An Aboriginal presence in the Sydney basin prior to the LGM; further investigations into the age and formation of the Parramatta Sand Body

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ABSTRACT

The Parramatta Sand Body (PSB) in Parramatta, New South Wales, Australia is an ancient sedimentary sand deposit bordering parts of the Parramatta River which today flows into Sydney Harbour. Whilst the lower portions of the sand deposit pre-date human occupation, some locations with near surface sand deposits contain dense Aboriginal archaeological sites with a profusion of stone tools and remains of hearths. We explored the timing of human occupation in Parramatta by applying optically stimulated luminescence (OSL) ages to archaeological evidence from site AT14. Interpretation of the OSL data was guided by particle size analysis and the resulting age estimates agreed with the radiocarbon dating of charcoal sampled from archaeological deposits at AT14, to provide a secure age for human occupation evidence in the Sydney region at 31 ± 2 ka. Results link the single grain overdispersion found in quartz OSL samples to trampling actions resultant of Aboriginal occupation and forms a future consideration for the effective dating of archaeological sites.

1. Introduction

Establishing timing of human arrival in Australia is fundamental to understanding the timing of global human migration, as an early arrival has implications for the timing of H. sapiens exit out of Africa (Mallick et al., 2016; Pagani et al., 2016) and subsequent arrival in Southeast Asia. The earliest dated human remains for inland southern Australia were identified at Lake Mungo, dated to 40,000 ± 2,000 thousand years ago (ka) (Fig. 1, Bowler et al., 2003). Ancient DNA (aDNA) studies place Australian arrival at no earlier than 50 ka (Mallick et al., 2016; Malaspinas et al., 2016), while other dated evidence from archaeological sites ranges from 50 to 65 ka (Roberts et al., 1990; Bird et al., 2002; Clarkson et al., 2015). Consensus has agreed with earlier entry into Australia, likely from 50 to 65 ka. While arrival in Australia is important to the global human dispersal story, identifying early sites on a local scale is equally vital to gain insight into migration paths and understand long term human behaviour. Environmental conditions are one factor which either enabled human migration or acted as a barrier preventing colonisation of different areas (Denham et al., 2009). The Last Glacial Maximum (LGM), ~22 ka to ~ 18 ka in Australia, was a period of cold which may have affected human mobility. Despite early sites in Australia dated to 65 ka, most areas lack evidence for human occupation prior to the LGM. The greater Sydney region (Fig. 1) lacks extensive dated evidence for Pleistocene occupation, particularly prior to the LGM, despite being one of the most extensively researched areas in Australia (due to the quantum of commercial archaeological excavation).

The absence of evidence could be partially attributed to the region’s location in regard to the former Pleistocene shoreline, which at the height of the LGM (~20 ka) was ~25 km offshore and 120 m lower (Albani et al., 2015). The Pleistocene shore and hinterland (Fig. 1) was consequentially submerged by the melting of the ice caps at the end of the Pleistocene (Albani et al., 2015; Attenbrow 2010; Reeves et al., 2013; Williams et al., 2018). Despite the marine submergence of the now offshore continental shelf, other parts of the Sydney basin do present evidence for pre-LGM human occupation. As the question is one of timing, three dating methods are commonly used in the Sydney region: thermoluminescence (TL), to determine when an artefact/item was last heated (e.g., cooking pits or baked clay); optically stimulated luminescence (OSL), to determine when sediment was last exposed to sunlight; and radiocarbon dating to determine when an organism was living (e.g., wood, bone, and organic material).

Outside Parramatta, the earliest dated Aboriginal archaeological evidence in this region is from the Nepean River (the Cranebrook...
Terrace) and on the Hawkesbury River on the Pitt Town and Windsor sands (Fig. 1). Cranebrook Terrace deposits associated with lithic tools were TL dated and returned an age estimate of over 40 ka (Nanson et al., 1987), with estimates ranging from 26,700 to 35,432 cal. yr BP from radiocarbon dating. The artefacts’ provenance has generated considerable debate (Karskens, 2020; Mulvaney and Kamminga, 1999; Williams et al., 2017). Near Pitt Town, a sand levee with a density of lithics was ascribed pre-LGM OSL dates from 30 ka (Williams et al., 2012).

A previous model for regional occupation before, through and after the LGM, identified the Sydney Basin bioregion as a possible pre-LGM and intra-LGM refugium (e.g., Barry et al., 2021: Fig. 3; Williams et al., 2014; Williams et al., 2021). Parramatta was considered a likely part of this model (Williams et al., 2014:746) but subsequently discounted (Williams et al., 2021:8). However, archaeological evidence from Parramatta indicates this inland riverine system should be considered within the proposed framework.

Numerous archaeological excavations adjacent to the Parramatta River have uncovered locations with evidence for long term Aboriginal occupation. These sites have been dated from the late Pleistocene to the late Holocene, on and within a sedimentary unit known as the Parramatta Sand Body (PSB). The distribution of Aboriginal archaeology sites, approximate extent of the PSB soil landscapes, and understood antiquity of most Aboriginal sites is shown in Fig. 2.

Recent publications on the archaeology of Parramatta (Barry et al. 2021; Owen and DCKN 2022; Williams et al. 2021) identify many late Pleistocene archaeological sites—however, pre-LGM sites have been contested in Williams et al. 2021:4.

