

# The Willandra Fossil Trackway: Assessment of ground penetrating radar survey results and additional OSL dating at a unique Australian site

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## Abstract

This paper presents some results of a ground penetrating radar survey conducted to establish the extent of the Willandra Fossil Trackway, and further mapping of the footprints and intermingled tracks. In addition, it includes a refinement of the age range of the trackway, through further OSL dating, to between 19,000 and 20,000 years ago. Finally, it also provides a discussion of the geochemical composition of the trackway.

## Introduction

Fossil footprints have been reported from near Lake Garnpung in the Willandra Lakes region in southwestern New South Wales (NSW), Australia (Webb et al. 2006) (Figure 1). The site consists of at least 26 human fossil trackways (individual sets of footprints), numbered T0–T26, as well as individual human footprints not linked to trackways, and the footprints of marsupials and birds. It is the first such fossil trackway site documented in Australia, and as such represents a very important record of a rare site type.

The Willandra Lakes system comprises a series of now-dry lake basins in the semi-arid interior of southeastern Australia that last contained water around 8000 years ago (Bowler 1998). The footprints are impressed into a hardpan unit located within dunes between Lakes Garnpung and Leaghur; approximately 820 m<sup>2</sup> of the surface of the hardpan has been exposed by erosion and excavation (Figure 2a). Originally, a total of 563 human footprints in 23 trackways were reported and previous publications have discussed the morphology, stature, weight, speed and alleged finger markings of the people responsible for them (Franklin and Habgood 2009; Webb 2007; Webb et al. 2006). Following investigation, the site was reburied and its location remains largely hidden to ensure its ongoing protection, with a regular monitoring program by NSW National Parks and Wildlife Service (NPWS) staff to ensure that it is appropriately conserved. In order to provide the public with an understanding of the site, a replica developed from digital scan data has been constructed at the Mungo National Park Visitor Information Centre.

In this paper we provide further contextual information relating to the site's environment, refining the age of the footprints to between 19,000 and 20,000 years ago. In addition,

we present further detail of the trackway mapping and revise the total number of footprints present, as well as assessing data from a ground penetrating radar (GPR) survey of the site commissioned for the NSW NPWS (Speer et al. 2006).

## Depositional Environment

The hardpan unit in which the footprints occur is approximately 150 mm thick and comprises thin (<10 mm thick) laminae of magnesian silty clay. The western edge of the hardpan is indurated and stable but the eastern edge is soft and disintegrating.

## Sedimentary Analysis

Webb et al. (2006) suggested that the hardpan unit was an aeolian deposit. They invoked a depositional model whereby fine-grained aggregates of carbonate minerals and silty clays had blown onto the site from the shore of an adjacent saline lake. To test this proposition, samples of the hardpan in which the trackway occurs were examined using powder x-ray diffraction and further analysed using Siroquant (version 2.5) and scanning electron microscopy (SEM) (AMBS 2008). Coupled with the examination of petrographic thin-sections (by author IG), results show the hardpan is comprised of thin laminae of sand-sized magnesian and silty clay pellets. Those layers near the surface of the unit contain silty clay cemented with magnesite. It is uncertain whether this cementation is primary, due to precipitation from magnesium-rich water ponded at the site, or caused by more recent dissolution and recrystallisation during diagenesis (Figure 3). The footprints of people, marsupials and birds crossing the hardpan could have been impressed during ponding, and the moulds preserved by subsequent magnesite cementation. Alternatively, rain events may have sufficiently moistened a pre-existing magnesian silty clay layer to enable casting to occur.

Mineral composition varies across the hardpan, with abundant quartz, magnesite, ferroan (iron-rich) magnesite and hydromagnesite, and lesser amounts of illite and kaolinite, in the western part. In contrast, the eastern section is dominated by magnesite and ferromagnesite, with minor illite, kaolinite and quartz. As a consequence of the differing mineral composition, the preservation of the footprints differs substantially across the hardpan surface.

