Williams, Alan, McDonald, Josephine, Atkinson, Fenella, Toms, Phillip ORCID logoORCID: https://orcid.org/0000-0003-2149-046X, Hobbs, Alistair, Barry, Laressa, Sapienza, Tom, Wood, Jamie C. and Doelman, Trudy (2021) Was Aboriginal population recovery delayed after the Last Glacial Maximum? A synthesis of a terminal Pleistocene deposit from the Sydney Basin, New South Wales, Australia. Journal of Archaeological Science: Reports, 40 (Part B). Art 103225. doi:10.1016/j.jasrep.2021.103225

Official URL: https://www.sciencedirect.com/science/article/pii/S2352409X21004375
DOI: http://dx.doi.org/10.1016/j.jasrep.2021.103225
EPrint URI: https://eprints.glos.ac.uk/id/eprint/10345

Was Aboriginal population recovery delayed after the Last Glacial Maximum? A synthesis of a terminal Pleistocene deposit from the Sydney Basin, New South Wales, Australia

Alan N. Williams [a,b,*], Josephine McDonald [c], Fenella Atkinson [d], Phil S. Toms [e], Alistair Hobbs [f], Laressa Barry [a], Tom Sapienza [f], Jamie C. Wood [e], Trudy Doelman [g]

[a] *EMM Consulting Pty Ltd, 20 Chandos Street, St Leonards, NSW 2065, Australia*

[b] *ARC Centre of Excellence for Australian Biodiversity and Heritage, School of Biological, Earth and Environmental Sciences, University of New South Wales, NSW 2052, Australia*

[c] *Centre for Rock Art Research Management, Faculty of Arts, Business, Law and Education, University of Western Australia, Crawley, WA, Australia*

[d] *Coast History and Heritage, PO Box A74, Arncliffe, NSW 2205, Australia*

[e] *Luminescence Dating Laboratory, University of Gloucestershire, Swindon Road, Cheltenham GL50 4AZ, UK*

[f] *Extent Heritage Pty Ltd, 3/73 Union Street, Pyrmont, NSW 2009, Australia*

[g] *Department of Archaeology, University of Sydney, Camperdown, NSW, Australia*

Abstract

We present a synthesis of 14 compliance-based investigations of an archaeologically significant sand body on the banks of the Parramatta River. We find the alluvial deposit initially formed ~ 50,000 years ago (50 ka), but with extensive portions reworked between ~ 20–5 ka. There is limited evidence of past visitation, with only three excavations having recovered substantive material culture (i.e. > 20 lithics/m2 across small areas, ≤35 m2). Following equivocal evidence of visitation prior to the Last Glacial Maximum (LGM), these assemblages generally demonstrate: i) widespread ephemeral, but repeated, activity between ~ 14–6 ka, dominated by indurated mudstone/tuff/chert raw materials (IMTC) and expedient technologies, overprinted by; ii) more extensive occupation of the landscape in the last few thousand years, with increasingly diverse and complex stone assemblages using heat-treated silcrete and additional raw materials from multiple geological sources. Notably, these two different phases are often found in the same locale, potentially suggesting a long continuity and repeated land use over 14,000 years. This synthesis demonstrates expansion away from cryptic refuges occupied during the LGM along the Hawkesbury-Nepean River corridor (some 40 km west of Parramatta) only occurred several thousand years after the height of this major climatic disruption. This timing is suggestive of a delayed recovery from the LGM and is coincident with changing environmental and sea-level conditions, which may have influenced, or been exploited by, people in the past. Our knowledge of Aboriginal societies during the terminal Pleistocene/early Holocene transition remains poorly understood in southeast Australia and is crucial to understanding demographic, symbolic and technological changes seen later in the Holocene.

Keywords

Cultural heritage management Cryptic refuge Parramatta River Alluvial terrace Terminal Pleistocene Cumulative impact

1 Introduction

The Sydney Basin is one of the most intensively archaeologically investigated areas in Australia. While initially the focus of academic and University-led research extending back to the 1940 s (e.g. McCarthy, 1949), this is now in large part the result of cultural heritage management (CHM). Due to robust environmental legislation, CHM investigations are required in advance of most forms of urban, infrastructure and mining development. A recent search of the Heritage NSW AHIMS database – the main repository for CHM studies – indicates some 12,500 archaeological sites, associated with ~ 900 reports, have been recorded in the region. Unfortunately, the number of sites destroyed is not readily accessible within the database. Investigations focussed on major urban centres are often in archaeologically sensitive locations (e.g. along river edges and coastlines) and impacts are significant due to the size of development (e.g. high-rise building). One of the key foci of CHM studies has been Parramatta Central Business District (CBD) situated in the centre of Sydney on the banks of Parramatta River (Fig. 1).

A plethora of CHM investigation has shown the Parramatta CBD to be situated on a Pleistocene alluvial terrace or levee of the river (Fig. 1), which retains an extensive archaeological archive. While only briefly referenced in published literature (e.g. McDonald, 2008; White, 2017), it has been locally known for almost two decades as being a significant archaeological deposit. The available disparate and often coarsely excavated evidence has hinted at potential activity and occupation over the last 35,000 years, and as such it represents a key locale within which to explore broader questions of societal change in temperate Australia through the Last Glacial Maximum (LGM) and terminal Pleistocene. At a continental scale, numerous models have been developed that suggest Aboriginal people survived the LGM in ecological or cryptic refuges (e.g. Veth, 1993; Williams et al., 2013), but only recently has focus shifted to the temporal and spatial recovery after the event (e.g. Barry et al., 2020; McDonald, 2015; Williams et al., 2018). These studies hypothesize that there was a substantial delayed recovery of populations and land-use following the LGM. However, to further explore this hypothesis using data from Parramatta, a synthesis of archaeological research is required.

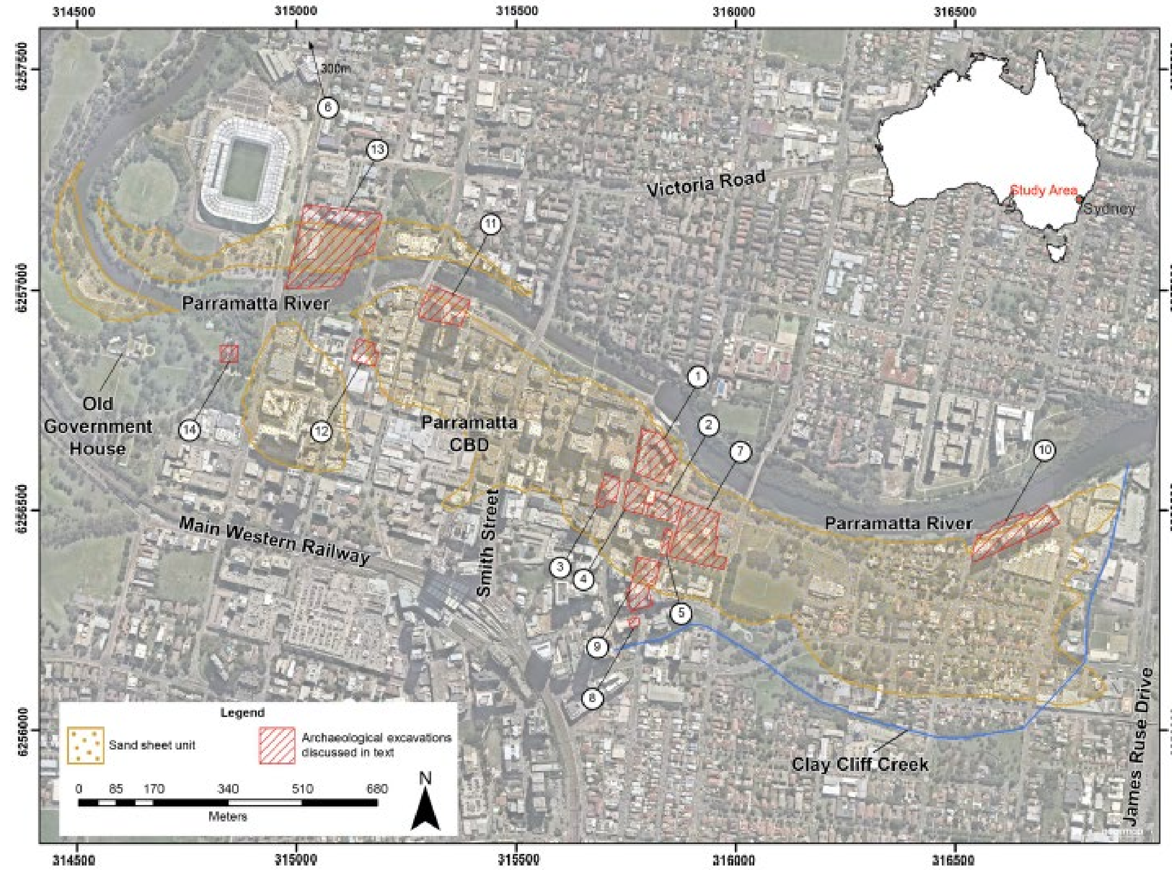


Figure 1 Location of the excavations discussed in the text (1. CG1; 2. RTA-G1; 3. CG2; 4. CG3; 5. 140 Macquarie Street; 6. Cumberland Hospital; 7. Cumberland Press Site; 8. 21 Hassall Street; 9. 189–190 Macquarie Street; 10. 2–8 River Road West; 11. 330 Church Street; 12. 95-95A Marsden Street; 13. O'Connell Street Public School; 14. George Street gatehouse). The distribution of the alluvial terrace as defined by GroundTruth Consulting (2008; 2011) is also shown. Clay Cliff Creek is presented as its modern canalised form, but which is broadly reflective of its original alignment. Co-ordinates are presented in Map Grid Australia (MGA) Area 56.

Here, we undertake a historical review of CHM investigations from across Parramatta to provide an improved understanding of the deposit. Along with documenting a recently excavated area of dense archaeological material and other regional data, our synthesis allows further exploration of the timing and behaviour of Aboriginal populations recovering from the climatic disruption of the LGM. Importantly, our data also provides an essential source of information for future researchers and heritage managers working across Parramatta, a major developing urban centre situated upon a significant Pleistocene landscape.

