Excavations, Surveys and Heritage Management in Victoria

Volume 9

2020

Excavations, Surveys and Heritage Management in Victoria
Volume 9, 2020

Edited by

Elizabeth Foley

David Frankel

Susan Lawrence

Caroline Spry

with the assistance of

Ilya Berelov

Shaun Canning

Front cover:
Dead standing black box Culturally Modified Tree along Kromelak *(Outlet Creek) (Photo: Darren Griffin)*

Excavations, Surveys and Heritage Management in Victoria Volume 9, 2020

Melbourne

ISSN 2208-827X

Contents

Abstracts

Editorial note

The papers included in this ninth issue of *Excavations, Surveys and Heritage Management in Victoria* were presented at the annual Victorian Archaeology Colloquium held at La Trobe University on 1 February 2020. Once again we had over 150 participants whose attendance testifies to the importance of this fixture within the local archaeological calendar. It continues to be an important opportunity for consultants, academics, managers and Aboriginal community groups to share their common interests in the archaeology and heritage of the State of Victoria.

The papers published here deal with a variety of topics that span Victoria's Aboriginal and European past. While some papers report on the results of specific research projects others focus on aspects of method, approach, education and the social context of our work. and approach.

In addition to the more developed papers, we have continued our practice of publishing the abstracts of other papers given at the Colloquium, illustrated by a selection of the slides taken from the PowerPoint presentations prepared by participants. These demonstrate the range of work being carried out in Victoria, and we hope that many of these will also form the basis of more complete studies in the future. All papers were refereed by the editorial team. This year Elizabeth Foley managed this process and the sub-editing of this volume under the guidance of Caroline Spry. Layout was again undertaken by David Frankel.

Previous volumes of *Excavations, Surveys and Heritage Management in Victoria* are freely available through La Trobe University's institutional repository, Research Online < www.arrow.latrobe.edu.au:8080/vital/access/manager/Repository/latrobe:41999 >. We hope that this will encourage the dissemination of ideas and information in the broader community, both in Australia and internationally.

We grateful to the Colloquium's major sponsors ACHM, Ochre Imprints, Ecology and Heritage Partners and Heritage Insight; sponsors Biosis, ArchLink, Christine Williamson Heritage Consultants and Extent; and to la Trobe University for continuing support. We would like to thank them, and all others involved for their generous contributions towards hosting both the event and this publication. Yafit Dahary of 12 Ovens was, as always, responsible for the catering.

Preparation of this volume was, like so much else in 2020, undertaken during the severe restrictions imposed because of the COVID-19 pandemic. We hope that 2021 will be a better year for all and that even if we are unable to hold our Colloquium at the usual time we will be able to do so later in the year.

The editors and authors acknowledge the Traditional Owners of the lands and heritage discussed at the Colloquium and in this volume, and pay their respects to their Elders, past and present.

Murrup Tamboore: community-led archaeological investigations at the former Keilor Archaeological Area

Rebekah Kurpiel[1], Catherine La Puma[2], Alex Parmington[2], Paul Penzo-Kajewski[1], Ron Jones[2], Allan Wandin[2], Bobby Mullins[2], Nathan Jankowski[3], Zenobia Jacobs[3], Molly Thomas[1], Fleur King[1] and Matthew Meredith-Williams[1]

Abstract

In 2018, Wurundjeri Woi-wurrung Cultural Heritage Aboriginal Corporation engaged La Trobe University to assist with archaeological investigations at the Keilor Archaeological Area (now known as Murrup Tamboore, or 'Spirit Waterhole'). Erosion control works were required at the site, providing an opportunity to investigate the stratigraphy close to the location where Ancestral Remains were uncovered in 1940. A narrow vertical section of the creek bank was exposed and sediment deposition was dated using OSL, with stone artefact-bearing layers dated to approximately 6.5 ka and 30 ka. Loose sediment and intact sediment block samples were collected for studying past environmental conditions and charcoal samples were subject to anthracological analysis. An archaeological survey was completed for the entire property, resulting in the identification of almost 300 stone artefacts. This paper reports on the results of the project to date.

Introduction

The Murrup Tamboore Archaeology Project is a collaborative project led by Wurundjeri Woi-wurrung Cultural Heritage Aboriginal Corporation (WWCHAC) with assistance from La Trobe University (LTU) and the University of Wollongong. Murrup Tamboore (formerly known as the Keilor Archaeological Area) is situated approximately 16.5 km northwest of the Melbourne CBD, at the confluence of Arundel Creek (formerly Dry Creek) and the Maribyrnong River (**Figure 1**). This Aboriginal place became known to the international scientific and broader community following the identification of Ancestral Remains in 1940 (Mahoney 1943a:31). The name *Murrup Tamboore* means 'Spirit Waterhole' in the Woi-wurrung language.

In recent years, water level fluctuations in Arundel Creek have eroded the creek bank. This erosion was recognised as having potential to impact on cultural heritage at Murrup Tamboore, prompting WWCHAC to arrange for erosion-control works. A number of options for erosion control were explored and it was decided that a custom rock wall design would result in the least additional short-term impact to the creek bank. WWCHAC decided that it would be necessary to understand how the construction of the rock wall would impact on any cultural material and decided that a small-scale archaeological investigation would be the best way to obtain the required information. WWCHAC were particularly interested in dating and characterising the creek bank stratigraphy and in understanding the possibility of Ancestral Remains being present in the proposed construction area. WWCHAC also decided that this project would provide a suitable opportunity to update the site records on the Victorian Aboriginal Heritage Register (VAHR) by conducting a survey of the property north of the confluence to identify cultural heritage present on the ground surface. LTU was engaged to assist with the investigation and a partnership with the University of Wollongong was also established.

Previous research at Murrup Tamboore

In 1940, Ancestral Remains were identified during commercial quarrying activities at the locality now known as Murrup Tamboore. The cranium was identified adjacent to Dry Creek (now Arundel Creek) and acquired by the National Museum in Melbourne (now Museum Victoria). Due to the nature of their recovery, the exact find location for the Ancestral Remains was unclear to the researchers who were trying to investigate their stratigraphic origin. Bosler (1975) noted that Daniel James Mahony, who worked at the Museum, described the find location in different ways: 'at a depth of 19ft' (Mahony 1943a:30), 'about 15ft below the surface of the ground and 18ft above the floor of the pit' (Mahony 1943a:31), and 'the skull was unearthed beneath undisturbed strata at 18ft below the surface of the terrace' in his second contribution to the same volume (Mahony 1943b:79). In the 1940s, there were no techniques available that could provide absolute age estimates for the Ancestral Remains, so their likely age was initially interpreted by drawing comparisons between terrace sequences in Europe and the Maribyrnong River terraces, which were (incorrectly) assumed to be associated with sea level change (Keble and Macpherson 1946).

[1] Department of Archaeology and History, La Trobe University, Bundoora Vic. 3086
< r.kurpiel@latrobe.edu.au >, +61403 165 203

[2] Wurundjeri Woi-wurrung Cultural Heritage Aboriginal Corporation, 1st Floor Providence Building, Abbotsford Convent, 1 St Heliers Street, Abbotsford Vic. 3067

[3] ARC Centre of Excellence for Australian Biodiversity and Heritage, University of Wollongong, Northfields Avenue, Wollongong NSW 2522

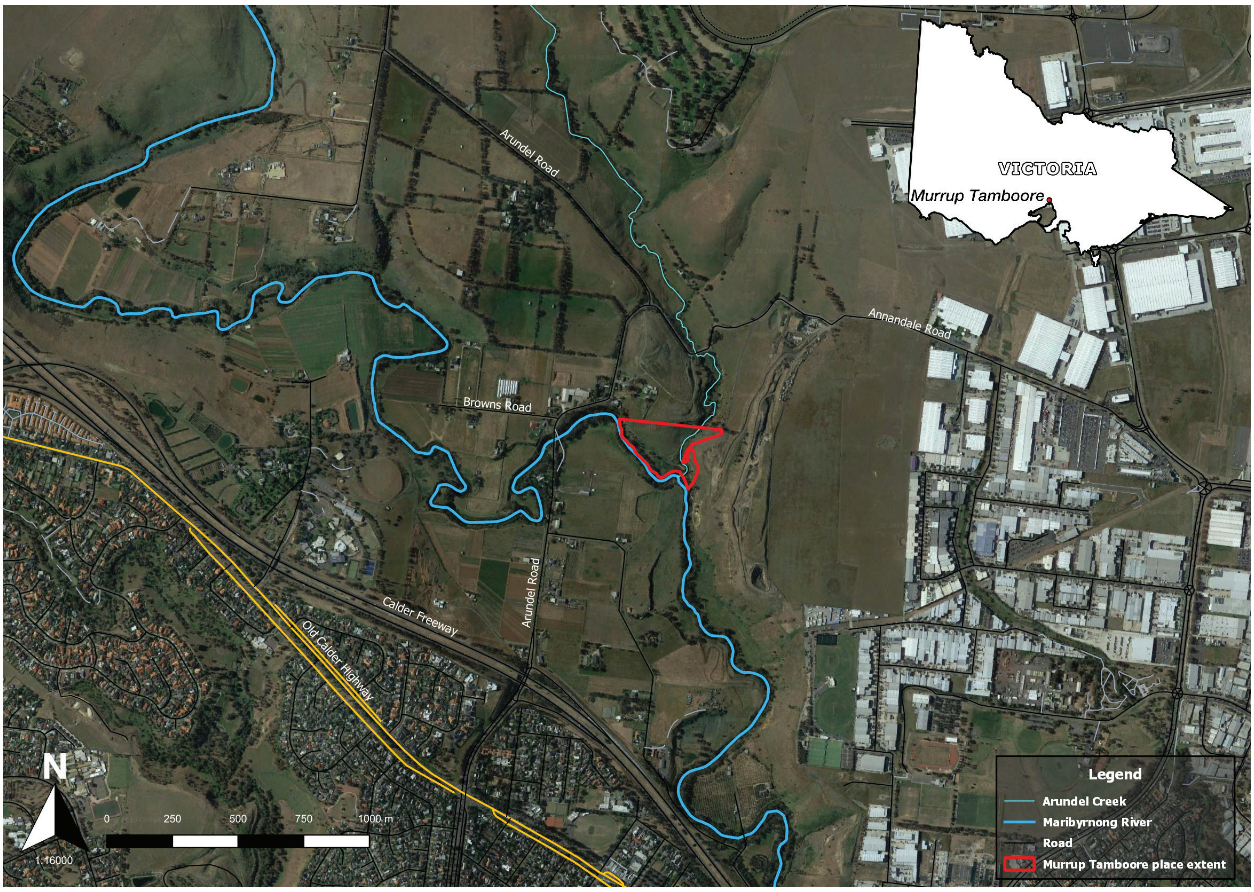


Figure 1. Map showing the location of Murrup Tamboore at the confluence of Arundel Creek and the Maribyrnong River

Subsequent reassessment of the geomorphological setting of the site by Edmund Gill, confirmed the presence of three distinct terraces (Gill 1966):

1. The Arundel Terrace—the highest and oldest terrace, comprised of 'Arundel Formation' sediments;
2. The Keilor Terrace—comprised of 'Doutta Galla Silts'; and
3. The Maribyrnong Terrace—the lowest and youngest terrace, comprised of 'Maribyrnong Alluvium'

The Braybrook Terrace, previously reported by Keble and Macpherson (1946), was reinterpreted as an eroded remnant of the Keilor terrace (Gill 1953:230).

Re-examining the Ancestral Remains, Gill noted sediments adhering to some surfaces (a yellow loess-like silt), which allowed a correlation to the exact layer from which they had originated (the upper part of the Doutta Galla Silt), ending the uncertainty of their provenance (Bosler 1975). The advent of the radiocarbon dating method provided an opportunity to radiometrically date the site; Murrup Tamboore was the second Australian site to be radiocarbon dated, providing an age of 8,500±250 BP (9,590±620 cal BP) (Bosler 1975:25). This was derived from charcoal from a hearth, located at least 'four feet' above the layer with the Ancestral Remains; this gave the first minimum age for the site (Rubin and Suess 1955:489). Gill (1971:75) went on to obtain a date of 7,360±105 BP (uncalibrated) derived from calcium carbonate precipitate adhering to the Ancestral Remains cranium (this provided further evidence for a minimum age.

When the Dry Creek channel was straightened, Gill returned to the site, documenting a further series of hearths through the terraces, and an additional date of 15,000±1,500 BP (uncalibrated) from a hearth at 'about the level' from which the Ancestral Remains originated (Gill 1966:584). Further research and analysis supported this, with a date of 18,000±500 BP (uncalibrated) coming from a hearth '5ft. 9in.' below the layer of the Ancestral Remains (Ferguson and Rafter 1959:232–233). At the time this was the earliest direct evidence for Aboriginal populations in Australia, and much earlier than other radiometrically dated sites in Australia.

Between 1966 and 1974 Gallus and the Archaeological Society of Victoria commenced large-scale excavations at Murrup Tamboore, with Gallus developing a number of contentious hypotheses (e.g. Gallus 1971:9), some of which have subsequently been disproven (e.g. Munro 1998). A series of radiocarbon dates were produced by the project, some of which were inverted, and thus likely either contaminated or impacted upon by intrusions (Duncan 2001). Faunal analyses were undertaken by Marshall (1974), which suggested the presence of megafauna at the site prior to ~20,000 years ago. In 1976, Joyce and Anderson published a summary of all available dates on the deposits: thirty-two dates in total, 24 from the Keilor Terrace and 8 from the Arundel Terrace.

On the 27th of September 1976, the Victoria Archaeological Survey (now Aboriginal Victoria) purchased the property adjoining the quarry on which the Ancestral Remains were identified. A team directed by Paul Ossa (LTU) and the Victoria Archaeological Survey (VAS) undertook excavations at Murrup Tamboore (at the property adjacent to the Ancestral Remains find location) between 1977 and 1982. These comprised three 3 x 3 m squares, with only one excavated to sterile sediments at a depth of 7.2 m (Duncan 2001). Only one date was processed from these excavations: 13,300±1,100 BP (uncalibrated) from the Keilor Terrace. The LTU/VAS excavations recovered a number of hearths, stone artefacts and faunal remains.

Duncan (2001) conducted an analysis of the faunal material found during the LTU/VAS excavations, identifying the presence of species from a number of categories: large marsupial, medium marsupial, small mammal, large macropod, medium macropod, small macropod, megafaunal macropod and megafauna (unidentified). Most of the specimens examined by Duncan (2001) were water rolled and therefore interpreted as having been transported to Murrup Tamboore by fluvial processes. However, a small number of specimens appeared to have been identified in situ in sediments dating to ~20,000 BP.

Investigations at Murrup Tamboore, over the course of the last eighty years, have established this place as a significant site in the story of Australia. It was the one of the first sites in Australia to be radiometrically dated, demonstrating the long history of Aboriginal presence in Australia. Unfortunately, none of the earlier phases of research incorporated consultation with the Traditional Owner community. The most recent research, which is the subject of this paper, has been led by WWCHAC.

Fieldwork activities in 2018

There were two fieldwork components to the project: pedestrian survey and excavation.

Survey

To improve ground-surface visibility for the survey, a controlled burn was undertaken on the property by the Narrap Team (part of the WWCHAC, who undertake environmental land management activities on Wurundjeri lands) and Habitat Land Management (HLM). The presence of moisture from recent rainfall inhibited the burn but some improvement to ground-surface visibility was achieved, particularly due to the reduction of dead grass buildup between extant clumps.

The pedestrian survey was undertaken on 18 and 19 June 2018, with detailed artefact recording continuing on 20 and 21 June. During the survey, participants were spaced approximately 2.5 m apart. Ground-surface visibility varied across the property, with particularly poor visibility (generally 0%) encountered close to the confluence of Arundel Creek and the Maribyrnong River and close to Arundel Creek further upstream. The highest artefact densities were identified in areas with better visibility, for example, at the most elevated part of the survey area near the northern boundary fence (visibility ~50%), and where part of the upper landform is eroding (visibility ~75%).

All of the 296 cultural material items identified during the survey are stone artefacts. The raw materials include silcrete, quartzite, quartz and basalt. Interpretation of the detailed information that was recorded about these artefacts is presented below.

Stone-working activities at Murrup Tamboore

At Murrup Tamboore, there is evidence for the use of a variety of mostly high-quality raw materials that were probably available in the region, including silcrete, quartzite, quartz and basalt. Basalt was used as a hammerstone on at least one occasion, probably to work large pieces of silcrete identified at the most elevated part of Murrup Tamboore until it broke and was discarded. Quartz and quartzite appear to have been obtained as pebbles and cobbles from streambed sources. The basalt hammerstone was probably also obtained from a streambed somewhere in the broader region. Research into stone sources on Wurundjeri Country is currently underway and it is therefore likely that further relevant information will be generated in coming years. At present, silcrete is known to outcrop at a number of locations along the Maribyrnong River Valley, including at Brimbank Park approximately 2.5 km to the south of Murrup Tamboore.

The range of knapping debris present suggests that all stages of reduction are represented at Murrup Tamboore, although there is more evidence for early and mid-stages of reduction (e.g. raw material testing and flake production) than later stages (e.g. tool use and maintenance). In general, cores were worked informally, with cores rotated to allow any suitable platform to be utilised. Suitable platforms were often worked bifacially. The bipolar technique was employed at least some of the time to work both quartz and silcrete. Evidence for systematic blade production is not common and there are few signs of a need to conserve raw material at Murrup Tamboore. On average, better quality raw material tended to be worked more intensively than poorer quality raw material but many cores were not worked to exhaustion. A small proportion of artefacts identified at Murrup Tambore during 2018 exhibit retouch or macroscopic signs of use.

Excavation

The excavation, located at the site of the proposed erosion-control works, exposed the full ~4.5 m stratigraphic profile of the Arundel Creek bank allowing the stratigraphy to be described and dated. The excavation trench varied from 0.5 to 1 m in width, allowing for sedimentological characterisation of the profile, while minimising impact on any cultural materials. This approach was in line with Wurundjeri's plan to learn more about the nature of the embankment location without causing unnecessary impacts to the site. It also reflected the engineering design for the rock embankment, which was to include no excavation into the creek bank, but had the potential to result in slumping of the face of the embankment.

Stratigraphy and dating

Six stratigraphic units have been defined for this profile (**Figure 2; Table 1**), with Unit 2 further divided into subunits 2a and 2b to reflect subtle differences in the lower and upper portions of the 'buff silts' unit. Nathan Jankowski collected samples for OSL analysis from all units except Unit 5, with two samples taken from Unit 2a, and one sample taken from several metres upstream of the excavation trench, where a suitable exposure of Unit 4 was identified (seven samples in total). These samples were processed at the University of Wollongong by Nathan Jankowski and Zenobia Jacobs. Age estimates for the uppermost 5 samples from Units 1 to 3 (MTAP18-01 to -05), range from ~6.5 to ~34 ka, with the lowest 2 samples (MTAP18-07 and -06) having minimum age estimates only (of >126 ka and >91 ka).

Unit 6 likely represents an overbank/floodplain swamp environment, with high clay content and abundant organic matter (charcoal). Significant redoximorphic gleying (red/grey mottling) and carbonate-nodule formation within this unit point to its significant antiquity. Unit 6 is eroded into by Unit 5 (lower grey sand) and Unit 4 (gravel); gravel clasts in these units indicate a shift in the depositional environment to river channel deposit. There is no significant difference in age between MTAP18-07 (>126 ka) and MTAP18-06, and it is likely that Units 4, 5 and 6 all date prior to ~126 ka, presumably during the penultimate glacial maximum.

The coarse gravel located in the base of Unit 3 (upper grey sand) suggests an erosive event prior to deposition, with the fining upwards sequence suggesting a point bar or other in-channel feature. The overlying Units 2a and 2b (upper and lower buffs silts, respectively) were deposited rapidly and are unable to be separated in time from each other (34±2–29±1 ka; n=3) or the underlying Unit 3 (29±1 ka). The silt-dominated sediments that comprise these units are likely to represent an overbank sequence deposited relatively close to the channel.

There is a significant time difference in the age estimates for Units 2a/b and Unit 1. There is no clear evidence in the investigated stratigraphic profile beyond the sharp erosive upper contact to explain this. The most likely cause for this truncation is thought to be associated with the lateral movement of Maribyrnong River after the deposition of Unit 2a (Bowler 1970). The sediment mixing associated with the Unit 1 OSL sample is most likely a result of the intense rootlet activity observed within the sediments here, but other biological activity, such as livestock trampling, is also possible.

Two stone artefacts (one quartz split flake and one silcrete core) were identified on the ground surface near the excavation location and 11 stone artefacts were identified during the excavation (three were identified in situ and eight in the sieve). Of the three in situ artefacts, two (one silcrete whole flake and one silcrete angular fragment) were found at the same depth as OSL sample MTAP18-01 and were therefore likely to

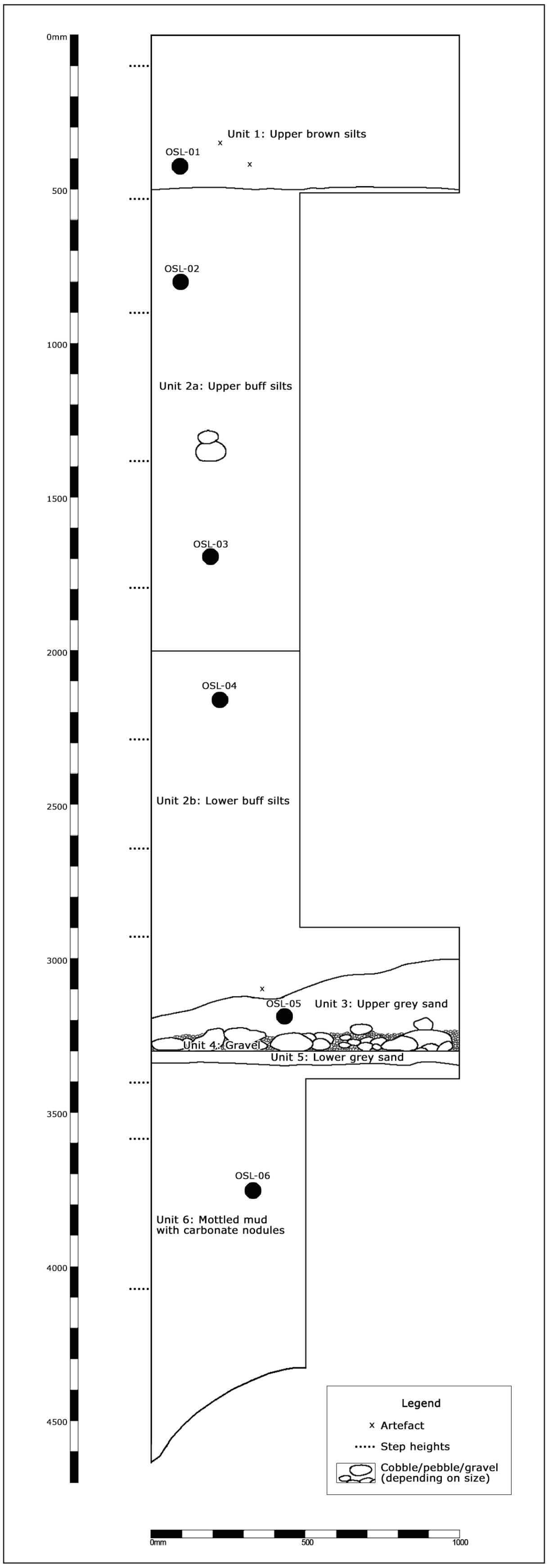


Figure 2. Section drawing for the excavation trench

Unit Number	Unit sedimentological description	Depth of lower boundary (cm)	Thickness of unit (cm)	Associated OSL samples (*Age estimates*)*
1	***Upper brown silts:*** mid-brown silts with minor very fine to fine sand. Sharp lower contact. Contains laterally continuous, buff-coloured, thin layers of fine silt. Rip-up clasts of underlying unit up to 1 cm in size present in base of unit. Slightly prismatic ped formation indicating shrink-swell clay within the sediment. Abundant rootlets throughout the back wall of the section.	50	50	MTAP18-01 (*6.5±0.8 ka*)
2a	***Upper buff silt:*** buff, homogeneous, moderately-sorted silts and fine sand. Fine laminations of sediment throughout. Upper surface contains abundant organic stained rootlet channels. Development of redoximorphic features at ~20 cm depth from upper surface in the form of red/orange iron-oxide staining along rootlet channels which persist throughout. Very rare clusters of pebbles and cobbles found mainly as sets of 2–4 clasts.	200	150	MTAP18-02 (*30±1 ka*) MTAP18-03 (*29±1 ka*)
2b	***Lower buff silts:*** similar in colour and composition as Upper buff silts but fining upwards, moving from coarser at the base to fine at the top of the unit. Upper most 25 cm is slightly darker in colour and has a slightly elevated clay and organic carbon content. Redoximorphic stained rootlet channels persist throughout. Small lenses of fine to medium sand found occasionally throughout the lowermost 10 cm of the unit and associated with moderately developed primary bedding planes.	305	105	MTAP18-04 (*34±2 ka*)
3	***Upper grey sand:*** light-grey fine to medium sand with minor silts. Scour surface lower boundary contact with infilling granules and fine pebbles.	320	15	MTAP18-05 (*29±1 ka*)
4	***Gravel***: clast-supported, poorly-sorted, pebble and cobble layer with interstitial sand and silt matrix. Strongly indurated with red-brown oxide staining. Lower surface scours into underlying unit. Sample collected from same unit several metres upstream of excavation trench	330	10	MTAP18-07 (*>126 ka*, -17/+∞)
5	***Lower grey sand:*** similar in composition as Upper grey sand. Coarsening upwards. Scour base.	335	5	-
6	***Mottled mud:*** red/brown, dense, heavy clay with minor very fine to fine sand. Strongly developed prismatic peds. Abundant carbonate nodules and mottled. Occasional charcoal fragments of up to 1 cm in size. Redoximorphic staining throughout.	400	75	MTAP18-06 (*>91 ka*, -10/+∞)

Table 1. Stratigraphic unit descriptions and OSL age estimates

have been incorporated into the creek bank sediments approximately 6,500 years ago. The other in situ artefact (a silcrete angular fragment) was found in Unit 2b and was therefore likely to have been buried by creek bank sediments approximately 30,000 years ago. These artefacts may have been incorporated into the creek bank sediments at approximately these times, or they may have worked their way down into these stratigraphic layers over time via cracks opening up during the wetting and drying of sediments with clay content. In the case of the artefact associated with the age estimate of 30,000 years, its vertical movement would have approximated 2.5 m for this artefact to descend to the level it was found, if it originated from the younger layers above. This is considered improbable.

Interpreting the sediments and age estimates with respect to the results of previous studies, including geomorphological studies of the broader Maribyrnong River valley terrace system, is a challenge that is currently being addressed in the next phase of the project. The sediments described for the 2018 excavation bear a resemblance to those described in previous research—in particular Units 2a and 2b most closely resemble the Keilor Terrace (Doutta Galla Silts), with Units 4, 5 and 6 appearing to correlate to the Arundel Terrace (Mottled Clays/gravels complex). However, the dates obtained from the 2018 excavation are older than what would be expected for the Keilor Terrace, and this requires explanation.

Anthracology (charcoal analysis)

Charcoal and possible charcoal samples obtained during the excavation were examined as part of a student project. Molly Thomas, who is an undergraduate student at LTU, has been learning how to identify plant taxa from the wood anatomy of charcoal remains under the guidance of Fleur King, a PhD student at LTU. This work has involved preparing a reference collection of some of the plant species that are likely to be represented in the charcoal from Murrup Tamboore.

To identify suitable species for the reference collection, King and Thomas consulted the pre-1750s Ecological Vegetation Classes model for the area around Murrup Tamboore and compiled a list of plant species thought to have been growing in the area in the recent past. To collect specimens for the reference collection, Thomas, King and Kurpiel collected branch wood from a number of different trees and shrubs from the LTU Wildlife Sanctuary with the assistance of Scott Tunbridge, who works there. The wood samples were then turned into charcoal using a muffle furnace. The samples were charred for 40 minutes at 400°C, which proved effective for the majority of the samples.

Thomas has completed the analysis of the 16 samples recovered from the site, five of which preserved adequate anatomical features to allow identification to various taxonomic levels: two samples were identified as *Eucalyptus camaldulensis* (river red gum) (**Figure 3**), one as *Eucalyptus* sp. (indeterminate Eucalyptus species), and two as belonging to the family *Myrtaceae*. The remaining samples were unable to be identified as they were either too vitrified or composed mostly of soil and rock. The next phase of the project will involve further analysis of the palaeoecology of the site.

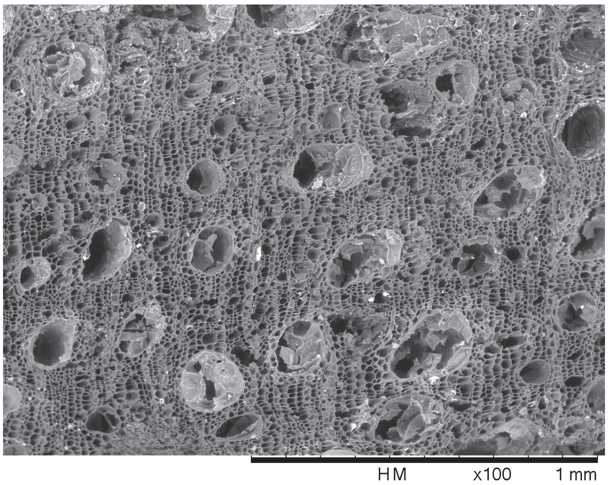


Figure 3. Scanning Electron Microscopy (SEM) image of charcoal identified as Eucalyptus camaldulensis *viewed at 100x magnification showing large solitary vessels and smaller wood fibre cells*

Site registration

The activities undertaken at Murrup Tamboore in 2018 resulted in the amalgamation of previous site registrations, and the extension of site boundaries to reflect the property parcel in its entirety, as well as the location where the Ancestral Remains were identified on the adjacent property. In addition, the project spurred the undertaking of a cultural values recording, which provided Elders with the opportunity to visit Country, and record knowledge and connections to both the Murrup Tamboore site, and the wider landscape of the Maribyrnong River valley. This approach recognised the importance of intangible values associated with archaeological sites, which are often overlooked within Victorian methods of undertaking site registrations.

Conclusion

The approach undertaken with this research, driven by the desire of the Traditional Owners to learn more about their cultural sites, and where impacts are minimised to those required, ensures that research is undertaken in a way that is sympathetic to Traditional Owner connection to Country and recognises their responsibility to care for their cultural places. The survey and excavation undertaken for this project achieved the primary aim determined by the WWCHAC, which was to understand the heritage values that may have been impacted by the erosion control works. In addition, the project was viewed as an educational opportunity for all participants involved; Wurundjeri community members gained the opportunity to connect to one of their significant cultural sites, and learn from LTU researchers techniques for advanced archaeological investigations, while researchers from LTU gained the opportunity to learn from Wurundjeri Elders information about culture and the history of the site. It is hoped that this project acts as an example of a collaborative method for undertaking archaeological investigations and drives further community-led archaeological projects in Victoria.

The results of the 2018 research activities have provided information about the stone-working activities that were undertaken at Murrup Tamboore, including the nature of the raw materials and how they were used to manufacture tools. The creek-bank stratigraphy has been characterised and age estimates for sediment deposition have been provided, ranging from ~6.5 to ~30 ka for artefact-bearing deposits. These results will now be interpreted in their broader geomorphological context, with the aim of bringing LiDAR datasets together with field observations and the results of previous archaeological investigations in order to determine how this part of the Arundel Creek bank relates to the broader terrace system. Future multidisciplinary research will also seek to generate information about the palaeoecology of the region surrounding Murrup Tamboore, expanding upon the results of the anthracological analysis undertaken by Thomas and King.

