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The archaeology, chronology and stratigraphy of Madjedbebe (Malakunanja II): A site in northern Australia with early occupation

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ABSTRACT

Published ages of >50 ka for occupation at Madjedbebe (Malakunanja II) in Australia's north have kept the site prominent in discussions about the colonisation of Sahul. The site also contains one of the largest stone artefact assemblages in Sahul for this early period. However, the stone artefacts and other important archaeological components of the site have never been described in detail, leading to persistent doubts about its stratigraphic integrity. We report on our analysis of the stone artefacts and faunal and other materials recovered during the 1989 excavations, as well as the stratigraphy and depositional history recorded by the original excavators. We demonstrate that the technology and raw materials of the early assemblage are distinctive from those in the overlying layers. Silcrete and quartzite artefacts are common in the early assemblage, which also includes edge-ground axe fragments and ground haematite. The lower flaked stone assemblage is distinctive, comprising a mix of long convergent flakes, some radial flakes with faceted platforms, and many small thin silcrete flakes that we interpret as thinning flakes. Residue and use-wear analysis indicate occasional grinding of haematite and wood-working, as well as frequent abrading of platform edges on thinning flakes. We conclude that previous claims of extensive displacement of artefacts and post-depositional disturbance may have been overstated. The stone artefacts and stratigraphic details support previous claims for human occupation 50–60 ka and show that human occupation during this time differed from later periods. We discuss the implications of these new data for understanding the first human colonisation of Sahul.

1. Introduction

Madjedbebe (MJB), or Malakunanja II as it was formerly known, has attracted much attention due to claims for early human occupation at the site between 50 and 60 ka (Roberts et al., 1990a). Previous work at the site established its scientific significance, particularly for understanding the timing of human colonisation of Sahul. It is also significant and unique in providing a dense lower cultural assemblage that includes evidence for early complex technological, subsistence, and artistic behaviours, with implications for understanding the economic and symbolic dimensions of the earliest societies in Sahul. The lowest artefacts at MJB are bracketed by Thermoluminescence (TL) and Optically Stimulated Luminescence (OSL) ages of 52 ± 11 and 61 ± 13 ka (Roberts et al., 1990a). The nearby site of Nauwalabila returned similar OSL ages, bracketing the ages of the lowest artefacts at between 53 ± 5 and 60.3 ± 6 ka (Roberts et al., 1994; Bird et al., 2002). Both sites potentially predate Lake Mungo, Devils Lair, Nawarla Garbarnmung, Riwi, Lake Menindee Lunette, and Carpenters Gap 2 by 5–14 ka (Bowler and Price, 1998; Roberts et al., 1998; Balme, 2000; Turney

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et al., 2001; Bowler et al., 2003; O'Connor and Veth, 2005; Cupper and Duncan, 2006), thereby increasing the period of human occupation substantially.

Sahul represents a geographic terminus in the journey of modern humans out of Africa along the southern arc through South and Southeast Asia. An early dispersal through these regions is supported by modern genetic analyses (Huoponen et al., 2001; Macaulay et al., 2005; Liu et al., 2006; Sun et al., 2006; Friedlaender et al., 2007; Hudjashov et al., 2007; Oppenheimer, 2009, 2012; Rasmussen et al., 2011), as well as modern human remains at sites such as Liu Jiung in China (estimated to be 65 ka), Tam Pa Ling in Laos (46–63 ka), Niah Cave in Borneo (40 ka), and Lake Mungo in Australia (40 ka; Shen et al., 2002; Barker et al., 2007; Demeter et al., 2012; Veth and O'Connor, 2013). The presence of an archaic species on Flores (Brown et al., 2004), and an unidentified species of *Homo* in the Philippines (Mijares et al., 2010), raises the possibility of contact and gene flow between species, as well as a potentially sparse and patchy modern human presence in this region prior to the colonisation of Sahul.

Early dates for colonisation suggest that modern humans had reached the end of the southern dispersal route before Europe was colonised—hence the European Upper Palaeolithic would have little bearing on understanding the origins or development of modern technology and symbolic expression in South and Southeast Asia and Oceania (e.g., Brumm and Moore, 2005; Habgood and Franklin, 2008; Davidson, 2010; Langley et al., 2011). A 'long' chronology for Sahul (cf. O'Connell and Allen, 2004) of 50–60 ka also substantially lengthens the period of contact between humans and megafauna, and requires further consideration of the nature of this interaction and the role of predation versus climate change in bringing about their demise.

Colonisation of Sahul as early as 50–60 ka would also offer an opportunity to closely examine the nature of the lithic technology employed by early colonists. Mellars and colleagues (Mellars, 2006; Mellars et al., 2013) have argued that modern humans left Africa with microlithic technology, artistic conventions, and bead-making technologies similar to those present in eastern and southern Africa after 60 ka. However, there is little evidence for this in sites >40 ka on likely dispersal routes between Africa and Sahul. Another possibility is that modern humans left Africa with Middle Stone Age (MSA) technology, including prepared core technology and projectile points, and that this technology is antecedent to the technologies found in Southern Asia and Sahul (Clarkson et al., 2012; Clarkson, 2014). Given its high artefact density and the presence of a hitherto undocumented stone technology in the earliest period of occupation, the assemblage from MJB is ideal for investigating the nature of the earliest Australian stone technologies.

Despite the significance of MJB for addressing questions of chronology, modern human origins, and early complex behaviour, no detailed report of its stratigraphy or assemblage has ever been published. This has resulted in persistent concerns about the chronology of human occupation at the site and the extent to which post-depositional disturbance and artefact movement have obscured patterns of cultural change. This paper will address some of these concerns in the form of a detailed examination of published and unpublished evidence. The specific questions that we address here are: (1) What is the chronology of the archaeological materials excavated in 1989? (2) How does evidence of human activities, especially stone artefact technologies, at the site change over time? (3) What are the implications of the stone artefact assemblage data for understanding post-depositional disturbance and artefact movement? Here we present new data on the chronology and stratigraphy of the site, the size and diversity of the lithic assemblage, and the pattern of technological change throughout the sequence at MJB. These data enable us to better understand the formation and age of the site, its stratigraphic integrity, the nature of the early lithic industry, and the subsequent technological changes through time. Our data are based on re-examination of the assemblage recovered during the 1989 excavations, as well as new information about the chronology, stratigraphy, biological components, and the changing nature of artefact deposition, obtained from unpublished field records.

2. Previous investigations at MJB

MJB is situated on the northwest face of a large sandstone massif known as Djuwamba, facing the edge of the Magela floodplain in Arnhem Land (Fig. 1). The site also lies within the current Environmental Resources Australia (ERA) Jabiluka mining lease encapsulated within Kakadu National Park. The shelter is long (~50 m), but the overhang protects only a narrow strip of less than 5 m width from the rock face to the dripline. The organic-rich deposit of the shelter grades evenly into the surrounding sandsheet within a few meters from the back wall, and the sandsheet slopes gently down to the wetlands about 1 km away. The site has a rich panel of rock art containing about 1000 motifs and is well-known for its contact paintings depicting guns, ships, wagons, and Europeans.

MJB was originally excavated by Johan Kamminga in 1973 as part of the Alligator Rivers Environmental Fact Finding study to gather information about the antiquity and richness of archaeological resources in the then-proposed Kakadu National Park (Kamminga and Allen, 1973). Kamminga excavated near the back wall to a depth of 2.48 m bs (below surface), unearthing a shell midden in the uppermost 60 cm, which contained human remains, faunal remains, and numerous stone artefacts, including several points. The mix of marsupial, reptile, bird, crustacean, and mollusc food remains from the midden was very similar to that found at the nearby sites of Malangangerr, Ngarradj, and Nawamoyn, with freshwater mussel shells occurring sporadically in the upper few spits. The midden was underlain by sandy deposits grading from brown to light yellowish brown at around 1.40–1.55 m bs, containing predominantly quartz artefacts. Kamminga's test excavation revealed several grinding stones near the base of the deposit, a very large mortar with cup-shaped ground hollow, and ground and striated haematite fragments near the base of the excavation. A single radiocarbon date of 18.04 ± 0.3 ka BP (SUA-265) was obtained from Spit 19 (1.88–2.15 m bs), but its significance was limited owing to the small sample size and the large area over which the sample was collected (Bird et al., 2002).

In 1988, Rhys Jones, Richard 'Bert' Roberts, and Christopher Chippendale augered a single core at the site, the initial TL results (KTL-158) from which suggested that artefacts were present in levels dating to 50 ka or earlier. Rhys Jones, Bert Roberts, and Mike Smith returned to the site in 1989 and excavated a 1.5 × 1 m trench positioned 0.5 m in front of Kamminga's pit (Fig. 2) to allow direct comparison with the 1973 test-pit stratigraphy and that of the auger, while maintaining a 0.5 m baulk between trenches to prevent cross-contamination by backfill.

A dense occupation layer was found in Spits 37–39/40 (2.14–2.50 m bs) of the 1989 excavation with a small number of artefacts continuing below this to Spit 46 (2.60 m bs). The excavators found a lens feature from 2.35 m bs (Spit 39/40) into the underlying deposits. The fill from this feature was excavated separately as Spits 41, 43, and 62 (Figs. 3 and 4). Nine TL ages and two radiocarbon ages relating to the excavation were published (Table 1). Later redating of samples KTL-162 and KTL-164 using single grain OSL technique revised the ages for these samples and reduced the size of the standard errors substantially (Roberts et al., 1994).

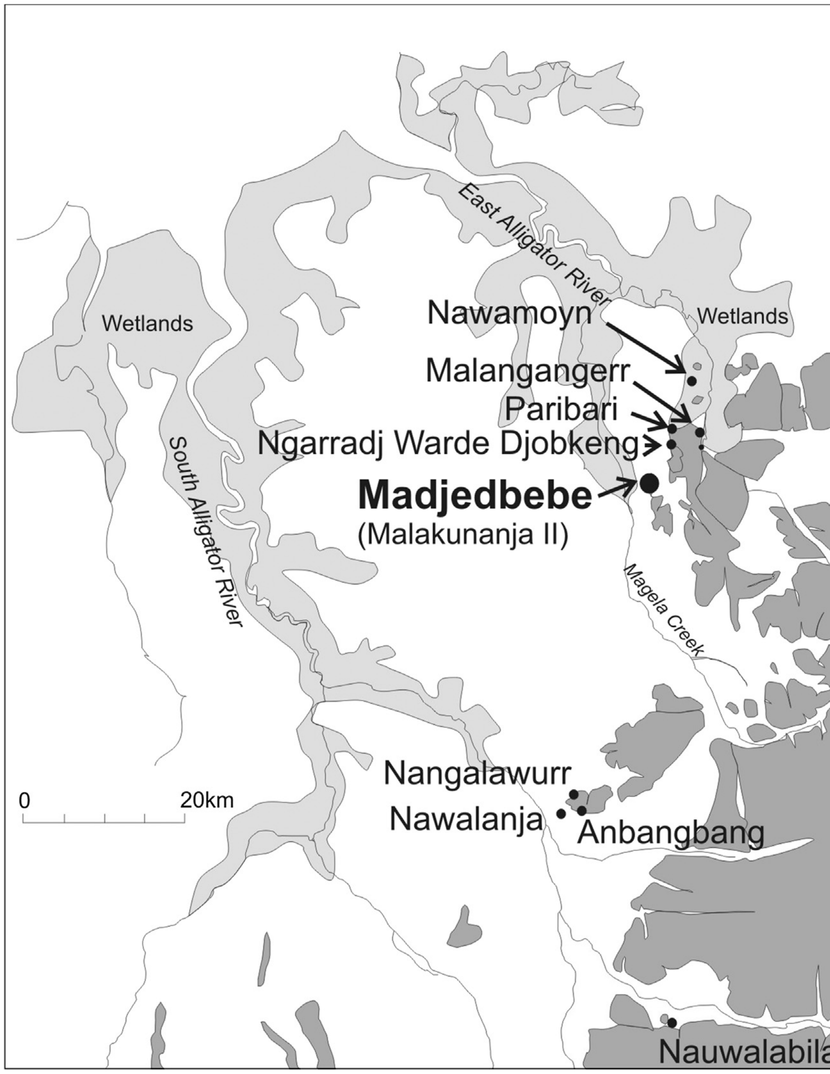

Figure 1. Map showing the location of MJB in relation to wetlands and excavated sites in KNP. Light grey = wetlands; dark grey = sandstone escarpment and outliers.