2 A history of investigation

The alluvial terrace was originally identified in 2003, during a CHM excavation in advance of high-density residential development at the corner of George and Charles Street in the heart of the CBD (Fig. 1). Historical excavations undertaken on a significant early European (convict) site (Casey and Lowe Pty Ltd, 2003) encountered many stone artefacts. There had been no requirement to undertake prior assessment for Indigenous heritage, because there was a large factory on the site, built in the 1950s. Development consent had already been granted. This rescue program for CG1 (#45-6-2648) uncovered a thick archaeological layer (up to 1 m deep) within the sand unit (JMDCHM, 2005a). Some 460 m^2 of excavation – a combination of manual (210 m^2) and mechanical (250 m^2) methods – recovered 6,763 stone artefacts ($\bar{x}$ = 32/ m^2) and 680 non-diagnostic pieces, many identified as heat retainers from living floors. Artefacts were primarily found in the upper 40 cm of the remaining soil profile: it was estimated that 20–30 cm of the original deposit had been truncated by former structures and the historical excavation program (JMDCHM, 2005a). Four open area excavations salvaged past foci each between 21 and 35 m^2 ($\bar{x}$ = 30.5 m^2) in size. No charcoal features were encountered, and being during the initial application of luminescence dating, no soils samples were collected for this purpose. Geomorphological investigation (a trench 8 m long × 3 m wide × 3 m deep) identified for the first time the alluvial nature of this sand body and its characteristics (GroundTruth Consulting, 2008, 2011; Supplementary Information). The recovered archaeological material was divided into two main periods of use: i) a lower assemblage (20–80 cm) broadly considered to be of terminal Pleistocene age, and cautiously placed at 10–20 ka; ii) and an upper assemblage (<20 cm) diagnostically aligned with the last 3,000 years. This more recent assemblage showed a diverse range of tool types, including backed artefacts, edge-ground hatchets, hammerstones, anvils, grindstone fragments, and cobble chopping tools. A perforated shark tooth thought to have been used as a hair ornament, was also found. Residue analysis identified starchy plant material indicative of food preparation occurring on grindstones at site (JMDCHM, 2005a).

Immediately following the works at CG1, excavations were undertaken some 50 m to the southeast at a site that became known as 'RTA-G1' (#45-6-2673) (Fig. 1). Large-scale archaeological salvage excavations (122 m^2) were undertaken of a surficial disturbed site in advance of development. This recovered an assemblage of 4,775 lithics ($\bar{x}$ = 39.1/ m^2) (JMDCHM, 2003; 2005b; Supplementary Information). The assemblage, again, had a two phase distribution: i) an upper unit – containing 75 % of the assemblage – found between 0 and 40 cm below surface, composed primarily of silcrete raw materials, and containing a number of formal tool types associated with the mid- to late Holocene (e. g. backed artefacts, edge-ground axes, heat-treated artefacts); and ii) a lower unit – ~25% of the assemblage – found between 40 and 60 cm below surface (with occasional artefacts to 80 cm), composed of indurated mudstone/tuff/chert (IMTC) raw materials, and reflecting a more expedient technology (Fig. 2). Importantly, five radiocarbon ages were recovered from the site, with the lowest date from below the assemblage (sieved residual charcoal from 80 to 100 cm) returning an age of ~ 34 ka (Wk-17435: 30,735 ± 407 14C years BP). The remaining ages were from the upper 30 cm of the alluvial terrace, and encompassing the archaeological assemblage returned results between ~ 3.5 and > 9.2 ka (Table 1; Fig. 2). The findings at this site were interpreted as reflecting initial, brief Late Pleistocene visitation to the river system, before a more systematic use and complex occupation of the locale in the Holocene (with the most recent surface evidence truncated by modern disturbance). For the first time, this provided chronological constraints on the archaeological assemblages of the region, and the alluvial terrace from which they were recovered (JMDCHM, 2005b).

Table 1 Radiocarbon dates archaeological excavations at RTA-G1 after JMDCHM (2005b). Ages were calibrated using Oxcal (ver. 4.2) (Bronk Ramsey, 2008, 2009a) and the ShCal13 (Hogg et al., 2013) calibration curve. Modelled ages are based on a P-Sequence deposition model (1, 0, U(-2,2)) (Bronk Ramsay, 2008, Bronk Ramsey, 2009a; 2009b; Bronk Ramsey and Lee, 2013), and is presented in Fig. 2. Outlier analysis of the ages (Bronk Ramsey, 2009a; Bronk Ramsey and Lee, 2013) suggest that Wk- 17432 is erroneous, as is evident from the significantly different unmodelled to modelled ages.

Location	**Depth (cm beneath surface)**	**Approximate Depth (m AHD)**	**Material dated**	**Lab code**	**^{14}C age**	**δ ^{13}C (‰)**	**Unmodelled calibrated age (BP), 1σ**	**Modelled calibrated age (BP), 1σ**
Sq. 45E, 60N	13	6.47	Charcoal (hearth)	Wk-17436	3270 ± 35	-25.9 ± 0.2	3542-3389	3454-3390
Sq. 56E, 57N	20	6.40	Charcoal (hearth)	Wk-17434	6078 ± 54	-26.1 ± 0.2	6949-6795	6956-6792
Sq. 36E, 56N	24	6.36	Charcoal	Wk-17433	8206 ± 51	-26.3 ± 0.2	9235-9016	9228-9010
Sq. 59E, 58N	30-33	6.27-6.30	Scattered charcoal (hearth)	Wk-17432	4433 ± 35	-26.2 ± 0.2	5035-4872	13801-9252
Sq. 35E, 57N	80-100	5.60-5.80	Scattered charcoal	Wk-17435	30735 ± 407	-25.6 ± 0.2	34994-34238	35061-34239

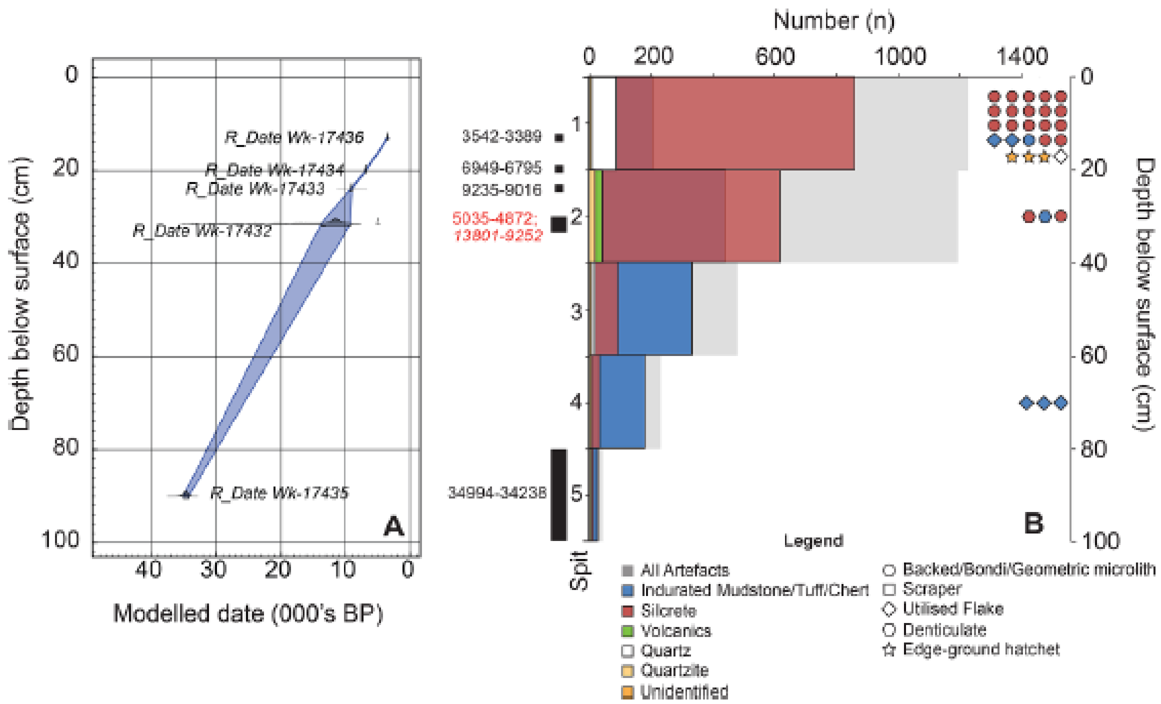


Figure 2 A summary of the radiocarbon chronology (A) and archaeological finds - stone artefacts, including main raw materials and formal tool types - (B) from the archaeological excavations at RTA-G1, adapted from JMDCHM (2005b). Supplementary Information provides the tabular artefact data. Radiocarbon ages were calibrated using Oxcal (ver. 4.2) (Bronk Ramsay, 2008, Bronk Ramsey, 2009a) and the ShCal13 (Hogg et al., 2013) calibration curve. Modelled ages (A) are based on a P-Sequence deposition model (1, 0, U(-2,2)) (Bronk Ramsay, 2008, Bronk Ramsey, 2009a; 2009b; Bronk Ramsey and Lee, 2013). Unmodelled ages (1σ) are presented with the exception of Wk-17432 (red) that includes modelled ages (italics). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

A number of sites in the adjoining properties to CG 1 and RTA-G1 were also excavated in 2005 and recovered a similar pattern of past occupation – albeit with less archaeological material and often more disturbed – including CG2 and CG3 (Fig. 1) (Austral Archaeology, 2007, JMDCHM, 2005b; 2006). At CG2, 601 artefacts were recovered from 65 m^2 of manual excavation ($\bar{x} = 8.7/m^2$), in a bi-modal distribution mainly in the upper 40 cm (Austral Archaeology, 2007). While at CG3, an initial test excavation of 43 test pits recovered 197 artefacts ($\bar{x} = 7.2/m^2$), before a larger salvage excavation of 126 m2 returned 847 artefacts ($\bar{x} = 6.79/m^2$) (JMCDHM, 2006). These works were undertaken in a heavily truncated and shallower part of the deposit. Both of these excavations indicated a dominance of IMTC suggesting they formed part of the earlier use of the locale (and again showed higher levels of disturbance to the top of the alluvial terrace), but in neither case were chronological samples recovered. Spatially, these excavations all suggest foci of past occupation (>30 artefacts/m^2) were in the order of 25–35 m^2 in size, interspersed amongst a wider background scatter of low-density stone artefacts (<10 artefacts/m^2).