Magnesite, ferromagnesite and hydromagnesite form by precipitation from water in which carbon dioxide has dissolved magnesium-bearing minerals. Their deposition in inland evaporite lakes has been documented where groundwater flows through mafic terrains (e.g. Pueyo Mur and Inglés Urpinell 1987; Renaut 1993; Warren 1990; Wright 1999). Such underlying geology has not previously been documented in the Willandra Lakes and magnesian evaporites have not been reported elsewhere in the region.

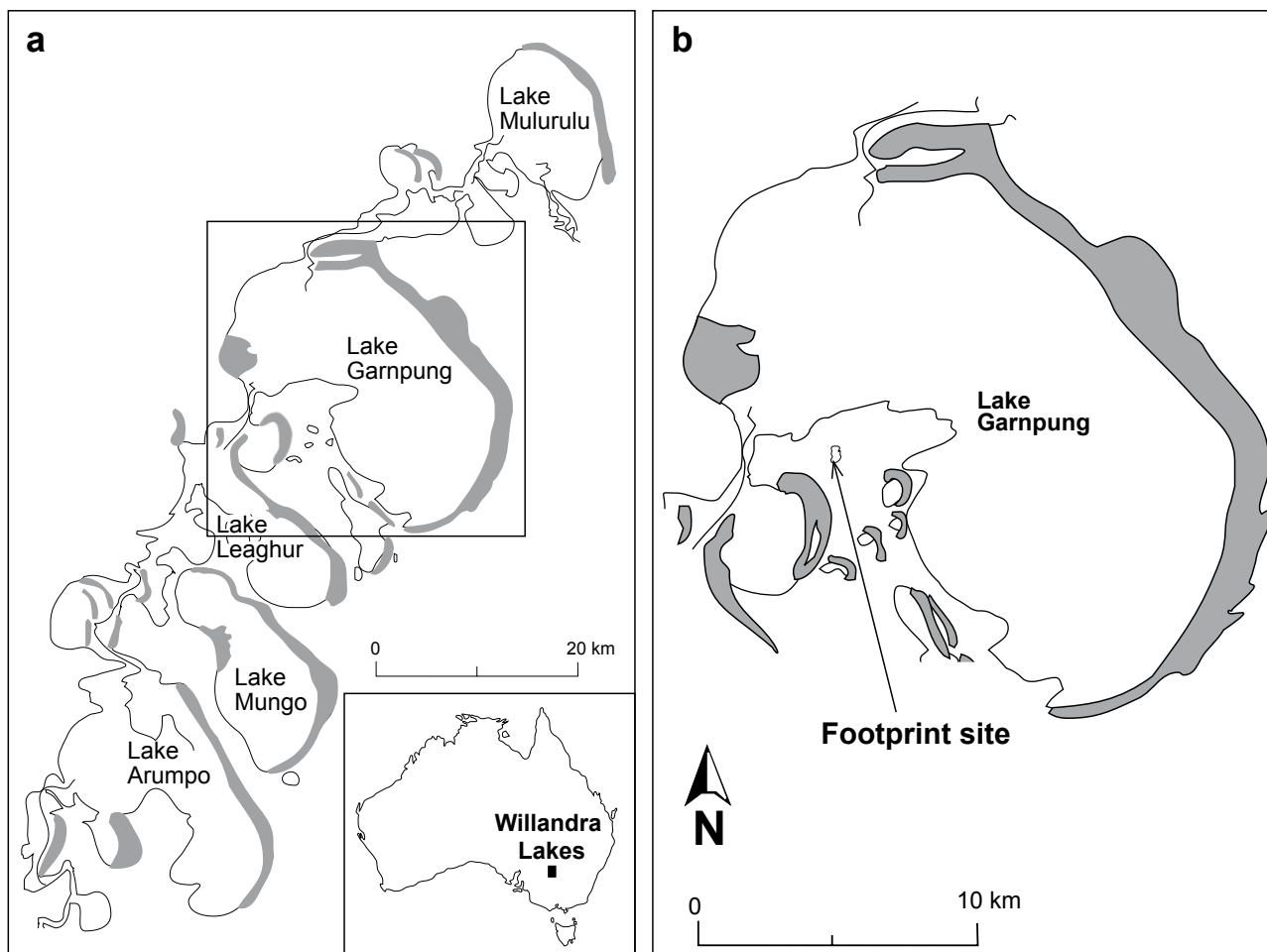
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**Figure 1** (a) General locality map and (b) Detailed map of Lake Garnpung showing the approximate location of the fossil trackways.

