EXCAVATIONS AT PARNKUPIRTI, LAKE GREGORY, GREAT SANDY DESERT:

OSL ages for occupation before the Last Glacial Maximum

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Abstract

We report on early occupation from the Parnkupirti site on Salt Pan Creek at Lake Gregory, on the edge of the Great Sandy Desert of northwest Australia. OSL ages from excavations, and stratigraphic correlations between dated exposures along Salt Pan Creek, show some stone artefacts *in situ* in sediments dating from greater than 37ka and most probably on stratigraphic grounds in the range of ~50–45ka. The deep stratigraphic section at Parnkupirti also provides a long record of the Quaternary history of Lake Gregory, which remained a freshwater system during the Late Quaternary.

Introduction

The Lake Gregory system in northwestern Australia is the desert terminus for the monsoonal catchment of Sturt Creek draining the eastern Kimberley (Figure 1). Previous studies have shown that the lakes preserve a palaeomonsoon record for northwest Australia (Bowler 2006; Bowler *et al.* 2001). Relict shorelines and lake deposits – as well as dunefields truncated by the palaeolake – show that Lake Gregory was much larger at times during the late Quaternary, and that it incorporated the smaller basins that make up the Gregory-Paruku system today (Figure 1). The juxtaposition of a rich freshwater ecosystem – with an abundance of birds, mussels and fish – set within arid dunefields means that the lake is likely to have been a focal point for late Pleistocene hunter-gatherer groups in this region. There are obvious parallels with the Willandra Lakes system in southeastern Australia (Bowler 1998; Bowler *et al.* 2003) and elsewhere in northern Australia at Lake Woods (Bowler *et al.* 1998; Hutton *et al.* 1984; Smith 1986; Veth 1980). One point of difference, however, is that Lake Gregory is still active.

The challenge for archaeologists has been to identify an early phase of occupation associated with Pleistocene lake phases. In 2006–2007, geomorphic fieldwork by Bowler (2006) identified a series of localities where artefacts appeared to be eroding from strata associated with an expanded lake phase. A preliminary series of optically stimulated luminescence (OSL) age determinations suggested ages of 20–50ka for these units (Bowler 2006). Our work in 2008 followed up these finds with an initial series of archaeological excavations to clarify whether or not there was a late Pleistocene archaeological record. This paper reports on these excavations and discusses the future potential of the Lake Gregory system for archaeological and palaeoenvironmental research.

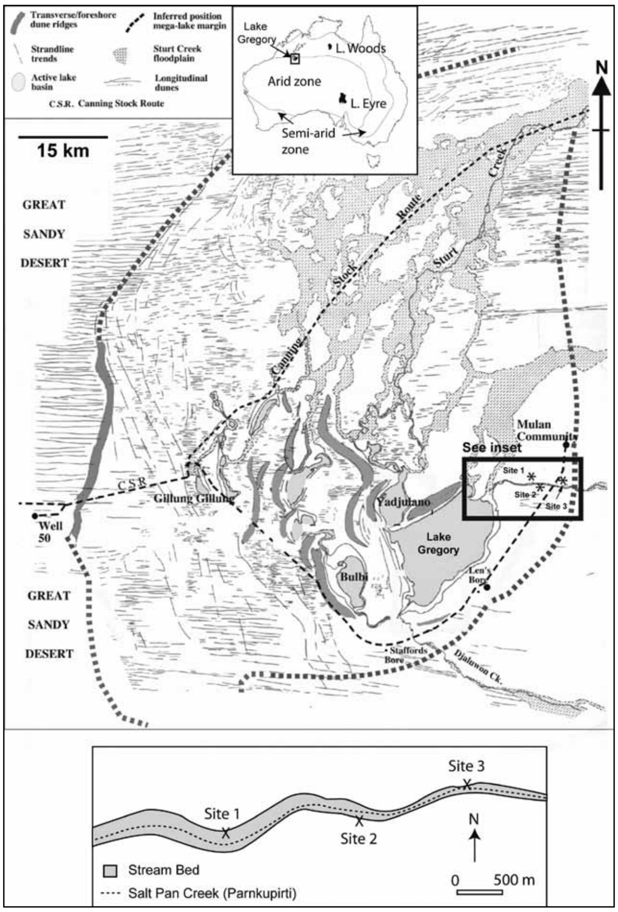

Figure 1 Geomorphic map of the Lake Gregory system, showing the boundaries of the palaeolake. Today, Lake Gregory is made up of a series of smaller basins, collectively known as the Gregory-Paruku lakes. The lower inset (outlined in bold on the geomorphic map) shows the Parnkupirti sites along Salt Pan Creek near Mulan community.

Regional Context

The Lake Gregory system represents a rare set of circumstances, where freshwater flowing into the desert juxtaposes two distinctive ecosystems: an alkaline freshwater system set within an arid environment. The area has an array of past shoreline features demonstrating periods when the lake area was some 10 times

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Figure 2 View of the creek section at Parnkupirti Site 3 (L-R: Jim Bowler, Peter Veth, Wade Freeman and Mulan community in frame) (Photograph: Mike Smith).

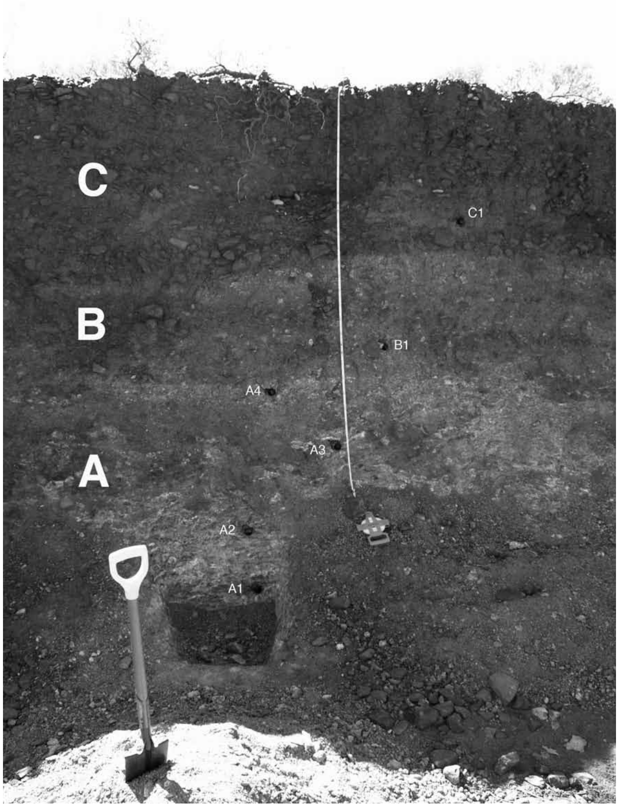

Figure 3 Site 3. Units A-C and location of OSL samples from the Parnkupirti section (Photograph: Mike Smith).

larger than today, interspersed with phases of dune building representing episodes of enhanced aridity. This represents an important archive of environmental history and of greatly amplified monsoonal activity. Earlier investigations (Bowler *et al.* 2001; Wyrwoll and Miller 2001) used thermoluminescence (TL) dating to provide a broad chronology for the lake system spanning the past 200,000 years. Later work, using OSL, allows some refinement of the Quaternary history of Lake Gregory. At the present time the lake stands at an intermediate phase with water level near 280m, well inside the perimeter of a former mega-lake phase where palaeoshorelines rose to 296–300m (Figure 1).

Salt Pan Creek Drainage

The northern catchment of Sturt Creek is supplemented by significant flow in creeks from the east and southeast. Salt Pan Creek and Djaluwon Creek drain catchments rising in low hills some 10–15km east of the lake.

Our data are derived mainly from stratigraphy exposed along the banks of Salt Pan Creek. Exposures on both the southern and northern banks of Salt Pan Creek (Figures 1-3) show a major sequence of channel gravels with interbedded fluvial and slackwater silt and clay deposits spanning the last 100ka. Eight OSL samples were taken from the section and pits on the northern bank of the creek (Site 3), and six OSL samples were collected from equivalent stratigraphic units from the southern bank (Site 2) to refine the existing palaeoenvironmental record for Lake Gregory. Bowler (2006) also mapped ironstone and silcrete artefacts within the gravels of Djaluwon Creek (to the south), which are heavily rounded and appear to be associated with a high-energy pluvial phase almost certainly of Pleistocene age.

Stratigraphy along Salt Pan Creek

A sequence of wet to dry environmental changes is defined by stratigraphic units from the northern and southern banks of Salt Pan Creek. Lying approximately 5m below the surface of the plain and incised into older lake sediments, the modern channel carries bedload sands. Lying several metres above

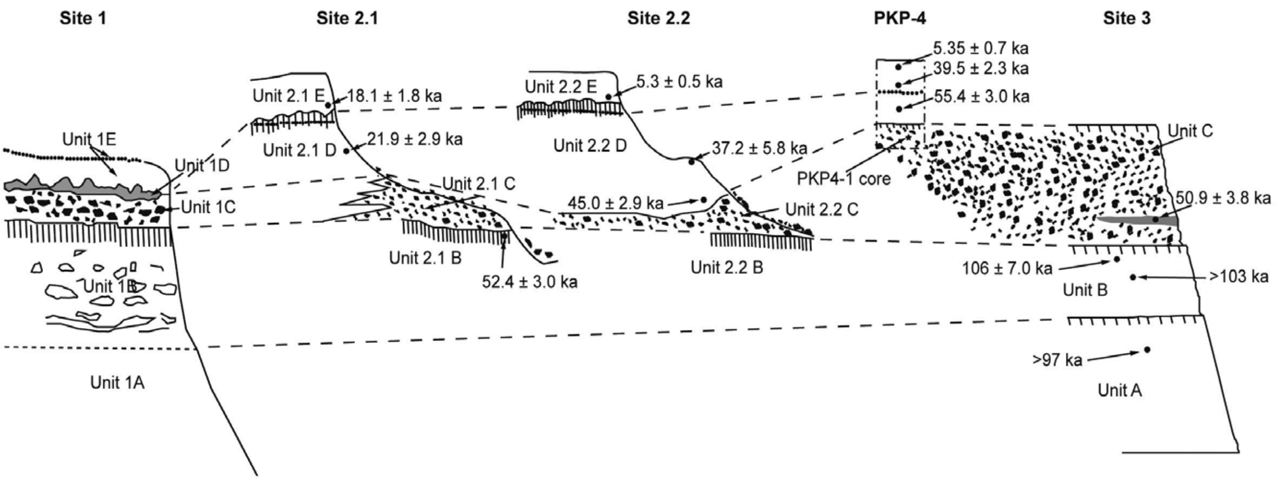

Figure 4 Correlation of stratigraphic units and location of OSL samples across Parnkupirti Sites 1-3. Vertical scale from top of Unit E to base of Unit A is c.5m. Note that OSL sample K2006 (37.2±5.8ka) is from Unit D overbank sediments inset into Unit C. The PKP4-1 core is located within the upper levels of Unit C pre-dating deposition of Unit D lake muds.

the channel floor and bearing no relationship to the modern regime, a lag of pebbles and cobbles remains from an earlier high discharge phase. By contrast, modern mobile gravels are absent, suggesting that even during modern monsoonal rains, discharges are insufficient to carry bedload larger than sand and occasional pebbles. This stands in marked contrast to the presence of earlier beds of large pebbles and cobbles, mainly of shiny dark brown quartzite, often greater than 10cm in diameter. Constituting torrent gravels, these represent periods of greatly increased discharge signaling the onset of former high lake levels, an observation supported by the presence of overlying limestone plates (Site 1, Unit 1D, Figure 4).

Site 1

Located on the relatively steep northern bank (Figure 4), the lower 2–4m (Unit 1A) consists of cemented and strongly weathered lake limestone. These relate to an earlier mega-lake phase around 100–120ka, with basal levels even older (Bowler *et al.* 2001). Weathered limestone passes up to a 1–2m zone of karstic weathering defined by red clays and secondary calcrete nodules (Unit 1B). Lying some 4m above the channel floor, this weathering zone identifies a long dry period during which the lake failed to rise to this level. This dry interval occurs immediately after the 100–120ka major expansion.

The red clays are overlain abruptly by a thin layer of brown silcrete pebbles (Unit 1C), evidence of the first return of water to this level after the long dry interval. These fluvial bedload sediments are in turn overlain by a thin plate of microcrystalline limestone (Unit 1D), evidence of quiet shallow water deposition some 5–6m higher than the present lake level. Karstic erosion, which has produced pitting and fluting of its upper surface, reflects a period of drying and weathering during a subsequent fall in lake levels.

The final depositional signature involves a thin 5–10cm cover of quartz sand and tabular silcrete pebbles (Unit 1E). These grade laterally some 100–150m north from the central channel to merge into beach sands, a zone commonly associated with artefacts. This represents a final late phase of lake expansion. Wind action removing fines results in a lag deposit of tabular pebbles forming a distinct desert pavement with an underlying red silt layer, the product of dust accumulation protected by the surface stone cover.

In summary, a long weathering period after ~100ka was interrupted by a phase of strong fluvial discharge depositing coarse clastic bedload over margins of the lake some 5m above present water level. Following a period of quiet-water limestone deposition, lake levels fell, marking another dry interval. A final high lake phase deposited the uppermost sand units (1E) on the northern bank. This sequence can be correlated with both the units on the south bank and the upstream sequence.

Site 2

The southern bank of Salt Pan Creek is marked by wider channel excavation, in contrast to the steeper cliff on the north. Although deposited on a lateral tributary, the units at this site (Figure 4) bear a strong stratigraphic correlation with those at Site 1. In this context, shallow water limestone in Unit 1D is equivalent to deeper water, muddy sediments at Site 2. This zone is frequently coated by a white saline efflorescence containing sodium sulphate, residual salts from alkaline lake waters. OSL ages for two adjacent sections – Sites 2.1 and 2.2 – are given in Table 1 and shown in Figure 4.

The stratigraphic sequence at Site 2 (Figure 4) shows gravels and cobbles over a basal weathering horizon (Unit 2.1B) passing laterally into a thick 1–2m zone of hard red sandy clays (Unit 2.1C). These grade upwards into a well-developed soil with prismatic and polygonal domal structure (Unit 2.1D) overlain by 20–30cm of red A-horizon clayey sands (Unit 2.1E). Some 30–40cm below the surface, a band of single pisolithic or pelletal ironstones defines a line, rising to the south to merge with beach sands near the surface (the corollary of the surface pelletal layer at Site 1). It is also associated with late Holocene artefacts such as tulas and tula slugs.

At Site 2, a major erosion surface (equivalent to the B-C disconformity at Site 1), truncates basal sediments and is overlain by channel gravels providing direct correlation between north and south bank sites (Figure 4). An OSL sample (K1528) from immediately below the disconformable contact provides an age near 52ka, giving an estimate for the end of a dry phase and initiation of burial. On the south bank, red clayey sands were deposited in slack water as muddy lakeshore environments (equivalent to limestone Unit 1D on the north bank) and provide basal ages near 45ka grading up to 37ka and 21ka. Ages of 18ka and 5ka are from samples likely to be subject to disturbance and bioturbation from a level near the surface soil – and we treat these as minimum ages only.

This sequence is consistent with the onset of fluvial deposition near 50ka leading to lake expansion, and deposition of near-shore muddy sediments by 45ka. While these sediments correlate closely with the cobbles and limestone units (1C and 1D) at Site 1, the actual age of lake retreat (equivalent to karstic development of Site 1 limestone) is not readily apparent at Site 2. That still-stand has been obscured here by the return and deposition of equivalent muddy facies which have all been oxidised and homogenised by pedogenic modification. In this context, deposition beginning near 50ka and lasting until at least 30ka is consistent with all evidence currently available.

Site 3

Located some 2km upstream from Site 1 on the north bank of Salt Pan Creek, a cutting (Figures 3-5) exposes 3m of gravels and cobbles overlain by 2m of surface red clayey sands grading onto the surrounding plain. Our main archaeological investigations lie within the upper 2m of this section.

The cutting displays three distinctive units separated by stratigraphic breaks (Figure 4). In the lowermost Unit A, indurated bands of sandy limestone with reworked cobbles of the underlying limestone are associated with bands of lithic sands and gravels heavily cemented by secondary carbonate. Well-defined traces of near-horizontal bedding relate this unit to a coarse textured lake marginal deposit. In its uppermost 20–30cm, vertical fractures, showing mottling with carbonate leaching, identify a substantial time break before deposition of the overlying Unit B.

Unit B contains well-rounded gravels and cobbles of brown Palaeozoic quartzite, and cobbles of lacustrine limestone. Cobbles are frequently >5–10cm in diameter and reflect high velocity discharge events involving large quantities of water discharging into the lake. Frequent carbonate encrustations on cobble surfaces point towards deposition of lacustrine limestone in the gravel interstices consistent with submergence for a relatively long period beneath expanded lake waters. This is further supported by a stone-free upper 20–30cm of highly weathered yellowish-red sandy clays with prismatic jointing, evidence of a substantial time break before deposition of Unit C.

Unit C is a 1–1.3m thick layer of well-rounded gravels and cobbles of dark brown silcrete, platy siltstone and associated Palaeozoic bedrock fragments. With an imbricate depositional fabric, these gravels represent a phase of major, high velocity discharge similar to the fluvial system responsible for the underlying Unit B. However, Unit C cobbles bear no trace of subsequent limestone deposition but are associated with a matrix of brick-red clayey sands. The red sands that fill voids in the coarse cobble fabric are incompatible with synchronous cobble transport, and were deposited from the overlying lacustrine muds. Unit C is separated from underlying Unit B by a well-defined disconformity representing a long time interval. The lensing gravels of Unit C grade into the basal sector of the overlying hard red sandy clays (Unit D). The latter include polygonal vertisol structures enclosing a pelletal, often pisolithic band of ironstone, both features identical with equivalent levels on the south bank (Site 2, Figure 4).

Excavations at Parnkupirti Site 3

Site 3 was chosen for a pilot excavation because it was one of the few points along Salt Pan Creek where a deep (3.5m) vertical section was exposed. A narrow elevated terrace led back from this face, representing a residual bench of Unit D palaeolake sediments 30m wide (Figures 5-6). A low density but extensive scatter of stone artefacts (averaging <1 artefact/m^2) occurs on the surface of this terrace as well as in a heavily scoured and eroded area immediately to the west. Our excavations in August

Table 1 OSL data and age estimates for Parnkupirti Creek North and South banks (Sites 3 and 2, respectively). Samples K1528, K2006 and K2007 represent the most reliable age estimates, yielding Gaussian or dominant age peaks (with varying degrees of saturation or mixing present in other samples – consistent with dynamism of lake muds).

Unit	Lab No.	Depth (m)	De (Gy)	K (%)	U (ppm)	Th (ppm)	Cosmic Dose Rate (Gy/ka)	Water Content (%)	Total Dose Rate (Gy/ka)	Age (ka)
North Bank (Site 3)										
A	K2056	2.6±0.1	239±42	0.73±0.04	1.36±0.07	19.5±0.98	0.1±0.01	4±2	2.45±0.12	**>97**
B	K2059	1.4±0.1	240±8	0.79±0.04	1.43±0.07	15.8±0.8	0.19±0.02	6±3	2.26±0.12	**106±7**
B	K2061	1.8±0.1	250±23	0.56±0.03	1.32±0.07	21.5±1.1	0.17±0.02	4±2	2.44±0.12	**>103**
C	K2062	1.1±0.1	264±17	0.87±0.04	1.77±0.09	15.6±0.8	0.20±0.02	4±2	2.4±0.11	**>108**
C	K2063	1.1±0.1	126±7	0.85±0.04	1.7±0.09	16.2±0.8	0.20±0.02	4±2	2.48±0.11	**50.9±3.8**
D	K2064	0.1±0.1	9.6±0.2	0.48±0.02	1.50±0.08	11.6±0.58	0.22±0.02	3±2	1.8±0.24	**5.3±0.7**
D	K2065	1.0±0.1	105±1	0.57±0.03	1.63±0.08	12.2±0.61	0.2±0.03	5±2	1.90±0.10	**55.4±3.0**
D	K2066	0.5±0.1	75.8±0.9	0.63±0.03	1.64±0.08	11.5±0.57	0.21±0.05	5±2	1.92±0.10	**39.5±2.3**
Site 2										
C	K1528	2.0±0.2	84.2±3.5	0.63±0.03	1.4±0.07	8.4±0.40	0.17±0.02	5±2	1.61±0.07	**52.4±3.0**
C	K2007	2.0±0.2	64.8±2.4	0.49±0.03	1.29±0.07	7.99±0.40	0.17±0.02	3±2	1.44±0.07	**45.0±2.9**
D	K1529	0.9±0.1	28.2±3.5	0.40±0.02	1.08±0.05	7.53±0.38	0.20±0.03	5±2	1.29±0.06	**21.9±2.9**
D	K2006	0.9±0.1	75.3±10.5	0.98±0.05	1.55±0.08	12.65±0.68	0.19±0.03	5±2	2.02±0.13	**37.2±5.8**
E	K1530	0.5±0.1	23.1±2.0	0.40±0.02	1.02±0.05	7.38±0.37	0.21±0.04	5±2	1.28±0.07	**18.1±1.8**
E	K2005	0.5±0.1	8.2±0.7	0.44±0.02	1.31±0.07	9.01±0.45	0.21±0.05	15±5	1.54±0.08	**5.3±0.5**

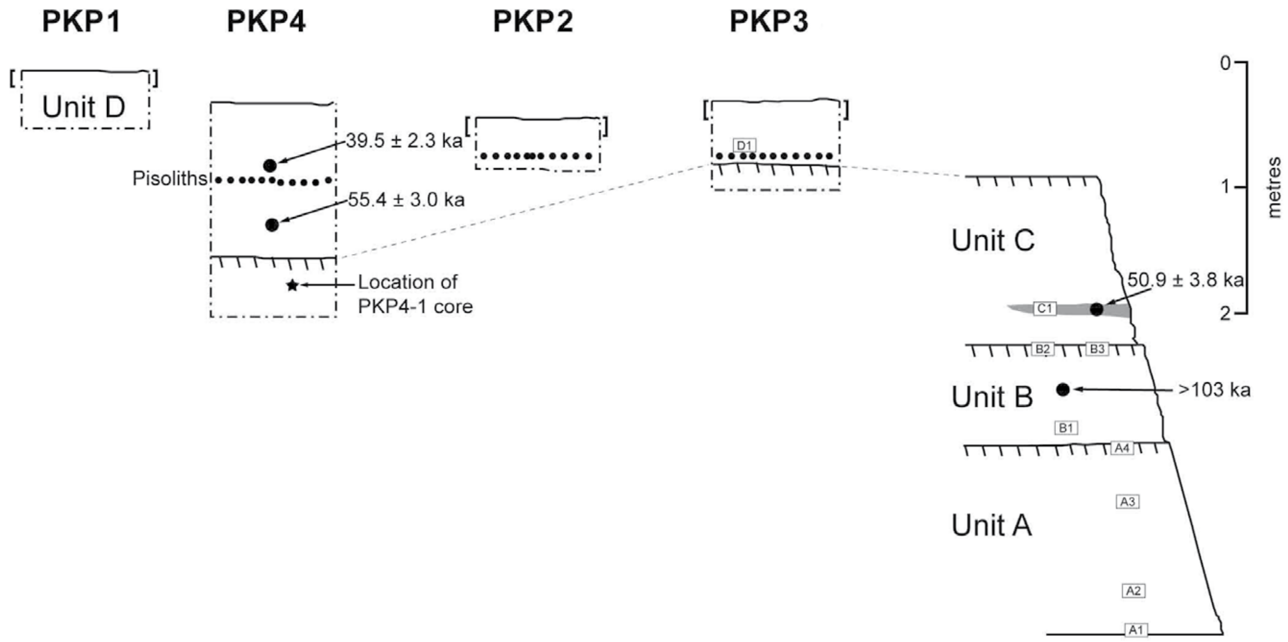

Figure 5 Archaeological excavations at Parnkupirti Site 3, showing stratigraphic correlations between the creek section and the excavation pits. OSL samples from Unit C were taken from a silty horizon interleaved within the fluvial cobbles (shown as grey lens). For Pits PKP1 to PKP3, brackets indicate the vertical distribution of artefacts in Unit D.

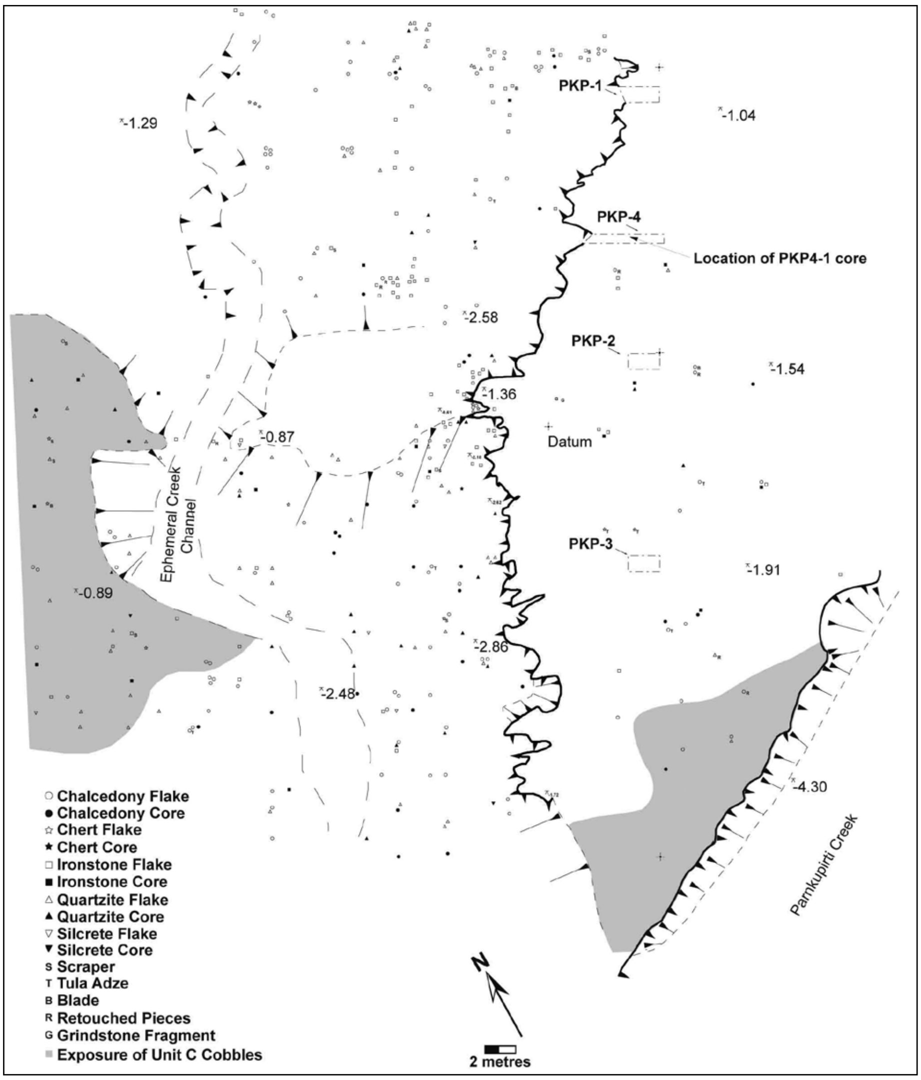

Figure 6 Plan of Parnkupirti Site 3, showing the location of excavated pits and the distribution of artefacts on the eroded area to the west. Relative heights show local topography.

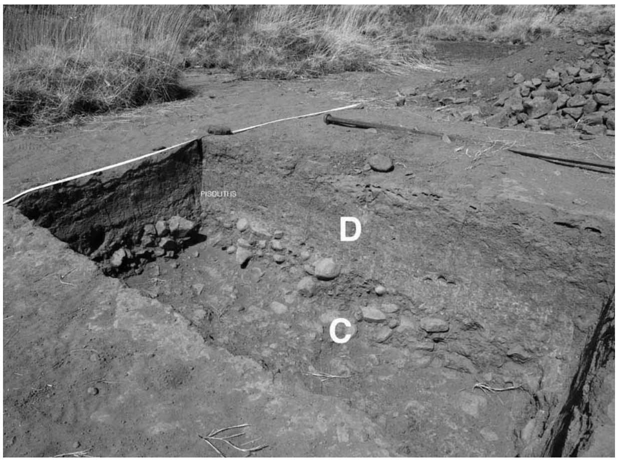

Figure 7 Site 3. Pit PKP2 showing the Unit C cobbles, pisolith horizon and Unit D sediments.

2008 sought to clarify the stratigraphic provenance of these artefacts, following Bowler's earlier reconnaissance, which had suggested that at least some were eroding from Pleistocene sediments (Bowler 2006).

Three 1m x 2m excavation trenches (PKP1-PKP3) were laid out in a transect running 50m back from the creek section (Figure 6). These were excavated with picks, trowels and mattocks and all sediments were screened for artefacts. The heavily indurated nature of Unit D lake sediments meant that the maximum depth reached in any of these pits was 70cm. Therefore, a fourth and deeper trench (PKP4) was excavated with a backhoe, providing a 1.8m section ito the lake deposits at a point 37m back from the creek section.

Collectively these excavations revealed an upper unit of heavily indurated lake muds (yellowish-red, 5YR 5/8-6/8, clayey silts) up to 127cm thick, with a well-developed polygonal structure and vertical cracks extending to 1m below surface. This unit – labelled Unit D – is divided into upper and lower sections by a thin band of pisoliths at 70cm below surface. Unit D overlies Unit C – a bed of large subangular and rounded cobbles (to 150mm) in a matrix of pisoliths and red (2.5YR 5/8) clayey sand. The surface of Unit C slopes down at 1° from the creek section (where it is exposed at the surface) and so was only reached in pits PKP3 and 4 (Figure 7).

The excavations recovered a small number of stone artefacts (N=14) in Unit D and all from the top 25cm of the unit. The larger pieces (>40mm) may be *in situ*. However, some are small enough to have been introduced into these levels via vertical cracks in these lake sediments – and their provenance is therefore not secure.

Table 2 provides a summary description of artefacts excavated from Unit D. These artefacts are made on local chert and quartzite – the latter probably sourced in streambed cobbles within a few hundred metres of the excavation site. None of the flakes was retouched and the assemblage generally reflects core reduction to produce large flakes. Our field observations at Site 3 indicate that the surface of Unit D has been stripped and eroded, and that artefacts on the scoured and eroded areas west of the excavations have been reworked from the upper part of this unit (Figure 6). Artefact typology points to a late Holocene age for much of this material as the scatter includes tulas and tula slugs

Table 2 Description of artefacts excavated from Unit D.

Artefact	Excavation	Provenance	Artefact Description
1	PKP1	Spit 1	Medial fragment of a flake, with bulb and portion of eraillure scar preserved on the ventral face and negative scar terminations on the dorsal face.
2	PKP1	Spit 3	Flaked piece containing one large negative step-terminated scar (8mm long) truncated by one of several breaks.
3	PKP1	Upper 25cm	Complete chert flake with intact platform, clear ring crack and bulb on ventral surface, and negative scars on the dorsal face. Length=9.4mm.
4	PKP1	Upper 25cm	Proximal fragment of quartzite flake. Ring crack and bulb preserved. It was removed from a water-smoothed cobble and contains the cortex on the dorsal face. Length=25.5mm.
5	PKP1	Upper 25cm	Complete quartzite flake with cone and bulb visible on the ventral face and one negative scar on the dorsal face. Length=43.6mm.
6	PKP1	Upper 25cm	Chert core with four negative scars originating from a single conchoidal platform. Weight=145g.
7	PKP2	Spit 1	Quartzite flake from a water-rounded cobble. Cortex covers the dorsal face. Ring crack and bulb visible on the ventral surface. Hinge terminated. Length=22.7mm.
8	PKP2	Spit 1	Chert flaked piece. Negative scars originate from the same platform. No ventral surface is discernable, instead there is a flat surface which may reflect the piece has split along a pre-existing plane. Length=10.9mm.
9	PKP2	Spit 1	Chert flake with distinct point of impact and cone. Length=16.5mm.
10	PKP2	Spit 2	Chert flake with visible ring crack and bulb on the ventral surface. On the dorsal face there are seven negative scars. Length=41.5mm.
11	PKP2	Spit 2	Quartz flaked piece. It contains five negative scars deriving from the same platform surface. Weight=4.2g.
12	PKP3	Spit 2	Complete chert flake. A distinctive ring crack and bulb is present on the hinge terminated ventral surface. On the dorsal face there are seven negative scars from the same platform surface. Length=17.9mm.
13	PKP3	Spit 2	Proximal end of a chert flake. Bulb with eraillure scar is preserved on the ventral face. Two negative scars from the same platform are visible on the dorsal face. Length=11.3mm.
14	PKP3	Spit 6	Flake from a quartz cobble. It has a clear fracture initiation point. Length=19.4mm.

Figure 8 View of the flaked face of PKP4-1 showing scars free of encrustations (Photograph: Peter Hiscock).

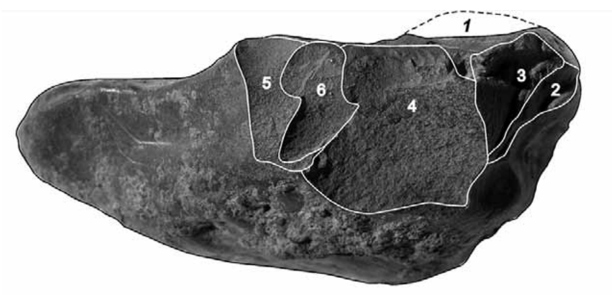

Figure 9 The order of flaking of the PKP4-1 core (Photograph: Peter Hiscock).

and is dominated by use of cryptocrystalline stone such as desert chalcedony (chalcedonic chert). A mantle of cobbles forms an apron in places along the margin of the scoured area and shows that erosion has also cut into Unit C. Some weathered silcrete artefacts are present in the artefact scatters. These may be the counterpart of the PKP4-1 core excavated from Unit C, but as yet we cannot securely establish their provenance.

In PKP4 a large silcrete core (PKP4-1) was recovered *in situ* within the Unit C cobble bed (Figures 8-9). As this was the most significant find during the 2008 excavations some comments on its provenance are warranted. The artefact was discovered whilst cleaning the PKP4 section. Only its edge was exposed after the section was cleaned back and it took some time to extricate the artefact from the tightly-bound cobble bed. The core lay platform down in the deposits at a depth of 149.5cm below ground surface – 23cm beneath the surface of Unit C and sealed within the cobble bed. A thorough search of other exposures of Unit C showed that flaked or angular pieces are otherwise absent from this cobble bed. In the absence of evidence for rolling and abrasion, the presence of PKP4-1 within the cobble layer suggests that Unit C was laid down in several lenses. People appear to have collected a silcrete cobble on the lake margin, then flaked and discarded the core, which was later covered by more torrent gravels.

Artefact Description: PKP4-1

PKP4-1 is a single platform core (159.7g) made on a rounded cobble of local silcrete (Figures 8-9). As this artefact is late Pleistocene in age a detailed description is given below.

Condition of the Core

Carbonate encrustations have built up on the rounded surface of the cobble but do not cover the flake scars, indicating that the knapping took place after transport of the cobbles in Unit C. There are none of the impact points or small scars that natural mechanical damage might produce. The flake surfaces are uniformly weathered and scar edges show rounding (especially on the platform edge), consistent with *in situ* weathering (but not rolling/abrasion). This eliminates any possibility that the scars are recent and were produced during the excavation.

The Pattern of Flaking

PKP4-1 has six negative conchoidal scars. All appear to have hertzian initiations and are positioned on one part of the piece. The pattern of flake removals is clear and is distinctive of human knapping. The cobble is an irregular, angular hemisphere with a relatively flat surface on one side. This surface is flatter at one end and it is here that the scars are located, a situation more consistent with human knapping choices than mechanical damage (which would easily have occurred at the thinner, angular end with a raised surface). The first scar runs across this flat surface and has removed a localised rise, thereby making the surface flatter and more suited as a platform. Subsequently five blows were struck to this prepared platform surface, removing scars from an adjoining face. All five blows were orientated in a similar direction, and the order of flake removal was (looking at the flaked face) right to left, with the exception of the final small flake removal. This was struck so that it ran down a ridge created by the intersection of the 4th and 5th flakes. The 5th flake was removed by a blow struck on the edge of a conchoidal platform surface – this being preferable as a platform rather than the smooth natural exterior.

This pattern, of platform construction then regular flake removal, restricted to the conchoidal platform and moving progressively from right to left for four flakes, is undoubtedly patterned in a way that is consistent with human knapping and inconsistent with natural processes.

OSL dating at Parnkupirti Sites 2 and 3

Eight OSL samples were collected from Site 3, and six samples were taken from Site 2 (Table 1). Samples were collected by hammering light-tight steel tubes into cleaned surfaces. All samples were capped immediately upon extraction to minimise exposure to light.

Methods

Samples were processed under low intensity red light to extract the 125–180µm modal size quartz fraction. Carbonates, organic materials and heavy minerals were removed by hydrochloric acid and hydrogen peroxide reaction, and sodium polytungstate density separation, respectively. Etching by hydrofluoric acid removed the outer parts of the grains exposed to α-radiation and any feldspars present in the sediments. Samples were cleaned in hydrochloric acid then loaded onto stainless steel discs as small aliquots containing fewer than 50 grains each. Between 18 and 24 aliquots were measured for each sample, with an additional three aliquots for each sample initially measured to identify the age range. OSL measurements for equivalent doses were made using the Single Aliquot Regenerative (SAR) dose protocol (Murray and Wintle 2000, 2003) on automated Risø TL-DA-12 and TL-DA-15 readers with OSL attachments (Bøtter-Jensen 1997; Bøtter-Jensen *et al.* 2000). Following a preheat plateau test on sample K2066 using six different preheat temperatures

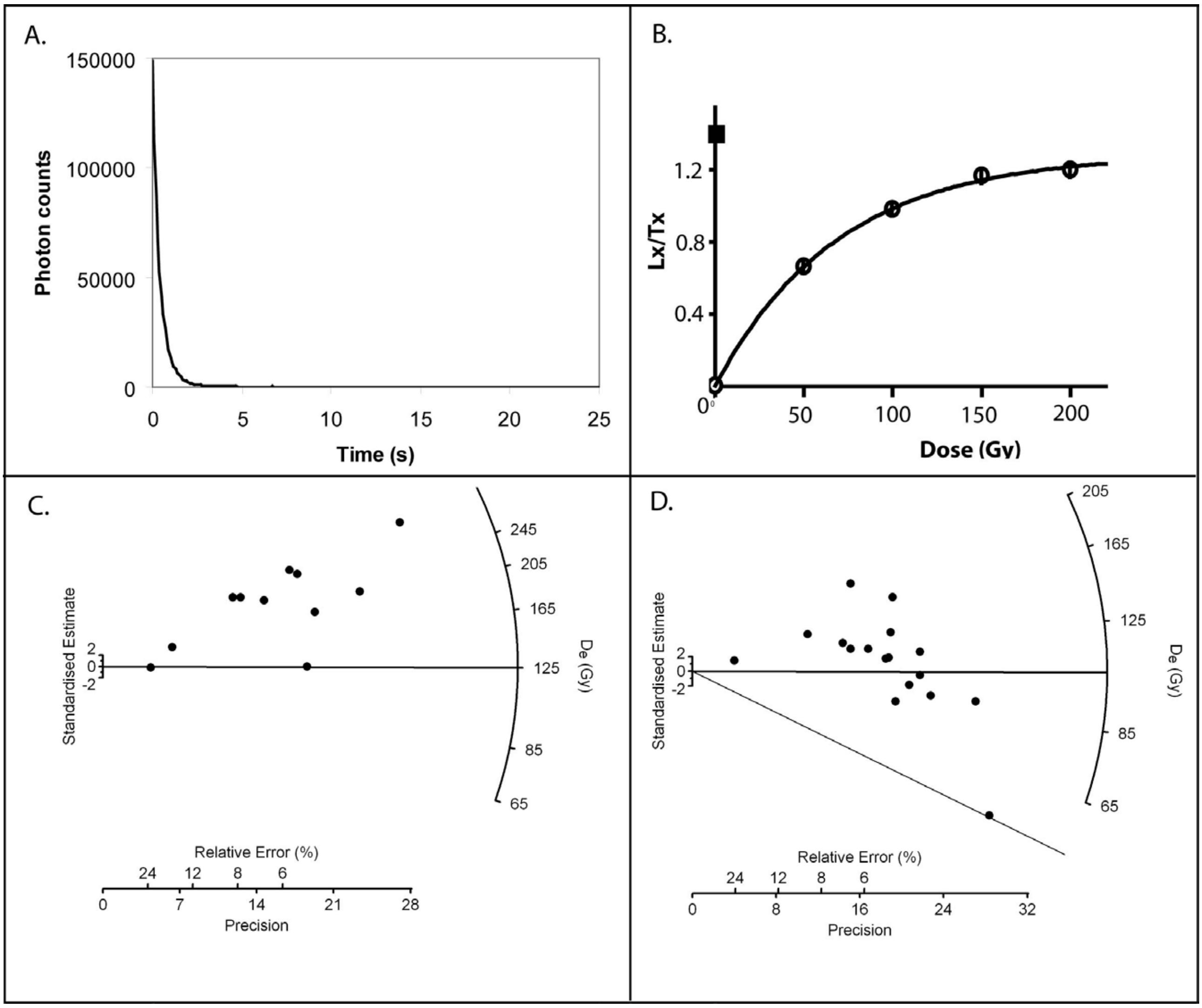

Figure 10 Dose distributions of OSL samples. (A) Natural OSL decay of sample K2056. (B) Indicative dose-response curve for sample K2056. (C) and (D) Radial plots showing dose distributions for small aliquots for samples (C) K2063 (Unit C) and (D) K2065 (Unit D). Note the mixed dose populations for both samples, indicating that these particular samples cannot be relied upon for age determinations.

ranging from 180°–280°C, the maximum preheat temperature on the plateau (240°C) was selected and applied to all samples. The SAR protocol used incorporated four regenerative dose steps, plus an additional repeated dose step to check recycling (Murray and Wintle 2003). Test doses of approximately 5 Gy were applied following each regenerative dose step, and measurement of the natural OSL signal.

All samples exhibited bright luminescence signals that rapidly decayed within the first few measurement channels (Figure 10A), indicating dominance of the fast component OSL signal. The samples exhibited luminescence behaviour indicating suitability to the SAR protocol, including recycling ratios close to unity, negligible thermal transfer, and minimal IRSL signals. However, equivalent dose distributions yielded either luminescence signal saturation (Figure 10B) or high degrees of mixing (Figure 10D) in all samples except K1528, K2007 and K2006. The ages as given in this paper either used the weighted mean or minimum age for D_e calculation.

Dosimetry

Dose rates were calculated from radioactive element concentrations analysed using inductively-coupled plasma mass spectrometry (for uranium and thorium) and atomic emission spectrometry (for potassium), undertaken at Genalysis Laboratories, Perth. Radionuclide concentrations were converted to beta and gamma dose rate components using the conversion factors of Adamiec and Aitken (1998). The present average water content was used to calculate dose rate attenuation by moisture (e.g. Aitken 1998), with significant uncertainties of >33% incorporated into the calculations to allow for variations in moisture content through time. Cosmic dose rate was calculated using the formulae of Prescott and Hutton (1994), with an additional soft component to the dose rate added to account for the shallow depth of sample K2064. The shallow depth (0.1m) of this sample was also used to correct for the lack of 4π geometry in the gamma component of the dose rate. Internal alpha dose rates were considered negligible in these quartz sediments. The OSL data are presented in Table 1 and correlations between Sites 1-3 are summarised in Figure 4.

Interpretation of the OSL Chronology

The samples taken from the two lowest stratigraphic units at Parnkupirti Site 3, Units A and B, were saturated with respect to the OSL signal and therefore yield minimum ages only. It is not possible to interpret these ages any further than suggesting that the shallow lacustrine and older fluvial sediments corresponding to these units were deposited at least 100,000 years ago.

Despite the apparent suitability of the OSL samples for dating using the SAR protocol, the dose distributions of those samples not saturated with respect to the luminescence signal were widely distributed, with signs of post-depositional mixing or incomplete bleaching (Figure 10). There were three exceptions to this (K1528, K2007, K2006) – all from Site 2. These yielded dose distributions in the form of Gaussian populations or dominant age peaks, and therefore more reliable age estimates were calculated. This is attributed to the more homogeneous nature of the sediments at this location. K1528 and K2007 lie within 2 standard deviations of one another, and are therefore statistically the same age, ~50–45ka.

Although K2063 from Site 3 gave a similar age (52ka) using the weighted mean of all aliquots, three age peaks were identified in different aliquots of this sample (at c.25ka, 50ka and 75ka). Therefore, this age estimate is only an average. Nevertheless, stratigraphic correlations between Sites 2 and 3 constrain the age of Unit C to ~40–50ka. By association, the PKP4-1 core is older than 37ka and given its location well within the Unit C gravels is most likely to be in the 50–45ka range.

The remaining OSL samples are subject to a number of limitations. The mixed dose distributions (observed for all samples except K2056, K2061, K2062, K1528, K2007 and K2006) may be a consequence of several factors. In Unit C, the sediment heterogeneity (with a mixed deposit of cobbles and pebbles in a fine-grained matrix) contributed to variability in dose rate estimates, resulting in a wide age distribution between measured aliquots. Moreover the luminescence signal may not have been completely reset within these sediments, since rapid deposition took place under turbulent subaqueous conditions with insufficient exposure to sunlight.

Within Unit D, evidence of bioturbation (in particular, termite activity) and swelling and cracking of lake muds indicates some post-depositional mixing. Only one sample (K2006) yielded a reliable age (37.2±5.8ka). This shows that little time elapsed between deposition of Units C and D, consistent with deposition of lake muds (Unit D) during an expanded lake phase initiated by the torrent gravels in Unit C.

Stratigraphic correlation between Sites 1, 2 and 3 underpins the chronology presented in this paper. The major disconformity (B-C) underlying the last phase of torrent gravels at all sites represents a crucial benchmark. From a relatively horizontal expression at Site 1, Unit C rises to Site 2 (Figure 4). Here torrent gravels grade laterally into, and are in part overlain by, red clayey sands, sedimentologically and stratigraphically equivalent to Units C and D at Site 3 respectively. At Site 2 the cobbles and upper 1.5m of clayey sands are constrained by an age of ~50–45ka at the disconformity, with the upper unit (equivalent to D at Site 3) deposited around 37ka. A depositional hiatus was followed by a later period of lake expansion depositing the final lake mud facies (Unit 1E, Site 1, Figure 4). Pedogenesis followed, with substantial termite modification in upper levels. In summary, the evidence is consistent with the onset of rapid torrent gravel deposition near 50ka. The rapid nature of deposition suggests that the age of the upper gravels will be close to that of the onset of lake mud deposition, and some time well before 37ka.

Lake Gregory: A Northern Analogue for Lake Mungo?

The archaeology and geomorphology of the Lake Gregory system have great potential for reconstructing prehistoric human-environment relationships in arid northwest Australia. The promise, of course, is that Lake Gregory will eventually prove to be a northern analogue for the Willandra Lakes, with a richly detailed record of late Pleistocene subsistence and occupation around freshwater palaeolakes on the margins of the arid zone. The difficulty is that Lake Gregory is a much more challenging geomorphic landscape for this kind of research. The size of the lake system makes it difficult to identify focal points for archaeological research. Expansion and contraction of the palaeolake has left a spatially diffuse suite of Quaternary landforms and sediments, where the correlation and relative sequence of geomorphic units is not straightforward and rests largely on luminescence dating. Lake Gregory does not have the deep stratigraphic and archaeological windows that are provided by extensive natural erosion in the Willandra Lakes system.

A multiyear and staged approach is needed to disentangle the complex environmental and human signals that are present in this highly active monsoonal area. In this context, our find of a core stratified within sediments dating to ~50–45ka, is a first step. This in itself is significant. For the first time, it indicates human activity within the arid northwest of the continent from an open context dating before the Last Glacial Maximum.

The trench at Parnkupirti Site 3 will be reopened in 2009 and further samples taken at the base of Unit D to better constrain the age of the PKP4-1 core. Background gamma spectrometry will be undertaken to provide better estimates of *in situ* dose rates and further excavations across the interface of C-D will test for further *in situ* artefacts.

Lake Gregory has been a permanent freshwater body on the edge of the desert since humans first occupied the northwest. This landscape has enormous potential for reconstructing deep-time human and environmental histories for northwestern Australia.

Acknowledgements

We are indebted to the community of Mulan and resident traditional owners for work on the Parnkupirti site, a major and 'open' Two Dog Dreaming mythological site. It was noted by several senior owners that this creation story represented the formation of Lake Gregory and surrounds (known in Walmajarri as 'Paruku'). That this should be the earliest site from the region was seen to be congruent with their origin narratives for the lake and its people. Some 300 people from Mulan, Billiluna and Balgo communities visited the site in various capacities – from the stage of gaining traditional owner consent, through to excavation and processing finds with IPA Rangers, structured visits and participation by school children and post-excavation presentations to the community and schools.

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