Since 2005, the alluvial terrace has been subject to over 40 CHM archaeological investigations. However, with few exceptions, the findings of RTA-G1 and CG1 have not been replicated, with most investigations elsewhere across Parramatta encountering more heavily impacted and/or shallower archaeologically sterile, or near sterile sand deposit.

Between 2009 and 2019, we (ANW, FA, LB, AH, TS) undertook a further six archaeological excavations across the alluvial terrace (Fig. 1): 21 Hassall Street (AHMS, 2016a), 189–190 Macquarie Street (AHMS, 2013), 2–8 River Road West (AHMS, 2014a), 330 Church Street (AHMS, 2014b), 95-95A Marsden Street (Extent Heritage, unpublished [undertaken in 2011]), and O'Connell Street Public School (Barry et al., 2020; Extent Heritage, 2018a). Two of these sites recovered significant terminal Pleistocene archaeological material: 21 Hassall Street (see below) and O'Connell Street Public School. The latter is presented in detail in Barry et al. (2020), but in brief consisted of ~ 150 stone artefacts (~24/ m^2) recovered from a 1 m thick portion of the sand unit on the northern bank of the Parramatta River. The assemblage was interpreted as a short term exploratory or hunting camp dating to ~ 14 ka, dominated by IMTC artefacts and one exotic raw material (andalusite hornfels), which suggested a connection with areas west of the Blue Mountains - some 75km to the west of Parramatta. A robust OSL chronology for the site indicated formation of the alluvial terrace at ~ 24 ka (GL15155) and continuing until the mid-Holocene where the upper soil profile was truncated (Table 2). Sedimentological and phytolith analysis suggested deposition through low energy alluvial processes within a herb- and sedge-dominated environment. The remaining four investigations recovered few stone artefacts, suggesting that these parts of the alluvial terrace are archaeologically sterile.

3 Chronology of the alluvial terrace

Following RTA-G1 few chronological samples were obtained for several years. Of note was an investigation at 140 Macquarie Street where excavations extended to 3.2 m below the modern surface (2 m of which was colonial and modern fill materials), and which found the southern edge of the alluvial terrace capped by more recent, likely Holocene, swamp deposits (Comber Consultants, 2010). This study collected a series of Thermoluminescence (TL) ages from the observed sand unit and suggested a formation age of ~ 50–60 ka (W4396: 49.5 ± 2.8 ka and W4398: 58.4 ± 6.1 ka at 30 cm below colonial surface; and W4397: 57.6 ± 5.1 ka at 80 cm below colonial surface). These ages remain some of the earliest for the alluvial terrace and some of the only TL samples collected, but the available report lacks any detailed information on their recovery, methods, or any caveats, and therefore cannot be robustly critiqued. They do, however, appear to broadly align with other more recent ages found in the lower parts of the unit (see below). A small number of primarily quartzite and IMTC artefacts (n = 67) were recovered from the upper part of this dated unit, but with recent detailed analysis suggesting they have been subject to pedoturbation and of terminal Pleistocene

Table 2 OSL data from our excavations between 2009 and 2018 CE within the sand sheet unit: (1. 21 Hassall Street (AHMS, 2016a), 2. 189–190 Macquarie Street (AHMS, 2013), 3. 2–8 River Road West (AHMS, 2014a), 4. 330 Church Street (AHMS, 2014b), 5. 95-95A Marsden Street (Extent Heritage, unpublished), 6. O'Connell Street Public School (Extent Heritage, 2018a), 7. Georges Street gatehouse (GML Heritage, 2019), 8. Cumberland Hospital (Geoprospection, 2019). Equivalent dose (De) values based on multi-grain, single-aliquot analysis (quartz; 125–180 µm) and single grain analysis (quartz; 180–250 µm), with each having a detectable natural signal (>3σ background), regenerative-dose and post-IR OSL ratios consistent with unity (0.9–1.1), and a regenerated zero dose signal not exceeding 5% of the natural signal (Murray and Wintle, 2000, 2003; Duller, 2003). Samples preheated for 260 ◦C for 10 s, based on dose recovery tests. Dose rate (Dr) values based on ex situ Ge gamma spectrometry (for γ and β Dr), Adamiec and Aitken's (1998) conversion factors, attenuation of present moisture content (Zimmerman 1971), current overburden and a geomagnetic latitude of 34◦S (Prescott and Hutton 1994). The degree of U-Series disequilibrium was assessed by 226Ra /238U. Age estimates based on the CAM - Central Age Model (Galbraith et al., 1999) and, additionally for single grain measurements, the MAM - Minimum Age Model; FMMMin - Finite Mixture Model (Minimum Population); and FMMMaj - Finite Mixture Model (Major Population) (Galbraith and Green, 1990). Ages are expressed relative to their year of sampling (2012–2017 CE as denoted by the first two numerical digits of the lab code). All uncertainties are quoted at 1σ confidence and reflect combined systematic and experimental variability. GL12036, GL12034, GL14032, GL14033, GL14029, GL16172, and GL16173 all had methodological issues (commonly U disequilibrium or failed dose recovery tests) and should be treated with caution.

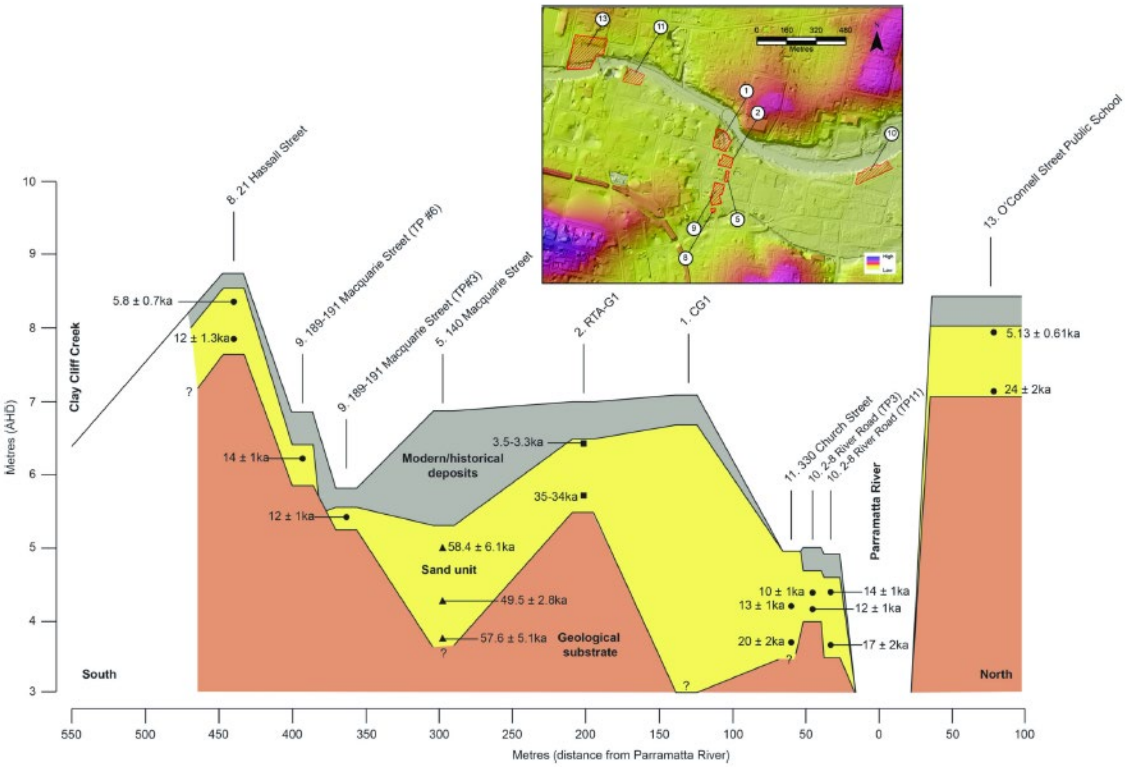
Site	Location	LabCode	Depth (cm beneath surface)	Depth (m AHD)	Moisture content (%)	Ge γ-spectrometry (ex situ)			$^{226}Ra/^{238}U$	Total D_r(Gy. Ka^{-1})	MAM D_e(Gy)	FMM_{Min} D_e(Gy)	FMM_{Maj} D_e(Gy)	CAM D_e(Gy)	MAM Age (ka)	FMM_{Min} Age (ka)	FMM_{Maj} Age	CAM Age (ka)
						K (%)	Th (ppm)	U (ppm)										
1	Test pit Q	GL15136	18	8.42	7 ± 2	0.07 ± 0.03	4.61 ± 0.40	1.08 ± 0.09	0.90 ± 0.18	0.75 ± 0.05	2.9 ± 0.3	3.1 ± 0.6	3.1 ± 0.6	4.3 ± 0.5	3.8 ± 0.5	4.1 ± 0.8	4.1 ± 0.8	5.8 ± 0.7
1	Test pit C	GL15138	21	8.33	8 ± 2	0.00 ± 0.00	4.96 ± 0.46	0.99 ± 0.09	1.24 ± 0.24	0.69 ± 0.05	1.5 ± 0.2	2.7 ± 0.2	5.7 ± 0.3	9.3 ± 0.6	2.2 ± 0.4	4.0 ± 0.4	8.3 ± 0.7	9.9 ± 1.4
1	Test pit Q	GL15141	40	8.20	7 ± 2	0.15 ± 0.03	5.22 ± 0.40	1.05 ± 0.09	1.15 ± 0.24	0.85 ± 0.05	2.1 ± 0.3	4.1 ± 0.3	4.1 ± 0.3	5.6 ± 0.6	2.5 ± 0.4	4.8 ± 0.4	4.8 ± 0.4	6.6 ± 0.8
1	Test pit C	GL15143	42	8.13	8 ± 2	0.23 ± 0.09	4.55 ± 0.52	0.94 ± 0.09	1.05 ± 0.28	0.66 ± 0.06	2.1 ± 0.2	4.9 ± 0.3	4.9 ± 0.3	14.5 ± 1.1	3.2 ± 0.4	7.5 ± 0.8	7.5 ± 0.8	12.9 ± 1.7
1	Test pit Q	GL15137	58	8.02	8 ± 2	0.14 ± 0.03	5.07 ± 0.40	1.03 ± 0.09	1.73 ± 0.50	0.81 ± 0.05	3.8 ± 0.05	4.9 ± 0.4	10.3 ± 1.0	15.9 ± 1.9	4.6 ± 0.7	6.1 ± 0.6	13 ± 1	20 ± 3
1	Test pit C	GL15144	62	7.91	8 ± 2	0.18 ± 0.03	4.79 ± 0.40	0.90 ± 0.09	1.00 ± 0.23	0.81 ± 0.05	2.1 ± 0.3	5.7 ± 0.3	5.7 ± 0.3	20.4 ± 1.1	2.6 ± 0.4	7.0 ± 0.6	7.0 ± 0.6	12.0 ± 1.4
2	Test pit 6	GL12036	22	6.44	8 ± 2	0.12 ± 0.02	6.09 ± 0.43	1.45 ± 0.09	1.43 ± 0.33	0.97 ± 0.05	-	-	-	13.2 ± 0.7	-	-	-	14 ± 1
2	Test pit 3	GL12034	23	5.61	7 ± 2	0.18 ± 0.02	6.82 ± 0.47	1.82 ± 0.10	1.55 ± 0.36	1.15 ± 0.06	-	-	-	14.2 ± 1.0	-	-	-	12 ± 1
2	Test pit 7A	GL12035	166	5.09	8 ± 2	0.05 ± 0.02	3.56 ± 0.32	0.80 ± 0.07	1.16 ± 0.43	0.58 ± 0.04	-	-	-	6.3 ± 0.2	-	-	-	11 ± 1
3	Test pit 11	GL13027	27	4.34	6 ± 2	0.40 ± 0.03	7.67 ± 0.49	1.40 ± 0.10	0.90 ± 0.12	1.31 ± 0.07	-	-	-	18.2 ± 1.0	-	-	-	14 ± 1

