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Murujuga Rockshelter: First evidence for Pleistocene occupation on the Burrup Peninsula

Jo McDonald [a,*], Wendy Reynen [a], Kane Ditchfield [a], Joe Dortch [a], Matthias Leopold [b], Birgitta Stephenson [c], Tom Whitley [a,d], Ingrid Ward [a], Peter Veth [a]

[a] *Centre for Rock Art Research and Management, School of Social Sciences, M257, The University of Western Australia, Perth, WA, 6009, Australia*
[b] *School of Agriculture and Environment, M079, The University of Western Australia, Perth, WA, 6009, Australia*
[c] *In the Groove Analysis Pty Ltd, 16 Charlane Avenue, Indooroopilly, QLD, 4068, Australia*
[d] *Anthropological Studies Center, Sonoma State University, 1801 East Cotati Avenue, Building 29, Rohnert Park, CA, 94928, USA*

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ABSTRACT

The Dampier Archipelago (including the Burrup Peninsula), now generally known as Murujuga, is a significant rock art province in north-western Australia which documents the transition of an arid-maritime cultural landscape through time. This archipelago of 42 islands has only existed since the mid-Holocene, when the sea level rose to its current height. Previous excavations across Murujuga have demonstrated Holocene occupation sequences, but the highly weathered rock art depicting extinct fauna and early styles suggests a far greater age for occupation and rock art production. The archaeological record from the Pilbara and Carnarvon bioregions demonstrates human occupation through 50,000 years of environmental change. While the regional prehistory and engraved art suggests that people were producing art here since they first occupied these arid rocky slopes, no clear evidence of Pleistocene occupation has been found across Murujuga, until now. Murujuga Rockshelter (MR1) reveals that occupation of this shelter began late in the Last Glacial Maximum, when the Murujuga Ranges would likely have served as one of a network of Pilbara refugia. In the terminal Pleistocene/Early Holocene, and likely in tandem with the last stages of sea level rise, the proportion of artefacts manufactured on exotic lithologies declines sharply, revealing a changed foraging range and increasing territorial focus in this period of increased demographic packing as the coastline advanced. Abandonment of the site as early as 7000 years ago is indicated, suggesting a changing resource focus to the increasingly proximal coastline. This paper provides the first evidence of how Aboriginal people adapted their Pleistocene procurement strategies in response to significant environmental and landscape changes in Murujuga. This changing logistical strategy provides an explanation for the increased rock art production in the terminal Pleistocene/Early Holocene.

1. Introduction

The estimated one million petroglyphs of the Dampier Archipelago include many thousands of motifs that are highly weathered and include locally extinct fauna, as well as an extensive repertoire of marine-themed rock art. This diachronic evidence for changed art production has prompted speculation that some of the rock art dates back to the first human occupation of the Australian continent from 50 ka (Balme et al., 2009; McDonald and Veth, 2009; Mulvaney, 2015; Veth et al., 2017). Our current project *Murujuga: Dynamics of the Dreaming* – is testing this possibility through archaeological excavations targeting prospective Pleistocene landscapes and deposits across the archipelago. These excavations had the dual aim of dating both Pleistocene occupation deposits and potentially any early rock art that may be uncovered through such excavation.

Previous attempts to date occupation have focused on shell middens which provide detailed stratigraphic sequences, but mostly date to the mid-Holocene (Clune and Harrison, 2009; Vinnicombe, 1987). Rock art has been found in reliable stratigraphic contexts and dated to 3.5 ka (Lorblanchet and Jones, 1980). The oldest dated shell middens (9.5 ka) are on Rosemary Island, at a

* Corresponding author.
E-mail address: jo.mcdonald@uwa.edu.au (J. McDonald).

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time when sea levels were c.15 m lower and this place was then a transgressive shoreline and part of the mainland (Bradshaw, 1995; McDonald and Berry, 2016). The archipelago contains very few rock shelters and consequently few protected archaeological deposits and also experiences extremely slow weathering regimes due to the resistant local volcanic geology. Potential and deep archaeological deposits are thus sparse.

This paper details the excavation of the largest known rockshelter on the archipelago; a shelter below a giant granite tor, at the junction with granophyre geology. The sheltered area affords a medium-sized liveable floor area. The site is located within an interior valley 1 km from the current southern shoreline of the Burrup Peninsula, facing towards the solar salt ponds which have been constructed in the shallows between what was Dampier Island and the mainland (Fig. 1). The nearest semi-permanent waterhole is located 400 m distant in an upland valley, but there is a gully adjacent the site which would flow with water after rain. There is no rock art in the immediate vicinity of the rockshelter, but motifs have been recorded less than 100 m upslope in the adjacent gully.

1.1. Formation of the Dampier Archipelago

The Ngarda-Ngarli people of the Dampier Archipelago believe that they have lived here since time immemorial (Mardudhunera Yaburara et al., 2004) and that Ancestral Beings created Murujuga during the Dreaming. Natural features such as the Marntawarrura ("black hills") are said to be stained from the blood of the creative beings, while some petroglyphs are seen to be images left by the ancestral beings (Robinson, 1997:4; Palmer, 1975).

The islands of the Dampier Archipelago represent an inundated coastal plain within the Pilbara bioregion. The archipelago formed when rising sea levels flooded the North West Shelf between 8000 and 6000 years ago. While the archipelago's formation is a relatively recent event, the underlying geology is some of the oldest on earth, formed by Archean volcanic activity more than 2400 million years ago (Pillans and Fifield, 2013, 2014). The striking igneous block structure across the Dampier Archipelago forms numerous ridgelines, valleys, gorges and rocky platforms, which are covered in engraved art, but with very few rockshelters. The Dampier Archipelago's volcanic geology provides a different canvas – and archaeological preservation environment – to the deep occupational history found on offshore Barrow and Montebello Islands (Fig. 1). These islands of the adjacent Carnarvon Bioregion are predominantly Quaternary and Tertiary limestones which provide excellent shelter formation opportunities as well as good preservation of deep-time archaeological and economic sequences (Veth et al., 2007, 2017). The geological differences between these study areas are significant. No rock art has been discovered on Barrow or the Montebello Islands to accompany this deep human time sequence. And until now, no rockshelter excavations on the Dampier Archipelago have provided a deep time sequence for human occupation to accompany the earliest rock art production.

Sea levels were at their lowest – at 130 m lower than today – during the Last Glacial Maximum (LGM). Quantitative estimates of precipitation and temperature levels from local marine core data suggest the period between 33 ka and 20.4 ka represents the driest climatic period in the past 100,000 years (van der Kaars and De Deckker, 2002; see also Slack et al., 2009; Williams et al., 2009: 2410) and that this continued until c. 19 ka (Lewis et al., 2013). At this time regional sea level curves indicate that the coast was 160 km distant (Ward et al., 2013). As the climate warmed, the marine transgression brought the coastline ever closer to what was once the 'Dampier Ranges' (Fig. 2a). By 10,000 years ago the coastline was approaching what is now Rosemary Island (Fig. 2b). A *Terebralia* midden excavated at Wadjuru Rock Pool (Fig. 1) demonstrates the exploitation of mangrove resources at this time (Bradshaw, 1995; McDonald and Berry, 2016), with ongoing work on Rosemary and Enderby Islands by the *Murujuga: Dynamics of the Dreaming* project illustrating that this occupation was part of a complex set of human behaviours which included art production and stone structure construction. Evidence for Pleistocene economies has been recovered from both the Montebello Islands (Veth et al., 2007) and Boodie Cave on Barrow Island, including the earliest dated marine economy at Boodie Cave between c.50 ka – 45 ka and a significant 10-fold broadening of marine and desert terrestrial species after the after Glacial Maximum between 14 and 8 ka (Veth et al., 2017). A significant observation for Murujuga is that the Pleistocene coastline was likely always productive for coastal foragers with evidence for marine economic dietary fauna being registered when the sea is within c. 15 km of occupied sites (Manne and Veth, 2015; Veth et al., 2017). At both Boodie Cave and Wadjuru Pool (McDonald and Berry, 2016) people engaged in broad-spectrum, energy-intensive activities long before the mid-Holocene. Until now, the exposed blocky granophyre landscape of Murujuga has provided little credible evidence from this period.[1]

Continued sea-level rise brought a plethora of new marine resources to the forming Dampier Archipelago. By 7.7 ka, large embayments had formed and a narrow channel separated a 'mega' Rosemary Island from Enderby and the Lewis Islands, which at this time were still connected to the mainland (Fig. 2c). Mangrove forests were extensive at this time due to the changed tidal and sedimentary regime (Morse, 1993; O'Connor, 1999; Semeniuk, 1983; Semeniuk and Wurm, 1987; Veth et al., 2007; Woodroffe et al., 1985). At this time Murujuga Rockshelter was on a peninsula which included Legendre Island. By c. 3.5 ka, the archipelago adopted its present configuration (Fig. 2d).

1.2. Human occupation of Murujuga in the Pleistocene and Holocene

Prior to this work, the only evidence that people had visited Murujuga in the Pleistocene was from a single *Syrinx* shell, dated to 22.5 ka, found wedged between rocks by Lorblanchet (1992) during his excavation at Gum Tree Valley 10 km to the south-west of Murujuga Rockshelter (Fig. 1). The age is a maximum age for transport, which could have occurred well after it was collected from an extant shoreline from this time period. Given the shoreline's distance and the fact that this would have been drowned once sea-levels began to rise at the end of the LGM, it is reasonably assumed that even if this was an heir-loomed shell, it must have been transported to the Murujuga Ranges during the Pleistocene.

Mangrove habitats and hence species abundance in the north-west appear to have declined around 4000 years ago and shell middens reveal that people switched their economic focus to a range of rocky shore, mudflat and sandy beach shellfish (Lorblanchet, 1992; Clune, 2002; Clune and Harrison, 2009). This switch is best exemplified by the change of focus from *Terebralia* species to (predominantly) *Anadara granosa*. Anadara mounds, presumably Mid-Holocene and up to 5 m in height and 300 + m in length, occur on West Intercourse Island (Fig. 1). As yet, none of these mound middens have been excavated. All Burrup shell

[1] Visualizations of possible past environments and shoreline changes are carried out by processing topographic and bathymetric terrain models and sea level rise models (Lambeck et al., 2014; Siddall et al., 2003; Waelbroeck et al., 2002; Yokoyama et al., 2001) in ArcGIS 10.4.1 (ESRI, Inc, 2017), and applying the results to photorealistic scenery-generator software (Terragen 4; Planetside Software, Inc. 2017).

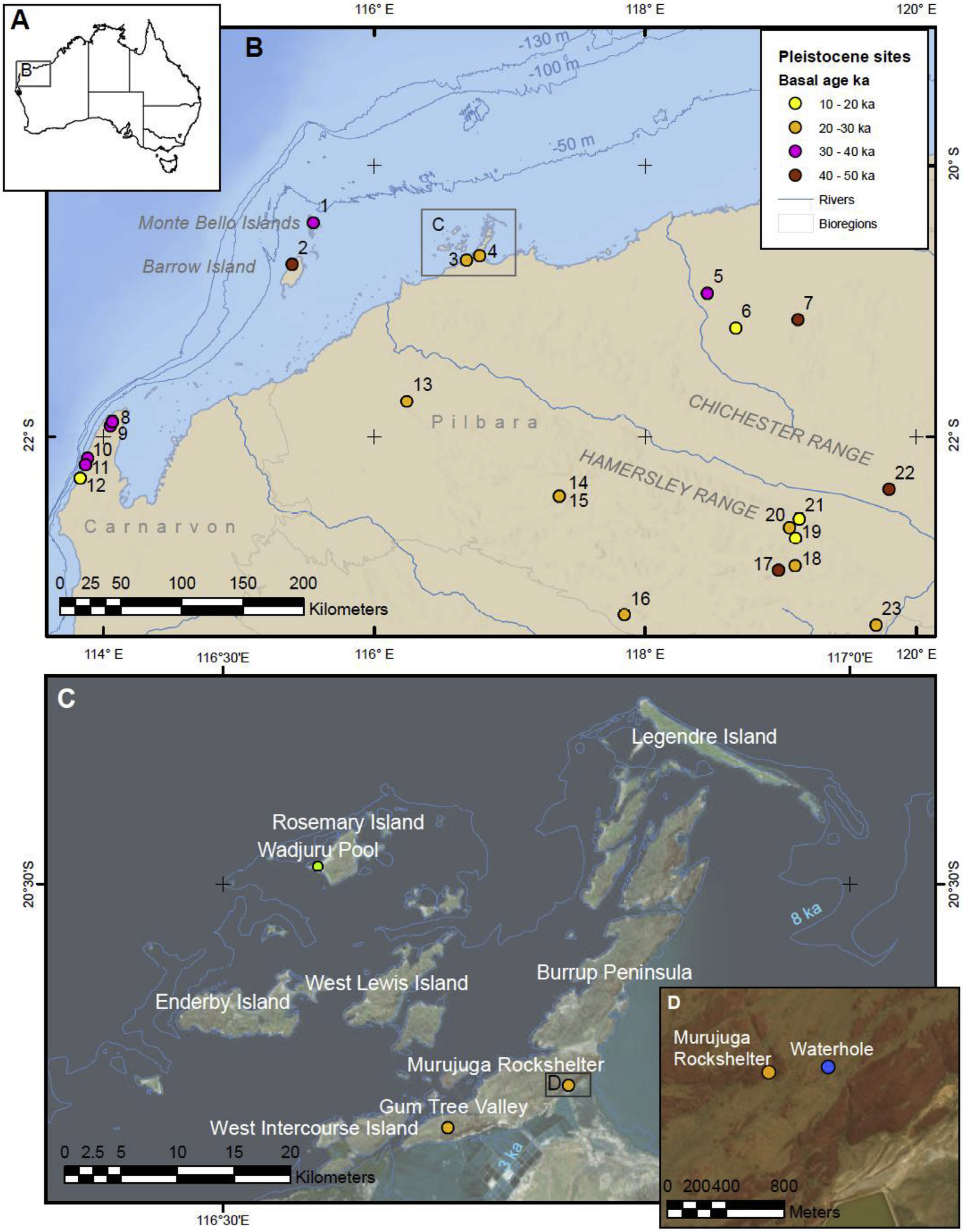

Fig. 1. Murujuga Rockshelter in regional context - (A) Australia showing location of north-western sites; (B) published north-western sites with evidence for Pleistocene occupation (see Supplementary Material for site index and references); (C) the Dampier Archipelago and places mentioned in the text; (D) location of rockshelter and nearest known water source, and current shoreline, now within a solar salt pond.