Acknowledgments

The authors would like to thank everyone who assisted with the fieldwork: Shane Nicholson, Willie Xiberras, Sean Wandin, Naomi Zukanovic, Gary Galway, Brendan Wandin, Shane Nicholson, Robert Jones, Erica Weston, Maddy Maitri, Caroline Hawker, Coen Wilson, Raquel Sundberg, Molly Thomas, Elizabeth Foley, Kathryn Lobs, Tim McLean, Jamie Spiteri, Alexandra Squires, Brandon Kerrigan, Kerry Hammond, Tamara Corfield and Aisling Beale. Project support was also provided by

David Wandin, Sean Hunter (and the Narrap Team), Anna Tuechler, Kellie Clayton and Rebecca McMillan (and other staff at Aboriginal Victoria), Penelope Spry (Melbourne Water), Peter Le (HLM), Scott Tunbridge and Andy Herries (LTU). Funding for the project was provided by Melbourne Airport.

References

Bosler, W. 1975 The Keilor Archaeological Sites: An historical survey. Unpublished Honours thesis, Australian National University, Canberra

Bowler, J.M. 1970 Alluvial terraces in the Maribyrnong valley near Keilor, Victoria. *Memoirs of the National Museum of Victoria* 30:15–58

Duncan, J. 2001 Megafauna at Keilor and the timing of their extinction. *Australian Archaeology* 53:16–22

Ferguson, G.J. and Rafter, T.A. 1959 New Zealand C14 age measurements. *N.Z. Journal of Geology and Geophysics* 2:208–241

Gallus, A. 1971 Excavations at Keilor: Report No. 1. *The Artefact* 24:1–12

Gill, E. 1953 Fluorine tests in Australia on the Keilor skull and a Tertiary marsupial. *Nature* 172(4374):409–410

Gill, E. 1966 Provenance and age of the Keilor cranium: oldest known human skeletal remains in Australia. *Current Anthropology* 7(5):581–584

Gill, E. 1971 Applications of radiocarbon dating in Victoria, Australia. *Proceedings of the Royal Society of Victoria* 84:71–85

Joyce, E.B. and J.R. Anderson 1976 Late Quaternary geology and environment at the Dry Creek archaeological sites near Keilor in Victoria, Australia. *The Artefact* 1(2):47–74

Keble, R.A. and J.H. Macpherson 1946 The contemporaneity of the River Terraces of the Maribyrnong River, Victoria with those of the Upper Pleistocene in Europe. *Memoirs of the National Museum of Victoria* 14:52–68

Mahony, D.J. 1943a The problem of antiquity of man in Australia. *Memoirs of the National Museum of Victoria* 13:7–56

Mahony, D.J. 1943b The Keilor fossil skull: geological evidence of antiquity. *Memoirs of the National Museum of Victoria* 13:79–81

Marshall, L.G. 1974 Late Pleistocene mammals from the Keilor cranium site, Southern Victoria, Australia. *Memoirs of the National Museum of Victoria* 35:63–86

Munro, M. 1998 The stone artefact assemblage from Keilor: A presentation of recent work on the stone material from the joint Victoria Archaeological Survey and La Trobe University excavation of a site at Keilor dug between 1977 and 1982. *The Artefact* 21:19–34

Rubin, M. and H.E. Suess 1955 U.S. Geological Survey radiocarbon dates II. *Science* 121:481–488

‘Scarred for life too’: measuring girth and estimating ages of culturally modified trees using comparative examples from Wotjobaluk Country, Western Victoria

Darren Griffin[1] and Abby Cooper[2]

Abstract

*Barengi Gadjin Land Council Aboriginal Corporation, Cooper Heritage Management and the Wimmera Catchment Management Authority recorded 172 culturally modified trees (CMTs) during the initial archaeological survey stage of the Lower Wimmera River Aboriginal Water Project, along a section of the Wimmera River (*Barringgi Gadyin*) between Lake Hindmarsh (*Guru*) and Lake Albacutya (*Ngalpakatia/Ngelpagutya*), known as Outlet Creek (*Kromelak*), on Wotjobaluk Country, western Victoria. This paper examines the role of tree girth in the study of CMTs, which is the most common CMT attribute recorded by archaeologists, and is often applied in assessments and interpretations of this place type. Tree-girth measurements and their use in estimating biological tree age is discussed, as well as the accuracy and expediency of other CMT age estimation techniques employed by archaeologists. The paper concludes by presenting five steps that could be adopted by archaeologists to improve the quality of CMT data collected in the field, and subsequently the registration, assessment and interpretation of CMTs in Victoria.*

Introduction

In 2017, the Wimmera Catchment Management Authority (WCMA) received funding from the Victorian Government’s Aboriginal Water Program to facilitate the Lower Wimmera River Aboriginal Water (LWRAW) Project, which was developed, managed and delivered by Wotjobaluk Traditional Owner’s (TOs) working at the WCMA and Barengi Gadjin Land Council Aboriginal Corporation (BGLC), in collaboration with Cooper Heritage Management (Cooper HM). The LWRAW project assessed the Aboriginal cultural values of the Wimmera River (*Barringgi Gadyin*) through recording, collating and mapping of TO stories, values and connections to the waterway central to Wotjobaluk culture, Country and identity.

A comprehensive description of the aims, methods, results and functional analyses of CMTs recorded during the LWRAW project is detailed in Griffin and Cooper (2019:97–130). The objective of this paper is to provide suggestions for methods of field data collection for CMTs in Victoria to generate more reliable information about the age and interpretation of these trees.

Tree girth

Tree girth is one of the primary pieces of quantitative data required on the Victorian Aboriginal Heritage Register (VAHR) scarred tree component form, determined by measuring circumference at 1.5 m height above ground (HAG) (AAV 2008:78). Other than the radius of the canopy, the remainder of quantitative data required relates specifically to the cultural scar or modification. Other information required relating to the tree itself is subjective, such as the tree’s condition (AAV 2008:78–80; AV 2019). Long (2003:36) explains the reason for collecting the girth attribute is simply ‘ ... to allow comparisons to be drawn between different trees’. This attribute appears to have been adopted from the diameter at breast height (DBH) measurement, which is the universal standard for expressing the size of the trunk or bole of a standing tree, and the most common data collected in dendrometry (the field of botanical research concerned with the measurement of the various dimensions of trees).

DBH and other dendrometric measurements are primarily used globally by the forestry industry for estimating timber volume. The theory that DBH can also be used to estimate age in large and veteran trees also appears to have originated from the forestry industry, based on the fact that trunk diameter increment is the only constant non-reversible feature of tree growth (White 1998:2).

In Victoria, the concept of relating DBH to tree age is used by ecologists determining the assessment pathway of applications to remove native vegetation (DELWP 2017a). However, this is only used in relation to large tree offset requirements, incorporating other data such as tree height and maturity. DBH benchmark

[1] Barengi Gadjin Land Council Aboriginal Corporation, 16a Darlot Street, Horsham Vic. 3400, +613 5381 0977
< ch@bglc.com.au >

[2] Cooper Heritage Management, Horsham Vic. 3400, +61429 360 403
< abby@cooperhm.com.au >

measurements are listed for every large tree species in corresponding bioregional Ecological Vegetation Classes (EVCs) (DELWP 2017b) and are never used to suggest the biological age of individual trees.

Bennetts and Jolly (2017:12) state that it is generally true that the larger the tree's girth, the older it is, although there are many exceptions to these rules. Trunk diameter growth varies, depending on a range of factors including tree species, soil type, climate, rainfall, and tree density. Evidence indicates growth rates of *Eucalyptus* spp. are not linear, changing from height-oriented to width-oriented once trees reach around 15 cm DBH, and with trunk growth declining at a greater rate once matured, after about 100 years (Beesley 1989:12; Bennetts and Jolly 2017:13; Klaver 1998:234). Therefore, making direct correlations between trunk diameter and tree age is problematic. For example, as Roberts and Marston (2011:8) note:

> *Black box trees are assumed to be long-lived; however, only a few have been reliably dated or aged. Two large trees ... with DBH of 65 and 143 cm respectively, were estimated to be about 250 years by radiocarbon dating (George et al. 2005), showing that size is not a reliable measure of age.*

Scientific methods for estimating tree age

CMT research in Australia continues to be undervalued and underrepresented (Dardengo et al. 2019:34; Morrison and Shepard 2013:158; Rhoads 1992:202). The primary reason, according to Morrison et al. (2012:19), is the difficulty in easily assessing the age of CMTs. The only accurate way to determine tree age is through the application of scientific methods, such as dendrochronology and radiocarbon dating (Long 2003:33).

Dendrochronology involves the study of data from ring-tree growth to determine the calendar age of a tree. It is based on the principle that each growth season, a tree will create a new ring that reflects the weather conditions of that season. However, ring counting does not ensure the accurate dating of every ring because '...each ring must be precisely dated to its year of formation before a chronology can be constructed' (Ogden 1978:340).

To assign absolute calendar ages to each ring without error, dendrochronology must account for the occasional presence of 'false rings' (multiple growth layers in a single year) and 'missing rings', known as standardisation (Dietrich and Anand 2019:4815; Leavitt and Bannister 2009:374–375). The frequency of false and missing rings depends on tree species and their climatic environments, with trees not forming annual growth rings when subject to severe climatic conditions, such as drought, or when located on 'sensitive' sites close to their limits of tolerance, such as steep rocky sites, shallow soil profiles and/or with soil moisture stress (Brookehouse 2006:438; Leavitt and Bannister 2009:374–375; Ogden 1978:340). These conditions are common for most Australian trees, making them difficult to age (Dunwiddie and LaMarche 1980:130). Cross-dating or cross-matching ring-tree sequences against other samples provides absolute dating control in these instances, however, in Australia, there is a general lack of regional chronological sequences to facilitate cross-dating (Brookehouse 2006:437; Spry et al. 2020:7).

Radiocarbon helps assign more accurate ages to wood that has not or cannot be effectively dendro-dated because of these issues. One of the main obstacles using radiocarbon dating for CMTs, is that in many cases, part or all of the tree has to be destroyed to obtain an appropriate sample. Tree coring can be used, not only as a method for investigating tree rings, but also to provide wood samples for dating that avoids tree death (Long 2003:33; Morrison et al. 2012: 19; Spry et al. 2020:7). Few examples exist in Australia where these scientific techniques have successfully provided absolute dates for CMTs (Long 2014; Long et al. 2002, 2005; Spry et al. 2020).

One example is located on Wotjobaluk Country. The CMT was a bark removal scarred black box (VAHR 7324-0495) near *Barringgi Gadyin* at *Bogambilor* in Horsham. Tree ring and radiocarbon data were combined, providing an estimated calendar date of 1714±70 BP for the original scar face, meaning it predated European colonisation of the region by at least 52 years (Long et al. 2002:19). This date was estimated by calculating the radiocarbon date for a sample of wood close to the tree centre (330±70 cal. BP, ANU-11816) and then adding tree ring data to obtain an estimate of the calendar date for the weathered scar face (Long et al. 2002:15–16).

Most recent is the investigation of bark removal scarred *Eucalyptus melliodora* (yellow box) CMT from Wiradjuri Country, Lachlan Tablelands, NSW (Spry et al. 2020). This study demonstrates the quality and quantity of information that can be obtained from CMTs using multi-disciplinary recording techniques, including photogrammetry surveys to record the CMT, and Accelerator Mass Spectrometry (AMS) dating of core samples to produce an absolute chronology. Results indicate the cultural modifications occurred after 1950, probably between 1966 and 1973, and the tree was approximately 97–108 years old when it died in 1998–1999 (Spry et al. 2020:14–15). This can be considered a relatively young age considering the tree-girth circumference at 1.7 m HAG was 4.8 m, once again demonstrating the problems with estimating tree age using girth measurements alone.

Growth-rate models

In the absence of scientific dating, growth-rate models have been used to provide relative age estimations for comparable CMTs. Growth-rate models rely upon a wealth of recorded dendrometric and environmental data, historical information, and comparison with known date measurements. The synthesis of this information creates a model where specific data can be extrapolated and correlated to a relative age (Morrison et al. 2012:41–42; White 1998:1).

Although no growth-rate models exist in the Wimmera-Mallee for the three CMT species recorded during the Stage 1 survey, there is a range of excellent models recently collated by Bennetts and Jolly (2017) for each species in the relatively comparable semi-arid environment of the River Murray region. Whilst the large amount of data containing numerous variables makes relevant comparative analyses difficult, Bennetts and Jolly's research is important because it highlights the problem of applying growth models to estimate tree age across different tree species. Bennetts and Jolly (2017) also demonstrate some of the many factors that affect growth rates in the two most common tree species in the Wimmera-Mallee: river red gum and black box. These factors include the effects of crown health (trees with healthy crowns generally had a higher annual increase in DBH than trees with poor crowns), flood frequency (red gum growth rates were affected by flood frequency, but this did not have a significant effect on growth rates of black box) and tree density (Bennetts and Jolly 2017:32–38). Their study also found that red gums grew faster than black box, because red gums are better at modulating their physical environment and resources (Bennetts and Jolly 2017:35). For example, over a seven year period, the mean annual growth rate (measured in change in DBH) for 584 red gum trees was 0.44 cm, whilst for 149 black box trees it was 0.15 cm (Bennetts and Jolly 2017:32) The slow growth rate of black box trees was also noted in a study by George (2004) located on the Chowilla floodplain, Lower Murray River, South Australia, where saplings remained approximately 150 cm high and 2 cm DBH for more than 50 years.

Klaver (1998:234-235) produced a growth-rate model for black box at Overland Corner on the River Murray by recording girth measurements of 12 trees with known ages, dated by recorded flood events to calculate radial growth per year for each tree. Klaver's (1998:234) results suggest black box trees in riverine environments with circumferences at breast height less than 1.5 m were unlikely to be sufficiently old to be related to traditional Aboriginal land use. However, Klaver (1998:234) recognises the model's limitations including small sample size, non-scientific absolute dating method, reliance on a single dendrometric measurement to calculate annual radial growth, and the presumption of linear growth. These limitations are highlighted when the model is applied to her survey results. Klaver (1988:236) claims that according to this model, six of the 155 black box CMTs recorded during her survey are too young to be of Aboriginal origin. However, she points out that other observational data collected from these trees, such as axe marks, indicate that all of them are likely to be Aboriginal CMTs (Klaver 1998:236).

These examples illustrate the main issues using comparative growth-rate models for estimating CMT age. Each model must be considered specific for each tree species and environmental context because of the various factors affecting individual trunk-diameter growth. They should be developed over time and well established for each tree species and relevant bioregional EVC before they can be used reliably. Therefore, archaeologists must be cautious applying comparative data from these models, as there are numerous variables to be considered and understood.

Survey area

Stage 1 of the LWRAW project involved four targeted archaeological surveys of Crown land within the Native Title determination area of the Wotjobaluk, Jaadwa, Jadawadjali, Wergaia and Jupagulk Peoples (the peoples of the Wotjobaluk Nations). The survey area comprised approximately 28.5 km of the riparian zone and floodplains along Outlet Creek (*Kromelak*), encompassing the northern extension of *Barringgi Gadyin* between Lake Hindmarsh (*Guru*) and Lake Albacutya (*Ngalpakatia/Ngelpagutya*) (**Figure 1**).

The survey area is covered by an Indigenous Land Use Agreement (ILUA) between the Wotjobaluk Peoples and the Victorian and Federal Governments and jointly managed as a national park reserve by BGLC and the Department of Environment, Land, Water and Planning (DELWP), through Parks Victoria (PV). The natural resources of the entire *Barringgi Gadyin* catchment area (Wimmera-Avon Catchment Basin) are managed at a broader level by the WCMA (BGLC 2017:7-8; BGLC 2020; WCMA 2020a, 2020b).

Landform, climate and vegetation

The landscape surrounding the survey area comprises gently undulating dunefields, floodplains and alluvial plains, lakes, lunettes, and elongated dunes. The area is classified as belonging to the North Western Dunefields and Plains (DP) tier-one geomorphic unit (GMU), which occurs in the western part of the Murray Basin Plains, submerged by Late Tertiary seas (Agriculture Victoria 2020). The centre and north of this GMU is known as the Mallee, whilst the south is known as the Wimmera. Subsequently, the landscape is divided into two landform regions. These are generally known as the Mallee Dunefields, formed primarily by aeolian sediment redistribution processes in the mid-late Pleistocene to Holocene periods; and the Wimmera Plain, created by the deposition of Loxton/Parilla Sands

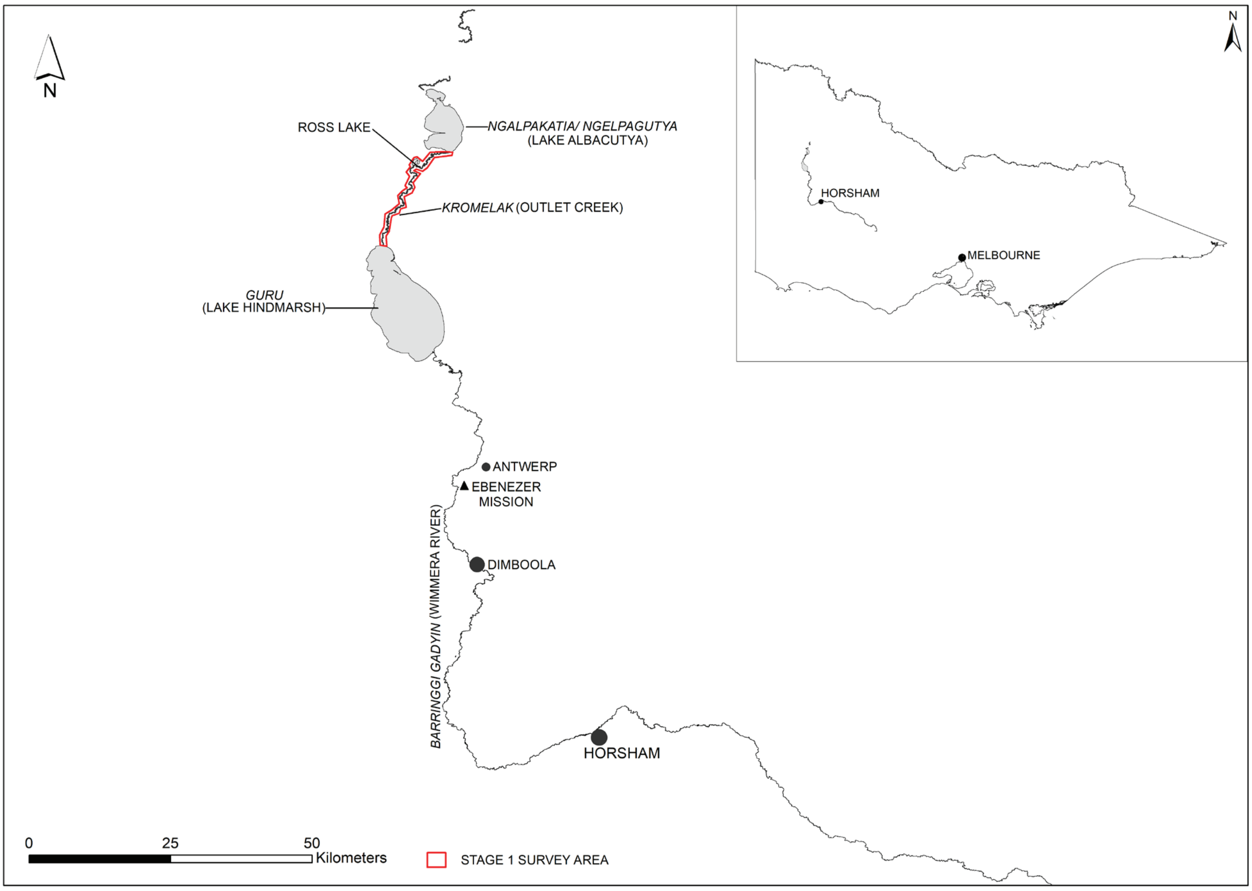


Figure 1. Stage 1 survey area, Targeted Archaeological Survey, Lower Wimmera River Aboriginal Water Project. Drawn by A. Cooper

during inundation and subsequent gradual shoreline retreat following sea level changes between 6 and 2 million years ago (Agriculture Victoria 2020; Bowler et al. 2006; MCMA 2018:16-17). Overall, this landscape is commonly referred to as the Wimmera-Mallee.

The Wimmera-Mallee's climate is semi-arid, ranging from almost arid in the north to sub-humid in the south. Average annual rainfall ranges from 1,000 mm in the south to 300 mm in the north (Agriculture Victoria 2020; WCMA 2020c). Rainfall is low and unreliable in the study area. The average maximum temperatures at the nearest recording station at Rainbow range from 14.4^{o}C in July to 30.8^{o}C in January, whilst temperatures of up to 46^{o}C have been recorded during summer (Cibilic and White 2010:43). Optimum temperatures for plant growth occur mainly in early autumn and late spring.

Before European interference, the vegetation of the Wimmera-Mallee was a diverse, complex mosaic of ecological communities and habitats, including riverine forests and woodlands; plains grassy woodlands; Mallee Dunefield shrublands, heathlands and woodlands; non-eucalypt lunette woodlands; and herblands surrounding ephemeral lakes and wetlands (Agriculture Victoria 2020; WCMA 2020c; MCMA 2018:17).

Eucalyptus largiflorens (black box) and *Eucalyptus camaldulensis* (river red gum) are the main large tree species of the Pre-1750 EVC 813 'Intermittent Swampy Woodland' (Murray Mallee Bioregion). This EVC was distributed along the floodplains, terraces and lacustrine verges of *Kromelak*, *Guru* and *Ngalpakatia/Ngelpagutya* before European contact (DELWP 2019a, 2019b; DSE 2005). The elevated riverine terraces surrounding *Kromelak* and Ross Lake supported another Eucalypt woodland dominated by black box (EVC 103 'Riverine Chenopod Woodland'). *Eucalyptus macrocarpa* (grey box) is another large tree species found in this environment, although not typical of these EVCs (DELWP 2019a, 2019b; DSE 2005).

Methods

The survey was undertaken over 19 days between June 2017 and July 2019. The primary aim of the survey program was to assess the condition and location of previously recorded Aboriginal places, and record any new Aboriginal places, focusing on areas not previously archaeologically surveyed. Another important aim of the survey was to provide training and field experience for TOs in standard archaeological fieldwork techniques and Aboriginal Victoria (AV) site recording standards. In order to achieve this aim, nine local TOs and one Aboriginal resident participated in the survey.

Three of the participants had existing experience in archaeological site recording gained through employment as field representatives at BGLC and having completed the Certificate IV in Aboriginal Cultural Heritage Management delivered by La Trobe University. The survey and training was led by the authors with the assistance of Dave Johnston (Aboriginal Archaeologists Australia).

A standard archaeological pedestrian survey was employed across the entire activity area, with team members walking parallel to each other as described in Burke et al. (2017:89). The intervals between individual survey members (transect widths) were 20 m, with each surveyor effectively scanning 10 m either side of them. Observational data for each CMT was logged directly onto hard copies of VAHR recording form templates for scarred trees (AV 2019), per AV standards (AAV 2008:78-80). Hard copies of AV's 'Scarred Trees: An Identification and Recording Manual' (Long 2003) were used for reference in the field. Spatial data for each CMT was recorded using Trimble handheld DGPS devices (Juno 5 and GeoExplorer 7), post-processed with Trimble Pathfinder Office software for centimetre-level positioning accuracy.

Data recorded for each CMT included tree species and condition, trunk girth, canopy radius, scar height above ground, scar dimensions (length and width of the dry face), scar overgrowth dimensions (thickness on each side, top and bottom), scar orientation and condition, and the presence of other features, including type, number and pattern of any tool marks, epicormic stems and other modifications. Tree species and girth is analysed in detail below as these relate directly to tree age estimations. However, all of these attributes are relevant, as they should be used in combination to determine if a scar or modification is of Aboriginal origin (Spry et al. 2020:5).

Results

The landscape within the survey area is largely flat and open. Ground surface visibility during the survey, however, was low. This would have affected the identification of Aboriginal places on the ground, but not the standing CMTs. The main obstacle encountered during the survey was the logistics required getting the team in and out of the survey area; a large linear space, with numerous surrounding landowners/managers and limited access points. For this reason, the Stage 1 program was divided in to four separate surveys.

Another obstacle encountered was the relocation of the 96 CMTs previously registered within the survey area, the majority of which were recorded in 1992 as part of the Victorian Archaeological Survey (VAS) program. Information on the original site cards was often too brief and coordinates on the VAHR mostly inaccurate, as these locations were recorded prior to the use of GPS. It was decided a more effective method was to record all CMTs identified within the survey area and undertake a cross-check at the conclusion of the survey to determine which CMTs were already registered on the VAHR.

To determine whether scars or modifications noted on a tree were natural or cultural, the methods outlined in Long (2003) and AAV (2008) were adopted. In addition, these characteristics, and all the attributes recorded as outlined above, were discussed by the survey team to ensure a consultative approach to assessing CMT identification was adopted for each tree. If there was any ambiguity in the scars/modifications, and it could not be stated by all survey team members that they were of definite Aboriginal origin, then the tree was not recorded as a CMT. There were a number of these trees identified, but they were not recorded.

A total of 172 CMTs, 25 low density artefact distributions (LDADs) where there are fewer than 10 artefacts observed in a 10 x 10m area (AV 2014), five earth features (remains of pit-earth ovens with clay ball heat-retainers) and four shell middens were identified during the survey. Place inspections were also undertaken of two known places containing Aboriginal Ancestral Remains. Of the 172 CMTs, 28 had previously been registered on the VAHR. The survey included the re-identification and re-recording of these trees, and the new recording of 144 CMTs. The survey did not re-locate the remaining 68 previously registered CMTs. Therefore, a total of 212 CMTs (144 new and 68 existing registrations) have been recorded in the Stage 1 survey area (**Figure 2**).

CMT species

Analysis of species for CMTs recorded within the Stage 1 survey area revealed black box comprised over half the total number of trees showing evidence of cultural modification, followed by grey box, and then river red gum (**Table 1**). The prevalence of black box, and similar representation percentages for grey box and river red-gum, has been observed in other archaeological surveys conducted in the Wimmera-Mallee (Bird 1990:27; Edmonds et al. 1997; Kamminga and Grist 2000:95-100; Rhoads 1992:207–209; Webber and Burns 2004:39–40; Webber and Richards 2004:56–58, 67).

CMT girth

Analysis of trunk girth for the three CMT species recorded during the Stage 1 survey is presented in **Table 2**. According to the relevant bioregional EVCs (Intermittent Swampy Woodland and Riverine Chenopod Woodland) black box are large trees with a DBH between 40–50 cm or more, and river red gum with a DBH of 70 cm or more (DSE 2005). The average DBH recorded for both these species are well above

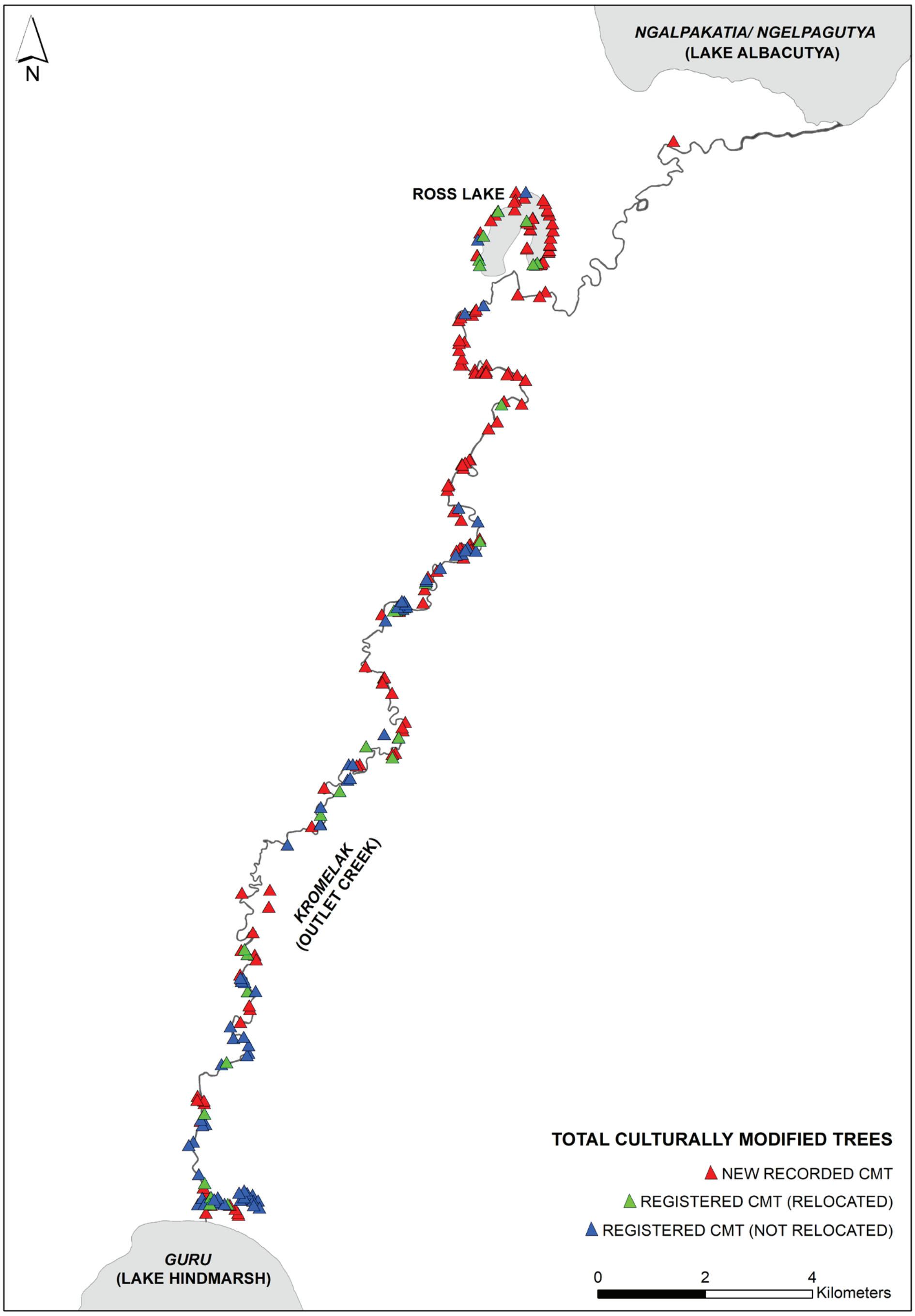


Figure 2. Total number of Culturally Modified Trees in Stage 1 survey area. Drawn by A. Cooper

Tree Species	Number	Percentage
black box	89	51.7
grey box	46	27.0
river red gum	13	7.5
other gum	1	0.6
uncertain	23	13.2
Total	**172**	**100**

Table 1. Species of Culturally Modified Trees within the Stage 1 survey area

these benchmarks, and only a few outliers are smaller.

Klaver's (1998) growth-rate model for black box suggests that CMTs with circumferences at breast height less than 1.5 m are too young to be of Aboriginal origin. Applying this model (and noting its numerous limitations, mentioned above) to the results of the survey would make these few outliers too young. However, these trees are likely to be Aboriginal CMTs based on the other observational data collected, similar to the six outliers in Klaver's (1998:236) survey.

The outliers in both studies may still be old enough to be Aboriginal CMTs, considering the numerous variables influencing trunk size, and more importantly, because the practice of culturally modifying trees has remained a continuing cultural practice amongst the Wotjobaluk Peoples, as it has for other Aboriginal peoples across Australia (Dardengo et al. 2019; Griffin and Cooper 2019; Griffin et al. 2013; Spry et al. 2020).

The results of the Stage 1 survey (**Table 2**) also correlate with previous studies, (e.g. Bennetts and Jolly 2017), which demonstrate that long-lived trees, such as the red gum, have larger average DBH measurements than black and grey box trees, even when subject to similar environmental conditions. Therefore, these results highlight the problem of using growth-rate models to determine the age of trees when recording CMTs, as DBH not only varies between different tree species, but also within the same species, depending on a range of factors discussed above.