### GPR Survey

In order to assess the extent of the hardpan beneath the adjacent dune, a GPR survey was commissioned (Speer et al. 2006). The survey used 1.5 GHz, 900 MHz and 2200 MHz ground-coupled radar antennae, proving resolution of 0.5 m, 1.8 m and 7.4 m, respectively. Radio pulse velocity was calibrated from a test pit within the dune. The survey was conducted over an area some 250 x 180 m to the north and east of the hardpan. Data profiles were collected in a grid that focused on areas close to the exposed hardpan. A 50 x 25 m area was sampled in 5 m squares, 150 x 150 m was sampled in 10 m squares, and 100 x 130 m was sampled in 25 m squares.

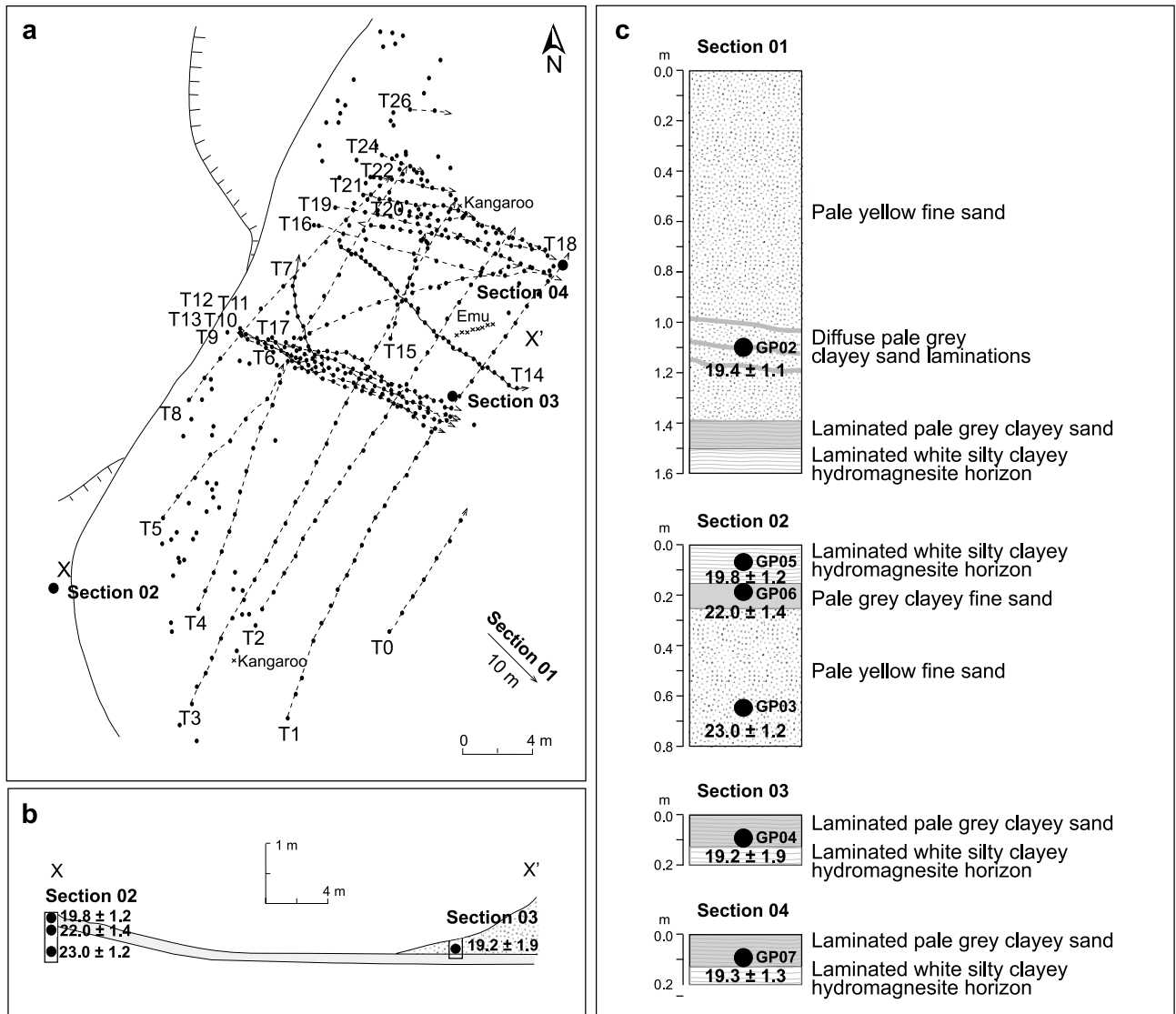
High amplitude responses have been interpreted as clay layers, with a total of eight distinct layers identified. The results indicate that the trackway hardpan—the ‘layer of interest’—extends 70 m to the east and 30 m to the north under adjacent dunes, and at least 2180 m<sup>2</sup> remain buried beneath overlying aeolian sands (Figure 4). The hardpan dips gently to the east and the lowest point is approximately 40 m east and 1.4 m below the visible trackway surface. It is possible that this was a depression that ephemerally retained water, as perched soaks where rain water ponds on hardpans are common within the interlake areas of the Willandra today. An additional feature to the north of the site identified in the GPR survey was originally interpreted by Webb (2007) as a gully or possible creek, but its slope has a gentle gradient and we argue that it more likely represents natural dune bedding.

