidental transfer, but the more orangey ochre on the distal end is embedded in the surface pitting and may reflect one of the functions of this tool in powdering ochre. The black residue in the centre of one side is unidentified, but may have resulted from the additional function of this tool as a muller.

3.6. Decorative pieces

Large pieces of red ochre were recovered from all layers except 5, 9B, and 10, with some black and white ochre pieces also found in layer 2B, a total of 554.47 g. The red ochre was a mixture of solid haematite, some with rounded surfaces and occasionally striations from rubbing, and soft powdery iron rich compact sediment, as well as one small piece of iron-rich shale in layer 2B. Despite having relatively few lithics, layer 6 produced 93.37 g of ochre. The bulk of the ochre was from the dense layers 2A, 2B, and 3, which produced 97.12, 164.58, and 143.53g respectively. Layer 9B yielded a fragment of giant clam shell that appeared to have been used as an ochre grinding vessel, with extensive ochre staining on its inner surface. Three flakes of chert from layer 2B were covered in ochre as though this had been done deliberately (Figure 4E). These ochred pieces are all Janus flakes (i.e. flakes struck from the ventral surface of large flakes), so there may be an association with a particular technology.

Two small green pebble manuports were found in layers 3 and 9. An unusual manuport from Watinglo was micaceous slate, 110.5 g of which was found in layers 1-2, 5-7, and 9A. A flake of this material from layer 1 (Figure 4G) shows that it was manually extracted, with rounding on the dorsal surface likely from rubbing. This rock may have been used to produce a glittery paint effect, with its association with the ochre pigment attested by two pieces from layers 1 and 2B with ochre residue (Figure 4B&G). Layer 2A produced 23 g of micaceous slate and layer 5 76.9 g. Interestingly, appreciable quantities of ochre were not present in layer 5, suggesting a different form of artistic expression in that layer.

4. Discussion

4.1. The lithic toolkit

Watinglo shows broad continuity in lithics across the sequence with the dominance of small chert flakes made using informal reduction techniques, alongside large retouched notches, flaked opercula, bifacial ground axe/adze reworking, elongate pounding stones, and red ochre. This continuity was perhaps engendered by the prevalence of tree crops in New Guinea domesticates, ensuring they could be incorporated by hunter-gatherers during the Holocene without major changes in lifeway (Kennedy 2012). The small size of the lithics and the low rates of retouch at Watinglo indicate a miniaturized mode of lithic function was dominant, whereby multiple small flakes were produced with unretouched sharp edges for presumably short use-lives (Shipton 2023). Miniaturized chert lithics with low rates of retouch are also known from the Pleistocene-Holocene transition at Panakiwuk on New Ireland (Allen, Gosden, and White 1989), and from the terminal Pleistocene to the late Holocene in the eastern Highlands (Huff 2016).

Notches were the principal retouched tool type at Watinglo. This pattern has also been documented at coastal sites in neighbouring Wallacea, including Asitau Kuru on Timor (Shipton et al. 2019), Leang Sarru in the Talauds, and Topogaro on Sulawesi (Ono et al. 2020). Microscopic examination and experimental comparison of notched lithics from Leang Sarru indicates their use in plant processing activities such as scraping tuber skins, extracting fibre, thinning strips, and smoothing rods (Fuentes et al. 2020). Larger lithics were preferred for the experimental plant working due to the ease of gripping them in relatively long (30 minutes) and robust activities, which probably explains the preference for larger clasts among the retouched pieces at Watinglo.

Elongate cobble manuports of the kind present at Watinglo, have also been identified in the Highlands at Kuk Swamp and the Ivane Valley in the early to middle Holocene, where they were used for mashing tubers including taro and yam, as well as processing nuts and grasses (Field et al. 2020; Fullagar et al. 2006). Cobble manuports are also known from early to middle Holocene occupations in northeastern Wallacea, including at Kelo on Obi island (Shipton, O'Connor, Kealy, et al. 2020), and Tanjung Pinang on Morotai (Bellwood, Irwin, and Tanudirjo 2019).