Discussion

Despite the problems with tree-girth measurements and growth-rate models, their use to provide an estimate of tree age in CMT analyses persists (Dardengo et al. 2019:41, 54, 56). The notion that there exists a rapid and inexpensive model for estimating the age of CMTs remains seductive for archaeologists struggling to place this site type into a basic temporal context for management, reporting, and registration purposes. For example, one of the essential criteria required to demonstrate the authenticity of CMTs submitted to the VAHR is ' ... the tree must be of sufficient age to carry a scar caused by traditional Aboriginal techniques' (AAV 2008:77). This has perhaps led both the CMT recorder and the assessor to accept the flawed concept that trunk-diameter size is directly related to calendar age.

The results of the Stage 1 survey highlight the inadequacies in adopting this approach to assessing and registering CMTs. Determining whether a tree is of 'sufficient age' is not a simple process that can be undertaken by archaeologists in the field, or assessors in the registry office, using observational measurements alone.

Based on a synthesis of information gathered during the survey and studies referenced in this paper, we propose the following five steps be adopted by archaeologists recording CMTs in Victoria. Incorporating these steps when recording CMTs in the field replaces subjective estimations of tree characteristics with a systematic approach to recording CMT attributes and dendrometric measurements. This quantitative data can be used to compile more scientifically valid records of CMTs and as a meaningful basis for comparative analyses.

1. Record the relevant bioregional pre-1750 EVC category and large tree benchmark DBH measurements for CMT location and species

This information is easily accessible through the DELWP website (DELWP 2019a; DSE 2005) and NatureKit search tool (DELWP 2019b). It would be useful to record this data on the VAHR scarred tree component form because it adds essential contextual information to the observational data recorded for CMTs. Researching pre-1750s EVCs prior to fieldwork can also aid in species identification, although not all species recorded for CMTs are listed in every bioregional EVC. This includes trees that were not indigenous to a study area pre-1750, but are present in a historical or contemporary context, or indigenous species that did not reach a particular EVC benchmark threshold. For example, the grey box CMTs recorded during the Stage 1 survey do not appear in any of the bioregional EVCs listed for the survey area. DELWP (2017a:9) provides recommendations for assessing large trees not listed in the relevant bioregional EVCs.

The effective adoption of this step into routine CMT analyses would benefit from the addition of the pre-1750s EVC to the Aboriginal Cultural Heritage Register and Information System (ACHRIS), thus enabling archaeologists and researchers to export data relating to CMTs in particular EVCs for comparative purposes.

2. Improve the accuracy of CMT species identification

Accurate species identification is important because it forms the basis for all CMT assessments and interpretations, including age estimations and CMT validity. Archaeologists working in the field in Victoria can improve their CMT species identification knowledge by attending native vegetation identification field-trips and information sessions organised through regional DELWP offices, adding the standard published reference guides to their field-kit (e.g. Costermans 2006a, 2006b), and downloading relevant plant databases to devices

Species	Number	Mean circumference (m) (1.5m HAG)	Circumference range (m) (1.5m HAG)	Mean DBH (cm)	DBH range (cm)
black box	81	2.24	0.7–3.4	71.3	22.3–108.2
grey box	42	2.37	1–3.4	75.4	31.8–108.2
river red gum	11	3.56	1.5–5.4	113.3	47.7–171.9

Table 2. Girth measurements for Culturally Modified Trees within the Stage 1 survey area

Figure 3. Dead standing grey box CMT at Ross Lake with 22.3 cm DBH, view looking north-west, 16 June 2017 (Photo: Darren Griffin)

Figure 4. Dying black box CMT at Ross Lake with 31.83 cm DBH, view looking north-east, 16 June 2017 (Photo: Abby Cooper)

Figure 5. Dead standing black box CMT along Kromelak (Outlet Creek) with 42.97 cm DBH, view looking north-west, 1 December 2017 (Photo: Darren Griffin)

Figure 6. Dead standing red gum CMT at Ross Lake with 1.01 cm DBH, view looking east, 16 June 2017 (Photo: Darren Griffin)

used in field recording, such as those of the Royal Botaniocal Gardens Victoria (2020) and the Australian Virtual Herbarium (2020).

Identifying and distinguishing between some tree species can nonetheless remain difficult in the field, even for experienced ecologists and arborists. Two good examples, as noted during the Stage 1 survey, are black and grey box. Some individuals in these species are hard to differentiate, and further complicated in the Wimmera-Mallee by the presence of a hybrid box species. In these instances, samples including seeds, flowers, leaves, and bark can be removed; and a photogrammetry survey of the CMT undertaken, producing a detailed record for subsequent expert analysis. The addition of a tree specialist/aborist is therefore an important inclusion to the field or laboratory team.

3. Improve the accuracy and consistency of girth measurement recording

This study encountered numerous inconsistent girth measurements collected by archaeologists across Australia. These include the circumference at 1.5 m HAG (AAV 2008:79), 1 m (Dardengo et al. 2019:43; Long 2002:20, 26), and chest height, HAG not defined (Klaver 1998:234–235). The units used to present trunk growth rates in Australian models are also inconsistent.

While the current AV standard is presently acceptable, it is recommended that archaeologists move towards consistent girth measurement collection standards. This should comprise DBH (1.3 m HAG), as collected by ecologists in Victoria. This is the universal dendrometric standard for girth measurement. To facilitate this move to consistency DBH (1.3 m HAG) should also be recorded on the VAHR scarred tree component form, and in cultural heritage reports. Archaeologists in Victoria already use DBH when calculating place extent and root protection zones for dead CMTs (AV 2008:78, 82).

The addition and standardisation of this attribute will lead to improved analysis of CMTs with comparable growth-rate models and other dendrometric studies, thereby reducing errors that may occur when converting data. For example, using trunk-girth data from existing VAHR scarred tree registrations that are recorded in metres at 1.5 m HAG for comparison with a growth rate model where girth is presented in centimetres DBH (1.3 m HAG).

4. Increase and improve CMT dating

Estimating CMT biological age using only girth measurements or any set of observational data must cease immediately. Using age estimates based on this data as evidence that a tree is of insufficient age to contain a scar of Aboriginal origin must also cease. As this paper has outlined, archaeologists must be wary of using growth-rate models or any other comparative dendrometric data to estimate CMT age.

Radiometric dating of CMTs should be undertaken more frequently. The Victorian cultural heritage management industry should incorporate this procedure in all relevant projects, as has been done for radiocarbon dating of salvaged archaeological material. The methodology used by Spry et al. (2020) should be considered best practice for recording CMTs and adopted as far as practicable. Essentially this includes photogrammetry surveys, tree coring for wood samples and dendrochronological analysis, and AMS dating.

5. Undertake photogrammetry surveys

Photogrammetry surveys producing 3D models and photorealistic 3D visualisations are the optimal methods for recording highly accurate observational data for Aboriginal cultural heritage, especially CMTs (Almeida and Lovett 2016; Spry et al. 2020) This information can then be examined by other researchers and used for comparative analyses of CMTs. 3D photogrammetry data should become the standard format used in CMT registrations, in addition to photographs and sketches, and uploaded on the VAHR as part of a CMT registration. Photogrammetry also creates a permanent archive of a CMT, which has a finite life span and may be destroyed by fires, deforestation, vandalism and other processes.

Conclusion

This paper has examined the collection and application of tree-girth measurements in estimating tree age and has facilitated a review of some current standard practices and requirements associated with field recording, assessment and registration of CMTs in Victoria following the preliminary results of Stage 1 of the LWRAW Project. The review addresses assumptions regarding the expediency with which observational data is used to estimate the ages of CMTs. Information collected for CMT analysis, as described in this paper, should not be used in isolation to discount the authenticity of a CMT, but instead be combined to undertake a suitable comparative analysis, forming the basis for CMT assessments, interpretations and registrations. The culmination of this review is the presentation of five steps that could be adopted by archaeologists to improve the quality of CMT data collected in the field and subsequent future research.

Acknowledgements

The authors thank the Wotjobaluk Peoples for their participation and support in this project and acknowledge that comments, opinions, and values expressed by individual Wotjobaluk people have been reflected in this paper. In particular, the authors thank the following Wotjobaluk Traditional Owners and Aboriginal participants in the survey: Ben Muir, Aunty

Sandra Knight, Michael Douglas, Belinda Marks, Tyson Secombe, Jordon Secombe, Geoffrey Marks, Tracey Rigney, Gavin Reid, Laurie Norman, Stuart Harradine, Damien Skurrie and Aunty Suzy Skurrie. The authors thank Joel Boyd, Dave Johnston, Dean Robertson, Brandon Galpin, and participating staff from BGLC, WCMA, and PV. We would also like to thank the anonymous reviewers for providing constructive comments and suggestions to the draft of this paper.

Note on terminology

'Wotjobaluk Nations' and 'Wotjobaluk Peoples' are contemporary terms used to collectively describe the Wotjobaluk, Jaadwa, Jadawadjali, Wergaia and Japagulk Peoples (BGLC 2017:7; BGLC 2020). The authors acknowledge that not all people belonging to these five groups agree with the use of this collective terminology.

Wergaia words and names are used according to the orthography in Reid (2007).

References

Aboriginal Affairs Victoria (AAV) 2008 *Standards for Recording Victorian Aboriginal Heritage Places and Objects*. Melbourne: Aboriginal Affairs Victoria

Aboriginal Victoria (AV) 2014 Low Density Artefact Distributions. Retrieved 20 May 2016 from < https://www.aboriginalvictoria.vic.gov.au/sites/default/files/2019-09/Low-Density-Artefact-Distributions-Updated-Recording-Guidelines 20 June 2014.pdf >

Aboriginal Victoria (AV) 2019 Victorian Aboriginal Heritage Register Recording form templates. Retrieved 2 May 2020 from < https://www.aboriginalvictoria.vic.gov.au/sites/default/files/2019-09/Scarred-Tree.doc >

Agriculture Victoria 2020 Victorian Resources Online: 5. North Western Dunefields and Plains (DP). Retrieved 2 May 2020 from < http://vro.agriculture.vic.gov.au/dpi/vro/vrosite.nsf/pages/landform geomorphological framework 5 >

Almeida, F. and T. Lovett 2016 At the distance of a snapshot (well, maybe more than one): Affordable 3D modelling of Aboriginal cultural heritage through photogrammetry. *Excavations, Surveys and Heritage Management in Victoria* 5:35–46

Australian Virtual Herbarium 2020 at < https://avh.chah.org.au/ >

Barengi Gadjin Land Council Aboriginal Corporation (BGLC) 2017 Growing What is Good Country Plan: Voices of the Wotjobaluk Nations. Wotjobaluk, Jadawadjali, Wergaia, Jaadwa and Jupagulk Peoples. Unpublished report prepared by Barengi Gadjin Land Council Aboriginal Corporation

Barengi Gadjin Land Council Aboriginal Corporation (BGLC) 2020 Native Title. Retrieved 1 May 2020 from < https://www.bglc.com.au/native-title >

Beesley, J. 1989 The Scarred Tree: A Project for the Victoria Archaeological Survey. Unpublished report prepared for the Victoria Archaeological Survey

Bennetts K. and K. Jolly 2017 Gunbower Forest Tree Assessment 2005–2017: a review of demographic and condition data for Red Gum, Black Box and Grey Box populations. Unpublished report prepared for the North Central Catchment Management Authority.

Bird, C. 1990 Aboriginal sites in the Horsham region. A report prepared for the Victoria Archaeological Survey. Unpublished report prepared for the Victoria Archaeological Survey

Brookhouse, M. 2006 Eucalypt dendrochronology: Past, present and potential *Australian Journal of Botany* 54:435–439

Bowler, J., A. Kotsonis and A. Lawrence 2006 Environmental evolution of the Mallee region, Western Murray Basin. *Proceedings of the Royal Society of Victoria* 118(2):161–210

Burke, H., M. Morrison and C. Smith 2017 *The Archaeologist's Field Handbook: The essential guide for beginners and professionals in Australia.* 2nd edition. Crows Nest, NSW: Allen and Unwin

Cibilic, A. and L. White 2010 Ecological Character Description for Lake Albacutya, a Wetland of National Importance. Unpublished report prepared for the Department of Sustainability, Environment, Water, Population and Communities

Costermans, L. 2006a *Trees of Victoria and Adjoining Areas*. 6th edition. Frankston, Vic.: Costermans Publishing

Costermans, L. 2006b *Native Trees and Shrubs of South-Eastern Australia.* 6th edition. Sydney, NSW: Reed New Holland

Dardengo, M., A. Roberts, M. Morrison and the River Murray and Mallee Aboriginal Corporation 2019 An archaeological investigation of local Aboriginal responses to European colonisation in the South Australian Riverland via an assessment of culturally modified trees. *Journal of the Anthropological Society of South Australia* 43:33–69

Department of Environment, Land, Water and Planning (DELWP) 2019a Bioregions and EVC Benchmarks. Retrieved 3 May 2020 from < https://www.environment.vic.gov.au/biodiversity/bioregions-and-evc-benchmarks >

Department of Environment, Land, Water and Planning (DELWP) 2019b NatureKit Victoria. Retrieved 3 May 2020 from < http://maps.biodiversity.vic.gov.

au/viewer/?viewer=NatureKit >

Department of Environment, Land, Water and Planning (DELWP) 2017a Guidelines for the removal, destruction or lopping of native vegetation. Melbourne: The State of Victoria, Department of Environment, Land, Water and Planning. Retrieved 3 May 2020 from < https://www.environment.vic.gov.au/ data/assets/pdf file/0021/91146/Guidelines-for-the-removal,-destruction-or-lopping-of-native-vegetation,-2017.pdf >

Department of Environment and Land Water and Planning (DELWP) 2017b Biodiversity information explanatory document: Measuring value when removing or offsetting native vegetation. Melbourne: The State of Victoria, Department of Environment, Land, Water and Planning. Retrieved 3 May 2020 from < https://www.environment.vic.gov.au/ data/assets/pdf file/0025/91267/Biodiversity-information-explanatory-document-Measuring-value-when-removing-or-.pdf >

Department of Sustainability and Environment (DSE) 2005 EVC/Bioregion Benchmark for Vegetation Quality Assessment, Murray Mallee bioregion. Retrieved 3 May 2020 from < https://www.environment.vic.gov.au/ data/assets/ pdf file/0026/48734/MuM EVCsombined.pdf >

Dietrich, R. and M. Anand 2019 Trees do not always act their age: size-deterministic tree ring standardization for long-term trend estimation in shade-tolerant trees. *Biogeosciences* 16:4815–4827

Dunwiddie, P.W. and V.C. LaMarche Jr 1980 Dendrochronological characteristics of some native Australian trees. *Australian Forestry* 43(2):124–135

Edmonds, V., A. Long and P. Schell 1997 The Wimmera River Cultural Heritage Study Stage 1: The Upper Wimmera Basin. Unpublished report prepared for Goolum Goolum Aboriginal Cooperative, Horsham

George, A.K. 2004 Eucalypt regeneration on the Lower Murray floodplain, South Australia. Unpublished PhD thesis, University of Adelaide

George, A.K., K.F. Walker and M.M. Lewis 2005 Population status of eucalypt trees on the River Murray floodplain, South Australia. *River Research and Applications* 23:271–282

Griffin, D., D.L. Freedman, B. Nicholson Jnr, F. McConachie and A. Parmington 2013 The Koorong project: Experimental archaeology and Wurundjeri continuation of cultural practices. *Excavations, Surveys and Heritage Management in Victoria* 2:57–67

Griffin, D. and A. Cooper 2019 'Scarred for Life:' A preliminary comparative functional analysis of culturally modified trees at Kromelak (Outlet Creek), Ross Lake and northern Guru (Lake Hindmarsh) on Wotjobaluk Country, Western Victoria, Australia. *Journal of the Anthropological Society of South Australia* 43:94–133

Kamminga, J. and M. Grist 2000 Yarriambiack Creek Aboriginal Heritage Study. Unpublished report prepared for Aboriginal Affairs Victoria

Klaver, J.M. 1998 Late Holocene Occupation of the Central Murrumbidgee Riverine Plain. Unpublished PhD thesis, Department of Archaeology and Anthropology, Australian National University

Leavitt, S. and B. Bannister 2009 Dendrochronology and radiocarbon dating: The laboratory of tree-ring research connection. *Radiocarbon* 51(1):373–384

Long, A. 2002 An Assessment of Scarred Trees at Horsham Saleyards, Horsham, Western Victoria. Unpublished report prepared for the Horsham Rural City Council and Goolum Goolum Aboriginal Co-operative

Long, A. 2003 Scarred Trees: An Identification and Recording Manual. Unpublished report prepared for Aboriginal Affairs Victoria

Long, A. 2014 Dating Assessment of Potential Aboriginal Scarred Tree (AC-ST-01), Mangoola Coal, Hunter Valley, NSW. Unpublished report prepared for Glencore Coal NSW

Long, A., A. Thorn and J. Banks 2002 The Origin and Date of Two Scarred Trees at Horsham Saleyards, Horsham, Western Victoria. Unpublished report prepared for the Horsham Rural City Council and Goolum Goolum Aboriginal Co-operative

Long, A., M. Brookhouse and A. Thorn 2005 The origin and date of three scarred trees at Minniedale Road, Loy Yang, Traralgon. Unpublished report prepared for Loy Yang Power Management P/L

Mallee Catchment Management Authority (MCMA) 2018 Mallee Regional Catchment Strategy 2013-2019. Melbourne: Mallee Catchment Management Authority. Retrieved 1 May 2020 from < https://mk0malleecmacomvmcpd.kinstacdn.com/wp-content/uploads/2019/07/MCMA-RCS-13-to-19.pdf >

Morrison, M., E. Shepard, D. McNaughton and K. Allen 2012 New approaches to the archaeological investigation of culturally modified trees: A case study from Western Cape York Peninsula. *Journal of the Anthropological Society of South Australia* 35:17–51

Morrison, M. and E. Shepard 2013 The archaeology of culturally modified trees: Indigenous economic diversification within colonial intercultural settings in Cape York Peninsula, northeastern Australia. *Journal of Field Archaeology* 38(2):143–160

Ogden, J. 1978 On the dendrochronological potential of Australian trees. *Australian Journal of Ecology* 3:339–356

Reid, J. 2007 Wergaia Community Grammar and Dictionary: Consultation Copy. Unpublished report prepared for Barengi Gadjin Land Council Aboriginal Corporation

Rhoads, J. W. 1992 Significant sites and non-site archaeology: a case-study from south-east Australia. *World Archaeology* 24(2):198–217

Roberts J. and F. Marston 2011 *Water regime for wetland and floodplain plants: A source book for the Murray–Darling Basin.* Canberra: National Water Commission.

Royal Botanic Gardens Victoria 2020 Victoria: Flora of Victoria. Retrieved 1 May 2020 from < https://vicflora.rbg.vic.gov.au/ >

Spry, C., E. Hayes, K. Allen, A. Long, L. Paton, Q. Hua, B.J. Armstrong, R. Fullagar, J. Webb, P. Penzo-Kajewski, L. Bordes and Orange Local Aboriginal Land Council 2020 *Wala-gaay Guwingal*: A twentieth century Aboriginal culturally modified tree with an embedded stone tool. *Australian Archaeology* 86:1:3–20

The Australian Virtual Herbarium 2020 Retrieved 1 May 2020 from < https://avh.chah.org.au/ >

Webber, H. and A. Burns 2004 Seeing the forest through the trees: Aboriginal scarred trees in Barrabool Flora and Fauna Reserve. *The Artefact* 27:36–45

Webber, H. and T. Richards 2004 Barrabool flora and fauna reserve Aboriginal heritage investigation and training project. Unpublished report prepared for Aboriginal Affairs Victoria

White, J. 1998 Information Note: Estimating the age of large and veteran trees in Britain. Issued by Forestry Practice. Edinburgh: Forestry Commission. Retrieved 3 May from < https://www.ancienttreeforum.co.uk/wp-content/uploads/2015/03/John-White-estimating-file-pdf.pdf >

Wimmera Catchment Management Authority (WCMA) 2020a Rivers & Streams. Retrieved 1 May 2020 from < http://wcma.vic.gov.au/rivers-and-streams >

Wimmera Catchment Management Authority (WCMA) 2020b About Us: What does Wimmera CMA do? Retrieved 1 May 2020 from < http://wcma.vic.gov.au/about-us/WhatWCMAdo >

Wimmera Catchment Management Authority (WCMA) 2020c About Us: Our Region. Retrieved 1 May 2020 from < http://wcma.vic.gov.au/about-us/Region >

Results of recent archaeological investigations at Pejark Marsh in Western Victoria

Asher Ford, Jocelyn DeJong Strickland and Linda Sonego

Abstract

This paper discusses recent archaeological investigations at Pejark Marsh which have re-examined earlier 20th Century archaeological investigations and commentary of the site. A discovery of an Aboriginal stone artefact, interpreted as a millstone and megafauna remains in and directly above nontronite yellow clay, but below volcanic tuff layers at Pejark Marsh, prompted several geological and climatic interpretations of the Pejark Marsh geological sequence . These earlier interpretations have been re-examined in light of recent well-dated pollen sequences revealed from Lake Terang and Pejark Marsh, providing a revised age of between 45 and 51 ka for the tuff layer, and a minimum age estimate for the Aboriginal millstone and megafauna remains.

Recent geotechnical testing indicates that there are likely more variations to the nontronite yellow clay layer than originally uncovered by Gill in 1953 which may reflect that deeper clay profiles are highly localised and represent changes in water levels and outlet locations of the marsh over time. Therefore, while it appears likely that the Aboriginal millstone may be contemporaneous with megafauna remains, the geomorphological processes that formed these deposits requires further investigation. More recent archaeological investigations have identified Indigenous cultural material above the volcanic tuff layer, indicative of later human activity focused on the fresh-water marsh. These recent investigations were limited in depth, not penetrating the tuff layer. Future work should focus on the sequence as a whole, particularly in regards to clarifying the geological and potential archaeological sequence below the tuff horizon.

Introduction

Pejark Marsh is a volcanic maar, a broad low-relief volcanic crater created by magma contacting water-rich sedimentary layers, located on the northeastern outskirts of Terang in Western Victoria. Following the identification of Aboriginal cultural material in 1908 by workers constructing a culvert, Pejark Marsh sparked archaeological interest in the early and mid-20th Century in regards to discussions on the antiquity of man and former climates in Australia (Gill 1953; Keble 1945, 1947; Mahony 1943; Spencer and Walcott 1911). Archaeological investigations have been undertaken in 2019 at Pejark Marsh by GHD on behalf of Acciona, in consultation and with the assistance of the Eastern Maar Aboriginal Corporation. This paper discusses the results of 2019 archaeological investigations, as well as the implications of palynology studies at the marsh (Wagstaff et al .2001) for interpreting the results of earlier studies.

GHD Pty Ltd, Level 9, 180 Lonsdale Street, Melbourne Vic. 3000
asher.ford@ghd.com, jocelyn.dejongstrickland@ghd.com, linda.sonego@ghd.com

Background information and description of Pejark Marsh

Pejark Marsh is one of 40 volcanic maars located on the southern edge of the Western Plains between Colac and Warnambool (Wagstaff et al. 2001:212). Volcanic activity in the area is believed to have started approximately 4.6 ma and has continued up until very recent times. There are few published ages for maars and scoria cones on the Western Plains, but some eruption dates for younger (< 100 ka) maar and scoria cone formations have been bracketed through radiocarbon or optically-stimulated luminescence (OSL) dating of the sediments overlying and underlying volcanic ash or tuff layers (Matchan et al. 2016:176).

Maars are low-relief volcanic craters caused by phreatomagmatic eruptions where rising magma has come into contact with surface water. They are usually surrounded by tuff rings, the result of rapid cooling of volcanic ash by water (Rosengren 1994). The typical bowl-shaped crater with a low rim of maars can be formed within a minute or up to half an hour (Nunn et al. 2019:1619). The majority of maars in the region are complex maar-scoria formations, for example, the scoria cone complexes of Mount Noorat and the Terang Township, located to the north and south of Pejark Marsh respectively (**Figure 1**). Pejark Marsh is rare in that it is a simple volcano, along with nearby Lake Keilambete (Boyce 2013:453, 457).

Pejark Marsh is more or less circular in shape with a northern protrusion and is surrounded by a wide

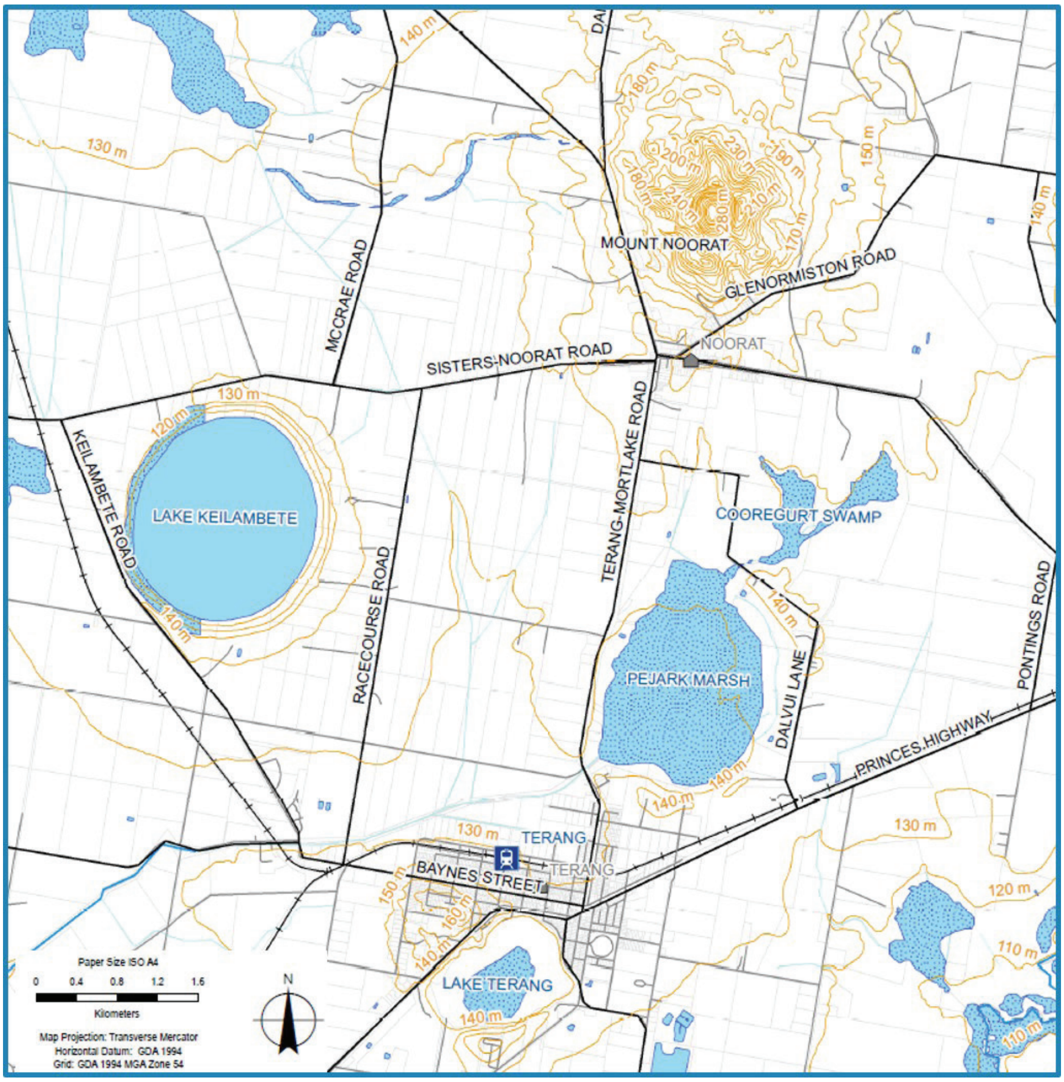


Figure 1. Pejark Marsh and surrounds

but shallow crater that evens out into the surrounding plains. The inside slope of the maar rim is reasonably steep at approximately 30 degrees. There are currently no streams flowing into the maar, but it does join with Cooregurt Swamp to the north and appears to have had an outlet to the southwest. Before European settlement, the marsh was a fresh-water swamp with a dense cover of *Leptospermum* tea tree scrub, surrounded by open eucalypt woodland (Keble 1947: 48; Wagstaff et al. 2001:213). In the early 1890s, vegetation was cleared and the marsh was drained via a series of channels (Spencer and Walcott 1911:93). The present-day vegetation in the area is largely open farmland and pasture for stock grazing (Wagstaff et al. 2001:213).

Pejark Marsh Archaeological Site

Pejark Marsh was a location of archaeological, geological and paleontological interest to the National Museum of Victoria (now Museums Victoria) during the early to mid-20th Century (Spencer and Walcott 1911; Keble 1947; Gill 1953), largely focused on the southwest outlet area (**Figure 3**). A review of these twentieth century studies including excavations undertaken by Spencer and Walcott (1911) and geological interpretations for the antiquity of Aboriginals in Australia (Keble 1947; Gill 1953), provides crucial information about the geology and history of settlement in the area.

Archaeological interest was sparked when in 1908, a local Terang resident, A. J. Merry, found what he believed to be an Aboriginal stone artefact in deep clays, while undertaking excavations for a culvert over the southwestern channel outlet at Pejark Marsh. Merry reported the find to the National Museum of Victoria, noting that the artefact was found within a yellow clay layer approximately 2.5 m below ground. He further stated that numerous megafaunal remains were located between the yellow clay and an overlying black clay (Keble 1947). A photograph of the stone artefact published in an article by Mahoney (1943), as shown in

Figure 2, and was characterized as a quartzite millstone.

Subsequent excavations by Spencer and Walcott (1911:93) in 1908 encountered variation in the depth of the stratigraphy, due to variation in the underlying clays and deposits. In one area they reported about 3 ft (0.9 m) of heavy black alluvial soil, 18 inches (0.45 m) of volcanic tuff and 5 ft (1.5 m) of black clay, overlying a yellow clay. Near the culvert that drained the marsh and the location of the millstone, the underlying clay was more like 'a few hardish, brown, ironstone nodules' (Spencer and Walcott 1911:93) rather than yellow clay. Further west there was a thinner layer of black clay and between the black and yellow clays there was a nodular cement. Spencer and Walcott (1911:93) found a few bone fragments in the thin layer of black clay, but all the remaining bones were found where the black and yellow clay layers met. The bones were found to have been modified by large animals, quite possibly by *Thylacoleo,* with no evidence for human involvement (Spencer and Walcott, 1911:103).

