THEMED SECTION

# What to make of the 'Murchison Cement'?

## A re-examination of a megafaunal fossil site in the Mid-West, Western Australia

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### *Abstract*

*The 'Murchison Cement' is a term that has been informally used since the 1960s to describe numerous stratigraphic units in the middle catchment of the Murchison and Greenough Rivers, in Mid-West Western Australia. The significance of these deposits relates to their embedded artefact and megafaunal assemblages, uncovered by investigations from the Franco-Australian Quaternary Project (FAQP) during the 1970s. Researchers still debate the contemporaneity of the archaeological and megafaunal material within these deposits because of the complex nature of the depositional environment. This paper questions the practicality of the term Murchison Cement and reports on a new megafaunal fossil and possible artefact find at Ballinu (Ballinyoo) Springs. Preliminary sedimentological and micromorphological analyses show similarities in the sediment directly associated with the fossil and some of the artefacts archived from the FAQP. Initial luminescence analyses of silicified sediments associated with the fossil indicate a depositional age of ~56 kya, with evidence of reworking at approximately 14 kya. Whilst late Pleistocene human occupation in the region is indicated, the contemporaneity with megafaunal fossils remains uncertain.*

### Introduction

During the 1960s, Duncan Merrilees found mammalian fossil bones, including a diprotodontid (*Zygomaturus trilobus*) mandible and stone artefacts, in cemented alluvial deposits in the middle reaches of the Murchison River, Western Australia (WA). The term 'Murchison Cement' was subsequently applied to the sediments associated with these discoveries. These findings contributed to Merrilees' (1968) seminal 'Man the Destroyer' theory that proposed human landscape burning as a causal factor in the extinction of megafauna in Australia.

Between 1978 and 1982 a number of researchers from the Western Australian Museum (WAM) (including Charlie Dortch), The University of Western Australia (UWA) and Bordeaux University carried out further archaeological investigations in the Murchison Basin (Bordes et al. 1979, 1983). The richest archaeological and fossil remain sites were located in the vicinity of springs, two of the most important of which were Ballinu (Ballinyoo) and Billabilong Springs (Figure 1). The exact stratigraphic origin of the collected artefacts was lost in the diaries of two key investigators, François Bordes and Claude Thibault, who both died within two years of the initial 1979 publication; attempts to recover these diaries have been unsuccessful. The informal use of the term Murchison Cement in the description of the museum archives, further adds to the ambiguity of the artefacts' stratigraphic origin.

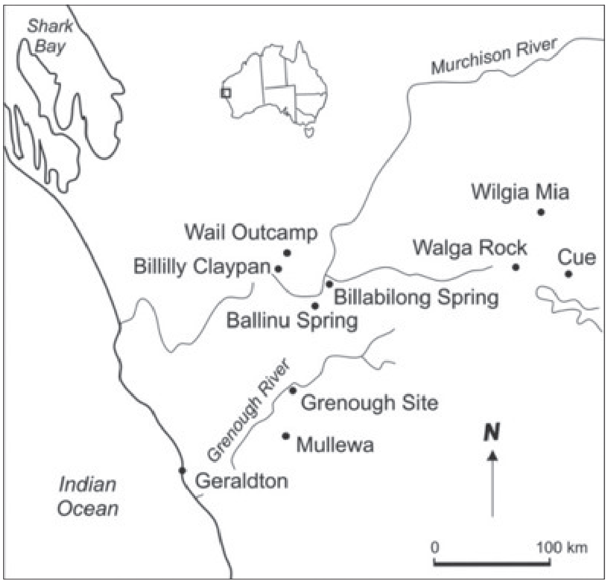



**Figure 1** Map of the Murchison Basin showing Ballinu Springs and other key sites (from Bordes et al. 1983).

Another partial mandible of *Z. trilobus* and stone artefacts were discovered in similar cemented alluvial deposits at Greenough River (DAA Site ID 214761), 75 km south of the Murchison River (Wyrwoll and Dortch 1978). The supposed