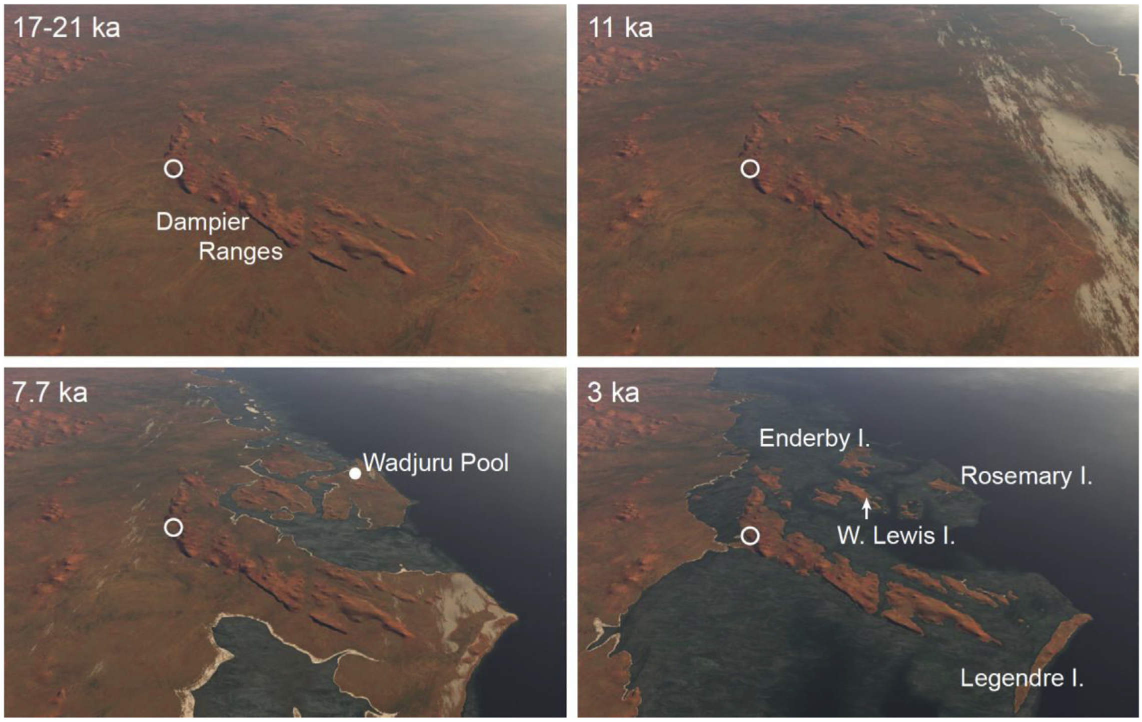

Fig. 2. Murujuga Rockshelter (location circled) at significant times during and after its occupation. Projected coastline and coastal plain at the four periods discussed throughout this paper based on Bayesian analysis and the recent bathymetric modelling. View to south-west.

middens excavated so far indicate Mid-Late Holocene exploitation of a range of resources (Lorblanchet, 1992; Vinnicombe, 1987). Exploitation of land animals such as euro (*Macropus robustus*), rock wallaby (*Petrogale rothschildi*), flying fox (*Pteropus alecto*) and quoll (*Dasyurus hallucatus*) has been documented, as well as an extensive range of marine fauna such as a variety of fish, dugong (*Dugong dugon*), turtles, crabs and birds.

The sundering of islands off the Australian coast often resulted in human abandonment for many millennia (e.g. O'Connor, 1999; Sim and Wallis, 2008). The outer islands of Murujuga – located 20 km off-shore – are potentially distant enough to have made long-term residential occupation more difficult. Rosemary and Enderby Islands, on the outer rim of the archipelago, were cut off by continued rising sea levels by 7.1 ka (Lewis et al., 2013). These islands provide an opportunity to explore early Holocene island use and – unlike Barrow and the Montebello Islands – art production at this time. The distance between Rosemary and Enderby Islands and their nearest landfall in the Dampier Archipelago (5 and 3 kms respectively) is minor compared with the c. 50 km distance to Barrow Island from the current coast. Without specialized water craft, a 50 km sea crossing would have prevented casual and continued occupation by social groups (Bailey et al., 2007) which has been confirmed by the excavations at Boodie Cave (Veth et al., 2017). Previous sporadic recording of art on the outer islands of the Archipelago (Dix, 1977; McDonald and Veth, 2006) indicated lower levels of recent rock art production. Current systematic survey recording and dating (e.g. McDonald and Berry, 2016), however, demonstrates a complex signature of symbolic behaviour and archaeological evidence on these outer islands during the Holocene.

Mulvaney's (2015) seven-phase art sequence predicts that art was produced at Murujuga from the earliest occupation of the region, and a model for Murujuga art production and occupation indices suggests how these different art phases may be correlated with broad environmental events (McDonald, 2015). Evidence from Barrow and the Montebello Islands (Veth et al., 2014, 2017), located c.90 km to the west from Murujuga, offer an occupation proxy for late Pleistocene coastal behaviours across what would have been a shared cultural landscape. The highly resistant weathering properties of the Dampier Archipelago's geology (Pillans and Fifield, 2013), provides the deep-time canvas for the range of symbolic and social behaviours also being practised across this north-western coastal plain.

2. Excavation at Murujuga Rockshelter

Murujuga Rockshelter is located below a large granite tor on the central-southern Burrup Peninsula. In 2014, with permission from the Murujuga Aboriginal Corporation (MAC) and support from Rio Tinto, two of us (JM and PV) undertook a 1×1 m test-excavation here (square A6; Fig. 3). This excavation revealed stratified evidence of human occupation. In July 2015, the *Murujuga: Dynamics of the Dreaming* team, after further consultation with the MAC Circle of Elders (CoE), completed excavation in square A6 and extended this to squares A5 and B5 (Fig. 3).

Excavation at Murujuga Rockshelter followed established archaeological techniques. Sediment was removed with trowels and brushes: a cold chisel was deployed (at the base) in the heavily compacted clays. All three $1 \text{ m} \times 1 \text{ m}$ excavation squares were excavated to bedrock. The deposits were excavated in 2–5 cm excavation units (XUs) or according to stratigraphic breaks (whichever was smaller), and all sediments sieved through nested 4 mm and 2 mm sieves. The excavation team recorded Munsell colours and pH in the field and collected c.100 g sediment samples from each XU. Stratigraphy was identified from wall sections and drawn at 1:10 scale. Sediment samples were collected for optically stimulated luminescence (OSL) dating by driving 35 mm diameter steel tubes into the southern wall of the final excavation square. These were sealed at both ends with plastic packing, metal caps and tape. Additional sediment and rock samples for dosimetry

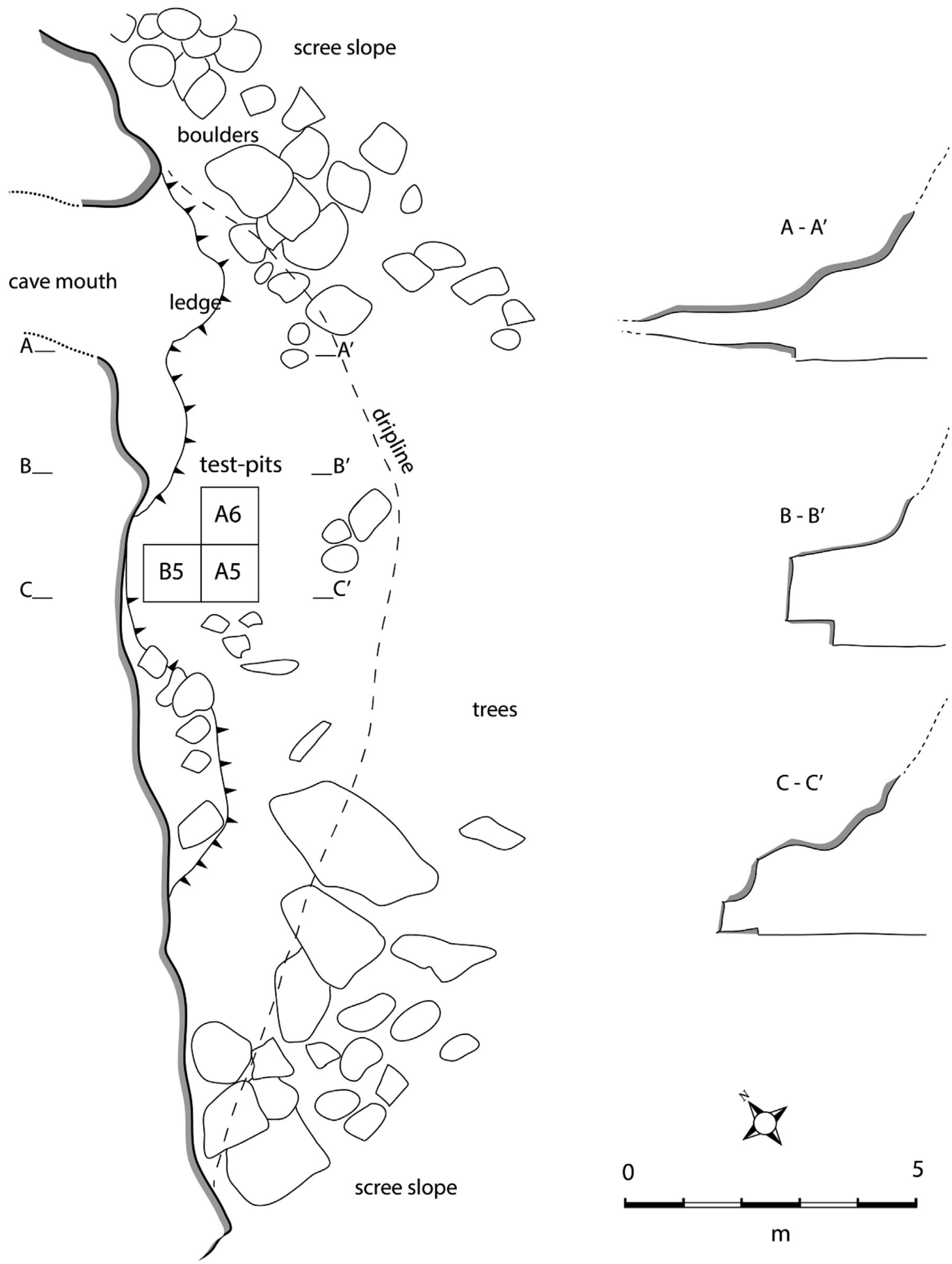

Fig. 3. Murujuga Rockshelter plan and cross-sections showing location of the three excavation squares.

calibration were collected from the wall adjacent to the OSL sample points.

2.1. Stratigraphy and sediment analysis

Four stratigraphic units (SU) were identified in the three excavated squares (Figs. 3 and 4) varying only in slight colour changes, and by increasing compaction towards the base. Sedimentological analyses indicate the deposits are uniform in nature with visual differences likely reflecting post-depositional changes. The depth and morphology of these units is affected by the underlying structure of the bedrock which slopes generally down from the rear of the shelter towards the front. The stratigraphic units identified in the field comprise:

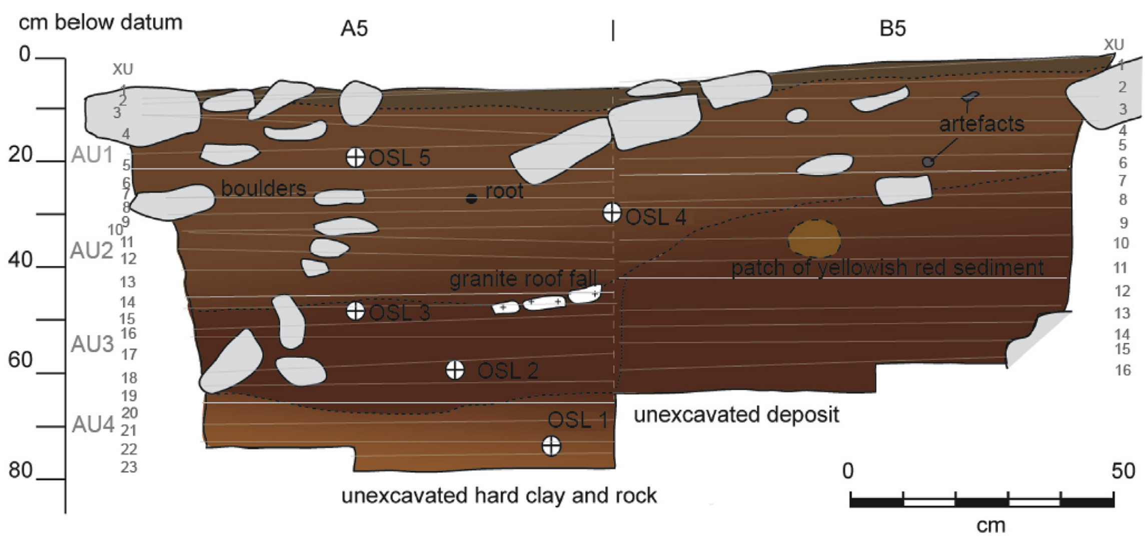

Fig. 4. Murujuga Rockshelter: Stratigraphic profile, showing OSL sample points, on south wall of squares A5, B5. Only protruding *in situ* artefacts are shown here.

- SU1: loose sandy silt, yellowish red (5YR 4/6), with a high proportion of tabular roof fall and surface organics (leaf litter and animal scats). Some horizontal roots, some charred;
- SU2: yellowish-red (2.5YR 3/6 to 5YR 4/6) compacted silt, with abundant flat tabular granite roof-fall;
- SU3: reddish brown (5YR 4/6) increasingly compacted silt with clay. Frequent cobbles and boulders of granite and granophyre; and
- SU4: very compact yellowish red (5YR 5/8) clay. Cobbles and boulders of granite and granophyre sitting above disintegrating bedrock.

In situ sediment samples were collected during the excavation from all excavation units in the three excavation squares. The sedimentological investigations used the excavated samples from square A5 (which had the most complete sequence) as well as surface sediment samples collected from the rockshelter surrounds (collected by ML and JD subsequently). Samples were dried at 40 °C and sieved to <2 mm for further analysis. Particle size distribution was calculated using a Malvern Mastersizer 2000 (v 5.6). Element distribution was obtained by *aqua regia* digestion and measurement using Inductively Coupled Plasma Optical Emission Spectroscopy (ICP-OES). General mineral composition was determined by preparing powder samples and subsequent analysis using X-ray diffraction techniques (XRD Philipps, from 10 to 60° angle). Soil pH, electric conductivity (EC) and $CaCO_3$ were measured in the laboratory following protocols of Rayment and Lyons (2010). Magnetic susceptibility was measured using a MS2 probe from Bartington Instruments.

Sediments from Murujuga Rockshelter comprised poorly-sorted, semi-angular grains that indicate minimal transport from the surrounding granite. The sediments show a predominantly bimodal distribution, strongly skewed towards the finer silt/clay fraction (Fig. 5). The two main modal sizes are a coarse sand fraction between 610 and 680 µm and a fine sand fraction between 125 and 140 µm. A broad clay peak (<10 µm) is present from XU5 (i.e. ~ 20 cm depth) and below. The fine sand fraction is dominant throughout most of the profile except in XU2 and XU5 which are dominated by coarse sand, probably reflecting the periods dominated by weathering of the local granite roof. The overall profile reflects a relatively constant source with slightly varying contributions of more mobile sands and silts.

Mineralogical analyses corroborate results from the texture analysis and indicate a rather uniform source area that reflects the local geology of predominantly granitic bedrock. Albite (Na-feldspar), quartz, microcline and orthoclase (K-feldspars) have been identified as the main mineral components in all tested sediments, in accordance with the additionally tested rock samples granite and granophyre (Fig. 6). The mineralogical similarity between individual sediment samples and between sediments and source rocks indicate that only locally weathered sediments have been transported into the rock shelter. The uniform mineralogy is also corroborated by the distribution of individual elements (Table 1). Lead (Pb) shows a slight increase in the original granite sample compared to the sediment samples. We interpret the increased Pb value as variability within the granite which is not reflected in the overall sediments.

Parameters such as pH value, electric conductivity (EC) and the magnetic susceptibility also point to generally uniform sediments with low intensity post-sedimentary pedologic processes. A consistent pH value of6.7 (H_2O) was recorded throughout the deposit while EC varies between 56 and 119 μScm^{-1}. A slight increase of EC towards the surface is most likely due to excrement from native fauna using the shelter. Magnetic susceptibility decreases from approximately 330 to 120 10^{-5}*SI with depth. The additional soil samples collected between 10 m and 100 m distant from the rockshelter are characterised by magnetic susceptibility values of 274 ± 180 on the surface and 301 ± 125 10^{-5}*SI at approximately 10 cm depth. Increased magnetic susceptibility in rockshelter sediments can often register anthropogenically induced fires (Lowe et al., 2016; Winton et al., 2016). This is not thought to be the case at Murujuga Rockshelter where there is an absence of identified hearths (i.e. charcoal pieces and reddish and/or ashy sediments from the excavated areas). The slightly increased magnetic susceptibility values at the surface of the rockshelter sediments point to stable surface conditions over a longer period of time (hundreds or even thousands of years). This indicates that humans have not used the shelter in the recent past, a fact that is supported by the decrease of artefacts found closer to the surface in the excavation pits, as well as the radiocarbon determination received from a near-

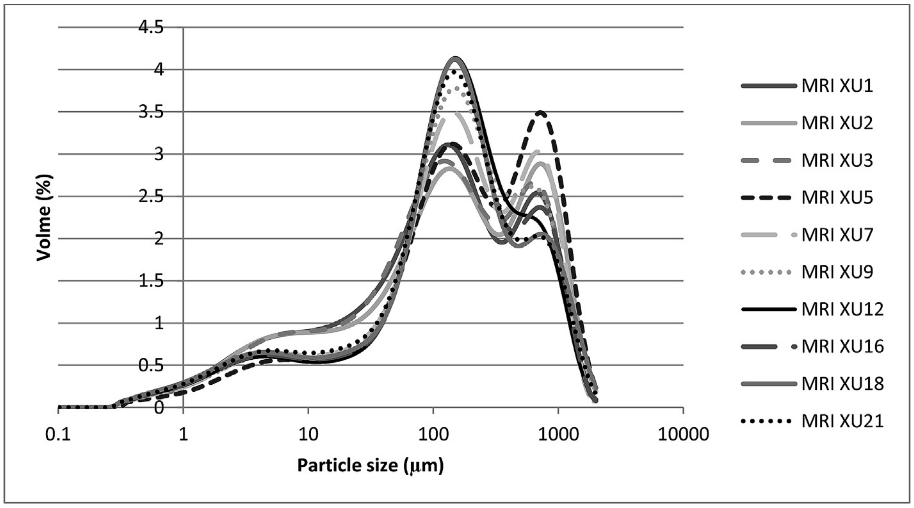

Fig. 5. Summary of particle size analyses (<2 mm) for Murujuga Rockshelter.