Lithics data from 25 archaeological sites across Parramatta (Owen and DCKN, 2022:12, Table 2) aligned ages against the New South Wales (NSW) Eastern Regional (lithics) Sequence (ERS) (Hiscock and Attenbrow, 2005). The ERS describes distinct phases for the Aboriginal occupation of Sydney and provides a chronological framework for changing stone material use and associated technological manufacture.

Parramatta’s archaeological record can be divided into four phases: Phase 1 (pre-7,000 BP), Phase 2 (after 7,000 BP to 1,500 BP), Phase 2B (after 1,500 BP to 1788 BP), and Phase 3 (the Contact Phase, following European invasion in 1788). Of the 15 Aboriginal sites located on the PSB, 11 are associated with Phase 1 archaeological evidence. The most often reported (from archaeological grey literature) is the high-density lithic site RTA-G1 with carbon-bearing sediments dated to 35,061–34,239 cal. yr BP (Wk-17435) (JMcDCHM, 2005).

A separate review of data from eight archaeological sites within Parramatta considered the potential for early pre-LGM archaeological deposits (Williams et al., 2021). The collation of 34 OSL age estimates obtained from the PSB range between 0.62 and 50.8 ka (Williams et al., 2021, Table 2). Proposed changes in occupation based on archaeological deposits favoured a two-phase model within the PSB, with initial and scattered occupation during the terminal Pleistocene and early Holocene, followed by intense and repeated occupation during the mid-Holocene. Williams et al. (2021:8) argued “… evidence for a pre-LGM or LGM occupation of the region is equivocal without more detailed chronological control …”.

Aboriginal site AT14, on the eastern banks of the Parramatta River in the grounds of the Cumberland hospital (part of site 1 in Fig. 2), retains a deep sequence of Aboriginal archaeological material within an in-situ aeolian expression of the PSB. It provides a unique opportunity to further constrain Aboriginal occupation in this region. In this paper, we investigate the age and deposition of early Aboriginal cultural material within AT14, to determine if this does indeed represent one of the oldest known sites with evidence of First Nations occupation in greater Sydney.

2. Background

2.1. Sedimentary context

South-eastern Australia is considered one of the richest archives of
Fig. 2. The location and age of most known Aboriginal sites within Parramatta, mapped against indicative extents of local soil landscapes. Under the Eastern Regional Sequence Phase 1 sites (Hiscock and Attenbrow 2005) date to the Pleistocene. (Modified from Owen and DCKN 2022, Figs. 2 and 3, with soil data from Mitchell 2008).
Fig. 3. Aboriginal site AT14, section diagram of the western trench face. Showing OSL sample locations, correlated with excavation units, and relative depth of radiocarbon dates. Insert (top left) provides breakdown of complete artefacts by size in the phased assemblages, MNI counts, and % frequency. Depth of hand excavation is shown. Insert (top right) shows OSL dates with paired radiocarbon from Aboriginal cultural features.
environmental change on the planet (Pethick et al., 2011). Source bordering dunes (SBD) are deposits of sand, which form when wind blows sand from an adjacent water source onto the banks of the water source. SBD’s are located on downwind margins of major fluvial systems, and are commonly investigated paleo-archives, storing high resolution sedimentological records of hydrological change.

Research indicates SBD’s are comprised of predominantly fine to medium sands, with a low percentage of silts and clays (less than 10%), formed through the aeolian reworking of river channel sediments during periods of riverbed deflation (Page et al., 2001; Cohen et al., 2010). These deposits have been identified within Kurnell (Roy and Crawford, 1979) and near the Hawkesbury River (Williams et al., 2014).

The LGM, the height of the last glacial period, was documented within Australia as a period of dune formation. Hesse (1994) found three periods of accumulation from the Tasman Sea, which is likely similar to southeast Australia, including one period from 25 to 16 ka. Multiple climate fluctuations within Australia include a large dry/cool period at 25–16 ka, correlating with the LGM. Dust accumulation was likely more intensive in this timeframe. Chen et al. (2002) finds the rate of accumulation during this period was 1.6–5 cm/ka, whilst the Holocene was 0.5–0.7 cm/ka.

A review of over 600 luminescence ages from dune sites within Australia found varied accumulation intensity, with the Mallege dune field showing low rates during the LGM while the Strzelecki Desert contained a period of higher rates (Thomas and Bailey, 2017). Within the Murrumbidgee basin, NSW, TL dating showed sand accumulation from 15 to 25 ka, 35–60 ka, and 80–120 ka (Page et al., 2001). Accumulation is likely controlled by regional and local drivers, mainly water flow and sediment availability (Thomas and Bailey, 2017).

Though dunes are the most extensive landform within Australia, little research has directly studied the mechanisms of dune formation within the larger Sydney Basin. Within Australia, research suggests multiple mechanisms for dune formation contribute to the process. Ash and Wasson (1983) linked dune formation to increased wind, while Wasson (1989) found an increase in aeolian activity and decrease in precipitation responsible for dune formation, and Hesse et al. (2004) suggests aeolian activity is not responsible, but dune formation is related to vegetation variation and forms in cold, dry time periods.

The PSB is a large sand deposit with an unknown depth and varying dimensions, at least four metres deep in certain locations and up to two kilometres long. Originally mapped in 2008 (Mitchell, 2008), recent investigations show the deposit is larger than thought and extends upstream for considerable distance (Fig. 2). The PSB holds significant Aboriginal archaeological and geomorphological heritage values, demonstrated through its statutory listing on the NSW State Heritage register.