Site	Location	LabCode	Depth (cm beneath surface)	Depth (m AHD)	Moisture content (%)	Ge γ-spectrometry (ex situ)			$^{226}Ra/^{238}U$	Total D_r(Gy. Ka^{-1})	MAM D_e(Gy)	FMM_{Min} D_e(Gy)	FMM_{Maj} D_e(Gy)	CAM D_e(Gy)	MAM Age (ka)	FMM_{Min} Age (ka)	FMM_{Maj} Age	CAM Age (ka)
						K (%)	Th (ppm)	U (ppm)										
3	Test pit 11	GL13028	54	4.07	6 ± 1	0.26 ± 0.03	6.02 ± 0.42	1.02 ± 0.09	0.80 ± 0.13	1.00 ± 0.06	-	-	-	20.4 ± 1.3	-	-	-	20 ± 2
3	Test pit 11	GL13029	96	3.65	14 ± 3	0.55 ± 0.04	12.43 ± 0.68	2.30 ± 0.13	0.93 ± 0.10	1.77 ± 0.12	-	-	-	30.7 ± 3.0	-	-	-	17 ± 2
3	Test pit 3	GL13025	40	4.41	11 ± 3	0.49 ± 0.04	10.92 ± 0.62	1.99 ± 0.12	1.99 ± 0.12	1.63 ± 0.10	-	-	-	16.9 ± 0.7	-	-	-	10 ± 1
3	Test pit 3	GL13026	65	4.16	8 ± 2	0.53 ± 0.04	10.36 ± 0.60	1.88 ± 0.11	1.88 ± 0.11	1.67 ± 0.09	-	-	-	19.8 ± 0.8	-	-	-	12 ± 1
4	Trench 8/2	GL14032	80	4.30	4 ± 1	0.47 ± 0.04	7.12 ± 0.48	1.24 ± 0.09	0.95 ± 0.15	1.35 ± 0.09	-	-	-	17.9 ± 0.8	-	-	-	13 ± 1
4	Trench 8/2	GL14033	125	3.82	0 ± 0	0.15 ± 0.03	2.53 ± 0.28	0.39 ± 0.07	0.92 ± 0.24	0.54 ± 0.05	-	-	-	11.0 ± 0.6	-	-	-	20 ± 2
4	Trench 8/3	GL13014	110	4.00	8 ± 2	0.16 ± 0.02	2.40 ± 0.30	0.55 ± 0.5	1.19 ± 0.34	0.53 ± 0.04	-	-	-	10.7 ± 0.7	-	-	-	20 ± 2
5	Test pit 2	GL14028	57	8.57	5 ± 1	0.00 ± 0.00	9.20 ± 0.56	2.06 ± 0.12	1.04 ± 0.12	1.22 ± - 0.13	-	-	-	2.11 ± 0.14	-	-	-	1.7 ± 0.2
5	Test pit 2	GL14029	70	8.44	5 ± 1	0.42 ± 0.04	10.94 ± 0.62	2.12 ± 0.02	0.88 ± 0.10	1.75 ± 0.11	-	-	-	29.9 ± 1.3	-	-	-	17 ± 1
5	Test pit 3	GL14030	56	8.79	4 ± 1	0.00 ± 0.00	9.61 ± 0.56	1.98 ± 0.12	1.07 ± 0.12	1.24 ± 0.08	-	-	-	0.77 ± 0.06	-	-	-	0.62 ± 0.07
5	Test pit 3	GL14031	96	8.39	5 ± 1	0.37 ± 0.03	9.74 ± 0.57	1.97 ± 0.12	0.99 ± 0.12	1.58 ± 0.08	-	-	-	17.4 ± 0.9	-	-	-	11 ± 1
6	Test pit 5	GL15151	60	7.85	8 ± 2	0.34 ± 0.04	11.04 ± 0.64	2.00 ± 0.12	1.25 ± 0.20	1.60 ± 0.09	-	-	-	8.2 ± 0.4	-	-	-	5.1 ± 0.3
6	Test pit 5	GL16195	60	7.85	11 ± 3	0.20 ± 0.05	11.77 ± 0.65	2.17 ± 0.15	0.79 ± 0.10	1.48 ± 0.10	1.6 ± 0.2	3.0 ± 0.4	5.9 ± 0.5	7.6 ± 0.8	1.09 ± 0.18.7	2.04 ± 0.3	3.97 ± 0.41	5.13 ± 0.61
6	Test pit 5	GL15152	80	7.65	9 ± 2	0.47 ± 0.04	11.11 ± 0.63	2.05 ± 0.12	1.22 ± 0.17	1.70 ± 0.09	-	-	-	18.1 ± 0.8	-	-	-	11 ± 1
6	Test pit 5	GL16196	90	7.55	12 ± 3	0.48 ± 0.05	11.83 ± 0.66	2.05 ± 0.15	0.97 ± 0.12	1.67 ± 0.11	14.3 ± 1.5	26.8 ± 1.2	53.5 ± 7.2	28.2 ± 1.9	8.6 ± 1.1	16 ± 1	32.0 ± 4.8	16.9 ± 1.6

Site	Location	LabCode	Depth (cm beneath surface)	Depth (m AHD)	Moisture content (%)	Ge γ-spectrometry (ex situ)			$^{226}Ra/^{238}U$	Total D_r(Gy. Ka^{-1})	MAM D_e(Gy)	FMM_{Min} D_e(Gy)	FMM_{Maj} D_e(Gy)	CAM D_e(Gy)	MAM Age (ka)	FMM_{Min} Age (ka)	FMM_{Maj} Age	CAM Age (ka)
						K (%)	Th (ppm)	U (ppm)										
6	Test pit 5	GL15153	100	7.45	10 ± 2	0.37 ± 0.04	11.58 ± 0.66	1.96 ± 0.12	1.03 ± 0.14	1.61 ± 0.09	-	-	-	25.7 ± 1.1	-	-	-	16 ± 1
6	Test pit 5	GL15154	120	7.25	10 ± 2	0.31 ± 0.04	10.54 ± 0.65	1.93 ± 0.12	1.00 ± 0.14	1.47 ± 0.09	-	-	-	30.3 ± 1.2	-	-	-	21 ± 1
6	Test pit 5	GL15155	140	7.05	12 ± 3	0.20 ± 0.04	10.56 ± 0.63	1.61 ± 0.11	1.08 ± 0.15	1.28 ± 0.09	-	-	-	30.2 ± 1.1	-	-	-	24 ± 2
7	Square 2/3	GL16169	10	9.54	0 ± 0	0.35 ± 0.05	9.49 ± 0.56	1.81 ± 0.14	0.94 ± 0.12	1.55 ± 0.08	-	-	-	29.7 ± 1.9	-	-	-	19.1 ± 1.6
7	Square 2/3	GL16170	20	9.44	0 ± 0	0.24 ± 0.05	8.77 ± 0.55	2.04 ± 0.15	0.91 ± 0.12	1.45 ± 0.08	-	-	-	47.1 ± 2.4	-	-	-	32.6 ± 2.4
7	Square 2/3	GL16171	30	9.34	1 ± 0	0.36 ± 0.05	9.97 ± 0.59	1.98 ± 0.14	1.06 ± 0.14	1.63 ± 0.08	-	-	-	61.2 ± 2.8	-	-	-	37.6 ± 2.6
7	Square 2/3	GL16172	60	9.04	0 ± 0	0.59 ± 0.06	11.98 ± 0.67	2.58 ± 0.16	0.96 ± 0.11	2.07 ± 0.10	-	-	-	101.3 ± 4.4	-	-	-	49 ± 3.2
7	Square 2/3	GL16173	100	8.64	2 ± 0	0.58 ± 0.06	11.60 ± 0.65	2.45 ± 0.16	0.81 ± 0.09	2.05 ± 0.10	-	-	-	90 ± 3.3	-	-	-	43.8 ± 2.6
8	-	GL17165	195	-	4 ± 1	0.19 ± 0.04	11.40 ± 0.64	2.02 ± 0.14	0.93 ± 0.12	0.78 ± 0.07	-	-	-	77.2 ± 3.6	-	-	-	50.8 ± 3.6