Figure 2. The Jones, Smith, and Roberts excavation in progress in 1989 (photo by Mike Smith and Rhys Jones).

Figure 3. Lens feature identified at the base of the occupation layer in the west corner of the 1989 trench (photo by Mike Smith and Rhys Jones). Also shown in Fig. 4.

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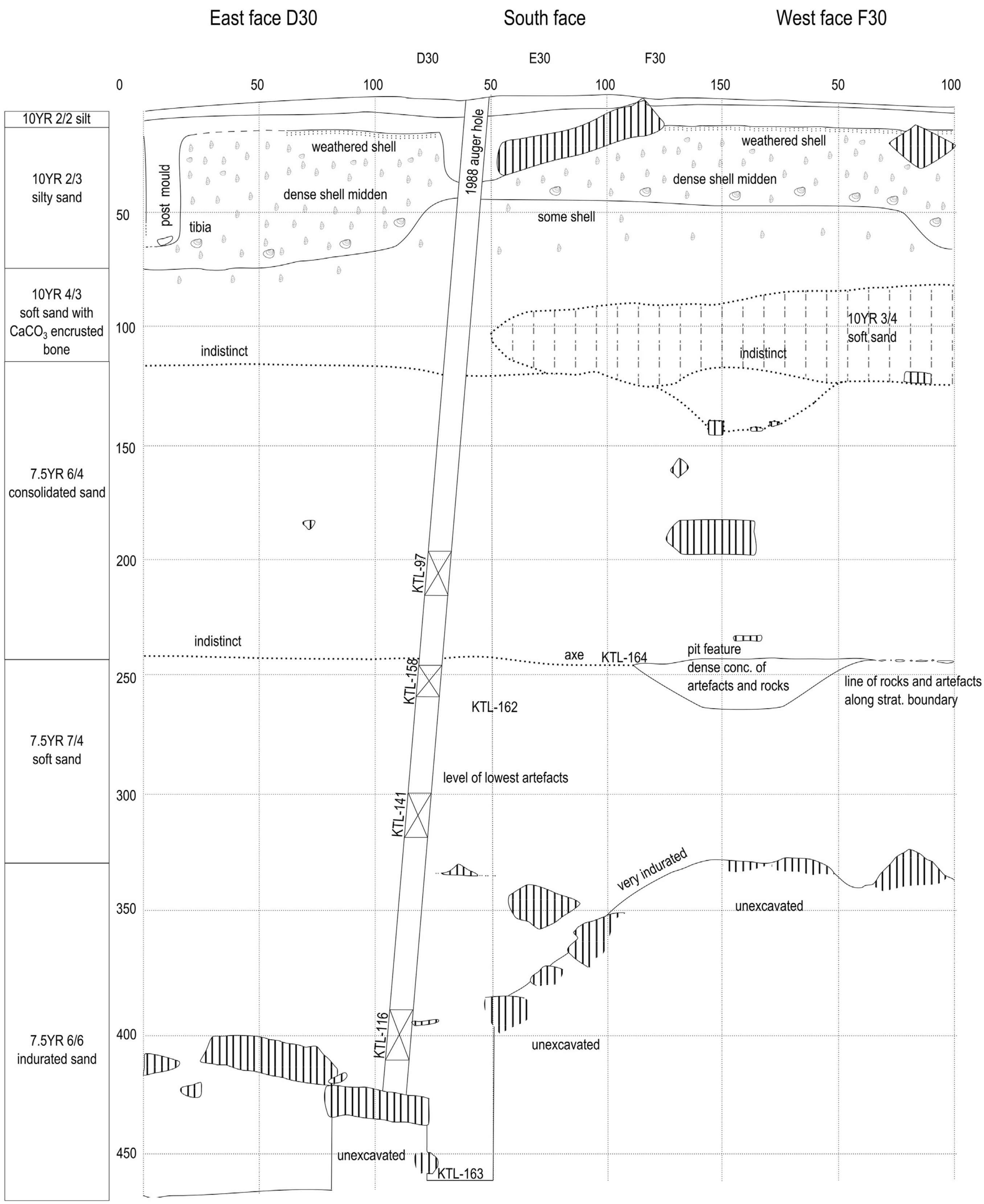

Figure 4. Section drawing of the 1989 MJB trench. The figure has been redrawn for the northwest and southwest walls from the original field notes and section drawings. Note the lens feature at 2.35 m bs described as 'dense conc. of artefacts and rocks.' This is the same feature shown in Fig. 3.

Table 1
Published and unpublished ages obtained for the 1989 excavation at Madjedbebe.[a]

Square	Spit	Method	Lab code	Type	Depth bs (cm)	Uncalibrated age	Error	Lower cal BP	Upper cal BP	Reference
DEF30		TL	KTL-156	Multiple grains	2	2000	1300			Roberts et al., 1990a
1972	2	C14	SUA-263	Charcoal	10	450	80	635	309	This paper
F30	4	C14	ANU-7002	Marine gastropod	13	3810	80	4420	3981	This paper
F30	12	C14	ANU-7003	Marine gastropod	59	6290	90	7420	6995	This paper
1972	8	C14	SUA-264	Charcoal	65–88	6440	200	7689	6883	This paper
F30	18	C14	ANU-7004	Charcoal	93	7300	230	8558	7676	This paper
DEF30	21	C14	ANU-7005	Charcoal	113	10,470	120	12,681	12,006	This paper
DEF30	26	ABOX	ANU-7006	Charcoal and sand	146	13,390	400	17,429	15,001	Bird et al., 2002
DEF30		TL	KTL-165	Multiple grains	155	15,000	3000			Roberts et al., 1990a
DEF30		ABOX	ANUA-9913	Charcoal	149	10,330	150	12,638	11,501	Bird et al., 2002
DEF30		ABOX	ANUA-9914	Charcoal	149	13,050	210	16,267	15,043	Bird et al., 2002
DEF30	28	C14	ANU-7007	Charcoal and sand	158	14,990	150	18,583	17,885	This paper
1972	19	C14	SUA-265	Charcoal	188–215	18,040	300	22,493	21,051	This paper
DEF30	31	C14	ANU-7115	Charcoal	178	18,810	2090	29,584	18,480	This paper
Auger		TL	KTL-97	Multiple grains	190	24,000	5000			Roberts et al., 1990a
DEF30		TL	KTL-164	Multiple grains	230	45,600	9000			Roberts et al., 1990a
DEF30		OSL	KTL-164	Single grain	230	44,200	4700			Roberts et al., 1998
Auger		TL	KTL-158	Multiple grains	242	52,000	11,000			Roberts et al., 1990a
DEF30		TL	KTL-162	Multiple grains	254	61,000	9300			Roberts et al., 1990a
DEF30		OSL	KTL-162	Single grain	254	55,500	8200			Roberts et al., 1998
DEF30		ABOX	ANUA-9915	Charcoal	254	10,810	200	13,108	12,159	Bird et al., 2002
Auger		TL	KTL-141	Multiple grains	295	65,000	14,000			Roberts et al., 1990a
Auger		TL	KTL-116	Multiple grains	390	86,000	18,000			Roberts et al., 1990a
DEF30		TL	KTL-163	Multiple grains	452	105,000	21,000			Roberts et al., 1990a

[a] Radiocarbon ages calibrated to 95.4% probabilities using OxCal 4.1 with IntCal13 (Bronk Ramsey, 2001). No marine calibration has been applied to ANU-7002 and ANU-7003.

3. Critiques of the previously published chronology of the deposit

The dates published by Roberts et al. (1990a) were questioned by Hiscock (1990) and Bowdler (1990), and later by Allen and O'Connell (2003, 2014). Hiscock (1990) pointed to an increasing divergence between the ^{14}C and TL ages with depth, suggesting that the latter could result in an over-estimation of the real age of the deposit. Hiscock also pointed to a possible hiatus in sedimentation up to 20 ka in duration between the 25 and 45 ka ages where deposits showed a change in sedimentation rates. His third concern related to the use of ages both from an auger hole as well as the excavated sections to establish the age estimates for the site. Fourth, Hiscock suggested the possibility of downward displacement of artefacts into sterile layers through human treadage. Finally, Hiscock concluded that, irrespective of all of these potential problems, the error ranges on the TL ages were too large to make a precise determination of initial occupation. Bowdler (1990) added to these criticisms and likewise asked for proof of association between ages and artefacts, and an explanation for the increasing disparity between the TL and ^{14}C ages.

Roberts et al. (1990b, 1990c, 1998) responded to these criticisms in detail. They noted that, while some post-depositional movement of artefacts by treadage could not be ruled out, the lithic assemblage showed no signs of size sorting with depth, artefact orientations were horizontal, the lowest peak in artefact abundance in Spits 38–40 (2.3–2.5 m bs) was sharply defined, raw materials showed significant differences through time, the lowest haematite pieces were sometimes very large and thus unlikely to have migrated downwards, and the sandy matrix in the lowest occupation layer was tightly packed and unsorted. In other words, they saw little reason to infer marked disturbance or downward displacement of artefacts on these grounds. They also pointed out that a lens feature at 2.35 m bs overlayed the lowest artefacts and that this feature (which could not be post-depositional) sat at, or slightly below, the date of 45 ka (KTL-164). They also showed that all TL ages sat within the 95% confidence interval for a linear depth-age regression performed for all TL ages (although no regression statistics were presented), providing no reason to suggest a hiatus in sedimentation. They argued that although the 'uncertainties' on the TL ages were large, these were constrained in a sequence of ages. In answer to the question of scuffage and downward displacement, they pointed out that the TL signal is reset upon exposure to sunlight and hence that TL ages would date the last episode of disturbance. Hence, the published TL ages would, if anything, provide a minimum age for scuffed deposits—though not for 'treadage.' However, while these observations ruled out displacement of artefacts into the 45 ka levels, they did little to distinguish between the 45 ka assemblage and artefacts at 50–60 ka.

Allen and O'Connell (2003) also questioned the age and stratigraphic integrity of MJB, and indeed all Sahul sites with ages greater than 45–46 ka. With respect to MJB, they pointed to an inverted radiocarbon date at the base of the occupation deposit published by Bird et al. (2002) as possible evidence of termite activity transporting organic particles through the sequence. The radiocarbon sequence, however, is robust to a depth of 1.78 m bs (see below). The charcoal dated by Bird et al. (2002) from 2.54 m depth was retrieved from a floated sediment sample and was <125 μm in size. The latter suggests that we should regard this as a minimum age for sediments at that depth. Furthermore, as its original location cannot be confidently identified, we cannot rule out the possibility that it was intrusive material that had fallen or blown in during excavation.

4. Methods

We analysed the stone artefact assemblage recovered during the 1989 excavations, currently held in the Museum and Art Gallery of the Northern Territory (MAGNT) in Darwin, where we conducted our data collection. The data collection protocols followed those described in detail in Clarkson (2007). We counted and classified the entire lithic assemblage based on technology and raw material, performed use-wear and residue analysis on select pieces, undertook attribute analysis on all complete artefacts, and photographed relevant specimens. Data were analysed and visualised with R (3.1.1) and RStudio (0.98.1030). The raw data and source code needed to reproduce all the results in this paper are freely available

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online at http://dx.doi.org/10.6084/m9.figshare.1297059 and available as Supplementary Online Material [SOM]. Stratigraphic and depositional information were obtained with permission from Mike Smith and Bert Roberts, including original field notes, photographs and section drawings.

In the course of the technological analysis, artefacts from the lowest levels were selected for microscope study based on macroscopic traces of use, and included all small flakes likely to have been detached from tool edges during retouching or from use (use flakes). The main aim was to assess the feasibility of more detailed usewear and residue analysis of the early MJB stone tools. The artefacts were examined under reflected light microscopes (Olympus SZ61 at 6× to 50×, and Olympus BH2 at 50× to 500×) to document wear and residues. Wear on grinding stones was also documented with polyvinyl siloxane surface impressions. Water extractions to remove residues were mounted on glass slides and examined under a transmitted light microscope (Olympus BH2). The wear and residue sampling procedures are described by Fullagar (2014) and Hayes et al. (2014).

5. Results

5.1. Stratigraphy and depositional history

The sandsheet that makes up the MJB deposit is part of the sand mantles that form Quaternary valley fills in western Arnhem Land. These were extensively studied by Roberts (1991), who found that the stratigraphy and chronology of MJB is consistent with regional sediment fluxes (Nanson et al., 1993; Nott and Roberts, 1996). In this context, the sediments at MJB are typical of sandstone rockshelter sequences in northern Australia with deposits of sands that vary slightly by depth in colour, compaction, and the proportion of silt. These variations are probably due to subtle changes in post-depositional over-printing, the origins of the sediments, and factors relating to the depositional environment, such as the frequency of wetting and drying.

Field notes from the 1989 excavations indicate that the MJB deposits consist of 4.6 m of poorly sorted medium quartz sands overlying basal rubble that had accumulated against the base of the cliff line. These moderately compacted sands span the last 100 ka and form a low-angled alluvial apron. The sands are ultimately derived from local bedded, cross-bedded, and laminated Proterozoic Kombolgie sandstones. Analysis of the 1989 sediment samples indicated a median particle size of 1.09–1.75Ø and silt–clay content <6.7% (with most samples comprising around 2–4% silt and clay). Although the luminescence and ^{14}C framework suggests there have been shifts in the rates of deposition, the deposits essentially form a massive sand unit, capped by a shell midden in the upper 60 cm. Field observations, section drawings, and photographs from the 1989 excavations show very limited evidence for changes in the character of the sediments, their source, the mode of sediment

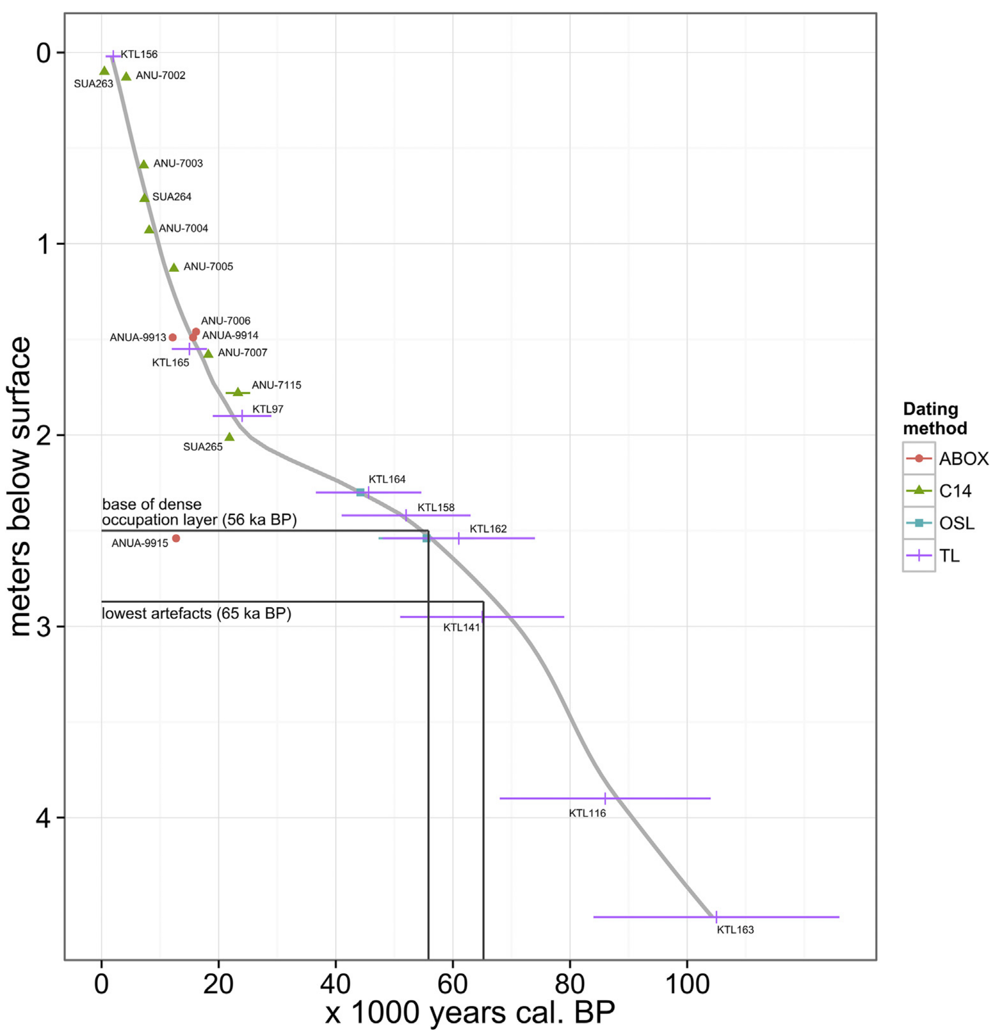

Figure 5. Depth-age curve for MJB showing calibrated ^{14}C (red) and luminescence ages (blue). Locally weighted regression line excludes the ANUA-9915 ABOX age. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

transport, cut-and-fill or other erosional features, depositional hiatuses, or palaeosurfaces.

Fig. 4 shows a series of gradual changes in colour and compactness down the site profile, representing post-depositional overprinting, produced by leaching and dissolution of the overlying shell midden and organics. These organics have infiltrated down the profile so that artefacts in the upper part of the sands have $CaCO_3$ concretions. Artefacts lower in the sequence also have sand cemented onto their upper (though not their underlying) surfaces.

The 1989 excavation also revealed lateral variation in organic staining and evidence for induration towards the dripline. Beyond the dripline the overlying shell midden had substantially dissolved. At the base of the sandsheet, the sands were heavily indurated and could only be removed with a geopick. These levels (3.5–4.6 m) probably reflect the effects of seasonal waterlogging at the base of the sediment profile. None of the sedimentary variations described above form abrupt stratigraphic boundaries and none appear to represent discrete depositional episodes.

The 1989 field notes reported evidence of termite activity restricted to some burnt ant bed near the base of the midden. Several features were preserved intact within the sand unit, including hearths in Spits 26 and 27 and a lens at 2.35 m, the latter excavated separately as Spits 41, 43, and 62. A horizontal or sub-horizontal band of artefacts was recorded at the same level. The lens feature and the associated band of artefacts represented the highest density (artefacts per unit volume) of artefacts in the MJB sequence. The sharp boundaries of the lens and the relatively narrow horizontal extent of the associated band of artefacts indicated to the excavators that post-depositional disturbance, at least here, was minimal. Single grain OSL dating of the 1989 samples, carried out in 1998, found a “lack of significant post-deposition disturbance of the Malakunanja II sediments, indicating that artefacts are unlikely to have intruded into these levels” (Roberts et al., 1998:21).

No definite artefacts were reported by the excavators below Spit 43 (2.52 m bs). However, our re-examination of the bagged ‘rubble matrix’ from the 6 mm sieve residue has revealed quartzite artefacts in small numbers down to and including Spit 49 (2.80 m bs).

The sandsheet is capped by a shell midden that is 60 cm thick (spanning from 11–68 cm bs) and dominated by *Cerithidea* sp. with smaller proportions of *Geloina* sp., *Telescopium* sp., and *Nerita* sp. The midden began to accumulate ~7 ka and continued through until ~4 ka. The midden contains stone artefacts (including bifacial stone points), bone bi-points, ground haematite pieces, animal bones, and both articulated and disarticulated human bones. The lower boundary of the midden is diffuse, with a gradual reduction in molluscs in the deposit, a change to a lighter sediment colour, and a reduction in organic inclusions. Molluscs at the base of the midden are frequently fragmentary and chalky, indicating chemical dissolution. The surface of the midden has weathered shells with an array of intrusive features. The latter include grave pits (for both secondary and primary inhumations) and other features, such as a post-hole, and animal burrows. The midden is overlain by a ~10 cm thick surface layer of soft, black, well-sorted, very silty sand, dating to within the last 1 ka. The surface layer, which is rich in organic matter and charcoal, has undergone extensive physical disturbance since the 1980s, with signs of pig wallows against the shelter wall and hearths from recent fires.

5.2. Chronology

Based on the TL age estimates and the artefact distribution, Roberts et al. (1990a) suggested first occupation at MJB began 55 ± 5 ka. Although the excavators were conservative in their interpretations—stressing the upper (i.e., 50 ka) limit of this age range and taking the lower limit of the high density band of artefacts (2.4 m bs) as the actual level of initial occupation—our analysis of the stone artefact assemblage confirms that the lowest artefacts occur in Spit 49, 2.76–2.8 m bs and are bracketed by the original OSL age estimate of 55.5 ± 8.2 ka (KTL-162) and the TL estimate of 65 ± 14 ka (KTL-141). Subsequent redating of several of the lower samples at MJB using single grain and single aliquot OSL methods reduced the error ranges for the lower dates substantially but did not alter the original results (Roberts et al., 1998).

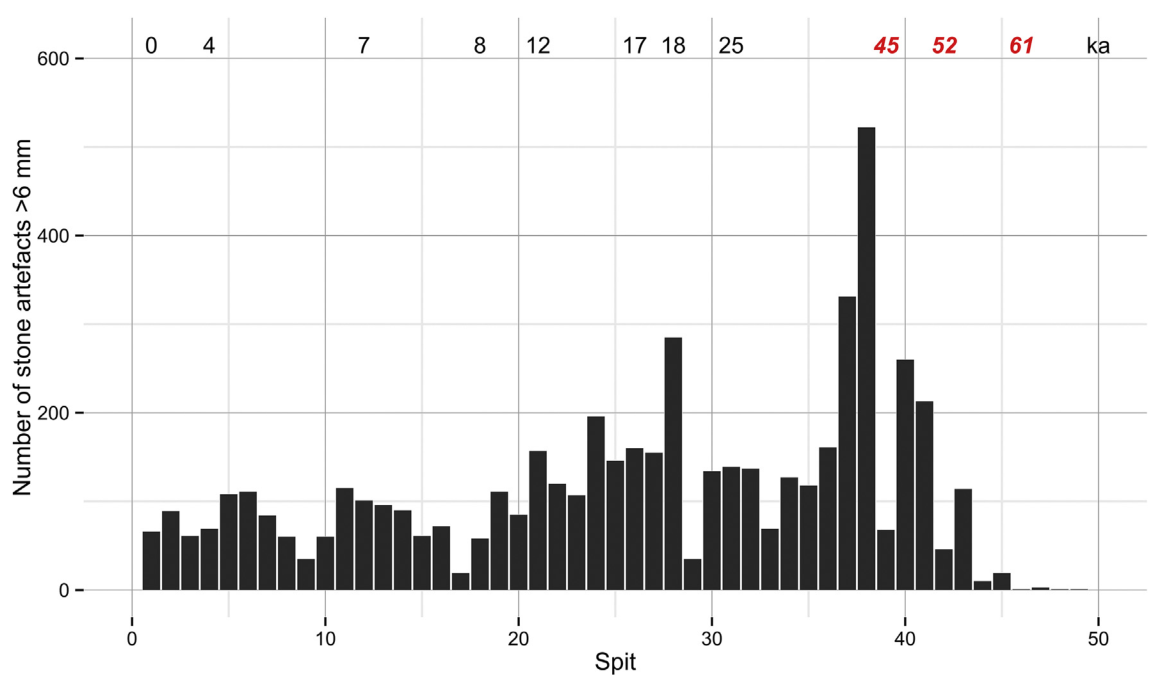

Figure 6. Counts of stone artefacts per spit from the 6 mm sieve, showing ^{14}C (black) and OSL/TL ages (in red italics) along the top. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

Table 2
Site contents from the MJB 1989 excavation from the 6 mm sieve.

Spit	Approximate depth (cm bs)	Sediment (kg)	Rocks/ rubble (kg)	Shell (g)	Haematite/ ochre (g)	Local coarse-grained quartzite	Exotic fine-grained quartzite	Quartz	Crystal quartz	Sandstone	Siltstone	Silcrete	Brown quartzite	Volcanic stone	Highly weathered volcanic stone	Oenpelli dolerite	Chert	Schist
1	1	26.6	0.4	2.20	2.50	8	9	47									1	
2	6	31.6	0	3.60	1.80	35	5	42	1									
3	8	31.6	0	6.20	12.80	14	5	38									2	
4	13	37.3	1.5	342.30	25.70	21	5	30		4							2	
5	18	62.1	0	1279.40	71.10	38	15	37		3							6	
6	24	61.8	0	1504.90	87.70	31	12	44						4			8	
7	32	71.8	1.2	1667.50	35.20	11	11	54	1	1							2	
8	41	33.3	0.3	682.30	10.80	4	1	52									1	
9	47	36.1	0.8	698.20	11.30	5		30										
10	50	43.3	1.6	799.40	7.30	9	1	50										
11	54	44.8	0.4	531.30	9.10	4		110									1	
12	59	47.5	0.7	488.30	4.70	8		90	1	1							1	
13	64	51.5	0.6	233.90				92									3	
14	68	66.6	0.7	146.90	24.10	1		85	1	1						1		
15	74	55.5	0.3	91.10	23.30	7		54										
16	82	57.5	0.3	46.40	13.40	1	1	64						5			1	
17	87	71.1	0.2	21.90	43.40			18									1	
18	93	71.1	0.3	1.00	21.60			57									1	
19	100	84.6	0.4		15.90	12	2	92									3	
20	106	168.7	0.5		44.20	1		81										
21	113	203.4	1.2		159.60	16	2	127				1				2	2	
22	120	184.2	0.9		86.50	9	3	94				1		4		2	3	
23	128	103.5	0.6		95.90	3	1	95									4	
24	133	225.1	2.1		137.50	18	12	144				3		1			6	
25	139	136.6	0.7		79.10	14	4	109	1	1	3	5		1			8	
26	147	128.9	1.3		80.70	13	10	111	7			1		7			9	
27	153	110.2	1.6		49.80	4		135	5			2		3			2	
28	158	226.6	1.5		142.40			257	15					6		1	5	
29	164					11		19				1					1	
30	172	143.5	0.4		16.00	6		118						5			4	
31	178	125.5	0.7		59.70	9		125									5	
32	184	178	1.6		329.10	13	1	122									1	
33	190	104.5	1.1		28.00	14		50	1							1	2	
34	196	165.5	1.4		130.50	26	1	98										4
35	206	229.5	0.9		222.30	7		100	1					3			1	1
36	217	195.5	0.8		250.40	88	7	51	5			1		1			6	2
37	225	155.5	1.9		439.40	125	28	113	19			20	3		11		4	
38	233	263	10.3		1920.00	141	8	248	13	1	19	76	3			3	4	4
39	243	269.3	14.6		2701.50	46	1	8	3		1	8		1				
40	243					127	1	57			9	56	6			1	2	2
41	243					117		79	6		1	5	2				3	2
42	250	150.5	1.6		76.40	24		6				11	1				3	
43	250					44		35	6			25	2				2	
44	258	171	2.4		17.20	9							1					
45	258					10	1	1	3			4						
46	265	175.5	6.6		2.80	1												
47	270	130.5	1			2						1						
48	279	312.5	4.7			1												
49	287	120	0.7			1												
50	294	236	0															
51	304	227.5	1.2															
52	312	198.7	0.7															
53	321	242.5	2.2															
54	333	286	26															
55	349	282	9.4															
56	366	239.5	4.2															
57	382	229.5	2.2															
58	399	197	15.6															
59	414	136.5	19.1															
60	431	150	14.8															
61	453	162.5	10.1															
62	240					90		60	11	3	1	5		1			2	

At the time of Roberts et al.'s (1998) publication and commentary, no calibration curve was available for radiocarbon dates greater than 11 ka, and hence the issue of underestimation of calendar years could not be resolved. A calibration curve is now available back to 50 ka (Reimer et al., 2013). The IntCal13 calibration curve results in a calibrated age for the 13.39 ka age (ANU-7006) of 15,001–17,429 cal BP, overlapping at 1σ with the TL age of 15 ± 3 ka (KTL-165) at equivalent depth. Kamminga and Allen's (1973) 18.04 ka age (SUA-265) calibrates to c. 22.4–21.0 ka, overlapping at 1σ with the TL age of 24 ± 5 ka (KTL-97) at equivalent depth. The 14.9 ka age (ANU-7007) provided by Roberts et al. (1998) calibrates to 18.5–17.8 ka, and remains within 1σ of the TL age of KTL-97. These new calibrations show that conventional radiocarbon years substantially under-estimate the ages of the sediments and that the calendar ages and luminescence ages are strongly correlated.

Several additional radiocarbon dates have been obtained by Smith and Jones (Table 1) since the last publication on MJB, increasing the number of available radiocarbon ages for the site to 13. With the exception of one anomalous age from the base of the sequence already discussed above (ANUA-9915), the additional ^{14}C

Table 2 (**continued**)
Site contents from the MJB 1989 excavation from the 6 mm sieve.

Mica	Ground ochre/ haematite	Axe flake/ frag	Convergent flake	Thinning flake	Ochre stained grindstone	Cylcon	Bifacial point	Grindstone	Ochred exfoliation from wall	Yellow ochre	Bipolar	Biface	Hammerstone	Redirecting flake	Core	Retouched flake	Total Artefacts
	1					1					3						66
	5									1	4						89
	1									1			1				61
	7							4							1		69
	9						2	3									108
	9	4							3	3	3						111
	4							1			1		1		1		84
	2										3						60
											1						35
											4						60
											3						115
								1			6						101
	1										9						96
	1	1						1			8						90
																	61
		1															72
																	19
											2						58
										2	2					1	111
										3	1					1	85
	4	1								3					1		157
	2	1								2							120
	4																107
	11	1?								1	1				1		196
					1?			1			1					2	146
	2	1?									2						160
		1								4	1						155
	1				1						5				1	1	285
	2									1					2	2	35
	1										6						134
											4						139
											4						137
	1																69
	2										1						127
	6																118
1	2														1		161
1	7	1	1	12						1		1		1	1		331
5	6		2	21							3					1	522
		1															68
1	1		4	11												1	260
2				3												4	213
	1		1	4												1	46
				7												2	114
																1	10
															3		19
																	1
																	3
																	1
																	1
			3	1				1			1					2	173

ages provide a picture of consistent depth-age relationships between radiocarbon and luminescence techniques down to 2 m bs. A test of the difference between the correlation coefficients for the linear regression slopes for ^{14}C and luminescence ages indicates no significant difference between slopes, indicating that both provide effectively identical age-depth relationships for the uppermost 2 m of deposit (Bayesian estimation of difference in means = 0.06, 95% HDI = −0.03, 0.15, the interval includes zero, indicating no credible difference). Concerns over the degree of fit between ^{14}C and luminescence chronologies for the upper half of the deposit can no longer be sustained (cf. Bowdler, 1990; Hiscock, 1990).

The full suite of available ^{14}C and luminescence ages for the site are shown in Fig. 5. The locally weighted regression line of best fit for these dates shows several changes in sedimentation rate but no obvious hiatus. Bayesian change point analysis indicates that sedimentation rates slow substantially from 2 m bs to the base of occupation (posterior probability of change is 0.924 at 22 ka) and then accelerate again below the lowest occupation (posterior probability of change is 0.912 at 65 ka). Sedimentation rates indicated by ^{14}C and OSL ages during the period 15–20 ka, just before the first major change in sedimentation rates, are not credibly different (Bayesian estimation of difference in means = 0.22, 95%

HDI = −0.75, 1.15, the interval includes zero, indicating no credible difference). Although there are no reliable ^{14}C ages older than 20 ka, the lack of difference in rates between the two methods before this time suggests that the change in sedimentation rates was a real event, rather than an effect of changes in the age-depth relationship between ^{14}C and luminescence methods. The depth-age curve also allows us to estimate the possible age of the lowest artefact from the 6 mm sieve as approximately 64 ka, and the base of the dense artefact layer as approximately 55 ka (though it must be acknowledged that the error ranges on these lowest luminescence ages are large). At present we take the 55 ka age as a more reliable indication of first occupation at the site. Non-local stone in the form of silcrete is present from Spit 47 (2.9 m bs), suggesting human activity at this level, but artefact numbers do not increase markedly until Spit 45.

5.3. Stone artefact analysis

One aspect of MJB that has been understated in published reports is the size and diversity of the artefact assemblage—and the pattern of technological change throughout the sequence.

Stone artefacts are present in every spit of the 1989 excavation at MJB (Fig. 6; Table 2). These show distinct pulses of accumulation, centred around 5, 7, 12.5, 18.4, 36.5, and 45–53 ka (Fig. 6). Between Spits 37–39 (2.2–2.4 m bs) there are 1900 flaked stone artefacts from the 6 mm sieve (including 41 of chert), numerous pieces of high-grade haematite (totalling 4.92 kg, including seven ground pieces), 143 g of red or yellow ochre, pieces of dolerite (presumed to be fragments of edge-ground axes), and fragments of grindstones; a further 568 flaked stone artefacts and 344 pieces of haematite were recovered from this level. All of these are associated with, or are slightly beneath, a TL age of 45 ± 9 ka. Beneath this, in levels dating 52 ± 11 to 61 ± 13 ka, there were an additional 82 flaked stone artefacts and 52 pieces of haematite recovered from the 6 mm sieve. From a trench measuring only 1 × 1.5 m, these materials represent a comparatively large assemblage.

Analysis of the MJB assemblage provides evidence for technological change through time (Fig. 8). The lowest band of occupation is dominated by silcrete and quartzite artefacts, and is overlain by an industry based on the bipolar working of white and crystal quartz; in turn, this is overlain by an assemblage in which chert and non-local quartzite were important (and were used in the manufacture of bifacial points). In broad terms, this industrial succession replicates the regional pattern in western Arnhem Land, though MJB has a longer sequence than most other sites and silcretes have never been mentioned before as a common raw material in the lowest assemblages. Recent inspection of the Malangangerr, Nauwalabila, Ngarradj Warde Djobkeng, and Nawamoyn assemblages confirms the hitherto unreported presence of silcrete (identified as quartzite in previous publications) in the lower spits at these sites as well.

The MJB lithic distributions reported here are valuable for supporting arguments about the integrity of the cultural stratigraphy. Stone artefacts are present in all spits above Spit 49 (2.87 m bs). A striking feature of the assemblage is the successive pulsing of different raw materials at different depths (Fig. 9). Substantial mixing of deposits would have blurred these pulses and made technological transitions more difficult to pinpoint. Fine-grained silcrete is present in the 6 mm sieve residue as a distinct pulse at the base of the deposit in both the 1972 and 1989 trenches (Fig. 9). Two sub-peaks are evident at the base of the deposit, one in Spit 42 (2.42–2.49 m bs) and another in Spit 40 (2.32–2.42 m bs) in the 1989 trench. Silcrete is an exotic raw material, presently of unknown origin, but known to be available in the upper reaches of the East Alligator River catchment near Jimeri (Schrire, 1982), and also observed by the authors in at least one location on top of the plateau above Jim Jim Falls. Inspection of the Nauwalabila (to the south) and Nawarla Garbarnmung (to the southwest) assemblages by CC and JM revealed that silcrete is virtually absent from the former and comprises only a very minor component at the latter (see also Matthews, 2013). Silcrete is absent in the 6 mm sieve residue at MJB between Spits 36–29 (2.05–2.26 m bs) and does not occur at all above Spit 21 (1.07–1.16 m bs; Fig. 9). Silcrete was therefore only selected for use from the earliest occupation until just after the LGM. The loss of silcrete from the record could reflect reductions in mobility, cessation of exchange networks, rising sea levels (if the source were located to the north), reductions in territory size, or change in the configuration of group territories. Unflaked schist and mica pieces (which we posit may have been ground to make sparkly paint) are also only present between Spits 34–41 (1.86–2.5 m bs) (see Table 2).

Above Spit 38 (2.22–2.32 m bs), quartzite and silcrete declines markedly and quartz dramatically rises in frequency (Fig. 9). Chert then peaks in Spit 28 (1.52–1.61 m bs) and declines above this. Quartzite frequencies, and especially very fine-grained quartzite, rise markedly in Spit 8 (0.36–0.42 m bs) and so too does chert, including a dark grey-to-black fine grained stone (Gerowie Tuff). Quartz declines as chert and fine quartzite rise again (Fig. 9). Silcrete remains absent in the uppermost spits despite the rise in non-local fine-grained stone.

Raw material changes are associated with technological change (Table 2), with the lower quartzite peak associated with freehand percussion and large flakes. Many of these large quartzite flakes are elongate and convergent in nature (Fig. 7: Nos 2, 3, 4, 7, 12, 14), and there are distal fragments of what may be unifacial points (i.e., pointed with retouch on the dorsal surface), one of which has a possible distal impact fracture (Fig. 8: Nos 3 and 13). Two large flakes have semi-radial dorsal scar patterns, and one also has a faceted platform, making it reminiscent of a Levallois flake. Several other large flakes also have faceted platforms, hinting at the existence of prepared core technology, although only one multiplatform quartzite core was found in the lower assemblage.

The lowest silcrete peak below Spit 39 (2.22–2.32 m bs) is associated with many small, thin flakes with tiny, lipped platforms, no cortex, and frequent platform preparation (Fig. 8). The ventrally curved nature of these flakes and their sometimes bidirectional dorsal scars suggest these may be thinning flakes of the kind typically associated with thinning points and bifaces. Some of these small flakes have faceted platforms suggesting they were struck from bifacially retouched edges. Several small possible unifacial point tips and a large biface are found in the assemblage, but these are not made from silcrete. Indeed, there is a very strong resemblance between these lowest thin silcrete flakes and a likely thinning flake found in Spit 5 from the uppermost assemblage associated with two bifacial points. The silcrete cores or retouched flakes that must have given rise to the many thinning flakes at the site have not yet been recovered, leaving the tantalising possibility that invasively flaked and thinned bifacial pieces lie unexcavated at the site or in other sites with levels of equivalent antiquity.

Volcanic flakes with ground portions on their dorsal surfaces are also found in the lower industry, in association with silcrete thinning flakes and quartzite convergent flakes. These flakes do not preserve a ground bevel, and hence it is not possible to confirm they are flakes from axes but this seems likely given that they occur throughout the sequence and in upper spits are found in association with complete axes and axe fragments. Volcanic stone is usually highly weathered in the lower assemblage, indicating that axes disintegrate over time. Ground sandstone flakes and fragments and grindstone fragments are also present in the lower industry, as further described below. In short, the MJB lower industry is unique in Oceania for the presence of such a large assemblage in the 45–55 ka period, and no industry of this kind (with convergent

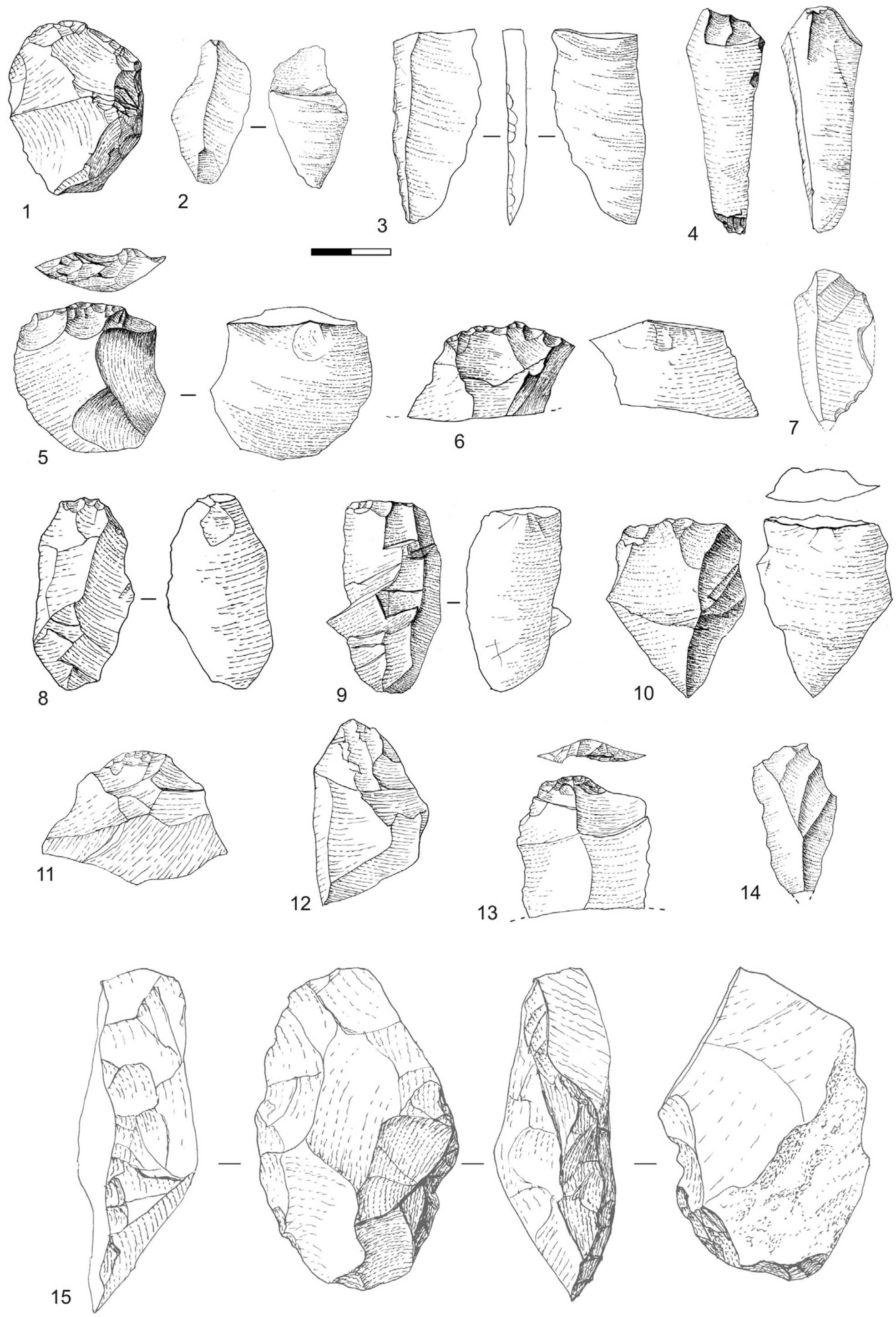

Figure 7. Large flakes from the base of MJB (Spits 38–45). 1: Large flake with semi-radial dorsal scars; 2: distal end (left) and proximal end (right) of convergent flake; 3: distal end of convergent flake; 4: convergent flake; 5: flake with radial dorsal scars and faceted platform ('Levallois-like'); 6: proximal end of flake with dihedral platform; 7: convergent flake with missing tip; 8: elongate flake; 9: elongate flake; 10: convergent flake with plain platform; 11: flake; 12: convergent flake; 13: proximal end of flake with faceted platform; 14: convergent flake with missing tip; 15: biface. All fine-grained quartzite except #5 (silcrete) and #15 (coarse-grained quartzite; drawings by Clarkson).

flakes, thinning flakes, possible points and bifaces) has ever been reported in Sahul at such great antiquity.

The substantive increase in quartz above Spit 38 is associated with a large increase in the frequency of bipolar technology and the complete disappearance of large convergent flakes of quartzite and silcrete thinning flakes. These distinct technological changes indicate that any possible mixing of sand from different levels has had minimal impact on what appear to be discrete phases of cultural deposition. The final phase of technological change, associated with the midden, sees a return to the use of fine quartzite over quartz, and the first use of Gerowie Tuff. Bifacial points and thinning flakes are found in the upper industry.

Variation in raw material and technology is evident within the lower industry, and the lens (i.e., Spits 41, 43, and 62) differs in assemblage composition from spits both above and below. This suggests that the lens artefacts are not simply derived from sediments excavated as Spit 40 and above but represent a slightly different mix of artefacts and raw materials (Fig. 10). The lens contains lower proportions of silcrete and chert and higher proportions of quartz to spits below, and higher proportions of quartzite and chert to those above. The lens also contains much higher proportions of convergent flakes, thinning flakes, and retouched flakes to spits above and below, relative to the total number of identified types in each assemblage. Chi square tests indicate that the differences in raw material proportions between all three assemblages are highly significant ($p = <0.0005$), although the differences in technological composition are not significant ($p = 0.60$), most likely due to small sample size ($n = 10$ for types in the assemblage below the lens). The comparison of assemblage composition between the lens and overlying and underlying sediments confirms the observation by the original excavators that the dense concentration of artefacts at 2.35 m bs is a discrete, and most likely anthropogenic, feature.

5.4. Use-wear and residue analysis

Microscopic examination of 119 of the lowest artefacts excavated in 1989 included 94 specimens from Spits 34–43, spanning a depth range from approximately 2.26–2.52 m bs and 25 specimens from Spit 62 (i.e., lens) deriving from 2.43 m bs. Residues are scarce, but signs of use occur on just over half (52%) of the examined specimens (Table 3). Pigment residues (smears and particles of

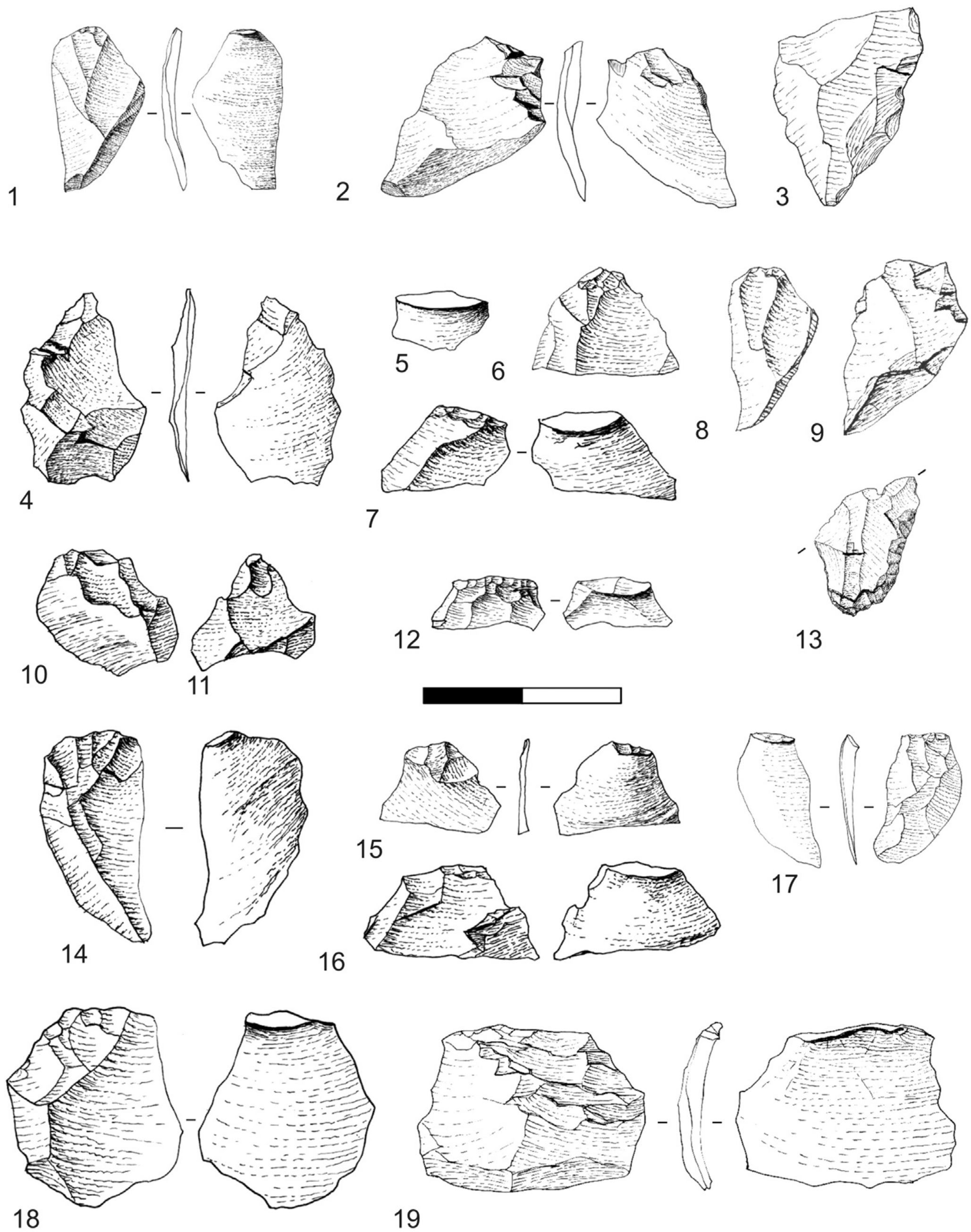

Figure 8. Small ('thinning') flakes and broken tips from unifacial and bifacial edges from the lowest spits (37–45) at MJB, except #17 which is from Spit 8. All silcrete except #17 (fine-grained quartzite). #3 is a broken tip from a possible unifacial point. #13 is a tip from a probable unifacial point with a possible impact scar (flute) originating from the crushed tip (drawings by Clarkson).

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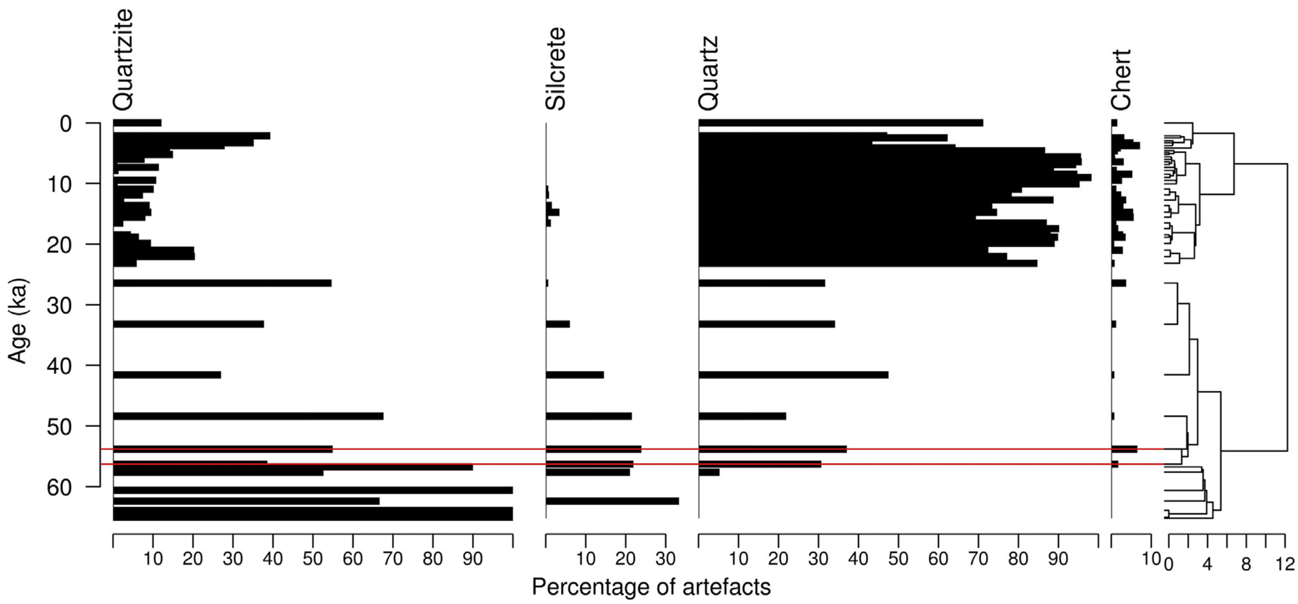

Figure 9. Raw material changes at MJB by interpolated age (from 6 mm sieve residue totals, 1989 excavation). The horizontal axis is percentage of all artefacts of each raw material. The thin red horizontal lines at c. 55 ka indicate the depth of the lens feature. The dendrogram to the right shows a stratigraphically constrained cluster analysis (Grimm, 1987). The dendrogram shows high-level clusters of spits for the upper and lower spits, and two clusters around the lens feature. This indicates distinct patterns of raw material preferences at different times of human occupation of MJB and highlights the dynamism of Pleistocene occupation with the changes surrounding the lens feature.

haematite and ochre) are common but most are unlikely to be linked with tool use because they are present on surfaces and edges that lack use-wear and probably derive from contact with haematite fragments during sieving and sorting. Grinding stones are rarely stained with haematite (although some specimens have discrete streaks of haematite, such as a fragment with a distinct streak from Spit 41 on display in the National Museum of Australia). Consequently, we conclude that grinding of pigment was

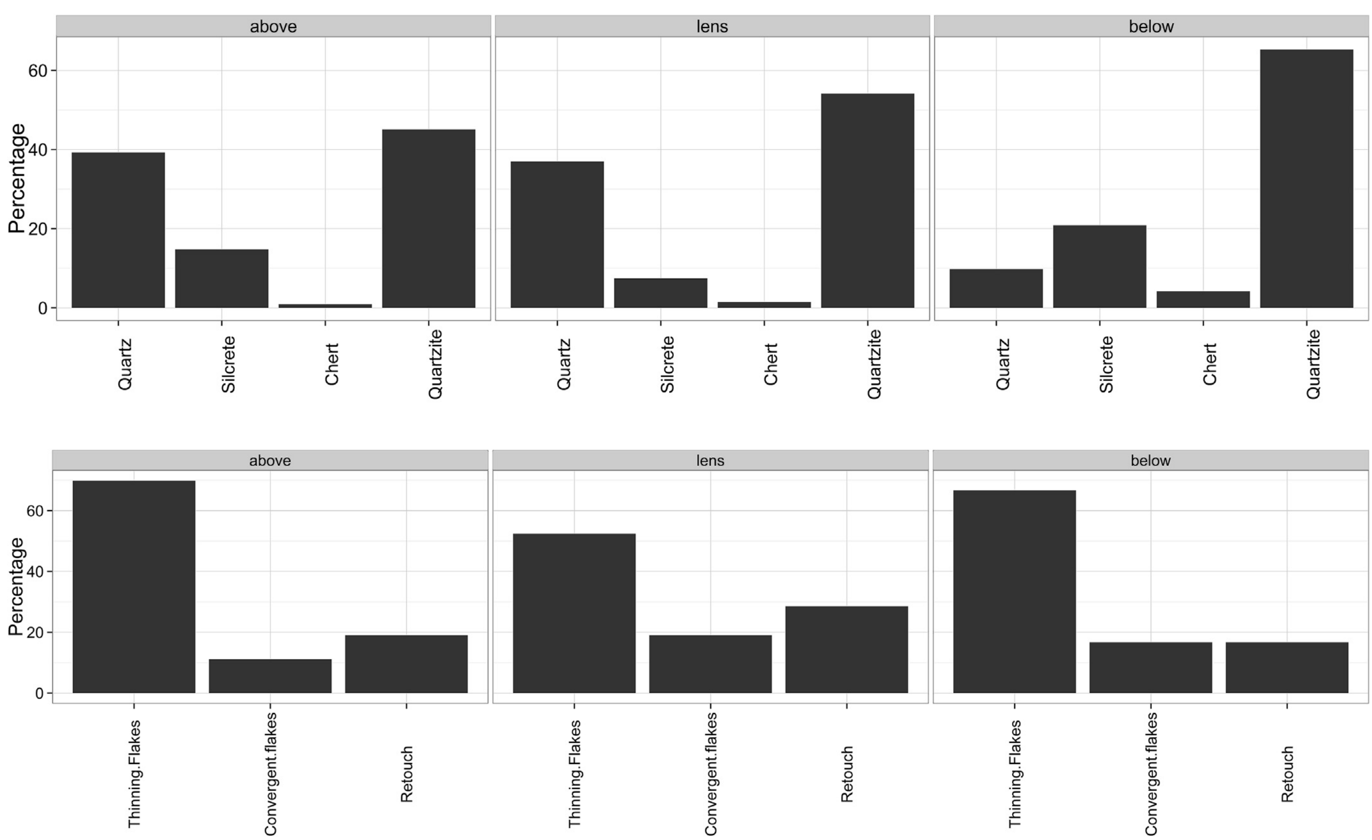

Figure 10. Differences in assemblage composition above and below the lens in the lower assemblage. Upper: raw material proportions within each zone; Lower: types (proportion of total types in each zone).

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Table 3
Artefacts selected for examination of use-wear and residues. Sample breakdown for preliminary functional analysis of MJB artefacts from Spits 34 and 43.

Technological class	Number of artefacts	% of artefacts examined ($n = 119$)	Number with traces of use
Core	1	0.8	0
Flake	94	79	42
Retouched Flake	9	7.6	8
Fragment	4	3.4	1
Grindstone	8	6.7	8
Haematite	2	1.7	2
Hammerstone	1	0.8	1
Total	119	100	62

performed at MJB but was not common. Preliminary microscopic analysis also found that wood-working was a likely activity, as indicated by characteristic use-wear on external platform edges. The high abundance of low-angled flakes with traces of use on the platform edge suggests that resharpening of tool edges was also common at the site (Hayes et al., 2014). Traces of stone on stone abrasion of the platform edge on silcrete thinning flakes, but no traces of use, are consistent with on-site shaping and implement manufacture rather than use (Hayes et al., 2014).

Fragments of ground volcanic artefacts, most likely axes, were found in Spits 38 and 39, dated to c. 45 ka based on the luminescence age estimates. The flakes are made from Oenpelli dolerite and hornfels (Fig. 11), the same raw materials used in the manufacture of intact axes found at Malangangerr and Nawamoyn dated to at least c. 20 ka (Schrire, 1982). The MJB volcanic artefacts are potentially the oldest evidence of ground axes manufactured in the world, some 10 ka older than those from Nawarla Garbarnmung (Geneste et al., 2012). They also provide evidence for the manufacture of complex artefacts, involving bifacial flaking, grinding, pecking, and hafting of the axe head to a prepared handle using thermoplastic resins. In recent times, Aboriginal people used axes for the extraction of difficult to obtain high ranked resources such as possums and honey in hollow tree trunks, and in the efficient shaping of large wooden tools such as spears, boomerangs, bowls,

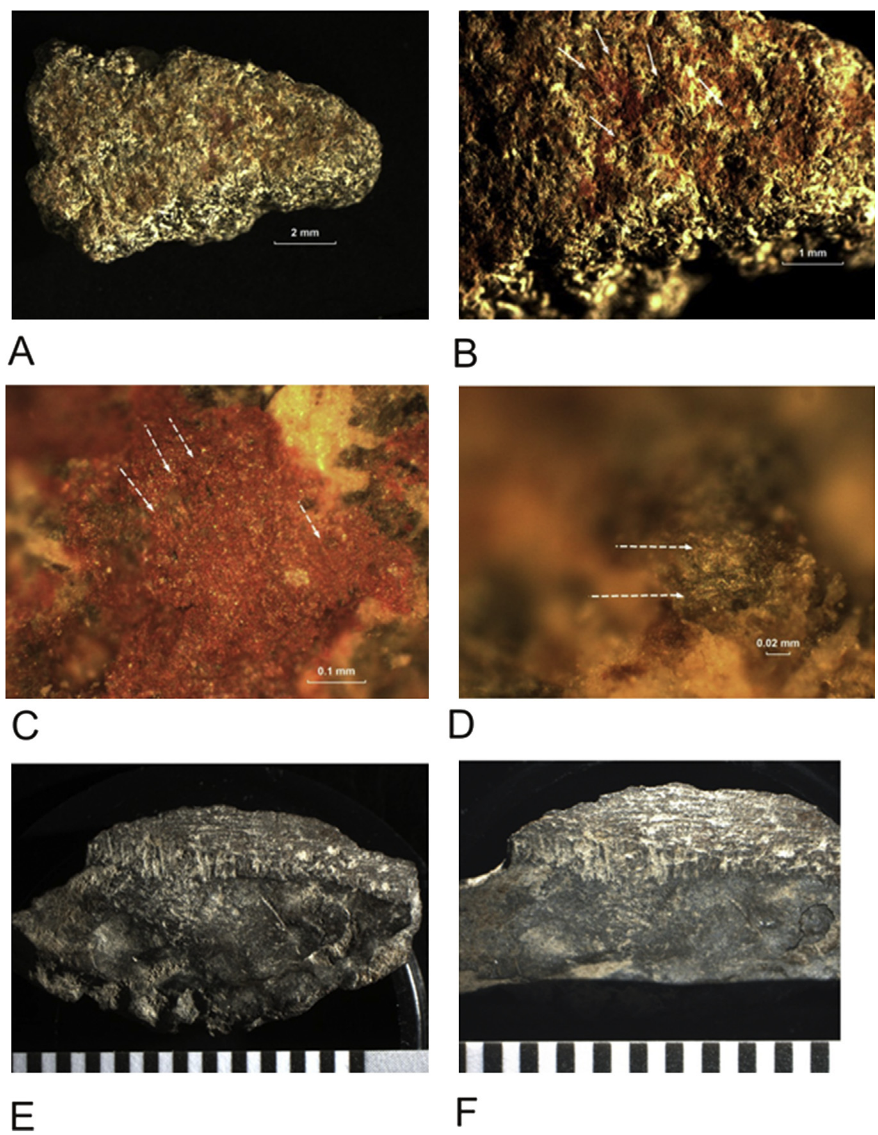

Figure 11. Volcanic flakes with ground surfaces from MJB interpreted as likely deriving from ground hatchet heads. (A) Ground dolerite flake, Spit 38; (B) detail of the ground surface of the dolerite flake from Spit 38; (C) fine striations (indicated by the white arrows) on and below a red surface residue on the Spit 38 ground dolerite flake; (D) polish and striations (indicated by white arrows) on the ground surface of the Spit 38 dolerite flake; (E and F) ground hornfels flake from Spit 39, note the pecking and numerous striations, probably from grinding on stone.

and shields (e.g., Brough Smyth, 1878:379; Dickson, 1976; Akerman and Bindon, 1984). Ethnographic evidence also clearly identifies axes as attaining highly ritualised, social, gendered, and mythological meaning in Australia (Brumm, 2010; Geneste et al., 2012). While we cannot extend such meaning into the distant past, the presence of axe fragments at MJB points to the existence of complex technical and symbolic behaviour surrounding these artefacts.

Grinding stones are intermittently present throughout the deposit and volcanic flakes with grinding on the dorsal surface are sporadically present from Spit 39/40 to the top of the deposit (Fig. 12). The grinding stone fragments are made from fine-grained sandstone, including some pieces clearly deriving from the back wall of the shelter. The surfaces of these fragments show levelling and smoothing of grain, striations, use-polish with alignments, collagen fibrils, and starch (Fig. 12).

5.5. Refits

In addition to evidence from residue survival, technology, and raw material changes, other lines of evidence suggest artefacts are likely to be in positions close to where they were originally discarded. Refits on microdebitage as well as larger flakes are an important means of demonstrating associations between artefacts sharing a common history, as well as discounting significant transportation of artefacts according to size class. Preliminary attempts at refitting artefacts from the 1989 assemblage found three pairs of refits on small-sized silcrete debitage in Spit 38 and 41 (Fig. 13). A refit was also found on a larger crystal quartz flake from Spit 43 at the base of the lens (Fig. 13). This refitted flake indicates that the lens contains material manufactured at that location and that these artefacts could not have moved far since their original deposition. This flake was longitudinally split as a result of excess force during percussion at the time of manufacture. Experimental evidence indicates that true longitudinal cone splits only occur during manufacture and do not occur as a result of trampling (Crabtree, 1972:4). Refits on cone-splits therefore provide a record of artefacts deposited close to one another at the time of manufacture. Transverse splits, on the other hand, could have taken place either at the time of manufacture or use, or from later trampling (Hall and Love, 1985). The transverse breaks do not show fresh fracture surfaces and did not take place at the time of excavation. We also found refitting pieces of ground haematite in Spit 28 whose weathered broken surfaces also reveal these are not excavation-related breaks (Fig. 13).

5.6. Fauna

Faunal remains are restricted to the midden and levels immediately below the midden where the infiltration of $CaCO_3$ provides the chemical conditions necessary for preservation of bone and teeth. The faunal remains in the midden represent a mix of estuarine/freshwater and sandplain/escarpment fauna. These include fish, reptiles (mostly in the form of turtle carapace and plastron, but also some material from medium-sized lizards), birds, marsupials (such as the common brushtail possum, *Trichosurus vulpecula*, and medium to large macropods like the agile wallaby, *Macropus agilis*), and a minor proportion of small rodents. The mammals (marsupials) appear to be more numerous deeper in the midden, but this needs to be confirmed through detailed analysis. Crustaceans, including crabs, are also present in the midden. The preliminary faunal analysis from the 1989 excavation indicates similarities to the faunal lists published by Schrire (1982) for the nearby sites of Malangangerr and Nawamoyn.

5.7. Shell

The data available from the 1989 shell assemblage (Spits 4–8) indicate a similar overall pattern to the rest of KNP, with the four

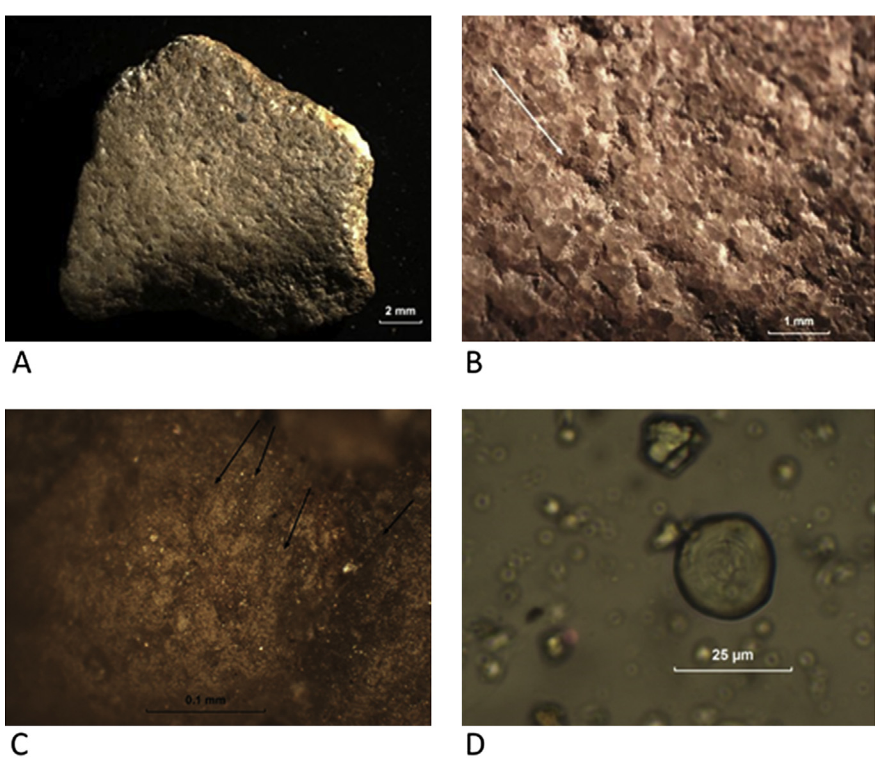

Figure 12. Grindstone fragment from Spit 62 (i.e., the rubble and artefact lens) of MJB. (A) fragment; (B) detail of surface smoothing and striation (indicated by the white arrow); (C) polish with striations (indicated by the black arrows) indicating direction of use; and (D) unidentified starch grain under plane-polarised light.

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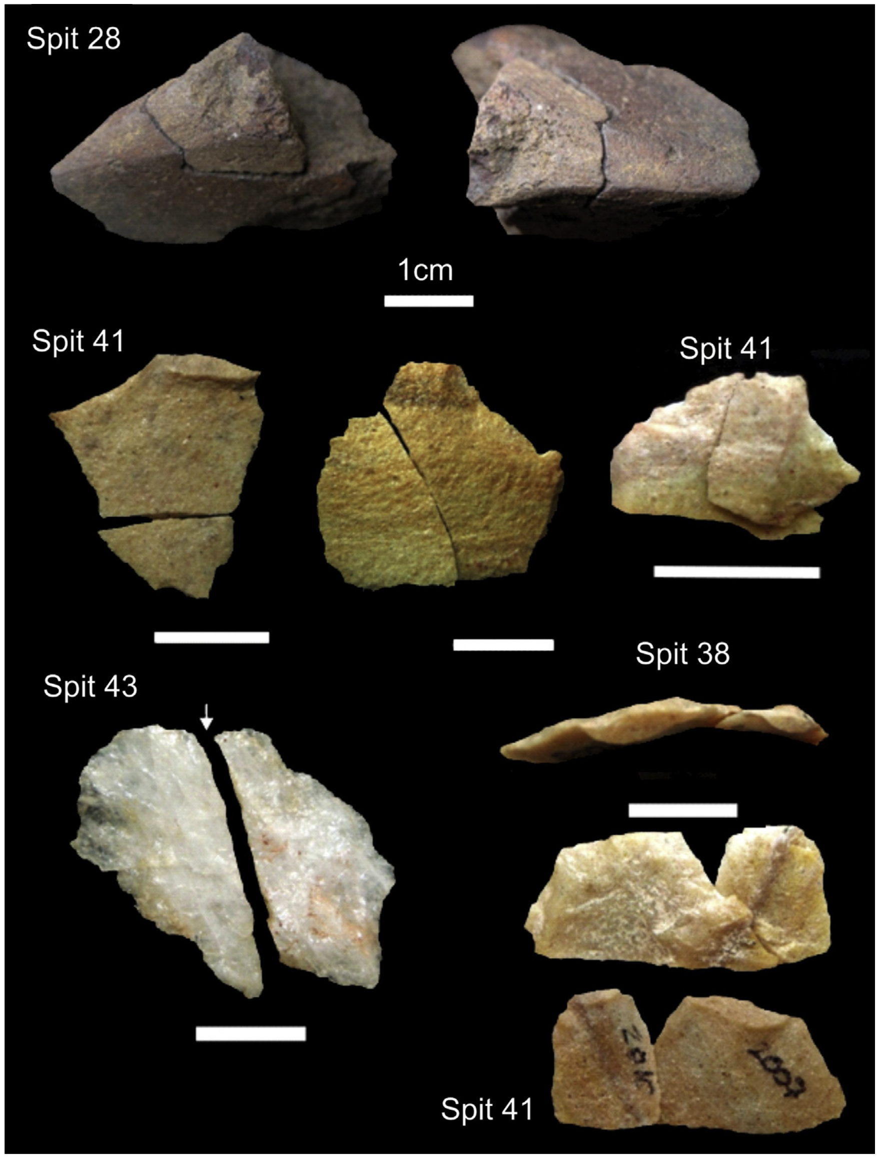

Figure 13. Refitting artefacts from the bottom few artefact bearing spits at MJB. Top row: refitting ground haematite, Spit 28. Middle row: (left) refitting broken silcrete thinning flake, Spit 41; (centre) refitting broken silcrete thinning flake, Spit 41; (right) two refitting silcrete thinning flakes, Spit 41. Bottom row: (left) refitting cone-split on quartz flake, Spit 38; (right) two sets of two refitting silcrete thinning flakes, Spit 41.

dominant species present. These are *Cerithidea* sp. (51.8% mass), *P. coaxans* (40.7% mass), *T. telescopium* (3.8% mass), and *Nerita* sp. (3.7% mass; Table 4). This supports previous suggestions that people commonly exploited the mangrove fringes during this period of midden deposition in shelters across the region (Allen, 1987:5, 1989:109, 1996:198; Allen and Barton, 1989:104; Hiscock, 1999:93–94).

Temporal changes in mollusc species composition were reported by Schrire (1982) for Malangangerr, Nawamoyn, and Paribari (based on taxa mass per excavation unit). Within these sites there was a change from *P. coaxans* and *T. telescopium* in the lower midden levels to *Cerithidea* sp. towards the top (Schrire, 1982:51, 87–89, 120–122, 233; Hiscock, 1999:94), a shift that may reflect environmental factors, including a change in mangrove species and therefore habitat availability during the Big Swamp phase (Allen and Barton, n.d.:135; Hiscock, 1999:95–96). In contrast, Allen and Barton (n.d.) suggested that *Cerithidea* sp. was the dominant taxon throughout the Ngarradj Warde Djobkeng midden, with *P. coaxans* more common in the lower levels of the midden due to differential preservation. These contrasting trends might indicate localised differences in the nature of mangrove environments or differential use of the landscape during this period (Allen, 1987; Hiscock, 1999).

Temporal changes in mollusc species composition at MJB (Fig. 14) broadly fit the patterns noted above for Malangangerr, Nawamoyn, and Paribari. By mass, *Cerithidea* sp. increases from the base of the midden to Spit 6, followed by a decline into the upper portions of the deposit. *Polymesoda coaxans*, while slightly more abundant in Spit 8, decreases in abundance relative to *Cerithidea* sp. through Spits 7–5, with an even mass distribution of both taxa in Spit 4. *Nerita* sp. declines slightly throughout the deposit, and *T. telescopium* increases slightly into Spit 7 relative to the decrease in *P. coaxans*, gradually declining throughout the remaining spits. When viewed as %mass per spit, the trends observed for *T. telescopium* and *Nerita* sp. do not change; however, *Cerithidea* sp. increases from 37.6% in Spit 8 to consistently occur at 55.1–57.3% through Spits 7–5, with a slight decrease to 50.1% in Spit 4. In

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Table 4
Abundance of the four dominant taxa recorded in the MJB midden by mass (g), including % mass (in brackets).

Excavation unit	*Cerithidea* sp.	*T. telescopium*	*P. coaxans*	*Nerita* sp.	**Total**
DE30/4	315.5 (50.09)	9.5 (1.51)	304.9 (48.4)	–	**629.9**
DE30/5	783.4 (57.26)	9.1 (0.67)	556.8 (40.7)	18.8 (1.37)	**1368.1**
DE30/6	939.9 (55.06)	48.0 (2.81)	704.2 (41.25)	15.0 (0.88)	**1707.1**
DE30/7	589.2 (55.76)	113.5 (10.74)	292.0 (27.63)	62.0 (5.87)	**1056.7**
DE30/8	424.2 (37.57)	42.0 (3.72)	539.8 (47.81)	123.1 (10.9)	**1129.1**
Total	3052.2 (51.81)	222.1 (3.77)	2397.7 (40.7)	218.9 (3.72)	**5890.9**

contrast, *P. coaxans* decreases from 47.8% in Spit 8–27.6% in Spit 7, followed by a gradual increase to 48.4% into Spit 4. This suggests that while there was a decrease in *P. coaxans* relative to an increase in *Cerithidea* sp., similar to that noted in other deposits, *P. coaxans* increased through time to relatively equal abundance prior to cessation of midden formation at MJB. While these trends require more detailed investigation, the available data from MJB might again reflect local variability in mangrove environments and/or a different use of the landscape and available resources (Hiscock, 1999).

5.8. Art

Madjedbebe provides some of the earliest evidence known in Australia for the processing of red pigments (cf. Roberts et al., 2001:153; David et al., 2013). Ground ochre and haematite were found in the MJB deposit in Spit 42 (2.42–2.49 m bs), associated with the 52 ± 11 ka TL age. The presence of ground pigment throughout the sequence indicates substantial continuity in this aspect of the assemblage. The presence of ground pigment traces on grindstones throughout the deposit also points to the production of pigment powder. Although the exact use of these ground pigment objects is unknown, further study of their origins, use actions, and contact surfaces may shed light on early artistic activities.

6. Conclusion

This reanalysis and review of data from the 1973 and 1989 excavations at MJB shows that the site preserves a detailed sequence of industrial succession and palaeoecological change overlapping with the regional pattern evident in other western Arnhem Land archaeological sequences. There is little to indicate that the process of displacement of artefacts or post-depositional disturbance to the deposit is exceptional at this site. Indeed, any post-depositional movement of sand appears to have had little impact on the integrity of the discrete cultural units, even at the lowest levels of occupation.

The major outstanding issue is the level of resolution in age-estimation that can be achieved for the initial occupation levels and, in particular, whether any material can be confidently assigned to the period before 45–46 ka. To return to the first specific question we asked in the introduction, based on current evidence, a date of 50–55 ka BP is likely to be a conservative age estimate for the lower occupation at MJB. At the 45–55 ka level there is a dense horizon of occupation debris and there are in situ artefacts below

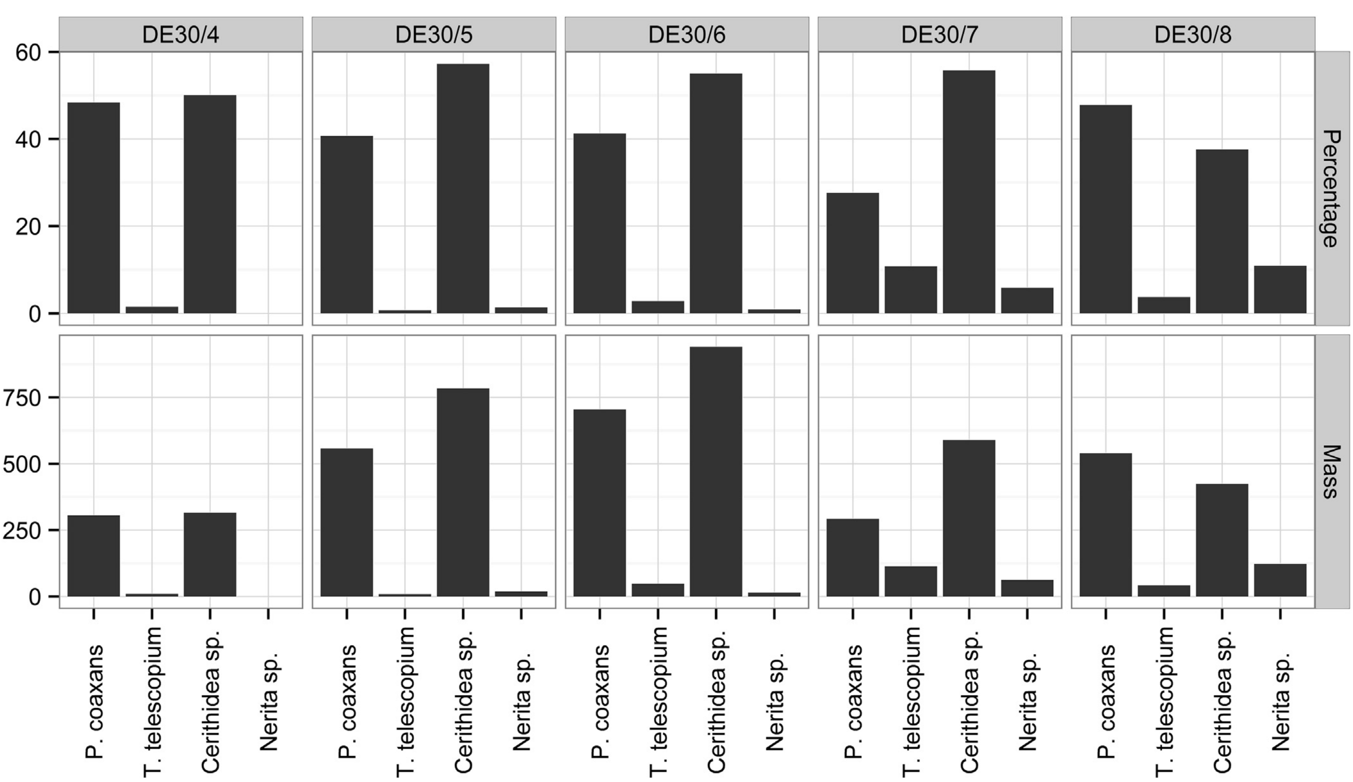

Figure 14. Mass (g; lower) and %mass (upper) of the four dominant taxa recorded in the MJB midden.

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this level. The new data presented here support the status of MJB as among the oldest archaeological sites in Australia. However, the key issue therefore is whether a more tightly provenanced series of luminescence ages, using an OSL technique that reduces uncertainties on individual age estimates and assesses any mixing of sand from different levels, will provide a fine-grained chronology capable of providing a high resolution age-depth curve for levels from 2.4–2.9 m bs. Alongside this, there is a need to further assess intrinsic differences between assemblages at the 45 ka levels and the material from earlier levels over a larger area across the site.

Our second question, about cultural change over time, has been addressed by examination of the assemblages above and below the lens at 2.39 m bs, which suggests the levels below 45 ka (i.e., below Spit 40) show differences in raw material and technological composition, including a discrete and technologically differentiable lens feature. Stone artefact raw material preferences show stark changes over time, with quartzite and silcrete dominant in the early phase and quartz and chert dominant in the later phase. These changes in raw materials are also associated with technological changes, such as ground-edge artefacts, convergent and radial flakes, and thinning flakes in the lower levels and points in the upper levels. Further analysis of the spatial structure of the lowest occupation is one of the priorities for analysis of the 2012 excavation. We have also described a major change in site use with the appearance of a shell midden in the Holocene, reflecting adaptation to local variability in mangrove environments and/or a different use of the landscape and available resources following sea level rise and landscape evolution in the mid-Holocene.

Critiques of the MJB site, following the brief 1989 excavation report, largely sought further clarification of dating, artefacts, and stratigraphy. Presentation of the new analysis here allays some of the original doubts surrounding possible inversions and downward displacement of artefacts. Re-examination of the unpublished ages, field notes, and lithic assemblage from the 1989 MJB excavations has resolved several issues critical to understanding the chronology, composition, and formation of the site. Returning to our third question about the implications of the archaeological data for understanding post-depositional disturbance and artefact movement, we have evidence of major changes over time in raw material preferences, which would not be visible if the deposit was highly disturbed. We also have been able to refit flakes within three spits in the lower deposit, suggesting that these spits have not been highly disturbed. While these results are insightful, a robust response to concerns about the age and integrity can only be provided with field collection of additional materials. Because this site saw one of the earliest applications of luminescence dating to an Australian site and the OSL dating technique has undergone significant technological and methodological developments since that time (see Jacobs et al., 2008; Wintle, 2008), there is now an urgent need to re-date MJB using modern luminescence dating techniques, as is currently underway with samples from the 2012 excavation.

While the new excavation campaign will reveal much more about the structure and formation of the deposit, as well as obtain a much larger sample of artefacts, it is possible to deduce from the material excavated in 1989 that the site contains intact succession of industrial changes, a consistent ^{14}C and OSL chronology, a record of ecological changes in the Holocene consistent with the Arnhem Land sequence documented at other sites, and the presence of artefact refits and cultural features in the lower layer. While all sites should be expected to show some degree of mixing consistent with deposition in a predominantly sandy matrix, we see no a priori reason to suggest that the MJB artefacts are heavily disturbed or seriously mixed. We await the results of the new dating campaign as well as new geoarchaeological investigations, such as micromorphology, to examine and refine our understanding of site formation and chronology.

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Supplementary Online Material

Supplementary online material related to this article can be found at http://dx.doi.org/10.1016/j.jhevol.2015.03.014.

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