2.2. Archaeological context

Archaeological excavations through the PSB have yielded a wealth of evidence for Aboriginal occupation typically dated through lithic technology to the late Pleistocene and the whole Holocene (White and McDonald, 2010; Owen and DCKN, 2022). At site RTA-G1 (JMDCfHM, 2005; site 19 in Fig. 2) radiocarbon age of carbon from sediments, cultural features, coupled with lithics analysis identified two distinct and separate phases of occupation; the earlier associated with the pre-LGM around 30 to 35 ka. A further pre-LGM site with an occupation date of 32.6 ± 2.4 ka (obtained using single-aliquot OSL) is the George Street Gatehouse (GML Heritage, 2019; site 7 in Fig. 2), although the association of cultural material with the ~33 ka age estimate was questioned (Williams et al., 2021). Lithic pre-glacial attributes are present within the lithic assemblages of Parramatta (e.g., JMDCfHM, 2005; White in GML Heritage, 2022) (These findings from AT14 will be the subject of future publication and are beyond the scope of this paper).

Investigations into the physical extent and characteristics of the PSB have been limited (e.g., Mitchell, 2008; Geoprospetion, 2019; GML Heritage, 2019; GML Heritage, 2022). In general, it is thought to be composed of two terraces, with the upper terrace containing Aboriginal archaeology and a lower terrace that is yet to be connected with archaeological evidence. The mode of PSB formation appears to be location and height dependent (height above sea level, measured against the Australian Height Datum (AHD)). Locations with lower elevation (5.5 m to ~ 8.0 m AHD), and (sometimes) proximity to the river channel, appears to have fluvial deposition as the primary mode of formation.

A rough model suggests PSB above 7.5 m (AHD), and notably above 9 m (AHD), are possibly aeolian in origin (GML Heritage, 2022). Previous particle size analysis (PSA) of samples from an elevated location (9.65 m) at George Street Gatehouse excavation suggested that the top metre of the upper terrace comprised aeolian material, while the lower excavated metre of the deposit at this locale was older (pre-Abriginal occupation) and potentially of fluvial origin (GML Heritage, 2019).

TL dating has been applied to the lower sterile terrace (>1.5 m below the surface). The results indicate the lower terrace was formed 58,000 to 50,000 years ago (Mitchell, 2010). OSL from a lower terrace Aboriginal site in North Parramatta resulted in an age of 51 ± 4 ka (Geoprospetion, 2019; near site 1 in Fig. 2), indicating some locations with PSB hold the potential to be an archive for the entire span of human occupation in the region (O’Connell and Allen, 2004).

2.3. Thermoluminescence and optically stimulated luminescence

OSL is useful for dating dunes because it measures when naturally occurring quartz or feldspar grains in sediments were last exposed to sunlight. This date of last exposure may be used to infer an age by association for artefacts within the sediment. If all grains are sufficiently exposed to sunlight prior to burial, then each grain would have a similar ‘equivalent dose’ (D$_e$), or energy in Grays (Gy). When grains are subjected to different sunlight exposure times during rapid or slow transportation, D$_e$ values will be distributed across a wider range than is predicted for a normal Gaussian population (known as over-dispersion) even if the grains were buried at the same time (Galbraith et al., 1999). Differential exposure is termed incomplete or partial bleaching (Aitken, 1998). Single-aliquot multiple-grain OSL techniques tend to average this effect across all grains and may overestimate the burial age when compared to single-grain (SG) OSL that allows the least affected grains to be isolated (Appendix 1). An ‘averaging’ effect is also present within TL dating due to the use of aliquots and the unbleachable portion of the signal.

3. Materials and methods

3.1. Archaeological methods

Site AT14 was archaeologically excavated across an area of 52 m$^2$. Excavation proceeded on a 1 m grid, with removal of vertical 50 mm spits. All cultural features were stratigraphically excavated. Aboriginal cultural material was recovered between 12.37 m and 11.82 m AHD. Hand excavation continued to 11.69 m, 130 mm below the lowest recovered lithic (Fig. 3). The site was excavated by machine (with all deposits wet sieved through a 3 mm mesh) for a further 1 m depth, confirming the maximum depth of cultural material. Post-excavation scientific analysis included lithics morphology, useware and conjoin analysis, OSL and radiocarbon dating, PSA, and pollen, spore, and lipid analysis.

Results of the archaeological excavation (GML Heritage, 2022) will be presented as a separate publication; however certain results are relevant to this paper. To demonstrate stratigraphic and archaeological integrity (particularly the in-situ nature of artefacts in the pre-LGM layers), we present (for the whole excavation) the total lithics count, mass of manuported stone (g), the minimum number of individual artefacts (MNI), and number of complete artefacts by size. Artefact conjoin analysis for excavation squares 5, 12, 13, 19 and 20 is provided; these
squares were located on the western edge of the excavation area including and immediately surrounding the OSL age determinations. The size of complete artefacts by depth allows for an examination of artefact 'mobility'. Conjoin analysis (undertaken for the whole assemblage) systematically compares all lithics of the same raw material type, fitting the pieces to reform complete artefacts, enabling an understanding of the vertical and horizontal movement of artefacts due to post depositional processes.

3.2. OSL methods

Seven opaque tubes (PSBA-PSBG) were hammered into the baulk of the excavation area (Fig. 3), at the boundary of excavation squares 12 and 24.