Mahony (1943) would later describe Pejark Marsh in a broader review of archaeological sites across Australia, while building an argument for a multi-phased Aboriginal occupation of Australia. He noted that:

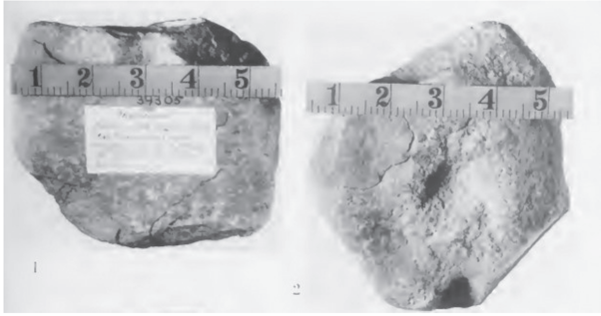


Figure 2. Quartzite millstone from Pejark Swamp top and base views (reproduced from Mahony 1943)

> ... *many claims for antiquity of man in Australia have been based on artefacts found, or alleged to have been found, in consolidated dunes, beneath lavas or tuffs of the Newer Volcanic period, in beds containing bones of extinct marsupials, associated with raised shorelines, or buried beneath alluvium (Mahony 1943:23).*

Mahony (1943:23–40) discussed both academic and amateur finds of Aboriginal cultural material in Australia in the context of developing geological and

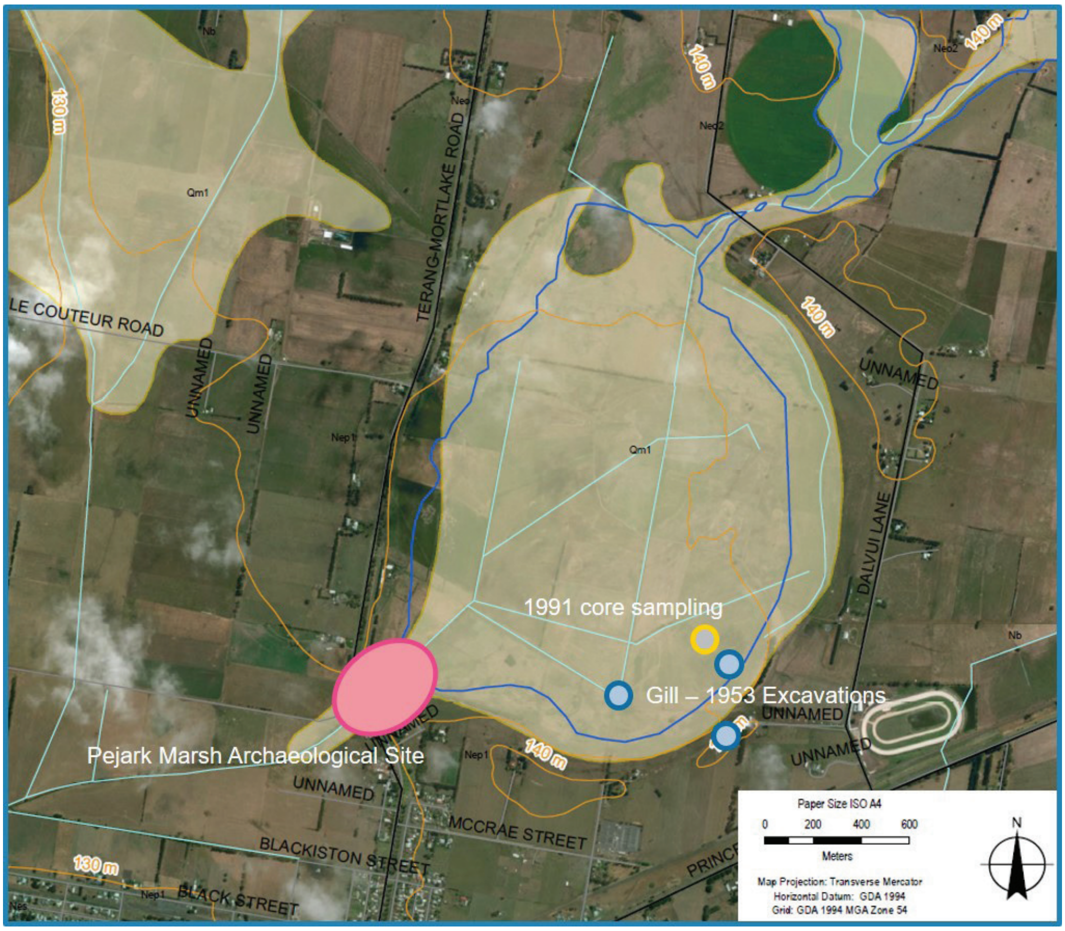


Figure 3. Locations of previous investigations at Pejark Marsh

climate interpretations, including the Wellington, Talgai, Tartanga, Devon Downs, Keilor, Aitape, Tower Hill, Myrniong Creek, Perjark Marsh and others. In the case of Pejark Marsh, Mahony (1943:39–40) described the finds by Merry and the results of the excavations by Spencer and Walcott. Mahony (1943:44) suggested that the Pejark Marsh site required further investigation and broadly concluded that Aboriginal arrival in Australia was likely to date to the Pleistocene and was 'certainly ancient in the historical and almost certainly the geological sense'.

Following Mahony's review, Keble (1947) undertook further archaeological investigation at Pejark Marsh, focused on verifying the original accounts of Merry and another local informant, Harvie, as well as confirming the results of Spencer and Walcott's excavations. In reviewing Merry's account, Keble was most interested in confirming the provenance of the millstone. Merry stated in correspondence to the Museum in 1909 that:

> *The implement was embedded with the bones in the yellow clay, it was impossible for it to have fallen in from the overlying beds and I was very careful with it, as when I struck it with the shovel I thought it was a large bone, and wanted to get it out without breaking it. It was 3 feet in from the bed of the drain, and 2 feet below same in the solid clay under sandstone 3 feet in width which I had cut away (Keble 1947: 47).*

Keble further summarises Merry on earlier finds by Harvie:

> *Mr R. Harvie, one of the men worked in the opening of the drain in the first place, informed Mr Merry that he dug up a stone implement, said to be a grindstone, about a chain below the culvert, 9 feet from the surface, which is about the top of the yellow clay, and 4 feet below the 'sandstone'. (Keble 1947:47).*

Keble also relates another find of a stone axe by Merry while excavating for the culvert:

> *Whilst removing some clay I had previously thrown out from the excavations I came on another broken implement, this time of a dark blue colour ... I missed seeing it when I first threw it out, I think it must have been in a big spit, and the clay all round it hid it from view (Keble 1947:47).*

Merry was unsure of the provenance of this second artefact, only that it was from below the 'sandstone', i.e. the volcanic tuff. Keble concluded that he found no reason to dispute the authenticity of Merry's account, as he was reliable witness and had no personal interest attached to the discovery. However, Keble (1947) dismissed the importance of the stone axe as it was not located in situ.

Keble excavated near Merry's original find and encountered stratigraphic profiles and fragmented megafauna remains similar to those described by Merry, Spencer and Walcott. Based on his interpretations of climate and nearby volcanic activity, Keble estimated that the Pejark Marsh upper tuff and underlying black clays, which also contained volcanic materials, likely accumulated 2,000 years ago (Keble 1947:45). Keble further suggested that the texture of the yellow clay suggested that it had accumulated from airborne material during the arid period of the last Postglacial Optimum. These geological and climatic interpretations led Keble to argue that Pejark Marsh millstone probably less than 3,000 years BP in age, relating to the Holocene (1947:50).

Gill (1953:64) also visited Pejark Marsh, building on Keble's investigations to further describe geological evidence in Western Victoria. His investigations at Pejark Marsh focused on further investigations into the extent and age of the volcanic tuff and the underlying yellow clay layer. Gill undertook a further three excavations near the drainage channel in the south-eastern margins of Pejark Marsh (**Figure 3**) and confirmed the presence of what he referred to as 'Terang Tuff' in these areas, however he was uncertain of its northern extent.

The stratigraphy uncovered during excavations in the southeast corner of Pejark Marsh were c. 15 cm (6 inches) of black peaty loam over the same amount of dark grey to black silty clay with pond snails (*Lenameria sp.*). The dark grey to black silty clay was found over a brownish tuff with a type of bacteria (*Coxiella sp.*), but this layer of brownish tuff layer was not penetrated (Gill 1956:66). Gill summarised archaeological investigations prior to 1953 and developed a geological profile that reflected the result of his (1953:63) and earlier excavations (Spencer and Walcott 1911; Keble 1947).

From a depth of 0–0.9 m the soil profile sequence consisted of black alluvium sticky clay. 0.9–1.5 m the soil profile is predominantly 'Terang Tuff'. 1.5–3.3 m a second band of black alluvium sticky clays occurs. 3.3–4.3 m nontronite sulphuric yellow clay is present. 4.3–5.3 m a reddish hard pluvial clay occurs. Lastly, from 5.3 m onwards a soft water baring stratum is present (Gill 1953:63).

In attempting to interpret the geological profile of Pejark Marsh, Gill (1953:66) speculated that both Lake Terang and Pejark Marsh were relatively young because they were fresh-water marshes. This was based on the contemporary understanding that salt accumulates over time and is derived from cyclic salt, that is salt from water that is transported by wind and deposited by rain. Gill (1953:62) further surmised that the tuff encountered at Pejark Marsh was probably associated with the Lake Terang maar eruption, approximately 1.6 km south of Pejark Marsh. The lack of additional sediment mixed in with the tuff layer also suggested to Gill (1953:62) that the tuff remains where it was deposited. He interpreted the upper sedimentary layers, black alluvium and tuff layers as likely dating to the Upper Holocene.

The lack of aeolian deposits at Pejark Marsh was also noted, and Gill (1953:70) interpreted a layer directly above the yellow clay as an eroded layer of the same clay. This theory was informed by laboratory tests of the yellow clay, which indicated that it was nontronite which develops under stagnant water-reducing conditions. Gill (1953:63–68) concluded that the bone fragments of the megafauna formed a cluster from an earlier bed that rested on top of the yellow clay that was deposited after the mid-Holocene arid period. As the millstone had been recovered from the yellow nontronite clay, Gill (1953:63, 69) concluded the millstone was likely to be from either the Early Holocene or late Pleistocene.

It should be noted that both Keble and Gill investigated and wrote about Pejark Marsh in the context of addressing broader research questions of the time, such as the antiquity of Aboriginal Australians using geological information. Walcott, Keble and Gill all held geological positions at the National Museum of Victoria. Interest in Pejark Marsh appears to have diminished with the introduction of direct dating techniques, of which Gill was an earlier adopter and academic interests shifted to other sites in Australia once these technologies become available (Spriggs 2020). While testimony from Merry and Harvie suggest that Aboriginal people were contemporary with megafauna at Pejark Marsh, the lack of overlap between megafauna and cultural material in any of the subsequent excavations by Spencer and Walcott, Keble or Gill, is likely to have dampened interest in Pejark Marsh as a potential research site (Gill 1953:25).

Geological and palynological investigations

Investigations into the geology and palynology of western Victoria continued outside of archaeological concerns in the 20th Century. Studies into the geological age of Pejark Marsh occurred as part of palynological research, with the aim of extending 'the Quaternary record of vegetation and climate within the Western Plains region and to contribute towards the establishment of a Quaternary biostratigraphy for southeastern Australia' (Wagstaff et al. 2001: 211).

The palynological sequence of Pejark Marsh suggests that it was originally an open un-vegetated water basin that was quite deep. It then became shallower with some vegetation, transforming into a swamp with peat deposits followed by a later larger infilling of the crater and an increase in the amount and variation of taxa (Wagstaff et al. 2001:228).

Core samples were taken from Pejark Marsh in 1991 (**Figure 3**) with some sample dated using radiocarbon dating, uranium/thorium (U/Th) disequilibrium dating and zircon fission-track dating. The core sample is significant because it was the first core sample to reach to the bottom of a volcanic crater sequence in Australia (Wagstaff et al. 2001:228).

Analysis of sediment core samples from a depth of seventy metres from the maar surface found that the basal 10 m of sediments were made up of Gellibrand Marl spanning from the Oligocene to Middle Miocene period (Wagstaff et al. 2001:214–215). Directly overlying this layer are 20 m of volcanic sands, which were deposited during volcanic activity in the area when material collapsed from the inner rim of the maar into carbonated shallow water. Above this is a layer consistent with lake deposits ranging from 6.9 to 0.36 m. These deposits are comprised of sandstone and mudstone, peppered with volcanic sands and bands of peat between 24.9 to 24 m and 4.3 m to 3.6 m. A layer of tuff follows the topmost band of peat deposits, the 'Terang tuff' identified by Gill.

Zircon fission-track dating has shown promise for estimating the age of tuffaceous layers that are considered to be geologically young (Wagstaff et al. 2001:213). It was applied to samples at a depth of 63.3 m yielding a date of 980 ± 9 ka. One sample from a depth of 3.1–3.5 m within the capping tuff, the 'Terang Tuff', yielded a date of 740 ± 11 ka (Wagstaff et al. 2001:229). Only one sample from 3.63–3.65 m was datable by U/Th. This layer is just under the Terang tuff layer and was dated to 15 ± 5 ka. Radiocarbon dating of a slightly higher layer, 3.5–3.6 m, yielded results of 45 ka (Wagstaff et al. 2001:215).

Palynological studies have also been used to establish a chronological record of Lake Terang, the eruption point cited as the likely source of the capping tuff at Pejark Marsh (Keble 1947, Gill 1953). While contamination of potential samples has limited radiocarbon dating, D'Costa and Kershaw (1995) correlated the pollen sequence of Lake Terang with the Lake Wangoon, which has a similar regional setting and more continuous pollen sequence that has been reliably dated. D'Costa and Kershaw (1995:65) suggest that the Lake Terang sequence has a basal age of 51,000 BP.

While the zircon fission-track and U/Th samples offer wildly different date ranges, the radiocarbon dating at Pejark Marsh correlated with pollen sequences from Lake Terang and Lake Wangoon suggest a date range somewhere between 45 and 51 ka for the Terang Tuff. This estimation would suggest that the geological interpretations made by Keble (1957) and Gill (1953) that the Lake Terang eruption was very recent (i.e. Upper Holocene) are incorrect and that the Terang Tuff and underlying layers likely date to the Late Pleistocene. The yellow clay in which the millstone was located does not correlate to a Holocene arid period as interpreted by Gill.

Recent CHMP investigations undertaken at Pejark Marsh

More recent archaeological investigations in the area of Pejark Marsh mostly consist of assessments for cultural heritage management plans (CHMPs) (Carr 2017, 2018; Ford and Macklin 2019) and salvage excavations (Sonego et al. 2020) (**Figure 4**). Investigations by Carr included archaeological survey and targeted archaeological hand excavation on the maar crest and rim, which had been identified as areas of potential for Aboriginal cultural material (Carr 2017, 2018). Excavations encountered shallow silty clays over a clay base (< 0.4 m), with no Aboriginal cultural material encountered.

Geotechnical testing in the area of the millstone discovery at Pejark Marsh was undertaken by Jacobs (Carr 2018). Testing was executed using push-tube bore holes at five locations searching for the yellow nontronite clay layer described by Gill (1953). Testing identified a high degree of disturbance in the upper stratigraphic layers and a pale brown silty clay layer that Carr suggested correlates to the yellow nontronite clay layer described earlier by Gill. The study recorded the pale brown silty clay being reached at depths varying between 3.5 m and 8 m (Carr 2018).

Ford and Macklin (2019) undertook an archaeological survey on the southern maar crest, inner slopes and maar base. As a result of greater surface visibility, surface artefacts were identified on the lower slopes of the maar and the maar base. A sample 1 x 1 m test pit was excavated near surface artefacts on the lower slopes of maar to 450 mm silty cracking clays, with seven quartz artefacts being recovered. Reflecting on the results of previous CHMP testing (Carr 2017, 2018), difficulties of hand excavation and relevant densities of artefacts being encountered, it was decided to undertake a mechanical test excavation program across the landforms of the maar.

A total of 15 mechanical test trenches (MTTs), 3 x 1.2 m in size, were excavated across the maar. MTTs were situated on the maar rim upper slopes (MTT1 and MTT6), maar rim lower slopes (MTT2 and MTT3), maar base (MTT4, MTT5, MTT10, MTT11, MTT12, MTT13, MTT14, MTT15), maar rim crest (MTT7) and sedimentary plains west of Pejark Marsh (MTT16 and MTT17). Excavations were limited to 2 m in depth, matching the proposed activities being investigated by the CHMP (Ford and Macklin 2019).

In total, 138 flaked artefacts were identified during the surface and subsurface investigations (three surface and 135 subsurface). All artefacts were found in the cracking silty clay layer of the Pejark Marsh maar rim and base, and were found at depths between 0 to 0.7 m. The majority of artefacts were found in the first 0.4 m and no artefacts were found in the tuff layer, which was considered to be a culturally sterile layer. It should be noted that the depth of volcanic tuff deposits underlying cracking silty clays varied across Pejark Marsh (between 0.6 and 1.5 m), with tuff on the slopes having a higher moisture and clay component, compared to tuff deposits on the maar base which are drier and characterised locally as 'Pejark Sandstone'. At no point was the tuff penetrated as excavations were limited to 2 m.

In particular, the previous borehole excavations identified significant variation in the depths (between 3.4 m and 8 m) of Gill's nontronite sulphuric yellow clay around the maar (Carr 2018). A likely explanation for this is that the borehole excavations as well as the discovery of the megafauna and Aboriginal artefacts were located on or near an outlet of Pejark Marsh. The deeper clay profiles may be highly localised and represent changes in water levels and outlet locations of the marsh over time. More definitive research would be required to confirm the age of the yellow clay and potential variations in the sequence.

Higher artefact densities and deeper deposits of silty clay were located on the lower slopes of the maar rim (between 7 and 11.6 artefacts per m^2), which is a sheltered location. Lower artefact densities were encountered on the base (between 2.5 and 3.8 artefacts per m^2) and upper slopes (between 1.1 and 6.9 artefacts per m^2) of the maar rim, which then appear to transition into low density artefact scatters north towards Pejark Marsh and south towards Terang. The low density of artefacts (0.3 artefacts per m^2) recorded on the crest of the maar are consistent with the absence of Aboriginal cultural heritage material encountered by Carr (2017, 2018) who concentrated on testing the upper maar landform.

It was concluded that the places around Pejark Marsh probably represent a low density scatter from movement of Aboriginal people around the marsh and the large artefact scatter found across the crest, upper and slower slope of the southern Pejark Marsh maar rim most likely represents repeat visitation to a sheltered location in close proximity to the marsh. These landforms would have been an ideal location for sheltering as the maar rim is both elevated and in close proximity to food and water resources (Ford and Macklin 2019). Broader testing of the landforms and other inner maar rim locations around Pejark Marsh are recommended in order to test this assumption.

A number of limitations were noted during the CHMP process. These limitations related to difficulties in dry sieving the cracking silty clay layer and the sticky tuff layer. Salvage excavation therefore offered opportunities to further assess the effectiveness of wet sieving versus dry sieving of the cracking silty clay and tuff layers of the marsh rim. It also offered opportunities to gather additional information regarding the stratigraphic deposition of the artefact scatter.

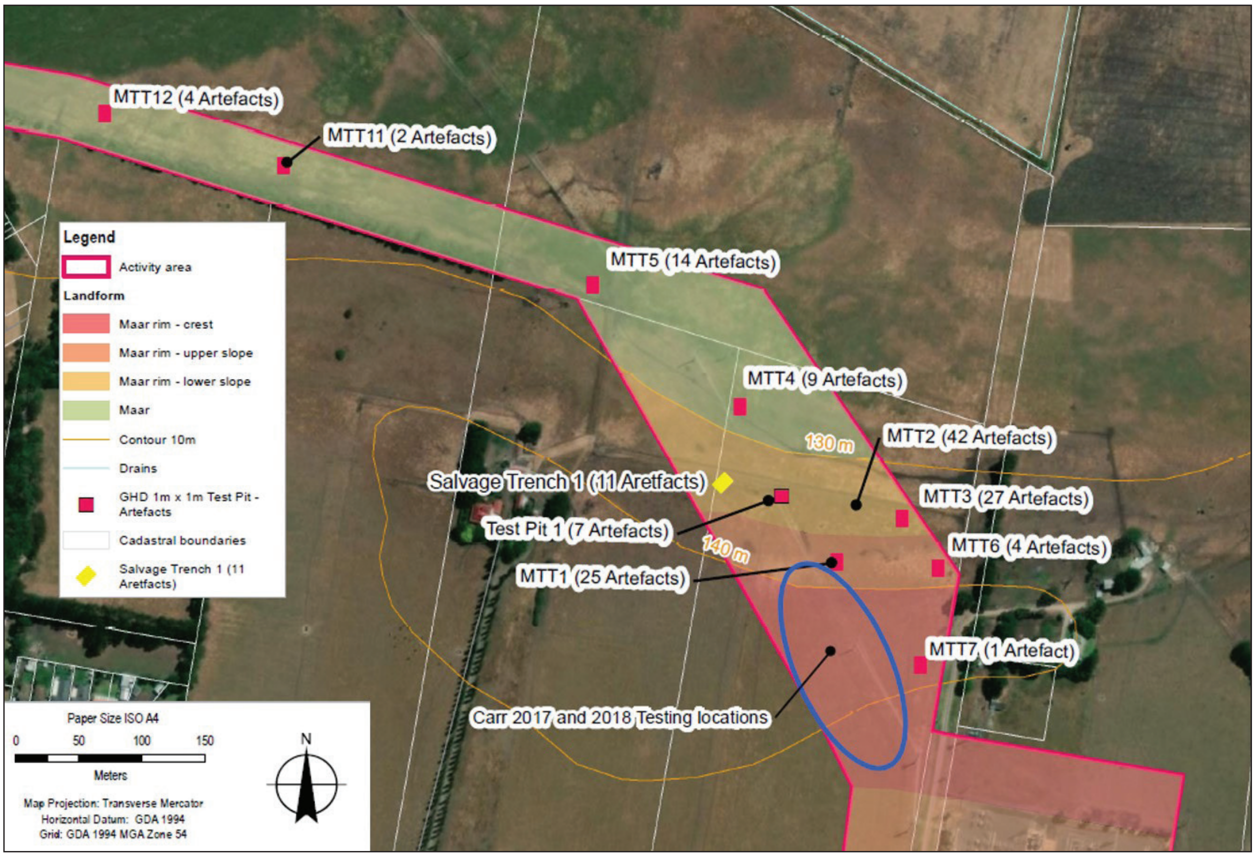


Figure 4. Recent CHMP investigations

A 1.2 x 3 m mechanical test trench was excavated to a depth of 1.5 m on the lower maar rim slope and wet sieved as part of salvage excavations (Sonego et al. 2020). The compact silty clays were very difficult to wet sieve and required high quantities of water; approximately 1000 l for each mud bucket of silty clay and 500 l for each mud bucket of tuff. Despite these limitations, wet sieving was found to be effective at establishing the presence/absence of Aboriginal cultural material, as all excavated material was able to be sieved. Eleven artefacts were found during excavation; all within the cracking silty clay layer between 0.1 and 0.8 m with the majority found in the first 0.4 m. No artefacts were located in the sticky tuff layers, supporting the findings of the complex assessment that this is a culturally sterile layer (Sonego et al. 2020:41).

CHMP (Carr 2017, 2018; Ford and Macklin 2019) and salvage excavations (Sonego et al. 2020) were limited to upper cracking silty clay and tuff layers dating from the present to the Upper Pleistocene (D'Costa and Kershaw 1995; Wagstaff et al. 2001). These limitations were largely a result of negative test results, i.e. artefacts were not encountered, or as a result of the limited depth of the activity (i.e .2 m) for which CHMPs were being prepared. However, the historical evidence indicates that there is further potential for Aboriginal cultural material to be present below tuff layers. Deeper geotechnical testing in the area of the millstone discovery at Pejark Marsh, suggests that soil profiles below the tuff are not uniform across the marsh or its outlet, particularly in regards to the yellow nontronite clay layer described by Gill (1953). This may be the result of highly localized changes in water levels and outlet locations of the marsh over time.

Conclusions

Recent investigations (Carr 2018; Ford and Macklin 2019) largely confirm the upper stratigraphic profile of Pejark Marsh as established in the mid-20th Century (Gill 1953; Keble 1947) but palynological investigations (Wagstaff et all 2001) significantly revise the chronological estimates made by Keble and Gill. The upper capping tuff layer is not as recent as first thought, with a probable date range of 45 to 51 ka (D'Costa and Kershaw 1995; Wagstaff et al. 2001). This also indicates that Gill's nontronite yellow clay deposit, and therefore the Aboriginal millstone excavated by Merry, situated below the tuff, likely date to the Upper Pleistocene.

Recent geotechnical investigations have documented that deeper clay profiles are not uniform. In particular, borehole excavations have identified significant variations in the depths (between 3.4 and 8 m) of Gill's nontronite yellow clay around the maar (Carr

2018). A likely explanation for this is that the borehole excavations, as well as the deeper clays where the megafauna and Aboriginal artefacts were found, are on or near an outlet of Pejark Marsh. The deeper clay profiles may be highly localised and represent changes in water levels and outlet locations of the marsh over time. More definitive research would be required to confirm the age of the yellow clay and potential variations in the sequence.

More recent archaeological investigations have also identified Indigenous cultural material above the volcanic tuff layer (Ford and Macklin 2019; Sonego et al. 2020), while Merry was confirmed to have located an Aboriginal millstone below it (Keble 1947; Gill 1953). The updated chronology for the tuff layer suggests that it separates a Pleistocene sequence, with any underlying deposits of considerable antiquity. Recent archaeological investigations have been limited in depth, not penetrating the tuff layer, and earlier archaeological investigations did not encounter any Aboriginal cultural material (Gill 1953; Keble 1947; Spencer and Walcott 1908). As a result, the geological and archaeological sequence below the tuff layer need further investigation, particularly in regards to teasing out the nature of the deeper nontronite yellow clay and its context.

Acknowledgments

GHD would like to acknowledge that these investigations took place on the traditional lands of the Eastern Maar and would like to thank the Eastern Maar Aboriginal Corporation and field representatives for their knowledge and input. GHD would also like to thank Eastern Maar Aboriginal Corporation and Acciona for permission to publish the material in this paper.

References

Boyce, J. 2013 The Newer Volcanics Province of southeastern Australia: a new classification scheme and distribution map for eruption centres. *Australian Journal of Earth Sciences* 60(4): 449–462

Carr, A. 2017 Salt Creek Wind Farm Transmission line Alignment, Complex Cultural Heritage Management Plan. Unpublished report prepared for Tilt Renewables Pty Ltd

Carr, A., 2018 Mortlake South Transmission Line Alignment, CHMP No. 15195. Unpublished report prepared for AusNet Services

D'Costa, D.M. and A.P. Kershaw 1995 A Late Pleistocene and Holocene pollen record from Lake Terang, Western Plains of Victoria, Australia. *Palaeogeography, Palaeoclimatology, Palaeoecology* 113:57–67

Ford, A. and R. Macklin 2019 Mortlake South Wind Farm Transmission Line, Mortlake Victoria, CHMP No. 16306. Unpublished report prepared forACCIONA Energy Australia Global Pty Ltd

Gill, E.D. 1953 Geological Evidence in Western Victoria Relative to the Antiquity of the Australian Aborigines. *Memoirs of the National Museum of Victoria* 18:25–92

Keble, R.A. 1945 Stratigraphical Range and Habitat of the *Diprotodontidae* in Southern Australia. Proc*eedings of the Royal Society of Victoria* 57:23–48

Keble, R.A. 1947 Notes on Australian Quaternary Climates and Migration. *Memoirs of the National Musuem of Victoria* 15:28–81

Mahony, D.J. 1943. The problem of the Antiquity of Man in Australia. *Memoirs of the National Musuem of Victoria* 13:7–56

Matchan, E.L., E.B. Joyce. and D. Phillips 2016 A new 40Ar/39Ar eruption age for the Mount Widderin volcano, Newer Volcanic Province, Australia, with implications for eruption frequency in the region. *Australian Journal of Earth Sciences* 63 (2):175–186

Nunn, P.D., L. Lancini, L. Franks, R. Compatangelo-Soussignan and A. McCallum 2019 Maar Stories: How Oral Traditions Aid Understanding of Maar Volcanism and Associated Phenomena during Preliterate Times. *Annals of the American Association of Geographers* 109(5):1618–1631

Rosengren, N., 1994 *Eruption Points of the Newer Volcanic Province of Victoria*. Melbourne: National Trust of Australia (Victoria) and the Geological Society of Australia (Victoria Division)

Sonego, L., A. Ford and R. Macklin 2020 CHMP 16306: Salvage Report. Unpublished report prepared for ACCIONA Energy Australia Global Pty Ltd

Spencer, B and R.H. Walcott 1911. The Origin of Cuts on Bones of the Australian Extinct Marsupials. *Proceedings of the Royal Society of Victoria* 24(1):92–123

Spriggs, M. 2020 Everything You've Been Told About the History of Australian Archaeology is Wrong! *Bulletin of the History of Archaeology* 30(1): 3

Wagstaff, B.E., A.P. Kershaw, P.B. O'Sullivan, K.J. Harle and J. Edwards 2001 An Early to Middle Pleistocene palynological record from the volcanic crater of Pejark Marsh, Western Plains of Victoria southeastern Australia. *Quaternary International* 83-85:211–232

Investigating anthropogenic and natural disturbance in Aboriginal archaeological contexts: a case study of sand sheets in southeast Melbourne

Karen Kapteinis[1,2] and Caroline Spry[1, 3]

Abstract

Understanding processes of site formation and disturbance is vital for establishing the archaeological context of Aboriginal places. Post-depositional processes that can impact the integrity of archaeological sites include both anthropogenic and natural factors. The study of particle size distribution of clay, silt and sand, and of the behavioural relationships between stone artefacts throughout a soil profile, provide a means for investigating the stratigraphic integrity of artefact-bearing soils. Particle-size and refit analyses were applied to two soil profiles in sand sheets during a recent salvage excavation program undertaken at an Aboriginal place in Clyde East, southeast Melbourne, to shed light on taphonomic processes that have affected tangible Aboriginal cultural heritage at this location. The first profile reflects natural pedogenic and aeolian processes, whereas the second displays evidence for recent (post-contact) anthropogenic activities. The results of these analyses, together with the observed stratigraphic profiles identified during excavation, provide valuable stratigraphic context for interpreting the nature of Aboriginal occupation in the study area. The results demonstrate the efficacy of this approach for distinguishing between anthropogenic and natural processes of sediment accumulation and reworking which, in turn, provides a more meaningful context for generating behavioural information from the activity traces that Aboriginal people left behind. In doing so, this broadens our knowledge of the interplay between archaeology and geomorphology in sand-sheet contexts of the greater southeastern Melbourne region.

Introduction

Sand dunes, sand sheets and lunettes in Australia have been the focus of many archaeological studies investigating Aboriginal occupation (e.g. Bowler et al. 1970; Coutts 1972; Fitzsimmons et al. 2014; Jankowski et al. 2020; Richards et al. 2007; Thorne and Macumber 1972; Williams et al. 2014). These landforms have been recognised as having a higher potential to contain Aboriginal archaeological sites compared to other landforms due to their elevated, well-drained nature (e.g. Ross 1981; Smith 1991). However, sand dunes and lunettes are dynamic landforms, subject to factors such as wind direction, an available sediment source, and vegetation coverage (Lancaster 2011). These processes act on both the soil profile of the landforms and the regolith below it; as a result, any cultural material deposited on the surface of these landforms will become subject to a particular set of dynamic natural disturbance processes, which are inherent to aeolian environments (Johnson et al. 2008; Schiffer and Rathje 1973).

Because of the particular set of geomorphological processes that affect these aeolian landforms, and by extension the artefacts within them, problems in discerning the stratigraphic context of Aboriginal cultural heritage can occur (Hiscock 1990; Johnson et al. 2008; Peacock and Fant 2002; Stern et al. 2013). It is generally accepted that once an artefact is dropped, it is subject to translocation processes, and to claim an artefact was found in situ requires extensive supporting evidence (e.g. Balek 2002; Fanning and Holdaway 2001; Hewitt and Allen 2010; Hiscock 1990; Stein 1983; Stern et al. 2013). Despite this assumption that no artefact is in situ, it is rare for consultant archaeological investigations in Victoria to assess in detail exactly how post-depositional disturbance has affected an archaeological deposit.

In the Melbourne region, previous archaeological assessments in sandy contexts that include a geomorphological component (Allen et al. 2008; Czastka and Canning 2015; Ellender and Leubbers 2009; Hewitt and de Lange 2007; Light 2010) have focused largely on stratigraphic profiles and geological chronologies, which can prevent a more detailed understanding of site-specific geomorphological processes. Detailed investigations of artefacts struck from the same core or tool are likewise rare. Despite one notable example at Bend Road (Allen et al. 2008; Hewitt and Allen 2010; Hewitt and de Lange 2007), which also involved stone artefact refitting, most investigations make use of geomorphological assessments based on 'naked eye'

[1] Ochre Imprints Pty Ltd, , 33 Johnston Street, Abbotsford, Vic. 3067

[2] Department of Environment, Ecology and Evolution, La Trobe University, Bundoora Vic. 3086

[3] Department of Archaeology and History, La Trobe University, Bundoora Vic. 3086

assessments such as using stratigraphic and regional environmental information to draw conclusions about the taphonomic and geomorphological history of the archaeological context. Such assessments are valuable for interpreting archaeological sites; they provide an additional layer of complexity to what would otherwise be a one-dimensional assessment of stone artefact presence/absence, raw material sourcing and utilisation, and stone artefact use and discard. However, by investigating the role of natural and anthropogenic processes in the formation and modification of a sand sheet, the causes of artefact spatial distribution as well as whether the assemblages reflect Aboriginal occupation or post-depositional events can be better understood.

This paper provides a method for compiling an environmental, post-depositional and archaeological history at a finer resolution; applying particle-size and refitting analyses to two sand-dominated soil profiles in Clyde East, located in the urban growth area to the southeast of Melbourne. Further, a more detailed understanding of what post-depositional processes have affected the stratigraphic profile brings the archaeological signature into focus. This paper presents a particle-size analysis of the different stratigraphic profiles encountered during a recent salvage excavation program; assesses the level of disturbance present within the soil horizons within two excavation pits; investigates the behavioural relationship between artefacts identified in each pit; and adds to our understanding of the interrelationship of the geomorphology and archaeology of the larger southeastern Melbourne region.

Project background

An archaeological salvage program was undertaken to comply with the requirements of previously prepared Cultural Heritage Management Plan (CHMP) 11740 (Dowdell et al. 2018). Commissioned by Balcon Group Pty Ltd, the CHMP was prepared in advance of ground-disturbing activity associated with a proposed residential subdivision (c.131 ha), located across four properties and an adjoining road reserve in Clyde East, 60 km to the southeast of Melbourne CBD (**Figure 1**).

The CHMP assessment identified one Aboriginal place within the activity area: a low-density and widely distributed occurrence of surface and subsurface stone artefacts (LDAD VAHR 7921-1715, n=27). A range of conditions and contingencies formed part of the CHMP, including the requirement for a geomorphologist to undertake a particle-size analysis of the different stratigraphic profiles within salvage excavation pits to assess the level of disturbance of soil horizons.

CHMP 11740 required the excavation of four 3 x 3 m salvage excavation pits (SEPs) on four of the five rises identified during the field survey, all of which contained subsurface stone artefacts (Dowdell et al. 2018:viii–x).

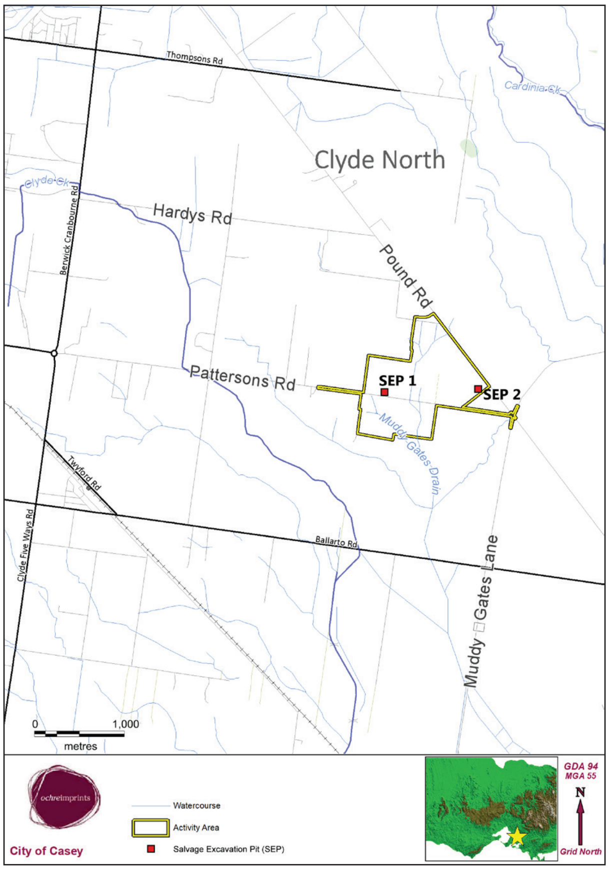


Figure 1. Location of study area and SEPs

The four SEPs were excavated manually in 1 x 1 m grids, with excavation proceeding in spits of 50 mm until an underlying basal layer predating human occupation was reached. All excavated sediments were sieved through 5 mm mesh. All stone artefacts were collected for analysis.

A total of 36 flaked stone artefacts were recovered during the salvage excavation program. These were registered as: a low-density occurrence of 10 subsurface artefacts (LDAD VAHR 7921-1767) and a higher density artefact scatter comprising 26 subsurface artefacts (VAHR 7921-1766). This study focuses on the results of the excavations of Salvage Excavation Pit 1 (SEP 1) and Salvage Excavation Pit 2 (SEP 2). These two SEPs were selected for detailed study as they provided two distinctly different profiles with the potential to provide a deeper understanding of the taphonomic processes acting within the study area. The two SEPs were located approximately 900 m apart on low rises (**Figure 1**).

Regional setting

Physical Environment

Geomorphologically, the study area is located within the Central Sunklands geomorphological subdivision, which comprises a range of landscapes from flat to undulating, on unconsolidated sediments formed over the last 4 million years (VRO 2019). The study area is characterised by a very gently undulating plain on the western edges of the Koo Wee Rup Plain (Spencer-Jones et al. 1975:45). The topography changes little, varying from 20 m above sea level in the north-west to 15 m above sea level in the southeast. The undulating land slopes very gradually to the southeast toward the central parts of the Koo Wee Rup Swamp.

The formation of the landscape in the region was largely driven by climatic changes over the Late Pleistocene and Holocene (120–0.1 ka). The landscape seen at present has formed on a surface of Red Bluff Sandstone, which was deposited in marginal marine conditions during the Neogene (5.8–4.6 Ma) (VandenBerg 2017:12, 17–19). This geological unit dominates the study area, and is comprised of poorly consolidated ferruginous sands, clay and quartz pebble beds (Bell et al. 1967; VandenBerg 2017:9–12). Given its age, this unit has undergone in situ weathering, resulting in the formation of a sand-rich clay regolith (Spencer-Jones et al. 1975:55–60). Developed on this regolith, the soil profile is characterised by acidic mottled yellow duplex soils with a silty A1 horizon overlying a bleached A2 horizon of sandy silt and silty sand. The B horizon comprises mottled yellow and grey, and yellowish-brown clays (Northcote et al. 1975:135–136).

Climatic cycles in the Late Pleistocene and Holocene were dominated by glacial and interglacial periods. Aridification increased from 50 ka onward, culminating in the Last Glacial Maximum (LGM), which lasted until ~18 ka (White and Mitchell 2003:570). During this period, vegetation cover decreased in response to colder and drier conditions, the effects of which destabilised unconsolidated sediments of the upper part of the Red Bluff Sandstone and other older material in the Port Philip Bay and Western Port Basins (Jenkin 1981:39–40). It is suggested that this destabilised material, in particular the sand component, was reworked and mobilised in large volumes to form the siliceous dunes and sand sheets of the Mornington Peninsula (Jenkin 1981:39–40; Keble 1968:50).

Parts of the study area are covered by a mapped deposit of Pleistocene-Holocene age alluvium (Welch et al. 2011). Variably comprised of gravel, sand, silt and clay, this unit typically derives from the local geology, having been transported by water from the surrounding land (Welch et al. 2011). Given these sediments typically originate from the erosion of the surrounding geological units, the soil profiles that developed closely resemble those of the Red Bluff Sandstone, although due to their younger age, they are less developed. However, due to the topographic highs presented across this area, it is likely that this unit may have a veneer of transported sand sheet overlying the deposit. Such soil profiles will typically be comprised of acidic yellow duplex soils with a dark greyish brown sandy silt A1 horizon grading to a slightly bleached A2 horizon, which in turn overlies a strong yellowish-brown B horizon (Northcote et al. 1975:137–138). Where a sand sheet overlies the Red Bluff Sandstone, the soil profile is expected to comprise sandy podosols, which are characterised by a dark grey brown silty sand/sandy silt A1 horizon overlying a bleached sand A2 horizon. Depending on local conditions, a Bhs horizon can form at the interface of the A2 and B horizons, comprising an organic and sesquioxide-rich indurated sand layer or mineral pan, colloquially known as 'coffee rock'. Depending on the depth of the sand sheet, additional sand layers may occur below the Bhs layer, or a clay B horizon may be present (Murphy et al. 2000:135).

Following the end of the LGM around 18–16 ka, an amelioration of environmental conditions occurred (Clark et al. 2009:710). In response to warming temperatures and increases in precipitation, vegetation cover increased, resulting in the stabilisation of sand dunes in the region (Kershaw 1995:655–656). Precipitation and temperatures continued to increase and warm into the Holocene, culminating in the Holocene Climatic Optimum of 9–6 ka (Dodson and Mooney 2002:456; Kershaw 1995:655–656, 667–669; White and Mitchell 2003:570). The wetter conditions promoted the increase of regional water tables, and thus the growth of the local and regional swamps in the low points of the landscape, the largest of which being Koo Wee Rup Swamp to the east and Carrum Swamp to the west.

Gradual aridification occurred at approximately 4 ka onward as the Holocene Climatic Optimum ended in southeastern Australia (Kershaw 1995:669). The decreasing precipitation and lowering of regional water tables resulted in the destabilisation of the landscape in the form of higher erosion rates and the re-mobilisation of dunefields (Dodson and Mooney 2002:457; Kershaw 1995:669). These trends continued into the post-contact period when European agricultural methods were introduced to the Australian landscape (Dodson and Mooney 2002:458). Land clearance, ploughing and urbanisation dramatically altered geomorphic landscapes, which saw order of magnitude changes to erosion and sedimentation rates (Dodson and Mooney 2002:458). In the local region surrounding the study area, widespread stream-channel modification occurred as local farmers tried to control flooding and improve land by draining the low points of the landscape. These land reclamation works began in the 1870s with reclamation of Koo Wee Rup Swamp to the east, and continued locally, as seen by the straight alignment of the man-made Muddy Gates Drain, which bisects the southwestern part of the study area (**Figure 1**).

Previous particle size analysis by Orr (2006) supports the environmental reconstructions undertaken at a broader level. The information provided in the Bend Road investigations showed that sand deposits had been subject to repeated reworking during the Late Pleistocene (Allen et al. 2008; Hewitt and Allen 2010; Hewitt and de Lange 2007), with a period of general landscape stability shown by the slow accumulation of sand and finer particles interrupted by substantial redeposition and reworking of sand during the drier periods at the LGM (Orr 2006).

Archaeology and ethnohistory

Aboriginal people have occupied the region for at least 35,000 years (Allen et al. 2008; Hewitt and Allen 2010; Hewitt and de Lange 2007). Previous archaeological studies suggest that most Aboriginal places that have been documented in the area comprise stone artefacts in surface and subsurface contexts, with occupation typically occurring on either elevated landforms such as sandy rises or within close proximity to perennial watercourses such as Cardinia Creek to the east. Where archaeological deposits have been dated, these generally show cultural material lain down throughout the Holocene, with a mid-Holocene peak (Czastka and Canning 2015; Filihia et al. 2016:11; Murphy and Rymer 2011).

In more recent times, the first Europeans to explore inland and traverse Carrum Swamp were a small group led by William Hovell in 1827, who was met by members of the *Bun wurrung* near Eumemmering Creek. Hovell noted that some of the men and boys present had a front tooth missing, indicating that tooth evulsion was practiced, however, it appears that this practise did not continue long after European contact. An early European settler in the area, Gordon McCrae, recorded that it was common for *Bun wurrung* people in the region to wear 'opossum skin rugs', which were worn with the skin on the inner surface, scored in various patterns and rubbed with red ochre. McCrae also noted that *Bun wurrung* people generally wore forehead bands of netted fibre, often coloured with red ochre, in which they stuck ornamental feathers (Gunson 1968:3–4).

Intertribal relationships with neighbouring groups varied, with the *Bun wurrung* enjoying good relations with the *Woi wurrung*, with whom they shared a similar vocabulary and culture (Broome 2005:xxi; Clark 1990:363). William Thomas, Assistant Protector, witnessed large traditional gatherings between the *Bun wurrung* and the *Woi wurrung* groups where intertribal matters were settled peaceably. Thomas also observed clans living a hunter-gather lifestyle, moving within their lands to make use of seasonal plant and animal resources, trading opportunities and to meet ritual and kinship obligations (Gaughwin and Sullivan 1984; Thomas in Gaughwin 1983:74). Early accounts indicate that the areas along Kananook, Mordialloc and Dandenong Creeks were popular camping places due to the supply of fresh water (Hibbins 1984:12; McGuire 1991:1).

Methods

Particle-size analysis

The particle-size analysis method is used to understand the relative distribution of varying sizes of particles in a sample and is commonly utilised for soil textural analysis (Eshel et al. 2004; Gee and Or 2002). Particle-size analysis, on its own, characterises the size of individual particles in a single particulate sample (Bernhardt 2012). There are multiple methods of particle-size analysis, including pipette methods, nested sieves of differing mesh diameters, hydrometers, and laser diffraction (Eshel et al. 2004). Each method has inherent strengths and weaknesses; this study used laser diffraction, primarily for ease of access and familiarity of the method by the authors. Laser diffraction is commonly used for its ability to provide fast results while only requiring small sample sizes, although there are some disadvantages with costs of the instrumentation (Eshel et al. 2004). Further to this, some misrepresentation of clay and silt fractions can occur in the event the sample is improperly pre-treated to account for aggregation of silt and clays (Eshel et al. 2004; Gee and Or 2002). Despite this, the reliability of accurately determining the various size fractions is increasing (Fisher et al. 2017). As a result, the ability of the instrument to quickly analyse a soil sample and populate a frequency distribution curve that is easily comparable to other samples is of benefit when assessing different soil profiles. When measured in bulk, numerous particle-size distributions can be characterised for a sample and presented as frequency-distribution curves and compared to other comparable samples, with the peak of the curve showing the modal size (Boggs 1987). In plotting the data in this way, the distribution of size particles throughout the sample and the stratigraphic profile can reflect the processes which acted on that material in the past (Lewis 1984:68).

Environmental processes are a significant controlling factor of particle-size distributions. By assessing the particle size distribution of a soil profile, an environmental history can be determined (Folk and Ward 1957; Lewis 1984; Plomaritis et al. 2013). Sedimentary processes such as sorting, deflating/winnowing, and deposition which act on individual particles will, in general, be determined by the size of that particle. Smaller and thus lighter particles have a greater chance of being transported further and more quickly than a larger, heavier particle (Folk 1968; McLaren and Bowles 1985). On this basis, it is known that sediment packages undergoing transport would be better sorted and finer grained than the sediment package left behind, which would be coarser grained and well sorted, with the latter becoming increasingly so with time (Folk 1968; Lewis 1984; McLaren and Bowles 1985). Therefore, by understanding the particle-size distribution of a stratigraphic profile, a conclusion can be made on what processes have acted on that deposit in the past (Folk 1968; Folk and Ward 1957). By extension, in knowing the conditions which would likely have formed a particular profile, it can be possible to identify if and how a profile has been disturbed.

In interpreting the environmental conditions from a particle distribution curve, the skewness and kurtosis (location of the peak along the graph, and how concentrated it is) of that particular sample is key; but note that a series of samples and their particle-size distribution curves for at least one stratigraphic profile is required to make any meaningful conclusions (Folk 1968). Typically, sand dunes which have had particles deposited by saltation (bounding and landing of particles across the surface) and creep (rolling and sliding of particles along the surface) display a bimodal distribution of two peaks along the curve which is negatively skewed (higher proportion of sand particles) (**Figure 2**) (Boggs 1987; Folk 1968; Friedman 1961; Lewis 1984). However, if the dune has been deflated and the finer particles removed leaving a well-sorted lag deposit, the frequency curve will show a unimodal, negatively skewed and often leptokurtic (high concentration of data across a small range) distribution (**Figure 2**) (Barndorff-Nielsen and Christianson 1988; Folk 1968; Friedman 1961; Lewis 1984). Any deviations from these typical frequency curve shapes can therefore indicate the presence of other depositional mechanisms occurring on the deposit.

In this study, soil samples were collected in the field at 100 mm intervals from the soil profile at SEP 1 and SEP 2. In the lab, the soil samples were passed through a 2 mm gauge sieve in order to remove particles larger than coarse sand. The samples were pre-treated by combining 50 g of soil with 50 ml of distilled water and 10 ml of 10% sodium hexametaphosphate (dispersant) and stirred to create a slurry of soil and liquid. The samples were analysed using a Malvern Mastersizer 2000 with pump and stirrer settings on 100%. A sample of the slurry mixture was added to the stirrer well of the instrument and mixed for approximately 30 seconds before being passed into the laser refractive unit for particle-size analysis.

The results of the analysis of each sample were processed into differential volume for each size fraction, which is defined using the Blott and Pye (2012) grain-

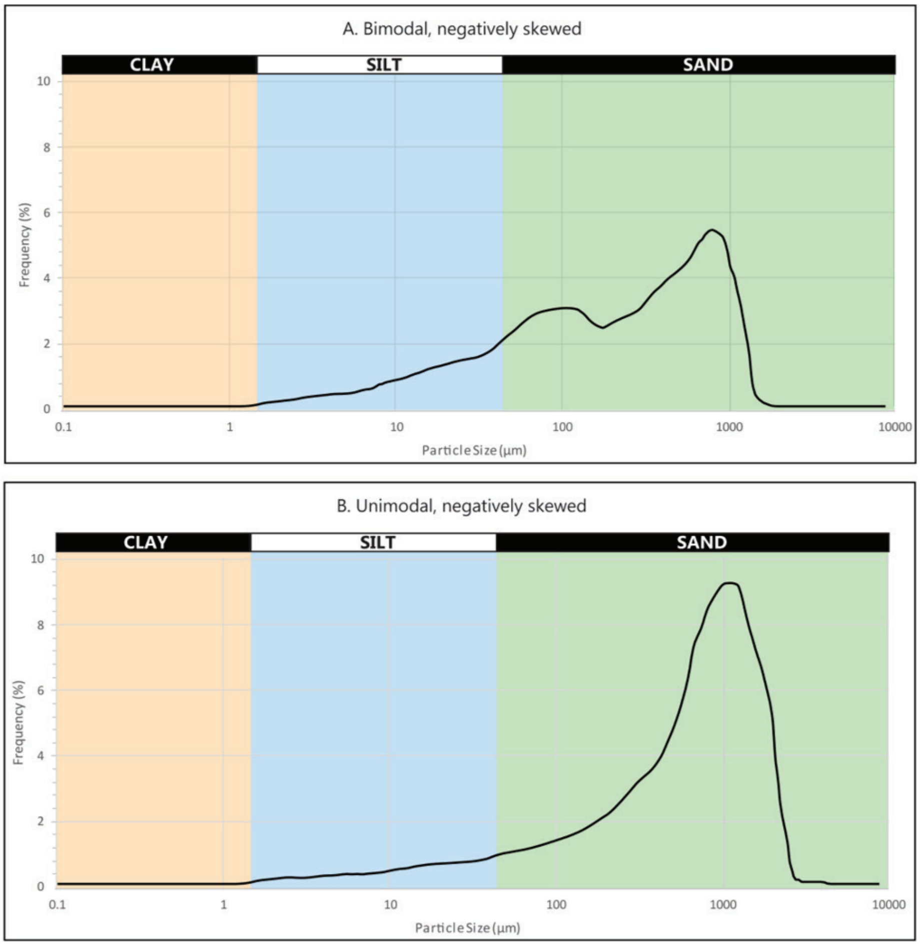


Figure 2. Model particle size distributions showing A) a negatively-skewed bimodal distribution commonly achieved by aeolian sediment transport via bouncing and rolling particles; and B) a negatively-skewed unimodal distribution achieved via deflation of sediment

size classification (clay: 0.01–2 μm; silt: 2–63 μm; sand 63 μm–2 mm) and then graphed logarithmically using Microsoft Excel according to particle-size. Results were grouped on two graphs according to which SEP the samples were derived from to show trends in the particle-size analysis.

Refit analysis and identification of knapping groups

Similar to particle-size analysis, investigation into the presence of artefacts with similar macroscopic and microscopic characteristics ('knapping groups') such as colour and texture, and artefacts that physically refit together ('refits'), in stone artefact assemblages can provide insights into site formation and disturbance (Cahen and Moeyersons 1977; Cahen et al. 1979; Foley et al. 2017; Petraglia 1992; Van Noten et al. 1980; Villa 1982). This analytical technique generates information about the physical and behavioural relationship between individual stone artefacts that were struck from the same piece of rock. In particular, it considers whether stone artefacts making up an assemblage have resulted from one or more stone-working and/or discard 'events'. The presence of knapping groups and refits indicates a common origin for a group of artefacts from the same core or tool. This analytical technique is commonly termed Minimum Analytical Nodule Analysis (Larson and Ingbar 1992; Larson and Kornfeld 1997), or the analysis of raw material units (Conard and Adler 1997; Roebrooks 1988; Roebroeks et al. 1997)—although earlier applications exist (Frison 1974; Kelly 1985).

An assemblage comprising artefacts from a single knapping group, and refits, suggests the working of at least one piece of rock at the same location, most likely during the same stone-knapping 'event'. Conversely, the absence of knapping groups in an assemblage suggests that no two artefacts derive from the same core or tool, and that the assemblage resulted from multiple episodes of stone working and/or discard. However, a scarcity of knapping groups and refits can also be the product of other intersecting processes over long periods of time, including Aboriginal people removing or scavenging stone artefacts from different locations in the landscape, post-depositional processes removing artefacts and reworking assemblages, and post-contact site disturbance. When combined with particle-size analysis, knapping-group and refit analysis is a powerful tool for investigating the nature and likely intactness of a stone artefact assemblage.

Here the investigation of knapping groups and refits followed the techniques outlined in Foley et al. (2017). The first step involves grouping artefacts with similar macroscopic features, including colour, texture, inclusions and cortex. Each knapping group is then assessed for the presence of refits. The process of identifying refits involves the systematic inspection of each artefact of similar colour and texture with all the other artefacts belonging to the same group. An attempt is made to refit each surface of every artefact with each surface of every other artefact from the same group. Where refits are identified, these are joined together using Blu Tack and photographed.

Results

The particle-size distributions, and stone artefact assemblages, for SEP 1 and SEP 2 show different patterns. These patterns are described below.

SEP 2

Particle-size analysis

The particle-size distribution of SEP 2 shows little variation throughout the soil profile, with minor differences likely representing changes in natural formation processes over time. Sand is the dominant size fraction in the soil profile of SEP 1 from 0 to 1600 mm (**Figure 3**; **Table 1**). The distribution of the sand fraction appears to follow two modes; trimodal distribution in the upper 100–900 mm, and unimodal distribution at 0–100m and from 900–1600 mm (**Figure 3**). The trimodal distribution observed between 100–900 mm comprises relatively equal peaks within the fine sand range (~63–140 μm), at the boundary between fine sand and medium sand (~180–320 μm), and in the coarse-sand range (500 μm–2 mm) with all samples negatively skewed. The percentage of sand in this part of the soil profile ranges from 77 to 84% and increases with depth. The distribution of the lower 900 mm and the top 100 mm follows a unimodal, negatively skewed distribution in comparison, with some difference in where each of the peaks fall. The upper 100 mm of the soil profile is dominated by fine sand (67% sand, 33% silt), while the lower 900 mm all have single peaks in the coarse-sand fraction. The percentage of 900–1600 mm sand ranges from 81 to 93%, with an increase down profile. Throughout the profile, the silt component steadily decreases, ranging in percentage from 32% (0–100 mm) down to 4% (1400–1500 mm). At a depth of 1600 mm, sand is removed from the profile and clay increases to 82%, and silt increases to 18%.

Comparison of stratigraphic evidence vs particle-size analysis data

SEP 2 does not contain obvious evidence for disturbance from anthropogenic processes such as earthmoving. Instead, the soil profile is more characteristic of natural processes, both pedogenic and aeolian in nature. The particle-size analysis illustrates two broadly different stratigraphic units; the upper part of the profile between 0–900 mm is much less well-sorted when compared to the lower 900–1600 mm, which is dominated by medium- and coarse-grained sand (**Figure 3)**. This difference indicates two potential periods of sedimentary deposition.

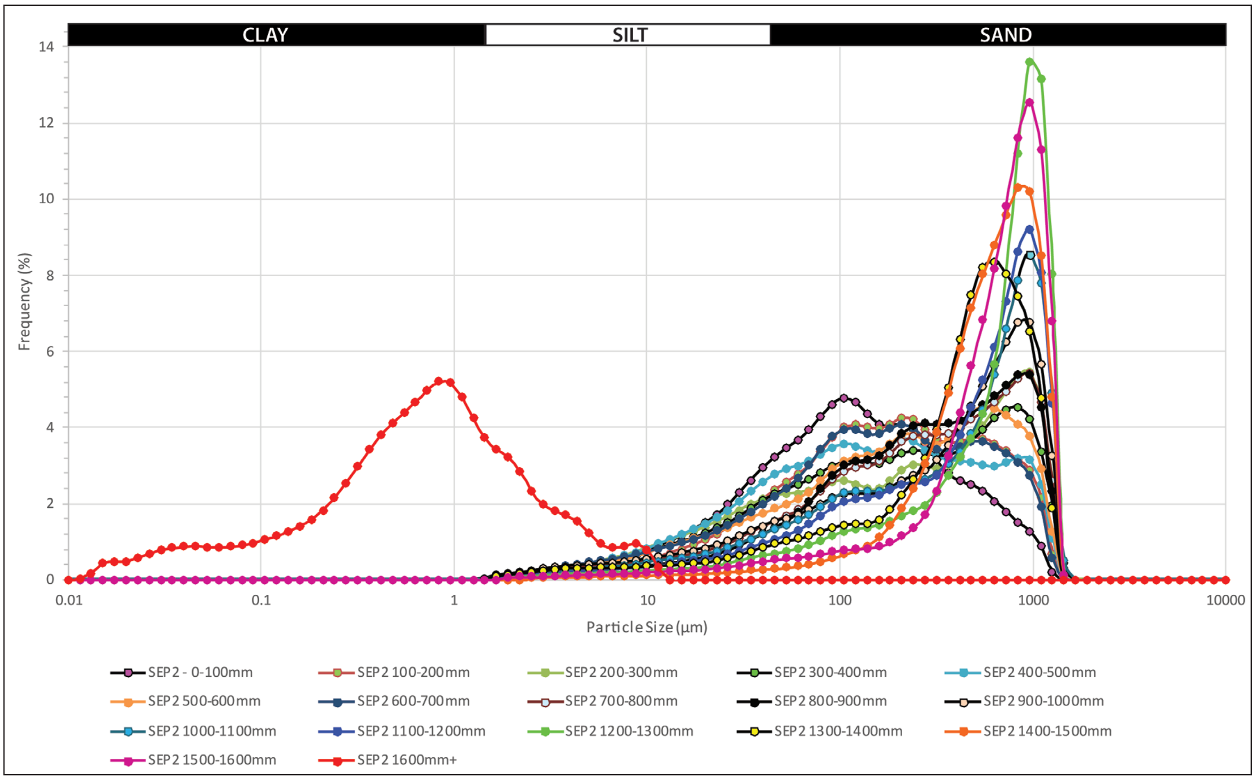


Figure 3. Particle size distribution for each 100 mm spit of SEP 2

	0–100 mm	100–200 mm	200–300 mm	300–400 mm	400–500 mm	500–600 mm	600–700 mm	700–800 mm	800–900 mm	900–1000 mm	1000–1100 mm	1100–1200 mm	1200–1300 mm	1300–1400 mm	1400–1500 mm	1500–1600 mm	1600+ mm
% clay	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	82
% silt	33	23	27	25	30	23	26	18	15	19	16	13	8	12	4	7	18
% sand	67	77	73	75	70	77	74	82	84	81	84	87	92	88	96	93	0

Table 1. SEP 2 percentage of sand, silt, and clay per spit

The upper 900 mm is characteristic of soil formation processes. Stratigraphically, the soil profile is dominated by silty sand, with fluctuating proportions of silt as the minor size fraction (**Figures 3** and **4**). Compared to the lower part of the profile (>900 mm), there is less evidence for deflation having winnowed out the fine sand and silt particles from the profile. It is likely that these sediments were deposited fairly rapidly by aeolian processes and stabilised shortly after, preventing finer particles from being removed. This also suggests that the deposit was derived locally, as deposits which travel long distances are generally well-sorted (Folk 1951; Lewis 1984). Combined with the presence of indurated sand formation in the lower part of the upper 900 mm of the soil profile, there is little evidence that this part of the soil profile has been subject to other processes besides pedogenic processes following deposition.

The lower 900–1600 mm indicates that aeolian processes, in particular deflation, have reworked the deposit. Over time, as low to moderate wind speeds transported the sand deposit via saltation and some suspension, the sand sheet was reworked, and the wind removed the finer grained particles, leaving a coarser grained lag deposit. This is typical of a sand sheet feature, which has been formed by reworking of older dune deposits. Due to the low proportions of fine-grained sand and silt, and the absence of clay, it is likely that the sediment had been transported slowly across the landscape, gradually losing the fine-grained component of the sediment before being deposited

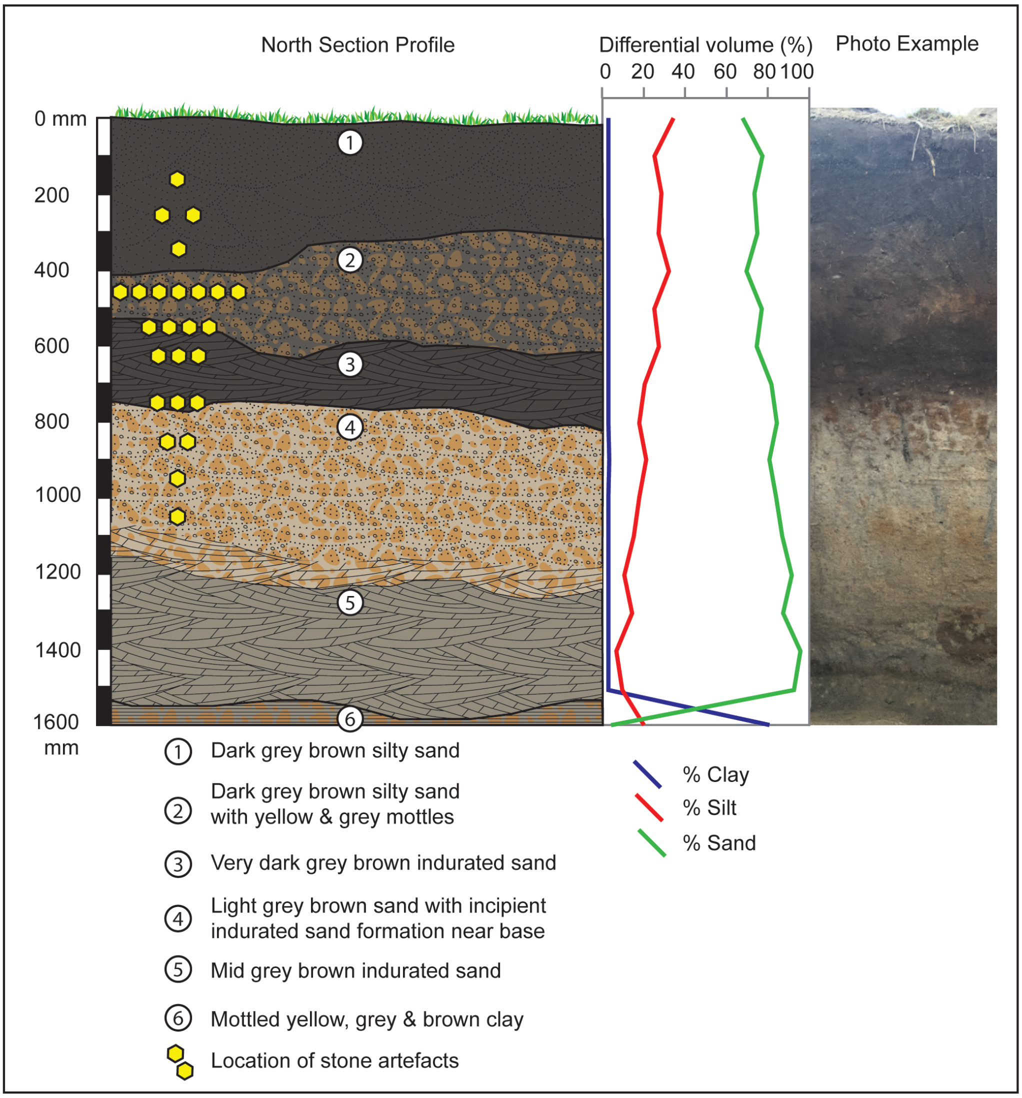


Figure 4. SEP 2 stratigraphic soil profile and particle-size distribution with indicative location of stone artefacts

within the activity area as a reworked sand sheet or lag deposit dominated by coarser material. This is further supported by the absence of bedding planes within the soil profile (although these may have been removed as a result of bioturbation).

The soil profile has also been subject to two periods of indurated sand (coffee rock) formation. This particular soil horizon is typical of sandy podosols, and forms over time at the interface between the water table and the downward movement of rainwater carrying dissolved organics (Conacher and Stanley 2000:331). Indurated sand is present at depths between 510 and 780 mm (indurated sand 1) and between 1090 and 1590 mm (indurated sand 2) (**Figure 4**). The upper unit (indurated sand 1) is characterised by a higher proportion of organics when compared to the lower unit (indurated sand 2). This is potentially due to the formation of indurated sand 1 prior to development of indurated sand 2, whereby the upper unit blocked downward transportation of organic material to the lower unit. The horizontal positioning of these units indicates that indurated sand 1 was formed during a period when water tables were higher, while indurated sand 2 was likely formed during a more recent period of lower water tables. The intact nature of these units further supports the absence of anthropogenic disturbance to the soil profile.

There is some evidence for bioturbation having reworked parts of the deposit, present as worm and root traces throughout the soil profile. Although numerous, these traces are generally discrete in area, and are therefore not detectible in the particle-size data. However, the movement of worms and roots throughout the profile are likely to have resulted in some form of mixing of sediment.

Aboriginal cultural heritage

A total of 26 stone artefacts were excavated from SEP 2 in subsurface contexts and from different squares, at discontinuous depths between 150 and 1100 mm below the ground surface (**Figures 4–5**). The largest part of the assemblage was identified at depths between 450 and 500 mm (n=7) (**Figure 4**). Most of the artefacts are silcrete (n=11) and quartz (n=9), followed by chalcedony (n=3), quartzite (n=2), and crystal quartz (n=1).

A single 'knapping group' was identified, comprising two artefacts made on a distinct light-brown silcrete of relatively homogeneous texture (**Figure 6**). The two artefacts comprise one complete flake (650–700 mm depth) and one distal flake used as a unidirectional core (750–800 mm depth). These artefacts were identified in different grid squares, approximately 2 m apart. While they do not refit, their identical colour and texture, and close proximity to one another, suggest that they derive from the same core, and that the other artefacts from the same core were taken away, and/or remain in unexcavated parts of the study area. The larger size of the overall assemblage from this pit (cf. SEP1, described below), its extended vertical distribution, and the presence of a knapping group and artefacts made on different rocks and minerals, suggests that Aboriginal people visited this location on more than one occasion, potentially over long periods of time, and that the assemblage remains reasonably intact.

The results of the particle-size analysis, and the features of the stratigraphic profile, lend support to this interpretation. The sediments enveloping the assemblage reflect natural, rather than anthropogenic, processes, including soil formation and sand sheet

Figure 6. The single knapping group identified in SEP 2, comprising two silcrete artefacts. The artefact on the left is a complete flake, and the artefact on the right is a distal flake that was used as a unidirectional core

Figure 5. Stone artefacts identified during the salvage excavation at VAHR 7921-1715. The three artefacts in the bottom row were recovered from SEP 1, and the 26 artefacts in the upper three rows were excavated from SEP 2

working. The assemblage from this pit therefore generates more meaningful information about the stone tool technologies that Aboriginal people used at this location, and the environmental conditions that prevailed as the assemblage accumulated over time. In this instance, the bulk of the assemblage accrued when conditions were relatively stable and humid, creating more favourable conditions for occupation. In contrast, few artefacts were made and/or left behind when sand sheet reworking was underway, and conditions were likely more adverse.

SEP 1

Particle-size analysis

This data for SEP 1 show distribution curves that differ significantly from each other, indicating a wide range of different particle-size distributions throughout the soil profile which had likely been affected by significant depositional processes over time. The particle-size distribution of SEP 1 shows a wide range of sizes within the profile, as shown by the multiple peaks in **Figure 7.** The dominant size fractions change multiple times throughout the soil profile, with silt dominating in the upper 200 mm, increasing from 66 to 96%, whereupon sand becomes the dominant size fraction from 200 to 500 mm, ranging from 71% at 200–300 mm, 59% at 300–400 mm, and 79% at 400–500 mm depth. Silt becomes dominant again at 500-600 mm (65%), before dropping again at 600–700 mm, where sand becomes dominant (63%). Clay remains very low in the soil profile between 0 mm and 700 mm, whereupon it becomes dominant at the base (700 mm+) (**Figure 7; Table 2**).

Four samples follow a negatively-skewed distribution typical of deflated sand deposits, differing from the remaining three distributions. They are comprised predominantly of sand; these are at 200–300 mm, 300–400 mm, 400–500 mm, and 600–700 mm depth (**Figure 7**). These samples have a slight bimodal distribution, with peaks occurring in medium to coarse silt (~15–60 µm) and at the boundary between fine- and medium-grained sand (~70–420 µm). The remaining samples

	0–100 mm	**100–200 mm**	**200–300 mm**	**300–400 mm**	**400–500 mm**	**500–600 mm**	**600–700 mm**	**700+ mm**
% clay	0	0	0	0	0	1	0	76
% silt	67	96	28	40	20	66	37	24
% sand	33	3	72	59	80	33	63	0

Table 2. SEP 1 percentage of sand, silt, and clay per spit

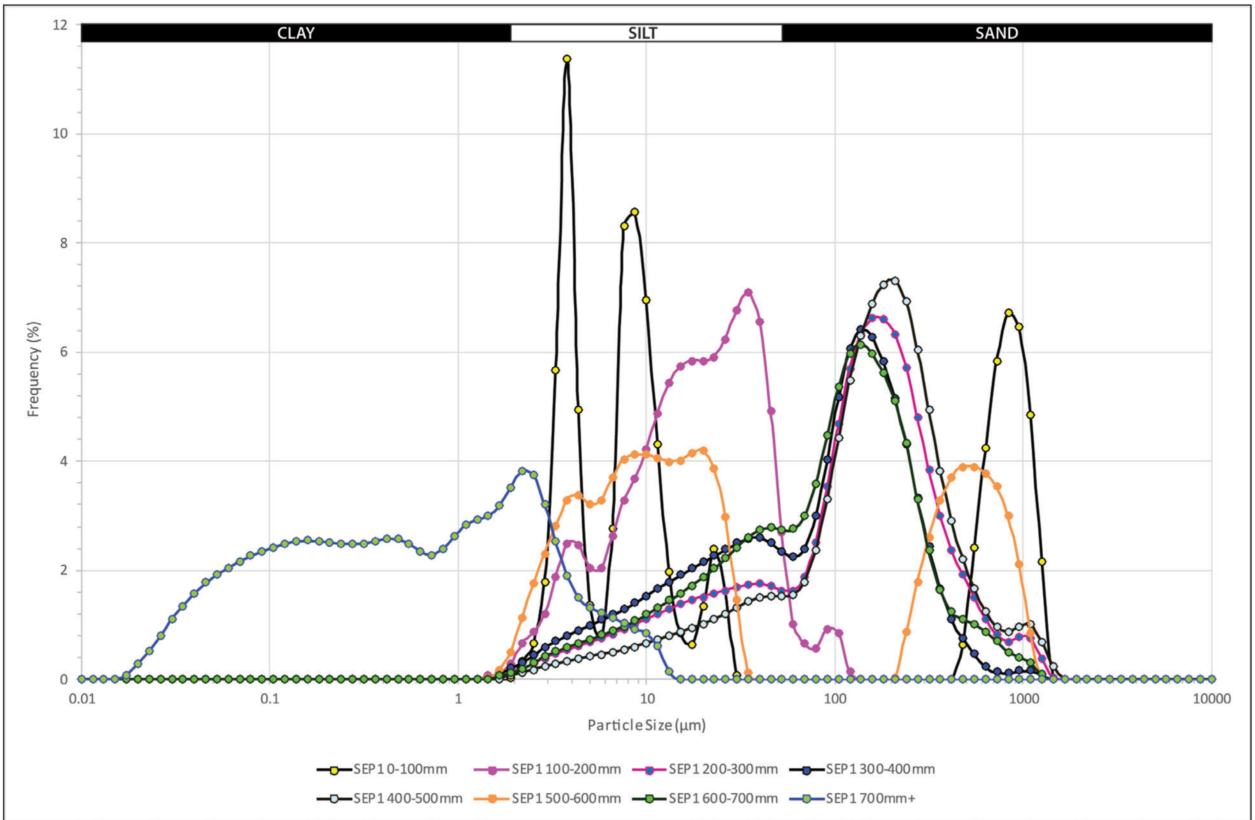


Figure 7. Particle size distribution for each 100 mm spit of SEP 1

have multiple peaks, two of which are skewed positively in the silt size fraction (0–100 mm and 500–600 mm; **Figure 7**).

Comparison of stratigraphic evidence vs particle-size analysis data

Stratigraphically, SEP 1 comprised a mixed soil profile, with inclusions of gravel, clay and indurated sand (coffee rock) nodules (**Figure 8**). Combined with data from the particle-size analysis, which shows a variable, poorly sorted composition of clay, silt and sand, the soil profile has been disturbed, probably from anthropogenic actions such as earthmoving. Only parts of the SEP 1 profile appear to show minimal soil disturbance in the particle-size data; these occur at 200–300 mm, 300–400 mm, 400–500 mm and 600–700 mm depth (**Figure 8**). At these spits, the soil profile comprises silty sand, and appears to represent a normal negatively-skewed distribution of particle-sizes as would be expected in a relatively well-sorted sand-sheet soil profile. However, combined with stratigraphic data, the particle-size distribution does not account for the gravels and clay nodules identified at these depths. This indicates that the whole profile has been disturbed. As a result, it is likely that there has been either:

a) Several periods of disturbance and mixing of the soil profile in SEP 1 mixing multiple sources or types of material; or,

b) One period of disturbance and mixing of the soil profile in SEP 1 with multiple sources of material, each comprising different combinations of particle-sizes.

Given the absence of obvious structures or signs of other forms of ground disturbance surrounding SEP 1, it is not possible to further refine the sources of disturbance. However, given the scale of the disturbance,

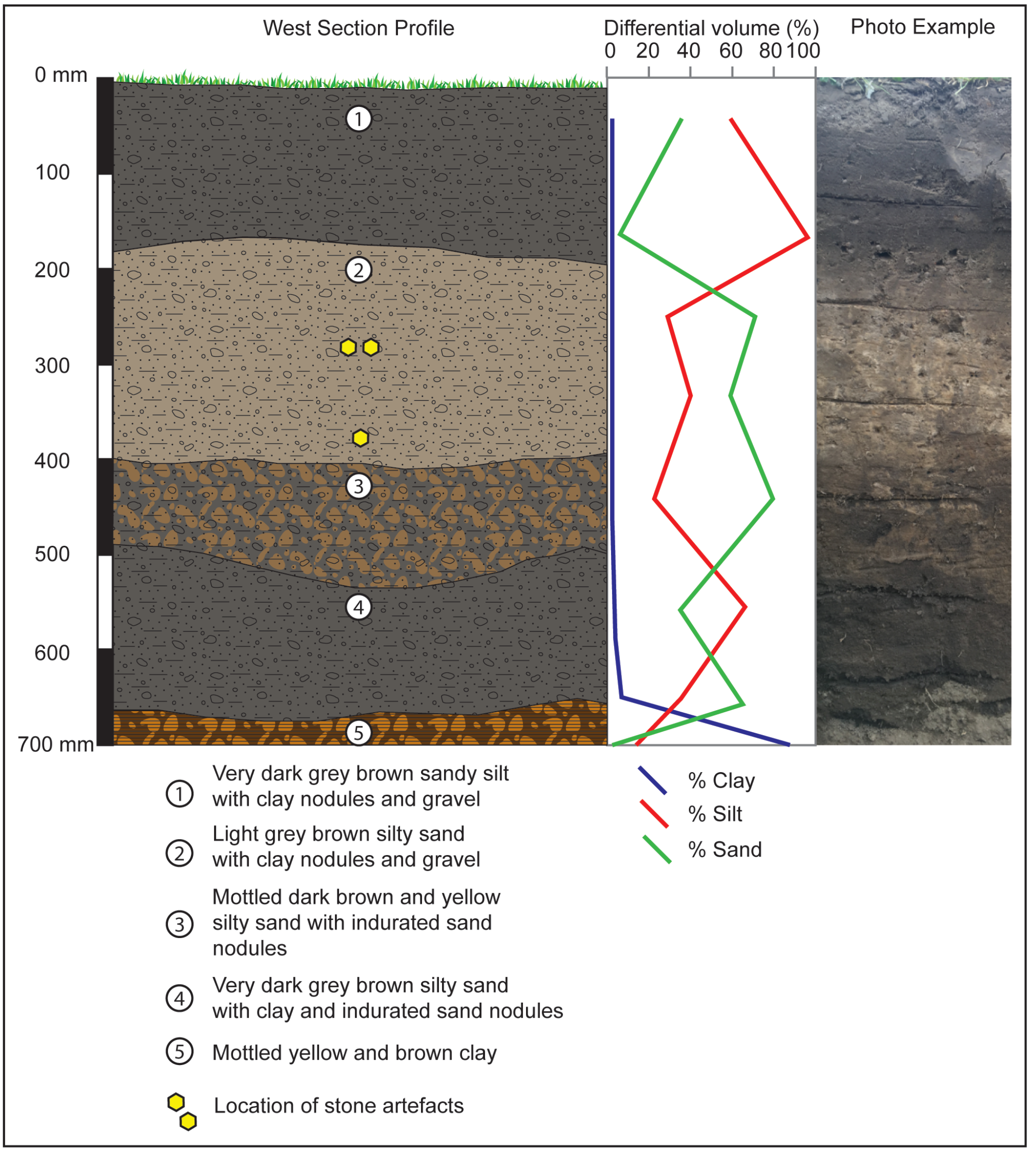


Figure 8. SEP 1 stratigraphic soil profile and particle-size distribution with indicative location of stone artefacts

it is likely that earth-moving machinery was involved.

Aboriginal cultural heritage

Three stone artefacts were recovered from SEP 1 in subsurface contexts and from different squares, at depths between 250–300 mm (n =2) and 350–400 (mm) below the ground surface (**Figures 5 and 8**). These artefacts comprise two complete silcrete flakes and one silcrete blade flake. The visual characteristics of the silcrete artefacts are dissimilar, and the artefacts could not be refitted. This suggests that the assemblage from SEP 1 represents the products of at least three different stone-working and/or discard events. Initially, the small number of artefacts identified in this pit and the absence of knapping groups/refit sets suggest that Aboriginal people did not spend much time, or leave substantial activity traces, at this location. However, when considered against the results of the particle-size analysis, and the stratigraphic profile of this pit, the history of disturbance at this location offers a more likely explanation for the nature and distribution of this assemblage. As a result, it is difficult to draw inferences about the nature of Aboriginal occupation at this location from the assemblage as it does not appear to be intact.

Discussion

The stratigraphic profiles of SEP 1 and SEP 2 show dramatically different particle-size distributions; SEP 1 is dominated by anthropogenic (probably earth-moving) disturbance, while SEP 2 is dominated by natural soil formation processes and sand-sheet reworking. The evidence for Aboriginal occupation in SEP 1 is therefore less intact, and not necessarily representative of what occurred at the location at the time of deposition. SEP 2, however, shows relatively intact evidence for Aboriginal occupation, providing a stronger basis for generating information about past Aboriginal occupation and the environmental conditions that prevailed at the time. There is an absence of archaeological material in the lower portions of the profile in this pit, where conditions are inferred to have been drier and cooler. It appears that Aboriginal occupation at this location coincided with conditions that appear to have been more stable and humid than at present. While no dating was undertaken as part of the salvage, it is possible that the sediments making up the lower part of the stratigraphic sequence accumulated during the Last Glacial Maximum, which was a period of significant aeolian activity in the region. On the other hand, the deposits identified in the upper part of the stratigraphic sequence, which contain Aboriginal cultural heritage, probably accumulated during the Holocene.

Similar inferences using the results of particle-size analyses have been made in the past during the Bend Road investigations (Hewitt and Allen 2010; Orr 2006). Orr's analysis of the Bend Road sand profiles was important in understanding not only the depositional history of the sand profile, but also the taphonomy of the archaeological material found at the site. Following particle-size analysis of two pits excavated during the investigation, Orr (2006) was able to conclude that the two soil profiles had different depositional histories. Bend Road 1 contained a bimodal particle-size distribution typical of aeolian processes with little post-depositional modification of the profile (Orr 2006). In contrast, the Bend Road 2 profile contained a unimodal particle-size distribution at depths of 0–700 mm while deeper deposits were bimodal; this indicated that the upper parts of the profile had been reworked, while deeper sediments had been subject to typical dune-formation processes such as saltation (bouncing particles) and creep (rolling particles) (Orr 2006). It was this understanding of the site formation processes that informed the in-depth analysis of the archaeological material which otherwise would not have been possible.

By comparison, the current study has established that mostly unimodal particle distribution dominates the more natural soil profile of SEP 2, which indicates that reworking was the main formation process. This is in contrast to Orr's (2006) results showing bimodal particle-size distribution at Bend Road 1, and in the deeper deposits of Bend Road 2, which was representative of normal dune-building processes that transported particles by a variety of processes, allowing a wider variation of particle-sizes to be deposited. The difference between the results from both studies highlights that dune and sand-sheet formation processes are dynamic and largely controlled by localised environmental conditions. Furthermore, the localised nature of disturbance identified through particle-size analysis, both in this study and that undertaken by Orr (2006), shows that results from a small number of excavation pits cannot be applied across an entire area; in order to understand landscape-level taphonomic processes, particle-size analysis on multiple soil profiles should be performed.

The results of the analyses broadly conform to the available information on sand-sheet contexts in southeast Melbourne. Given the archaeological signature can be affected to a significant degree by the taphonomic processes acting on that deposit, the environmental history has thus been controlled to a significant degree by aeolian processes in the form of sand-dune and sand-sheet deposition and reworking during drier climatic periods. This is particularly illustrated in SEP 2 where the lower part of the profile contains a particle-size signature characteristic of reworked sand sheets. Furthermore, the upper part of the profile provides evidence of the processes which dominated when climates warmed, and precipitation increased; such conditions occurred in the Early–Middle Holocene. These conditions stabilised sand deposits and prompted pedogenic processes to dominate. During this stage, the archaeological signature in SEP 2 is most abundant; by comparison, many previous assessments show concentrations of archaeological material in the Holocene. Furthermore, the influence of more recent human activity is highlighted at SEP 1, which contains a minimal archaeological signature and an anthropogenically disturbed soil profile. This information has therefore provided insight into the at-times highly localised geomorphic processes which have affected the archaeological material of the study area in southeast Melbourne.

Conclusion

The analysis of two sand-dominated soil profiles at Clyde East illustrates how particle-size analysis, and the investigation of knapping groups and refitting stone artefacts, can assist with understanding the taphonomic processes of an archaeological site. Rather than making assumptions about the disturbance history based on a simplified stratigraphic profile or a geological chronology, this approach has generated information about specific processes, particularly in the context of SEP 2, revealing instances of deflation and reworking of a sand sheet that were not visible at the scale of a stratigraphic profile. Furthermore, by understanding the environmental conditions at the time of creation of the archaeological site, richer interpretations of contemporary environments can be made rather than focusing only on an analysis of stone artefact use and discard. This investigation further provides detail on the geomorphological history of a sand sheet in southeast Melbourne, adding to our understanding of past environments and the effects these had on the movement of archaeological material.

Acknowledgements

We would like to thank the following individuals and organisations for their assistance in this project:

Bunurong Land Council Aboriginal Corporation, Wurundjeri Woi-Wurrung Cultural Heritage Aboriginal Corporation, and Yaluk-Ut Weelam Elders Council Aboriginal Corporation for their input and participation during the conduct of the CHMP and the salvage program. Balcon Group Pty Ltd for Sponsoring the CHMP and salvage program. Petra Schell for reviewing this manuscript and providing valuable feedback, and Jodi Turnbull for her mapping. Krista Whitewood, Jacqueline Anderson, Melathi Saldin, Cassandra Kiely, Thanos Matanis for their assistance during the salvage program. John Webb and the Department of Ecology, Environment and Evolution for their assistance in accessing the particle-size facilities at La Trobe University. Finally, thank you to the organisers of the Victorian Archaeological Colloquium for organising a platform to present this work, and to the two reviewers for providing useful feedback on an earlier version of this paper.

References

Allen, J., G. Hewitt, J. de Lange and A. Long 2008 Report on Bend Road Archaeological Investigations: Bend Road Phases 1 to 3. Unpublished report prepared for Thiess John Holland

Balek, C.L. 2002 Buried artifacts in stable upland sites and the role of bioturbation: a review. *Geoarchaeology* 17(1):41–51

Barndorff-Nielsen O. and C. Christianson 1988 Erosion, deposition and size distributions of sand. *Proceedings of the Royal Society of London. Series A, Mathematical and Physical Sciences* 417(1853):335–352

Bell, G., K.G. Bowen, J.G. Douglas, J.S. Hancock, J.J. Jenkin, P.R. Kenley, J.L. Knight, J.L. Neilson, D. Spencer-Jones, J.A. Talent, D.E. Thomas and R.G. Whiting 1967 *Geology of the Melbourne District, Victoria*. Geological Survey of Victoria Bulletin 59. Melbourne: Mines Department

Bernhardt, I.C. 2012 *Particle Size Analysis: Classification and Sedimentation Methods*. Dordrecht: Springer Science & Business Media

Blott, S.J. and K. Pye 2012 Particle size scales and classification of sediment types based on particle size distributions: review and recommendations. *Sedimentology* 59:2071–2096

Boggs Jr, S. 1987 *Principles of Sedimentology and Stratigraphy*. Melbourne: Merrill Publishing Company

Bowler, J.M., R. Jones, H.R. Allen and A.G. Thorne 1970 Pleistocene human remains from Australia: a living site and human cremation from Lake Mungo. *World Archaeology* 2:39–60

Broome, R. 2005 *Aboriginal Victorians: A History Since 1800*. Crows Nest, NSW: Allen and Unwin

Cahen, D., L.H. Keeley and F.L. Van Noten 1979 Stone tools, toolkits, and human behavior in prehistory. *Current Anthropology* 20:661–683

Cahen, D. and J. Moeyersons 1977 Subsurface movements of stone artefacts and their implications for the prehistory of central Africa. *Nature* 266:812–815

Clark, I. 1990 *Aboriginal Languages and Clans: An Historical Atlas of Western and Central Victoria, 1800-1900*. Monash Publications in Geography 37. Melbourne: Department of Geography and Environmental Science, Monash University

Clark, P., A.S. Dyke, J.D. Shakun, A.E. Carlson, J. Clark, B. Wohlfarth, J.X. Mitrovica, S.W. Hostetler and A.M. McCabe 2009 The Last Glacial Maximum. *Nature*

325:710–714

Conacher, P.A. and R.J. Stanley 2000 Soils and coastal dune management. In P.E.V. Charman and B.W. Murphy (eds), *Soils: Their Properties and Management,* 2nd edition, pp. 328–335. Melbourne, Oxford: Oxford University Press

Conard, N.J. and D.S. Adler 1997 Lithic reduction and hominid behavior in the Middle Paleolithic of the Rhineland. *Journal of Anthropological Research* 53(2):147–175

Coutts, P.J.F. 1972 Interpretation of archaeological material eroded from coastal dune sites. *Journal of the Royal Society of New Zealand,* 2(3):407–412

Czastka, J. and S. Canning 2015 Salvage Excavations for Australand's Proposed Residential Subdivision 865 Cranbourne-Frankston Road, Cranbourne, Victoria. Unpublished report prepared for Australand Holdings Limited

Dodson, J.R. and S.D. Mooney, 2002 An assessment of historic human impact on south-eastern Australian environmental systems, using late Holocene rates of environmental change. *Australian Journal of Botany* 50:455–464

Dowdell, M., C. Montero-Lopez, C. Spry and K. Whitewood 2018 Residential Subdivision: Pattersons, Hardys & Pound Road Properties, Clyde East. CHMP 11740. Unpublished report prepared for Balcon Group

Ellender, I. and R. Leubbers 2009 The Royal Botanic Gardens, Cranbourne, Victoria. Completion of Landscape Development in the Australian Garden Stage Two. CHMP 10038. Unpublished report prepared for The Royal Botanic Gardens, Cranbourne

Eshel, G., G.J. Levy, U. Mingelgrin and M.J. Singer 2004. Critical evaluation of the use of laser diffraction for particle-size distribution analysis. *Soil Science Society of America Journal* 68(3):736–743

Fanning, P. and S. Holdaway 2001 Stone artifact scatters in western NSW, Australia: geomorphic controls on artifact size and distribution. *Geoarchaeology* 16(6):667–686

Fisher, P., C. Aumann, K. Chia, N. O'Halloran and S. Chandra 2017 Adequacy of laser diffraction for soil particle size analysis. *PLOS ONE* 12(5):e0176510

Filihia, M., P. Kucera, R. Minos and K Oataway 2016 Salvage Excavations at VAHR 7921-1151 'Lyndhurst Inland Port 6': Carrum Swamp: Analysis of the Archaeological Assemblage. *Excavations, Surveys and Heritage Management in Victoria.* 5, pp.7–15

Fitzsimmons, K.E., N. Stern and C.V. Murray-Wallace 2014 Depositional history and archaeology of the central Lake Mungo lunette, Willandra Lakes, southeast Australia. *Journal of Archaeological Science* 41:349–364

Foley, E., C. Spry and N. Stern 2017 Establishing the integrity and stratigraphic origin of stone artefact scatters on the surface of the Lake Mungo lunette in south-eastern Australia. *Journal of Archaeological Science: Reports* 13:547–557

Folk, R.L. 1951 Stages of textural maturity. *Journal of Sedimentary Petrology* 21:127–130

Folk, R.L. 1968 *Petrology of Sedimentary Rocks*. Austin, Texas: University of Texas & Hemphills

Folk, R.L. and W.C. Ward 1957 Brazos River Bar: a study in the significance of grain size parameters. *Journal of Sedimentary Petrology* 27(1):3–26

Friedman, G.M. 1961 Distinction between dune, beach, and river sands from their textural characteristics. *Journal of Sedimentary Petrology* 31(4):514–529

Frison, G.C. 1974 *The Casper Site: A Hell Gap Bison Kill on the High Plains*. New York: Academic Press

Gaughwin, D. 1983 Coastal Economies and the Western Port Catchment. Unpublished MA thesis, La Trobe University, Melbourne

Gaughwin, D. and H. Sullivan 1984 Aboriginal boundaries and movements in Western Port, Victoria. *Aboriginal History* 8(1):80–98

Gee, G.W. and D. Or 2002 Particle-size analysis. In R. Horton Jr (ed.), *Methods of Soil Analysis: Part 4 Physical Methods*, pp.255–293. Madison, Wisconsin, USA: Soil Science Society of America

Gunson, N. 1968 *The Good Country; Cranbourne Shire*. Melbourne: F.W. Cheshire Publishing Pty Ltd

Hewitt, G. and J. Allen 2010 Site disturbance and archaeological integrity: the case of Bend Road, an open site in Melbourne spanning pre-LGM Pleistocene to late Holocene periods. *Australian Archaeology* 70:1–16

Hewitt, G. and J. de Lange 2007 Report on Bend Road Archaeological Investigations. Bend Road 2 Phases 1 to 4. Unpublished report prepared for Thiess John Holland

Hibbins, G.M. 1984 *A History of the City of Springvale: Constellation of Communities*. Port Melbourne: City of Springvale in Conjunction with Lothian Publishing Company

Hiscock, P. 1990 How old are the artefacts in Malakunanja II? *Archaeology in Oceania* 25(3):122–124

Jankowski, N.R., N. Stern, T.J. Lachlan and Z. Jacobs 2020 A high-resolution late Quaternary depositional history and chronology for the southern portion of the Lake Mungo lunette, semi-arid Australia. *Quaternary Science Reviews* 233:106224

Jenkin, J.J. 1981 Evolution of the Victorian coastline.

Proceedings of the Royal Society of Victoria, 92(1):37–54

Johnson, D.L., D.N. Johnson, D.W. Benn and E.A. Bettis III 2008 Deciphering complex soil/site formation in sands. *Geomorphology* 101:484–496

Keble, R.A. 1968 *The Mornington Peninsula*. Memoir 17. Memoirs of the Geological Survey of Victoria. Melbourne: Department of Mines

Kelly, R.L. 1985 Hunter-gatherer Mobility and Sedentism: A Great Basin Study. Unpublished PhD thesis, Department of Anthropology, University of Michigan, Ann Arbor

Kershaw, P. 1995 Environmental change in greater Australia. *Antiquity* 69:656–675

Lancaster, N. 2011 Desert dune processes and dynamics. In D.S.G. Thomas (ed.), *Arid Zone Geomorphology: Process, Form and Change in Drylands,* pp.487–515. Chichester: John Wiley & Sons Ltd

Larson, M.L. and E.E. Ingbar 1992 Perspectives on refitting: critique and a complementary approach. In J.L. Hofman and J.G. Enloe (eds), *Piecing Together the Past: Applications of Refitting Studies in Archaeology*. BAR International Series no. 578, pp.151–162. Oxford: Archaeopress

Larson, M.L. and M. Kornfeld 1997 Chipped stone nodules: theory, method and examples. *Lithic Technology* 22:4–18

Lewis, D.W. 1984 *Practical Sedimentology*. New York: Hutchinson Ross Publishing Company

Light, A. 2010 135 Evans Road, Cranbourne West (Residential Subdivision). CHMP 10714. Unpublished report prepared for Peet Cranbourne Syndicate Ltd

McGuire, F. 1991 *They Built a River: A Short History of the Carrum Swamp, its People and its Reclamation.* Chelsea: City of Chelsea Historical Society

McLaren, P. and D. Bowles 1985 The effects of sediment transport on grain-size distributions. *Journal of Sedimentary Petrology* 55(4):457–470

Murphy, B.W., D.J. Eldridge, G.A. Chapman and D.J. McKane 2000 Soils of New South Wales. In P.E.V. Charman and B.W. Murphy (eds), *Soils: Their Properties and Management,* 2nd edition, pp.133–149. Melbourne, Oxford: Oxford University Press

Murphy, A. and T. Rymer 2011 Victorian Desalination Plant Transfer Pipeline Corridor Wonthaggi to Cranbourne Salvage Excavation. Unpublished report to Thiess Degremont Nacap

Northcote, K.H., G.D. Hubble, R.F. Isbell, C.H. Thompson and E. Bettenay 1975 *A Description of Australian Soils*. Clayton, Victoria: CSIRO

Orr, M. 2006 Appendix B Particle Size Analysis Report: Bend Rd sites Bend Rd 1 and Bend Rd 2 Pit C. In G. Hewitt and J. de Lange 2007 Report on Bend Road Archaeological Investigations Bend Road 2 Phases 1 to 4. Unpublished report prepared for Thiess John Holland

Peacock, E. and D.W. Fant 2002 Biomantle formation and artefact translocation in upland sandy soils: an example from the Holly Springs National Forest, north-central Mississippi, USA. *Geoarchaeology* 17(1):91–114

Petraglia, M.D. 1992 Stone artifact refitting and formation process at the Abri Dufaure, an Upper Paleolithic site in southwest France. In J.L. Hofman and J.G. Enloe (eds), *Piecing Together the Past: Applications of Refitting Studies in Archaeology*. BAR International Series no. 578, pp.163–178. Oxford: Archaeopress

Plomaritis, T.A., I. Puyana-Cruces, J. Benavente and S. Rodriguez-Polo 2013 Can grain size trend analysis be used to identify aeolian sediment transport pathways? The case of Bolonia dune (SW Spain). In D.C. Conley, G. Masselink, P.E. Russell and T.J. O'Hare (eds), *Proceedings 12th International Coastal Symposium* (Plymouth, England), *Journal of Coastal Research* 65:1325–1330

Richards, T., C. Pavlides, K. Walshe, H. Webber and R. Johnston 2007 Box Gully: new evidence for Aboriginal occupation of Australia south of the Murray River prior to the Last Glacial Maximum. *Archaeology in Oceania* 42(1):1–11

Roebrooks, W. 1988 From Find Scatters to Early Hominid Behaviour: A Study of Middle Palaeolithic Riverside Settlements at Maastricht-Belvédère (The Netherlands). Unpublished PhD thesis, Leiden, University of Leiden

Roebroeks, W., Kolen, J., Poecke, M.V. and A.L. Van Gijn 1997 Site J: an early Weichselian (Middle Palaeolithic) flint scatter at Maastricht-Belvedere, The Netherlands. *Paléo* 9(1):143–172

Ross, A. 1981 Holocene environments and prehistoric site patterning in the Victorian Mallee. *Archaeology in Oceania* 16(3):145–155

Schiffer M.B. and W.L. Rathje 1973 Efficient exploitation of the archaeological record: penetrating problems. In C.L. Redman (ed.), *Research and Theory in Current Archaeology*, pp.169–179. New York: Wiley-Interscience

Smith, L. 1991 *Berwick-Pakenham Corridor: Aboriginal Archaeology*. Melbourne: Victoria Archaeological Survey, Department of Conservation and Environment

Spencer-Jones, D., M.A.H. Marsden, C.M. Barton and J.J. Carrillo-Rivera 1975 Geology of the Westernport Sunkland. *Proceedings of the Royal Society of Victoria*

87(1):43–67

Stein, J.K. 1983 Earthworm activity: a source of potential disturbance of archaeological sediments. *American Antiquity* 48(2):277–289

Stern, N., J. Tumney, K.E. Fitzsimmons and P. Kajewski 2013 Strategies for investigating human responses to changes in landscape and climate at Lake Mungo in the Willandra Lakes, southeast Australia. In D. Frankel, J. Webb and S. Lawrence (eds), *Archaeology in Environment and Technology: Intersections and Transformations*, pp. 31–50. New York: Routledge

Thorne, A.G. and P.G. Macumber 1972 Discoveries of late Pleistocene man at Kow Swamp. *Nature* 238:316–319

Van Noten, F.L., D. Cahen and L.H. Keeley 1980 A Palaeolithic campsite in Belgium. *Scientific American* 242:48–55

VandenBerg, A.H.M. 2017 Depositional facies and extent of the Late Neogene Sandringham Sandstone in southern Victoria, Australia. *Proceedings of the Royal Society of Victoria* 128:7–24

Victorian Resources Online (VRO) Accessed May 2019 via < http://vro.agriculture.vic.gov.au/dpi/vro/vrosite.nsf/pages/vrohome >

Villa, P. 1982 Conjoinable pieces and site formation processes. *American Antiquity* 47:276–290

Welch, S.I., D.V. Higgins and G.A. Callaway 2011 Surface Geology of Victoria 1:250 000. Melbourne: Geological Survey of Victoria, Department of Primary Industry

White, S. and M.M. Mitchell 2003. Palaeoclimates: the influence of continental drift and latitude change on climate. In W.D. Birch (ed.), *Geology of Victoria*, pp.563–571. Sydney: Geological Society of Australia (Victorian Division), Geological Society of Australia, Special Publication 23

Williams, A.N., F. Atkinson, M. Lau and P.S. Toms 2014 A glacial cryptic refuge in south-east Australia: human occupation and mobility from 36,000 years ago in the Sydney Basin, New South Wales. *Journal of Quaternary Science* 29:735–748

Update on the Radiocarbon Dating Visualisation Project for Aboriginal places in the State of Victoria, southeastern Australia: insights and issues

David Thomas[1], Caroline Spry[2], Jacqueline Tumney[2] and Rebekah Kurpiel[2]

Abstract

For several years, staff at Aboriginal Victoria, a government agency responsible for administering the Aboriginal Heritage Act 2006 (Vic.)*, have been compiling a dataset of radiocarbon age determinations from Aboriginal places in the State of Victoria, southeastern Australia. The dataset currently contains nearly 1,000 radiocarbon age determinations calculated over the past 65 years, but has not yet been made more readily available due to concerns over its accuracy and completeness. A time-consuming and complex process of verifying the sample information, methods and results for each radiocarbon determination has just been completed, following a partnership between Aboriginal Victoria and researchers in the Department of Archaeology and History at La Trobe University. In this paper, we describe the data-verification process behind the Radiocarbon Dating Visualisation Project, share some of the issues we have encountered, and outline the future directions and proposed outcomes of the project. The data-verification process has highlighted the need to improve standards for building radiocarbon chronologies and publishing radiocarbon age determinations, particularly through the provision of laboratory reports and more careful consideration of the contextual integrity of samples for dating.*

Introduction

Archaeologists have been collecting samples for radiocarbon dating from Aboriginal places in Victoria since Edmund Gill sent a charcoal sample from Koroit Beach midden to the pioneer of radiocarbon dating, Willard Libby (Gill 1953:82). This was, to the best of our knowledge, the first radiocarbon age determination in Australia. Numerous researchers have since periodically attempted to compile lists of radiocarbon age determinations in Victoria, and more broadly across Australia (e.g. Bird and Frankel 1991; Godfrey et al. 1996; Polach et al. 1978; Vines 2015; Williams et al. 2014, inter alia). These lists, however, are necessarily snap-shots of the available information at any particular time, and are often incomplete and contain erroneous information, issues not unique to Australia (Jacobsson 2019).

Indeed, there is no central database of radiocarbon dates at the global level (Wood 2015:69), although attempts are increasingly being made to collate regional databases, such as the Southern African Radiocarbon Database (SARD) (Loftus et al. 2019), and to study local chronologies, such as in Ancient Egypt (Bronk Ramsey et al. 2010; Shortland and Bronk Ramsey 2013). As Wood (2015:61) notes, however: 'the largest and most pressing problem facing the field is appropriate publication of dates'.

In Victoria, the problems of accuracy, consistency and completeness of the data pertaining to radiocarbon age determinations are further compounded by the fact that much of these data are buried in 'grey literature'. Many of these reports are held in the Victorian Aboriginal Heritage Register (VAHR), a restricted-access dataset with limited search capabilities managed by Aboriginal Victoria (AV), the government agency responsible for administering the *Aboriginal Heritage Act 2006 (Vic.)*. Once lists of radiocarbon age determinations are published, any gaps or errors in the lists become replicated as subsequent researchers assume the published lists are relatively complete and accurate. Unfortunately, this assumption has proved not to be the case (Thomas et al. 2018).

The lack of a central, complete list of radiocarbon age determinations that has been through a rigorous process of verifying the sample information, methods and results for each radiocarbon determination is a major limitation to research on the radiocarbon age determinations from Aboriginal places in Victoria. Staff at AV started addressing this problem several years ago, when Thomas and colleagues reported on a research project to collate previous researchers' lists and parse the grey literature. This process resulted in the compilation of a list of 930 radiocarbon age determinations in 2018 (Thomas et al. 2018). By the middle of 2019, the list had grown to 1,130 radiocarbon age determinations and AV committed funding to start a data-verification phase of the project, in partnership with La Trobe University, which also contributed funding. In 2020, the list contained a total of 1,150 radiocarbon age determinations, prior to

[1] Aboriginal Victoria, 1 Treasury Place, East Melbourne VIC 3002
<david.thomas@dpc.vic.gov.au>
03 8392 5354

[2] Department of Archaeology and History, La Trobe University, Bundoora VIC 3086
<C.Spry@latrobe.edu.au>,<J.Tumney@latrobe.edu.au>,<R.Kurpiel@latrobe.edu.au>

completion of the data verification.

This paper outlines the preliminary data-verification process for the Radiocarbon Dating Visualisation Project and some of the key learnings we have identified, as well as the next stages of the project. Future papers will analyse the dataset and discuss in more detail its implications for our understanding of Aboriginal occupation of Victoria and methodologies for building and interrogating radiocarbon datasets.

Data-verification process

The data-verification process over the past year has been necessarily slow and complex, given the range and varying quality of the available information on the 1,150 radiocarbon age determinations in the original dataset, stretching back nearly 70 years. The initial part of the data-verification process was to review and expand the existing categories of information in the spreadsheet initially compiled by AV. This was a collaborative and iterative process to ensure standardisation between different verifiers, as well as incorporating the flexibility to build in learnings as the data-verification process progressed. A future phase of verification will involve technical assessment by a radiocarbon dating specialist of the dating samples and methods used.

Where possible, our first point of reference was the original radiocarbon laboratory report for each radiocarbon age determination to cross-check the sample information, and the dating methods and results. Unfortunately, we have only been able to access laboratory reports for just over half of radiocarbon age determinations in the verified dataset, although the current State of Emergency has prevented us from attempting to access hard copies of site cards in the VAHR. In some cases, the Radiocarbon Dating Laboratory at the University of Waikato, the Radiocarbon Facility at the Australian National University, and Beta Analytic Testing Laboratory were able to assist by providing relevant information from their databases and digital archives. However, this largely depended upon how recently the sample was submitted and each laboratory's digital archiving policies and procedures (see below). The limited ability to access laboratory reports significantly constrained the amount of information we could verify and/or add to the spreadsheet of radiocarbon age determinations.

In addition to laboratory reports, we checked information concerning the archaeological context, cultural status and/or association, and stratigraphic integrity of the sample material, using the original source where possible. Typically, these sources were a Cultural Heritage Management Plan (CHMP) on the Aboriginal Cultural Heritage Register and Information System (ACHRIS) for Victoria, or academic publications. Other sources included salvage reports, cultural heritage assessments, VAHR site cards and/or files appended to site cards, also available on ACHRIS.

The data-verification process concluded with a subjective assessment of the reliability of each radiocarbon age determination (**Table 1**). Categories ranged from 'Unreliable' to 'Secure'. Any technical or archaeological problems identified for each radiocarbon age determination were noted in a 'Problems' column. We selected the 'Incomplete' category when the lab report or sufficient archaeological information was unavailable.

Overall, the method of assessing reliability for each radiocarbon age determination is broadly similar to the assessment criteria used in other studies, including Jacobsson's (2019:4) evaluation of 547 published radiocarbon samples in the Levant (**Table 2**), and Rodríguez-Rey and colleagues' (2016) assessment of the quality of Middle Pleistocene to Holocene vertebrate fossil ages (**Table 3**).

Criteria	Definition	% pass
Technical	Pre-treatment, calibration	68.0
Strict contextual	Unambiguous connection to a feature; no risk of old wood effects	4.2
Relaxed contextual	Unresolved stratigraphic contradictions relating to the sample	44.2

Table 2. Jacobsson's (2019) criteria for assessing the reliability of radiocarbon age determinations, and the percentage of age determinations which meet these criteria

Category	Definition	Number of age determinations	% of age determinations
Secure	No issues relating to the type, pre-treatment, cultural status/ association, and/or stratigraphic integrity of sample material	175	19.5
Uncertain	Uncertainty over one or more of the above	330	36.8
Unreliable	Specific issues with the date identified in the laboratory report and/ or archaeological report/publication	42	4.7
Inomplete information	No lab report, or not enough information accessible to determine the archaeological context	350	39.0
Total		897	100

Table 1. Categories for assessing the reliability of each radiocarbon age determinations, and preliminary totals for each category

Where possible, we developed data-validation lists in Excel to increase the speed of data entry, consistency and accuracy. Two of the authors (CS, JT) verified roughly equal shares of 87% of the radiocarbon age determinations, reducing the potential problem of inconsistency between multiple verifiers, while regular meetings and a workshop at the end of the verification process to discuss and compare results further improved standardisation across the dataset. A single verifier (CS) checked all the radiocarbon ages at the conclusion for consistency within and between Aboriginal places and verifiers. The ability to filter entries in Excel, and identify and correct inconsistencies rapidly, has also been highly beneficial.

A total of 968 radiocarbon age determinations have been verified during this project, following the removal of 182 determinations from the original list (**Table 4**). A further 71 determinations were excluded from the analysis because they relate to Aboriginal Ancestral Remains and are therefore sensitive information. This results in a total of 897 determinations in the dataset which can be analysed.

Preliminary analysis of the dataset indicates that the largest proportion of verifications are incomplete (**Table 1**). The main reason for this is that the original lab report is not included with the archaeological report/publication or associated VAHR record, or, conversely, a lab report is available but no archaeological report/publication can be located to provide more detailed contextual information. A similar proportion of verifications are uncertain, typically because the association between the cultural material and sample dated is tenuous (e.g. charcoal and stone artefacts), or the material dated is not unequivocally cultural (e.g. shell midden, hearth).

Quality-rating criteria	Definition
A*	The most reliable ages—direct age estimates (i.e. on the fossil material itself) using the most appropriate, up-to-date dating protocols
A	Reliable indirect ages obtained using the most appropriate or just appropriate dating protocols on material that is not the fossil but has a close or unambiguous association with it. Includes reliable direct ages where the quality of the dating technique is appropriate, but not ideal
B	Direct ages that are unreliable due to sub-optimal dating protocols, or indirect ages dated with appropriate methods but with uncertain association
C	Unreliable—outdated protocols or material unsuited to the dating technique used, or indirect ages with appropriate dating, but with no association

Table 3. Quality-rating criteria by Rodríguez-Rey et al. (2016) for Middle Pleistocene to Holocene vertebrate fossil ages

Reason for removal	Number of age determinations	% of age determinations
Not from Victoria	74	40.6
Duplicate	56	30.8
Does not date cultural material/ horizon	44	24.2
Other	8	4.4
Total	182	100

Table 4. Reasons for removing age determinations

Charcoal is the most dominant type of material dated, followed by smaller quantities of marine and freshwater shell (**Table 5**). The dating of a large proportion of samples coincides with the establishment and operation of the Victoria Archaeological Survey, a government body which had primary responsibility for state archaeological functions, including Aboriginal, historic and maritime archaeology, from 1975 until 1992 when it became the Heritage Services Branch of Aboriginal Affairs Victoria (currently Aboriginal Victoria). Just over half of the radiocarbon age determinations were calculated since 1995, and a third of the radiocarbon age determinations post-date the introduction of the *Aboriginal Heritage Act 2006 (Vic.)* (**Figure 1**).

Material dated	Number of age determinations	% of age determinations
Charcoal	553	64.7
Shell – marine	221	25.8
Shell – freshwater	62	7.3
Other	19	2.2
Total	855	100

Table 5. Proportions of different materials dated '(excluding 42 Unreliable determinations)

Major issues and key learnings

The presentation and detailed analysis of the verified dataset are the subject of a report to the VAHR (Kurpiel et al. 2020) and publications in preparation, but in the meantime it is important to discuss some of the major issues and key learnings that we identified during the data-verification process. The issues fall into three major interrelated categories: data presentation, methodology, and changing dating techniques.

Data presentation

As noted above, many of the original sources we reviewed do not include the radiocarbon laboratory report. Our data-verification process also revealed that typographic errors and inconsistencies are common in the presentation of radiocarbon age determinations. These errors often then become replicated and entrenched in secondary sources as authors did not check the original sources, and potentially misrepresented further by subsequent typographic errors and inconsistencies.

Our work to date has highlighted the importance of including a copy of the original lab report for each

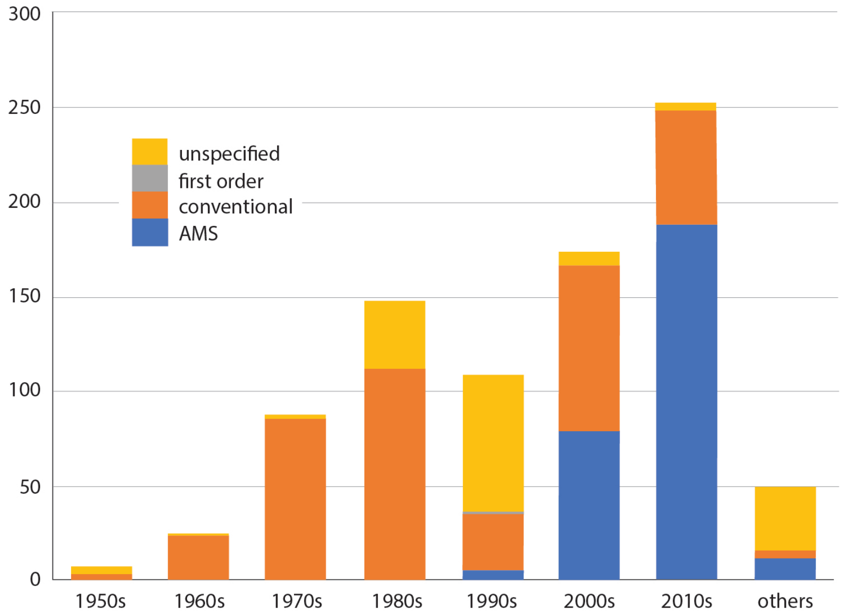


Figure 1. Counts of radiocarbon age determinations generated in Victoria for each decade since the 1950s. This breakdown also shows changes in methods of radiocarbon dating over time

radiocarbon age determination in archaeological reports and publications (e.g. in Supplementary Information) to provide essential information about these ages and reduce errors in their reporting. In most cases, it was not possible to verify ages effectively without this information.

Methodology

Numerous dated samples lack a clear association with cultural remains, while the grounds for determining whether shell, charcoal and 'possible hearths' are cultural or natural are often unclear or not discussed. In other cases, stratigraphic integrity is assumed rather than demonstrated (where contextual details are provided, which was often not the case). Relatively few studies have dated multiple samples from the same stratigraphic unit and/or excavation trench to investigate whether ages appear in stratigraphic sequence; many extrapolate information about chronology based on a single sample from an excavation trench and/or site, where in fact multiple ages are required to build a robust chronology. As well as providing reassurance about stratigraphic integrity, obtaining multiple ages provides opportunities to compare different dating techniques (e.g. radiocarbon vs optically stimulated luminescence) or to compare different materials (e.g. charcoal vs shell, to generate information about the marine reservoir effect).

One, perhaps surprising, learning from the data-verification process and review of CHMPs and other cultural heritage assessments is that archaeologists sometimes find suitable material for dating but do not collect or date it. This, in part, reflects the development-driven nature of most archaeological investigations in Victoria, where profitability is a significant factor in the commodification of Aboriginal cultural heritage and archaeology (Zorzin 2014). However, it represents a missed opportunity to develop more detailed insights into the chronology of Aboriginal places and change over time.

Changing dating techniques

The techniques and technology used to generate radiocarbon age determinations have changed significantly since Libby first pioneered the radiocarbon dating technique (Libby 1952; Van Strydonck 2017). Although most archaeologists have a general understanding of the principles behind radiocarbon dating, the science has become increasingly complex and the gap in mutual understanding between archaeologists and radiocarbon laboratory specialists is problematic (Bronk Ramsey 2008; Wood 2015).

'Older dates' (in the sense of when they were submitted for dating) were often obtained using techniques now deemed unreliable, particularly in relation to the collection and pre-treatment of samples, and the calibration of dates. Additionally, the 'scant details published alongside the majority of dates means assessment of their quality is impossible, either in terms of association with archaeology or accuracy of the number' (Wood 2015:61).

The standard deviations for 'older dates' are often much larger than is achievable and acceptable today, while many laboratories in the mid-1970s did not yet use the $\delta^{13}C$ correction, to take into account variations in $\delta^{13}C$ due to non-climatic factors (Van Strydonck 2017:1242, 1244). 'Older dates' also tend to be more difficult to verify, since numerous radiocarbon laboratories are no longer operational, do not have good or accessible archives, or have lost data. Similarly, different dating laboratories have slightly different methodologies, pre-treatment techniques and standards, which further inhibit the comparison of dates (Waterbolk 1971:19–20).

Chronologically older dates (i.e. early Holocene/late Pleistocene) also suffer greater taphonomic biases, particularly given sea-level rises since the Last Glacial Maximum (Frankel 1991). These dates tend to have larger standard deviations and are also more sensitive to contaminants, a fact most archaeologists are aware of (Wood 2015:68).

The variation in reliability of radiocarbon age determinations submitted over time raises questions over the broader research value of these sorts of datasets. Wood (2015:68) argues that it 'is simply impossible to assess the quality of the vast majority of published radiocarbon dates with any certainty. As a result, it is difficult to include the majority of published radiocarbon dates in statistical analyses to produce high-precision chronologies in the Holocene, or accurate chronologies in the Pleistocene'. This issue, as well as others, has led some researchers to challenge the validity of the 'dates as data' / population proxy studies pioneered by Rick (1987) in the 1980s (Becerra-Valdivia et al. 2020; Contreras and Meadows 2014, inter alia).

Future work

The data-verification process is merely the first, albeit significant, stage of the Radiocarbon Dating Visualisation Project. Although we intend to publish further papers which analyse the dataset in more detail, we are committed to making the dataset accessible to Traditional Owners, Heritage Advisors and researchers within the appropriate access restrictions of the VAHR. We are currently exploring a variety of ways of making the dataset more dynamic, spatially based and visual than a simple spreadsheet to download.

We intend to update the VAHR so that the 'earmark facility', which highlights key features of a report, more accurately identifies reports with dating information to assist in searching the register. Further work is also required to create place registrations for radiocarbon age determinations which are currently not associated with registered places.

Another part of the project is to present the radiocarbon age determinations to a more general audience, via Matthew Coller's Time Machine/Temporal Earth model—the successor to Sahul Time (Coller 2009; < https://temporalearth.org/ >). This has the potential to model radiocarbon age determinations in conjunction with the effects of sea-level and climate/environmental change over time, and create a time-lapse animation of radiocarbon age determinations for Victoria. Dynamic forms of data visualisation have the potential to transform a dataset into a stimulating narrative exploring the time depth and changing nature of Aboriginal settlement in Victoria, whilst acknowledging its limitations.

Lastly, AV intends to publish a Practice Note for radiocarbon dating, drawing on existing advice from radiocarbon laboratories and standard archaeological practice (Millard 2014), while an online database with clear compulsory fields would help to force complete publication (Wood 2015:69). That said, archaeologists are required to submit radiocarbon age determinations to the VAHR but often forget to, and Wood (2015:69) notes that guidelines have been available since 1959, yet significant problems remain.

Conclusions

The verified list of 968 radiocarbon age determinations for Aboriginal places in Victoria has created a useful dataset for future generations while also highlighting several areas of concern. It is crucial that relevant laboratory reports are included in publications and archaeological reports, but other agreed standards in generating and reporting radiocarbon age determinations seem to be required. This will be addressed through the publication of a Practice Note by AV. The Radiocarbon Dating Visualisation Project has laid a foundation for creating an accurate dataset of radiocarbon age determinations for Victoria, and for building on this dataset in a way that improves scientific understanding of the dates of Aboriginal places in Victoria.

Acknowledgements

We would like to acknowledge the Traditional Owners whose ancestors have long inhabited Victoria, archaeologists who have taken samples for dating, their Sponsors/funding bodies who have paid for the dating, and the numerous researchers who have previously compiled lists of radiocarbon age determinations. The verification stage of the project has been funded by Aboriginal Victoria, with a contribution from La Trobe University—we are very grateful to Harry Webber (Aboriginal Victoria) and Prof. Andy Herries (La Trobe University) for their ongoing support of the project. The verification process would have been a lot more difficult, and less complete, without the assistance of the major dating laboratories—in particular, we would like to thank Dr Fiona Petchey (University of Waikato), Dr Rachel Wood (ANU) and Ron Hatfield (Beta Analytic) for the information, insights and advice they provided.

References

Becerra-Valdivia, L., R. Leal-Cervantes, R. Wood and T. Higham 2020 Challenges in sample processing within radiocarbon dating and their impact in ^{14}C-dates-as-data studies. *Journal of Archaeological Science* 113:105043 DOI: <https://doi.org/10.1016/j.jas.2019.105043>

Bird, C.F.M. and D. Frankel 1991 Chronology and explanation in western Victoria and south-east South Australia. *Archaeology in Oceania* 26(1):1–16

Bronk Ramsey, C. 2008 Radiocarbon dating: revolutions in understanding. *Archaeometry* 50(2):249–275

Bronk Ramsey, C., M.W. Dee, J.M. Rowland, T.F.G. Higham, S.A. Harris, F. Brock, A. Quiles, E.M. Wild, E.S. Marcus and A.J. Shortland 2010. Radiocarbon-based chronology for dynastic Egypt. *Science* 328:1554–1557

Coller, M. 2009 SahulTime: rethinking archaeological representation in the digital age. *Archaeologies*

5(1):110–123

Contreras, D.A. and J. Meadows 2014 Summed radiocarbon calibrations as a population proxy: a critical evaluation using a realistic approach. *Journal of Archaeological Science* 52:591–608

Frankel, D. 1991 First-order radiocarbon dating of Australian shell middens. *Antiquity* 65(248):571–574

Gill, E.D. 1953 Geological evidence in Western Victoria relative to the antiquity of the Australian Aborigines. *Memoirs of the National Museum of Victoria* 18:25–92

Godfrey, M.C.S., C.F.M. Bird, D. Frankel, J.W. Rhoads and S. Simmons 1996 From time to time: radiocarbon information on Victorian archaeological sites held by Aboriginal Affairs Victoria. *The Artefact* 19:3–51

Jacobsson, P. 2019 Challenges and prospects for building radiocarbon chronologies of the earlier Holocene of the Levant. *Levant* 51(1):6–25. DOI: <https://doi.org/10.1080/00758914.2019.1689747>

Kurpiel, R., D.C. Thomas, C. Spry, J. Tumney 2020. Radiocarbon Dating Visualisation Project for Victoria. Unpublished report prepared for Aboriginal Victoria, accessible from < https://doi.org/10.26181/5f41f7247da76 >

Libby, W.F. 1952 *Radiocarbon Dating*. Chicago: University of Chicago Press

Loftus, E., P.J. Mitchell and C. Bronk Ramsey 2019 An archaeological radiocarbon database for southern Africa. *Antiquity* 93(370):870–885

Millard, A.R. 2014 Conventions for reporting radiocarbon determinations. *Radiocarbon* 56:555–559

Polach, H.A., M.J. Head and J.D. Gower 1978 ANU Radiocarbon Date List VI. *Radiocarbon* 20(3):360–85

Rick, J.W. 1987 Dates as data: an examination of the Peruvian preceramic radiocarbon record. *American Antiquity* 52:55–73

Rodríguez-Rey M., S. Herrando-Pérez, R. Gillespie, Z. Jacobs, F. Saltré, B.W. Brook, G.J. Prideaux, R.G. Roberts, A. Cooper, J. Alroy, G.H. Miller, M.I. Bird, C.N. Johnson, N. Beeton, C.S.M. Turney and C.J.A. Bradshaw 2015 Criteria for assessing the quality of Middle Pleistocene to Holocene vertebrate fossil ages. *Quaternary Geochronology* 30:69–79

Shortland, A.J. and C. Bronk Ramsey 2013 *Radiocarbon and the Chronologies of Ancient Egypt*. Oxford and Oakville: Oxbow Books

Thomas, D.C., A. Martin and W. van der Stelt 2018 A radiocarbon dating visualisation project for Aboriginal places in Victoria. *Excavations, Surveys, and Heritage Management in Victoria* 7:13–17

Van Strydonck, M. 2017 A personal reflection on 40 years of radiocarbon dating and archaeology. *Radiocarbon* 59(5):1241–1250

Vines, G. 2015. Radiocarbon dates in Victoria. Retrieved 3 March 2020 via <https://www.researchgate.net/publication/281276982_Radiocarbon_dates_in_Victoria>

Waterbolk, H.T. 1971 Working with radiocarbon dates. *Proceedings of the Prehistoric Society* 37:15–33

Williams, A.N., S. Ulm, M.A. Smith and J. Reid 2014 AustArch: a database of ^{14}C and non-^{14}C ages from archaeological sites in Australia—composition, compilation and review (data paper). *Internet Archaeology* 36. retrieved 3 March 2020 via <https://doi.org/10.11141/ia.36.6>

Wood, R. 2015 From revolution to convention: the past, present and future of radiocarbon dating. *Journal of Archaeological Science* 56:61–72

Zorzin, N. 2014 Heritage management and Aboriginal Australians: relations in a global, neoliberal economy—a contemporary case study from Victoria. *Archaeologies: Journal of the World Archaeological Congress* 10:132

Investigating marsupial bone weathering: implications for understanding the taphonomy of Australian zooarchaeological assemblages

Kimberley Crabtree and Jillian Garvey

Abstract

Modern baseline data is necessary to understand the taphonomic or depositional history of a faunal assemblage. Taphonomy investigates what happens to an animal from its time of death until it becomes part of the archaeological or palaeontological record. In Australia, we have had to routinely rely on international models of bone taphonomy including Behrensmeyer's (1978) bone-weathering stages. The majority of these studies have focused on exotic placental ungulates (medium to large-sized hooved mammals such as sheep, pig and cattle) making the results difficult to apply to Australia's endemic, predominately marsupial fauna. To try and provide baseline data the 'Victorian Native Animal Body Farm' was established in the La Trobe University Wildlife Sanctuary in 2016. Currently focusing on macropods (Eastern grey kangaroo and Swamp wallaby) and wombats, this experiment is aimed at investigating bone-weathering patterns for these taxa. Whilst more time is required to generate comprehensive data, the preliminary results presented here indicate that only approximately 25% of the total experimental assemblage are consistent with Behrensmeyer's (1978) bone-weathering stages. This may be due to limited scavenger access to the carcasses, the retention of soft tissue and fur on the specimens, the cooler and temperate climate of Victoria, and/or that these are marsupials. Furthermore, there appears to be differences between the way that macropod and wombat marsupial carcasses decompose and weather. These preliminary results provide important baseline data for bone weathering specific to macropods and wombats in Victorian contexts. To further understand marsupial bone weathering, the current carcasses will continue to be monitored. This will aid in generating more Victorian specific data that can also be applied to the wider Australian zooarchaeological record to better understand site formation processes.

Department of Archaeology and History, La Trobe University, Melbourne, Vic. 3086.

kecrabtree@hotmail.com

Introduction

Zooarchaeology focuses on the remains of animals in the archaeological record to assist with interpreting past human behaviour such as hunting, butchery patterns and use of the landscape, as well as paleoenvironmental reconstruction (Reitz and Wing 2008). In zooarchaeology, taphonomy investigates the processes that create and modify bone assemblages from the time that an animal dies until it is found in the archaeological record (Behrensmeyer and Kidwell 1985; O'Connor 2000:19). One way to better understand the taphonomic record is to study modern analogues to identify the effects of various depositional processes on bone preservation (Hill 1979). Bone weathering is one such area of taphonomic research; with the 'weathering of bones [by] the chemical and mechanical deterioration and destruction occurring over time' (Lyman and Fox 1997:293). Bone weathering can be used to describe the post-mortem changes that alter either the chemical composition or physical condition of skeletal remains. It can also be used to infer time since death, local soil conditions and chemistry, and temperature and humidity. Thus, it can generate important information regarding the time period over which bone assemblages were deposited.

Behrensmeyer's (1978) seminal research on bone-weathering stages is commonly applied to bone assemblages to ascertain the time since death and burial. Over a two year period, Behrensmeyer (1978) observed several large placental ungulate taxa, including zebra (*Equus burchelli*), wildebeest (*Connochaetes taurinus*), cow (*Bos taurus*), and Grant's gazelle (*Gazella granti*), with a known date-of-death in dense and open woodland, swamp, bush and lakebed habitats within the Amboseli Basin, Southern Kenya. She noted that these animals had six stages of distinctive weathering characteristics (**Table 1**). Despite the importance of this research, there have been limited follow-up studies conducted, primarily because the process of generating bone-weathering data takes a significant amount of time (Blau 2017).

In Australia, there has been comparatively little zooarchaeological research, particularly studies of

Stage number	Time since death (years)	Description
0	0–1	Bone surface shows no sign of cracking or flaking due to weathering. Usually bone is still greasy, marrow cavities contain tissue, skin and muscle/ligament may cover part or all of the bone surface
1	0–3	Bone shows cracking, parallel to the fibre structure. Articular surfaces may show mosaic cracking of covering tissue as well as in the bone itself. Fat, skin and other tissue may or may not be present
2	2–6	Outermost concentric thin layers of bone show flaking usually associated with cracks. The long bone edges along the cracks tend to separate and flake first. Long, thin flakes with one or more sides still attached to the bone are common in the initial part of Stage 2. Deeper and more extensive flaking follows, until most of the outermost bone is gone. Crack edges are usually angular in cross section. Remnants of ligaments, cartilage and skin may be present
3	4–15	Bone surface is characterised by patches of rough, homogenously weathered compact bone, resulting in a fibrous texture. In these patches, all the external, concentrically layered bone has been removed. Gradually the patches extend to cover the entire bone surface. Weathering does not penetrate deeper then 1.0–1.5 mm and bone fibres are still firmly attached to each other. Crack edges usually are rounded in cross-section. Tissue rarely present at this stage
4	6–15	Bone surface is coarsely fibrous and rough in texture; large and small splinters occur and may be loose enough to fall away from the bone when it is removed. Weathering penetrates the inner cavities. Cracks are open and have splintered, rounded edges.
5	6–15	Bone is falling apart in situ, with large splinters lying around what remains of the whole, which is fragile and easily broken by moving. Original bone shape may be difficult to determine. Cancellous bone usually is exposed, and when present may outlast all traces of the former more compact outer parts of the bones

Table 1. Behrensmeyer's (1978:151) bone weathering indices

bone weathering. This is likely in part a reflection of the small number of focused zooarchaeology courses, meaning that there are only a few formally trained zooarchaeological specialists compared to Europe and North America (Cosgrove 2002). Due to the scarcity of Australian-based taphonomic research, interpretations of Australian archaeological and palaeontological assemblages have had to commonly rely on taphonomic models generated elsewhere (e.g. Dortch et al. 2016; Garvey et al. 2016; Fillios et al. 2010a, 2010b; Littleton 2000). This is problematic as the application of overseas' taphonomic models, including Behrensmeyer's (1978) bone-weathering data, is difficult to apply to Australia's unique, predominately marsupial fauna, as these studies focused on placental ungulates in different geographic and environmental conditions.

This scarcity highlights the necessity to create baseline data for marsupial bone to assist in understanding the zooarchaeological record in Victorian contexts. In response to this issue, the 'Victorian Native Animal Body Farm' was established in 2016 (Crabtree 2017). This project aimed to investigate the decomposition, disarticulation and initial stages of bone weathering, in order to compare the results with Victorian bone assemblages containing macropod and wombat bones. Macropods and wombats were chosen for the investigation of bone weathering as both species are commonly found as road-kill in south-eastern Australia (Butt 2016), there has been limited research on both species, and modern macropods and wombats can potentially be used as analogues for their extinct larger relatives. Further, macropods and wombats, although the latter is not as common, are both found in Aboriginal sites, and macropods sometimes occur in historical assemblages (Fillios and Blake 2015).

This paper presents the preliminary results of bone weathering for the first (almost) 3.5 years of the project. This baseline data has the potential to assist with the analysis and interpretation of Victorian palaeontological and archaeological assemblages.

Methods

The Victorian Native Animal Body Farm is located in the La Trobe University Wildlife Sanctuary in Bundoora, 19 km north of the Melbourne CBD, Victoria. Four macropods (three Eastern grey kangaroos *Macropus giganteus,* EGK #1, EGK #2 and EGK #3, and a Swamp wallaby *Wallabia bicolor* SW #1) and two Common wombats (*Vombatus ursinus,* CW #1 and CW #2) specimens were collected as fresh roadkill from Victorian public roads under research permit 10006756 under the *Wildlife Act 1975* (VIC) (**Table 2**).

The carcasses were stored in a chest freezer at La Trobe University until enough samples had been collected to begin the experiment. The animals were laid out at the same time (13/05/2016) to ensure they were subjected to the same environmental and temperature

Species	***Macropus giganteus***	***Macropus giganteus***	***Macropus giganteus***	***Wallabia bicolor***	***Vombatus ursinus***	***Vombatus ursinus***
Common name	Eastern Grey Kangaroo	Eastern Grey Kangaroo	Eastern Grey Kangaroo	Swamp Wallaby	Common Wombat	Common Wombat
Field ID	EGK #1	EGK #2	EGK #3	SW #1	CW #1	CW #2
Sex	Male	Female	Female	Female	Male	Female
Age	Adult	Juvenile	Juvenile	Adult	Adult	Adult
Date of collection	14/04/2016	15/05/2016	29/04/2016	20/10/2015	6/05/2016	6/05/2016
Collector	Kimberley Crabtree	Kimberley Crabtree	Kimberley Crabtree	Jillian Garvey	Kimberley Crabtree	Kimberley Crabtree
Weight (kg)	34	9	8.5	23	26	17
Cause of death	Vehicle trauma	Vehicle trauma	Vehicle trauma	Vehicle trauma	Vehicle trauma	Vehicle Trauma
Area	Hesket	Hurstbridge	Craigieburn	North Warrandyte	Macedon	Macedon
Coordinates	-37.2923 114.7455	-37.639895 145.215004	-37.601661 144.957405	-37.729481 145.229835	37.392686 144.592461	-37.359412 144.585603

Table 2. Information regarding the specimens as required by research permit 10006756

conditions. An initial bone-weathering experiment conducted in the La Trobe Wildlife Sanctuary by JG in 2015 was abruptly terminated after the animal carcasses were completely scavenged by foxes. To avoid this happening again, homemade chicken-wire cages were placed over the carcasses.

Over approximately 3.5 years (between 13/05/2016 and 15/10/2019), the carcasses were inspected 29 times. Initially, the carcasses were monitored once every few days. Then, as the decomposition and weathering process slowed, monitoring occurred less often. Table 3 indicates that the weathering on the bones was not recorded until more than 8 months after the experiment commenced, on Recording Day 21. Prior to this the carcasses were recorded as undergoing the initial stages of decomposition including bloating, active decay, dehydration, skeletonisation and insect activity (**Tables 3** and **5**).

Bone weathering was monitored via visual inspection by the senior author. Large and easily identifiable skeletal elements including the long bones, pelvis, crania and mandibles were individually inspected for weathering. Alternatively, the smaller, more compact, and hence difficult to individually identify and record elements such as the ribs, metacarpals, metatarsals, carpals, tarsals, phalanges and vertebrae were grouped according to their specific body part. Each of these smaller groups were then analysed as an 'elemental unit' (**Table 4**). Therefore, as outlined in Table 4, using this method the 180 individual bones per macropod and the 184 individual bones per wombat, have been reduced to 41 element units per individual. It should be noted that one of the macropods (EGK#2) had only 38 element units recorded as it was missing the distal part of its lower right hind leg. Therefore, the total 'element unit' NISP for this assemblage was calculated from the three complete macropods EGK#1, EGK#3 and SW#1 (3x 41 = NISP 123), the 2 complete wombats CW#1 and CW#2 (2x 41 = NISP 82), and the incomplete macropod EGK#2 (NISP 38) with a total NISP of 243 (123 + 82 + 38). For the remainder of this paper the reduced NISPs that include the elemental units outlined in Table 4 will be used.

The carcasses were photographed, and the temperature and rainfall data were logged. Insect activity and the stages of decomposition were also recorded. Behrensmeyer's (1978) six-stage weathering system was used to measure the stages of bone weathering (**Table 1**).

Results

Over the 3.5 years of the experiment, weathering was observed on approximately 25% of all skeletal elements, or 61 bones of the total element unit NISP of 243 (this is derived from the element units of the macropods and wombats outlined in **Table 4**) from the six carcasses.

These results are similar to Behrensmeyer's (1978) observations where ungulate bones displayed Stage 1 weathering after three or four years of exposure. For example, as indicated in **Table 3**, after eight months only one of the macropod bones had reached Weathering Stage 1, and after almost three and a half years only 45 (28%) of the macropod bones had reached Weathering Stage 1. This was predominately observed on the long limb bones which exhibited cracking parallel to the fibre

Recording day	Date	Time elapsed	Changes observed
1	13/05/2016	0 days	EGK#2, EGK#3, SW#1 – Stage 1 of decomposition. EGK#1, CW#1, CW#2 – Stage 2 of decomposition.
2	14/05/2016	1 day	
3	18/05/2016	5 days	EGK#2, EGK#3, SW#1 – Stage 2 of decomposition
4	22/05/2016	1 week, 2 days	
5	26/05/2016	1 week, 6 days	CW#1 – Stage 3 of decomposition
6	28/05/2016	1 week, 8 days	
7	02/06/2016	2 weeks, 6 days	EGK#3 – Stage 3 of decomposition
8	09/06/2016	3 weeks, 6 days	EGK#2 – Stage 3 of decomposition
9	16/06/2016	1 month, 3 days	
10	27/06/2016	1 month, 14 days	
11	06/07/2016	1 month, 23 days	
12	18/07/2016	2 months, 5 days	EGK#2 – Transitioning between Stage 3 and Stage 4 of decomposition, joint disarticulation begins. SW#1 – Transitioning between Stage 2 and Stage 3 of decomposition CW#1 – Stage 4 of decomposition
13	02/08/2016	2 months, 20 days	EGK#1 – Transitioning between Stage 2 and Stage 3 of decomposition EGK#2 – Stage 4 of decomposition SW#1 – Stage 3 of decomposition
14	22/08/2016	3 months, 9 days	EGK#1 – Stage 3 of decomposition
15	19/09/2016	4 months, 6 days	EGK#1 – Joint disarticulation begins EGK#3 – Stage 4 of decomposition CW#1 – Transitioning between Stage 3 and Stage 4 of decomposition CW#2 – Joint disarticulation begins
16	17/10/2016	5 months, 4 days	CW#1 – Stage 4 of decomposition SW#1 – Transitioning between Stage 3 and Stage 4 of decomposition EGK#1 – Joint disarticulation begins
17	31/10/2016	5 months, 18 days	SW#1 – Stage 4 of decomposition
18	15/11/2016	6 months, 2 days	
19	01/12/2016	6 months, 18 days	SW#1 – Joint disarticulation begins
20*	21/12/2016 23/12/2016	7 months, 8 days 7 months, 10 days	
21*	16/01/2017 18/01/2017	8 months, 3 days 8 months, 5 days	CW#1 – Joint disarticulation begins All specimens display joint disarticulation
22	08/02/2017	8 months, 26 days	EGK#1 – Transition between Stage 3 and Stage 4 of decomposition EGK#2 – Transitioning between Stage 4 and Stage 5 of decomposition
23*	28/02/2017 03/03/2017	9 months, 15 days 9 months, 18 days	EGK#1 – Stage 4 of decomposition EGK#2 – Stage 5 of decomposition
24*	26/03/2017 28/03/2017	10 months, 13 days 10 months, 15 days	
25	19/04/2017	11 months, 6 days	
26	13/05/2017	1 year	EGK#3 – Stage 5 of decomposition SW#1 – Stage 5 of decomposition
27	24/06/2018	2 years, 1 month and 11 days	EGK#1, CW#1, CW#2 – Stage 5 of decomposition All specimens have reached Stage 5 of decomposition
28	25/03/2019	2 years, 10 months and 12 days	
29	15/10/2019	3 years, 5 months and 2 days	

*Table 3. Recording days, date, time elapsed and changes observed over almost three and a half years for EGK #1, EGK #2, EGK #3, SW #1, CW#1 and CW #2. Stage 1 of decomposition is classified by fresh decay, Stage 2 by bloating, Stage 3 as active decay, Stage 4 by dehydration and Stage 5 as skeletonisation (Goff 2009). *indicates that this 'recording day' was conducted over 2 to 3 days due to time constraints*

Element or Body Part	Symmetry	Macropods EGK#1, EGK#3 and SW#1		EGK#2		CW#1 and CW#2	
		Individual bones	Element Unit	Individual bones	Element Unit	Individual bones	Element Unit
Crania	Midline	1	1	1	1	1	1
Mandible	Left	1	1	1	1	1	1
	Right	1	1	1	1	1	1
Clavicle	Left	1	1	1	1	1	1
	Right	1	1	1	1	1	1
Scapula	Left	1	1	1	1	1	1
	Right	1	1	1	1	1	1
Humerus	Left	1	1	1	1	1	1
	Right	1	1	1	1	1	1
Ulna	Left	1	1	1	1	1	1
	Right	1	1	1	1	1	1
Radius	Left	1	1	1	1	1	1
	Right	1	1	1	1	1	1
Carpals	Left	5	1	5	1	5	1
	Right	5	1	5	1	5	1
Metacarpals	Left	5	1	5	1	5	1
	Right	5	1	5	1	5	1
Phalanges (Manus)	Left	14	1	14	1	14	1
	Right	14	1	14	1	14	1
Cervical vertebrae	Midline	5	1	5	1	5	1
Thoracic vertebrae	Midline	12	1	12	1	12	1
Lumbar vertebrae	Midline	6	1	6	1	6	1
Caudal vertebrae	Midline	19	1	19	1	19	1
Ribs	Left and right combined	24	1	24	1	24	1
Sacrum	Midline	1	1	1	1	1	1
Pelvis	Left and right combined	1	1	1	1	1	1
Sternum	Midline	1	1	1	1	1	1
Femur	Left	1	1	1	1	1	1
	Right	1	1	1	1	1	1
Tibia	Left	1	1	1	1	1	1
	Right	1	1	1	1	1	1
Fibula	Left	1	1	1	1	1	1
	Right	1	1	1	1	1	1
Patella	Left	1	1	1	1	1	1
	Right	1	1	1	1	1	1
Tarsals	Left	5	1	5	1	5	1
	Right	5	1	-	-	5	1
Metatarsals	Left	4	1	4	1	4	1
	Right	4	1	-	-	4	1
Phalanges (Pes)	Left	12	1	12	1	14	1
	Right	12	1	-	-	14	1
TOTAL		180	41	159	38	184	41

Table 4. The individual bones per animal and the element unit grouping of bones used in this experiment

Day	Stage 0			Stage 1			Stage 2		
	EGKs	SW	CW	EGKs	SW	CW	EGKs	SW	CW
1	100	100	100	0	0	0	0	0	0
2	100	100	100	0	0	0	0	0	0
3	100	100	100	0	0	0	0	0	0
4	100	100	100	0	0	0	0	0	0
5	100	100	100	0	0	0	0	0	0
6	100	100	100	0	0	0	0	0	0
7	100	100	100	0	0	0	0	0	0
8	100	100	100	0	0	0	0	0	0
9	100	100	100	0	0	0	0	0	0
10	100	100	100	0	0	0	0	0	0
11	100	100	100	0	0	0	0	0	0
12	100	100	100	0	0	0	0	0	0
13	100	100	100	0	0	0	0	0	0
14	100	100	100	0	0	0	0	0	0
15	100	100	100	0	0	0	0	0	0
16	100	100	100	0	0	0	0	0	0
17	100	100	100	0	0	0	0	0	0
18	100	100	100	0	0	0	0	0	0
19	100	100	100	0	0	0	0	0	0
20	100	100	100	0	0	0	0	0	0
21	99	100	100	1	0	0	0	0	0
22	99	100	100	1	0	0	0	0	0
23	99	100	100	1	0	0	0	0	0
24	99	100	100	1	0	0	0	0	0
25	99	100	100	1	0	0	0	0	0
26	99	95	100	1	5	0	0	0	0
27	85	93	98	13	7	2	2	0	0
28	73	90	95	21	10	5	6	0	0
29	58	85	95	32	15	5	10	0	0

Table 5. Percentage of specimens displaying bone weathering for Eastern grey kangaroos (EGKs), Swamp wallaby (SW) and Common wombat (CW)

structure (**Figure 1**). Behrensmeyer (1978) recorded similar observations with parallel cracking occurring on ungulate long bones.

A small proportion of the macropod bones (NISP = 2, 1%) began to display Weathering Stage 2 after two years (Recording Day 27). After almost three and a half years, just 12 (7%) macropod bones exhibited characteristics consistent with Behrensmeyer's (1978) Weathering Stage 2. This was common on elements such as the metatarsals, tibia, fibula, humerus, crania, femur, pelvis, radius and ulna of the macropods. These bones had incipient flaking that was typically associated with longer cracks that had developed during Stage 1 (**Figure 1**). Behrensmeyer (1978) noted that Stage 2 occurred on her ungulate bones after two to six years of exposure.

Interestingly, several macropod skeletal elements were first recorded being at Stage 2 (skipping Stage 1): flaking of cortical bone was observed on the skull of EGK #2; and on the pelvis, sacral vertebrae, metatarsal, radius and ulna of EGK #1. Overall, a higher percentage of bone weathering was observed on the macropod elements (NISP = 57, 35%) compared to the wombat (NISP = 4, 5%). Furthermore, bone weathering was more commonly observed on the Eastern grey kangaroo specimens compared to the Swamp wallaby. No wombat bones reached Stage 2 weathering at the end of this

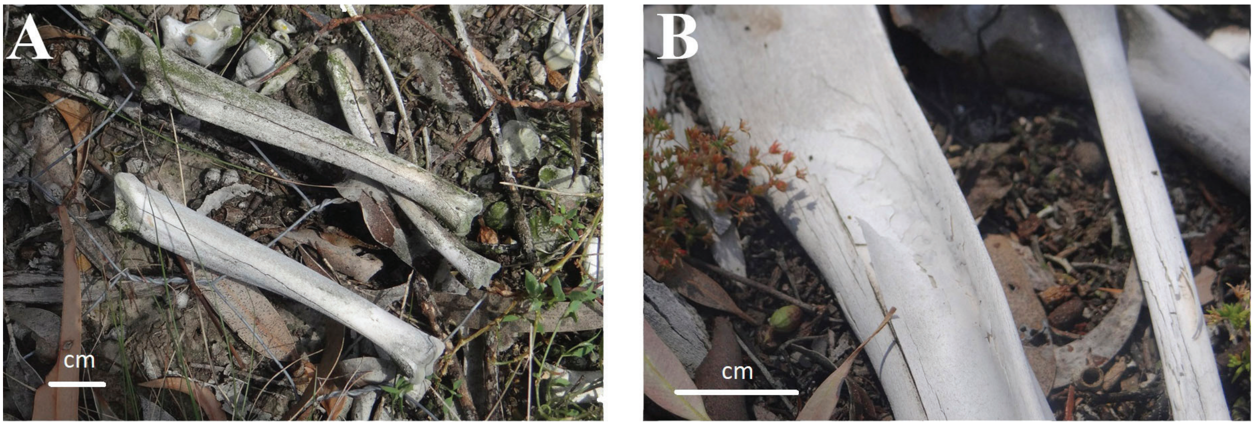


Figure 1. The progression of weathering on the macropods: A) Weathering Stage 1 on EGK#3 on the fourth metatarsal on Recording Day 29; B) Weathering Stage 2 on the tibia of EGK#1 on Recording Day 29

experiment (Recording Day 29) (**Table 5**), and both carcasses still retained much of their thick pelts. Overall, it was noted that decomposition and skeletonisation was a slow process, with only the macropods becoming fully skeletonised after 3.5 years (**Table 3**). Skeletonisation is the final stage of decomposition where the last remnants of soft tissues disappear, and the skeleton is exposed.

Discussion

The results from this experiment provide important preliminary baseline data on how marsupial bones weather in Victorian contexts and suggest that different skeletal elements can produce different weathering patterns. For example, flaking on macropod bone, which is typically associated with Weathering Stage 2, is more common on the flat and irregular shaped elements such as the crania, vertebrae and pelvis. It is also a minor component of the long skeletal elements before Weathering Stage 1. Cunningham et al. (2011) also observed differences of weathering between skeletal elements in their study of juvenile pigs (*Sus scrofa*). The results indicated that specific skeletal elements (metacarpals, metatarsals and phalanges) were more prone to flaking of the outer layers of cortical bone, whilst the long bones, vertebrae and ribs were more likely to have loss of bone at the articular facets. In addition to variations of weathering patterns on different skeletal elements, differences of bone weathering can also be due to placental versus marsupial bones, juveniles versus adults, sexual dimorphism, as well as ecological and climatic variation. Future research into these variables would be beneficial.

Behrensmeyer (1978) observed that ungulate bones reached Weathering Stage 1 between 0 to 3 years, thus implying that the entire skeleton underwent some degree of weathering during this time. This contrasts with this experiment where 75% of the total number of skeletal elements (NISP = 109, 68% of the macropod bones and NISP = 78, 95% of the wombat bones) did not exhibit any weathering (Stage 0) after three and a half years. This difference may be due to the cooler and more temperate Victorian climate, limited scavenger access, and the retention of soft tissue and fur on the specimens, especially the wombats.

Previous studies suggest that environment and climate can affect the appearance of weathered bones (Blau 2017; Marden et al. 2013). Cooler temperatures have been found to slow the process of decomposition (Bunch 2009; Carter and Tibbet 2008) and can have a significant effect on skeletonisation (Rodriguez and Bass 1983). Overall, Victoria has a milder climate than other Australian mainland states (Menkhorst 1996), and this experiment commenced in late autumn. Typically, the earlier stages of decomposition occur quite rapidly (Carter and Tibbett 2008), however, this may have been hindered by the cooler temperatures. Additionally, as mentioned earlier, weathering may have been slowed by the use of protective cages, as previous Australian research has indicated that scavengers influence carcass breakdown (e.g. Brown et al. 2006; Cameron 2008; O'Brien et al. 2007; Reed 2001). Together these characteristics may have slowed the decomposition and skeletonisation of the carcasses, leading to slower rates of bone weathering due to reduced periods of aerial exposure.

Furthermore, the observed differences in weathering between macropods and wombats may be explained by their anatomy and morphology. Wombats retained their fur thick pelt after almost three and a half years, whilst the macropods had typically skeletonised (**Figure 2**). The average thickness of wombat pelts from mainland Australia ranges between 3.88 and 5.02 mm, weighing between 1.18 and 3.75 kg; fat around the body is evenly distributed (Garvey et al. 2016). In contrast, macropods are leaner, with a smaller amount of body fat (Garvey 2010:148). The anatomical and morphological variation between these two groups could have affected decomposition rates, and subsequent skeletonisation,

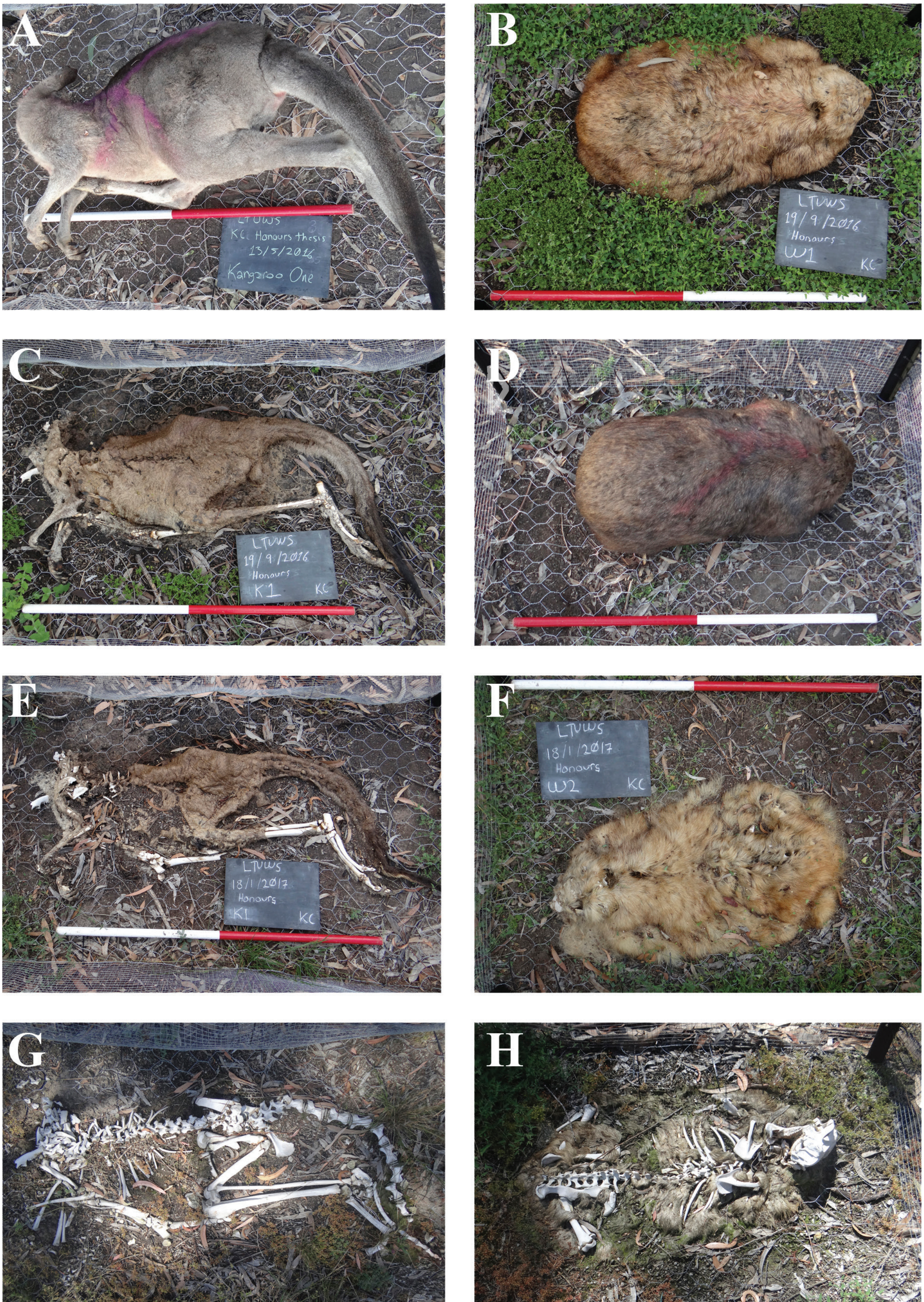


Figure 2: The differences in skeletonisation of EGK #1 (left) and CW #1 (right); A and B on Recording day 1; C and D on Recording day 15; E and F on Recording day 21; and G and H on Recording day 29

producing a slower rate of bone weathering for the wombats.

Conclusion

This bone-weathering experiment is ongoing, with monitoring occurring several times a year. It is also anticipated that other native species will be added. The experiment is also being utilised as a teaching resource for zooarchaeology students in the Department of Archaeology and History at La Trobe University. These preliminary results indicate that Behrensmeyer's (1978) bone-weathering indices are not a uniform measure of how much time has elapsed between death and burial, with variation dependent on species, skeletal elements, and climate and ecological conditions. There may also be differences between juvenile and adult bones, and female and male specimens, however more research is needed to test these variables. The preliminary results discussed here suggest that it is important to develop taxon- and climate-specific baseline weathering data to accurately measure the time since death and the burial of archaeological assemblages. Therefore, this research has the potential to provide important data for bone weathering specific to Victorian contexts and can assist archaeologists in the interpretation of faunal remains.

Acknowledgements

We would like to acknowledge La Trobe University and the Wildlife Sanctuary for providing the location for the ongoing bone weathering experiment. We would also like to acknowledge Regan Grose and Jaq Anderson for their assistance in setting up the experiment and construction of cages; Robert 'Bobby' Fabiny, for assisting in transport of the carcasses; Kathleen Crabtree who assisted in the collection of wombat carcasses; Rachel Gedye for compiling and editing the photographs, and Talia Green, Jen Burch and Emily Evans for advice and support. Our thanks also go to the two anonymous reviewers who commented on this paper.

References

Behrensmeyer, A. 1978 Taphonomic and ecologic information from bone weathering. *Paleobiology* 4(2):150–162

Behrensmeyer, A. and S. Kidwell 1985 Taphonomy's contribution to paleobiology. *Paleobiology* 11:105–119

Blau, S. 2017 The effects of weathering on bone preservation. In E. Schotsmans, S. Forbes and N. Marquez-Grant (eds), *Taphonomy of Human Remains: Forensic Analysis of the Dead and the Depositional Environment*, pp.307–331. Oxford: John Wiley and Sons

Brown, O., J. Field and M. Letnic 2006 Variation in the taphonomic effect of scavengers in semi-arid Australia linked to rainfall and the El Niño Southern Oscillation. *International Journal of Osteoarcheology* 16:165–176

Bunch, A. 2009 The impact of Cold Climate on the Decomposition Process. *Journal of Forensic Identification* (59): 26–29

Butt, C. 2016 The animal that causes the most car crashes in Victoria. *The Age*. Retrieved 28 September 2017 from < http://www.theage.com.au/victoria/the-animal-that-causes-the-most-carcrashes-in-victoria-20160412-go46rw.htm >

Cameron, A. 2008 A forensic study of disarticulation, scattering and scavenging. Unpublished Honours thesis. Australian National University, Canberra

Carter, D. and M. Tibbett 2008 Cadaver decomposition and soil: Processes. In M. Tibbet and O. Carter (eds), *Soil Analysis in Forensic Taphonomy: Chemical and Biological Effects of Buried Human Remains*, pp. 29–35. Boca Raton, Florida: CRC Press

Cosgrove, R. 2002 The role of zooarchaeology in archaeological interpretation: A view from Australia. *Archaeofauna* 11:173–220

Crabtree, K. 2017. Investigating marsupial disarticulation and weathering: Implications for Australian zooarchaeology. Unpublished Honours thesis. Department of Archaeology and History, La Trobe University, Melbourne

Cunningham, S., S. Kirkland and A. Ross 2011 Bone weathering of juvenile-sized remains in the North Carolina Piedmont. In Ross, A. and S. Abel (eds), *The Juvenile Skeleton in Forensic Abuse Investigations*, pp. 179–196. New York: Humana Press

Dortch, J., M. Cupper, R. Grün, B. Harpley, K. Lee and J. Field 2016 The timing and cause of megafauna mass deaths at Lancefield Swamp, south-eastern Australia. *Quaternary Science Reviews* 145:161–182

Fillios, M. and N. Blake 2015 *Animal Bones in Australian Archaeology: A Field Guide to Common Native and Introduced Species*. Sydney, NSW: Sydney University Press

Fillios, M., J. Field and B. Charles 2010a Investigation of human and megafauna co-occurrence in Australian prehistory: Mode and causality in fossil accumulations at Cuddie Springs. *Quaternary International* 211:123–314

Fillios, M., C. Gordon, F. Koch and M. Letnic 2010b The effect of top a top predator on kangaroo abundance in arid Australia and its implications for archaeological faunal assemblages. *Journal of Archaeological Science* 37: 986–993

Garvey, J. 2010 Economic anatomy of the Bennett's wallaby (*Macropus rufogriseus*): Implications for understanding human hunting strategies in late Pleistocene Tasmania. *Quaternary International* 211(1): 144–156

Garvey, J., G. Roberts and R. