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Long-term occupation on the edge of the desert: Riwi Cave in the southern Kimberley, Western Australia

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ABSTRACT

Aboriginal people occupied Riwi, a limestone cave in the south-central Kimberley region at the edge of the Great Sandy Desert of Western Australia, from about 46000 years ago through to the historical period. The cultural materials recovered from the Riwi excavations provide evidence of intermittent site use, especially in climatically wet periods. Changes in hunting patterns and in hearth-making practices about 34000 years ago appear to accompany a change to drought resistant vegetation in the site surrounds. Occupation during the Last Glacial Maximum highlights variation in aridity trends in the broader environmental record. The most intensive use of the cave was during a wet period in the early to middle Holocene, when people appear to have received marine shell beads from the coast through social networks. While there is less evidence for late Holocene occupation, this probably reflects deposition processes rather than an absence of occupation.

Keywords: Kimberley archaeology, Pleistocene, Holocene, Last Glacial Maximum variation, intra-site variation

RÉSUMÉ

Les fouilles archéologiques de Riwi, une grotte karstique au sud du Kimberley (région située à la lisière nord du Great Sandy Désert en Australie-Occidentale) ont permis de mettre en évidence des traces d'occupation aborigène datées entre 46000 ans jusqu'à la période historique. Le matériel découvert et les analyses paléoenvironnementales démontrent une utilisation intermittente du site, avec une préférence pour les périodes humides. Autour de 34000 ans, on observe un changement des pratiques liées à la chasse et la construction de foyers associé à l'expansion d'une végétation xérophile (adaptée à la sécheresse). La présence de niveaux datés du dernier maximum glaciaire démontre une fois de plus qu'il existe une grande variabilité au sein même des enregistrements environnementaux datés de cette époque. La période d'occupation la plus intense se situe durant une période humide au début de l'Holocène moyen au cours de laquelle on observe aussi des échanges culturels de longues distances mis en évidence par la présence de perles de coquillages marins provenant de régions costales. L'occupation datant de l'Holocène tardif est discrète, probablement due à un changement de dynamique sédimentaire dans la grotte.

Mots-clés: archéologie du Kimberley, Pléistocène, Holocène, Dernier Maximum Glaciaire variabilité, stratigraphique intra-site

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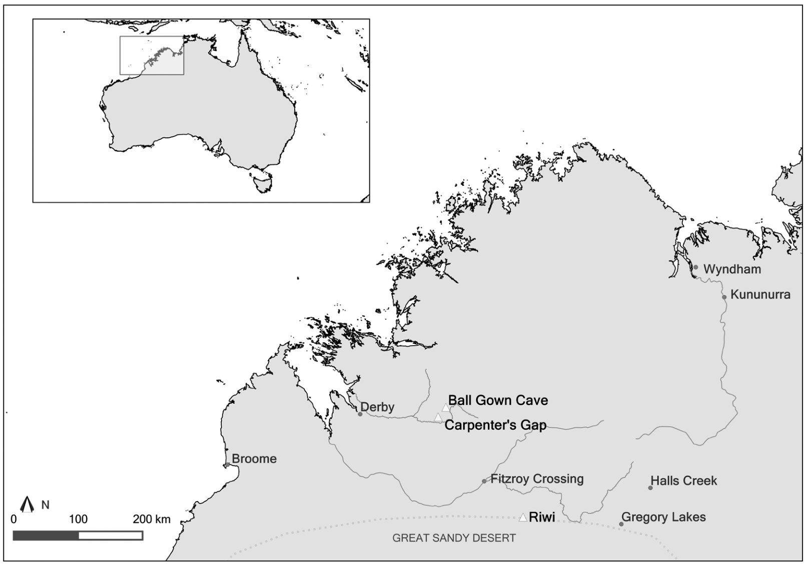
INTRODUCTION

Riwi, a limestone cave situated on Gooniyandi traditional lands in the south-central Kimberley region of Western Australia (Figure 1), contains evidence for human occupation from about 46.4–44.6 kya calBP to the present (Wood *et al.* 2016). A single 1 m^2 test excavated in 1999 (Balme 2000) was extended in 2013 as part of the "Lifeways of the First Australians" project' in order to test whether the chronological sequence obtained from the 1999 test trench could be extended and to obtain a larger sample of Pleistocene cultural materials. The site is important because of its fine resolution dating spanning a long time period, and the variety of archaeological materials that it preserves, including scaphopod beads (Balme & Morse 2006; Balme & O'Connor 2017; Balme *et al.* 2018), wood charcoal (Whitau *et al.* 2017), wooden artefacts (Langley *et al.* 2016; Whitau *et al.* 2016) and macrobotanic remains

Figure 1. The Kimberley region of north-west Australia, showing the position of Riwi and other places mentioned in the text.



(Dilkes-Hall 2014). Its location on the edge of the Great Sandy Desert (Figure 1) provides an opportunity to examine responses to environmental change. In particular, the effect of Last Glacial Maximum (LGM) aridity on desert populations has been a much debated topic in Australian archaeology (Veth 2005; Veth *et al.* 2008, 2009, 2014, 2017a), with suggestions that discontinuities in cultural evidence at lowland arid sites reflect population reconfigurations in these areas. Given Riwi's location on the edge of the desert and the absence of permanent water in the immediate region, it might be expected that during the LGM aridity, there could have been a reduction in frequency or intensity of occupation and changes in economic resource use at Riwi. In this paper, we present the archaeological evidence from Riwi in its environmental context over time. The fine-resolution chronological sequence, based on optically stimulated luminescence and radiocarbon dating, has been published elsewhere (Wood *et al.* 2016). Here, we focus our discussions on the unpublished cultural remains recovered during 2013.

REGIONAL ENVIRONMENTAL RECORDS

The south-central Kimberley where Riwi lies is within the 500 mm isohyet of the Australian summer monsoon. At the time that the site was first occupied by people, the climate was more humid than today. The evidence for this humidity derives from interpretation of sediments within the monsoon influenced arid zone in the Gregory Basin to the south-east (Fitzsimmons *et al.* 2013; Veth *et al.* 2009) and pollen records from deep-sea core Fr10/95-GC17, collected offshore from Cape Range peninsula (De Deckker *et al.* 2014; van der Kaars & De Deckker 2002; van der Kaars *et al.* 2006).

Between about 40 and 30 kya, the climate is generally characterised by humid conditions (Fitzsimmons *et al.* 2013), although from about 32 kya conditions appear to have become cooler and drier, as indicated by a variety of palaeoenvironmental records in northern Australia (Reeves *et al.* 2013), intermittent dune building in the Gregory Lakes area (Figure 1) (Fitzsimmons *et al.* 2013) and in the pollen records from the offshore Cape Range peninsula core (van der Kaars & De Deckker 2002).

The LGM from 22000 to 18000 BP (Ishiwa *et al.* 2015) is generally considered to be the coolest and driest period of human occupation with, for example, van der Kaars *et al.* (2006) suggesting that the driest phase occurred between 33 and 20 kya – with virtually no summer rain – and Fitzsimmons *et al.* (2013) suggesting that lakes and rivers in the Gregory Lakes area experienced lower levels and reduced flow respectively, as a result of an absence of the monsoon in northern Australia. However, a stalagmite record from Ball Gown Cave, about 175 km to the north-west of Riwi (Figure 1), suggests an active monsoon across the western Kimberley during the LGM between 24 and 20 kya (Denniston *et al.* 2013a).

From about 14 kya, evidence from the area suggests greater moisture. This evidence includes higher than present lacustrine deposits at Lake Paraku at ~14 kya BP (Wyrwol & Miller 2001), speleothem evidence from Ball Gown Cave from 13 kya calBP (Denniston *et al.* 2013a), and pollen and microcharcoal records from Black Springs (Field *et al.* 2017), a mound spring about 300 km to the north of Riwi.

The evidence from Black Springs shows a particularly wet period between 8.5 and 7 kya (Field *et al.* 2017: 13). Other evidence for a wet period at that time derives from the KNI-51 speleothem record in the north-east Kimberley, which indicates the greatest precipitation between ~9 and 7 kya calBP (Denniston *et al.* 2013b). In addition, offshore

Figure 2. Riwi in its environmental setting, from the south-west. [Colour figure can be viewed at wileyonlinelibrary.com]

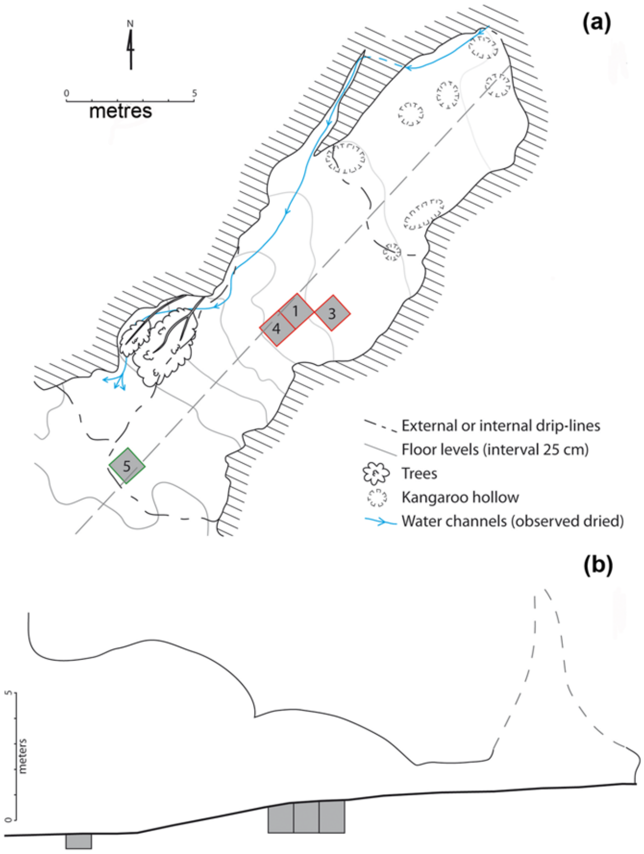
pollen records also indicate a thermal maximum at 8 kya calBP and peak precipitation between 7 and 6 kya calBP (van der Kaars *et al.* 2006).

THE SITE AND EXCAVATIONS

Riwi is located on the west side of the South Lawford Range, within a valley through which an ephemeral creek flows during the wet season. Skeletal soils within the valley support low scattered trees and spinifex (Figure 2). The two-chambered cave is cut deep and high into the Devonian limestone range. The floor of the cave covers about 146 m^2 (Figure 3) and gently slopes towards the entrance. A small washway on the north-west side of the first chamber indicates water movement within the cave during the wet season.

The 1999 trench (Square 1) was excavated by Balme with Gooniyandi elders about 9 m inside the drip-line (Figure 3) to a depth of 50 cm in three of its four 50 cm^2 quadrants and to about 105 cm in the remaining quadrant, where it reached bedrock. Radiocarbon age estimates obtained on charcoal from that excavation demonstrated that occupation spanned over 40000 years, but with a discontinuity between 35 kya calBP and 7 kya calBP (Balme 2000). In August 2012, we returned to Riwi with Zenobia Jacobs to empty Square 1 and take samples for OSL dating from its eastern section. Once sampling was complete, the trench was refilled and in August of the following year we again returned to the site to conduct further excavations. Square 1 was emptied and the excavation in the remaining three quadrants was continued to bedrock. Three more 1 m^2 trenches were excavated to bedrock: Squares 3 and 4, adjoining Square 1, and Square 5, just inside the drip-line of the cave (Figure 3).

Figure 3. (a) A plan of the cave floor, showing the positions of trenches excavated in 1999 and 2013. (b) A section through the cave (after Vannieuwenhuyse 2016). [Colour figure can be viewed at wileyonlinelibrary.com]



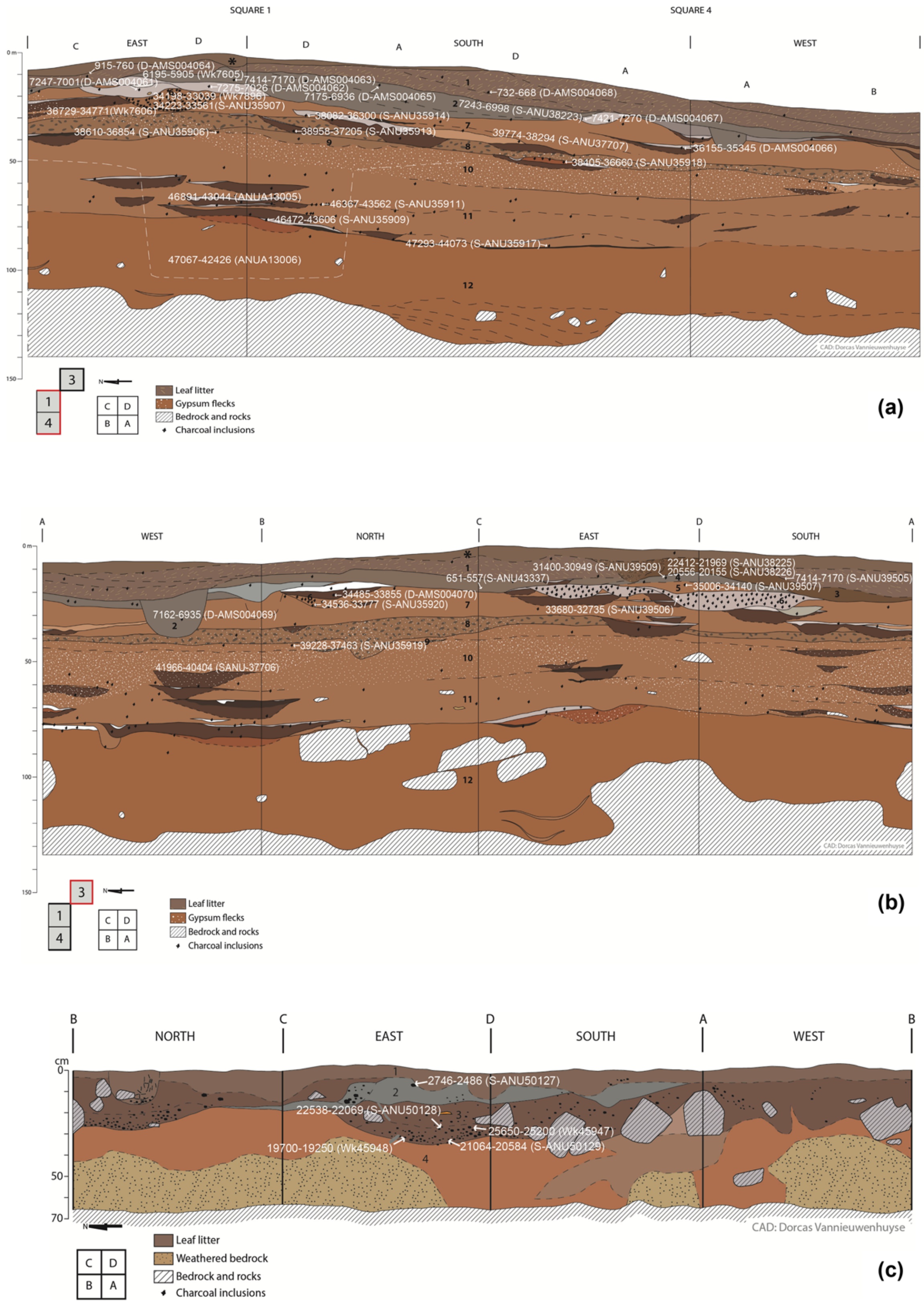
Excavation techniques

The 1999 and 2013 excavation techniques differed. In 1999, excavation was carried out in 5–10 cm excavation units (XUs) (except where guided by changes in stratigraphy). In the upper part of the deposit, the XUs averaged ~5 cm, whereas in the lower deposits where little or no cultural material was encountered, the XU thicknesses were greater. All excavated deposit was dry sieved at the site using nested 6 mm and 2 mm sieves. In 2013, excavation was carried out in 2 cm XUs (although the deepest four XUs in the sterile part of the deposit were slightly thicker, at ~5 cm) and a 5 mm and 1.5 mm sieve set was used for screening. Because it was difficult to identify some stratigraphic changes during excavation, especially in the upper part of the deposit, the XUs were horizontal and this has resulted in some XUs cross-cutting stratigraphic layers, particularly in the Holocene part of the deposit and where a remnant area of LGM deposits occurs in Square 3.

STRATIGRAPHY AND THE CHRONOLOGICAL SEQUENCE

As Figure 4a,b shows, there are some stratigraphic changes visible in the profiles of Squares 1, 3 and 4 and, on the basis

Figure 4. Excavation sections (after Vannieuwenhuyse 2016) with the positions of ^{14}C dates: (a) Square 1, east wall and Square 4, south and east walls; (b) Square 3; and (c) Square 5.



of these, 12 stratigraphic units (SUs) were identified (Vannieuwenhuyse 2016; Wood *et al.* 2016). The sediments of SUs 12–3 (120 cm to approximately 20 cm below the surface) are dominated by brown sediments and interspersed with hearths. SU 2 and SU 1 unconformably overlie SU 3 and their grey appearance results from the high proportion of ash (Vannieuwenhuyse 2016).

Square 5 is about 67 cm deep. Four SUs were identified in this square on the basis of textural and colour changes (Figure 4c).

The results of the radiocarbon and OSL dating of Squares 1, 3 and 4 demonstrate an excellent agreement between the two techniques (Wood *et al.* 2016). The modelled dates for each of the stratigraphic units are summarised in Table 1. In summary, deposition began about 50 kya, with the earliest clear evidence for first human occupation being a hearth at the top of SU 12 with a modelled date of 46.4–44.6 kya calBP (95.4% probability range) (Wood *et al.* 2016: 17) (Figure 4a,b). Sedimentation was rapid between the top of SUs 12–4, with around 0.5 m of sediment deposited between 16.8–13.8 kya calBP (68.2% probability). After this relatively continuous sedimentation, three hiatuses interspersed with short, discrete pulses in sedimentation occur at c.32 kya calBP (SU 4), c.25 kya calBP (SU 3) and c.7 kya calBP (SU 2).

The causes of these hiatuses probably vary, but the slope of the sediments and the presence of a water channel within the cave today suggest that water run-off may be the major cause of erosion. Higher precipitation between 24 and 20 kya, and especially between about 9 and 7 kya, most probably accounts for sediment removal, producing the first two hiatuses. The contact between the Pleistocene and Holocene layers is particularly sharp, suggesting high-energy erosion consistent with this interpretation. Secondary formation of gypsum, particularly visible in the upper Pleistocene deposits between SUs 10 and 4, suggests that some moisture has penetrated the sequence and this could have well occurred at the time of the erosion event about 7 kya.

Vannieuwenhuyse (2016: 167) has suggested that the reduced rate of deposition in the sequence from about 34 kya, after which only pulses of sediment are present (such as at 31 kya and the remnant hearth feature dating to the LGM within SU 3 in the south-east corner of Square 3) might indicate that the cave has reached its maximum potential to hold sediment unless erosion occurred. Once the high-energy erosion event occurred before 7 kya, it was possible for more sediments to accumulate, but this perhaps reached its maximum capacity quickly. This might explain the absence of sediments after that time, requiring further erosion before the small amount of cultural deposit representing the past 1000 years could accumulate.

Since the publication of Wood *et al.* (2016), we have received radiocarbon results on charcoal from Square 5 that provide confirmatory evidence of the occupation of the site during the LGM (Figure 4c and Table 2). The charcoal for four of these dates was removed *in situ* from hearth deposits. The remaining date was on charcoal recovered from XU 7 sieve residue. XU 7 is at the top of SU 4, and we were hoping to be able to date the red sediments of SU 4, where no charcoal was otherwise present. However, the radiocarbon results suggest that the sieve sample may, in fact, derive from SU 3. The colour and texture of SU 4 are similar to those of the Pleistocene sediments in the other squares. A sixth radiocarbon date from Square 5 (S-ANU 50032), obtained on a scaphopod bead, produced a date of 6898 ± 40 (7792–7600 calBP). This bead was recovered from SU 1 and is not included in the discussion of the square's chronology as it may have been recycled from older deposits elsewhere in the site or from sites elsewhere.

The radiocarbon dates on charcoal indicate a hiatus between about 20 and 2.6 kya calBP in Square 5. The difference between the sequence at the entrance of the cave and those of the squares inside of the cave no doubt reflects greater sediment loss near the entrance and closer to the drip-line. It is also in the area of main access trampling by people and other animals.

DEPOSITIONAL PROCESSES

Vannieuwenhuyse (2016) described and analysed the sedimentary sequence including the sediment micromorphology of the site. In summary, the bulk of the sediment is dominated by geogenic sediment during the Pleistocene and anthropogenic and biogenic inputs during the Holocene.

The particle size distribution of the sediment suggests two different sources of the sands: well-sorted very fine (63–125 μm) subangular sands and coarser (250 μm – 2 mm), generally rounder sands. The coarser sands derive from *in situ* chemical weathering and physical breakdown of calcareous sandstone cave walls and bedrock. These sands are particularly prevalent in the bottom of the sequence, where they represent about 25% of the under 2 mm fraction in SU 12, 10–20% in strong brown reddish layers (SUs 11, 10, 7 and 5), 30% in SU 8 and between 10% and 15% of the Holocene layers (SUs 2 and 1).

Evidence of reworking by water is visible at the base of the sequence in the form of several water channels displaying concave shapes and showing fine silt sorting under the microscope. This suggests medium-energy water discharge through Riwi during the early phase of its depositional history and is consistent with the regional palaeoclimate evidence.

The bulk of the Pleistocene sediment is composed of well-sorted very fine quartz sands (63–125 μm), with proportions varying from 65% to 90% of the fraction < 2 mm, which is characteristic of aeolian deposits (Cooke *et al.* 2006; Goldberg & MacPhail 2005: 120–30). The subangular shape of these grains suggests that they have not been transported over a long distance. In addition, most of the grains are partially coated with a thin film of orange haematitic clay, which is a very common characteristic of Australian desert sands (Mabbutt 1988: 363). Thus aeolian reworking of exogenous material from local dunes seems to

Table 1. The stratigraphic unit boundaries and the time periods represented (95.4% probability range) as per the Bayesian analysis of radiocarbon dates for SUs 1–11 and the OSL modelled dates for SU 12 (after Wood *et al.* 2016, S4 and S5).

	Modelled boundary start date (calBP)		Modelled boundary end date (calBP)	
Stratigraphic unit	**From**	**To**	**From**	**To**
1	2530	700	660	–580
2	7685	7195	7155	5585
3	29140	20440	20570	16470
4	32800	30930	31390	24690
5	33710	31790	33330	31230
6	34920	33850	33970	32830
7	37670	35590	36040	34130
8	38430	36620	38130	36010
9	39590	37790	38600	37360
10	44060	40490	41530	38130
11	45420	43900	45080	42110
12			45860	44500
12 OSL	50860	46020	45250	42510

Table 2. Radiocarbon dates for Square 5. The radiocarbon dates have been calibrated against SHCal13 (Hogg *et al.*2013) in OxCal v.4.3 (Bronk Ramsey 2009).

Stratigraphic unit	Depth below surface (cm)	Laboratory code	Radiocarbon age	Calibrated date (95% probability)
1	4	S-ANU 50127	2560 ± 30	2746–2486 (95%) 2476–2471 (0.4%)
2	15	S-ANU 50128	18513 ± 82	22539–22070
3	21	S-ANU 50129	17306 ± 74	21064–20585
3	27	WK-45947	20997 ± 101	24592–25012
3	30	WK-45948	16153 ± 62	19633–19225
3/4	29–32	WK-45949	21082 ± 104	25656–25119

be the main agent of deposition within Riwi during the Pleistocene. There is no dune system in the direct vicinity of the cave today, but its position on the edge of the Great Sandy Desert and the presence of linear dunes less than 15 km to the south of the cave indicate probable sources of the sediments.

EVIDENCE FOR HUMAN OCCUPATION

In addition to the rock art on the walls, evidence for human occupation in Riwi includes artefacts of stone and organic materials, fauna and plant remains, pigment and hearths. The distribution of the most common types of evidence (charcoal, stone artefacts, macrobotanical remains and bone, as well as pigment), for Squares 3, 4 and 5 is shown in Figure 5. These distributions vary but there are some clear patterns visible. First, unsurprisingly, the Holocene part of the deposit contains the greatest diversity and quantities of archaeological evidence. Second, apart from bone, the organic materials have a unimodal distribution and are largely confined to the Holocene part of the deposit. In addition to the organic materials shown in Figure 5, all of the wood shavings, string and hair were recovered from the top SUs in all squares. This no doubt reflects the greater alkalinity and younger age of these units as the average pH of SUs 1–8 is 9, while the SUs below SU 8 range from pH 8 to pH 7.5. Most of the remaining types of evidence have a bimodal distribution with a large peak in the Holocene sediments and a second, smaller peak towards the base of the deposit between about SUs 9–11; that is, between about 38 and 46 kya. The distribution of hearths (Figure 4) is more even, although the thick ashy layer across the deposit in SU 2 probably represents several superimposed combustion events (Whitau *et al.* 2017) and so might suggest a Holocene peak in hearth making associated with the peaks in other materials.

Stone artefacts

A total of 2710 flaked stone artefacts were recovered from Squares 3, 4 and 5 (see Section S1 of the online Supporting Information). Following Hiscock (2002), the artefact counts presented in Section S1 of the online Supporting Information include the minimum number of flakes, which provides an additional measure of discard rates, free from the bias created by artefact fragmentation. Figure 6 demonstrates that the minimum number of flakes for each XU is consistent with the total number of artefacts discarded throughout each square. The minimum number of artefacts is particularly useful for the Riwi assemblage, as a notable number of heat-shattered fragments (pieces with varied degrees of crazing, crenulations and pot-lidding,

Figure 5. The distribution of quantities of archaeological materials per cubic metre of sediment excavated from Squares 3, 4 and 5 at Riwi. Stone artefacts and pigment fragments are measured as frequency per cubic metre and other materials by mass. The materials in each column are organised according to scale similarities. [Colour figure can be viewed at wileyonlinelibrary.com]

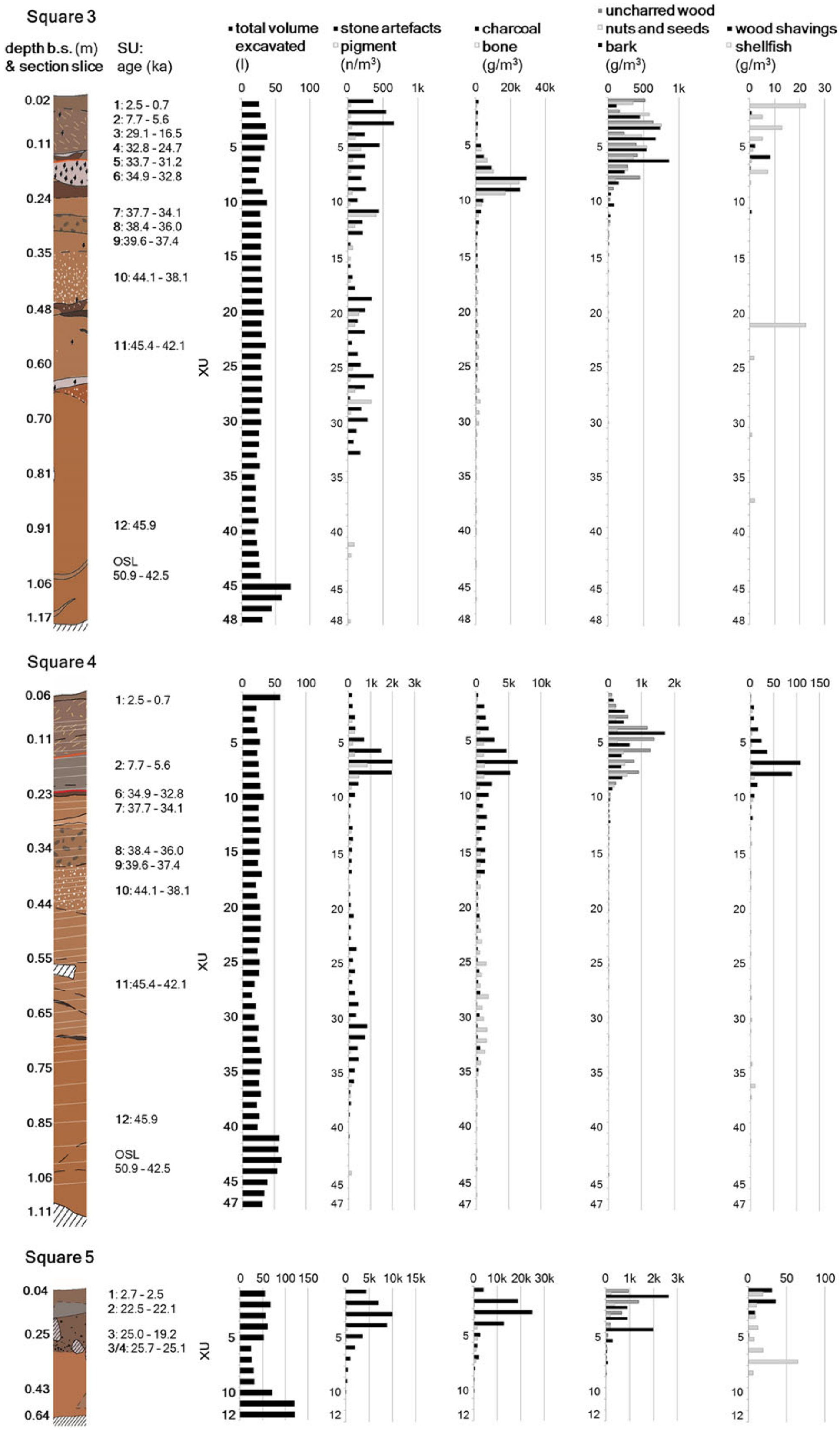
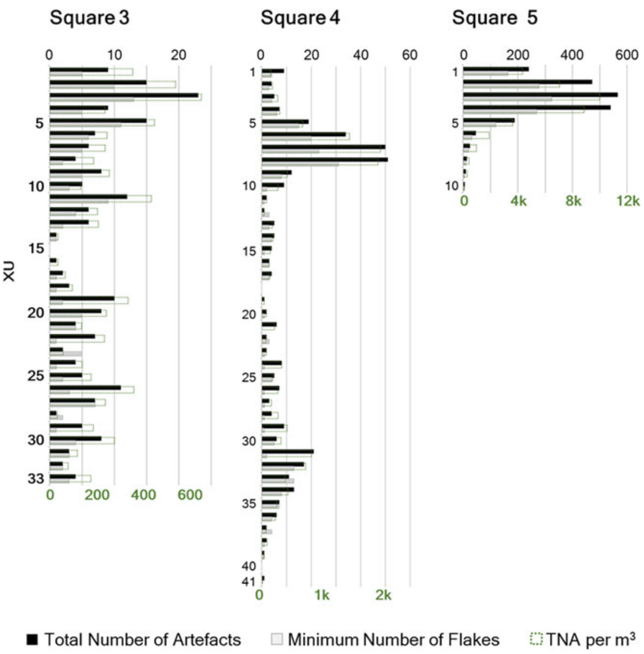


Figure 6. Artefact frequencies for Squares 3, 4 and 5, including the total number of artefacts, minimum number of flakes and artefacts per cubic metre. [Colour figure can be viewed at wileyonlinelibrary.com]



which cannot be attributed to other artefact classes), are present throughout each square (Square 3, $n = 12$, 5.6%; Square 4, $n = 43$, 12%; Square 5, $n = 165$, 8%). Together with the recovery of pot lids, the heat-shattered pieces indicate that artefacts were affected by heat while within the shelter. Flakes and cores also display consistent signs of heat throughout the sequence in each square, with no obvious change over time in the deeper squares (Square 3, $n = 25$, 11%; Square 4, $n = 58$, 16%; Square 5, $n = 209$, 10%). This is no surprise given the number of hearth features, although the distribution of heat signals across all artefact categories probably rules out deliberate heat treatment of the stone.

Despite the low numbers of artefacts per XU in Squares 3 and 4, the discard trends depicted in Figure 6 suggest a bimodal peak. In Square 4, this trend is most pronounced between XUs 38–29 and 9–5, with the former discard occurring during the Pleistocene, and the latter deriving from two distinct Holocene units towards the surface of the deposit, around 7 kya calBP and 1 kya calBP (Figure 5). Comparison between these two peaks reveals no change in raw material procurement, as measured by the number of raw material types ($\chi = 246.000$, $p = 0.381$), or in flake morphology, as measured by percussion length using a Mann–Whitney test ($Z = -0.745$, $p = 0.456$), width ($Z = -0.136$, $p = 0.892$) or mass ($Z = -0.331$, $p = 0.741$). Adjusting artefact densities per unit of excavated sediment volume in these squares, the lower-discard trend is slightly less pronounced (Figure 6).

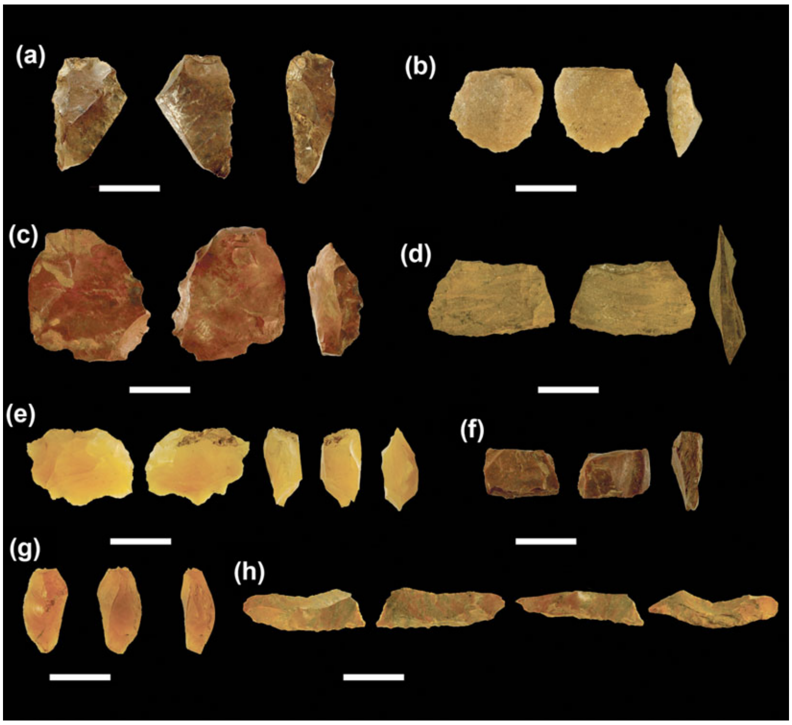
No morphological change was identified in the artefact sequences of Squares 3 and 4 throughout the sequence, suggesting a stable system of flake production with little technological change. There are few retouched flakes ($n = 8$) in the Pleistocene units, although the presence of concentrated step fractures ~1 mm with pronounced marginal rounding (Square 3, $n = 10$; Square 4, $n = 13$) suggests that the margins of morphologically varied flakes were frequently utilised. A single tula adze recovered from Square 4 derives from XU 7 in SU 1, dated to between c.2.5–0.6 kya calBP. Core reduction ($n = 21$) displays no obvious change throughout the sequence, with unidirectional, multidirectional and bipolar cores throughout. Core morphology is varied, with between one and four rotations, and 7–23 scars at discard.

Artefacts recovered in Square 5 suggest some technological difference from the squares within the shelter. First, the Square 5 assemblage contains proportionately more retouched flakes ($n = 17$), retouched flake fragments ($n = 5$) and utilised flakes ($n = 76$), suggesting greater technological diversity towards the front of the shelter. Of the retouched flakes, six tula adzes and five stone points were recovered (Figure 7).

Tula adzes are recognised by their high width-to-length ratio, a prominent bulb of percussion, a relatively wide gull-wing platform and characteristically steep retouch (Figure 7d-h) (Hiscock & Veth 1991: 333–4). A range of retouch intensities are evident in the discarded tulas from Square 5, with some rotated multiple times (Figure 7g), and others retouched from the ventral surface until the bulb is obliterated (Figure 7h), resembling what is often referred to as a tula adze slug (Hiscock & Veth 1991: 339). Four of the tulas were from units above charcoal dated to 2745–2470 calBP 95.4% (S-ANU50127). Two other tulas were recovered from units associated with LGM dates (XUs 6 and 8). We attempted to directly date resin adhering to one of these (Figure 7e) but were unsuccessful, as the samples did not survive pre-treatment. We suggest that the shallow, loosely compacted sediments in Square 5, coupled with high treadage in this zone of the cave, most probably resulted in vertical downward movement of these artefacts. This proposition is supported by univariate, general linear model tests ($F = 0.961$, $df = 1$, $p = 0.614$; $r_s = 0.034$). A single bifacial preform, a production stage of Kimberley points (similar to Moore 2015: 926), was recovered from XU 2 in this same square. The other reported points ($n = 4$) were recovered in lower units and reduced from flakes, with a diversity of unifacial and bifacial retouch. One of these (Figure 7a) retains the steep-angled bipolar retouch, identified by Maloney and O'Connor (2014) as backed Kimberley points.

Comparison between the lithic assemblages of Square 5 and the inner two squares using a Mann–Whitney test, reveals significant differences in percussion length (Square 5 vs. 4, $Z = -1.892$, $p = 0.05$; Square 5 vs. 3, $Z = -3.270$, $p = 0.001$), further suggesting that flakes are typically larger towards the front of the shelter. Other measures of reduction such as flake cortex, measured as primary, secondary and tertiary, display no significant change throughout the sequence in the deepest squares (Square 3,

Figure 7. Retouched flakes from Riwi. (a) A chert unifacial point, with a steep retouched edge angle ~90° and some crushing on the opposite dorsal ridge, similar to backed points described by Maloney and O'Connor (2014). (b) A quartzite adze tula with unifacial retouch. (c) A red chert retouched flake with steep, tula-like retouch along the left ventral margin. (d) A fine-grained sedimentary adze tula with very light retouch. (e) A chalcedony adze tula showing multiple rotations and traces of hafting resin: attempts at dating the resin failed to survive pre-treatment. (f) A red chert retouched flake fragment, showing crazing. (g) A chalcedony adze tula reducing close to the bulb. (h) A mottled brown chert adze tula reduced close to the bulb. Scale bar 10 mm.



$Z = –0.085$, $p = 0.932$; Square 4, $Z = –1.492$, $p = 0.163$). The ratio of flakes to cores is high throughout (see Section S1 of the online Supporting Information), which may indicate that cores were frequently transported away from the site.

Chert and chalcedony are the main raw materials, with little variation through time and across the squares. In the immediate vicinity of the site, and at several locales within 3 km, there are multiple chert seam outcrops emerging from skeletal soils. Macroscopically, these resemble the artefacts recovered from within the shelter. Flakes made on volcanic material are present in Square 3 ($n = 2$) and Square 4 ($n = 17$), including two from Pleistocene layers, although none of these have evidence for ground-edge axe maintenance as has been found at other early sites in the region (Hiscock *et al.* 2016; O'Connor *et al.* 2014). The inclusion of small amounts of silcrete, crystal quartz, agate and quartzite are most notable in the artefact peaks of Square 3, yet across the whole site make up less than 8% of exploited stone.

The flakes from the LGM units preserved in Square 3 (XUs 5, 4 and 3 in Quadrant D), display no morphological difference with surrounding units in flake percussion length ($n = 22$, $\chi^2 = 112.000$, df $= 108$, $p = 0.377$) or mass ($n = 48$, $\chi = 131.968$, df $= 138$, $p = 0.629$), which suggests that no significant technological change accompanied this period. While there is a high probability of vertical movement within the upper units of Square 5, markedly fewer artefacts were recovered below XU 6 than in the upper units in this square, suggesting that during the LGM, artefacts were less frequently used or at least discarded, than during the late Holocene occupation.

Organic artefacts

Organic artefacts recovered from Riwi include shell beads, four wooden artefacts, wood shavings, twisted fibre fragments, spinifex that has been used to encase edible freshwater shell and bone artefacts. All of these derive from Holocene deposits. Previous suggestions that the beads recovered from Square 1 may be Pleistocene (Balme & Morse 2006) were based on their stratigraphic position within Pleistocene sediments. However, a direct date on one of these was assayed at 7644–7459 calBP (Balme & O'Connor 2017: 10; Balme *et al.* 2018: 263), suggesting that it is likely that all of the Riwi beads date to the early Holocene, and that the Square 1 beads may have been moved downwards into the immediately underlying Pleistocene sediments.

One of the wooden objects, dating to about 700 years ago, has been interpreted as a fragment of boomerang (Langley *et al.* 2016). A second wooden object is interpreted as the negative part of a fire drill (Whitau *et al.* 2016). The material from which the former object was made was identified as *Grevillea*/*Hakea* sp., while the latter object was made from Lamiaceae (Whitau *et al.* 2016). The remaining two wooden objects are sticks from Square 5, XUs 6 and 7. One end of each stick is burnt and flattened slightly and the shafts have been decorated with white dots. The shape and flattened end of these objects are similar to several fire drills collected in the early twentieth century and now held at the Western Australian Museum (e.g. E9406 and A848) and so they have been tentatively identified as fragments of fire drills. The abundant wood shavings found in the Holocene deposits in all squares indicate that wooden artefacts were made inside the cave.

Nine fragments of twisted fibre have been recovered from the site – all from Holocene contexts. Two fragments are made from human hair, one from Square 3, XU 3 and one from Square 4, XU 6. The remaining seven fibre fragments are two-ply and made from plant material. Five of these come from the XUs 2 and 3 in Square 5, but at least two separate twines appear to be represented, as two fragments are much thicker than the other three. One of these fragments has a knot joining two pieces. The remaining two fibre fragments come from Square 4, XU 6 and Square 3, XU 4.

Spinifex and clay used to wrap freshwater shellfish (*Lortiella froggatti*) found in the Holocene deposits of Square 1 provide evidence of a use for spinifex not previously recorded in archaeological contexts.

Pigment

Small amounts of orange and red ochre (total 108 g) are consistently found throughout the deposit from XU 11 (Figure 5). Although no grinding surfaces were noted, its distribution closely matches the distribution of other archaeological materials from the site.

Animal bones

Variation in the distribution of quantities of animal bone from all squares closely matches the distribution of other archaeological material (Figure 5). Apart from the small number of remains below XU 31 and the pronounced concentration of remains in XUs 5–10 of Square 3, the stratigraphic distribution of 5 mm bone in Squares 3 and 4 match reasonably well. Square 3 has a more strongly differentiated stratigraphic pattern in bone quantities (Figure 5), with a huge spike in 5 mm bone quantities between XUs 5 and 10, where hearth features F2, F4, F5 and F8 have been identified (Whitau *et al.* 2017). Below XU 10, there are three lesser peaks centred on XUs 16–18, XUs 22–24 and XUs 27–30 that contain hearths and correspond to a similar distribution of other archaeological materials (Figure 5).

A preliminary analysis of the animal bones recovered from the 5 mm sieve of Square 3 was undertaken by inspecting each bone for taphonomic markers, such as chew marks, analysing variations in the degree of burning as a measure of preservation and taxonomic identification. The bones and teeth are relatively well preserved throughout. Some of the bone from the uppermost levels of the site (XUs 2–6 of Square 3) has adhering faecal material, often with embedded animal hairs and with rounded edges, suggesting that these fragments have passed through a carnivore's gut (Gifford-Gonzales 2018: 237-8). The most likely responsible carnivore is the dingo, either in direct association with human visitors to the site, or as feral animals visiting the site when it was not in human use.

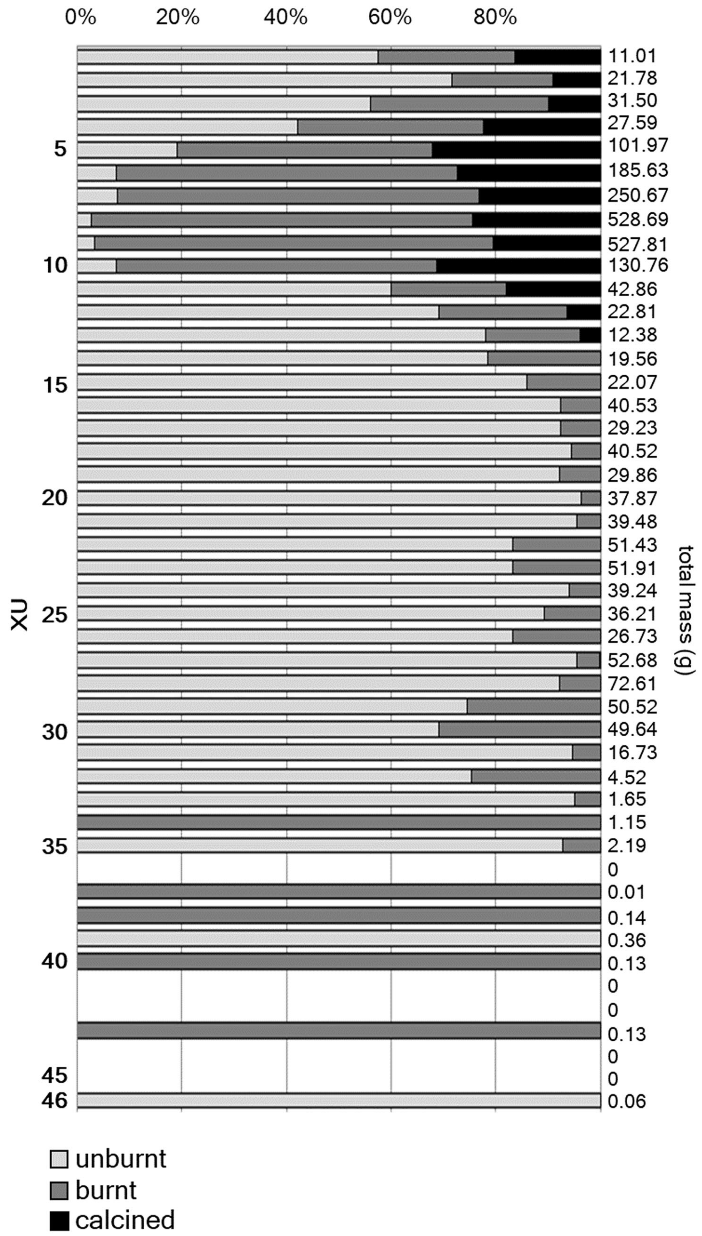
Evidence of burning provides insights into the extent to which post-depositional degradation has affected the faunal assemblage and, where degradation is not supported by the condition of bone fragments, variation in burning composition can also provide insights into aspects of human behaviour such as cooking and disposal practices (Aplin *et al.* 2016). The bone from Square 3 were categorised by burning condition using a three-stage system developed by Aplin *et al.* (2016): unburnt – with no or little heat modification; burnt – charred, carbonised and partially calcined; calcined – most of the fragment fully calcined. Remains from the lower levels of Riwi are darkly stained, presumably by manganese oxide, and this sometimes blurs the distinction between unburnt and burnt bone. In such cases, only the most compelling examples were classified as burnt.

The burning composition varies through the stratigraphic profile (Figure 8). These variations do not appear to reflect differential preservation of bone according to its state, as none of the unburnt remains display the characteristic surface alterations typical of microbial degradation (Aplin *et al.* 2016: 702). Instead, the variation in burning composition most probably reflects variation in human behaviour through time or across the site, especially the concentration of calcined bone in the upper part of the deposit, where the most hearth evidence is found (Whitau *et al.* 2017).

Every bone from Square 3 was then closely examined for taxonomically assignable remains such as teeth, fragments of cranium, pelvic and pectoral girdles, bones of the hand and foot, and the articular ends of all limb elements. Taxonomic identifications were made only at a relatively coarse level, usually to family or genus in the case of reptiles and mammals, with additional size categories employed where appropriate. The taxonomic composition is provisionally quantified by numbers of identified specimens (NISPs). The "unidentified" fraction of each sample consists primarily of bone fragments derived from medium- to large-sized mammals, including small pieces of long bone shaft, and fragments of vertebrae and ribs. It probably also contains a smaller representation of highly fragmentary reptile and bird bones.

The taxonomic identifications are provided as Section S2 of the online Supporting Information and are summarised in Figure 9. Four main groups of vertebrates make up the bulk of the Riwi assemblage. These are macropodids (wallabies and kangaroos), other smaller mammals (such as bandicoots, rat kangaroos, possums, rats and flying foxes), reptiles of various kinds and birds. In terms of

Figure 8. The burning composition of the 5 mm bone fraction through the stratigraphic profile in Square 3 of Riwi.



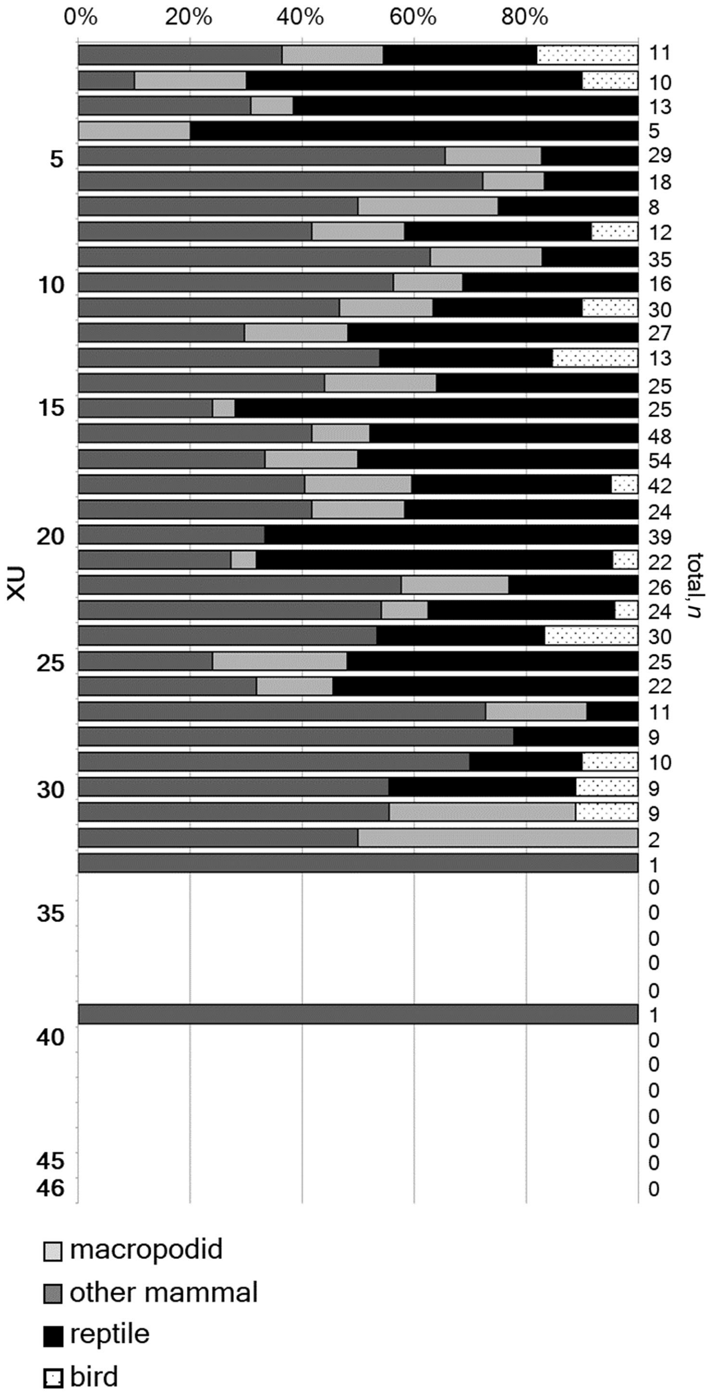
palaeoecological interpretation, it is clear that the fauna contains a mix of taxa associated with three main habitats: tropical savannah, sandy desert and rocky hillsides/gorges. There is no evidence for the presence of extinct megafaunal macropodids, such as species of *Sthenurus* or *Protemnodon*, and none of the *Macropus* dental remains are obviously outside of the ranges of contemporary populations.

The distribution of the macropodid remains is shown in Figure 10, in which the remains have been provisionally scored according to four size categories:

- small (e.g. species of *Lagorchestes*, *Onychogalea* or *Petrogale*);
- medium (probably agile wallaby, *Macropus agilis*);
- medium to large (possibly some agile wallaby, some wallaroo [*M. robustus*]);
- large (probably red kangaroo [*M. rufus*] and/or antilopine kangaroo [*M. antilopinus*]).

The proportion of macropodid remains in each size category shows several shifts and trends through the stratigraphic profile (Figure 10). The major contrast distinguishes XUs 2–10, covering the periods c.34–31 kya calBP and c.7–0.6 kya calBP) from all lower spits – the upper levels are dominated by large kangaroo remains, whereas the lower levels have larger numbers of small wallabies of various kinds, along with a significant representation of a medium-sized wallaby (most likely the tropical savannah inhabitant *M. agilis*). The lowermost part of the sequence also features a higher proportional representation of large macropodid remains, with small

Figure 9. The broad taxonomic composition of the 5 mm bone fraction through the stratigraphic profile in Square 3 of Riwi.



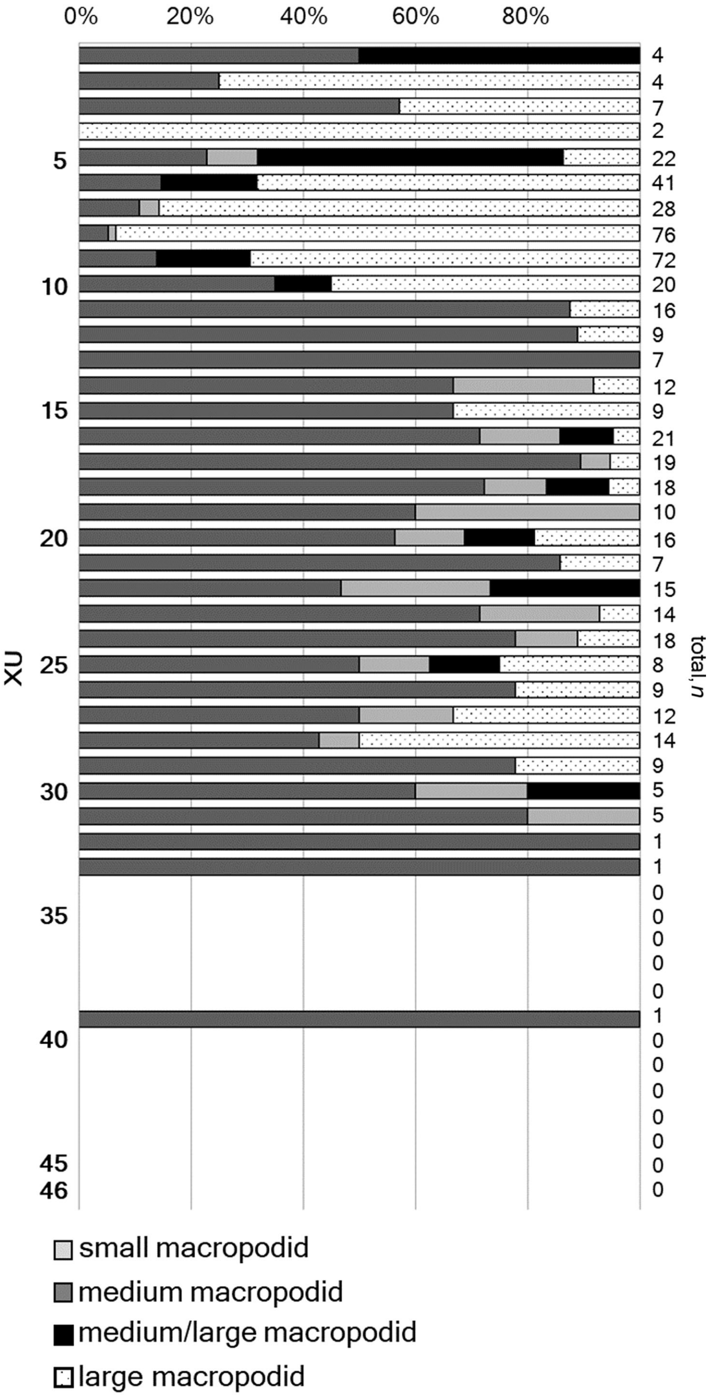
macropodid remains gradually becoming more prevalent and reaching peak levels in XUs 11–13.

Other medium-sized species identified include a burnt lower molar of *Sarcophilus* from XU 9, *Tachyglossus* (short-beaked echidna), *Macrotis* sp. (bilby), *Trichosurus* sp. (brush-tailed possum), two *Isoodon* species (short-nosed bandicoots) and a potoroid (probably a species of *Bettongia*). The reptile remains include representatives of the families Agamidae (dragons), Scincidae (several kinds of large skinks), Varanidae (monitors), Pythonidae (pythons), Colubroidea (fanged snakes) and Typhlopidae (blind snakes) (see Section S2 of the online Supporting Information). Most of the reptile bone is from medium-sized to large individuals and most are likely to be human prey remains. The exception is material from SU 1, which appears to be derived mainly from dog scats.

Bone artefacts

The bone artefacts from Riwi are the subjects of a separate study, but they include points made from macropod fibulae

Figure 10. A representation of the four macropodid size categories through the stratigraphic profile in Square 3 of Riwi.



and fragments of long bones that have been highly polished. They occur throughout the sequence. Several of the more obviously modified artefacts derive from the earliest contexts; for example, SU 12 in Square 3, XU 33 contains a modified and utilised small wallaby fibula fragment and, from an almost identical stratigraphic position, a modified fibula of a medium-to-large macropodid was recovered from Square 1. There are also a small number of pieces with clearly defined cut marks. A more thorough examination of each fragment will no doubt result in the recognition of many other examples and kinds of modification.

Shellfish

Freshwater mussel fragments were identified as *Lortiella froggatti* (Iredale 1934), the only species found in the Kimberley. Its primarily Holocene distribution within the site may be an effect of preservational differences.

Eggshell

Only six fragments of emu egg shell were recovered – all from Pleistocene deposits. Four of these were recovered from the interface of SUs 11 and 12 (three from Square 1 and two from Square 4) and one from the LGM deposits in Square 5.

Macrobotanical remains

Charcoal fragments are present throughout the occupation sequence but are not found in the archaeologically sterile XUs at the base of the sequence. The analysis by Whitau *et al.* (2017) of the charcoal primarily representing fuel wood from Squares 3 and 4 shows it to be dominated by Myrtaceae species. A dramatic change occurs within this family in the Pleistocene sediments at SU 7, dated to c.38–35 kya, where *Corymbia* sp. increases and *Eucalyptus* sp. decreases in abundance and diversity (Whitau *et al.* 2017). This has been interpreted to indicate a change in species composition of the woody component of the savanna/steppe vegetation, from mixed *Eucalyptus* sp. with subdominant *Corymbia* sp., to the modern composition of *Corymbia* with subdominant *Eucalyptus*. At the same time, there is an increase in *Erythrophleum* sp. and *Vachellia* sp., suggesting a co-current increase in shrub cover. Although *Eucalyptus* and *Corymbia* species within the northern savanna regions are adapted to tolerate the dry season of the Australian summer monsoon, *Corymbia* sp. are more likely to survive extended drought periods.

The results of detailed analyses of other macrobotanical remains (seeds, fruits, nuts and other floristic elements) are currently being prepared for a separate paper by Dilkes-Hall, but some of her findings are available in Dilkes-Hall (2014). Macrobotanical remains are primarily preserved by desiccation and carbonisation in Pleistocene hearths. The oldest macroplant remains derive from two hearths, F5-B and F4-B, dated to 34–33 kya calBP. Thus, the macroplant remains are preserved in contexts dating from the time at which changes in fuel wood charcoal indicate a change to more drought-resistant vegetation. Despite this, macroplant remains suggest that plants identified as food resources primarily represent monsoon rainforest taxa that are now only present in small pockets in the region (Whitau *et al.* 2017). *Vitex glabrata* (black plum) is by far the most frequent of the fruit and seed remains represented, followed by *Cynanchum* sp. (bush banana) and *Ficus* sp. (fig). All of these plants fruit during the wet season (Kenneally *et al.* 1996; Wheeler *et al.* 1992), suggesting that occupation of the site was linked to the availability of seasonal economic botanical resources.

Hearths

Whitau *et al.* (2017) and Vannieuwenhuyse (2016) described three types of hearths at Riwi, all of which are clearly visible in section (Figure 4). Type A hearths are flat and were lit directly onto the deposit surface; they are only type found in deposits older than 34 kya. Type B hearths were dug into the surface and occur from about 34 kya. Type C features are only present in the Holocene deposits and are accumulations mainly composed of by-products of combustion (predominantly ash and charcoal), along with a mix of non-burnt vegetal parts and a minor proportion of sediment.

DISCUSSION

Sediment began accumulating in Riwi from about 50 kya. Although 26 stone artefacts have been recovered from otherwise sterile SU 12 deposits, all but two of these are within 10 cm of the interface between SUs 12 and 11, suggesting that they probably derive from above SU 12. The oldest clear evidence for occupation is a hearth on the surface of SU 12, dated to 46.4–44.6 kya calBP. The records from the squares inside the cave indicate that the lower part of SU 11 to the surface of SU 12, from ~46–41 kya, is the smaller of two distinct more intensive periods of occupation coinciding with a time when conditions were more humid than today.

More humid conditions may have continued until about 37 kya, as indicated by the lake high conditions at Gregory Lakes until that time (Veth *et al.* 2009) and by macrobotanical remains from Carpenter's Gap 1 (Figure 1), to the west of Riwi (McConnell and O'Connor 1997; Wallis 2001). From about 34 kya, several changes appear to have occurred at Riwi. The numbers of artefacts discarded increased, the surrounding environment changed from eucalypt open woodland to shrubland dominated by *Corymbia* sp., dug hearths appear in the record and larger macropods became more frequently hunted than medium- and smaller-sized macropods. This corresponds to a time of humid conditions but with intermittent dune activity in the Gregory Lakes Basin (Figure 1) (Fitzsimmons *et al.* 2012: 475–6). The Riwi vegetation record suggests that the area may have endured longer drought, but the change in hunting and cooking practices at the site is difficult to explain. All of the recorded macropod species are present in the area today, but red kangaroos generally inhabit arid desert environments. If the kangaroos from these deposits are red kangaroos, this may indicate a more arid environment, but it does not explain why the pattern of hunting large kangaroos continued into the Holocene. As the overall proportion of macropods in the faunal assemblage does not change dramatically (Figure 9), the trend towards larger macropods suggests either a change in the species available or a cultural decision to focus on larger macropods that presumably must have been no more difficult to hunt than smaller macropods. The use of oven hearths and of larger hunted animals could indicate use of the site by larger groups of people. These changes were not accompanied by a change in stone tool technology – although, of course, there may have been changes in organic technology.

Apart from a remnant hearth feature near the cave wall in Square 3, LGM deposits in the cave were probably gutted by water in the early Holocene. However, evidence for LGM occupation is represented in Square 5, outside the cave entrance. While the samples are small, the numbers of artefacts per XU (Figures 5 and 6) are higher than for the pre-34 kya layers inside the cave. The LGM occupation dates may well be tied to the dramatic increases in precipitation in the area between 24 and 20 kya suggested from nearby speleothem records (Denniston *et al.* 2013a). The abundant freshwater shell remains recovered from these deposits support this interpretation. A similar increase in stone artefact numbers and a focus on the use of resources associated with fresh water, such as fish and mussel shell, has been noted to occur in the LGM unit at Carpenter's Gap 1 to the west of Riwi, but also in the southern Kimberley (Maloney *et al.* 2018).

Discontinuities in the desert lowland archaeological record during the LGM have been frequently recorded in the Australian archaeological record, where they have been usually interpreted as site abandonment as a result of people moving to more productive areas during the associated aridity (e.g. Morse 1988; O'Connor *et al.* 1999; Przywolnik 2005; Vannieuwenhuyse 2016; Veth *et al.* 2014, 2017b). Smith (2013: 130-2) and Veth *et al.* (2017a) discussed the problem of interpreting discontinuities as cultural absences. Veth *et al.* (2017a) conclude that the LGM discontinuities in arid Pilbara lowlands were a result of people moving to more productive areas such as the Pleistocene coastline and the Pilbara uplands. In the case of Riwi, the LGM to early Holocene discontinuity speculated by Balme (2000) to be possibly the result of site abandonment has been found to be the result of erosion and deposit removal. The LGM deposits identified in the 2013 excavations suggest relatively greater use of the cave than in the period between first occupation and 30 kya.

Other Australian sites in marginal areas that contain an LGM record, such as Carpenters Gap 1 (Frawley & O'Connor 2010; Maloney *et al.* 2018; Wallis 2001) and those in the Pilbara uplands, including Milly's Cave (Marwick 2002), Yirra (Veitch *et al.* 2005), Juukan 2 (Slack *et al.* 2009) and Yurlu Kankala (Reynen *et al.* 2018), have been argued to be LGM refuges because of their location near water, making them more productive than lowland areas. It seems that at Riwi there were also times when sufficient water was available for it to be occupied during an otherwise arid phase.

The terms "cryptic refugia" – or "microrefugia" – are used to refer to pockets of favourable microclimates in areas otherwise regarded as uninhabitable (Bennett & Provan 2008). Originally used in European studies to refer to regional climates during the LGM (e.g. Ashcroft 2010; Rull 2009), the terms have wider use (e.g. Byrne 2008) for Australia. These terms have been used to ascribe some areas with evidence for human occupation during the LGM in the arid zone (Smith 2013: 116) and elsewhere (Williams *et al.* 2014). If the suggestion by Denniston *et al.* (2013a) that the intertropical convergence zone moved southwards during periods of high northern latitude cooling, producing an active Indo-Australian summer monsoon during the LGM, then the southern Kimberley may have sometimes been a "microrefuge". However, the variable nature of this monsoon activity, and the position of Riwi on the edge of the desert, means that these southern Kimberley sites cannot be considered to be within an LGM refuge as in the concept as discussed in the biogeographical literature, or in the sense that Veth (1989) originally suggested. Instead, the southern Kimberley was, at times during the LGM, an area that people could expand into, from the more humid north, to exploit the desert edges, but at other times it was probably too arid to sustain occupation.

In Riwi's early Holocene layers, the numbers of artefacts are higher than at any other occupation time and this especially high occupation corresponds to a period of intense monsoon activity. The excellent preservation of organics within these layers shows that people made and used stone artefacts to produce wooden objects, used fibre technology and were involved in social networks that reached as far as the Kimberley coast. They continued to concentrate on larger macropods rather than the small- and medium-sized species hunted in the early part of the sequence. It is possible that the greater numbers of artefacts and other materials represent an acceleration in population increase, as Williams *et al.* (2015: 97) have suggested occurred in the tropics from about 8000 years ago, based on time-series modelling of radiocarbon dates from archaeological sites.

Within the shelter, the lack of deposition between about 6 and 1 kya calBP may be because the cave had filled to its capacity and required a further erosion event before more sediment could be retained (Vannieuwenhuyse 2016: 167). In these squares, the rates of artefacts discarded and the quantities of faunal remains gradually reduce in SU 1, dating to the past 1000 years. However, in Square 5 there is evidence of occupation dating to about 2000 years ago and, although there is a reduction in the rate of discard in these upper units (Figure 5), for the first time there is evidence of change in the stone technology, indicated by the appearance of hafted adzes and points. McGowan *et al.* (2012: 2) reported very dry conditions indicated by the pollen sequence at Black Springs between 2.75 and 1.3 kya. If the Riwi region was similarly affected, it represents an occupation pattern not seen previously – cave use during a dry phase.

The decrease in the number of artefacts over the past 1000 years (Figure 5) in all squares suggests a reduction in visitation during a time in which McGowan *et al.* (2012: 2) recorded a return to wetter conditions at Black Springs. This reduction in artefact numbers is unlike almost all other northern Australian sites, including Carpenter's Gap 1 (Maloney *et al.* 2018) and Carpenter's Gap 3 (O'Connor *et al.* 2014). At Riwi, the reduction in artefact discard is coupled with a change in the fauna to an emphasis on reptiles. However, these probably derive from the abundant dingo coprolites and may therefore indicate the greater use of the cave by dingoes during the late Holocene, either accompanying or without humans. We do know that Riwi was used by Aboriginal people in early European pastoral times, as the site was originally shown to Balme in 1999 by a Traditional Owner who related that his father had camped at this and other cave and rock-shelter sites in the region.

CONCLUSION

Riwi and its environment have provided shelter and resources for Aboriginal people for 46000 years. However, the lack of permanent water in the immediate area makes it unlikely that it was occupied during the monsoonal dry season (May to October) in conditions such as those that prevail today. The distribution of archaeological materials within the site closely tracks humid periods in the past, including monsoon activity during the LGM when water was available in the valley-floor creek and pockets of dry rainforest expanded. Riwi's position on the edge of the desert may well have provided a retreat when resources were depleted in the south and an opportunity to expand when during wet pulses of arid periods. The Riwi sequence is also heavily shaped by depositional and erosional processes resulting in cave filling and gutting, which are largely independent of human use of the site. As a consequence, little can be said about occupation and abandonment or population fluctuations over time. In this respect, the results of the 2013 excavation are salutary in demonstrating the utility of sampling different parts of cave deposits.

The limestone belt of the southern Kimberley has produced one of the most diverse and rich cultural records including hearths, stone and organic artefacts, botanical and faunal remains as well as symbolic materials representing about 50000 years available for the Australian continent. Riwi provides further evidence of the variation within Australia's terminal Pleistocene and Holocene climate and the need for finer regional investigation of both archaeological and palaeoenvironmental archives.

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SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section at the end of the article.

S1: Artefact frequency represented as the total number of artefacts (TNA) and minimum number of flakes (MNF) for each excavation unit of squares 3, 4 and 5.
S2: Faunal identifications from Square 3, Riwi.