Canarium is present from the early Holocene at Watinglo (Table 2), while flotation of middle Holocene layers at nearby Taora has shown tree species including fig, coconut, and sea almond were used (Fairbairn 2005). The axe technology at Watinglo may be implicated in arboricultural practices, prevalent across New Guinea in the Holocene (Denham 2004; Kennedy 2012). Axes in New Guinea are also ethnographically documented in the predation of cuscus: through improving visibility at ambush sites; felling small trees containing dens; or accessing dens in larger trees (Dwyer 1983; Sillitoe 2002).

A high discard rate of 3.1 lithics per kg of sediment and low retouch rates of <2.5% across all layers except 10, suggest low overall mobility in a model of place provisioning (Kuhn 1992). In Late Pleistocene New Guinea by contrast, both the Ivane Valley in the eastern Highlands (Ford 2017) and the Yombon region of New Britain (Pavlides 2004) have small assemblages (<200) and retouch rates of 10% and 31% respectively; indicating high mobility, person provisioning modes of lithic use. The sequence from Nombe rockshelter in the Highlands sees a change from person provisioning in the Late Pleistocene to place provisioning in the Holocene (Evans 2000). Similarly, the sequence from Buang Merabak on New Ireland shows more direct provisioning of the rockshelter from specific primary volcanic sources rather than diverse secondary sedimentary sources from the Late Pleistocene to the early Holocene (Kerby et al. 2022). Increased population density in the Holocene may have resulted in more restricted territories in general in New Guinea, while the advent of aboriculture may have allowed groups to be sustained by smaller territories.

4.2. Occupation history

Each layer at Watinglo has its own distinctive characteristics in terms of occupation intensity and the range of rock types used. The terminal Pleistocene occupation in layer 1 features a low density of artefacts and a relatively high proportion of flaked shell, perhaps reflecting initial use of marine resources with the newly transgressed coastline. Indeed, crab remains are prominent in the upper spits of this layer (Kaharudin 2023).

Layer 2A presents a high density of lithics and a high diversity of materials, suggesting a more established group with access to a broad range of rocks in the wider region. The giant clam shell adze from this layer (Figure 6) adds to the corpus of these artefacts from both the Admiralty islands to the east and Wallacea to the west (Fredericksen, Spriggs, and Ambrose 1993; Shipton, O'Connor, Reepmeyer, et al. 2020). A possible function of this pointed-tip adze from Watinglo is gouging tree-trunks to make dug-out canoes.

The bifacial point from layer 2A is thin, with scars on the butt suggesting deliberate thinning which would have allowed it to be hafted as an arrowhead. Its tip cross-sectional area (34.7 mm^2) is within the range of unpoisoned arrow tips from elsewhere in the world (Lombard, Lotter, and Caruana 2024), while the mean size of notch widths (7.66±4.11 mm) is consistent with their use as spokeshaves for arrow shafts. Bamboo tipped arrows are ethnographically documented in northern New Guinea (Fyfe and Bolton 2011) and it is possible that these had stone-tipped antecedents.

Layer 2B is the peak in occupation intensity in the sequence in terms of both lithics and bone, possibly when the coastline was stable in the initial Holocene. The rubble in layer 2 in general may reflect increased weathering of the shelter with more human activity. Increased occupation intensity may be part of a broader regional pattern evident in the anthropogenic charcoal signature in the lake Hordorli core from 10.9 ka. Every knapped material is represented in layer 2B, including a peak of 7% quartz lithics and four of the six aquamarine quartz artefacts, showing broad territorial access. The presence of low Rb igneous material supports this as it probably derives from the ophiolites of the Cyclops Mountains ~50 km west of Watinglo, where mafic igneous rocks are known to contain less than <1ppm Rb (Monnier et al. 1999).

Three ochred chert Janus flakes from layer 2B suggest symbolism for this particular technology. In the western Highlands, flake scars on adzes that were too deep to be ground were sometimes painted red to show the 'life-blood' to the tool (Pétrequin and Pétrequin 1993). The presence of two 'inner' ventral surfaces on a flake may have similarly reflected its internal 'life-blood'.