PSB-A through PSB-F were taken to constrain the artefacts and to determine a rate of sedimentation. PSB-F was sampled one spit (50 mm) above the lowest cultural lithics from the adjacent squares and represents a minimum age for the timing of occupation at the site. PSB-G was taken from the base of the excavations, to further examine the sedimentation rate along with the antiquity of the PSB itself. The tubes were wrapped in black plastic and a separate bag of sediment was collected within a 30 cm radius around the tubes for water content and dosimetry analysis. Detailed methodology can be found in the Appendix.

3.3. Particle size methods

Two separate independent studies investigated opposing profiles (northwest and northeast) within AT14. A comparative analysis of PSB sedimentology with that of two known SBD deposits in south-western NSW was also undertaken. PSA was performed on the dose rate bag samples also used for OSL dating, detailed methodology of which can be found in the Appendix.

4. Results

4.1. Archaeological outcomes

From the 52 m² excavation area, a total of 1,128 artefacts, 249 heat shatters, 99 other lithics (indeterminate and broken) and 255 pieces of manuported stone, alongside 20 discrete cultural features (cultural hearths and pits) were recovered. The quantity (and density) of cultural material is high for Parramatta, and Sydney in general, (c.f. Owen and DCKN, 2022: Table 1; White and McDonald 2010: Tabs. 3, 7–9). We estimate that around half of AT14 was archaeologically excavated, the remaining portion has been permanently conserved. We also note that further similar archaeological deposits (in composition and depth) remain in close proximity to AT14 (e.g. site B10.14d, in Geoprospection, 2019). AT14 is therefore interpreted as one location among possibly several, with evidence for Aboriginal occupation, on a short stretch of the Parramatta River’s eastern PSB SBD.

4.2. Particle size analysis

Sedimentology throughout the profile is consistent. All samples show distinct bi-modal particle size distributions (Fig. 4). The dominant grain size is a medium sand (modal average ~ 291.9 µm) with a secondary distinct silty population (modal average 42.7 µm). There are slight variations in grain size proportions between samples, namely PSB-E with a greater volume of finer material (difference is negligible).

Sediment profiles from two NSW SBD’s are strikingly similar to Parramatta: both bimodal (Fig. 4). Medium sand dominates the profiles at both sites, with an average of 317.7 µm, whilst the secondary finer mode is silty (37.24 µm).

Accumulation is controlled regionally and locally by water flow and sediment availability (Thomas and Bailey, 2017), and that at AT-14 was likely controlled by local environmental factors. Variation in rate of sediment deposition is likely due to fluctuating environmental conditions around site AT-14. All observed rates are within typical estimations for Australia.

The data presented here shows an increase in formation activity from PSB-E to PSB-F, as well as a decrease from PSB-D to PSB-E, both of which may be related to climate changes. Australia’s dunes are largely documented as forming during this period and the entirety of the Holocene (Thomas and Bailey, 2017).

The sedimentary units at AT14 display stratigraphic integrity with clear bedding, a lack of erroneous features, e.g., lumps of clay within the sandy matrix, an absence of bioturbation, clear sedimentary features (e.g., hearths) and OSL ages in stratigraphic ‘order’ (see below). We note that Williams et al. (2021) identify that the PSB was reworked at certain locations, however we found no evidence to support this claim at this site.

4.3. OSL

The finite mixture model for samples PSB-A to PSB-E produced age values of 4.47 ± 0.29 ka, 8.37 ± 0.60 ka, 14.47 ± 1.13 ka, 13.01 ± 0.85 ka, and 29.51 ± 5.84 ka, respectively. Using the central age model, PSB-F and PSB-G produced D_{50} values of 40.656 ± 1.26 and 48.65 ± 1.46 Gy, resulting in age estimates of 31 ± 2 ka and 38 ± 3 ka (Fig. 6). PSBF, the lowest OSL sample with conclusive evidence of human occupation, constrained the occupation at the site to 31 ± 2 ka (Fig. 5). Overdispersion in the OSL samples tended to increase from oldest to youngest (Fig. 7), with PSB-G (30%) bring the lowest and PSB-A (60%) as the highest.

4.4. Carbon samples

Three carbon samples were obtained from three hearth features close to the OSL sample location. The relative depth of each charcoal sample is shown in Fig. 3. Feature 6, square 19, was an oval pit (280 mm by 380 mm, by 450 mm deep), cut down from spit 4. The radiocarbon age of 6,878 ± 21 BP (7,750–7,058 cal. yr BP, Wk-52570) was consistent with the Early Holocene age determination for PSB-B at the spit 4/5 interface.

Feature 20, square 30, was a round heating hearth (220 mm by 220 mm, by 10 mm deep), within spit 10. The radiocarbon age of 30,185 ± 180 BP (35,100–34,250 cal yr BP, Wk-52574) was stratigraphically comparable to the PSB-E and PSB-F.

Carbon adhering to manuported cultural sandstone, square 7, returned a radiocarbon age of 30,087 ± 171 BP (34,850–34,150 cal. yr BP, Wk-52567). This was stratigraphically comparable to the PSB-E.