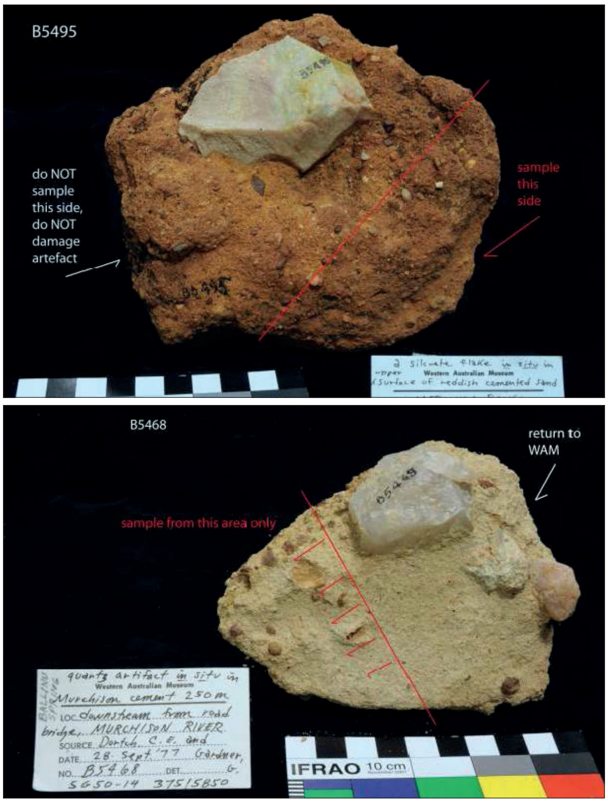



**Figure 2** Examples of some of the WAM archived artefacts embedded in Murchison Cement from Ballinu Springs and marked sections for analysis: (upper) B5495; and (lower) B5468.

age and origin of these silicified alluvial sediments is uncertain, though they are proposed to be >37 kya based on the supposed date for megafaunal extinction in the Mid West (Prideaux et al. 2010; Wyrwoll and Dortch 1978: 412). The term 'Older Fill' was used to differentiate these partly cemented, red-brown to green-grey alluvial deposits from the overlying 'Younger Fill', the latter consisting of pale red-brown fine sand and silt (Wyrwoll and Dortch 1978). The assumption was that the Older Fill was essentially equivalent to the Murchison Cement. However, in the absence of any absolute dates, it is not possible to know whether the artefacts and fossil remains from the silicified alluvium at Greenough River are associated with, or even broadly contemporaneous with, these other discoveries. Thus, although the archaeological significance of the Murchison Basin lies with its fossil and artefact assemblage, a better understanding of the age and formation history of both the Greenough River and Murchison River sites is needed (Balme 1979:145; Wyrwoll 1977:148; Wyrwoll and Dortch 1978).

According to Charlie Dortch, a key member of the FAQP, this research 'is truly a subject whose resolution has eluded a dozen field researchers' (pers. comm. 2011). The FAQP provides a valuable basis for current studies that aim to reassess the age and geological formation history of the Murchison, as outlined by Dortch (and echoed by others) in his final ARC report. This paper presents some of the initial results of recent investigations on archived and new Mid-West sediments, as well as another *Zygomaturus* fossil find from Ballinu Springs. These assessments are aimed at determining the stratigraphic context of artefact and fossil material based on diagnostic sedimentological and micromorphological features within a well-preserved section of the profile. Further details are presented in Murszewski (2013).

## Methods

### Field Samples

In 2013 a three-day field trip to Ballinu Springs uncovered another *Z. trilobus* fossil fragment on the riverbank that was embedded in cemented alluvium approximately 500 m due west of the Ballinu Bridge. Embedded clasts of quartz and silcrete were also identified in close proximity to the fossil, one of which was later determined to be a possible artefact by lithic specialists at UWA (Figure 3). Other potential embedded artefacts were also observed in the nearby sites of Collins Well and Coollaburloo Brook (DAA Site ID 12077), downstream and upstream respectively, of Ballinu Springs.

After the exact location and dimensions of the fossil specimen were recorded, it was cautiously unearthed with a large portion of cemented sediment still attached to the base of the sample (Figure 4). After extraction, the sample was wrapped in plastic film to prevent drying. Radiocarbon dating was not attempted due to the deteriorated nature of the bone and the lack of datable collagen in the fossil fragment.

### WA Museum Samples

Assessing the stratigraphic context of museum artefacts was essential to understand the archives and to identify samples that had sufficient cemented sediment associated for further analyses. The WAM archive samples derive from Walga Rock, New Forest, Wooleen homestead, Coolarbooloo Brook, Yallalong Station, Billilly claypan, Billabilong Spring, Ballinu Springs and many other sites throughout the Murchison Basin. The collection of more than 500 artefacts includes cores, grinding stones, flakes and blades, predominantly made from quartz, quartzite and silcrete, with lesser amounts of chert, granite and mafic rocks. Of these, a total of 17 archive samples had a ≥1:1 sediment:artefact ratio (examples are shown in Figure 2); five of these had no site location or artefact association and were excluded from this study, while eight were from the site of Ballinu Springs. The latter were all recorded in the WAM archives as having been lodged by Charlie Dortch in September 1977.

Portions of cemented sediment were cut from the selected museum samples. These and collected field samples of sediment were impregnated with resin and cut into thin-sections for micromorphological analysis following Fitzpatrick (1984). There was insufficient material apportioned from the WAM samples to carry out any grain size or geochemical analysis; however, field samples were subject to x-ray diffraction (XRD) following Moore and Reynolds (1997), grain size analysis (using sieves) and micromorphological analysis. Clay fractions were separated from bulk samples and also analysed using XRD following Brindley and Brown (1980).