age (Norma Richardson, pers comm. 9 August 2021). Other early dates have been identified by subsequent excavations at the Georges Street gatehouse where basal ages of ~ 43–49 ka were recovered some 1 m below a truncated soil profile (Table 2) (GML Heritage, 2019). However, this site similarly recovered very limited archaeological material, eight artefacts, mostly in the upper soil profile, which has been heavily bioturbated – evident by a post-contact ceramic artefact in depths dated to > 19.6 ka. The authors argue that an ochre cooking pit was found at lower depths aligned with > 30 ka, but we are sceptical of this identification based on the description and photographs provided. More recent, and ongoing, works at the Cumberland Hospital (north Parramatta) have recovered a comparable Optically Stimulated Luminescence (OSL) age of 50.8 ± 3.6 ka (GL17165) at 1.95 m below surface (Table 2) (Geoprospection, 2019), lending further support to the alluvial terrace's formation in Marine Isotope Stage (MIS) 3.

Our more recent excavations all have chronological samples recovered, frequently including surface and/or basal ages of the excavation. There are now 28 OSL ages from the alluvial terrace (Table 2, Fig. 3). These ages suggest that significant parts of the deposit formed only at the peak of, and immediately following, the Last Glacial Maximum (LGM) through to the middle of the Holocene. In several instances, these ages have been recovered from the base of the sand unit where it overlies an indurated heavy clay (geological substrate) (e.g. GL12034, GL13029, GL14029, GL15137, GL15141, GL15155,) and/or from significant depth (GL13014, GL14033), such as beneath a basement at 330 Church Street, reflecting depths of ~ 2–3 m below the natural colonial surface (Fig. 3). As such, these depths are comparable with RTA-G1 and suggest a much later formation than those encountered at 140 Macquarie Street and the Cumberland Hospital. Similarly, at the Georges Street Gatehouse, a significant change in sedimentology at ~ 50 cm below surface is marked by much later ages associated with the onset or post-LGM period (Table 2).



While there is no reason to dispute the older ages outlined above, it does suggest that significant parts of the alluvial terrace were formed and/or reworked into their current form only in MIS 2. Further, while a handful of ages show late Holocene dune activity, overall the deposit appears to have stabilised and stopped forming by ~≥5 ka (Fig. 3), and any later archaeological materials have likely become integrated through pedoturbation and/or surface re-working. Indeed, a number of the OSL ages show a complex and highly mobile history, with significant over-dispersion and/or zero dose grains, all indicative of such processes (Table 2). In all instances, the upper soil profiles are disturbed by colonial and post-colonial activities.

4 Composition and formation of the alluvial terrace

The Sydney Basin is a major sedimentary basin, some 60,000 km^2 in size, situated on the eastern coast of Australia and encompassing major conurbations of Sydney, Newcastle and Wollongong. Initially formed on Palaeozoic (541–250 million years ago [ma]) metamorphosed rocks, the basin is primarily a series of Permian (300–250 ma) and Triassic (250–200 ma) sandstones and siltstones that were formed by a massive delta, and then subject to a range of uplift and subsidence (see Gale, 2020 for a comprehensive review). This has resulted in a series of smaller plateaus and basins surrounded by elevated dissected sandstone uplands on its periphery (e.g. the Great Dividing Range to the west). Over-laying these basal sandstone and siltstones are Wianamatta shales (also of Triassic age), and then more recent Quaternary alluvium and other pedogenetic units. The Parramatta CBD is situated on these later shales and alluvia, while the Parramatta River originates out of dissected Triassic Hawkesbury sandstone to the northwest.

We provide further detail of the physical and sedimentology characteristics of the alluvial terrace in Supplementary Information. The extent of the alluvial terrace is well documented. Initially modelled using desktop resources in 2008, large numbers of excavations have repeatedly demonstrated the accuracy of these predictions. The sand deposit is some ~ 69 ha in size, extending ~ 2.5 km along the river, up to 300 m away from the water's edge, and commonly ~ 4–7 m above the river's surface (Fig. 1). On reviewing the current development of the region, we find that nearly 19 ha (~29%) of the deposit has been destroyed through urbanisation, including many of the sites reviewed here.

The vast majority of the excavations outlined above undertook some consideration of the soil profile, primarily based on field observations. Laboratory analyses (e.g. particle size) has been undertaken mostly associated with our 2009–2019 excavations. While there is variation across the deposit, the terrace is dominated by medium to coarse sand (250–1,000 µm) in close proximity to the Parramatta River, indicative of a fluvial deposition from a moderate river flow; and increasing fine clays and silts (0.5–55 µm) more suggestive of aeolian processes further away from the river. These later deposits probably reflecting a latter re-working of the initial alluvium, and accounting for the substantive distance they are found from the river.

The terrace has been shown to extend to > 3 m in depth before reaching under-lying geological substrate, which consists of Wianamatta shales(Gale, 2020). More commonly, however, excavations find the alluvium to be ~ 1–1.3 m thick before reaching an indurated heavy clay unit, which is visibly comparable to Cenozoic units found elsewhere in the Cumberland Plain (e.g. Londonderry Clay) (Gale, 2020). Visually, the unit has variable colours, but is typically a yellowish to reddish brown homogenous unit, with the upper portion (<40 cm) darker and intermixed by later colonial activities; and the lower portion often mixing with the under-lying heavy clay strata.

5 Recent high resolution excavations

Excavations of the alluvial terrace have often been at a coarse recovery resolution (e.g. 20 cm excavation units), contained a general paucity of archaeological material and/or lacked important chronological information. Here we present the archaeological excavation and analysis at 21 Hassall Street (#45–6-3180) that recovered a high-resolution assemblage with a more detailed chronology. Importantly, it is one of the only sites to recover substantial archaeological materials from the deposit similar to those found at RTA-G1 and CG 1. The deposit appears to reflect a levee bank of Clay Cliff Creek and has yet to be robustly shown as connected with the broader alluvial terrace – noting that these locales are from beneath a now highly urbanised landscape. The chronological, sedimentological and archaeological records are nonetheless extremely similar between the two deposits, and they are situated < 50 m apart (Figs. 1 and 3; Supplementary Information).

Our archaeological excavation of the site was undertaken in advance of a proposed residential re-development. Prior to 2016, the 450 m2 site contained a two-storey structure in its southern portion, surrounded by gardens and landscaping, and represented a minor elevation (~3 m AHD) adjacent to Clay Cliff Creek (Fig. 1). Investigative and salvage excavations were undertaken, primarily focussing on the undeveloped northern parts of the site. This included an initial investigative phase of ten 1 m2 test pits situated across the site, followed by open area excavation of 23 contiguous 1 m2 squares. The open area targeted both an area of high artefact density, and the deepest part of the deposit, within the constraints of this small site (Fig. 4). All excavations were undertaken manually. The investigative phase was excavated in 10 cm intervals (spits), while the salvage phase used 5 cm intervals, and all sediment was recovered and sieved through a 3 mm mesh for archaeological material.

Figure 4 A photograph of the archaeological salvage excavation completed at 21 Hassall Street, looking northeast towards the corner of Hassall Street and Wigram Street. Scale = 20 cm increments.

Beneath ~ 15 cm of modern overburden, the site presented an ~ 80 cm deep portion of the alluvial terrace (between ~ 7.7–8.5 m AHD). The deposit could be divided into three units based on field observations (Fig. 4 and Fig. S1): i) 0–20 cm – a compact dark grayish brown (10YR 4/ 2) sandy loam with frequent colonial debris, and likely representing topsoil development (A1 horizon), potentially with some introduced fill materials; ii) 20–80 cm – friable yellowish brown (10YR 5/4) clayey sand with single grained structure, and occasional ironstone/manganese pisoliths, and reflecting the main terrace sand unit (B2 horizon); and iii) 50–80 cm, intermittent – friable to compact reddish yellow (5YR 5/4) sandy clay with frequent ironstone/manganese pisoliths, and reflecting a B/C transition with the under-lying geological substrate (heavy clay). While no particle size analysis was undertaken, this deposit is part of the same levee landform documented at 189–191 Macquarie Street, situated some 40 m northeast of these excavations, which suggests the units here are dominated by silt and clay fractions (see Supplementary Information).

Six single-grain OSL ages were recovered from the salvage excavations, ranging from 18 to 62 cm below surface (Table 2; Fig. 5). These revealed significant over-dispersion (69–113 %) of the samples, likely the result of micro-dosimetry from the increasing precipitated minerals at depth (iron and manganese), and/or the partial bleaching as a result of some sediment mixing with the under-lying Tertiary age unit. Given these complications, analysis suggested that a combination of the finite mixture (major population) and central age models were most robust, and these values were variously explored until a successful P_sequence deposition model could be created without substantial outliers (Fig. 5); and notably several of the paired ages selected are statistically indistinguishable. Ultimately, these ages provide a consistent record of formation beginning at ~ 13 ka, and terminating at ~ 6 ka, with an accumulation rate of ~ 60–330 years/cm (x = 158 years/cm) (Fig. 5; Supplementary Information). Given the OSL ages come from 18 cm below the surface and 20 cm above the under-lying geological strata, these accumulation rates suggest a slightly earlier formation age at ~ 15 ka, and a termination age of ~ 4 ka is probable. This range appears to align well with the broader OSL ages recovered from across the sand unit (Table 2; Fig. 3).

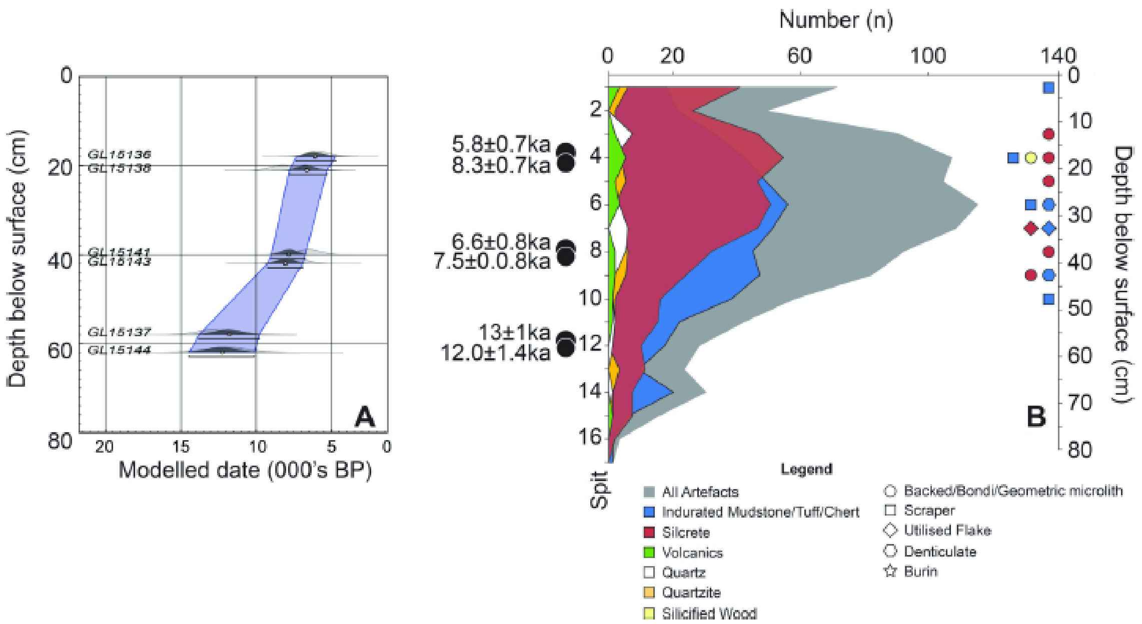


Figure 5 The archaeological salvage results from 21 Hassall Street. A) An age-depth model of the OSL ages using Oxcal v4.2 and a P_Sequence deposition model (1,0, U (-2,2)) (Bronk Ramsay, 2008; Bronk Ramsey, 2009a; Bronk Ramsey and Lee, 2013). Outlier analysis of the ages (Bronk Ramsey, 2009a; Bronk Ramsey and Lee, 2013) identified none as outliers, although GL15138 had slightly elevated posterior values; and B) number of artefacts from the salvage excavations (undertaken in 5 cm intervals), shown by raw material type, with each individual tool also presented. Supplementary Information provides artefact data in tabular form.

The excavations recovered 1,730 stone artefacts (x = 52.2/m^2; ranging between 24 and 101/m^2), 704 from the investigative phase and 1,026 from the salvage works (Fig. 5). Given the consistency of artefact density across the salvage area (~300 m^2), we recovered a sub-sample of an assemblage likely to have consisted of some 17,000 artefacts. The temporal pattern of the assemblage suggests an early Holocene IMTC dominated occupation ranging between ~ 13–6 ka (and centred on ~ 7 ka), *overprinted* by a late Holocene visitation composed primarily of silcrete raw materials. While the latter assemblage is only slightly offset vertically from the earlier phase of activity, and appears centred on ~ 5.6 ka, the typological characteristics, including Bondi points, backed artefacts, burin-blade cores, geometric microliths and an edge-ground axe, all relate more closely to visitation only over the last few thousand years (Fig. 5; Supplementary Information) (Hiscock and Attenbrow, 2005;

JMDCHM, 2005a; b). This overlapping of earlier and later assemblages is not uncommon in the region (see AAJV, 2017; McDonald, 2008; Williams et al., 2012, 2014) for other examples), and aligns well with the broader history of a deposit that had stabilised by the mid- Holocene with later archaeological material integrated through pedoturbation. Further investigation is needed into why the early Holocene assemblage appears to retain some evidence of compositional and spatial integrity, in contrast to clear evidence from the OSL data and the integration of the late Holocene assemblage suggesting that pedoturbation must have been extensive.

The lower assemblage was reflective of the expedient flakes, cores and tools commonly found during the early Holocene and terminal Pleistocene. The raw material types and their fluvial origin strongly suggests movement between this site and the Hawkesbury-Nepean River, which is the nearest documented source of such materials in the region, and has been shown as a foci of population during the LGM and terminal Pleistocene (e.g. McDonald, 2008; White, 2017; White and McDonald, 2010; Williams et al., 2012, 2014, 2017); and aligns with the broader picture of past movements across the Sydney Basin (Barry et al., 2020). The dominance of broken flakes (~44 %) implies repeated use and trampling of the site, while a significant percentage of heat-shattered lithics (~19 %) may indicate camp-fires and/or cooking on site. The upper assemblage has many attributes similar to the earlier phase, with the high quality silcrete raw material that visibly aligns with well documented outcrops variously found across northwest Sydney (~20 km) (Doelman et al., 2015), and here to extensive trampling suggests lengthy occupation (~38 % of artefacts broken). Heat shatter, angular fragments and burin-blade cores all suggest the manufacture of small artefacts (microliths, etc.), although few tools were found on site suggesting opportunistic re-tooling, rather than any more substantial activity (Supplementary Information). While the pedoturbation makes any definitive understanding of the level of activity and/or number of people from the recovered artefacts problematic, the two assemblages were of a similar size, but the lowest extended over a ~

6,000 year span, whereas the upper was likely < 3,000 years; and hence the upper assemblage may suggest either a doubling of the activities and/or population size through the Holocene.

6 Discussion

We present a history of discovery and synthesis of archaeological information recovered from an alluvial terrace deposit within Parramatta CBD. Well-known in local CHM grey literature, it has not been formally published in detail beyond brief mention in academic literature. Our review demonstrates that this alluvial deposit along the banks of Parramatta River, encompasses a relatively complete, but complex, record of past human activity. The deepest sections of the deposit on the banks of the Parramatta River have returned ages of 50–60 ka, and hence has the potential to be an archive for the complete human occupation of the region (O'Connell et al., 2018). With increasing distance from the river the deposit becomes shallower and has been subject to aeolian re-working and/or periodic flooding, and primarily dates to the LGM. All parts of the alluvial feature contain extensive evidence from the mid-Holocene; and colonial and urban development have truncated the most recent layers across much of the feature. These deposits allow an interrogation of past Aboriginal behaviour in the Sydney Basin, especially during the terminal Pleistocene/Holocene transition, which is poorly represented in the Sydney region.

Archaeologically, only three sites so far have revealed substantial evidence for deep-time occupation, CG1 (#45-6-2648), RTA-G1 (#45-6- 2673), and 21 Hassall Street (#45-6-3180) - each returning several thousand artefacts, and with average artefact densities of ~ 32–52/m^2. Many other excavations demonstrate either sterile deposits or contain very few stone artefacts (generally < 10/m^2) and are indicative of only ephemeral or transient visitation. The evidence for a pre-LGM or LGM occupation of the region is equivocal without more detailed chronological control. Relatively small numbers of IMTC artefacts found at these depths in RTA-G1 (Area A), CG1, 140 Macquarie

Street and the Georges Street gatehouse, are hypothesised to reflect such deep-time occupation, but at least in some cases are considered more likely to reflect post depositional taphonomy. Rather, the sites generally reveal two major phases of past use: i) initial and repeated visitation in the terminal Pleistocene and early Holocene, characterised by an IMTC-dominated assemblage of relatively expedient technologies; and ii) a more intense use/occupation of the river corridor in the mid-late Holocene, and characterised by a silcrete-dominated assemblage with a wide variety of tool types and increasingly complex technologies (e.g. backed artefacts, heat treatment, ground edge axes). At RTA-G1, the majority of the IMTC assemblage within this site indicates peak activity (20–40 cm) occurring at a modelled age of ~ 14–9 ka (Fig. 2), correlating closely with the findings of 21 Hassall Street (~13–6 ka) (Fig. 5). This suggests that the locale was subject to increased and/or repeated visitation only at the end of the Pleistocene; and significantly several thousand years after the end of the LGM.

These findings correlate well with established models for the region (Barry et al., 2020; McDonald, 2008; White, 2017; Williams et al., 2014), as well as providing new insights into the wider Sydney Basin, and southeast Australia more broadly. Prior to the terminal Pleistocene, archaeological evidence in the Sydney Basin is sparse and indicates the presence of highly mobile groups whose lithic resources are provisioned by the Hawkesbury-Nepean River gravels (Kohen et al., 1984; McDonald, 2008; White, 2017, 2021; Williams et al., 2014,2017,2019), one of southeast Australia's major rivers. The IMTC raw material sources that dominate these earlier Parramatta assemblages derive only from gravels sourced in the Hawkesbury-Nepean River corridor, although it is possible that there may be drowned sources downstream of Parramatta in this smaller river system.

Recovered assemblages suggest small bands of people repeatedly occupying a series of key nodes – cryptic refuges – along the Hawkesbury-Nepean river corridor immediately prior to, and during the LGM, with little evidence for use of the intervening, less well watered country (cf. White, 2017). A question remains whether these earliest hunter-gatherers where interior forest dwellers or coastal people tethered to large river systems draining the coastal plain. These refugia-like behaviours appear to have continued at least some 3–4,000 years after the LGM, although the reasons why remain unclear (e.g. AAJV, 2017; Williams et al., 2014). Our results here (and see Barry et al. 2020), suggest that the significant change in behaviour, notably a moving out of the Hawkesbury-Nepean River into other parts of the Cumberland Plain and Hawkesbury tributaries, began after 14 ka and continued into the early Holocene. This period also sees the first exploration of the nearby Blue Mountains and other parts of the Dividing Range (Theden-Ringl, 2016, 2017; Theden-Ringl and Langley, 2018), as well as the establishment of local populations in areas like Mangrove Creek to the north of Sydney (Attenbrow, 2004).

The delayed use of the wider region suggests either a significant period of time was needed after the LGM for environmental stabilisation to be useful for resource exploitation and/or for socio-economic reasons to prompt populations to explore them. This period is coincident with major climatic change, including rapid sea-level rise from Meltwater Pulse 1A (~14.7–13.5 ka), during which significant tracts of the coastal shelf were lost and/or disrupted (Williams et al., 2018); and the Antarctic Cold Reversal (ACR) (~14.5–12.5 ka BP) that arguably resulted in colder, but probably wetter conditions (Fletcher and Moreno, 2011). These changes would have likely both impacted existing resources, such as the re-alignment of the Hawkesbury-Nepean River thalweg (thereby impacting the availability of river cobble raw materials), as well as opening new environmental niches to exploit. Evidence for repeated visitation and occupation along the Parramatta River can perhaps then be considered some of the first evidence of these changing social, environmental and economic conditions, and of a re-exploration and/or expansion of populations into more marginal or recovering resource areas following the LGM.

While an argument can be made that the absence of terminal Pleistocene deposits in the Sydney Basin is related to an absence of geomorphologically suitable sediments capturing and preserving this period rather than societal change, there are numerous examples that disprove this in both academic and CHM literature. Excavation of the Glenrowan sand sheet in Tarro that recovered archaeological material only after 13 ka (Mooney et al. 2020); RH/SP12 South that sat upon an archaeologically sterile alluvial terrace, adjacent to a pond dating to ~ 10 ka (JMDCHM, 2005c; JMCDHM, 2005d); OSL ages from the banks of Eastern Creek that reveal deposition from 16 ka, but an assemblage characteristic of the late Holocene (AHMS, 2016b); and source-bordering dune deposits on a ridge overlooking Georges River extending back to ~ 60 ka, but only containing archaeological material after the LGM and primarily in the terminal Pleistocene and early Holocene (Extent Heritage, 2018b). There are numerous other examples that lend support to our findings not being a result of geomorphology of the region, although we acknowledge this may play some role in the archaeological remains surviving across the Cumberland Plain. There are also a tantalising number of deeper sand body deposits with significant early artefact assemblages which were uncovered prior to OSL dating being as reliable as it is now (e.g. RH/CC1, CG1 and RTA-G1: all now destroyed by urban development), meaning that we have potentially lost the evidence needed to confirm this earliest phase of occupation in these contexts.

At both RTA-G1 and 21 Hassall Street, a larger assemblage is dated to the mid- to late Holocene, and suggests more intensive occupation during this time period. At the Hassall Street site, the evidence for late Holocene use is more complex, with a divergence between the chronological framework for the site and the assemblage characteristics, but overall is it considered the silcrete-dominated components reflect use only in the last few thousand years. At RTA-G1, the truncated upper spit (0–20) dating to the late Holocene encompassed ~ 35% of the assemblage recovered. This increased to 65% when including spit 2 (20–40 cm) which dated to the early to mid-Holocene. This overprinting of archaeological evidence from different time periods in key parts of the sand body, particularly given the large parts of the alluvial terrace found to be archaeologically sterile - suggests a continued and/or repeated use of key loci in the landscape over 14,000 years. All sites reviewed are consistent with existing regional models which see intensive use of the region from the mid-Holocene, with widespread evidence for occupation and increased production of rock art (McDonald, 2008) and a switch to exploitation of major silcrete raw material sources in the northwest of the Cumberland Plain (Doelman et al. 2015; White and McDonald, 2010; White, 2017, 2021). While the data in Parramatta is subject to pedoturbation and often truncation of the uppermost layers, we suggest that artefact numbers in this latter phase appear around double those in the terminal Pleistocene and early Holocene. Acknowledging that artefact numbers do not necessarily directly correlate with population size (e.g Way, 2018a,b), these trends nonetheless support increasing activity and/or growth demonstrated in other indices, such as radiocarbon data (Williams, 2013; Williams et al., 2015).

7 Conclusions

Locally, our synthesis provides a greater understanding of the nature and composition of the Parramatta sand deposit and corrects several misconceptions about this feature that have been propagated through disparate CHM investigations over the last 15 years. The potential archaeological significance of the remaining portions of this feature is high. Current calculations indicate at least 29% of the deposit has been completely lost to urbanisation, although this may be an under-estimate with much of the eastern portion yet to be subject to systematic investigations. The remaining portions of this archaeological landscape – particularly those with the potential to retain the deeper and earlier formation components – should be identified as highly significant conservation targets for the region.

Regionally, our synthesis proposes a narrative wherein Aboriginal populations remain tethered to the resources of the Hawkesbury-Nepean River and other major river systems before the LGM. This occupational focus remains throughout the LGM, and only expanded into the surrounding regions a considerable time later in the terminal Pleistocene/ early Holocene (<~14 ka). The timing of this expansion is coincident with major coastal disruption and changing moisture conditions, both of which can explain this human behavioural change in the region. This initial expansion into environmental niches, such as the alluvial terrace of the Parramatta River is the precursor to later significant activity and/ or population growth during the early and mid-Holocene, culminating in the last few thousand years. The terminal Pleistocene and early Holocene, however, remain poorly understood in southeast Australia, with limited regional archaeological evidence across this timeframe. It is vital to understand the connections between the earliest Aboriginal societies peopling Sahul, the strategies used to survive the LGM, and the drivers of more socially complex populations during the last 10,000 years.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

This paper is based on fieldwork that was undertaken and funded by various developments across Parramatta between 2003 and 2019. We thank the various proponents, including Toplace Pty Ltd, Blue Land Parramatta Pty Ltd, Meriton Apartments Pty Ltd, Landcom and the NSW Department of Education. The data from CG1, CG3 and RTA-G1were generated by fieldwork undertaken by Jo McDonald CHM Pty Ltd. Bayesian analysis of this earlier data was undertaken by AW. The more recent data on which this article is based was generated during fieldwork undertaken by Extent

Heritage Pty Ltd (formerly AHMS). Extent Heritage has provided assistance to some of the co-authors of the article as part of its policy of professional development for early- and middle-career practitioners. We thank the Deerubbin Local Aboriginal Land Council and Darug Traditional Owners for their assistance and participation in all of these projects. We thank Jillian Comber for her provision of unpublished data, and Tessa Bryant, Megan Sheppard Brennand, Georgia Burnett, and Ashley O'Sullivan (during their employment with Extent Heritage) and Tony Barham, Mark Rawson and Fran Scully and Beth White (during their employment as project archaeologists and lithic specialists with Jo McDonald CHM) for their assistance in various aspects of generating the data upon which this paper is based. Thanks also to Beth White for her assistance in generating some of the supplementary material presented here.

Appendix A. Supplementary data

Supplementary data to this article can be found online.

References

AAJV (Austral – Extent Heritage Joint Venture), 2017. Windsor Bridge Replacement Project – Aboriginal Archaeological Excavation Report. Unpublished Report to NSW Roads and Maritime Services (http://www.rms.nsw.gov.au/projects/sydney-west/windsor-bridge-replacement/project-documents.html).

Adamiec, G., Aitken, M.J., 1998. Dose-rate conversion factors: Update. Ancient TL 16 (2), 37–50.

Archaeological and Heritage Management Solutions Pty Ltd, 2013. 189-191 Macquarie Street, Parramatta – Aboriginal Cultural Heritage Assessment. Unpublished Report to Toplace Pty Ltd.

Archaeological and Heritage Management Solutions Pty Ltd, 2014a. 2-8 River Road West, Parramatta – Aboriginal Cultural Heritage Assessment. Unpublished Report to Toplace Pty Ltd.

Archaeological and Heritage Management Solutions Pty Ltd, 2014b. 330 Church Street, Parramatta – Aboriginal Heritage Impact Assessment. Unpublished Report to Meriton Apartments Pty Ltd.

Archaeological and Heritage Management Solutions Pty Ltd, 2016a. 21 Hassall Street – Aboriginal Cultural Heritage Assessment. Unpublished Report to Blue Land Pty Ltd.

Archaeological and Heritage Management Solutions Pty Ltd, 2016b. Aboriginal Cultural Heritage Assessment – 81 Riverstone Parade. Unpublished Report to Riverstone Parade Pty Ltd, Riverstone West, NSW.

Austral Archaeology, 2007. Archaeological Salvage Excavations 95-101 George Street, Parramatta, NSW. Section 90 Consent #2176 Salvage Excavation Report.

Attenbrow, V., 2004. *What's Changing: Population Size or Land-Use Patterns? The Archaeology of Upper Mangrove Creek, Sydney Basin*. Terra Australia 21, ANU E-Press.

Barry, L., Graham, I., Mooney, S.D., Toms, P.S., Wood, J.C., Williams, A.N., 2020. Tracking an exotic raw material: Aboriginal movement through the Blue Mountains, Sydney, NSW during the Terminal Glacial. *Australian Archaeol.* DOI: 10.1080/03122417.2020.1823086.

Bronk Ramsay, C., 2008. Deposition models for chronological records. Quat. Sci. Rev. 27 (1–2), 4260.

Bronk Ramsey, C., 2009a. Bayesian analysis of radiocarbon dates. Radiocarbon 51 (1), 337360.

Bronk Ramsey, C., 2009b. Dealing with outliers and offsets in radiocarbon dating. Radiocarbon 51 (3), 1023–1045.

Bronk Ramsey, C., Lee, S., 2013. Recent and planned developments of the program OxCal. Radiocarbon 55 (2–3), 720730.

Casey and Lowe Pty Ltd, 2003. Archaeological Investigation of 109–113 George Street. Unpublished report to Landcom, Parramatta.

Comber Consultants, 2010. Preliminary Excavation Report 140 Macquarie Street. Unpublished Report to Integral Energy Pty Ltd, Parramatta.

Doelman, T., Webb, J., Williams, A.N., May, J., Barry, F., 2015. Paleochannels and patches: a geoarchaeological assessment of Silcrete sources in the Cumberland plain, Eastern Australia. *Geoarchaeology* 30 (6), 495–510.

Duller, G.A.T., 2003. Distinguishing quartz and feldspar in single grain luminescence measurements. Radiat. Meas. 37 (2), 161–165.

Extent Heritage, 2018b. Moorebank Intermodal Terminal Package (Stage 1) – Aboriginal Archaeological Salvage Report. Unpublished Report to CPB Contractors Pty Ltd.

Extent Heritage, 2018a. Aboriginal archaeological excavation report – O'Connell Street Public School. Unpublished Report to NSW Department of Education, Parramatta, NSW.

Fletcher, M.-S., Moreno, P.I., 2011. Zonally symmetric changes in the strength and position of the Southern Westerlies drove atmospheric CO2 variations over the past 14 k.y. Geology. https://doi.org/10.1130/G31807.1.

Galbraith, R.F., Green, P.F., 1990. Estimating the component ages in a finite mixture. Nucl. Track. Radiat. Meas. 17, 196–206.

Galbraith, R.F., Roberts, R.G., Laslett, G.M., Yoshida, H., Olley, J.M., 1999. Optical dating of single and multiple grains of quartz from Jinmium rock shelter (northern Australia): Part I, Experimental design and statistical models. Archaeometry 41, 339–364.

Gale, S.J., 2020. Age and origin of the Cumberland (Inner Sydney) Basin of southeast Australia. Aust. J. Earth Sci. 68 (3), 299–315.

Geoprospection, 2019. Assessment of Regolith Formation at Cumberland Hospital, Parramatta North, New South Wales. Unpublished Report to Comber Consultants Pty Ltd.

GML Heritage, 2019. Parramatta Park, George Street Gatehouse Geomorphology and Aboriginal Archaeology Report. Unpublished Report to Parramatta Park Trust.

GroundTruth Consulting, 2008. Nature and distribution of Parramatta Terrace Sand. Unpublished Report to City of Parramatta Council.

GroundTruth Consulting, 2011. Sand body auger hole testing in the Parramatta local government area. Unpublished Report to NSW Department of Planning and Heritage Branch.

Hiscock, P., Attenbrow, V., 2005. *Australia's Eastern Regional Sequence Revisited: Technology and change at Capertee 3.* Oxford: Archaeopress. BAR International Series 1397.

Hogg, A.G., Hua, Q., Blackwell, P.G., Niu, M., Buck, C.E., Guilderson, T.P., Heaton, T.J., Palmer, J.G., Reimer, P.J., Reimer, R.W., Turney, C.S.M., Zimmerman, S.R.H., 2013. SHCal13 Southern Hemisphere Calibration, 0–50,000 Years cal BP. Radiocarbon 55 (4), 1889–1903.

Jo McDonald Cultural Heritage Management, 2003. Test excavations at the Old RTA Building, 109-113 George St, Parramatta, NSW. Unpublished report to Landcom.

Jo McDonald Cultural Heritage Management, 2005a. Archaeological salvage excavation of site CG1 (#45-5-2648) at corner of Charles and George Streets, Parramatta, NSW. Unpublished Report to Meriton Apartments Pty Ltd.

Jo McDonald Cultural Heritage Management, 2005b. Archaeological salvage excavation of site RTA-G1 109-113 George Street, Parramatta, NSW. Unpublished Report to Landcom.

Jo McDonald Cultural Heritage Management Pty Ltd, 2005c. Archaeological salvage excavation of eight archaeological landscapes in the Second Ponds Creek valley Rouse Hill Development Area, NSW. Plain English Report. Unpublished Report to RHI (Stage 3) Pty Ltd and Landcom.

Jo McDonald Cultural Heritage Management Pty Ltd, 2005d. Salvage Excavation of Six Sites along Caddies, Second Ponds, Smalls and Cattai Creeks in the Rouse Hill Development Area NSW. AACAI Monograph No. 1. Sydney, AACAI.

Jo McDonald Cultural Heritage Management, 2006. Archaeological salvage excavation of site CG3 101A-105A George Street, Parramatta, NSW. Unpublished Report to Rahi Development Pty Ltd.

Kohen, J.L., Stockton, E.D., Williams, M.A.J., 1984. Shaws Creek KII Rockshelter: A prehistoric occupation site in the Blue Mountains piedmont, eastern New South Wales. Archaeol. Oceania 19 (2), 57–73.

McCarthy, F.D., 1949. The prehistoric cultures of Australia. Oceania XIX (4), 305–319.

McDonald, J., 2008. *Dreamtime Superhighway - Sydney Basin Rock Art and Prehistoric Information Exchange.* Terra Australis 27. ANU Press, Canberra, ACT.

McDonald, J., 2015. I must go down to the seas again: Or, what happens when the sea comes to you? Murujuga rock art as an environmental indicator for Australia's north-west. Quater. Int. 385, 124–135.

Mooney, S.D., Hope, G., Horne, D., Kamminga, J., Williams, A.N., 2020. Fire, humans and climate as drivers of environmental change on Broughton Island, New South Wales, Australia. *Holocene* 30 (11), 1528–1539.

O'Connell, J.F., Allen, J., Williams, M.A.J., Cooper, A., Williams, A.N., Turney, C.S.M., Spooner, N.A., Kamminga, J., Brown, G., 2018. When did Homo Sapiens firs reach Southeast Asia and Sahul? Proceedings of the National Academy of Sciences of the United States (Perspectives), www.pnas.org/cgi/doi/10.1073/pnas.1808385115.

Prescott, J.R., Hutton, J.T., 1994. Cosmic ray contributions to dose rates for luminescence and ESR dating: large depths and long-term time variations. Radiat. Meas. 23 (2–3), 497–500.

Theden-Ringl, F., 2016. Aboriginal presence in the high country: new dates from the Namadgi Ranges in the Australian Capital Territory. Austr. Archaeol. 82 (1), 25–42.

Theden-Ringl, F., 2017. A reassessment of technological change models for the Australian high country. Archaeol. Oceania 52 (2), 81–97.

Theden-Ringl, F., Langley, M.C., 2018. At the margins of the high country: a terminal Pleistocene to late Holocene occupation record from Wee Jasper, southeastern Australia. Austr. Archaeol. 82 (2), 145–163.

Veth, P., 1993. Islands in the Interior: The Dynamics of Prehistoric Adaptations within the Arid Zone of Australia. International Monographs in Prehistory. Ann Arbor, Michigan.

Way, A.M, 2018a. Event-based analysis: Identifying and sequencing prehistoric activities in buried palimpsests. An example from Lake George, Australia. Volume 1: Text. Unpublished Doctoral dissertation thesis, Department of Archaeology, The University of Sydney, Sydney.

Way, A.M., 2018b. A behavioral approach to cumulative palimpsests: An example from Weereewaa (Lake George), Australia. J. Anthropol. Archaeol. 52, 59–70.

White, B., 2017. Analysis with confidence: distinguishing pre-Bondaian and Bondaian silicified mudstone artefact assemblages from the Cumberland Plain of Western Sydney, New South Wales. *Austr. Archaeol.* 83 (3), 143–161.

White, B., 2021. The survival of artefacts from different historical phases in shallow open sites and the need for spit excavations: An overview from the Cumberland Plain, Western Sydney, Australia. *Austr. Archaeol.* 2021, 1–11.

White, B., McDonald, J., 2010. Lithic artefact distribution in the Rouse Hill Development Area, Cumberland Plain, New South Wales. Austr. Archaeol. 70, 29–38.

Williams, A.N., 2013. A new population curve for prehistoric Australia. Proc. Royal Soc. B 280, 20130486.

Williams, A.N., Mitchell, P., Wright, R.V.S., Toms, P., 2012. A Terminal Pleistocene open site on the Hawkesbury River, Pitt Town, NSW. Austr. Archaeol. 74, 85–97.

Williams, A.N., Ulm, S., Cook, A.R., Langley, M., Collard, M., 2013. Human refugia in Australia during the Last Glacial Maximum and Terminal Pleistocene: A geo-spatial analysis of the 25-12ka Australian archaeological record. J. Archaeol. Sci. 40 (12), 4612–4625.

Williams, A.N., Atkinson, F., Lau, M., Toms, P., 2014. A Glacial cryptic refuge in southeast Australia: human occupation and mobility from 36,000 years ago in the Sydney Basin, New South Wales. J. Quat. Sci. 29 (8), 735–748.

Williams, A.N., Ulm, S., Turney, C.S.M., Rodhe, D., White, G., 2015. The establishment of complex society in prehistoric Australia: demographic and mobility changes in the Late Holocene. PLoS One 10 (6), e0128661.

Williams, A.N., Burrow, A., Toms, P., Brown, O., Richards, M., Bryant, T., 2017. The cranebrook terrace revisited: recent excavations of an early holocene alluvial deposit on the banks of the Nepean river, NSW, and their implications for future work in the region. Austr. Archaeol. https://doi.org/10.1080/03122417.2017.1392834.

Williams, A.N., Ulm, S., Sapienza, T., Lewis, S., Turney, C.S.M., 2018. Sea-level change and demography during the last glacial termination and early Holocene across the Australian continent. Quat. Sci. Rev. 182, 144–154.

Williams, A.N., Toms, P.S., Marcus, D., Yousif, A., McGuinness, J., O'Sullivan, A., Barry, L., Bryant, T., Wood, J.C., 2019. The first successful application of optically stimulated luminescence dating to a colonial era (<0.25ka) archaeological site in Australia. J. Archaeolog. Sci.: Rep. 24, 993–1002.

Zimmerman, D.W., 1971. Thermo-luminescent dating using fine grains from pottery. Archaeometry 13 (1), 29–52.