Layer 3 shows a relative reduction in artefact density and the loss of ophiolite derived igneous material from the sequence. Layer 4 shows a further reduction in the density of lithics and a low diversity of materials, with the highest proportion of chert in the sequence. The rockshelter may have been used less frequently at this time due to the disruption of early-middle Holocene sea-level rise (Ota and Chappell 1999).

Layers 5 and 6 have low artefact densities but high diversities of material, and high proportions of cores and retouched artefacts, suggesting Watinglo was a node for a higher mobility population during the deposition of these layers. Notwithstanding this mobility, there is an absence of chalcedony in these layers and layer 4. Despite having low numbers of lithics, layer 5 has the largest proportion of micaceous slate, while layer 6 accounts for 17% of the ochre by weight. Social signalling involving these materials was perhaps important during a phase of higher mobility when encounters with people outside the residential group were more frequent. The high proportion of shell artefacts in layer 6 may reflect more foraging along the coast ~7500 BP, with a very high frequency of crab shell in this layer perhaps reflecting mangroves being closer to the site at this time (Kaharudin 2023).

Following layer 6, ~7250 BP, the breccia seems to have formed to a height ~30 cm above the current cave floor before an erosive phase brought the sediment back down to the base of layer 7 or 8. A similar erosive phase leaving breccia stranded on the rockshelter wall has also been documented at Lachitu, and it is hypothesized that it may have resulted from local land clearance destabilising the slope below the shelter (O'Connor et al. 2017). A gravel lag on the rockshelter floor below the breccia may represent the remnant coarse fraction of sediment that was otherwise eroded away (Figure 2). Increased lithic density in layers 7 and 8 attests to more anthropogenic activity, with layer 8 dated to 7000-5500 BP. The other known archaeological sites to the east, Paleflatu, Lachitu, and Taora, were also occupied at this time, with an increase in charcoal in the Siassano lagoon lake core suggesting anthropogenic land clearance.

Layer 7 features a high diversity of material including chalcedony, but an absence of quartz, while layer 8 includes only a single piece of quartz, but nearly all the quartzite artefacts. Access to the Cyclops Mountains is suggested by the presence of metamorphic quartzite, but to a different source than the igneous ophiolites. Low proportions of cores and retouch in layer 8 suggest Watinglo was a residence for a low mobility population, which accords with a more settled mode of subsistence perhaps featuring cultivation. The diverse materials in this layer were perhaps accessed through inter-group exchange connections rather than group movement.

A hiatus of several millennia between layers 8 and 9 may reflect sea-level recession after the middle Holocene high-stand resulting in the abandonment of the site. On the edge of the Sepik-Ramu Basin, changes in lithic technology have been associated with population rearrangement due to sea-level changes in the later Holocene (Gorecki and Gillieson 1989).

When occupation returns in the ceramic-bearing layer 9 at Watinglo, very low proportions of cores and retouched pieces and an absence of quartz, suggests low mobility. However, an obsidian flake from the Lou source in the Admiralties indicates occasional long-distance exchange connections. Four ground stone disc beads from layer 9 at Watinglo as well as the ceramics may have been part of inter-group exchange networks as there is no evidence for on-site manufacture of these pieces (O'Connor and Dickinson 2010; Beaumont et al. 2019). A similar situation of low mobility but high connectivity in the last millennium has been documented through lithics at the site of Tilu on the Madang Lagoon further east along the north New Guinea coast (Gaffney and Summerhayes 2019). The Sepik Basin has obsidian from the Admiralties, New Britain, and even Fergusson Island in the last two thousand years (Golitko, Schauer, and Terrell 2013), but on the adjacent north central coast, Watinglo and neighbouring sites do not seem to have been part of such extensive networks.