### OSL Analysis

The layer immediately below the *Z. trilobus* fossil was sampled for optically stimulated luminescence (OSL) analysis, using the standard method of inserting stainless steel coring tubes into a cleaned section surface. A separate bulk sample was also collected from the sampling point for environmental dosimetry (burial dose) calculations. The sample was then sent to the Environmental Luminescence Laboratory at the University of Adelaide for analysis.

**Figure 3** Possible silcrete artefact in situ in pebbly sediment ~2 m from the fossil fragment found in the same unit. Scale is 9 cm. Note the similar size clasts in the surrounding sediment.


**Figure 4** Fossil fragment of *Zygomaturus trilobus* in situ. Note the coarse sediment in which the fossil is embedded.

| WAM No. | Artefact Description | Sediment Description |
|---|---|---|
| B5442 | Notched quartz stone artefact | Poorly sorted pink (7.5YR 8/3) coarse grained sandy clay. Green rind present (2 mm thick). |
| B5448 | Possible quartz artefact | Well sorted medium to fine grained red (7.5YR 6/6) sand. Small clasts of clay throughout parts of sediment. |
| B5467 | Milky quartz stone artefact | Moderately sorted white (2.5Y 8/1) sandy clay. Larger clasts (~2–4 mm) scattered throughout sample. Obvious cementation over top of artefact in a 'fracture like' pattern. |
| B5466 | Possible quartz artefact | Poorly sorted, whitish-yellow (10YR 8/1) coarse grained pebbly sandy clay. |
| B5468 | Possible quartz artefact | Poorly sorted white-yellowish (2.5Y 8/2) clayey sand, with white matrix. Large clasts (~1 mm–3 cm) mixed with subrounded quartz grains. Thin layer of greenish discolouration around contact of sand with quartz artefact (possibly clay alteration). |
| B5495 | Silcrete flake | Poorly sorted, coarse grained red (5 YR 6/6) pebbly sandy clay, angular clasts present throughout matrix. |

**Table 1** Summary of artefacts recorded from Ballinu Springs in the WAM collection.

Lithogenic radionuclide concentrations (U, Th and K) were determined and measured by Genalysis Laboratories, Perth, using Inductively Coupled Plasma Mass Spectroscopy (ICPMS) for U and Th, and x-ray fluorescence (XRF) for K. Cosmic dose rates were calculated based on Prescott and Hutton (1994) and the results combined to calculate environmental dose rate (Spooner and Questiaux 2013) (Table 1).

Sample preparation was designed to isolate pure extracts of 212–250 µm light safe quartz grains from the centre of each sampling tube by following standard procedures (after Aitken 1998). Treatments were applied to remove contaminant carbonates, feldspars, organics, heavy minerals and acid soluble fluorides. The outer ~10 µm alpha-irradiated rind of each grain was removed by etching in 48% hydrofluoric acid. The grains were then washed in warm 10% hydrochloric acid to remove any precipitated fluorides, and finally re-sieved to recover the 212–250 µm fraction (Spooner and Questiaux 2013).

Equivalent doses (ED) of radiation received by the sample during burial were determined from measurement of the OSL signals emitted by single grains of quartz using the Single Aliquot Regeneration (SAR) protocol devised by Murray and Wintle (2000). OSL measurements were made on a Risø TL/OSL DA-20 reader using a green (532 nm) laser for optical stimulation, and the ultraviolet emissions were detected using an EMI 9235QB photomultiplier optically filtered by a 7 mm thick UV-transmitting Hoya U 340 glass filter. Laboratory irradiations were conducted using a calibrated $^{90}Sr/^{90}Y$ beta source mounted on the reader.

| U (ppm)* | Th (ppm)* | K (%)** | H2O % | Cosmic (Gy/ka) | Dose Rate (Gy/ka) |
|---|---|---|---|---|---|
| 5.01±0.30 | 18.83±1.09 | 1.49±0.01 | 23±3 | 0.19±0.09 | 3.25±0.13 |

**Table 2** Nuclide concentrations and environmental dose rates for the Ballinu Springs sample (Lab. code AD13027).

Eleven discs, totalling 1100 grains, were loaded and run, and a dose-response curve was constructed for each grain. Grains having a recycling ratio of 80% or better, recuperation less than 15%, and reasonably smooth regeneration and test dose response curves were accepted for analysis (Spooner and Questiaux 2013). The age of the sample was calculated by dividing the equivalent dose by the dose rate of the environment surrounding the sample, i.e. Age (kya) = Equivalent Dose (Gya)/ Dose Rate (Gya/kya). The values of ED, determined from the central age method (Galbraith et al. 1999), minimum dose (Galbraith and Laslett 1993) and finite mixture model (Galbraith 2005; Galbraith and Green 1990), are shown in Table 2.

