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40,000 years of technological continuity and change at Matja Kuru 2, Timor-Leste

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ABSTRACT

Timor-Leste is known for long-term continuity in lithic manufacturing techniques that span at least the last 44,000 years. Here we confirm this pattern of long-term continuity in stone tool manufacture at the site of Matja Kuru 2, located on Timor-Leste close to the freshwater Lake Ira Lalaro. The lithic assemblage is characterised by high reduction intensity and frequent use of bipolar, 'core-on-flake', discoidal and multiplatform core reduction to produce small flakes while high levels of retouch, heat damage and breakage. While continuity is an important feature of the assemblage, we also document important changes in technology, raw material selection and recycling/extension strategies over time. We posit that the long periods of absence at MK2 may coincide with drier phases when Ira Lalaro likely dried and that more extensive use of the cave occurs during wet phases with attendant lake high conditions. The lithic assemblage indicates increased mobility and individual provisioning in the transitions between these phases of site use and abandonment. The Matja Kuru 2 lithic assemblage also reveals the earliest known evidence yet found for obsidian and possible inter-island transport in Wallacea.

1. Introduction

Timor-Leste is known for the earliest appearance of pelagic fishing worldwide (O'Connor et al., 2011), the earliest production of shell fishhooks in SE Asia (O'Connor et al., 2011), the earliest use of ochred shell beads and pendants in SE Asia (Langley et al., 2016a), and at site of Matja Kuru 2 itself, the earliest hafted osseous projectile (O'Connor et al. 2014) and dog burial in SE Asia (Gonzalez et al., 2013). Analyses of the lithic assemblages from sites in Timor-Leste and across Wallacea more generally (the 347,000 km^2 region comprised of >1600 islands in an intervisible island chain (Norman et al., 2018) stretching between Sunda in the west and Sahul in the east) have emphasized long-term continuity and a virtually unchanging lithic technology over the last 50–40,000 years.

Lithic analyses from five sites - Liang Bua, Leang Burung 2, Makpan, Laili, Asitau Kuru (formerly known as Jerimalai) – document the lithic procurement and reduction strategies employed by *Homo sapiens* in occupying caves and rockshelters of Wallacea over this time. Themes emerging from the results of these analyses include: 1. Long-term stability in the use of several core reduction strategies (core-on-flake, discoidal, bipolar and multiplatform core technologies) that are differentially emphasized but remain present throughout the entire span of occupation, 2. Relatively unstandardized and informal retouching comprised predominantly of notching and irregular retouch of varying intensity, 3. Small-sized flake and core production ('miniaturization') sometimes even when larger stone clasts are available (Shipton, 2023; Shipton et al., 2021a), and 4. High levels of heat breakage. Alongside these markers of long-term continuity in stone artefact manufacture is the pervasive early use of ground ochre and *Oliva* sp. shell bead technology (Langley et al., 2016a; 2016b, 2019; Shipton et al., 2020b).

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Against this picture of long-term stability is the appearance in the terminal Pleistocene of: 1. Flakes with glossed edges indicative of new plant processing activities (Shipton et al., 2019); 2. The importation of exotic obsidian from a single unknown source island beginning around 16 ka indicating new or intensified seafaring and inter-island visitation (O'Connor et al., 2022; Reepmeyer et al., 2011, 2016, 2019); 3. The first appearance of shell adze technology around 14 ka (Shipton et al., 2019, 2020a, 2020b); 4. The intensification of maritime exploitation and niche broadening (Roberts et al., 2020; Hawkins et al., 2017); 5. The first appearance of inter-island shell fishhook technology around 16 ka (Langley et al., 2023b; O'Connor et al., 2011, 2019, 2022); 6. *Nautilus* bead production from around 12 ka (Langley and O'Connor, 2016b; Langley et al., 2023a; O'Connor, 2010), 7. The first dated appearance of distinctive engraved anthropomorphic faces (O'Connor et al., 2010, 2021); and from the early Holocene, 8. The introduction of ground stone axe technology in Obi in north-eastern Wallacea (Shipton et al., 2020a).

In this paper, we report long-term technological changes at the site of Matja Kuru 2 (8′24.88′ S, 127′07.42′ E), a limestone cave located on Timor-Leste close to the freshwater Lake Ira Lalaro at *c.* 370 m a.s.l. (Fig. 1a and b). It is currently *c.* 6 km from the northern coastline and is one of two neighbouring caves (Matja Kuru 1 and 2) excavated on the south facing limestone ridge close to the village of Poros with evidence of exploitation of marine, freshwater and terrestrial resources.

2. Methods

Six 1 × 1 m squares were excavated at Matja Kuru 2 (Fig. 1c). Square D was excavated by O'Connor in 2001 (Veth et al., 2005) while the remaining five squares (AA, B, BB, C and DD) were excavated by Clarkson and O'Connor and team in 2015 (Roberts et al., 2020). The chronology and Bayesian age model are reported in detail along with non-lithic cultural materials in Samper Carro et al. (2023b). The stratigraphic section, spit boundaries and radiocarbon dates are shown in Fig. 1d. Several recent papers also report on the fauna Matja Kuru 2 (Boulanger et al., 2023; Samper Carro et al., 2023a).

Stone artefacts were either plotted *in situ* with a total station at the time of excavation or later recovered from 1.5 sieve fraction and flotation residue. Artefacts were sorted in the field by local residents from Poros village working with the archaeological team. All stone artefacts were bagged and numbered individually. Artefacts were first counted and classified into major raw material, technological and typological groups by square and spit, and individual attributes and measurements taken. Artefacts attributes were defined and recorded following Clarkson (2007, 2008). Retouch extent was quantified using both the Index of Invasiveness (Clarkson, 2002) and the GIUR/Kuhn Index (Kuhn, 1990) following procedures outlined in Hiscock and Clarkson (2008). Results are reported below by depth in 10 cm intervals within the three main chronological phases at the site as determined by Samper Carro et al. (2023b). The three phases are:

Phase I - Late Pleistocene: 41,533 BP (43,942–39,843 BP at 95.4% probability). This phase recovered the earliest direct date for human activity at the site of 42,040–40,403 cal BP (37,442 ± 598 Wk-41365) from square DD spit 49. Phase 1 covers a period of ca. 11,000 years with a median modelled end date of 30,401 BP (33,329–27,605 BP).

Phase II - Pleistocene-Holocene transition: The second phase of occupation at MK2 begins with a median modelled start date of 13,124 BP (13,558–12,617 BP). Representing a period of ca. 5000 years, Phase 2 has a median modelled end date of 8188 BP (8370–7641 BP).

Phase III - Late Holocene: The final occupation phase at MK2 has a median modelled start date of 4578 BP (5218–4182 BP). With a median modelled end date of 880 BP (1064–369 BP), Phase 3 spans a period of ca. 3700 years.

3. Results

3.1. Raw materials

A total of 3886 stone artefacts were recovered from six 1 × 1 m squares at Matja Kuru 2. As for other sites in Timor-Leste (Marwick et al., 2016; Hawkins et al., 2017; Shipton et al., 2020b), the Matja Kuru 2 lithic assemblage is primarily comprised of chert in a variety of colours, predominantly red and grey with some yellow and other colours (see Table 1). Chert is the dominant material used in stone artefact manufacture over time, making up 97.07% of the assemblage (Fig. 2), with obsidian making up 2.55%, limestone 0.33% and sandstone 0.05% (Table 2). The source of the chert is unknown but is unlikely to be local given the very small size of pieces, the low density of artefacts at the site (319 artefacts per m^3 of sediment excavated) and very low occurrence of cortex on flakes and cores (mean = 8% coverage). Obsidian artefacts occur to a depth of 1.6 m in Phase I, peaking in abundance at a depth of 0.9 m (N = 17) in Phase II, but peaking as a proportion of depth interval at 0.5 m in Phase III (8.33%%) (Table 2). The occurrence of obsidian in Phase I dated to between 30.4 and 41.5 ka makes this the oldest known appearance of obsidian in Timor-Leste. The increase in the number of obsidian pieces in Phase II at the site in the terminal Pleistocene/early Holocene through to the late Holocene conforms with the regional pattern of importation of the exotic obsidian known as 'Group 1' to Timor-Leste from an unknown off-island source at this time (Reepmeyer et al., 2011, 2016, 2019; O'Connor et al., 2022). If, as seems likely, these are also made on the exotic Group 1 obsidian, then this indicates that the maritime exchange between the source island and Timor occurred earlier than previously documented, between 30.4 and 41.5 ka.

Obsidian artefacts are all flakes, bipolar flakes and flaked pieces with no cores or retouched pieces present. Limestone and sandstone artefacts are almost exclusively hammerstones and anvils. The dominance of chert throughout the sequence means there is no significant difference in raw material proportions through time despite the later additions of obsidian and limestone ($X^2 = 1.78$, df = 2, p = 0.41).

3.2. Discard rates

Three distinct peaks in artefact discard are evident at the site (Fig. 3). The first occurs at 1.6 m depth in Phase I, the second at 1 m depth in Phase II, and the third, a small peak in discard which occurs at 0.4 m depth in Phase III. The peak at 1.6 m depth sits in the middle of Phase I with associated median calibrated age ranges of 41,707 - 30,251 BP. The peak in discard at 1 m corresponds to the middle of Phase II with associated median calibrated age ranges of 13,225 - 8171 BP. When average artefact accumulation per year is compared by occupation phase, we see that artefact discard is highest in Phase II, lower in Phase I and lowest in Phase III.