5. Conclusion

The high-fidelity recovery methods used in the excavation and sorting of Watinglo yielded over 12,000 artefacts, making this one of the largest excavated lithic assemblages in New Guinea. The sequence is one of technological continuity without evidence for incursions of markedly different cultures. The dominance of chert suggests primarily local resource procurement, with this sedimentary material presumably locally available in the limestone. Aside from the single obsidian flake, the regional geology suggests the knapped rocks were all available within ~50 km. Local materials, low levels of retouch, and high discard rates throughout much of the sequence suggest an overarching place provisioning model for Watinglo. The use of groundstone axes across the sequence points to aboriculture as a possible mechanism by which occupation was sustained locally with low mobility.

Diverse, but local materials were similarly used during the late Holocene occupation of the Paimbumkanja rockshelter in the Sepik region (Forestier et al. 2020). However, at Watinglo there were marked shifts in rock type use through the sequence. Chalcedony, which constitutes 10% of retouched lithics, is entirely absent from layers 1-2A and 4-6. Conversely, quartz, which constitutes 17% of cores, comprises only a single artefact from layers 7-10. Occasional ophiolite is all found in layer 2, aquamarine quartz is all from layers 2-3, while the quartzite is nearly all from layer 8. We may contrast this with the lithic material sequence at Nombe, where continuity in specific volcanic lithic sources alongside local chert was observed throughout the Holocene (Nutman et al. 2025; Evans 2000). We hypothesize that phases of enmity between neighbouring groups at Watinglo may have cut-off access to previously used rarer stone sources.

Material culture is more likely to be moved between groups with a shared language. This is true for items ranging from baobab fruit in north-western Australia (Rangan et al. 2015), to Lapita pottery in the Bismarck archipelago (Summerhayes 2000). High quality lithic materials such as obsidian are one such category of exchange item that is more likely to move further within linguistic ranges (Whitaker et al. 2008). In eastern New Guinea, long-distance transport of obsidian presaged the introduction of Austronesian languages (Shaw et al. 2022). The lack of long-distance movement of lithic materials at Watinglo until the most recent occupation suggests a relatively isolated population.

Similarly to material use, occupation intensity varies markedly through the Watinglo sequence. The numbers of lithics per litre in layers 2B and 8 are over 20x that of layers 1, 6, and 10, while there seems to have been a complete hiatus for several millennia between layers 8 and 9. Intensive use of the site in layers 2-3 and 7-8 accords with regional records suggesting anthropogenic impacts on the landscape in the early and middle Holocene, the former perhaps related to aboriculture and the latter to the cultivation of domesticate plants. In layers 5-6 the site seems to have been more sporadically occupied as a node for a higher mobility group, with more of an emphasis on coastal foraging shown by both a high frequency of crab shell and flaking opercula.

Family level linguistic diversity is particularly high in northern New Guinea (Foley 2000). The lithic record of the north coast indicates regional population continuity, extending back at least to the terminal Pleistocene, if not to 40 ka with the early date for Lachitu; providing a timescale for such diversity to develop. The localised use of resources and lack of evidence for long-distance connectivity in most of the Watinglo sequence, coupled with fluctuations in both resource procurement territories and levels of occupation intensity indicate isolated groups and cycles of fragmentation. The recurrence of such a pattern over tens of thousands of years may have contributed to the unparalleled linguistic diversity of the region.

Supplementary Materials

The supporting information can be downloaded at https://doi.org/10.70460/jpa.v16i1.392 S1: Elemental values of obsidian as well as core and retouch measurements.

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Data Availability Statement

All data is contained within the article or the Supplementary Materials.

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The Watinglo excavation was undertaken with permission and assistance from the Wutung community.

Conflicts of Interest

The authors declare no conflicts of interest.

Author Contributions

Conceptualization, C.S., S.O'C.; methodology, C.S., S.O'C.; investigation, S.O'C., L.H., J.S., S.K., P.B., C.S.; formal analysis, C.S., E.N.; resources, S.O'C.; data curation, C.S., E.N.; writing—original draft preparation, C.S.; writing—review and editing, C.S., S.O'C., E.N., S.K.; visualization, C.S., S.O'C., E.N.; supervision, S.O'C.; project administration, S.O'C.; funding acquisition, S.O'C. All authors have read and agreed to the published version of the manuscript. Please turn to the CRediT taxonomy for term explanation.

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