## Results

### Sedimentology and Micromorphology

The stratigraphy was described and sampled from the same locality as the 2013 fossil and artefact discovery at Ballinu Springs (Figures 5 and 6). Exposures of the underlying granite basement were evident in multiple outcrops near

**Figure 5** Photograph of section of Murchison River, downstream of Ballinu Bridge, where the megafaunal fossil find was located.





the Ballinu Bridge and Greenough River. Ten stratigraphic units were identified, two of which comprise distinct hardened, silicified duricrusts that are relatively continuous throughout riverbank exposures. A consistent alkaline pH of 8 was recorded in the sediment suspensions throughout the profile. Zones of cemented sediment along the riverbed tested positive for $CaCO_3$ when treated with dilute HCl acid, yet any carbonate minerals present were below the level of detection using XRD.

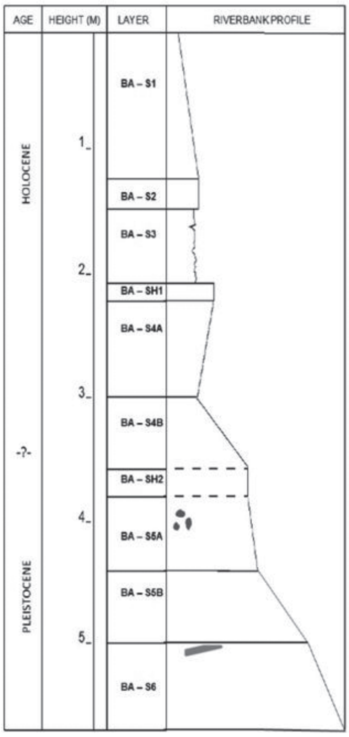
Units at the top of the sequence are distinctly reddened (5YR 6/8) in comparison to the green-grey (5Y 6/3) units at the base of the strata (Figure 6). These colour variations within the cementing material were evident in the micromorphology of both field and museum samples. Bulk XRD results indicated that all samples were overprinted by quartz, although they contained variable quantities of kaolinite, muscovite, feldspar, goethite, hematite and halite. Independent XRD results of separated clay minerals revealed no new mineralogies. Micromorphological investigations confirmed that the sedimentary matrix of the lowermost stratigraphic units consisted mostly of a siliceous cement, with discrete carbonate zones and rinds around larger clasts indicating periods of dissolution and reprecipitation (Figure 7).

Grain size distribution is highly variable throughout the entire sequence, ranging from large conglomerates (>10 cm) to finer clay and silt particles (<63 µm); however, no continuous trend exists throughout the profile. Specifically, BA-S03 shows the highest percentage (~29%) of material recovered from the ≤63 µm fraction and is likely to have been deposited under a low fluvial current event. In the lowermost stratigraphic units, sediments directly associated with the fossil-bearing unit (BA-S06) comprise moderately sorted sands, with very few clasts >2.0 mm. Clear differences are observed in Units BA-S4B and BA-S5A, which show very high percentages (~43%) of larger clasts (≥2 mm). Two possible artefacts were identified within the BA-S5A unit, along the riverbank of the same site where the *Z. trilobus* fossil was uncovered.

These differences within the strata proved most useful when attempting to source WAM archived samples that had been extracted from so-called Murchison Cement. Most of the museum samples display a deep red colour, characteristic of sub-aerial exposure and the formation of iron oxides in the upper part of the stratigraphy (Figure 8). Few of the WAM specimens possess siliceous cements, characteristic of Units BA-S5A/B and BA-S06 from Ballinu Springs. Of the WAM specimens, six artefacts from Ballinu Springs (B5442, B5468, B6693, B5448, B5467 and B5466) were embedded in silica cement that had little oxidised clay infilling. Although these six samples were collected in relatively close proximity to one another, only B5466, B5467 and B5468 possessed grain size attributes and siliceous cements equivalent to those directly associated with the *Z. trilobus* remains identified in Unit BA-S06 during the 2013 fieldwork. Sediment attached to archived *Z. trilobus* specimens underwent brief visual examination, where the same sedimentological attributes of Unit BA-S06 were distinguished. The remaining artefacts in the WAM archive, analysed during this research, contained highly oxidised clay-rich infillings and are argued not to be contemporaneous with the *Z. trilobus* remains.

### Chronology

The sediments sampled for OSL are assumed to have been buried by river channel deposits; however, there is no indication of when and how often this layer was exposed by erosion—it certainly had a greater time-averaged burial depth than the present-day depth of 10 cm. Consequently, cosmic dose rates have been calculated (following Prescott and Hutton 1994) for both 10 cm of overburden of pebbly sand (current depth) and 5 m of overburden (total depth from top of river bank) and the results amalgamated (Table 2). The cosmic ray dose-rate contribution, if assuming 10 cm time-averaged burial depth, is about 8% of the dose-rate produced by radioisotopes, due to the high content of U, Th and K (Table 2), and only about 3% if a 5 m burial depth is assumed. Hence, this uncertainty in the cosmic ray contribution is not of significant impact on the age derived.