3.3. Stone artefact manufacture

There is evidence for a variety of stone reduction technologies at MK2, including bipolar reduction, single and multiplatform core reduction, burination and systematic flaking of the ventral surface of large flakes ('core-on-flake' technology), here termed 'ventral flaking' or 'truncated faceted' technology after Dibble and McPherron (2006). Each technology created distinctive artefacts as discussed below. The proportions of major technologies at the site vary by phase (Table 3). A Chi Square analysis shows that the differences in proportions for ventral flaking, retouch, bipolar, gloss and redirecting flakes between phases is significant ($X^2 = 18.77$, df = 8, p = 0.016).

3.4. Flake production

In general, complete flakes in the assemblage (N = 1414) are very small in all dimensions with a mean mass of 0.78 ± 1.82 g and a mean

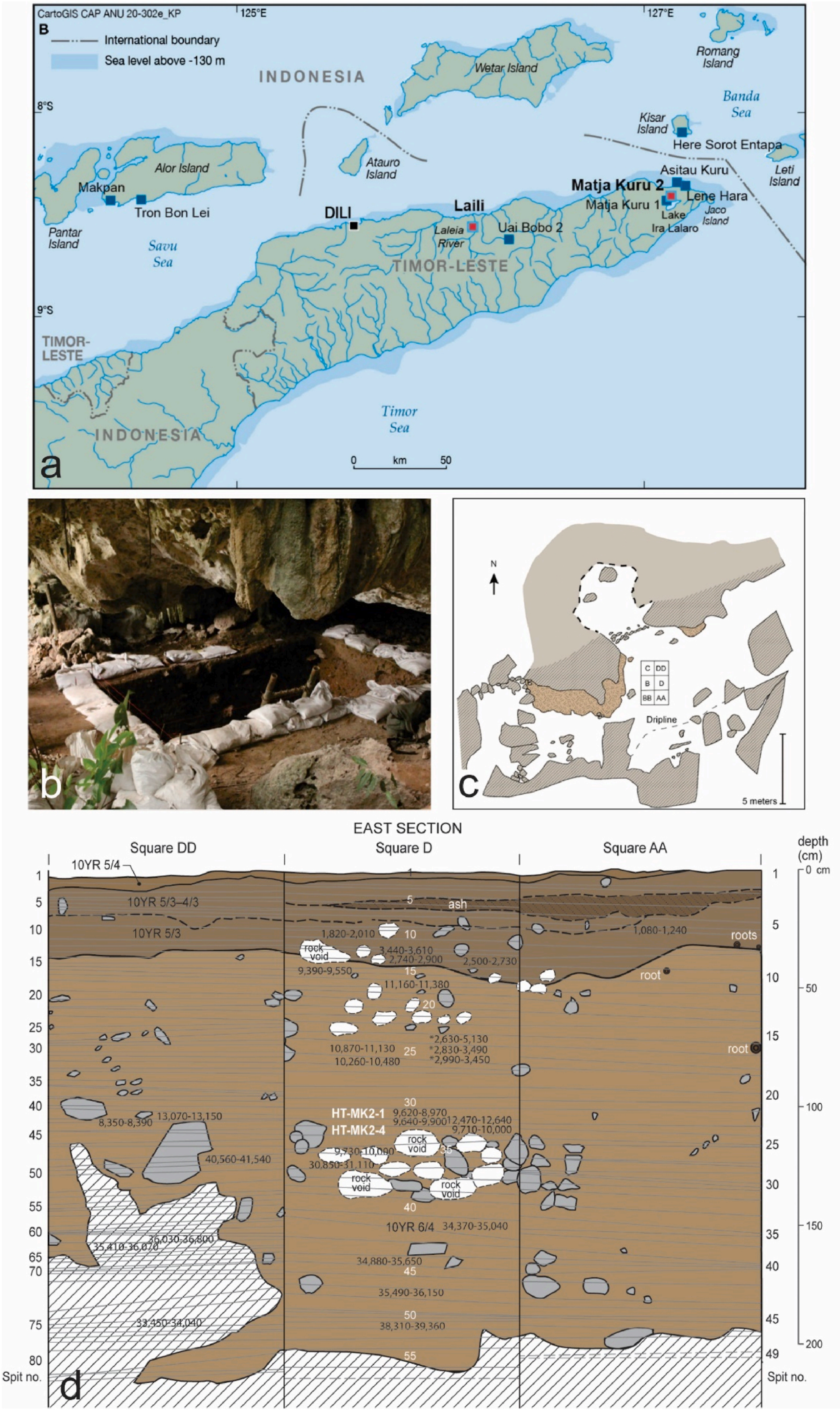

Fig. 1. Matja Kuru 2 location and excavation: **a** regional map showing sites mentioned in the text (map produced by ANU CartoGIS with permission); **b** photograph of site (after Samper Carro et al., 2023a with permission); **c** site plan and excavation square layout; **d** stratigraphy and occupation phase boundaries (from Roberts et al., 2020 with permission).

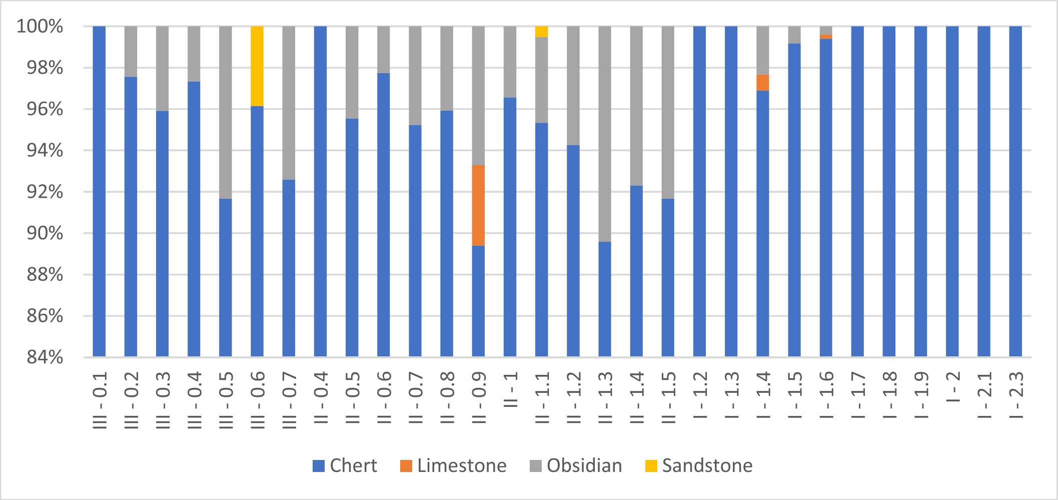

Fig. 2. Raw material proportions by phase and depth.

Table 1
Raw material totals and percentages by phase and depth.

Phase/Depth	No. Chert	% Chert	No. Limestone	% Limestone	No. Obsidian	% Obsidian	No. Sandstone	% Sandstone
III - 0.1	40	100.00		0.00		0.00		0.00
III - 0.2	40	97.56		0.00	1	2.44		0.00
III - 0.3	47	95.92		0.00	2	4.08		0.00
III - 0.4	73	97.33		0.00	2	2.67		0.00
III - 0.5	11	91.67		0.00	1	8.33		0.00
III - 0.6	25	96.15		0.00		0.00	1	3.85
III - 0.7	25	92.59		0.00	2	7.41		0.00
II - 0.4	43	100.00		0.00		0.00		0.00
II - 0.5	86	95.56		0.00	4	4.44		0.00
II - 0.6	130	97.74		0.00	3	2.26		0.00
II - 0.7	80	95.24		0.00	4	4.76		0.00
II - 0.8	165	95.93		0.00	7	4.07		0.00
II - 0.9	253	89.40	11	3.89	19	6.71		0.00
II - 1	281	96.56		0.00	10	3.44		0.00
II - 1.1	184	95.34		0.00	8	4.15	1	0.52
II - 1.2	82	94.25		0.00	5	5.75		0.00
II - 1.3	172	89.58		0.00	20	10.42		0.00
II - 1.4	36	92.31		0.00	3	7.69		0.00
II - 1.5	11	91.67		0.00	1	8.33		0.00
I - 1.2	14	100.00		0.00		0.00		0.00
I - 1.3	42	100.00		0.00		0.00		0.00
I - 1.4	125	96.90	1	0.78	3	2.33		0.00
I - 1.5	242	99.18		0.00	2	0.82		0.00
I - 1.6	500	99.40	1	0.20	2	0.40		0.00
I - 1.7	423	100.00		0.00		0.00		0.00
I - 1.8	294	100.00		0.00		0.00		0.00
I - 1.9	172	100.00		0.00		0.00		0.00
I - 2	152	100.00		0.00		0.00		0.00
I - 2.1	23	100.00		0.00		0.00		0.00
I - 2.3	1	100.00		0.00		0.00		0.00

Table 2
Changes in proportions of raw materials by phase.

Phase	Chert	Obsidian	Limestone	Sandstone
I	99.55	0.35	0.10	0.00
II	94.01	5.19	0.68	0.12
III	97.03	2.97	0.00	0.00
Total	97.88	2.02	0.34	0.05

maximum dimension of 15.09 ± 6.79 mm (Table 4). Cortex is minimal at 4.28 ± 17.05% with 5 ± 2.67 dorsal scars (Tables 3 and 4). Flakes are almost as wide as they are long at 11.61 ± 6.8 mm length and 10.88 ± 6.02 mm (length:width = 1.18), and are relatively thick at 2.71 ± 2.26 mm thick. Platforms are small relative to ventral area with a ratio of 0.14 ± 0.19. Complete flakes larger than 20 mm (N = 183) are rare at the site and make up only 4.7% of the assemblage. The mean mass for complete flakes larger than 20 mm in maximum dimension is 2.62 ± 3.41 g with a mean maximum dimension of 25.95 ± 6.5 g (Table 5). The largest complete flake in the assemblage is only 64.43 mm in maximum dimension.

Platforms are prepared in 78% of cases, with 63% exhibiting overhang removal, 9% faceting and a further 5% with both kinds, and have moderately low exterior platform angles at 66 ± 14°. Platforms are varied but predominantly formed of single (32%) or multiple conchoidal surfaces (28%), with frequent focalised platforms (20%), and less common cortical (5%), crushed (8%), dihedral (4%) or ventral (0.5%) surfaces. Analysis of changing proportions of platform types also reveals changing use of the platform over time (Table 6), with a Chi Square

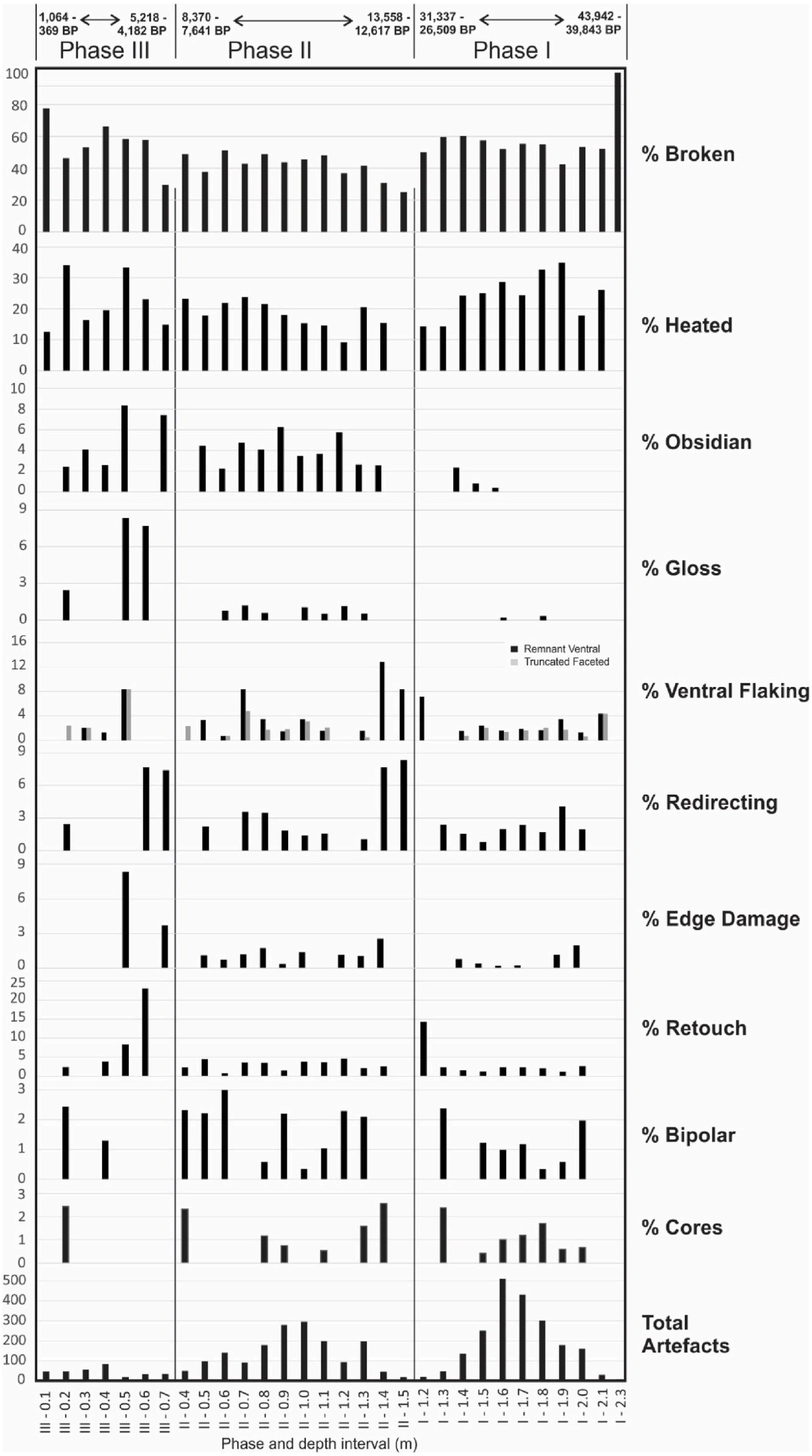

Fig. 3. Changes in lithic technology at Matja Kuru 2 by phase and depth (m).

analysis of the proportions of focalised, single scarred and multiple scarred platforms yielding significant differences by phase ($X^2 = 13.11$. df = 4, p = 0.01). Changes in proportions of platform preparation (Table 7), however, are not significant ($X^2 = 1.93$, df = 2, p = 0.38).

When metrics are examined for flakes, retouched flakes and cores, however, artefact dimensional attributes show no significant differences between phases (ANOVA test), with the exceptions being width, platform thickness, platform angle and the angle of platforms on the dorsal

Table 3
Proportions of key technologies and raw materials by phase at MK2.

Phae	Ventral Flaking	Retouch	Bipolar	Gloss	Redirecting	Discoidal	MP Core	Burin	Microblade
III	1.95	2.10	0.95	0.10	2.20	0.00	0.10	0.45	0.05
II	2.69	2.87	1.50	0.56	1.75	0.12	0.00	0.37	0.12
I	1.47	4.04	0.74	1.47	1.84	0.00	0.00	0.00	0.00

Table 4
Summary statistics for complete flakes from MK2 by phase.

Phase		Mass (g)	Max Dimension (mm)	Length (mm)	Width (mm)	Thickness (mm)	Platform Width (mm)	Platform Thickness (mm)	Platform Angle (Degrees)	Cortex %	Elongation (L:W)	Platform Area: Ventral Area
I (N = 683)	Mean	0.78	15.09	11.53	10.49	2.86	6.07	2.15	55.36	4.85	1.21	0.15
	SD	1.82	6.79	6.88	5.57	2.45	4.43	1.96	31.12	17.96	0.65	0.19
II (N = 642)	Mean	0.79	15.20	11.64	11.21	2.50	6.06	1.96	54.40	3.75	1.15	0.13
	SD	2.05	7.21	6.50	6.03	1.88	4.38	1.64	32.33	16.28	0.61	0.17
III (N = 89)	Mean	1.25	15.68	11.91	11.58	3.08	6.89	2.43	52.58	3.82	1.17	0.16
	SD	3.58	10.03	8.19	8.66	3.03	6.32	2.36	32.55	15.19	0.54	0.25
Total (N = 1414)	Mean	0.81	15.18	11.61	10.88	2.71	6.12	2.08	54.75	4.28	1.18	0.14
	SD	2.08	7.22	6.80	6.02	2.26	4.55	1.86	31.75	17.05	0.62	0.19

Table 5
Summary statistics for complete flakes >2 cm from MK2 by phase.

Phase		Mass (g)	Max Dim (mm)	% Cortex	Length (mm)	Width (mm)	Thickness	Platform Width	Platform Thickness	Platform Angle	Dorsal Scars	Elongation	Platform Area: Ventral Area
I (N = 133)	Mean	2.52	25.94	13.30	21.48	17.10	5.23	10.86	3.63	68.16	4.59	1.40	0.14
	SD	2.41	6.21	25.19	7.16	5.55	2.43	6.41	2.52	15.35	2.29	0.66	0.16
II (N = 177)	Mean	2.54	25.69	8.15	19.56	18.82	5.31	9.87	3.40	65.46	5.56	1.14	0.14
	SD	3.91	6.63	16.81	8.45	5.23	2.74	5.97	2.55	13.83	2.79	0.60	0.22
III (N = 23)	Mean	3.89	28.36	10.83	23.00	18.65	6.64	12.38	9.52	69.58	6.00	1.46	0.27
	SD	2.94	6.84	21.09	8.34	5.37	3.22	7.16	18.85	11.09	2.90	1.08	0.42
Total	Mean	2.62	25.95	10.10	20.45	18.22	5.37	10.38	3.91	66.66	5.25	1.25	0.15
	SD	3.41	6.50	20.37	8.06	5.38	2.68	6.21	5.63	14.20	2.67	0.67	0.23

Table 6
Proportions of platform types and preparation for complete flakes by phase.

Phase	Crushed	Focalised	Multiple	Cortical	Cortical and Scarred	Single	Ventral	Overhang Removal and Faceting	Faceted	Overhang Removal
I	10.84	17.65	39.50	5.88	2.52	22.69	1.68	9.30	20.93	69.77
II	17.00	21.08	34.94	3.01	0.00	29.52	0.00	13.18	12.40	74.42
III	0.00	13.64	31.82	0.00	0.00	50.00	0.00	8.33	25.00	66.67

Table 7
Significant differences in flake dimensions between phases determined using an ANOVA test.

Attribute		Sum of Squares	df	Mean Square	F	p
Width	Between Phases	482.12	3	160.71	3.37	0.02
	Total	17190.06	353			
Platform Thickness	Between Phases	275.8	3	91.9	4.21	0.01
	Total	6323.9	280			
Platform Angle	Between Phases	2235.9	3	745.3	2.81	0.04
	Total	75804.3	280			
	Total	2741.0	323			
Old Dorsal Angle	Between Phases	1611.6	2	805.8	2.97	0.06
	Total	14921.9	51			

surfaces of redirecting flakes (Table 5). Tests yielding non-significant differences are not reported here. Significant differences in these attributes are, however, unlikely to represent meaningful differences in manufacturing technology at the site.

3.5. Bipolar

Bipolar technology is rare at only 1.1% of the assemblage, but occurs throughout the sequence (Figs. 3 and 4). There is a significant negative correlation ($r = -0.553$, $r^2 = 0.31$, $p = 0.017$) between artefact discard and bipolar artefact frequency, indicating bipolar is more common when artefact deposition is low. Bipolar is most common in Phase II at 1.44% and least common in Phase I at 0.95%.

Bipolar flakes are small on average at 1.19 ± 10.27 g, 22 ± 4 mm in maximum dimension, and squat with a length of 20 ± 5 mm and a width of 15 ± 5 mm and relatively thick at 6 ± 2 mm. Cortex is minimal at 3 ± 6% with 6 ± 2 dorsal scars.

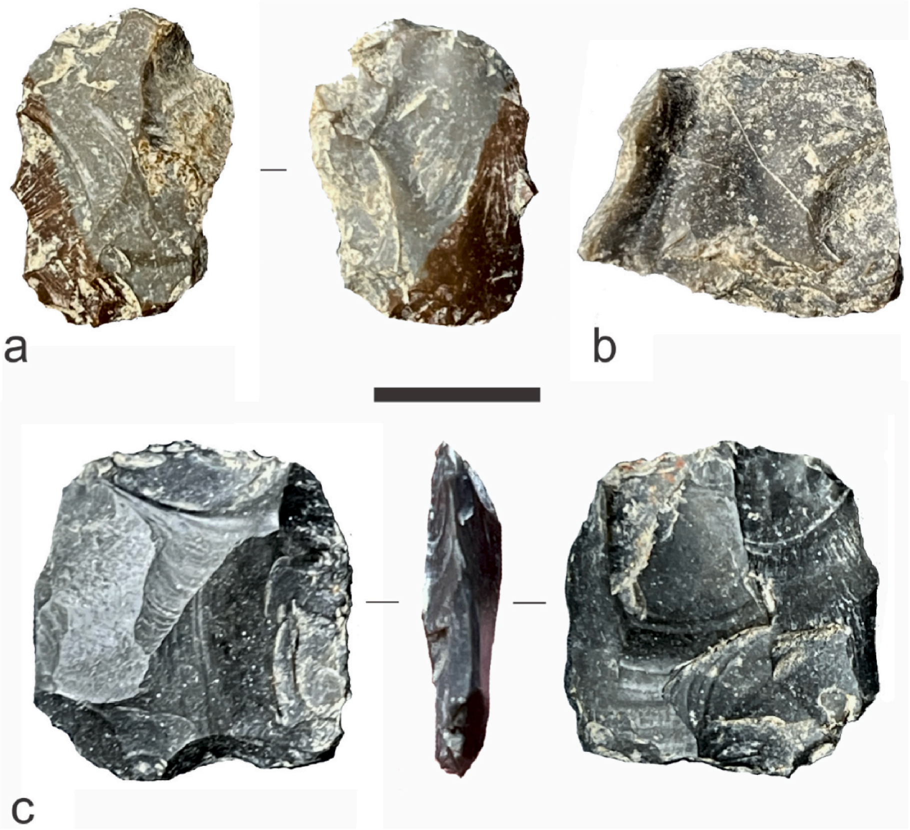

Fig. 4. Bipolar cores from MK2. **a** B/38; **b** B/61; **c** D/30. Scale bar = 1 cm.

3.6. Breakage and heat damage

Breakage is extremely common in the MK2 assemblage, with 50% of artefacts showing breakage in the form of heat breaks, lateral or transverse snaps or flaked pieces that show conchoidal flaked surfaces, but the orientation and location of the specimen cannot be determined. Breakage remains at around 40–60% over the depth of the site, with peaks in the topmost and bottommost depth intervals resulting from very small sample size. Breakage is slightly elevated during periods of higher artefact discard, dropping to around 25–30% during periods of low discard.

Heat damage was identified by the occurrence of pot lids and pot lid scars, heat fragments, spalling, crazing, unequal lustre between original and fractured surfaces, and crenated fractures often associated with discoloration or demineralisation. Heat damage occurs throughout the assemblage in trimodal peaks. The highest proportions at 1.9 m depth in Phase I, a second peak at 0.6 m depth in Phase II, and a third set of peaks at 0.2 and 0.5 m in Phase III. Heat damage is at its lowest frequency at 1.5 m depth in Phase II. As a proportion of phase, heat damage is most common in Phase I at 26% and lowest in Phase II at 18%. Heat damage is most likely post-depositional and results from proximity to hot fires as heat damage overlies retouch and other technological features and does not appear to represent deliberate heat treatment.

3.7. Cores

Cores are rare in the assemblage (N = 16, 0.8%) and take a variety of forms. Truncated faceted cores (33%), core fragments (27%), and bipolar cores (27%) are the most common, but rare examples of discoidal cores (7%), single platform (3%) and multiplatform cores (3%) are also found. Cores are most common in Phase I at 0.95% and least common in Phase III at 0.37% of the assemblage. Cores occur sporadically through the deposit, with peaks in Phase III at 0.2 m and 0.4 m depth, in Phase II at 1.4 m depth, and again in Phase I at 1.3 m and 1.8 m depth. Small sample size likely gives rise to this patchy distribution in Phases III and II. Although multiplatform cores are very rare, redirecting flakes (Fig. 7 l and m) struck from the core during core rotation are also present (2%) and indicate multiplatform cores were being worked at the site. Redirecting flakes are most common during times of low artefact discard (Fig. 3) indicating that core rotation may have been more frequent at these times. Like flakes, cores are very small, with an average mass of 6.7 ± 2.9 g, a maximum dimension of 27 ± 5 mm, with only 7 ± 13% cortex (Table 8). Cores are generally heavily flaked with 12 ± 6 flakes scars (not including overhang or faceting removal scars), 3 ± 2 platforms. Cores show high levels of exhaustion, with 4 ± 2 steps and steep final external platform angles of 76 ± 15°. Summary statistics for cores by type are provided in Table 5. Discoidal and multiplatform cores are the largest in the assemblage, while bipolar cores are the smallest, supportive of the notion that bipolar cores were likely once freehand percussion cores that were further reduced by striking on an anvil. The largest flake scars on cores are found on truncated faceted cores, at 21 ± 9 mm, and the smallest scars on multiplatform cores, at 15 ± 3 mm. In general, the flake scars on cores correspond well with the small average size of flakes in the assemblage, at 20 ± 8 mm average maximum dimension, and indicate that large flakes were seldom removed form cores at the site, with the largest scar on a core being only 32 mm long.

3.8. Truncated faceted technology (‘core-on-flake’)

Truncated faceted pieces are typically small flakes struck from the ventral surfaces of larger flakes (‘flake cores’) with steeply faceted lateral margins (Dibble and McPherron, 2006). This is achieved by faceting the dorsal lateral margins with steep retouch and using this steeply retouched edge as a platform to strike flakes from the ventral surface. The resultant flakes will include Janus flakes with two bulbs, a mix of ventral surface and negative flake scars from previous TFF

Table 8
Summary statistics for complete chert cores by type.

Type		Mass (g)	Max Dim (mm)	No. Scars	No. Steps	Largest Scar	No. Platforms	Final Platform Angle	% Core Face Length
Bipolar Core (N = 5)	Mean	4.99	24.26	9.20	3.25	17.72	2.60	89.50	92.14
	SD	4.00	6.15	5.26	2.06	2.80	1.34	0.71	20.94
Discoidal Core (N = 2)	Mean	6.52	24.81	23.00	6.50	17.16	2.00	77.50	70.62
	SD	0.83	0.81	2.83	3.54	0.30	0.00	3.54	5.65
Multiplatform Core (N = 2)	Mean	6.57	25.31	12.50	3.50	15.11	4.00	96.50	76.43
	SD	1.41	3.81	3.54	2.12	2.98	0.00	19.09	0.00
Truncated Faceted Flake Core (N = 7)	Mean	8.12	30.58	9.71	3.00	21.21	2.71	65.43	78.35
	SD	2.49	4.81	5.06	0.89	8.76	1.98	9.66	23.08
Total	Mean	6.75	27.22	11.56	3.64	18.85	2.75	75.77	81.79
	SD	2.98	5.46	6.32	2.02	6.22	1.53	15.62	20.49

removals around the ventral margin, to fully negative centripetal flake scar patterns that resemble small Levallois flake removals (Marwick et al., 2016, Fig. 10). Some flakes may run along the platform/ventral edge and remove a section of faceting from the edge of the ventral surface and some of the ventral surface as well, and these are termed débordant flakes (Fig. 5j), as distinguished from redirecting flakes (Fig. 7l and m). Other flakes may have remnant ventral portions on the dorsal but lack a faceted platform. These flakes are distinguished here as having remnant ventral portions on the dorsal surface but are not identified as TFF since there is no obvious faceting of the platform.

Truncated pieces from MK2 indeed fall into many of the categories described above (Fig. 5), with remnant ventral flakes being the most common (58%), truncated faceted flakes with one or more additional scars being the second most abundant (33.4%) (Fig. 5a–i), followed by débordant flakes (Fig. 5j) and TFF 'flake cores' (6.8%) (Fig. 5k-n). The various products of this ventral flaking exploitation strategy are present throughout the entire sequence at MK2, however they are most common in periods of lower discard, as is the case with bipolar and retouched artefacts. A regression analysis reveals a significant negative correlation between artefact discard and proportions of ventral surface flake removals per depth interval ($r = -0.54$, $r^2 = 0.29$, $p = 0.01$).

Flakes with remnant ventral portions are slightly larger than other flakes with an average of 1.63 ± 1.37 g and 19.7 ± 7.1 mm maximum dimension but the differences are not significant (mass: Mann Whitney $U = 2729$, $df = 216$, $p = 0.380$, maximum dimension: Mann Whitney $U = 2747$, $df = 216$, $p = 0.480$). For the complete flakes >20 mm population, truncated faceted and flakes with remnant ventral surfaces are also larger, with an average mass of 3.04 ± 2.82 g and 27.06 ± 4.2 mm maximum dimension (Table 9). Truncated faceted flakes are more elongate and have slightly fewer dorsal scars than other flakes. Platforms are mostly formed from multiple or single scars, followed by focalised, cortical and crushed platforms (Table 10). Most ventral removal flakes have overhang removal (85%) and many have faceting (29%). Proportions of platform preparation are not significantly different by phase ($X^2 = 7.27$, $df = 4$, $p = 0.12$).

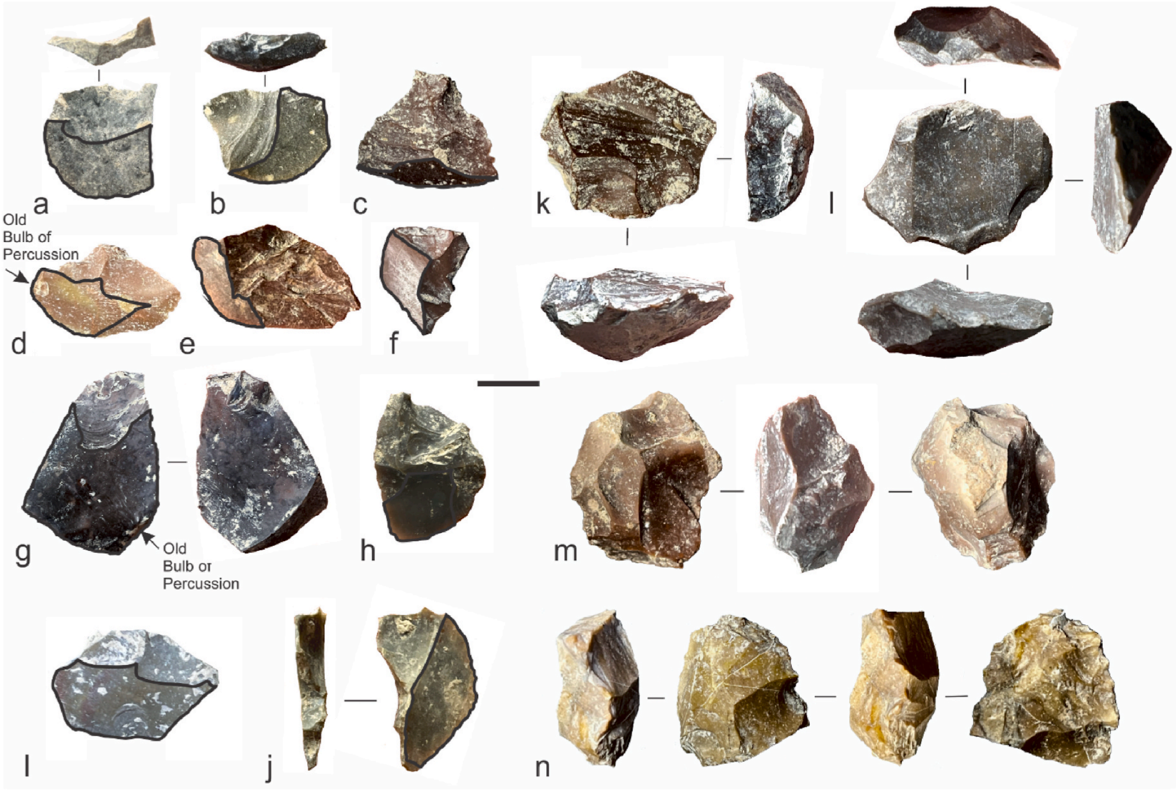

Fig. 5. Truncated faceted flakes, truncated faceted débordant flake, truncated faceted cores and discoidal cores. Heavy line indicates areas of remnant ventral surface. Truncated faceted flakes: **a** B/27; **b** C/11; **c** B/76; **e** B/45; **d** D/41; **f** D/43; **g** D/53; **h** B/73; **i** AA/33. Débordant flake: **j** D/41. Levallois-like truncated faceted 'flake cores': **k** B/16; **l** BB/15. Discoidal cores: **m** BB/15; **n** D/33. Scale bar = 1 cm.

Table 9
Summary statistics for truncated faceted flakes and flakes with remnant ventral portions on the dorsal surface.

Phase		Mass (g)	Max Dim (mm)	% Cortex	Length (mm)	Width (mm)	Thickness (mm)	Platform Width (mm)	Platform Thickness (mm)	Platform Angle (degrees)	Number of Dorsal Scars	Elongation (L:W)	Platform Area: Ventral Area
I	Mean	2.80	25.30	1.54	20.05	17.79	6.78	11.90	4.45	71.00	4.58	1.44	0.19
	SD	2.12	4.18	6.13	6.37	5.96	3.53	7.21	2.60	16.50	2.73	1.24	0.18
II	Mean	3.00	27.45	1.67	20.52	19.98	5.86	13.23	3.28	65.29	4.54	1.14	0.17
	SD	3.28	6.69	5.92	6.68	6.60	3.70	8.35	2.34	13.39	3.71	0.56	0.25
III	Mean	4.59	33.96	0.00	25.56	24.18	5.39	14.38	4.72	62.75	5.75	1.01	0.16
	SD	3.15	14.09	0.00	13.43	4.75	1.45	4.64	1.18	13.07	1.50	0.33	0.17
Total	Mean	3.04	27.06	1.48	20.65	19.31	6.23	12.74	3.91	67.60	4.64	1.27	0.18
	SD	2.82	6.89	5.73	7.08	6.36	3.52	7.55	2.43	14.86	3.16	0.91	0.22

Table 10
Proportions of platform types and platform preparation by phase for truncated faceted flakes and flakes with remnant ventral portions on the dorsal surface.

Phase	Cortical	Multiple	Single	Focalised	Crushed	Faceting	Both	Overhang Removal
I	3.85	42.31	42.31	11.54	0.00	17.53	9.28	73.20
II	2.22	40.00	40.00	13.33	4.44	12.42	13.07	78.43
III	0.00	28.57	57.14	14.29	0.00	26.67	6.67	73.33
Mean	2.02	36.96	46.48	13.05	1.48	18.87	9.67	74.99

3.9. Retouch

Retouched flakes make up 2.5% of artefacts. Retouch is found on flakes, bipolar flakes, Janus flakes and in rare cases also includes burination (Fig. 6g–i) of the lateral margins (Fig. 6). Retouch occurs throughout the sequence but is most common at times of lowest artefact discard (as was the case with redirecting flakes), such as at the base of Phase III at 0.5–0.6 m depth and at the top of Phase 1 at 1.2 m depth (Fig. 3). Retouch is most common in Phase III (4.04%), followed by Phase II (2.87%), and least common in Phase I (2.1%). Most retouched flakes fit the typological categories of 'scrapers' and 'notches', with many exhibiting only light retouch (Fig. 6b and c) but some showing heavy retouch (Fig. 6a, d, e, f). Another type of retouched flake with retouched convergent projections have been termed 'piercers/drills' in sites in Island SE Asia. Several examples of these artefacts are found throughout all phases of occupation (Fig. 6j-m).

Retouched flakes are larger on average in all dimensions than unretouched flakes, with a mass of 8.1 ± 8.2 g (three times that of flakes), a maximum dimension of 31 ± 9 mm, length of 25 ± 10 mm, width or 22 ± 8 mm and a thickness of 10 ± 4 mm. The largest retouched flake is also twice the size of unretouched flakes at 60 mm maximum length. Platforms are also larger relative to ventral area than flakes too, at 27% as opposed to 15%. Retouched flakes, however, possess much less cortex on average (5% vs 10%) but possess the same number of dorsal scars on average (5 ± 4). Retouch is mostly of the steep 'scraper' type, quite extensive on average with an index of invasiveness of 0.48, a Kuhn Index of 0.71 ± 0.27, and showing on average 48 ± 28% of the perimeter retouched. Most retouched flakes possess at least one well-defined notch (mean = 1.3 ± 0.62). Burins are not quite as large as other retouched flakes, at 5.3 ± 3.6 g and a maximum dimension of 24 ± 4 mm. Burins have between one and three large burin spalls. The burin spalls themselves are light (1.7 ± 0.86 g), longer than average flake length (26 ± 4 mm) and very elongate (length:width = 3.25). There are no significant differences in degree of retouch between phases (Kuhn Index, Index of Invasiveness, proportion of edge retouched, number of notches or retouched edge angle) as determined by an ANOVA test and are not reported here.

3.10. Edge gloss

This is a highly reflective polish on the lateral margins of flakes likely formed by intensive slicing of silica rich plants, as documented by Glover (1986), Luong et al. (2019) and many others in sites in the region (Marwick et al., 2016). Further microscopic study of use traces is required to accurately identify this other and functional attributions on lithics from Matja Kuru 2 in future (Fuentes and Pawlik, 2023). Edge gloss increases in frequency over time at the site, with low frequencies in Phase I, several small peaks in frequency in Phase II, and high abundance of gloss in Phase III. Flakes with gloss are also larger than regular flakes on average, with a mass of 3.9 ± 2.3 g and a maximum dimension of 31 ± 9 mm and quite elongate with a length:width of 1.7.

3.11. Other artefacts of interest

A number of other types of artefacts occur at MK2 that warrant mention. For example, a chert flake with massive bending initiated fracture, burin-like spall and overshot flute emanating from the tip is found in B/37 in Phase II (Fig. 8). The damage to the tip closely resembles experimental high-speed projectile impacts on stone points as well as damages found on archaeological points in northern hemisphere kill sites (Fischer et al., 1984; Clarkson, 2016; Iovita et al., 2014). At least one similar impact fracture was noted at Asitau Kuru (Jerimalai) by Shipton et al. (2019a,b) with bidirectional STBFs (Shipton et al.'s Figure 19D) and possible burin impact spall (Shipton et al.'s Figure 16I). These fractures could result from forceful distal longitudinal impacts. A number of bifacially flaked distal tips or possible points are also found at Asitau Kuru (Marwick et al., 2016), raising the possibility that stone Pleistocene projectile technology was present in Timor-Leste alongside osseous projectile points (O'Connor et al. 2014).

Split flakes are those that were struck on an anvil to break them transversely, as indicated by the presence of a distinct cone of force and bulb of percussion on the transverse break surface (Fig. 7a and b). The breaks resemble those seen on gunflints which were broken in a similar manner by striking on an anvil. They are documented at other sites in Timor-Leste and on Flores (Marwick et al., 2016; Moore et al., 2009).

Several hammerstones and anvil stones also occur at MK2 in DD/53 in Phase I and C/31 in Phase II. Occasional microblades and pointed flakes not dissimilar to the Levallois point from Leang Burung 2 are also found at MK2 but are likely fortuitous.

3.12. Extension strategies

A number of technologies at MK2 are indicative of attempts to extend the supply of raw material by continuing to reduce it further rather than

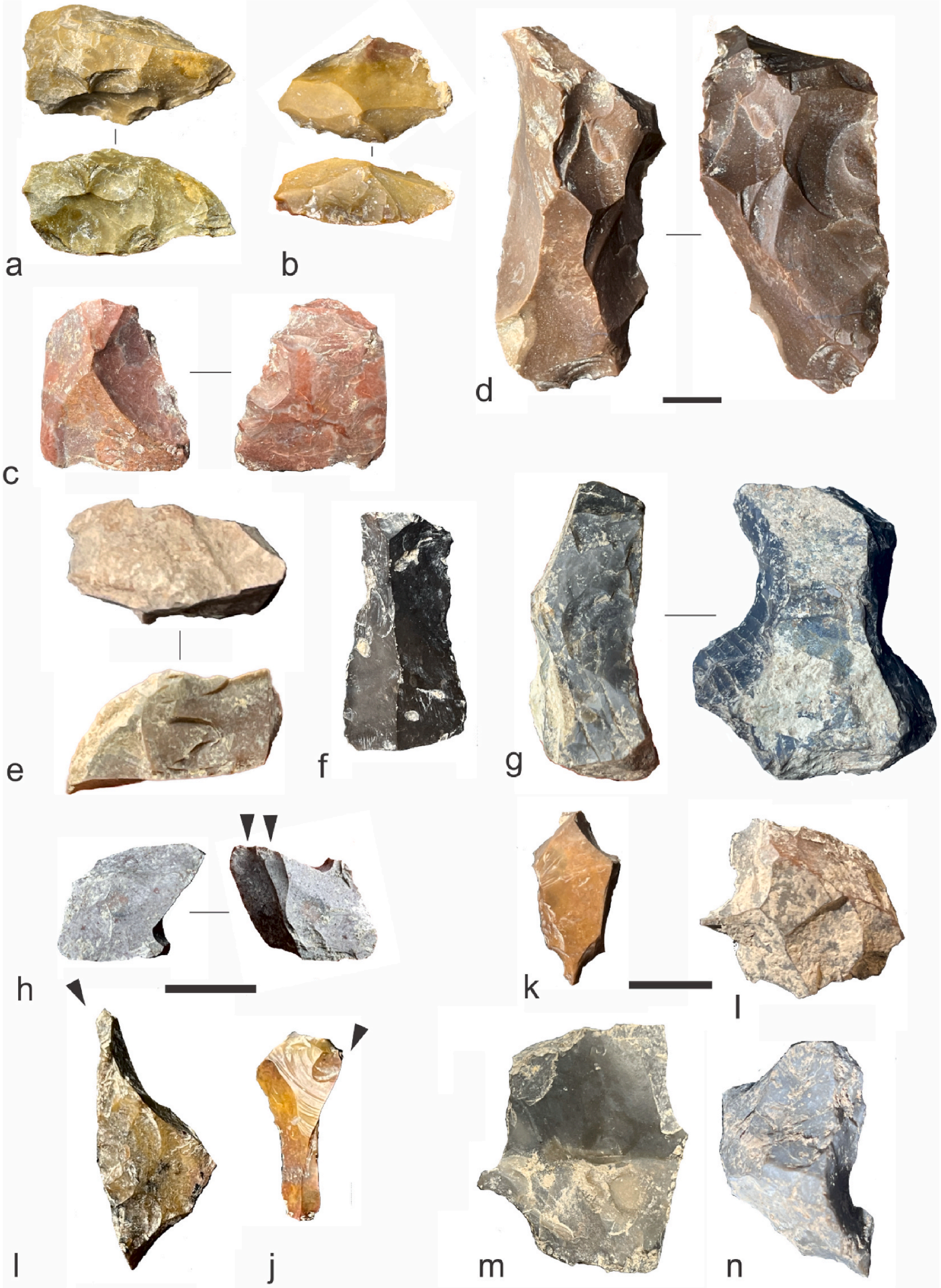

Fig. 6. Examples of retouched flakes from Matja Kuru 2, indicating square/spit and phase. Scrapers and notches: **a** B/42 Phase II; **b** C/48 Phase I; **c** DD/31 Phase II; **d** DD/28 Phase II; **e** B/34 Phase II; **f** B/38 Phase II; **g** DD/24 Phase II. Burin: **h** C/61 Phase I. Burin spalls: **i** B/38 Phase II; **j** D/42 Phase I. Piercers: **k** D/44 Phase I; **l** AA/9 Phase III; **m** B/36 Phase II; **n** DD/24 Phase II. Scale bar = 1 cm.

seek fresh material. Such strategies include bipolar reduction, which allows small cores to be reduced beyond the usual size threshold required for freehand percussion, retouching to resharpen flakes and extend their use lives, core rotation to create new platforms on cores as old platforms become unsuitable due to high edge angles and step terminations and resulting in the creation of redirecting flakes, and finally, a ventral flaking retouching strategy involving striking flakes from the ventral surfaces of larger flakes (TFF cores) in order to supply fresh flakes from the surfaces of larger retouched flakes. Evidence of utilisation of unretouched flakes in the form edge damage also indicates prolonged use of flakes rather than resupply with fresh flakes.

Combining the proportions of artefacts resulting from each of these strategies aimed at extending the useable supply of raw material, we see that such extension strategies are most commonly employed at MK2 during the two periods of low artefact discard at the base of Phase III from 0.5 to 0.7 m depth, and at the interface between Phase II and I

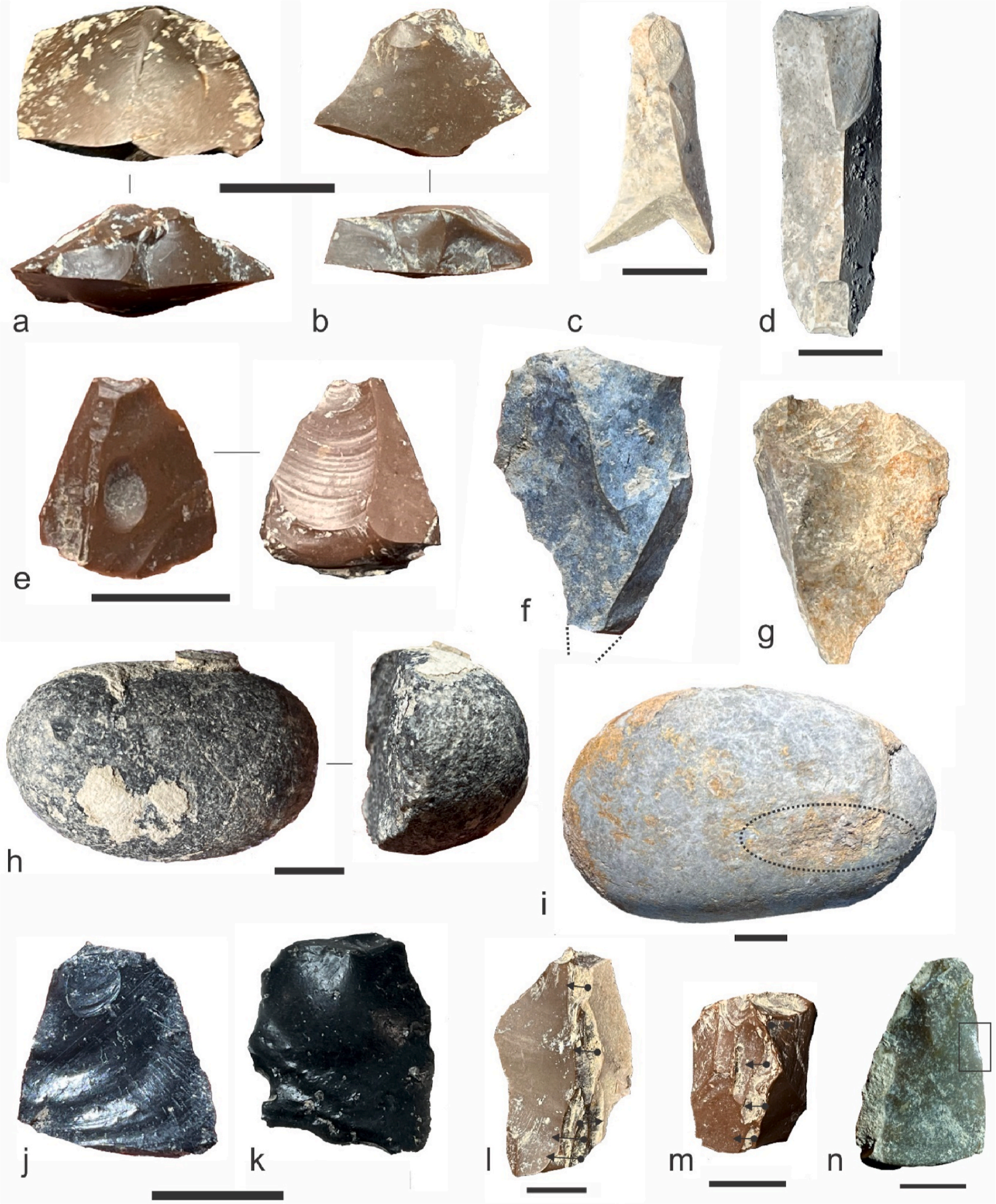

Fig. 7. Assorted artefacts of interest. **a** and **b** split flakes (C/11 and AA/27); **c** and **d** microblades (AA/37 and AA/36); **e** possible impact fractured flake (B/37); **f** and **g** convergent flakes (B/20 and AA/26); **h** hammerstone (DD/53); **i** hammerstone and anvil (C/31); **j** and **k** obsidian flakes (AA/19 and DD/33); **l** and **m** redirecting flakes (AA/24 and D/45); **n** flake with gloss on the margin AA/15. Scale bar = 1 cm.

between 1.2 and 1.4 m depth (Fig. 9). Retouch is also markedly more intense during periods of low discard at the interface between phases (Table 10) as opposed to periods of high discard (all phases of low and high discard are combined in this table to increase sample size). We see increases in all measures of retouch intensity increasing significantly as discard drops, with significant differences in the index of invasiveness and Kuhn Index (Table 11).

4. Discussion

Continuity in technological reduction strategies and even artefact metrics is certainly present in the MK2 assemblage, as with many other sites in Wallacea and the Nusa Tenggara region. Nevertheless, important changes are evident in the lithic assemblage of MK2 in terms of discard, raw material selection and the emphasis placed on various reduction and extension strategies through time. Such changes invite consideration of why these might exist at MK2 and perhaps in the broader region, and how they correspond with climatic shifts and regional cultural changes.

Stone artefact discard peaks in the middle of Phases I and II, and is highest in Phase I and lowest in Phase III with the first appearance of pottery at the site. Artefact discard drops away noticeably at the transitions between each phase and in Phase III. This appears to be a common pattern in sites across the Timor-Leste and in Alor for which data is available (Fig. 10) (Hawkins et al., 2017; Kealy et al., 2020; Maloney et al., 2018; O'Connor et al., 2002; O'Connor et al., 2010; Shipton et al., 2019; Veth et al., 2005). High artefact discard is noted at many sites between 40 and 30 ka, often followed by a period of low discard or a hiatus in site occupation, followed by another peak in discard in the terminal Pleistocene/early Holocene, and finally a period of lower

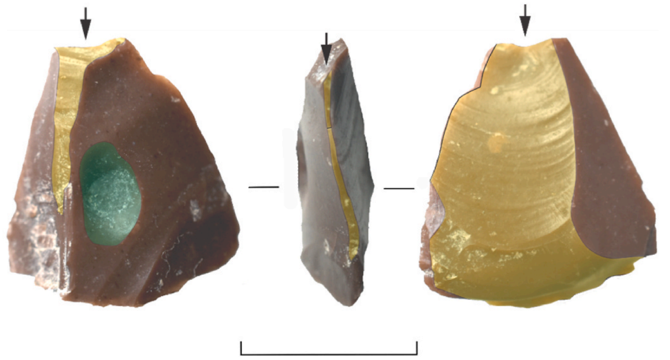

Fig. 8. Possible impact fractures on chert flake from Phase II, B/37. Arrows indicate initiation points for three separate scars (STBF, burin spall and overshot flute) initiated from the distal end. Yellow areas indicate possible impact fractures. Green area indicates pot lid scar unrelated to possible impact fractures. Scale bar = 1 cm.

discard in the late Holocene after 3.8 ka with slight upturn in the very final period of occupation in some cases. This pattern can also be seen at Bui Ceri Uato on the central coast of Timor Leste, adjacent to a permanent spring, which hosts a diverse array of lithic artefacts, marine exploitation and anvils and grindstones for plant and nut processing activities (O'Connor and Veth, 2005; Glover, 1986: 90–126). Recent redating of Bui Ceri Uato shows that artefact numbers peak between the Terminal Pleistocene ~13 ka and mid Holocene ~6 ka (Oliveira, 2008: 305; Glover, 1986:98). At the inland site of Uai Bobo 2, which dates to the terminal Pleistocene 13.8 ka (ANU-238), 5969 artefacts were recovered, but all but 8 were found in the Holocene horizons and artefacts peak in the mid Holocene (Glover, 1986: 169–70). The onset of occupation and intensity of occupation seems to occur later at these inland sites.

These phases of high discard between 40 and 30ka and the terminal Pleistocene/early Holocene, and to a far lesser degree in the late Holocene, likely indicate periods of intensive site occupation as they are accompanied by peaks in artefact damage from burning (Fig. 1). These phases of intensive cave occupation we note also correspond to wetter climatic phases between 40 and 27ka and between 13-7ka, and again in the last 1000 years. The pollen and charcoal records recovered from the Banda Sea and Aru Sea marine cores are likely the most indicative of Timor conditions with the pollen source being mostly from the Wallacea region and only minimally from Sahul lying further to the east. These records confirm wetter conditions during periods of occupation at Matja Kuru 2 and much drier phase during the LGM indicated by low rainforest trees (Dipterocarps) and low ferns (Pteridophytes) – particularly between 27 and 13ka when grasses and fire are at their maximum (see Core SHI-9014 and Core MD98-2175 in Kershaw and van der Kaars, 2012).