A series of closely spaced high resolution GPR profiles, using a 1.2 GHz antenna, were also measured over 3 x 3 m in an attempt to trace one particular set of footprints (T14) east into the overlying dune. Three anomalous signatures were detected beneath the adjacent blanketing dune, 95–150 mm below the surface. Speer et al. (2006) have speculated that these may be caused by the depression of footprint casts and the compaction of the underlying sediment. However, on the basis of location, step length and sub-surface depth, we argue these signatures must be discounted as a continuation of T14. The signatures may be a continuation of T0 that ends 6 m to the south; the step length of the possible footprints is around 1.4 m, within the range of T0 step lengths (1.24–1.45 m). Whether or not these anomalies are indeed footprints will only be resolved by excavation.

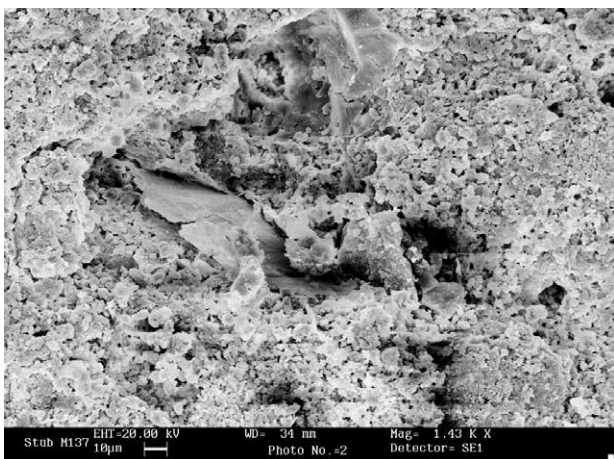
### Age of the Hardpan Unit

Webb et al. (2006) bracketed the age of the hardpan layer by dating quartz sand from over- and underlying units using optically stimulated luminescence (OSL). They reported a sandy unit 0.5 m beneath the hardpan to be 23,000±1200 years old (GP03) and sediments 0.4 m and 0.01 m above as being 19,400±1100 (GP02) and 19,200±1900 years old (GP04), respectively.

We used OSL to date the hardpan directly and also obtained additional samples from the bounding units (Table 1). A sample from the middle of the hardpan produced an age determination of 19,800±1200 years (GP05). Laminated pale



**Figure 2** (a) Willandra Fossil Trackway Site plan (note that T25 is located 110 m to the west and is not shown) (b) Site section and (c) Site stratigraphy and ages.