| LAYER | DESCRIPTION |
|---|---|
| BA-S01 | Uppermost unit in the stratigraphy consisting of mostly fine-grained sands and small angular clasts. Soil poorly cemented with no evidence of bedding or trends within layer. Munsell colour: 5 YR 4/6 and thickness is approximately 150 cm. Layer is covered with biological material, mostly small shrubs and trees. |
| BA-S02 | Weakly cemented, poorly sorted pebbly sandy clay with prismoidal angular clasts present. Munsell colour 5 YR 6/8 and thickness is approximately 60 cm. |
| BA-S03 | Moderately cemented, well sorted, very fine grained mudstone with no larger clasts present. The 5 cm above the silicified horizon (i.e. lower BA-S03) is coarser pebbly sands. Munsell colour: 7.5 YR 7/4. |
| BA-SH1 | Silicified Horizon (duricrust) 1: Continuous layer of consolidated sediment hardly cemented together by a silica matrix. Material moderately sorted and fine grained throughout. Layer is approximately 10 cm wide; however few sections observed during brief analysis downstream exceed 20 cm in width. Munsell colour: 7.5 YR 6/6. |
| BA-S4A | Poorly cemented, moderately sorted coarse grained pebbly sand with a fine grained matrix. Fining upwards trend with bottom of layer consisting of cobbles up to 10 cm in length. Munsell colour: 7.5 YR 6/6 and thickness is approximately 90 cm. |
| BA-S4B | Weakly cemented, poorly sorted cobbly pebbly sands with large clasts exceeding 5 cm in length. Bedding planes trending NW. Layer is variable with finer grained zones lacking the coarser cobbles. Munsell colour: 7.5 YR 4/6. |
| BA-SH2 | Silicified Horizon (duricrust) 2: Discontinuous throughout river bank, however is well exposed at Site 1 (+ 10 cm thick). Material moderately sorted, with few larger clasts (5 cm) present in the firmly cemented matrix. Munsell colour: 7.5 YR 6/6. |
| BA-S5A | Discrete layer along the riverbed sediments, however reasonably exposed at Site 1. Sediments comprise of well cemented, poorly sorted, pebbly sandy clays. Layer abundant with large clasts exceeding 5 cm in length, indicating that these deposits are the product of sheet wash zones during deposition. Diagnostically different in colour from upper layers with a Munsell colour of 5 Y 7/3. Source where artefacts were extracted from during fieldwork in May 2013. |
| BA-S5B | Continuation of Layer 5 however, does not possess larger clasts from sheetwash zones. This layer is finer grains, moderately sorted and moderately cemented. Thickness varies from centimetres to ~30 cm throughout site 1. Munsell colour: 7.5 YR 6/4. |
| BA-S06 | Moderately sorted, sandy clay continuing down below Layer 5 on the bank of the river. Very distinctive green-grey material, OSL dated. Munsell colour: 5 Y 6/3. |

**Figure 6** Stratigraphic profile of Ballinu Springs. Stratigraphic section showing relative age, height and riverbank profile and tabulated description of stratigraphic units alongside their relative position within the profile.

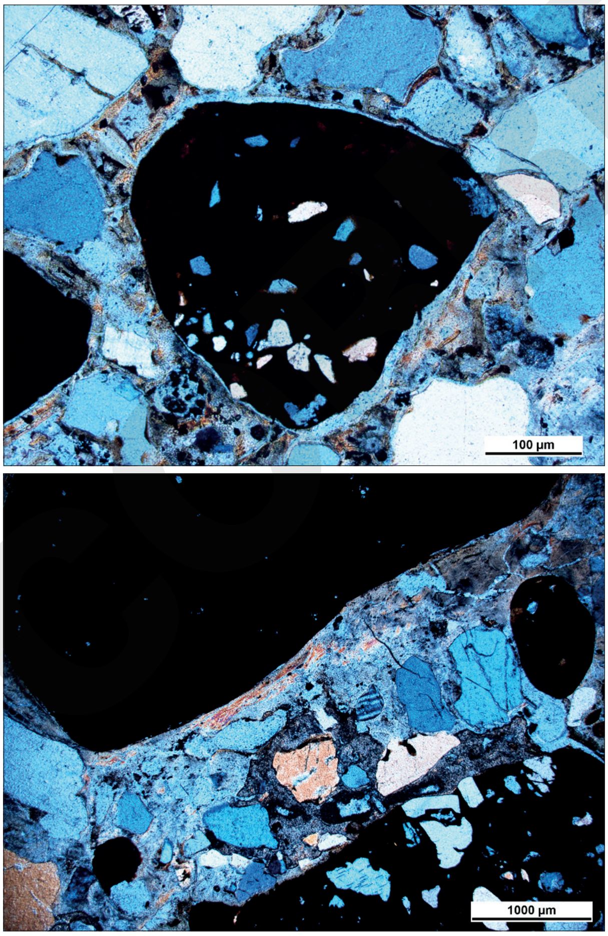



**Figure 7** Micromorphological image of field samples showing evidence of (upper) rinds (light grey ring) around larger clasts and (lower) very discrete areas of highly birefringent (multi-coloured) carbonate cement adjacent to larger clast.

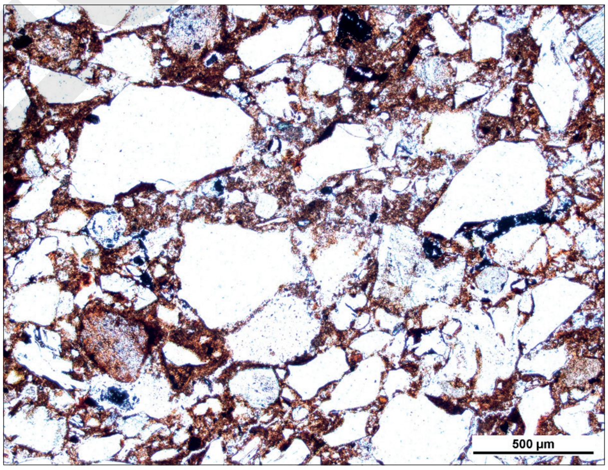



**Figure 8** Thin-section showing typical deep red infill of majority of museum samples of Murchison Cement, characteristic of sub-aerial exposure in the upper part of the stratigraphy.

With no precise overburden history, the conservative approach is to use the average of the two extreme values for the cosmic rays: 50% contribution for 5 m of overburden (0.26±0.03 Gya/kya), combined with 50% contribution for 10 cm overburden (0.11±0.01 Gya/kya present day). We note that the difference in the two total dose-rates obtained lies within the error estimate for the age. Water content of the sample was relatively high (23%) but was given as the time-averaged value on the assumption that the sample in the base of the river was likely at, or near, water saturation through most of its history. However, given probable long periods of regional aridity and variations in water content, the final calculated age should be assumed to be a maximum (Spooner and Questiaux 2013).

The total number of valid EDs was 129 or 11.7% (65% showed no luminescence, 11% had low counts and 9% were saturated). The central age method, which uses all the valid results and finds the central age on assumption that the distribution is Gaussian, shows a 61% dispersion; this is much higher than the usual 15% dispersion obtained with an artificially bleached then dosed sample. This would reflect the probable occurrence of partially or unbleached (older) sediment and well-bleached sediment deposited in the same horizon, as would be expected from waterlain sediments where erosion from the channel is an obvious source of such grains. In such cases, the distribution of the EDs usually tends to be skewed to higher values, with a very sharp and well defined lower limit of EDs and a tail of higher EDs corresponding to grains that were not fully bleached prior to deposition (Spooner and Questiaux 2013).

The radial plot (Figure 9) clearly shows two distinct groupings of results, with the highest proportion (59.4%) centred around 181.4±8.9 Gya and the other 40.6% centred around 46.5±2.4 Gya using the finite mixture model (Galbraith 2005; Galbraith and Green 1990). The occurrence of two distinct populations indicates that there could arguably be two events recorded: one at about 55.6±4.2 kya, with reworking at about 14.3±1.4 kya (Table 2). The minimum dose method (Galbraith and Laslett 1993), where one estimates the lowest possible Gaussian peak, gives an ED result centred around 35.8±3.5 Gya, which is slightly below the lowest peak with the mixed population (Table 3). Using this model the reworking event would be younger, at approximately 11±1.5 kya (Spooner and Questiaux 2013).

| | Over-Dispersion | % of Results | ED (Gy) | Age (kya) |
|---|---|---|---|---|
| Central Age | 61% | | ≥99.8±8.4 | ≥30.7±3.7 |
| Minimum Age | | | ≥35.8±3.5 | ≥11.0±1.5 |
| Mixed Population 1 | | 41±6 | ≥46.5±2.4 | ≥14.3±1.4 |
| Mixed Population 2 | | 59±6 | ≥181.4 8.9 | ≥55.6±4.2 |

**Table 3** Equivalent doses and calculated ages for the Ballinu Springs sample (BS_OSL1, Lab. code AD13027).

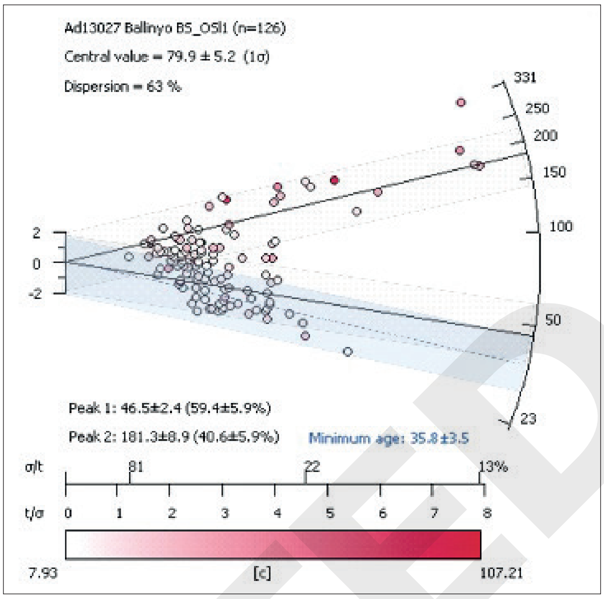



**Figure 9** Radial plot for the Ballinu Spring sample (AD13027). Grey areas show confidence bands for the peaks obtained within the mixed population. Blue shaded area and dotted lines are ED resulting from the minimum age model.

## Discussion

### Origin of WAM Archived Samples

The artefacts (n = >500) located during FAQP investigations indicated widespread land use, particularly through the late Holocene (Bordes et al. 1983). Recent field observations support this suggestion, with numerous surface artefact concentrations, as well as occasional evidence of embedded artefacts in the upper units along the riverbank and on the floodplain surface adjacent to the Murchison River. The results from our investigations of the sediments associated with the archived artefacts in WAM indicate that the term Murchison Cement has been applied to stratigraphic units ranging from the late Holocene to the upper Pleistocene. Whilst this implies long, as well as widespread, occupation the term itself is clearly ambiguous.

If embedded artefacts analysed in this research are used as representative samples of the entire FAQP assemblage, it is likely that most artefacts located by previous researchers were extracted from red-brown, clay-rich Holocene deposits in the upper (Younger Fill) part of the stratigraphy. However, we have identified three (B5466, B5467 and B5468) that are likely to have originated from the stratigraphic unit containing megafaunal fossil material, which consists of a fine-grained, siliceous matrix with very little evidence of sub-aerial oxidation (hence the white/grey-green colouration).

### Contemporaneity of Artefacts and Fossils

This research has attempted to address questions of geological age and formation at one site in the Upper Murchison. Owing to the complexities of these alluvial systems, it is not possible to prescribe a direct association of artefacts and fossils at Ballinu Springs based on this study alone. Micromorphological results indicate multiple episodes of flooding and reworking interspersed with long periods of pedogenesis, particularly in the lowermost units. As found by Wrywoll and Dortch (1978) for the Greenough sediments, these lowermost (Older Fill) sediments show intense pedogenesis with marked carbonate and silica segregation and cementation. However, the amount of carbonate cementation in the Ballinu sediments is minimal and very discrete (only visible in thin-section).

Measured pH values were relatively constant throughout the profile (n= 8), which defines the necessary chemical conditions for both carbonate and silica cementation. It is important to note that numerous duricrusts throughout the world are often a mixture of calcrete-silcrete cementation and various transitions have been documented (Nash and Shaw 1998). Silcretes contain by definition more than 85% silica (Summerfield 1983), whereas calcretes show a global average of 79% $CaCO_3$ (Goudie 1972). Dissected sheets of calcrete do occur along parts of the Upper Murchison River (Laws 1994), but thick silcrete duricrusts were observed at Ballinu Springs.

We do not provide bulk chemical data for the sediments; however, XRD and micromorphological (including scanning electron microscopy) analyses show that the lowermost green-grey sediments in the Murchison River area are silica cemented. Silica cement is common in the Murchison region and elsewhere across the Yilgarn due to the abundance of weathered granites in the vicinity, resulting in high levels of dissolved silica in groundwater. Consequent evaporation and the absence of reactants causes silica to then precipitate, either at or above the watertable or in the soil profile (vadose zone). Many modern groundwater analyses in the middle reaches of the Murchison River document very high silica values (English et al. 2012). Also, multiple phases of cementation and dissolution are common in these environments.

Grain angularity and poor sorting supports an interpretation of minimal transport of sediments in the fossil-bearing unit. Although this unit possesses fewer large clasts, the margins of the fossil fragment itself shows little evidence of splintering and damage, indicative of a short transport period (Alex Baynes pers. comm. 2013). The possible silcrete artefact similarly shows sharp edges with little wear that are consistent with prolonged submergence (cf. Thompson et al. 2011). These results indicate that sediments at Ballinu Springs, including their associated artefacts and fossils, were not transported far from the source location. Despite this it remains uncertain whether the fossils and artefacts were deposited contemporaneously or asynchronously during different flood events.

In general, alluvial systems in semi-arid environments represent a discontinuous sedimentary record that influences the accessibility and consequent interpretation of associated archaeological material. The Murchison region is no exception, with previous research confirming a complex formation history that varies within separate riverbank exposures (Wyrwoll 1984, 1988). Therefore, a more extensive appreciation of the fluvial history is needed before the context of the archaeological material can be fully understood.

### Depositional Age

It has been stated that the fossils and artefacts are older than the silicified alluvium in which they are embedded (Bordes et al. 1983) and that the major periods of cementation predate the last major dune building episode around 17,000 kya during a period of more semi-arid conditions (Wyrwoll 1979). The OSL measurements indicate two distinct age populations, an older ~56±4.2 kya population and a younger reworking event around 14±1.4 kya. The older age is in broad agreement with the extinction age of megafauna around 40–50 kya in this region (Prideaux et al. 2010) and, although only a single age estimate, it is assumed, for now, to provide a maximum age for the *Zygomaturus* fossil. This bone may have been deposited and rapidly buried as part of a channel bar in an early flood event and only exposed during a subsequent flood event later in the Pleistocene.

During previous fieldwork, one of the FAQP researchers indicated evidence of a magnetic reversal in the lowermost 'green/grey lithology' (Peter Bindon pers. comm. 2013), or what we define as Murchison Cement. Recent research supports the occurrence of a full magnetic reversal, known as the Laschamp Event, at 41 kya, in addition to the post-Blake Event at 120 kya (Singer 2014). However, in the absence of the field diaries, we have no details regarding how the magnetic measurements were recorded at Ballinu Springs, or by whom. Hence, until the observed anomaly at Ballinu Springs is substantiated by further measurement, it is not possible to draw any comparison with the late Pleistocene OSL age estimate.

The lowermost units at Ballinu Springs are extremely hard when dry but become soft when wet. Hence, it is equally possible that the fossil was transported, albeit only minimally, and redeposited in the uppermost part of the grey-green unit as part of the later reworking event around 14 kya. Similarly, the possible silcrete artefact may have been deposited during the same early flood event or in the later reworking event. Our working hypothesis is that the fossil belongs to the early 56 kya event and the possible artefact to the later 14 kya reworking event, but further studies are needed to test this. Attempts to obtain an absolute age for the Older Fill have been unsuccessful (Wyrwoll and Dortch 1978:412). Thus, although not definitive, this study at least offers the first insight into the depositional age of the fossil-bearing stratigraphic unit at Ballinu Springs. Additional dating is currently in progress.

### What to Make of the Murchison Cement?

For decades many researchers have titled any sediment that holds embedded artefacts within the reaches of the Murchison and Greenough Rivers as the Murchison Cement. There is a clear similarity between the lowermost units at Ballinu Springs and the Older Fill recorded by Wyrwoll and Dortch (1978), described as a weakly indurated, partially cemented, red-brown to green-grey alluvial deposit with lenses of conglomeratic cobble and pebble sized clasts. Similarly, the recent red-brown, clay-rich alluvial structures in the upper part of the stratigraphy at Ballinu Springs correspond with the Younger Fill of Wyrwoll and Dortch (1978). As found at Greenough, the Younger Fill and Older Fill are separated into two discrete units by a strong silcrete horizon (Figure 5). Therefore, we recommend that this terminology be used in future research in the Murchison Basin. As current and previous research indicates that only one single lithology holds megafauna, the green-grey horizon at Greenough River and Ballinu Springs is the true Murchison Cement.

The geographical distribution of this stratigraphic unit is unknown. Recent fieldwork failed to identify this deposit within the lower margins at surrounding sites, including Billabilong Spring, Island Well and Collins Well. It is likely that the true Murchison Cement occurs discretely within the current or former fluvial system of the Murchison River. Therefore, defining the palaeodrainage system of the Murchison may help to delineate the possible distribution of Murchison Cement and any associated fossil and/or artefact material.

This study has shown that many different units exposed in the riverbank preserve embedded artefacts. The informal classification that has been adopted has created confusion that will undoubtedly continue to affect future researchers who attempt to relocate fossil-bearing strata within the Murchison Basin. Hence, as a response to Charlie Dortch's query, 'what to make of it', we argue that, although the specific phrase Murchison Cement is essentially obsolete, it does hold value in its original reference to sediments that contain evidence for the co-occurrence of humans and megafauna in the Murchison region (Merrilees 1968). The ongoing assessment of its chronology and geographical distribution, and the contemporaneity of megafauna and people in the Murchison continue.

## Conclusion

The findings of this preliminary research are insufficient to conclude the contemporaneity of people and megafauna in the

Murchison; however, our results do not exclude it. Fieldwork during 2013 identified new *Zygomaturus* sp. remains and produced the first absolute date for the depositional age of the fossil-bearing stratigraphic unit. New micromorphological and sedimentological data offer one of the first detailed studies focusing on the geological profile at Ballinu Springs, which has already aided a broader study of the geomorphological investigation of the Murchison region. An important outcome of this study has been the reclassification of the term 'Murchison Cement/s', removing any ambiguity for future research. These outcomes will hopefully be combined with forthcoming results by researchers from Bordeaux University from their earlier excavations. It has also provided the means to reinvigorate relations with Indigenous representatives from the Murchison Basin and reunite the team of researchers who found material that potentially holds a much wider significance than previously anticipated.



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