Periods of lower occupation or breaks in site use between the wet phases corresponds well to drier phases as seen from the Banda and Aru Sea proxy records and the marine records of the coast of the Kimberley, NW Australia, where burning and grasses are at their maximum (see Core MD98-2167 and Core G6-4 in Kershaw and van der Kaars, 2012). Relatively warm SST south of Timor recorded in marine cores during the 27-16ka (Mohtadi et al., 2010) occurs during the LGM but this may be a function of low sea level and limited Indonesian Throughflow resulting in drier conditions on land – as indicated by the Banda and Aru Sea records. Intensified El Nino Southern Oscillation events during the mid-late Holocene may have also affected the Timor region, creating greater climate variability and drier climates (Gagan et al., 2004). For the residents of Matja Kuru 2, this is likely to have been particularly disruptive as the nearby Lake Ira Lalaro is likely to have contracted and dried completely during these drier phases.

This hypothesis of oscillating periods of intensive and minimal artefact discard perhaps relating to wet and dry climatic shifts, while tentative and requiring rigorous testing at each site, finds some support from the nature of technological changes at MK2 in the transitions between phases. At both the interfaces between Phase I and II, and between Phase II and III, there is a pronounced spike in the use of extension/recycling strategies, indicating the need to make raw materials and tools available for longer through greater reduction and extended use life of implements. Such changes are often interpreted as changes in lithic provisioning, in particular a shift from on-site place provisioning with raw material and tool making potential when habitation is regular and predictable, to individual provisioning when mobility increases and site use becomes infrequent and/or unpredictable (Kuhn, 1995).

The fact that enormous changes take place in Wallacea, particularly in the well-studied Nusa Tenggara region, during the terminal Pleistocene/early Holocene period of intensive occupation during a likely wetter period, suggests that populations may have increased at this time. This may have fostered or accelerated inter-regional interaction, innovations and exchange of new technologies, new personal ornamentation styles, intensification of marine subsistence and innovations in fishing technology as well as niche broadening (Roberts et al., 2020) in response to larger populations, in turn giving rise to inter-regional obsidian trade (Reepmeyer et al., 2019) perhaps facilitated by the appearance of ground edge tools that enabled manufacture of new forms of watercraft (Clarkson et al., 2021; Shipton et al., 2020a, 2020b; Normile, 2019; Kaifu, 2022). That this cultural efflorescence and possible increase in population size took place as sea levels were rising rapidly

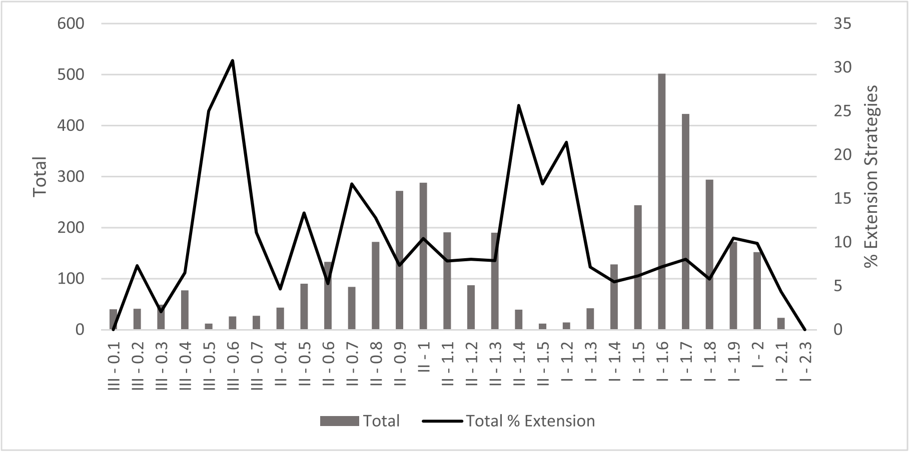

Fig. 9. Frequency of extension/recycling strategies by phase and depth at MK2.

Table 11
Measures of retouch intensity compared between phases of low artefact discard and high artefact discard.

	# Notches	Kuhn Index	% Perimeter Retouched	Retouched Edge Angle	Index of Invasiveness
High Discard: Phase III 0.1–0.4 m, Phase II 0.5–1.3 m, Phase I 1.4–1.8 m, 2.1–2.3 m	1.10	0.53	35.57	65.66	0.22
Low Discard: Phase III 0.5–0.7, Phase II 0.4, 1.4–1.5 m Phase I 1.2–1.3 m, 1.9–2.0 m	1.25	0.86	57.53	72.75	0.46
t	0.19	−2.38	−1.5	1.18	−2.29
df	14	19	19	20	19
p	0.85	**0.03**	.15	.08	**0.03**

(Kealy et al., 2020; Shipton et al., 2021b), albeit with limited effect on islands with steep offshore profiles, likely added pressure in the form of demographic compression, fragmentation and dislocation as larger islands split (e.g. Alor and Pantar) (O’Connor et al., 2017), small islands disappeared under the sea (Kealy et al., 2016), and shorelines changed (though possibly becoming more productive in some cases as a result of extended coastlines and increases in marine productivity).

5. Conclusion

Detailed analysis of the MK2 lithic assemblage confirms the widespread pattern of continuity in lithic technology in the Nusa Tenggara region and a consistent pattern of small-sized artefact production from small cores. Nevertheless, significant changes in emphasis on certain technologies as well as changes in raw material selection do occur through time. In particular, the most dramatic change in technology appears at the transition between phases either side of long periods of absence from the site. We interpret these changes as reflecting increased reliance on lithic extension and recycling strategies that may be driven by increased mobility and unpredictability of site use, prompting greater reliance on a transported supply of raw material whose utility was extended. We note that increased reliance on these strategies appears to coincide with shifts from wetter to drier conditions in Wallacea. Detailed lithic analyses have been completed for numerous sites in Nusa Tenggara, and it is now time to compare these records in detail to determine whether patterns of changing site use and occupational intensity correspond to behavioural patterns in lithic reduction, curation and transport across this island chain as well as throughout Island Southeast Asia more generally.

Author contributions

Chris Clarkson: Conceptualization, Methodology, Formal analysis, Investigation, Writing - Original Draft, Writing - Review & Editing, Visualization. Simon Haberle: Writing - Review & Editing. Susan O’Connor: Conceptualization, Investigation, Writing - Review & Editing.

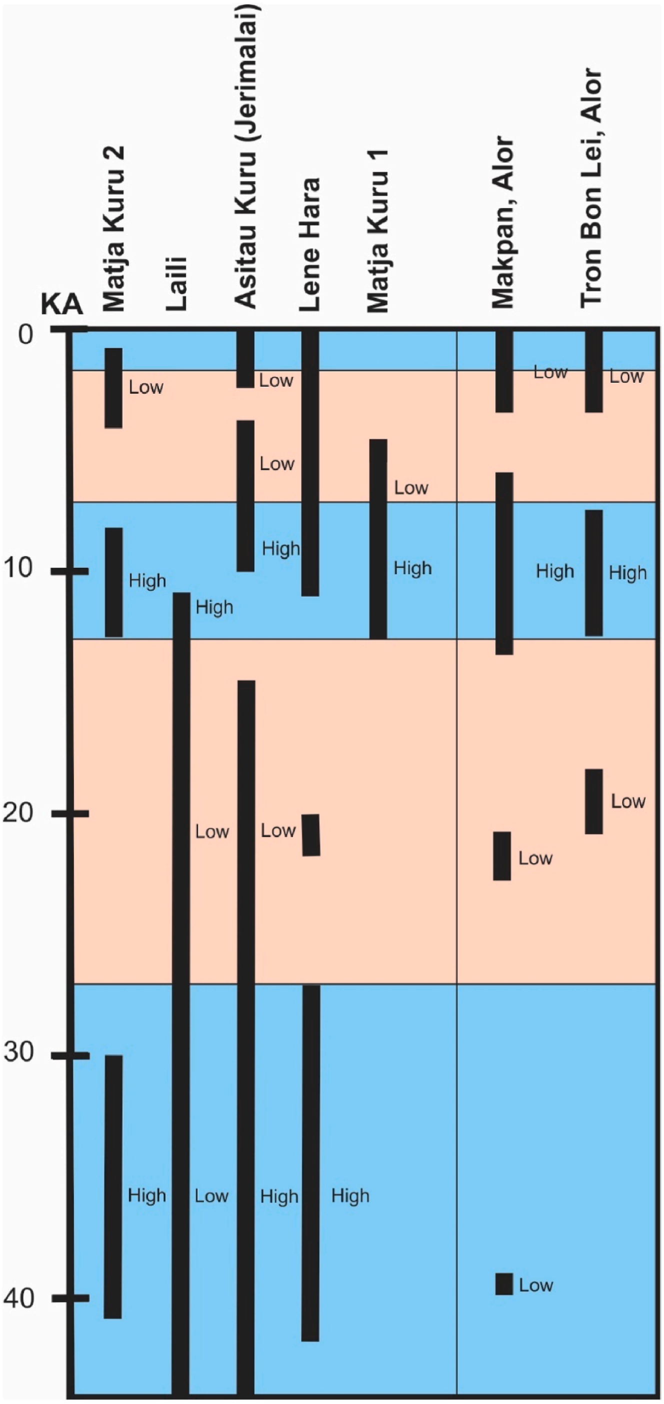

Fig. 10. Phases of occupation and stone artefact discard intensity in sites on Timor and Alor for which data exists, also showing proposed wet (blue) and dry (dry) climatic periods.

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

Data will be made available on request.

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