4.5. Lithics overview

Specialist lithics analysis (lithics count, mass of manuported stone (g), and to eliminate bias due to artefact breakage the minimum number of individual artefacts (MNI), and number of complete artefacts) is

<table>
<thead>
<tr>
<th>Phase</th>
<th>Total lithics</th>
<th>MNI artefacts</th>
<th>Complete artefacts</th>
<th>Artefact breakage (%)</th>
<th>Mass manuported stone (g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Early Holocene</td>
<td>412</td>
<td>194</td>
<td>91</td>
<td>78%</td>
<td>3751</td>
</tr>
<tr>
<td>Terminal Pleistocene</td>
<td>409</td>
<td>186</td>
<td>105</td>
<td>74%</td>
<td>1342</td>
</tr>
<tr>
<td>Pre-LGM</td>
<td>239</td>
<td>128</td>
<td>79</td>
<td>67%</td>
<td>3218</td>
</tr>
</tbody>
</table>
provide in Table 1 and shown in Fig. 3. Artefacts were assigned into four climatic phases by technological attributes, materials, stratigraphy and dating. There were significant differences in assemblage composition between phases.

The late Holocene assemblage comprised a small assemblage of bipolar quartz, and no backed artefacts—a composition typical of this time period. We note that some of the late Holocene assemblage could have been partially lost through truncation of parts of the uppermost portion of the deposit. This phase is therefore not included in the totals in Table 1. Increased counts of MNI artefacts occurred in spit 6
(Terminal Pleistocene) with a slight increase in spit 9 (pre-LGM). The differences between the three phases were characterised through analytical avenues, which identified statistical differences in aspects including: raw material types, total lithics (flaked artefacts, heat shatters and non-diagnostic items, Fig. 7), MNI (194 Early Holocene, 186 Terminal Pleistocene and 128 Pre-LGM, Fig. 3), complete and broken artefacts, modified artefacts (e.g. differences in flake bodies, or serrated retouch), size, weight, platform types and flake production methods. The mass of manuported (unworked) sandstone varied significantly between the three climatic phases, with pre-LGM and Early Holocene deposits having twice the stone mass of that from the Terminal Pleistocene (Table 1, presented as percentages in Fig. 7).

4.6. Lithics Conjoin, manuport stratigraphy and size sorting

Across the whole excavation, conjoin analysis was used to identify 50 conjoin sets comprising a total of 121 cultural lithics. The results were interpreted through five separate sets by association (GML Heritage, 2022). One association set was connected with deposits at the OSL sample location (squares 5, 12, 13, 19 and 20). Here, 194 lithics formed eight conjoins in spits 6 to spit 10. Two sets linked lithics in spit 7 to lithics in spit 6, three sets lithics in spit 7 to spit 8. One set was confined horizontally to spit 6, and another set was confined to spit 9. The remaining set linked spit 8 to spit 10. The conjoins identified indicate a low amount of vertical movement between the Terminal Pleistocene and Pre-LGM deposits (between spits 8 and 10).

The manuport sandstone demonstrated distinct stratigraphy. Spit 6 (PSB-C/D) had 274 g, Spit 7 had zero, Spit 8 (PSB-E) had 478 g, and Spit 9 had 579 g. Overall, the vertical distribution of manuport stone, MNI counts, and conjoin results indicated that the majority of lithics had good vertical integrity moving less than 50 mm—not more than one excavated spit.

The size of complete artefacts varied through time (Fig. 3). The highest proportion of small artefacts (≤15 mm in maximum size) occurred in the Terminal Pleistocene assemblage (chi-squared = 8.31, df = 2, p = 0.016). Increased numbers of small artefacts (flakes) could have resulted from increased retouching of tools and/or from more intensive core flaking. The proportions of large artefacts (>30 mm in maximum size) did not vary substantially through time. However, no artefacts weighing >40 g each occurred in the Terminal Pleistocene assemblage, while five occurred in the early Holocene assemblage and three occurred in the pre-LGM assemblage. The absence of heavy artefacts from the Terminal Pleistocene assemblage may not have arisen by random chance (Fisher exact test p = 0.026). Heavy artefacts may have been reduced to small sizes and/or removed for use on other sites during this phase.

These results clearly demonstrate the integrity of the archaeological deposit within the PSB. AT14 was not subject to a level of post deposition artefact mobility present in some sand bodies (Marwick et al., 2017; Way, 2018; Hughes and Lampert, 1977).
Fig. 6. PSB A – PSB G; an accepted grain for each sample with dose response curves and radial plots.
5. Discussion

PSA from this study indicates the samples from the PSB were all likely formed under similar environmental conditions. Based on statistical modes identified by PSA at AT14 and comparative sites, it can be concluded samples were deposited through the same depositional process. This result does not support a differentiation between a basal fluvial and upper aeolian phase at AT14, though a lower fluvial phase with higher grain size has been observed elsewhere in the PSB at greater depth (GML Heritage, 2019). The previously mentioned lower terrace of the PSB has observed to be fluvial in origin, though this depth AHD was not reached at AT14 by hand or machine excavation.

Final transport and deposition of sediment of AT14 samples was likely to be as an aeolian source-bordering dune (SBD). Particle size curves are within the range of typical SBDs (Fig. 4). The Parramatta River has likely undergone episodes of fluvial activity coupled with episodic deflation. AT14 samples are from the eastern bank, meaning dominant westerly winds would have resulted in deposition. Previous research indicates SBD’s are likely to form within Australia during high wind, cold, or dry periods, with archaeological implications. It is possible that as the PSB was forming, cold periods may have made the coast milder and more suitable for habitation than the interior and triggered human migration into the Sydney Basin. Alternatively, perhaps occupation next to the Parramatta River (freshwater) would be a refuge in times of little/lower precipitation. During the Pleistocene the Parramatta River at Parramatta was entirely freshwater, rather than the brackish saltwater mix of the later Holocene. However, dune formation occurs in phases, and quite slowly compared to archaeological evidence, meaning that artefacts could accumulate in times of dune reduction and formation though sediment will only show the latter. As such, some caution in these interpretations must be taken.

Evidence has found that from 100 ka to present, wind within Australia was strong enough to rework available sand, yet the deposit at Parramatta was not subject to extensive reworking as seen in the stratigraphic integrity of OSL dating samples and lithic conjoin. It is possible the location was slightly protected from extensive wind due to local geography or vegetative cover. Subsequently, the temporal integrity displayed by the OSL results within AT14 suggests occupation throughout the LGM within the region, and therefore during dusty and dry conditions. Continuous occupation through varied climate indicates that the Aboriginal people occupying AT14 show a capacity to adapt to environmental conditions.

The aeolian nature of dune formation implies PSB-A through PSB-G should be well bleached before deposition and burial due to the nature of the windblown process that affords longer exposure times during transport. Thus, overdispersion observed in the samples, which varies throughout the stratigraphy (from 59 to 29%) despite consistent particle size, is likely due to some small amounts of mixing of well bleached sediment populations by trampling rather than by incomplete bleaching prior to deposition.
Artefact MNI increases up profile, as does artefact breakage (Table 1). This potentially represents increasing occupational frequency; though we note that artefact numbers may not reflect the actual size of the population (Way, 2018). Frequency of evidence for visitation could be a factor of many agents, including increased use of some sites because of a reduction in available land mass across the wider Sydney basin (eg inundation of the continental shelf at the end of the Pleistocene, Fig. 1), changing ecological regimes creating new ecotones in Parramatta (eg Parramatta River becoming tidal (estuarine) to a point immediately downstream of AT14), or changes in the regional economies (eg changes shown in ERS Phase 1 to Phase 2).

This pattern of increasing visitation correlates very closely with the increase in overdispersion. The proportion of broken lithics also increased through time, indicating increased trampling or burning (Table 1). This is also supported by the relatively dense and high number of hearth and pit features located in the Early Holocene and Terminal Pleistocene AT14 stratigraphy. Use of these features likely caused sediment to be mixed in specific locations through digging, hearth use and reburial. However, this mixing only occurred in specific areas, as lithic composition analysis (across all five separate sets by association) indicates that the deposit at AT14 retained considerable vertical integrity, with artefacts not vertically displaced more than one spit, or 50 mm.

Previous studies have linked human activity to artefact movement (Birin et al., 2021). High artefact counts coinciding with high overdispersion supports this as a viable explanation for the pattern of overdispersion present at AT14. As artefact numbers are much greater from PSB-A to PSB-D (Fig. 5), it is possible that increased visitation to the site at this time resulted in higher overdispersion and some anthropogenic mixing of sediment. Low overdispersion in PSB-F could be attributed to less intensive human activity, and in PSB-G, deposition prior to human activity. Thus, for the layers interpreted with some trampling (PSB-A through PSB-E) we employed the finite mixture model (FMM) to deal with more than one well bleached but mixed population. In contrast, samples PSB-F and PSB-G, representing less intensity/no occupation and thus less trampling were calculated using the central age model (CAM) that assumes well-bleached sediments. We interpreted the correlation of changing overdispersion with intensity of occupation as indicating that the sediments have been anthropogenically modified (in line with the human use at the site).

FMM revealed that most samples contained two components, and the component with the highest proportion of grains was used to represent the original bleached sample prior to trampling. One inversion occurred with PSB-C and PSB-D but indistinguishable within error margins. As the samples were taken directly adjacent to one another (Fig. 3), the similarity in ages may represent the precision limitations of the technique rather than a difference in the burial ages.

A slow sediment accumulation rate is present from PSB-D to PSB-E, with age estimates of 13 ± 1 ka and 30 ± 6 ka, respectively (Units 7 and 9). This represents a sediment accumulation rate of 0.60 cm / ka, which is well within the rate of accumulation observed in other dune forming sites in Australia (Chen et al., 2002). As discussed previously there is no evidence of reworking or erosion at this site despite the fact there were more artefacts between PSB-D and PSB-E than other units. Thus, rather than a disconformity/erosion feature we interpret this section as a slow but continuous accumulation of dune material and artefacts that represents an intense period of activity. The large artefact quantities during this time period, when considered with the refugia/late expansion model posed by Williams et al. (2014), could indicate AT14 as what Williams et al. would consider a refuge site next to a large river system.

We note the charcoal sampled from comparable spits agree with the oldest cultural results of ~35–34 cal. ka BP, providing a supporting independent age estimate for the extended OSL chronology in the PSB (Fig. 3). In contrast to the conclusions of Williams, et al. (2021), site AT14 provides strong evidence for pre-LGM occupation on the PSB, with dense evidence for occupation, associated with paired OSL and radiocarbon ages.

6. Conclusion

The resulting PSB-F date of 31 ± 2 ka, supported by radiocarbon age determinations of 30 ka (c.35–34 cal. ka BP), are amongst the oldest Aboriginal evidence in the Sydney region. Site AT14 presents a high density of stratigraphically secure and robustly dated First Nations cultural material, recovered from carefully controlled archaeological excavations. This evidence clearly demonstrates human occupation on the Parramatta River banks prior to the LGM, through the Terminal Pleistocene, and the Early Holocene, which provides new evidence to counter the claim for an absence of pre-LGM occupation in this region.

With respect to further research into early Australian occupation sites close to rivers or former paleo-channels, we have demonstrated the value of contextualising the sedimentation process prior to the interpretation of OSL dating results. The origin of the PSB at this location had not previously been demonstrated as a likely SBD, and as such has implications for its timing, formation and analysis.

The observed correlation between occupational trampling and overdispersion along the Parramatta River, or in other sand deposits within Australia, demonstrates the impact of occupation on the stratigraphy and provides a useful explanation for rates of OSL overdispersion. This has implications for use of OSL dating at heavily used archaeological sites.

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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.

Data availability

Data will be made available on request.

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Appendix

1. OSL background

OSL dating samples the most light-sensitive signal that can be fully reset and is inherently more precise at estimating the amount of trapped
charge prior to burial than TL dating. The TL signal is reset by extreme heat and always retains a portion of unbleachable charge representing a residual luminescence, which must be corrected during analysis. When multiple grain TL dating is applied to windblown quartz, this residual signal can be estimated, but accuracy is influenced by the averaging effect of partial bleaching for multiple grains, resulting in potential overestimation.

Previous OSL age estimates from the PSB relied on single-aliquot multiple-grain OSL, which averages the luminescence of a number of grains (1000 +), in comparison to single-grain OSL, which estimates the luminescence of each individual grain. As single-aliquot protocols typically have multiple grains that may contain aberrant luminescence characteristics and a large unbleached luminescence signal, they can also potentially overestimate the depositional age. In contrast, the use of single-grain techniques allows the rejection of the non-favourable luminescence characteristics and isolation of the most well-bleached grains (Jacobs et al. 2006).

Resulting high over-dispersion requires the use of an appropriate statistical model to determine the most reliable De according to depositional circumstances. The application of a minimum age model (MAM) (Galbraith 1999), rather than the use of the central age model (CAM) is more appropriate in sedimentary environments that have a high occurrence of partial bleaching as it allows identification and isolation of the most bleached grains to provide a more accurate estimation of the time since last exposure to sunlight (Van der Touw 1997; Galbraith 1999; Olley et al. 2003). Alternatively, if samples are assumed to be well bleached but are highly mixed due to reworking, bioturbation, or trampling, then a finite mixture model can be applied (FMM) (Galbraith and Green 1990).

Determining the degree of bleaching in the sedimentary environment of deposition is crucial for accurate OSL calculations; as it influences which statistical model is applied to the resulting single-grain De values. Using MAM on well bleached samples will produce a similar age as the CAM as the overdispersion is generally quite low. However, using CAM with partially bleached fluvial sediments will likely overestimate the age of last exposure due to the presence of partially bleached luminescence signals.

2. Methodology

2.1. Archaeological methods

Archaeological excavation adjacent to the Cumberland Hospital recently exposed a dense sub-surface archaeological site, AT14 (Fig. 1), that provided an opportunity to further investigate the chronology of the PSB. Approximately 50% of site AT14 was excavated across an area of 52 m2. Excavation was undertaken in 11 horizontal spits each 50 mm in depth. The remainder of AT14 remains unexcavated and intact within a conservation zone. Scientific investigations undertaken included cultural lithics analysis (functional, technical, conjoin and use-wear), palynology, radiocarbon dating of carbon from cultural features, and two independent sedimentology studies.

To assess the intensity of human occupation it was necessary to consider the vertical integrity of the deposits, the period of time represented by the deposits, and the number of flakes discarded. Detailed analysis (involving both artefact attributes and conjoining) was undertaken (GML Heritage, 2022); 39 squares (of 52 m2) within the excavation area were deemed to have relatively good vertical integrity (under 100 mm vertical movement). With consideration for some variation in the slope of prior land surfaces, the lithics in each spit of the 39 squares accounted for partial impact to the upper horizon of the site (five LGM. Few Late Holocene lithics were recovered, which could be 100 mm vertical movement). With consideration for some variation in two independent sedimentology studies.

OSL was taken from the boundary of squares 19 and 12. Each was excavated several spits below the lowest recovered cultural lithics to confirm the absence of cultural material, and allow for OSL sampling of deposits which predated the commencement of Aboriginal occupation in this location.

In subdued red-light conditions at ‘Traps’ Macquarie University (MQ) luminescence dating facility in Sydney, the tubes were opened and ~ 2 cm of sediment closest to each end was discarded. The inner section of each tube was processed according to the techniques of Aitken (1998), including sieving (90–212 um size fraction), chemical treatments (24-hour soak in both 10% hydrogen chloride and 10% hydrogen peroxide), separations using sodium polytungstate and a 45 min etch in 40% Hydrofluoric acid.

Single-grain quartz analysis incorporated a single aliquot regeneration (SAR) protocol (Murray and Wintle, 2006) for between 100 and 500 grains loaded on aluminium single-grain discs and measured in a TL-DA-20 Risø unit containing the single-grain attachment (Bøtter-Jensen and Mejdahl, 1988). Each of the quartz grains was stimulated for 2 s using a 10 mW 532 nm Nd:YVO4 solid-state diode-pumped green laser with 90% power corresponding to 25 W/cm2, and the ultraviolet emissions were detected by an Electron Tubes Ltd 9235QA photomultiplier tube fitted with 7.5 mm of Hoya U-340 filter. The first 0.03 s was integrated as the signal and the last 40–100 s was used as a background from each single grain shine down curve.

To obtain an estimate of the environmental dose rate for each of the samples, beta dose rates were first measured using a Geiger-Muller multi-counter to perform beta counting of dried and powdered sediment samples (Bøtter-Jensen and Mejdahl, 1988). Allowance was made for the effect of sample moisture content (Aitken, 1998), different grain sizes (Brennan, 2003) and HF etching (Bell and Zimmerman, 1978) on attenuation of the beta dose. The total beta dose-rate contribution was calculated by comparing the beta count rate to a standard beta source (SHAP with a dose rate of 5.99 Gy/ka) and magnesium oxide as a non-beta emitting background material. Secondly, thick source alpha counting was completed using a Daybreak 583 intelligent alpha counter to obtain estimates of Uranium and Thorium (Wang and Xia, 1991) in order to estimate the gamma dose rate. Finally, the difference between beta and alpha counting was used to estimate potassium values. These estimates were then converted to gamma dose rates using the conversion factors of Guerin et al. (2011). In addition, in situ gamma measurements were conducted at the sites to estimate the in-situ contribution of the gamma dose, which can differ from the sedimentary estimations depending on the composition of material within a 30 cm radius of the sampling location. Allowance was made for the effect of sample moisture content (Aitken, 1998) on the external beta and gamma dose rates using a long-term water content of between 4 and 6%, which is similar to the measured (field) water content of 4%. Cosmic-ray dose rates were estimated from published relationships (Prescott and Hutton, 1994), making allowance for the thickness of sediment overburden at the sample locality (1.8 m with an assumed density of 2.0 g/cm3), the altitude (~18 m above sea level) and geographic latitude and longitude (33.802°S and 150.997°E) of the sampling site.

Preheat plateau and dose recovery tests were performed on PSB-C as a representative sample using 180–212 um size fraction loaded onto single aliquots. SAR runs were conducted on three aliquots at each of the preheat temperatures tested; 200, 210, 230, 250, 270 °C for 10 s (a total of 24 discs). When plotted, this revealed that the De values plateaued at ~ 250 °C. Dose recovery tests were conducted at this temperature to determine if a surrogate dose of 20 Gy could be recovered using these measurement conditions. 100% of the discs recovered the surrogate dose within a one sigma error margin. Single aliquot regeneration (SAR)
single grain (SG) runs were then conducted at the chosen temperature (250 °C) on five single grain discs (500 grains) for each sample. Grains were rejected according to the protocols of Jacobs et al. (2006). The accepted single grains were plotted on a radial plot using the central age model (CAM) to determine the central point in the data set.

The application of a statistical model to the SG data was dependent on sample overdispersion results, as well as the results from the PSA analysis. Both the finite mixture model (FMM) and CAM were applied to samples to determine the De (see discussion for justification). For FMM the largest population of grains was used as the De.

All samples contained quartz grains that were bright with strong decays, high sensitivity to dose Appendix low recuperation and De values within the range 2–80 Gy. The percentage of grains that emitted luminescence was high (typically 20–30%), and as a result most of the grains were accepted (24–26%). The dose rates were fairly homogenous ranging from 1.276 ± 0.074 to 1.456 ± 0.287 Gy/ka. Single grains of quartz were discarded when the recycling ratio exceeded 1.2 or was less than 0.8, and when the recuperation ratio exceeded 5% (Jacobs et al., 2003). Grains were additionally rejected if the test dose error was above 5%, when no dose response was calculable (i.e., no curve, straight line). The overdispersion within the samples decreased down section with the upper samples A-D ranging between 59 and 50%, samples D-E between 45 and 41% and the two lowermost samples ranging between 32 and 30%.

3. Particle size methodology

Laser diffraction in the Malvern Mastersizer 2000 with a Hydro 2000G (A) accessory was used to determine the particle size of seven 3.05 mm samples. Grains were additionally rejected if the test dose error was above 5%, when no dose response was calculable (i.e., no curve, straight line). The overdispersion within the samples decreased down section with the upper samples A-D ranging between 59 and 50%, samples D-E between 45 and 41% and the two lowermost samples ranging between 32 and 30%.

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1. Approximately 100 g of bulk sediment was taken from each sample using a dry sediment splitter, ensuring a representative grain size distribution was measured.

2. Samples were dry sieved to remove the > 1.4 mm fraction. Grains above this size are unable to be pumped through the laser particle analyser. Zero of the samples had any grains above this threshold.

3. Organic (carbon) material was removed from each sample using a 10% hydrogen peroxide (H2O2) solution (Callesen et al., 2018) for 24 h.

4. Carbonates were removed from each sample using a 10% hydrochloric-acid (HCl) treatment for 24-hours (Murray and Olley, 2002) following each chemical treatment, deionised water and a centrifuge (2 × 10 min cycles) were used to remove aqueous waste from the samples.

5. Sodium hexametaphosphate solution (Na6 [(PO4)3] – 5.5 g/l) was applied to disperse samples for 24 h, removing any fine-particle aggregates which may be mis-represented as coarse grains during laser diffraction.

6. A final wet split of each sample into two representative aliquots was performed.

Following sample preparation, the Malvern Mastersizer was used to measure particle size. Three measurement cycles per aliquot was performed and an average was taken. Particle refractive index was set at 1.55 and an obscuration between 50 and 70% for each run. Results were accepted with a weighted residual of error less than 1%. Particle size distribution was graphed using the percent volume (%) of each grain size (µm).

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