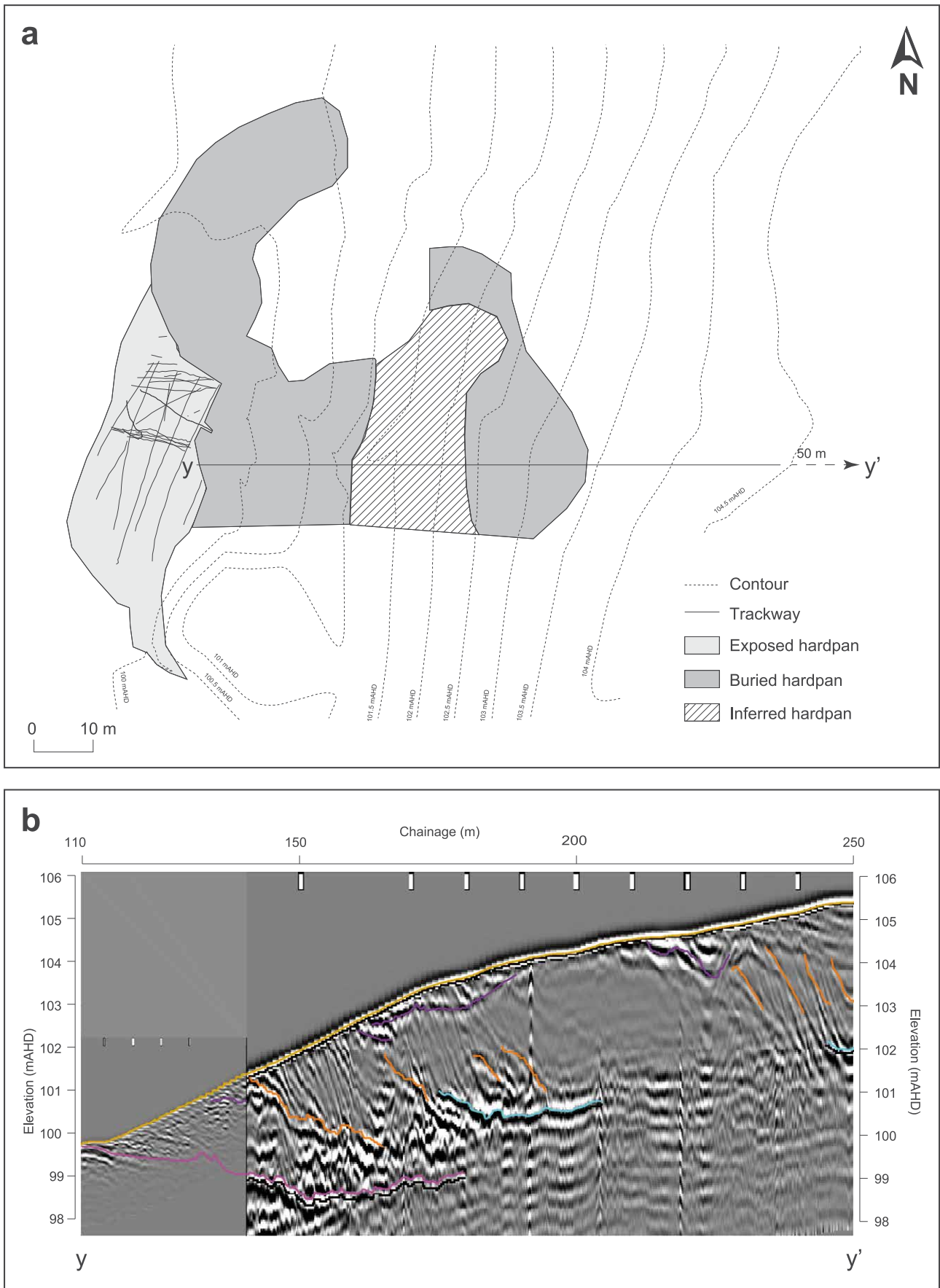


**Figure 3** SEM image of the footprint-bearing sediment showing its fine-grained nature and relatively high porosity and permeability in Sample G4, beside Section 04. Siroquant (modal%) analysis in this sample is magnesite 88%, illite 6%, kaolinite 3%, and quartz 3% (image by Sue Lindsay, Australian Museum).

grey clayey sand immediately above the footprints, in a similar stratigraphic position to sample GP04 (i.e. 19,200±1900 years old; Webb et al. 2006), was revealed to have been deposited 19,300±1300 years ago (GP07). Pale grey clayey fine sand immediately below the base of the magnesian silty clay unit is dated to 22,000±1400 years old (GP06). These additional ages show that the hardpan was deposited, and the footprints made, around 19,000–20,000 years ago.

### Additional Mapping and Interpretation of the Footprints and Trackways

The previously published site maps of the trackway (Webb 2007; Webb et al. 2006) were based on field surveys and mapping conducted in 2004 and 2005 using a Sokkia Electronic Total Station. Further mapping of the site in 2006, along with digital scanning of the ground surface and photography (Ogleby 2007), has revealed additional details of the tracks and peoples' movement patterns. A total of 533 footprints have now been mapped and the majority of these have been digitally scanned and the images georectified on to site plans. This number is smaller than the ca 563 footprints reported by Webb (2007), as we only include mapped and photographed locations with clearly defined



**Figure 4** (a) Site plan showing the GPR results, buried hardpan and inferred hardpan to the east and north of the exposed hardpan with tracks (b) GPR cross-section through  $y - y'$  from Speer et al. (2007). The hardpan is indicated by the purple line on the lower left of the profile and represents the inferred extent of the magnesian silty clay layer that contains the footprints.

Sample <sup>a</sup>	Depth <sup>b</sup> (m)	Water <sup>c</sup> (%)	K <sup>d</sup> (%)	Th <sup>d</sup> (ppm)	U <sup>d</sup> (ppm)	Radiation <sup>e</sup> (Gy ka <sup>-1</sup> )	$\delta$ Radiation <sup>f</sup> (Gy ka <sup>-1</sup> )	$\gamma$ Radiation <sup>g</sup> (Gy ka <sup>-1</sup> )	Cosmic-ray Radiation <sup>h</sup> (Gy ka <sup>-1</sup> )	Total Dose Rate (Gy ka <sup>-1</sup> )	Equivalent Dose <sup>i</sup> (Gy)	Optical Age (ka)
GP05	0.05	5.0 ± 1.0	0.44 ± 0.03	2.60 ± 0.14	1.20 ± 0.10	0.03 ± 0.01	0.52 ± 0.03	0.28 ± 0.02	0.16 ± 0.02	0.99 ± 0.05	19.5 ± 0.7	19.8 ± 1.2
GP06	0.20	5.0 ± 1.0	0.50 ± 0.03	3.60 ± 0.18	0.80 ± 0.10	0.03 ± 0.01	0.53 ± 0.03	0.27 ± 0.02	0.16 ± 0.02	0.99 ± 0.05	21.9 ± 0.7	22.0 ± 1.4
GP07	0.10	5.0 ± 1.0	0.42 ± 0.03	2.40 ± 0.13	1.30 ± 0.10	0.03 ± 0.01	0.51 ± 0.03	0.27 ± 0.02	0.17 ± 0.02	0.98 ± 0.05	19.0 ± 0.8	19.3 ± 1.3

<sup>a</sup> Samples were collected by driving 20 mm diameter stainless steel tubes into cleaned sections. The samples were processed under subdued red light, with the 90–125  $\mu\text{m}$  quartz fraction extracted for dating using standard procedures (e.g. Galbraith et al. 1999). A single-aliquot regenerative-dose protocol was used to calculate equivalent doses (Murray and Roberts 1998; Murray and Wintle 2000) following the analytical procedures described in Stone and Cupper (2003).

<sup>b</sup> Depths prior to recent erosion estimated to be ~1.6, 1.7 and 1.6 m for GP05–7, respectively.

<sup>c</sup> Long-term estimate based on measured values.

<sup>d</sup> Obtained by INAA (Becquerel Laboratories, Mississauga, ON).

<sup>e</sup> Assumed internal alpha dose rate based on measured values for quartz elsewhere in the Willandra Lakes (e.g. Bowler et al. 2003; Thorne et al. 1999).

<sup>f</sup> Derived from INAA concentrations using the conversion factors of Adamiec and Aitken (1998), with a beta attenuation factor of  $0.93 \pm 0.03$  (Mejdahl 1979), accounting for attenuation by water (Aitken 1998).

<sup>g</sup> Derived from field gamma spectrometry measurements using the conversion factors of Adamiec and Aitken (1998), accounting for attenuation by water (Aitken 1998).

<sup>h</sup> Determined from equations of Prescott and Hutton (1994).

<sup>i</sup> Central age model (Galbraith et al. 1999), including a  $\pm 2\%$  systematic uncertainty associated with calibration of the laboratory beta-source.

**Table 1** Summary luminescence age data.

footprints that showed evidence of either a complete footprint outline, the toes and ball of the foot, or the ball and heel of the foot. The surface contains many indistinct depressions that do not meet these criteria; while these depressions may represent eroded or incomplete footprints, they have not been included in this analysis.

Of the 533 footprints, 405 have now been matched into 26 trackways; these include a number of amendments to the previous trackway mapping. Three new tracks have been identified: T24 (comprising four footprints) and T26 (comprising two footprints) are located at the northern edge of the visible hardpan. New track T25 is located in the lowest part of the swale, 110 m to the west of the main concentration of footprints. An additional five prints each have also been added to tracks T5 and T22. As such, there remain 128 isolated footprints that have not been linked to tracks.

Tracks T6 and T11 have been published as two separate individuals (Webb et al. 2006). Both contain small prints, approximately 200 mm in length, with very similar step, stride and footprint lengths. These two tracks are aligned and we argue they are likely to be from the same individual. Tracks T7 and T14 may also be different parts of the one individual's track: both are small, possibly child-sized footprints, approximately 160 mm in length. T7 is the most sinuous track on the site, following a meandering path initially heading in a southeasterly direction, then veering towards the northwest before disappearing. T14 then commences from the northwest and travels to the southeast. Together T7 and T14 comprise 63 footprints and analysis of the stride length reveals a juvenile variously walking, stopping, running and then briskly walking.

The superimposition of individual tracks at a number of locations indicates the complex sequence of the group's movement (Table 2). For example, one sequence of superimpositions shows footprints of a large adult running to the north (T2), overprinted by two smaller tracks walking east (T11 and T13). These footprints are in turn covered in places by those of a large adult (T4) hopping to the north on the right foot only. Another sequence shows an adult walking east (T10), followed by an adult running north (T3) and then a juvenile walking east (T12).

A possible indicator of the seasonal timing of when the tracks were created is provided by a series of eight juvenile emu prints at the site (Figure 2). Based on foot measurements of modern emus, those at the site are estimated to be from 50–70 day old chicks (Stephen Davies pers. comm. 2006). Presently, emus mainly lay eggs in autumn between March and May (Davies 2002), although they also regularly nest after heavy rain events; incubation averages 56 days, suggesting that the prints may have been made in winter or early spring (i.e. between June and October).

## Conclusions

In this paper we have provided additional information on the Willandra Fossil Trackway, the only such archaeological site of its type published in the Australian record. The Willandra Fossil Trackway provides a novel record of Pleistocene Australians existing in the Willandra landscape at the peak of the Last Glacial Maximum, possibly during winter. Further sedimentary research at the site has revealed a clearer understanding of the likely natural

Event Order	Sequence 1	Sequence 2
1st	T2	T10
2nd	T11 and T13	T3
3rd	T4	T12

**Table 2** Sequence of superimposed tracks.

site formation processes responsible for creating this unique site. Understanding this contextual data is important for any future interpretation, and indeed conservation work, on the trackway. OSL analysis has refined our understanding of the age range of the site, confirming its age at 19–20,000 years BP. Reassessment of the GPR results has indicated that a number of features previously identified as a buried creek and a continuation of a trackway are more likely to represent less dramatic features.

### Acknowledgements

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