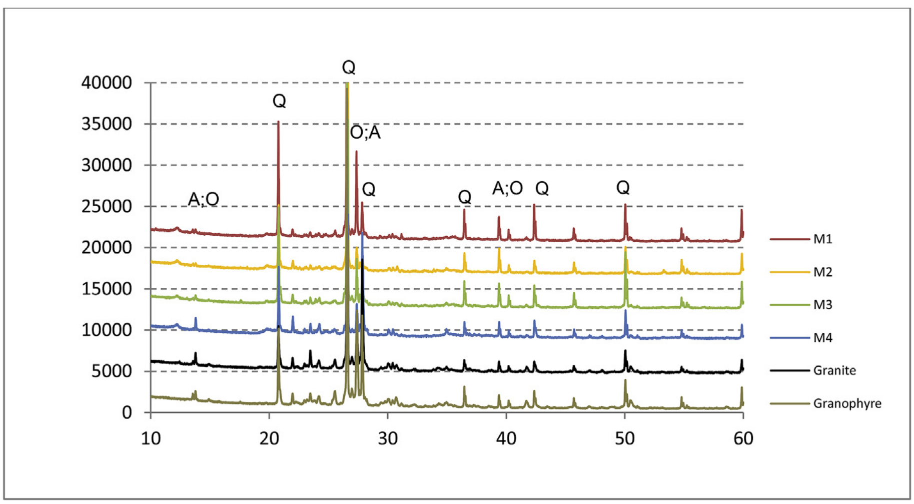

Fig. 6. Mineralogical XRD pattern of the tested sediment samples and two rock samples from Murujuga Rockshelter indicating close mineralogical similarity. A = Albite, Q = Quartz, O=Orthoclase.

Table 1
Overview of the selected elements in different sediment and rock samples from Murujuga Rockshelter. Sample names labelled "m" are from OSL dosimetry samples (e.g. OSL5, OSL 4, etc.). Samples starting with MR are from square A5 in Murujuga Rockshelter and identify XU.

SAMPLE ID	Depth (cm)	Zr mg/kg	Pb mg/kg	Fe %	Mn mg/kg	Ti %	Ca %	K %	Ba mg/kg	Al %	Si %
m5	12	299	22	3.12	412	0.38	0.49	1.46	414	4.51	29.92
m4	23	286	14	2.68	388	0.41	0.48	1.47	313	3.99	28.86
m3	42	262	20	2.96	474	0.41	0.38	1.27	497	4.5	27.39
m2	53	227	20	1.96	216	0.36	0.36	1.61	425	3.57	31.79
m1	67	250	41	3.63	247	0.34	0.39	0.93	144	4.5	24.19
r1 (Gr)	NA	236	101	2.55	166	0.34	0.16	3.34	780	4.53	31.81
r2 (GrPy)	NA	300	15	1.75	234	0.16	0.65	3.99	2356	4.41	34.03
MR A5 XU2	9–15	293	28	3.93	876	0.39	0.6	2.28	713	5.93	33.21
MR A5 XU5	20–24	266	30	3.13	782	0.38	0.46	2.47	757	5.63	35.22
MR A5 XU7	27–29	334	27	3.24	575	0.42	0.5	2.2	647	5.21	34.8
MR A5 XU12	36–39	312	20	3.04	452	0.44	0.46	2.17	632	5.02	35.39
MR A5 XU18	58–60	360	31	3.18	427	0.45	0.43	2.19	659	5.1	35.75
MR A5 XU21	67–70	302	22	2.85	360	0.4	0.45	2.14	607	5.35	36.34

surface fragment of Terebralia (the only faunal remains recovered from the site).

2.2. AMS radiocarbon dates

One *Terebralia* shell fragment from near the surface (in XU3) and two very small fragmentary pieces of charcoal (also from XU3) were submitted in 2014 for dating from test square A6 (Table 2). These were the only organic samples recovered that were suitable for radiocarbon dating. The single fragment of *Terebralia* shell returned an age determination of c. 7.8–7.6ka (Wk-41847). The two charcoal results submitted in 2014 were on small fragments and are outliers. Subsequent excavation revealed the presence of charred roots in the upper stratigraphic units, and thus these two determinations are rejected (and see Table 4, below).

2.3. OSL dating

Five OSL samples were collected and submitted to Oxford Luminescence Dating laboratory for dating (Table 3). Samples were collected using light-proof stainless steel tubes, and accompanied by sediment samples for dosimetry measurements and water content analyses. Sample points were constrained by the presence of large amounts of roof-fall but were selected to represent stratigraphic units and boundaries perceived at the time of excavation.

2.3.1. Sample preparation and analysis

Isotopic concentrations and radionuclide activities (^{232}Th, ^{238}U and ^{40}K) for each sample were determined using inductively coupled plasma mass spectrometry (ICP-MS). These were converted to external beta and gamma dose rates using published conversion factors (Guérin et al., 2011), beta attenuation factors (Adamiec and Aitken, 1998; Mejdahl, 1987), assuming radioactive equilibrium in the ^{238}U and ^{232}Th series. A relative uncertainty of 25% was applied to the measured water contents to account for possible variations in long-term hydrological conditions during burial. Cosmic ray contribution was calculated using the relationship between cosmic ray penetration, sample burial depth, bedrock overburden thickness, altitude, longitude and latitude (Prescott and Hutton, 1994).

Single grain measurements were performed on coarse grains (180–210 μm) of quartz using Risø TL/OSL Mini-sys readers (TL/OSL-DA-15) equipped with a calibrated ^{90}Sr/^{90}Y β radiation source. Single-grain measurements were made by stimulating individual grains using a focused 10 mW green (532 nm) diode-pumped laser. Equivalent Doses (De) were estimated using the Single Aliquot Regeneration (SAR) protocol (Wintle and Murray, 2006): preheats as PH1 = 260 °C, 10 s and PH2 = 220 °C, 10 s; OSL measurements were made at 130 °C for 1 s; test dose = 13 Gy. Sensitivity corrections were monitored using recycled dose points and IR-OSL depletion ratios (Duller, 2003) were used to detect feldspar contamination; a zero dose point was used to monitor thermal transfer as a percentage of the natural signal. Dose response data were fitted to 'exponential plus linear' functions for De interpolation, and fitting uncertainties were calculated using 1000 Monte Carlo iterations as described by Duller (2003).

The accepted grain De distributions are presented as radial plots in Appendix 1. The final burial doses were determined using the Central Age Model (CAM; Galbraith et al., 1999), given the type of De scatter present, amount of observed overdispersion, and the outcomes of applying the log likelihood ratio test (Arnold et al., 2009). With the exception of L010OLS5, the overdispersion values are ~38% (Table 2), which is greater than the global average for fully bleached and undisturbed samples (Arnold et al., 2011). L010OLS5 from near-surface has an even higher overdispersion value of 73%, and indicates extensive post-depositional mixing of these shallower rocky sediments.

The single-grain De distribution (sample L010OSL1, L010OSL3 and L010OSL4) show a broadly symmetric spread of dose estimate. Any skewness (mainly negative) may reflect the poorly sorted nature of the host deposits and/or minor contamination by (unbleached) roof spall. Beta dose rate heterogeneity in the surrounding sediments (particularly from pebbles and boulders) could also account for skewness and high overdispersion values in these single-grain datasets, particularly for L010OSL5. L010OSL2 shows a symmetric but slightly bimodal distribution. Application of the CAM is statistically favoured over MAM-3 and FMM for all these datasets according to the log likelihood ratio (LLIK) test (Arnold et al., 2009). Final burial doses and OSL ages are summarised in Table 3.

2.4. Bayesian analysis

To provide the most probable chronology for Murujuga Rockshelter, we conducted a Bayesian chronological analysis, entering radiocarbon and OSL determinations into sequence depositional models in OxCal 4.2 (Bronk Ramsey, 2008, 2009a). Dated determinations are entered into the model in the order of their deposition (Bronk Ramsey, 1998, 2008). Given the absence of clear sedimentary breaks in the deposit, the radiocarbon and OSL determinations were simply grouped between two boundaries which represent the top and bottom of the deposit. To do this, we used uniform boundaries which assume a uniform distribution of events within a bounded group (Bronk Ramsey, 2009a). The ShCal curve (Hogg et al., 2013) was used for charcoal dates and the Marine13 curve (Reimer et al., 2013) was used for the shell date. Marine reservoir correction (ΔR) followed O'Connor et al. (2010). To assess the likelihood of any one sample being an outlier, a General t-type Outlier Model was inset into the Sequence model (Bronk Ramsey, 2009b). All dates were assigned a prior outlier probability of 0.05. An Agreement Index (A-index) was also used. This index indicates the 'goodness-of-fit' for individual dates and the whole model at a 60% threshold value (Bronk Ramsey, 1998).

Two sequence models were run for Murujuga Rockshelter. The first included all radiocarbon and OSL determinations in their depositional order (Table 4). The 'top' boundary was constrained at U(0,1000) to prevent the model from estimating deposit ages into the future. The first run registered two major outliers: Wk-41848

Table 2
Murujuga Rockshelter radiocarbon dating results.

Lab. code	Sample context	Sample weight (g)	Dating method	Pre-treatment method	Material- species	14C age - uncalibrated	Standard error
Wk41847	Sq A6 XU3	0.38	AMS	Acid wash (0.1M HCl)	Shell *Terebralia*	7316	20
Wk41848	Sq A6 XU3	0.02	AMS	Acid-base-acid	Charcoal - *Ficus*?	979	20
Wk41849	Sq A6 XU8	0.02	AMS	Acid-base-acid	Charcoal - *Ficus*?	1753	20

Note: δ^{13}C was measured on prepared graphite using AMS and is corrected for isotopic fractionation. As the δ^{13}C of the original material can vary from the AMS-measured δ^{13}C it is not shown. Shell was etched in 0.1M HCl at 80 °C to remove ~45% of the surface, and then tested for recrystallization by Feigl staining (Friedman, 1959) to ensure only aragonite was present in the shell.

Table 3
Summary of the Murujuga Rockshelter optical dating results and final age estimates.

Lab code	SU	Depth below datum (cm)	U (ppm)	Th (ppm)	K (%)	Total dose rate (Gy/ka)[b]	Accepted/measured D_e values[c]	Over-dispersion (%)[d]	Equivalent dose (D_e) (Gy)[e]	Age (ka)[f]
L010OSL5[a]	2	21.5	2.4 ± 0.24	14.5 ± 1.45	6.7 ± 0.67	5.53 ± 0.70	120/200	73 ± 7.5	16.6 ± .1.08	3.0 ± 0.43
(rock)			4.2 ± 0.42	19.9 ± 1.99	11.0 ± 1.1					
L010OSL4	2	32.5	6.4 ± 0.64	15.5 ± 1.6	2.5 ± 0.25	4.76 ± 0.34	104/200	39 ± 4.0	52.0 ± 1.96	10.9 ± 0.88
L010OSL3	3	50.5	5.8 ± 0.58	14.7 ± 1.5	2.2 ± 0.22	4.32 ± 0.30	85/200	39 ± 4.2	66.0 ± 2.75	15.3 ± 1.23
L010OSL2	3	61.5	6.8 ± 0.68	15.6 ± 1.6	2.5 ± 0.25	4.83 ± 0.33	91/200	38 ± 4.2	81.9 ± 3.54	16.9 ± 1.38
L010OSL1	4	76.5	8.0 ± 0.8	18.6 ± 1.9	1.5 ± 0.15	4.9 ± 0.29	70/200	39 ± 4.4	94.8 ± 4.60	21.5 ± 1.75

[a] Dose rates for L010OSL5 are calculated as sediment as 70% by volume and 30% rock.
[b] Water content were estimated at 7.5% expressed as % of dry sediment mass.
[c] Number of De measurements that passed the SAR quality assurance criteria/total number of grains analysed.
[d] The relative spread in the De dataset beyond that associated with the measurement uncertainties for individual De values, calculated using the central age model of Galbraith et al. (1999).
[e] Mean ± total uncertainty (68% confidence interval), calculated as the quadratic sum of the random and systematic uncertainties.
[f] Total uncertainty includes a systematic component of ±2% associated with laboratory beta-source calibration.

Table 4
Bayesian Sequence models and results for Murujuga Rockshelter. Age BP is modelled age BP at stated probabilities.

Name	Age BP – 68.2%		Age BP – 95.4%		μ	Σ	Agreement	Outlier	Convergence
	From	To	From	To			Index	Posterior	
Model 1									
Boundary: Surface	1951	1310	1951	1004	1479	288	100		99.9
Modelled Span	17990	23913	16138	30607	22333	4150			99
L10/OSL-5	3308	2413	3743	1950	2861	456	97.2	95.4	91.4
Wk-41848	7532	2399	7623	2307	4383	1460	5.5		8.7
Wk-41847	7755	7671	7806	7640	7720	53	103.3	98.2	99
L10/OSL-4	11581	9854	12422	8981	10718	866	100.7	95.3	70.6
Wk-41849	16200	10822	16465	9908	12998	1638	5.5		2.5
L10/OSL-3	16521	14269	17458	13170	15326	1099	105.5	95.4	62.7
L10/OSL-2	18379	16058	19573	15036	17276	1139	108.3	95.4	96.8
L10/OSL-1	22200	18848	23913	17475	20636	1649	94.9	95	98.9
Boundary: Base	25571	19276	31606	17796	23812	4136			88.8
Model 2									
Boundary: Surface	1951	1296	1951	993	1472	288	100		100
Modelled Span	18229	25738	16304	36078	24097	5719			98.9
L10/OSL-5	3440	2558	3860	2133	3005	440	100.7	95.6	99.4
Wk-41847	7755	7672	7806	7640	7719	99	101	96.1	99.7
L10/OSL-4	11808	9999	12691	9140	10918	889	100.6	95.4	99
L10/OSL-3	16161	13934	17191	12785	15003	1110	104.5	95.4	99.3
L10/OSL-2	18337	15978	19555	14921	17200	1174	107.6	95.4	99.3
L10/OSL-1	22561	19095	24227	17646	20907	1674	98.3	95.2	98.9
Deposit: Base	27406	19579	36989	17936	25568	5709			90.3

and Wk-41849, the two apparently anomalous charcoal dates mentioned above (see Table 2). These dates registered very low Agreement Index results (both 5.5) and convergence values (8.7 and 2.5, respectively) which caused the model to return a low A-model (18.1) and A-overall (17.9) values (Table 4). The initial sequence run allows us to conclusively reject these two dates.

With these two anomalous determinations removed, a second model was run. This showed excellent A_{index} results all round ($A_{model} = 105.4$, $A_{overall} = 104$ and all individual Agreement indices = >98), convergence values in excess of 95, and no outliers (Fig. 7; Table 4). All radiocarbon and OSL determinations have less than a 5% chance of being an outlier (Table 4). These results put the oldest age determination for Murujuga Rockshelter at 24,230–17,650 cal. BP (95.4%), with a median value of 20,910 cal. BP. The model estimates continuous deposition over a period of 24,230 years and corroborates the sediment analyses.

The youngest OSL date is considerably younger than the *Terebralia* date recovered from around the same depth, even considering potential R-delta errors for *Terebralia* of around 600 years (Petchey and Ulm, 2012). Bioturbation of loose surface sediments are indicated by high overdispersion values identified in the OSL analyses.

2.5. Artefact analysis

Analysis aimed to investigate the procurement, use and discard of stone artefacts at the site through time to enable understandings about how Aboriginal people adapted to significant environmental and landscape changes on what became the Dampier Archipelago. A total of 1220 flaked stone artefacts were recovered from the 4 mm and 2 mm sieve fractions from Murujuga Rockshelter. Two basal grindstones were found in the deposit (in AU 1 and AU 2) and six flaked stone artefacts were found across the ground surface inside the shelter.

Since the sedimentological analysis demonstrates homogeneity throughout the sequence, excavated units (XUs) from the three squares were organised into analytical units (AUs) within the chronological span suggested by the Bayesian analysis. These analytical units correspond to four broad climatic/environmental phases (Table 5). Date ranges discussed were extrapolated from the depth-age graph using the modelled mean value at 94.5% (Fig. 8)

The lithic analysis aimed at characterising the diversity and proportions of different artefact types and raw materials via counts and percentage abundances, supported by statistical analyses. Three statistical analyses were used: the independent two sample

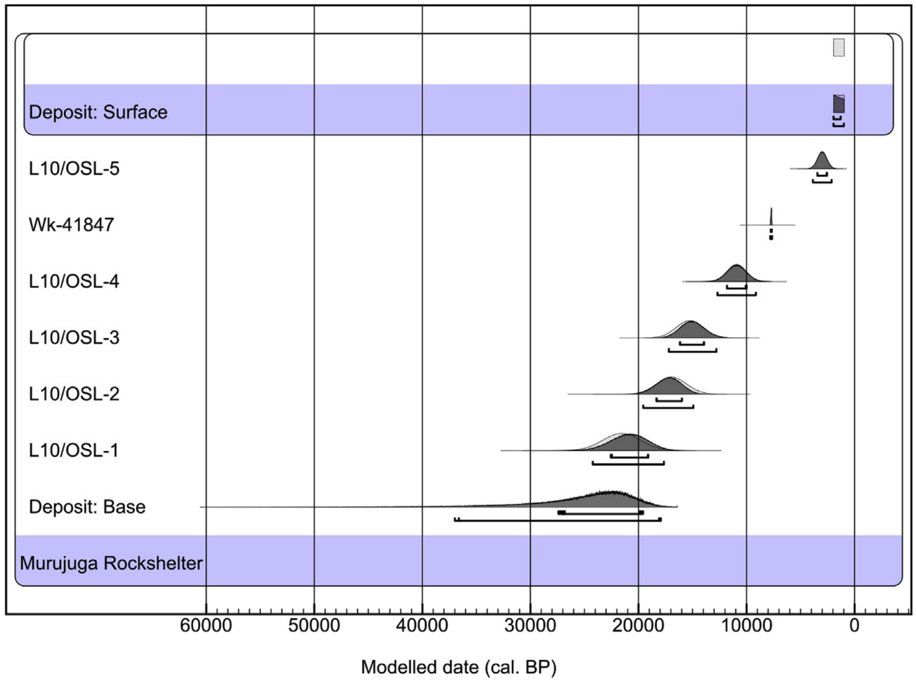

Fig. 7. Bayesian analysis results from the accepted OSL dates and AMS dates. 68.2% and 95.4% error margins are indicated by black bars under each posterior age distribution. Light probability distributions show un-modelled dates, dark probability distributions show modelled dates.

Table 5
Murujuga Rockshelter Analytical Units (AUs) – see Figs. 2 and 8 for correlation with excavation units (XU).

AU – environmental phase	95.4% mean age range (ka)	# artefacts	AU depth below datum	
			top (cm)	base (cm)
1 - Islandisation	≤9	238	6.9	24.1
2 - P/H transition	14–9	606	24.1	43.9
3 - climatic amelioration	18–14	338	43.9	64.2
4 – LGM/post-LGM	24.6–18	38	64.2	77.6

t-test, chi-square test and the Pearson correlation coefficient. The Shapiro-Wilk test was used to assess normality. Datasets with skewed distributions were transformed, using the natural logarithms, before t-tests were conducted to satisfy the prerequisite assumption of normality.

2.5.1. Artefact discard rates

The five lowest artefacts in the deposit (SQ A5 XU 22, XU base depth 74.7 cm bd; at the level of OSL-1) indicates that the site was first visited around 20,900 cal. BP (mean modelled Bayesian age) during the LGM (Figs. 8 and 9). Artefact discard rates increased after this time as the climate ameliorated and peaked between 14 and 9 ka (Fig. 10). The frequency of lithics discarded per 1000 years was highest between c. 9-7.7ka as the coastline approached its current stand. Discard rates dropped substantially after 7720 cal. BP when a small quantity of Terebralia was deposited at the site (Fig. 10).

2.5.2. Raw material selection

Granophyre grain sizes across the Dampier Archipelago vary from coarse and porphyritic to uniform and fine-grained (Lorblanchet, 1977; Veth, 1982). This likely affects the flaking quality (predictability and ease) of this material, and it is therefore appropriate to categorise and analyse stone artefacts made from these varieties separately. Granophyre was divided into fine-grained and medium-grained varieties after Veth (1982), with fine-grained granophyre defined as showing little or no macroscopic detail of minerals or components. The dominant raw materials worked (Fig. 11), accounting for over 90% of all artefacts, are medium-grained granophyre (MGG, $n = 934$, 76.6%) and fine-grained granophyre (FGG, $n = 170$, 13.9%) which are both locally available. Granophyre occurs in abundance around the rockshelter – both as smaller cobbles and as large blocks, many of which have evidence of quarrying in the form of negative flake scars. Proportions of local granophyre shift significantly through time ($\chi 2 (1) = 44.32$, $p = <0.01$) because of the declining presence of non-locally sourced lithologies at the site. Non-local (i.e. geologically exotic) chalcedony ($n = 31$, 2.5%) and chert ($n = 10$, 0.8%), while recovered in much smaller numbers, are only found in the pre-Holocene analytical units.

The nearest known sources for chert and chalcedony are located c. 10–12 km away on what is now the mainland. A search of surface artefact collections held at the Western Australian Museum indicated that chalcedony and chert are found, albeit rarely, in other surface artefact scatters on the mainland. A possible source of white chalcedony (Department of Planning, Lands and Heritage, Place ID 27864 WLP Quarry 01) was identified by Veth in 1983 at Cajuput Well approximately 15 km south of the site. These distances lie within a typical daily foraging roundtrip (15–30 km) of a hunter-gatherer group as documented in modern ethnography (Binford, 2001; Kelly, 2007). However, accessing these sources requires higher time-investment and transport cost from Murujuga Rockshelter than locally available granophyre. Other materials identified

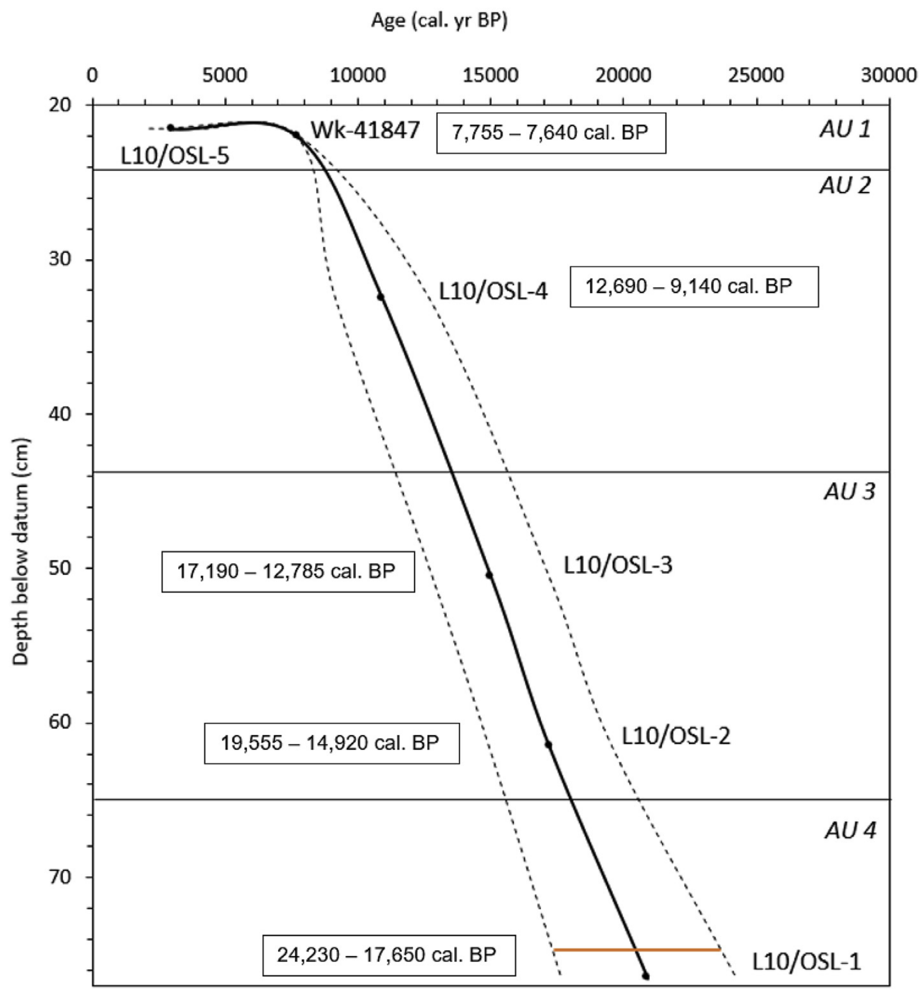

Fig. 8. Age-depth curve showing AUs correlated with OSL dates and the Bayesian modelled ages (black line is mean age; dashed lines denote upper and lower 95.4% age ranges). The orange line signifies the depth of the lowest artefacts found in the deposit (SQ A5 XU 22 base). (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

at Murujuga Rockshelter include quartz (n = 68, 5.6%) and other igneous rock (n = 7, 0.6%). The primary sources of these materials are unknown, although quartz may have been locally procured from small seams in granite and granophyre or from small nodules of quartz across the Dampier Archipelago.

Raw material richness (raw material diversity/sample size) plotted against artefact discard rates show that the lowest artefact discard rates and the highest raw material richness occur during the earliest occupation of the rockshelter, 24.6–18 cal. BP (Fig. 12). This suggests that the earliest occupants of Murujuga Rockshelter visited a greater range of resource zones (i.e. discrete, localised concentrations of resources) while travelling to and from the site: and that they had a higher foraging range during this earliest phase of occupation.

2.5.3. *Assemblage composition*

Unmodified flakes (n = 618, 50.6%), longitudinally broken flakes (n = 283, 23.2%) and other broken flakes (n = 257, 21.1%) dominate the assemblage throughout the sequence, showing that f flakes were the most commonly discarded artefact. Low numbers of bi-polar artefacts (n = 18, 1.5%), predominantly of quartz (94.4%), were recovered during the excavation. Bi-polar reduction is a common technique used to reduce small quartz nodules (de Lombera-Hermida and Rodríguez-Rellán, 2016; Hiscock, 1996). Retouched and utilised artefacts (n = 27, 2.21%) were discarded more frequently during the Pleistocene/Holocene transition and cores and core fragments (n = 18, 1.48%) are not found during the LGM but become increasingly common through the Pleistocene. Total numbers of cores and retouched/used artefacts are, however, very low and it is difficult to extrapolate patterns from this sample. None occur in the Holocene sample.

To control for variation in the mechanical properties of different raw materials, MGG artefact types (n = 934) were examined separately through the time phases (Fig. 13). Except for the increase in retouched and used artefacts, no major differences in MGG artefact type proportions are observable in comparison to the complete assemblage. Assemblage composition does not vary markedly through time. There are no statistically significant differences between proportions of complete and broken flakes r (χ^2 (3) = 1.49, p = 0.685).

A black quartz manuport (MR1A520A015, Fig. 14) was deposited at the site between 23.6 and 15.5-ka (extrapolated from depth-age graph). Its rare black colour is most likely the result of long-term exposure (over a period of c. 3.5–4 billion years) to a radiation source (e.g. thorium) at an Archean granite/granophyre unconformity - e.g. as is found on Enderby and Rosemary Islands (R. John Reeve pers. comm. 2016; Hickman, 2001). Several surface conchoidal and other fracture features on this piece were

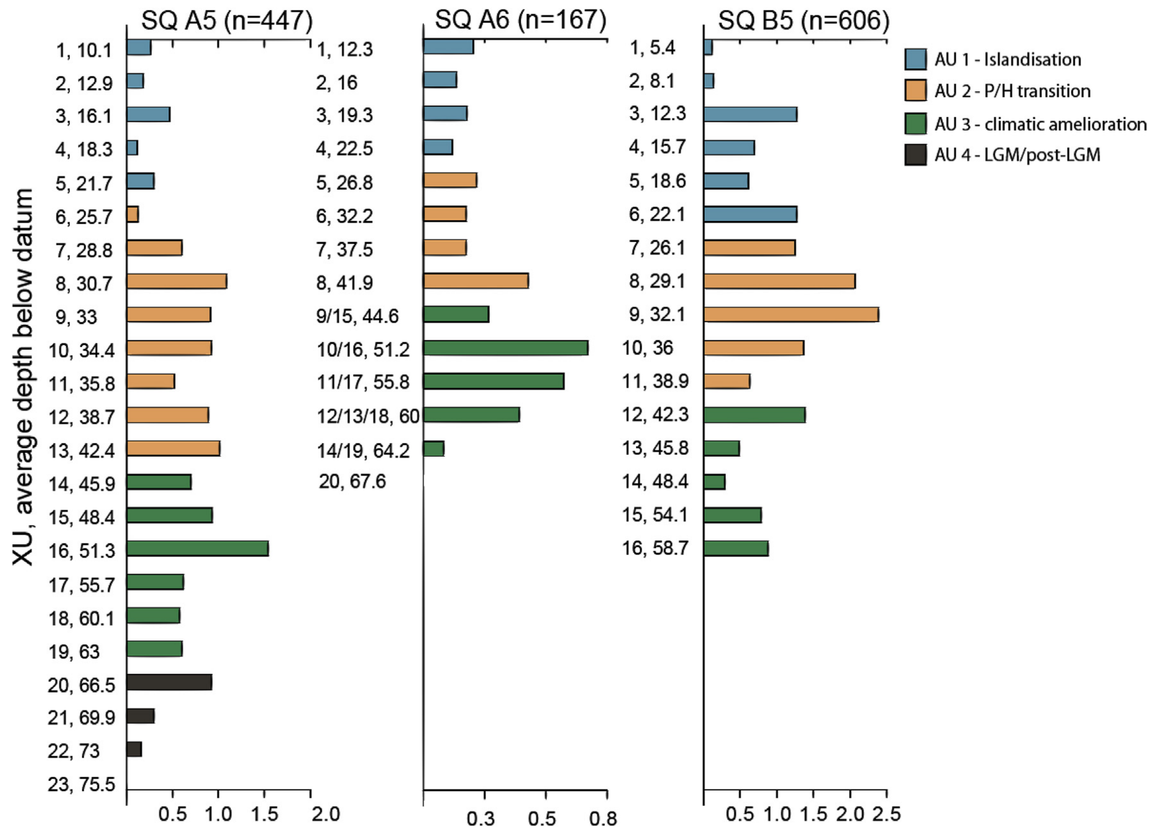

Fig. 9. Stone artefact discard rates per excavation unit (standardised per kilogram sediment excavated). SQ = excavation grid square.

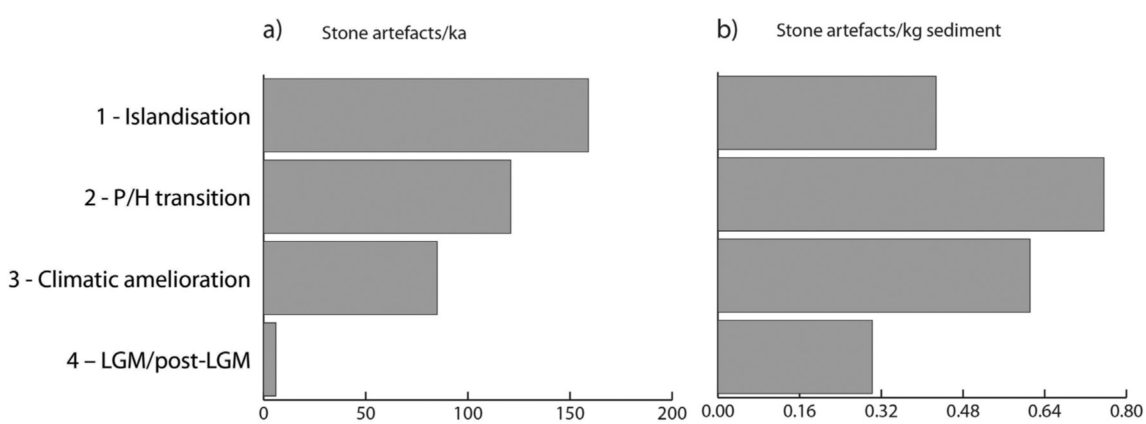

Fig. 10. a) Total number of artefacts per 1000 years and analytical unit, and b) total number of artefacts per kilogram of sediment.

microscopically inspected but it was not possible to determine whether they are the result of deliberate flaking or use. The presence of a rare black quartz manuport dating to the Pleistocene is unique and intriguing.

In addition to the flaked stone artefacts, two large granophyre grindstones (GBS1 and GBS2) were uncovered during excavation, with their bases exposed in SQ A5 XU 7 (GSB1) and SQ B5 XU4 (GSB2). Age-depth modelling indicates that they were most likely deposited at the site sometime between 11 and −8 ka (GSB1, AU2) and after 7.7 ka (GSB2, AU1).

Grindstone GSB1 measures 56.5 × 26.7 × 10.7 cm and is ground on both sides of the slab (Fig. 15). The surface with the most intensively ground area (approximately half of the total available surface area) was recovered lying face down in the deposit. This surface measured 40 cm × 15 cm and was flat, smooth and pecked in patches. The second ground surface only represents c. 10% (13 × 6 cm) of the available surface. In addition to this smooth ground area, several distinct areas of pecking are visible, possibly representing anvil use.

Grindstone GSB2 measures 43 × 22 × 9 cm and has one ground surface which is flat, smooth and pecked in places (Fig. 15). This grindstone was also found with its worked face downwards: perhaps suggesting that its user intended to return to the site to re-use it (Pitman and Wallis, 2012). No use-wear or residue analysis was undertaken on these grindstones, as they were returned to the deposit during backfilling at the request of MAC traditional

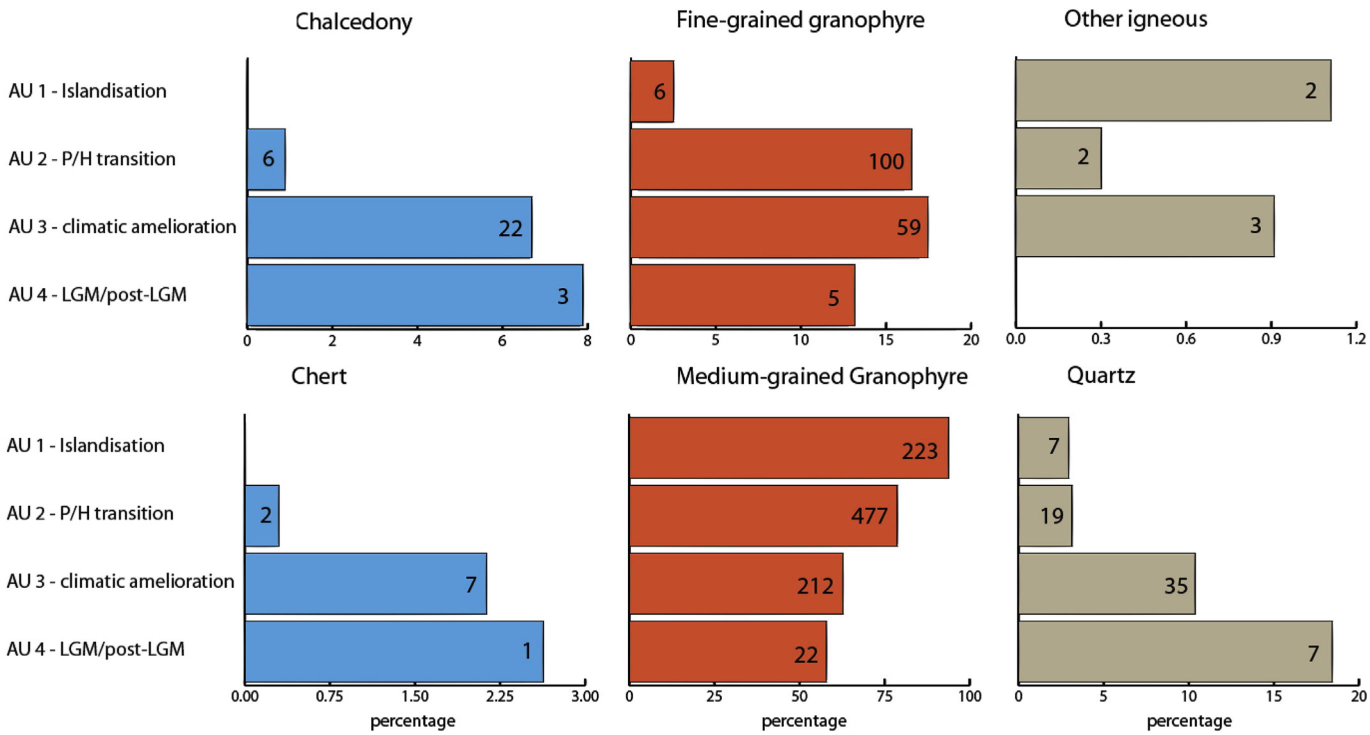

Fig. 11. Percentage of raw material type across AUs (blue: non-local materials; orange: local materials; grey: unknown) Artefact count is shown. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

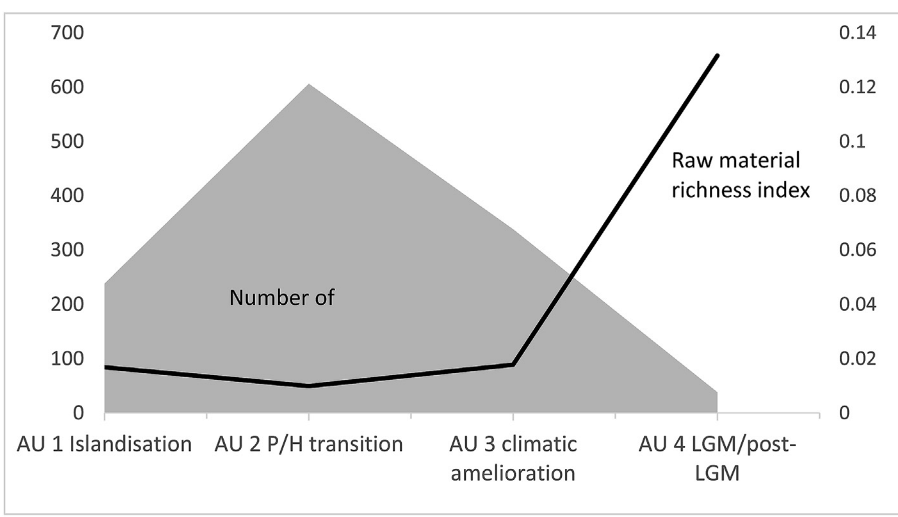

Fig. 12. Changes in raw material richness (line) across AUs against artefact discard (shaded area).

custodians. However, their presence gives some indication of site activities beyond stone knapping, such as seed-grinding or processing of tubers, nuts, seeds, wood, bone, small animals, shell and ochre pigments (Fullagar et al., 2015, 2017; Hayes and Fullagar, in press; Pitman and Wallis, 2012; Reynen and Morse, 2016).

2.5.4. Unmodified complete flakes

Since we can differentiate between local and non-local sources, we examined flaking and reduction methods in unmodified complete flakes to identify whether different strategies were used. No marked differences exist between the mass, surface area and elongation indices (oriented length divided by oriented width; Clarkson, 2007) of FGG and MGG flakes (Table 6). This indicates that, although the number of MGG artefacts outweighs the FGG artefacts consistently through time, there are negligible differences between FGG and MGG flake size and shape at the point of discard. This is not surprising as both MGG and FGG are found in abundance around the rockshelter. Quartz flakes have a significantly lower mass and surface area than both MGG flakes (mass $t\ (28) = -3.8$, $p = <0.05$, surface area $t\ (28) = -6.13$, $p = <0.05$) and FGG flakes (mass $t\ (43) = -2.48$, $p = <0.05$, surface area $t\ (43) = -4.65$, $p = <0.05$) and were often reduced using a hammer and anvil – probably to better control small quartz nodules.

While sample sizes are too small for statistical testing, the

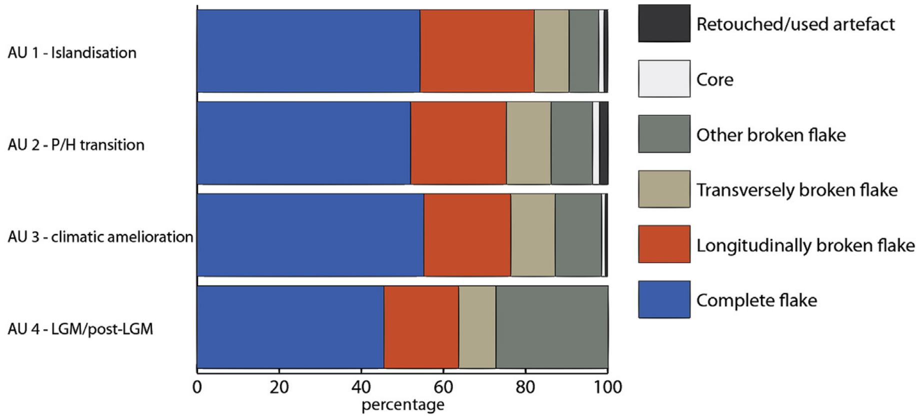

Fig. 13. Proportions of MGG artefact types (n = 934) across AUs.

Fig. 14. Black quartz manuport (MR1A520A015).

median mass and surface areas of chalcedony and chert flakes are also noticeably lower than granophyre flakes. These differences probably relate to tool-stone nodule sizes (*sensu* Ditchfield 2016). Chert and chalcedony flakes made from small nodules were carried to the rockshelter, from quarries located elsewhere. Reduction intensity on all materials is typically low. Most flakes have a flat platform with a single flake scar. Chert and chalcedony contain slightly higher frequencies of feather terminations than granophyre. Median dorsal scar counts on non-local and local materials are similar. Overhang removal is more common on chalcedony and chert than on MGG and FGG flakes (although only statistically significantly different between MGG and chalcedony ($\chi 2$ (1) = 6.88, p = <0.05) and quartz and chalcedony ($\chi 2$ (1) = 7.18, p = <0.05), suggesting efforts to strengthen platforms and control flake removals on nodules of these materials (Clarkson, 2007; Marwick, 2008). This difference alone is not a strong indicator of differential reduction of these materials.

MGG flakes deposited during the earliest phase of the site (AU4) appear smaller than flakes discarded during the three later phases (Table 7). However, no significant differences occur in the size and shape of MGG flakes through time except for surface area between phases AU1 and AU4 (t (87) = 2.24, p = 0.04). Flakes are squarish

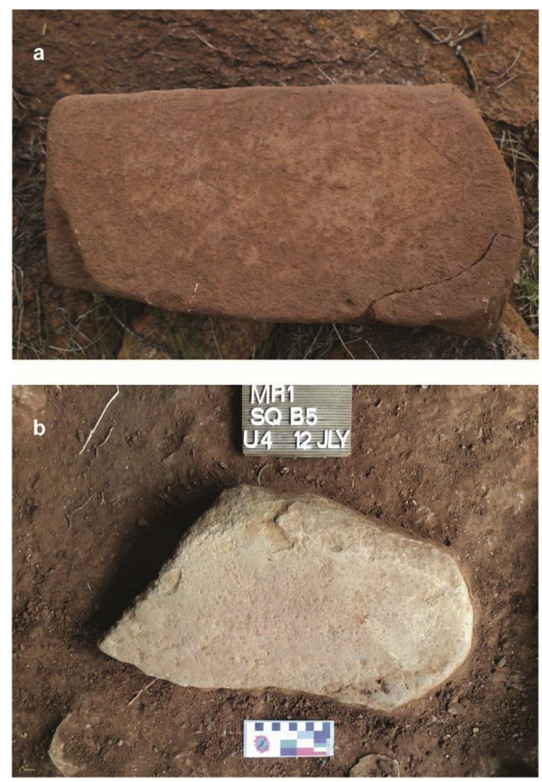

Fig. 15. Grindstones identified in the excavation: a) GSB1, length 56.5 cm, turned over to show most heavily ground surface; b) GSB2, length 43 cm, *in situ*.

(elongation index of 0.9–1.1) throughout with an average of two dorsal scars and little platform preparation. Sample sizes for other materials are too small for any meaningful temporal patterns to be made.

2.5.5. Core reduction

Nine single platform cores (47.4%), six multi-platform cores (36.8%), a bi-polar quartz core and two core fragments - representing three core technologies - were discarded at Murujuga Rockshelter. The highest number of cores (n = 11) were deposited between 14 and 9 ka (AU2). Three cores derive from AU1 and two from AU3. Cores were made on MGG (n = 13, 73.7%), FGG (n = 2, 11.1%), quartz (n = 1, 5.5%) and chalcedony (n = 2, 11.1%).

No cores were rotated more than once. Cortex is present on most

Table 6
Summary of unmodified complete flake attributes. Each cell contains median and interquartile range unless otherwise stated.

Lithology (# of flakes)	Chalcedony (n = 14)	Chert (n = 5)	Quartz (n = 26)	FGG (n = 74)	MGG (n = 496)
Mass (g)	0.6 ± 0.5	0.5 ± 0.4	1 ± 2.1	1.8 ± 5.2	2.2 ± 6.3
Surface area estimate	127.3 ± 111.5	159.6 ± 129	122.1 ± 163.1	274.7 ± 531.8	340.2 ± 517.7
Elongation index	1.1 ± 0.4	1 ± 0.5	0.9 ± 0.4	1 ± 0.5	1.1 ± 0.7
Number of single scar platforms (#, %)	10 (71.4)	5 (100)	60 (81.1)	446 (89.9)	25 (96.1)
Overhang removal (#, %)	7 (50)	3 (60)	3 (11.5)	27 (36.5)	102 (20.6)
Number of dorsal scars	3 ± 1.5	3 ± 2	2 ± 1	3 ± 2	2 ± 1
Feather terminations (#, %)	8 (57.1)	4 (80)	8 (30.8)	40 (54)	253 (51.1)

Table 7
Technical attributes of MGG flakes across AUs showing median and interquartile range (unless otherwise stated).

AU (# of MGG flakes)	AU1 (n = 121)	AU2 (n = 248)	AU3 (n = 117)	AU4 (n = 10)
Mass (g)	2.4 ± 7.2	2.2 ± 5.5	2.2 ± 7.3	1.8 ± 3.3
Surface area estimate	348.2 ± 512.1	334.3 ± 523.3	350.9 ± 559.6	248.5 ± 273.6
Elongation index	1 ± 0.8	1.1 ± 0.7	1.1 ± 0.9	1 ± 0.5
Number of dorsal scars	2 ± 2	2 ± 1	2 ± 2	2 ± 1.5
Overhang removal (#, %)	24 (19.8)	58 (23.4)	19 (16.2)	2 (20)

complete cores (n = 12, 75%). Although sample sizes are admittedly low, MGG and FGG cores are larger than the chalcedony and quartz cores, which may reflect the size of raw material nodules (Table 8). The chalcedony core is notably smaller than other cores but has many more flake scars suggesting it was more heavily reduced. The cores discarded at Murujuga Rockshelter do not suggest an extensive core reduction strategy. The low ratio of chalcedony cores: flakes at the rockshelter suggest that people were continuing to curate this non-local material – taking cores and smaller nodules with them as they left the site.

2.5.6. Tool use and rejuvenation

Artefacts exhibiting evidence for resharpening (n = 8) and/or use-wear (n = 19) make up only 2.2% of the total assemblage, suggesting that tool resharpening was not frequently undertaken at the site. The presence of only 34 (2.8%) small (<10 mm) flakes in the deposit, most likely produced as a result of modification of primary flakes, affirms this view. The low numbers of retouched artefacts and higher number of used flakes is typical of Australian Pleistocene arid zone sites (Gould, 1971; Holdaway and Stern, 2004; Veth, 2005). Over half of these retouched and used artefacts (n = 14, 51.9%) were discarded in the late Pleistocene/Holocene transitional period (AU2). People at this time used and retouched flakes made of a range of materials: most commonly MGG (n = 10, 71.4%), followed by FGG (n = 3, 21.4%) and chalcedony (n = 1, 7.1%).

With the exception of a MGG scraper (MR1B56A003), all retouched artefacts (n = 8) were only lightly reworked, exhibiting either unifacial scalar or notched retouch along their lateral or distal margins (Fig. 16). Complete retouched/used MGG and FGG flakes (n = 10) have noticeably larger median platform surface areas (MGG n = 5, 91.6 ± 366.2, FGG n = 5, 356 ± 233.2) than complete and unmodified flakes (MGG: 65.8 ± 119.6, FGG: 61.2 ± 103). This suggests that larger flakes were selected for use and/or rework (a Pearson correlation coefficient shows a positive correlation between unmodified MGG platform surface area and flake mass $r = 0.504$, $n = 473$, $p < 0.05$). The intensity of retouch was low on the five complete retouched flakes, as gauged by the Index of Invasiveness (mean 0.0937; Clarkson, 2002) and the Average Geometric Index of Unifacial Reduction (AGIUR; mean 0.436 on four flakes with dorsal retouch; Kuhn, 1990, see also Hiscock and Clarkson, 2005a, 2005b, 2008). The MGG scraper, discarded within the last 9000 years, was the most heavily reworked at the site, exhibiting edge rejuvenation around c.35% of its margin (Fig. 17). Notches – deep retouched concavities along a flake margin – were found on two flakes, one of which is shown below (Fig. 18).

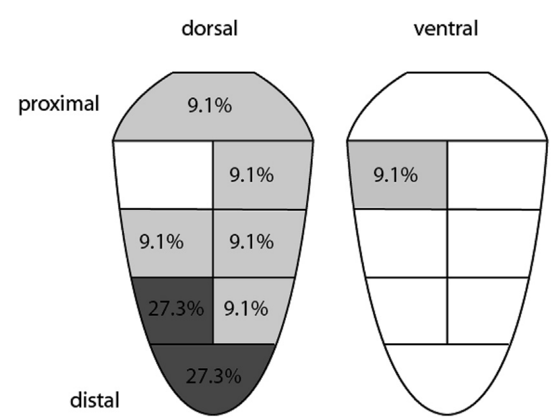

Fig. 16. Representations of retouch location recorded across 16 segments for modified complete flakes (n = 5).

2.5.7. Microscopic and residue analyses

A sample of 34 artefacts with potential use-wear and/or residues was selected for microscopic investigation. Use-wear is

Table 8
Attributes of cores at Murujuga Rockshelter (median and interquartile range shown, unless otherwise stated).

Lithology	Chalcedony (n = 1)	FGG (n = 2)	MGG (n = 12)	Quartz (n = 1)
Mass (g)	10.9	31.89 ± 20.6	254.69 ± 336.9	24.8
Maximum dimension	35.1	42.82 ± 14	88.5 ± 35.1	37.3
n with cortex (#, %)	1 (100)	1 (50)	10 (83.3)	0
n with multiple platforms (#, %)	1 (100)	1 (50)	4 (33.3)	bi-polar
n of scars	9	4 ± 1	3 ± 4	3

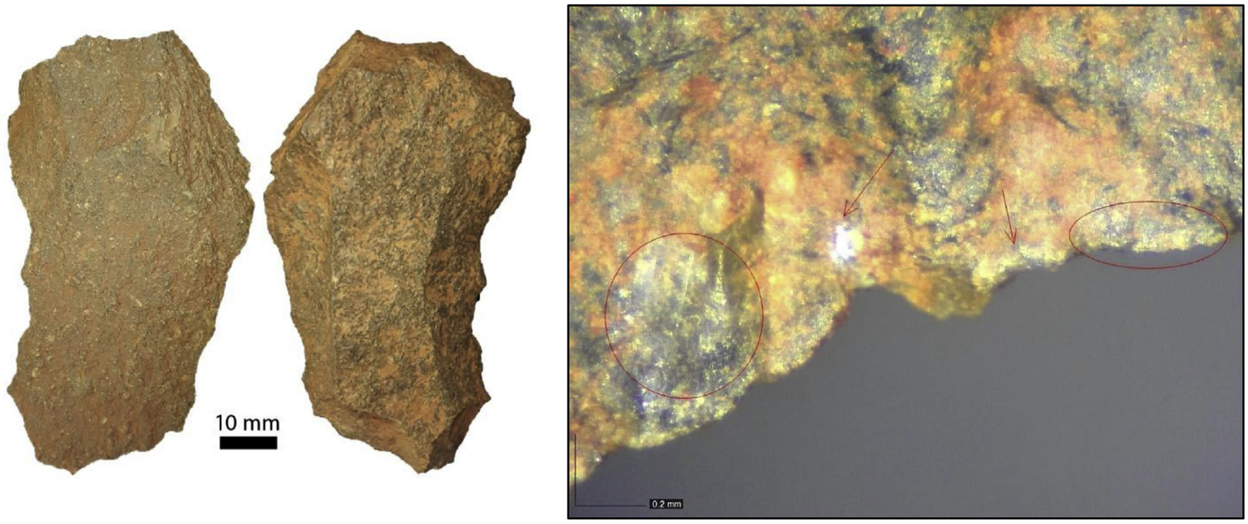

Fig. 17. MR1B56A003. MGG scraper (l) ventral and (r) dorsal and 205× magnification of right lateral margin showing low polish associated with bending flake scars.

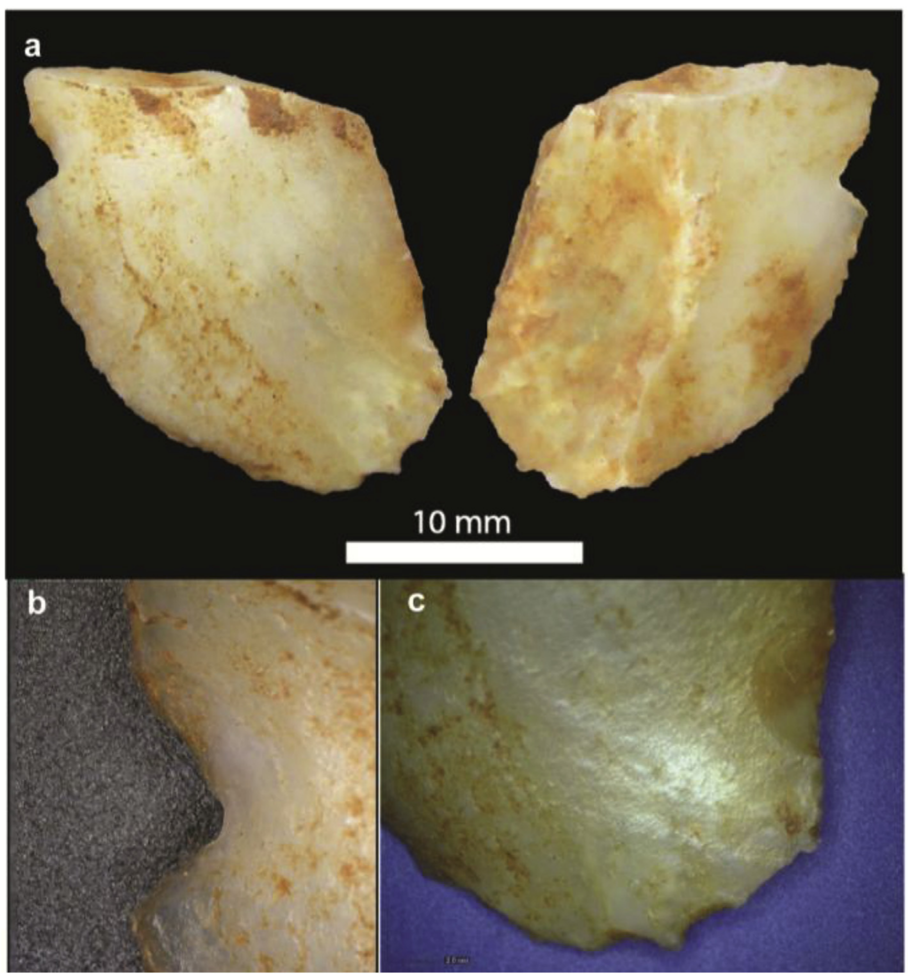

Fig. 18. Chalcedony flake MR1B513A03: a) (l) ventral and (r) dorsal, b) close-up of notch on ventral (55× magnification), c) bending and step flake scars on working distal margin (35× magnification).

regarded as the modifications to tool working edges and surfaces resulting from friction between the worked material and the tool (Kononenko, 2011:7). Use-wear studies utilised a hand-held polarising Dino-Lite AM4815ZT microscope at a magnification of 30 times (30×) up to 230 times (230×). Observations of artefact margins included the general surface topography, modifications, the presence and/or absence of striations, polish and the presence of any residue and/or resinous material. Initial investigations determined that five of these artefacts did not require further microscopic investigation.

Residue analysis involves the microscopic identification of surviving residues which commonly derive from plants (e.g. starch, raphides, phytoliths and pollen), animals (e.g. blood, bone, hair and collagen), or inorganic matter (e.g. vivianite, aragonite, ochre and resin). Residue material on seven artefacts was extracted using ultra purified water as a lifting medium, pipettes to create a Venturi effect and a Dino-lite to guide the process.

The samples were stained with a 0.25% solution of Picro-sirius Red (PSR) and Wiesner reagent (acidified Phloroglucinol) specifically adapted to identify archaeological residues. Residue identification using biochemical staining relies on colourmetric changes resulting from chemical interactions between substrates or residues and class-specific stains, so is not dependent on the residue structure being pristine or intact (Stephenson, 2015). A Leitz Dialux 22 transmitted light microscope with polarising capability and a Tucsen ISH 500 camera were used to examine and photograph the stained slides in plane (pp), part polarised (part pol) and cross-polarised (xp) light at magnifications from 100× to 400×.

Residues associated with use-wear included plant fibres, amorphous cellulose, phytoliths, cells with helical wall thickening, carbonised material, wood fibres and wood tissue, fungal filaments, minerals, collagen fibres, folded collagen, amorphous collagen and collagenous sections (Table 9, Fig. 19). Use-wear, use-related residues, residue combinations and residue density comparisons with controls were used to determine activities.

Wood-working was identified by rounded edges and a continuous distribution bending flake scars with associated woody fibres, wood tissue and cells with helical wall thickening. A positive Wiesner reaction was recorded with these extractions from MR1B56A003 and MR1B56A005 (Table 9). Micro-flake scars and polish combined with use-related collagen fibres, folded collagen, and collagenous structures indicated animal processing. The presence of fungal hyphae suggested animal processing activities (fungi feed on organic residues). Combinations of plant fibres, amorphous cellulose and phytoliths in greater densities than the control samples and use-wear which included slight rounding and small bending flake scars were used to determine plant processing tasks.

Activity tasks could be assigned to 20 artefacts (Table 10), including plant working (35%), animal working (45%) and a mixture of plant and animal working (20%). Tasks associated with animal processing were frequently seen during the period of climatic amelioration (AU3(whilst plant working was commonly observed during the P/H transition (AU2). No identifiable residues and/or tasks were identified in the smaller sample of artefacts from the LGM/post LGM unit. Specific tasks included wood-working, impact fractures from hunting, and plant scraping, cutting and shredding (Table 10). Low polish and plant residue consisting of woody tissue, wood fibres, plant fibres and elongated phytoliths on the edges of the MGG scraper (MR1B56A003) indicates it was probably used for wood-working or plant processing.

3. Discussion

The absence of dated deposits for early occupation of Murujuga has stood in stark contrast to the numerous indications of Late Pleistocene occupation from across the Pilbara and Carnarvon bioregions (Fig. 1; Law et al., 2010; Morse et al., 2014; Przywolnik, 2005; Reynen and Morse, 2016; Slack et al., 2009; Veth et al., 2014, 2017). The Murujuga Rockshelter deposits confirm that people were living in the Murujuga Ranges during the late Pleistocene, and that this occupation was repeated and represented multiple activities. Initial occupation began during the LGM (before c.21 ka).

At this time the rocky hills of Murujuga were located some 160 km from the coastline, forming a c.200 m high blocky granophyre range in the midst of a broad limestone coastal plain. A notable landmark jutting on an otherwise flat coastal plain, the ecotone at the interface between the rocky volcanic ranges and limestone coastal plain may have also been attractive for human settlement. Increased biodiversity would have been highly attractive for human settlement, with the rocky valleys entrapping water and providing refugia for food plants and animals.

Lithic analyses indicate that people visited Murujuga Rockshelter from as early as 24,230 cal BP, through the Pleistocene/Holocene transition and into the Holocene. Significantly, Murujuga Rockshelter was occupied first during the LGM, by people who flaked locally available stone but who also carried small nodules of non-local materials to the site.

Murujuga Rockshelter is now the sixth site in northwest Australia to exhibit unequivocal evidence for occupation during the LGM (Marwick, 2002; Morse et al., 2014; Slack et al., 2009) – but it is the only one of these sites not located in the inland Pilbara region. This lends support to the notion that the once rocky ranges of Murujuga – an ecotone on the edge of the limestone plain with more reliable water and food sources – functioned as a refuge for human populations during increasingly arid periods during the Pleistocene (Smith, 2013; Veth, 1993, 2005).

Artefact discard rates at Murujuga Rockshelter suggest that occupation intensified post-LGM with increasing monsoonal activity (Field et al., 2017; Ishiwa et al., 2016; van der Kaars and De Deckker, 2002; van der Kaars et al., 2006), and then decreased again in the Early Holocene. This Early Holocene decrease in artefact discard rate is atypical of northwest upland sites with similarly long occupation sequences which generally exhibit significantly higher Holocene than Pleistocene discard rates. Falling artefact discard rates at Murujuga Rockshelter during the Holocene appear to represent a reorganisation of land-use focused on coastlines rather than more upland areas, around the time of sea-level stabilisation, resulting in decreased site visits or even complete abandonment of the site after 7 ka. This reorganisation represents an initial shift to the encroaching coastline, and then on Dampier Island (Burrup Peninsula) as occupation continued throughout the Holocene and focussed on the newly established coastal resource zones (Fig. 2). Our ongoing research into terminal Pleistocene and early Holocene sites across the Dampier Archipelago will help test

Table 9
Extractions with positive Wiesner reaction and associated residues (Wiesner reagent (acidified phloroglucinol) detects lignin or lignified tissue).

Artefact ID	SQ	XU	AU	Lab.#	Residues	Wiesner Reaction
MR1B56A003	B5	6	1	1	Wood residues including woody tissue and wood fibres, cells with helical wall thickening, plant fibres and elongated phytoliths and minerals	Weak Positive
MR1B56A005	B5	6	1	27	Plant, fungal, phytoliths in low densities collagen and carbonised material which was morphologically similar to wood and animal residues. Fibre tearing and fraying present.	Weak positive

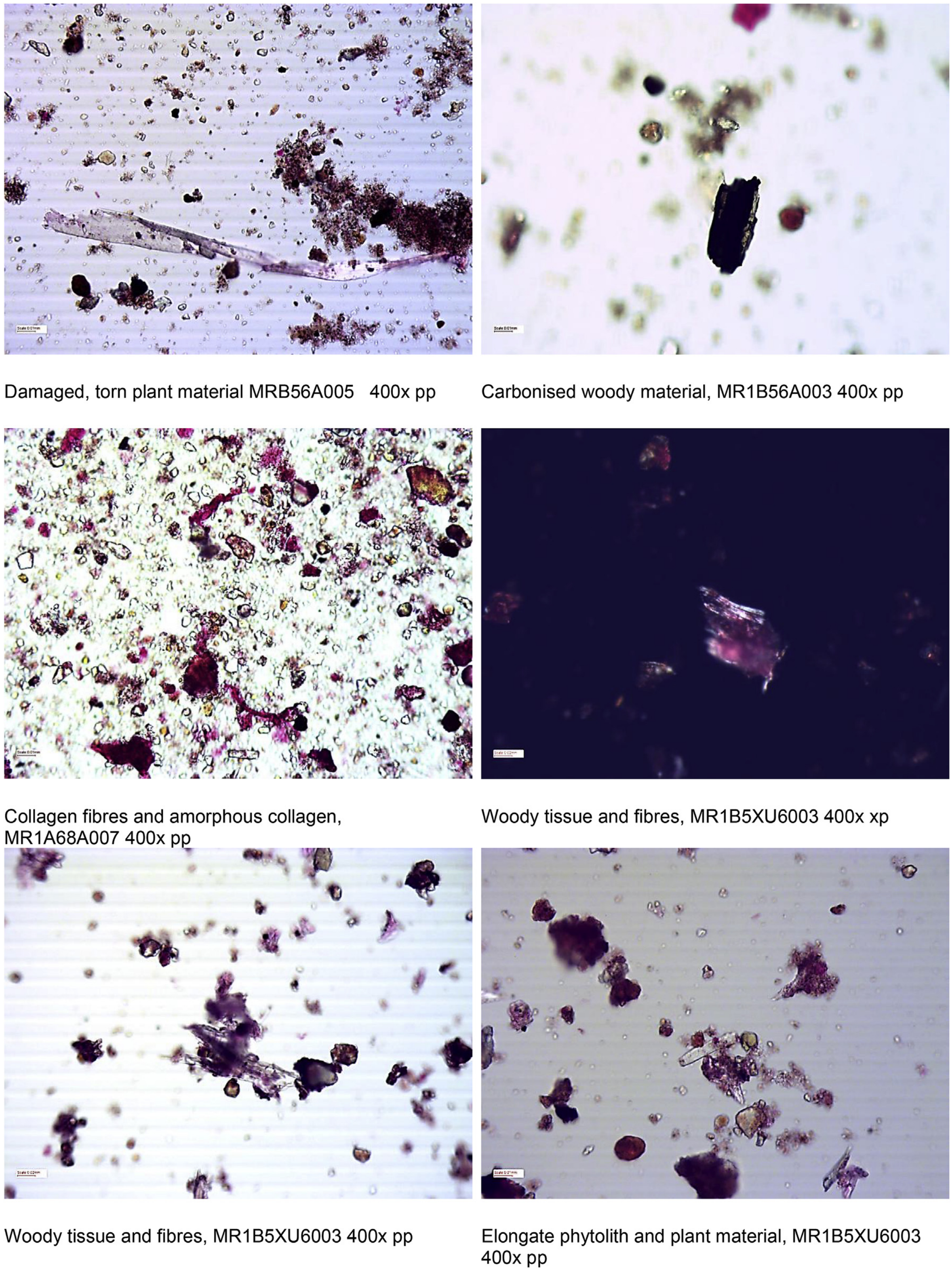

Fig. 19. Selected artefact residues indicating work on plant and animal tissue at Murujuga Rock Shelter.

the arguments for these regional trends.

As with other similar-aged Pilbara (arid zone) rockshelters, site visits to Murujuga Rockshelter appear to have been short-term and sporadic. This possibly reflects the marginal role that rockshelters played in overall hunter-gatherer land-use systems, in a landscape where most occupation evidence is found in open contexts. Ethnographic evidence suggests that arid zone rockshelters were peripheral in hunter-gatherer settlement patterns (Binford, 1978; Brown, 1987; Gorecki, 1991; Nicholson and Cane, 1991; Parkington and Mills, 1991; Veth, 1993; Walthall, 1998). Sites such as Murujuga Rockshelter have functioned, however, as persistent places in the landscape that became records of long-term use of a locale

Table 10
Activity assignments for the 23 artefacts assessed as having microscopic or residue evidence.

Artefact ID	AU	Square	XU	Laboratory #	Assigned activity
MR1B56A003	1	B5	6	1	Plant - wood working
MR1B56A005	1	B5	6	27	Mixed - plant and animal including wood working
MR1A510A002	2	A5	10	6	Animal
MR1A510A005	2	A5	10	7	Plant working
MR1A513A011	2	A5	13	28	Mixed plant and animal
MR1A513A015	2	A5	13	13	Plant working - cutting, chopping, scraping
MR1A56A006	2	A6	6	2	Plant working
MR1A57A023	2	A5	7	4	Mixed plant and animal (possible bone working)
MR1A66A004	2	A6	6	8	Animal cutting and spearing
MR1A67A003	2	A6	7	9	Plant scraping
MR1A68A007	2	A6	8	12	Mixed - plant and animal (cutting, scraping)
MR1B57A005	2	B5	7	21	Plant cutting and scraping
MR1B57A041	2	B5	7	24	Other – core
MR1B59A008	2	B5	9	22	Animal spearing and stabbing
MR1B59A015	2	B5	9	23	Animal
MR1A5 East Wall	3	A5	NA	26	Other – indeterminate
MR1A515A015	3	A5	15	14	Animal spearing and stabbing
MR1A517A003	3	A5	17	16	Plant working
MR1A518A002	3	A5	18	3	Animal - hunting
MR1A518A003	3	A5	18	17	Animal
MR1B512A011	3	B5	12	25	Animal
MR1B513A003	3	B5	13	29	Animal
MR1A520A015	4	A5	20	18	Other – black quartz

(Olszewski & al-Nahar, 2016).

Flake production and maintenance were the primary activities undertaken in the rockshelter and no major shifts in artefact technology and stone reduction intensity are apparent through time. Larger flakes were selected for plant working, animal processing and combinations of plant- and animal-working tasks.

The superficial reduction of local granophyre is typical of situations where good quality material is in abundance: there is little incentive for conservation (Andrefsky, 1994; Elston, 1990) and correspondingly lower levels of reduction and tool maintenance and raw material conservation. Quarrying marks on large granophyre boulders near Murujuga Rockshelter demonstrates that this locale provided a place for people to provision themselves with suitable toolstone. The chert and chalcedony artefacts discarded at the rockshelter required higher time-investment and transport than granophyre but these too were not intensively conserved. Most striking is the decrease in the proportions of these non-local materials through time which suggests that people changed the ways that they used the rockshelter and its surrounding landscape.

Before sea levels rose, mobile people transported chert and chalcedony to the site — possibly from nearby geological contexts on the open (now inundated) plains or further afield from known sources (e.g. in the Chichester Ranges). High levels of mobility across the now-drowned North West Shelf have been inferred from the numerous open sites recorded on Barrow Island. Decreased use of non-local materials in the terminal Pleistocene and Holocene may reflect shifts in mobility systems or changes in the configuration of group territories or territory size. This period represents one of rapidly changing sea-levels and a diminishing coastal plain, requiring regional groups to adapt to both changing lithic resource distributions and broader landscape and environmental changes. This analysis provides further evidence for shifts in mobility and territorial configurations through time, such as are inferred in rock art production in this time frame (McDonald, 2015).

We suggest that Murujuga Rockshelter reflects a restructuring of settlement patterns in association with the transforming landscapes of the Dampier Archipelago over time. In the late Pleistocene, Murujuga Rockshelter served as a base for hunting forays or short visits into the Ranges. With the marine transgression and formation of the islands, marine resources became increasingly proximal to Murujuga, which led to a refocussing of populations to shorelines and inter-tidal zones. Extensive Terebralia midden deposits along the western coastlines of Rosemary and Enderby Islands provide evidence for this Early Holocene marine-economic focus. Through the Holocene, intensive use of midden sites associated with intensive rock art production in proximity to reliable seasonal rock holes implies that water sources became even more important, or more frequently used. Occupation foci in the more inland rocky ranges, especially those without reliable water, may have been abandoned. The absence of rock art production in and immediately around Murujuga Rockshelter indicates that occupation here was focussed on a range of short-term economic activities – stone tool production, plant working, seed grinding and animal processing. This rockshelter evidence provides us with important contextual information to better understand the Pleistocene use of the Murujuga landscape.

4. Contributions

JM, who is Lead Chief Investigator of the *Murujuga: Dynamics of the Dreaming* Linkage Project, directed excavations and analyses, and drafted and edited the text with specialist contributions from other authors. WR analysed the artefacts as part of her PhD research. KD conducted the Bayesian analysis of radiocarbon and OSL dates. JD assisted excavations and artefact analysis, and organised dating and sedimentological analyses. ML and IW analysed sediments and IW also analysed raw OSL results. TW modelled palaeo-shorelines using bathymetric data and Terragen software. BS undertook the microscopic and residue analyses. PV identified the site's potential with colleagues Elizabeth Bradshaw and Peter Kendrick, undertook excavations, and contributed to the text. TW, WR, JD, KD, IW, ML and BS created the figures. All authors contributed to discussions and edited and approved the final text.

Conflicts of interest

None.

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Appendix A. Supplementary data

Supplementary data related to this article can be found at https://doi.org/10.1016/j.quascirev.2018.06.002.

References

Adamiec, G., Aitken, M., 1998. Dose-rate conversion factors: update. Ancient TL 16, 37–50.
Arnold, L.J., Roberts, R.G., Galbraith, R.F., DeLong, S.B., 2009. A revised burial dose estimation procedure for optical dating of young and modern-age sediments. Quat. Geochronol. 4, 306–325.
Andrefsky, W., 1994. Raw-material availability and the organization of technology. Am. Antiq. 59, 21–34.
Arnold, L.J., Roberts, R.G., McPhee, R.D.E., Haile, J.S., Brock, F., Möller, P., Froese, D.G., Tikhonov, A.N., Chivas, A.R., Gilbert, T.P., Willerslev, E., 2011. Paper II – dirt, dates and DNA: OSL and radiocarbon chronologies of perennially frozen sediments in Siberia, and their implications for sedimentary ancient DNA studies. Boreas 40, 417–445.
Bailey, G.N., Flemming, N.C., King, G.C.P., Lambeck, K., Momber, G., Moran, L.J., Al-Sharekh, A., Vita-Finzi, C., 2007. Coastlines, submerged landscapes, and human evolution: the red sea basin and the farasan islands. J. I. Coast Archaeol. 2, 127–160.
Balme, J., Davidson, I., McDonald, J., Stern, N., Veth, P., 2009. Symbolic behaviour and the peopling of the southern arc route to Australia. Quat. Int. 202, 59–68.
Binford, L.R., 1978. Dimensional analysis of behavior and site structure: learning from an Eskimo hunting stand. Am. Antiq. 43, 330–361.
Binford, L.R., 2001. Constructing Frames of Reference: an Analytical Method for Archaeological Theory Building Using hunter-gatherer and Environmental Data Sets. University of California Press, Berkeley.
Bradshaw, E., 1995. Dates from archaeological excavations on the Pilbara coastline and islands of the dampier archipelago, western Australia. Aust. Archaeol. 41, 37–38.
Bronk Ramsey, C., 1998. Probability and dating. Radiocarbon 40, 461–474.
Bronk Ramsey, C., 2008. Radiocarbon dating: revolutions in understanding. Archaeometry 50, 249–275.
Bronk Ramsey, C., 2009a. Bayesian analysis of radiocarbon dates. Radiocarbon 51, 337–360.
Bronk Ramsey, C., 2009b. Dealing with outliers and offsets in radiocarbon dating. Radiocarbon 51, 1023–1045.
Brown, S., 1987. Toward a Prehistory of the Hamersley Plateau, Northwest Australia. Australian National University, Canberra.
Clarkson, C., 2002. An index of invasiveness for the measurement of unifacial and bifacial retouch: a theoretical, experimental and archaeological verification. J. Archaeol. Sci. 29, 65–75.
Clarkson, C., 2007. Lithics in the Land of the Lightning brothers the Archaeology of Wardaman Country, Northern Territory. ANU E Press, Canberra.
Clune, G., 2002. Abydos: an Archaeological Investigation of Adaptations on the Pilbara Coast, Northwest Western Australia. PhD Thesis. University of Western Australia.
Clune, G., Harrison, R., 2009. Coastal shell middens of the Abydos coastal plain, Western Australia. Archaeol. Ocean. 44, 70–80.
de Lombera-Hermida, A., Rodríguez-Rellán, C., 2016. Quartzes matter. Understanding the technological and behavioural complexity in quartz lithic assemblages. Quat. Int. 424, 2–11.
Dix, W., 1977. Facial representations in Pilbara rock engravings. In: Ucko, P.J. (Ed.), Form in Indigenous Art: Schematisation in the Art of Aboriginal Australia and Prehistoric Europe. Australian Institute of Aboriginal Studies, Canberra, pp. 227–285.
Duller, G.A.T., 2003. Distinguishing quartz and feldspar in single grain luminescence measurements. Radiat. Meas. 37, 161–165.
Elston, R.G., 1990. A cost-benefit model of lithic assemblage variability. In: Elston, R.G., Budy, E.E. (Eds.), The Archaeology of James Creek Shelter. University of Utah Anthropological Papers 115, Salt Lake City, Utah, pp. 153–164.
ESRI Inc, 2017. ArcGIS Desktop: Release 10.4.1. Environmental Systems Research Institute, Redlands, CA.
Field, E., McGowan, H.A., Moss, P.T., Marx, S.K., 2017. A late Quaternary record of monsoon variability in the northwest Kimberley, Australia. Quat. Int. 449, 119–135.
Friedman, G.M., 1959. Identification of carbonate minerals by staining methods. J. Sediment. Res. A Sediment. Petrol. Process 29, 87–97.
Fullagar, R., Hayes, E., Stephenson, B., Field, J., Matheson, C., Stern, N., Fitzsimmons, K., 2015. Evidence for Pleistocene seed grinding at lake mungo, south-eastern Australia. Archaeol. Ocean. 50, 3–19.
Fullagar, R., Stephenson, B., Hayes, E., 2017. Grinding grounds: function and distribution of grinding stones from an open site in the Pilbara, Western Australia. Quat. Int. 427, 175–183.
Galbraith, R.F., Roberts, R.G., Laslett, G.M., Yoshida, H., Olley, J.M., 1999. Optical dating of single and multiple grains of quartz from Jinmium Rock Shelter, Northern Australia: Part 1, experimental design and statistical models. Archaeometry 41, 339–364.
Gorecki, P., 1991. Review of Prehistoric Hawaiian occupation in the Anahulu valley, O'ahu island: excavations in three inland rockshelters (P.V. Kirch, ed.). Archaeol.

Ocean. 26, 87.
Gould, R.A., 1971. The archaeologist as ethnographer: a case from the Western desert of Australia. World Archaeol. 3, 143–177.
Guérin, G., Mercier, N., Adamiec, G., 2011. Dose-rate conversion factors: update. Ancient TL 29, 5–8.
Hayes, E.. Fullagar, R. in press. Food or fibre craft? Grindstones and Triodia grass (spinifex). Quat. Int..
Hickman, A.H., 2001. Geology of the Dampier 1:100 000 Sheet. Geological survey of Western Australia, Department of Minerals and Energy, Perth.
Hiscock, P., 1996. Mobility and Technology in the Kakadu Coastal Wetlands, vol. 15. Bulletin of the Indo-Pacific Prehistory Association, pp. 151–157.
Hiscock, P., Clarkson, C., 2005a. Experimental evaluation of Kuhn's geometric index of reduction and the flat-flake problem. J. Archaeol. Sci. 32, 1015–1022.
Hiscock, P., Clarkson, C., 2005b. Measuring artefact reduction: an examination of Kuhn's geometric index of reduction. In: Clarkson, C., Lamb, L. (Eds.), Lithics 'Down under': Australian Perspectives on Lithic Reduction, Use and Classification. BAR International Series 1408. Archaeopress, Oxford, pp. 7–19.
Hiscock, P., Clarkson, C., 2008. The construction of morphological diversity. In: Andrefsky, W. (Ed.), Lithic Technology: Measures of Production, Use, and Curation. Cambridge University Press, Cambridge, pp. 106–135.
Hogg, A.G., Hua, Q., Blackwell, P.G., Niu, M., Buck, C.E., Guilderson, T.P., Heaton, T.J., Palmer, J.G., Reimer, P.J., Reimer, R.W., Turney, C., Zimmerman, S.R.H., 2013. SHCal13 southern hemisphere calibration, 0–50,000 Years cal BP. Radiocarbon 55, 1889–1903.
Holdaway, S.J., Stern, N., 2004. A Record in Stone: the Study of Australia's Flaked Stone Artefacts. Aboriginal Studies Press, Canberra.
Ishiwa, T., Yokoyamaa, Y., Miyairia, Y., Obrochta, S., Sasaki, T., Kitamura, A., Suzuki, A., Ikehara, M., Ikehara, K., Kimoto, K., Bourget, J., Matsuzaki, H., 2016. Reappraisal of sea-level lowstand during the last glacial maximum observed in the bonaparte gulf sediments, northwestern Australia. Quat. Int. 397, 373–379.
Kelly, R.L., 2007. The Foraging Spectrum: Diversity in Hunter-gatherer Lifeways, Revised edn. Smithsonian Institute Press, Washington.
Kononenko, N., 2011. Experimental and archaeological studies of use-wear and residues on obsidian artefacts from Papua New Guinea. Technical Reports of the Australian Museum. Online 21, 1–244.
Kuhn, S., 1990. A geometric index of reduction for unifacial stone tools. J. Archaeol. Sci. 17, 585–593.
Law, W., Cropper, D.N., Petchey, F., 2010. Djadjiling rockshelter: 35,000 14C years of aboriginal occupation in the Pilbara, western Australia. Aust. Archaeol. 70, 68–71.
Lambeck, K., Rouby, H., Purcell, A., Sun, Y., Sambridge, M., 2014. Sea level and global ice volumes from the last glacial maximum to the Holocene. Proc. Natl. Acad. Sci. Unit. States Am. 111, 15296–15303.
Lewis, S.E., Sloss, C.R., Murray-Wallace, C.V., Woodroffe, C.D., Smithers, S.G., 2013. Post-glacial sea-level changes around the Australian margin: a review. Quat. Sci. Rev. 74, 115–138.
Lorblanchet, M., 1977. Summary Report of Fieldwork, Dampier, W.a, vol. 77. Australian Institute of Aboriginal Studies Newsletter, pp. 36–40.
Lorblanchet, M., 1992. The rock engravings of Gum Tree Valley and skew valley, dampier, western Australia: chronology and functions of sites. In: McDonald, J., Haskovec, I. (Eds.), State of the Art: Regional Rock Art Studies in Australia and Melanesia. AURA, Melbourne, pp. 39–59.
Lorblanchet, M., Jones, R., 1980. Les premières fouilles á Dampier (Australie de l'ouest) et leur place dans l'ensemble Australien. In: Garanger, J. (Ed.), La Prehistoire de l'Océanie. Société des Océanistes, Paris.
Lowe, K.M., Shulmeister, J., Feinberg, J.M., Manne, T., Wallis, L.A., Welsh, K., 2016. Using soil magnetic properties to determine the onset of Pleistocene human settlement at Gledswood Shelter 1, Northern Australia. Geoarchaeology 31 (3), 211–228. https://doi.org/10.1002/gea.21544.
McDonald, J.J., 2015. I must go down to the seas again: or, what happens when the sea comes to you? Murujuga rock art as an environmental indicator for Australia's north-west. Quat. Int. 385, 124–135.
McDonald, J., Berry, M., 2016. Murujuga, northwestern Australia: when arid hunter-gatherers became coastal foragers. J. I. Coast Archaeol. 12, 24–43.
McDonald, J.J., Veth, P., 2006. A Study of the Distribution of Rock Art and Stone Structures on the Dampier Archipelago. Report to the Department of Environment and Heritage, Canberra.
McDonald, J.J., Veth, P., 2009. Dampier archipelago petroglyphs: archaeology, scientific values and national heritage listing. Archaeol. Ocean. 44, 49–69.
Manne, T., Veth, P., 2015. Late Pleistocene and early Holocene exploitation of estuarine communities in northwestern Australia. Quat. Int. https://doi.org/10.1016/j.quaint.2014.12.049.
Mardudhunera Yaburara, et al., 2004. Unpublished Nomination for Burrup Peninsula, Islands of the Dampier Archipelago and Dampier Coast to the National Heritage List. Nomination Held by the Department for Sustainability. Environment, Water, Population and Communities, Canberra.
Marwick, B., 2002. Milly's Cave: Evidence for Human Occupation of the Inland Pilbara during the Last Glacial Maximum, vol. 7. Tempus, pp. 21–33.
Marwick, B., 2008. What attributes are important for the measurement of assemblage reduction intensity? Results from an experimental stone artefact assemblage with relevance to the Hoabinhian of mainland Southeast Asia. J. Archaeol. Sci. 35, 1189–1200.
Mejdahl, V., 1987. Internal radioactivity in quartz and feldspar grains. Ancient TL 5, 10–17.
Morse, K., 1993. New radiocarbon dates from North West cape, western Australia: a preliminary report. In: Smith, M.A., Spriggs, M., Fankhauser, B. (Eds.), Sahul in Review: Pleistocene Archaeology in Australia, New Guinea and Island Melanesia. Australian National University Press, Canberra, pp. 155–163.
Morse, K., Cameron, R., Reynen, W., 2014. A tale of three caves: new dates for Pleistocene occupation in the inland Pilbara. Aust. Archaeol. 79, 167–178.
Mulvaney, K.J., 2015. Murujuga Marni: Rock Art of the Macropod hunters and Mollusc Harvesters. CRAR+M Monograph Series, No. 1. UWA Press, Perth.
Nicholson, A., Cane, S., 1991. Desert camps: analysis of Australian proto-historic campsites. In: Gamble, C.S., Boismier, W.A. (Eds.), Ethnoarchaeological Approaches to Mobile Campsites. International Monographs in Prehistory, AnnArbor, Michigan, pp. 263–354.
O'Connor, S., 1999. 30,000 Years of Aboriginal Occupation: Kimberley, North-West Australia. Terra Australis 14. Australian National University, Canberra.
Olszewski, D.I., al-Nahar, M., 2016. Persistent and ephemeral places in the early epipaleolithic in the wadi al-hasa region of the western highlands of Jordan. Quat. Int. 396, 20–30.
Palmer, K., 1975. Petroglyphs and associated Aboriginal sites in the north-west of Western Australia. Archaeol. Phys. Anthropol. Ocean. 10, 152–160.
Parkington, J., Mills, G., 1991. From space to place: the architecture and social organisation of southern African mobile communities. In: Gamble, C.S., Boismier, W.A. (Eds.), Ethnoarchaeological Approaches to Mobile Campsites. International Monographs in Prehistory, AnnArbor, Michigan, pp. 355–370.
Petchey, F., Ulm, S., 2012. Marine reservoir variation in the Bismarck region: an evaluation of spatial and temporal change in ΔR and R over the last 3000 years. Radiocarbon 540, 45–58.
Pillans, B., Fifield, K., 2013. Erosion rates and weathering history of rock surfaces associated with Aboriginal rock art engravings (petroglyphs) on Burrup Peninsula, Western Australia, from cosmogenic nuclide measurements. Quat. Sci. Rev. 69, 98–106.
Pillans, B., Fifield, L.K., 2014. Reply to watchman, taçon and aubert. Quat. Sci. Rev. 91, 73–75.
Pitman, H.T., Wallis, L.A., 2012. The Point of Spinifex: Aboriginal uses of spinifex grasses in Australia. Ethnobot. Res. Appl. 10, 109–131.
Planetside Software Inc, 2017. Terragen 4. Planetside Software LLC, Los Angeles.
Prescott, J.R., Hutton, J.T., 1994. Cosmic ray contributions to dose rates for luminescence and ESR dating: large depths and long-term time variations. Radiat. Meas. 23, 497–500.
Przywolnik, K., 2005. Long-term transitions in hunter-gatherers of coastal north western Australia. In: Veth, P., Smith, M., Hiscock, P. (Eds.), Desert Peoples: Archaeological Perspectives. Blackwell Publishing, Oxford, pp. 177–205.
Rayment, G.E., Lyons, D.J., 2010. Soil Chemical Methods – Australasia. Australian Soil and Land 558 Survey Handbooks Series. CSIRO Publishing, Clayton, Victoria.
Reimer, P.J., Bard, E., Bayliss, A., Beck, J.W., Blackwell, P.G., Bronk-Ramsey, C., Buck, C.E., Cheng, H., Edwards, R.L., Friedrich, M., Grootes, P.M., Guilderson, T.P., Haflidason, H., Hajdas, I., Hatté, C., Heaton, T.J., Hoffmann, D.L., Hogg, A.G., Hughen, K.A., Kaiser, K.F., Kromer, B., Manning, S.W., Niu, M., Reimer, R.W., Richards, D., Scott, E.M., Southon, J.R., Staff, R.A., Turney, C.S.M., van der Plicht, J., 2013. IntCal13 and Marine13 radiocarbon age calibration curves 0–50,000 years cal. BP. Radiocarbon 55, 1869–1887.
Reynen, W., Morse, K., 2016. Don't forget the fish – towards an archaeology of the abydos plain, Pilbara, western Australia. Aust. Archaeol. 82, 94–105.
Robinson, M., 1997. Woodside Burrup Extensions: Anthropological Survey for Aboriginal Sites. Unpublished report prepared for Woodside Offshore Petroleum Pty Ltd.
Sim, R., Wallis, L.A., 2008. Northern australian offshore island use during the Holocene: the archaeology of vanderlin island, sir edward pellew group, gulf of Carpentaria. Aust. Archaeol. 67, 95–106.
Semeniuk, V., 1983. The Pilbara coast: a riverine coastal plain in a tropical arid setting, northwestern Australia. Sediment. Geol. 83, 235–256.
Semeniuk, V., Wurm, P.A.S., 1987. Mangroves of dampier archipelago, western Australia. J. Roy. Soc. West Aust. 69, 29–87.
Siddall, M., Rohling, E.J., Almogi-Labin, A., Hemleben, Ch, Meischner, D., Schmelzer, I., Smeed, D.A., 2003. Sea level fluctuations during the last glacial cycle. Nature 423, 853–858.
Slack, M., Fillios, M., Fullagar, R., 2009. Aboriginal settlement during the LGM in brockman, Pilbara region, western Australia. Archaeol. Ocean. 44, 32–39.
Smith, M.A., 2013. The Archaeology of Australia's Deserts. Cambridge University Press, Cambridge.
Stephenson, B., 2015. A modified Picro-Sirius Red (PSR) staining procedure with polarization microscopy for identifying collagen in archaeological residues. J. Archaeol. Sci. 61, 235–243.
O'Connor, Sue, Ulm, Sean, Fallon, Stewart J., Barham, Anthony, Pre-Bomb, Ian Loch, 2010. Marine Reservoir Variability in the Kimberley Region, Western Australia. Radiocarbon 52 (3), 1158–1165 (20th Int. Radiocarbon Conference Proceedings).
van der Kaars, S., De Deckker, P., 2002. A late quaternary pollen record from deep-sea core Fr10/95, GC17 offshore Cape Range Peninsula, northwestern Western Australia. Rev. Palaeobot. Palynol. 120, 17–39.
van der Kaars, W.A., De Deckker, P., Gingele, F.X., 2006. A 100 000-year record of annual and seasonal rainfall and temperature for northwestern Australia based on a pollen record obtained offshore. J. Quat. Sci. 21, 879–889.
Veth, P., 1982. Testing the Behavioural Model - the Use of Open Site Data. Honours Thesis. University of Western Australia.
Veth, P., 1993. Islands in the interior: the Dynamics of Prehistoric Adaptations within the Arid Zone of Australia. International Monographs in Prehistory. Archaeology Series no. 3, Ann Arbor, MI.

Veth, P.M., 2005. Cycles of aridity and human mobility: risk minimisation among late Pleistocene foragers of the Western Desert, Australia. In: Veth, P.M., Smith, M., Hiscock, P. (Eds.), Desert Peoples: Archaeological Perspectives. Blackwell Publishing, Oxford, pp. 100–115.
Veth, P.M., Aplin, K., Wallis, L., Manne, T., Pulsford, Chappell, A., 2007. Late Quaternary Foragers on Arid Coastlines: Archaeology of the Montebello Islands, Northwest Australia. Archaeopress, Oxford.
Veth, P.M., Ditchfield, K., Hook, F., 2014. Maritime deserts of the australian northwest. Aust. Archaeol. 79, 156–166.
Veth, P., Ward, I., Manne, T., Ulm, S., Ditchfield, K., Dortch, J., Hook, F., Petchey, F., Hogg, A., Questiaux, D., Demuro, M., Arnold, L., Spooner, N., Levchenko, V., Skippington, J., Byrne, C., Basgall, M., Zeanah, D., Belton, D., Helmholz, P., Bajkan, S., Bailey, R., Placzek, C., Kendrick, P., 2017. Early human occupation of a maritime desert, Barrow Island, North-West Australia. Quat. Sci. Rev. 168, 19–29.
Vinnicombe, P., 1987. Dampier Archaeological Project: Resource Document of the Survey and Salvage of Aboriginal Sites, Burrup Peninsula, Western Australia. Department of Aboriginal Sites, Western Australian Museum, Perth.
Waelbroeck, C., Labeyrie, L., Michel, E., Duplessy, J.C., McManus, J.F., Lambeck, K., Balbona, E., Labracherie, M., 2002. Sea level and deep-water temperature changes derived from benthic foraminifera isotopic records. Quat. Sci. Rev. 21, 295–305.
Walthall, J.A., 1998. Rockshelters and hunter-gatherer adaptation to the pleistocene/holocene transition. Am. Antiq. 63, 223–238.
Ward, I., Larcombe, P., Mulvaney, K.J., Fandry, C.A., 2013. The potential for discovery of new submerged archaeological sites near the Dampier Archipelago, Western Australia. Quat. Int. 308/309, 216–229.
Williams, M., Cook, E., van der Kaars, S., Barrows, T., Shulmeister, J., Kershaw, P., 2009. Glacial and deglacial climatic patterns in Australia and surrounding regions from 35 000 to 10 000 years ago reconstructed from terrestrial and near-shore proxy data. Quat. Sci. Rev. 28, 2398–2419.
Wintle, A.G., Murray, A.S., 2006. A review of optically stimulated luminescence characteristic and their relevance in single-aliquot regeneration dating protocols. Radiat. Meas. 41, 369–391.
Winton, V., Brown, V., Leopold, M., D'Ovidio, B., Yushiharni, E., Carson, A., Hamlet, C., 2016. The first radiometric Pleistocene date for aboriginal occupation at weld range, inland mid-west, western Australia. Aust. Archaeol. 82, 60–66.
Woodroffe, C.D., Thom, B.G., Chappell, J., 1985. Development of widespread mangrove swamps in mid-Holocene times in northern Australia. Nature 317, 711–713.
Yokoyama, Y., De Deckker, P., Lambeck, K., Johnston, P., Fifield, L.K., 2001. sea level at the last glacial maximum: evidence from northwestern Australia to constrain ice volumes for oxygen isotope stage 2. Palaeogeography, palaeoclimatology. Palaeoecol. 165, 281–297.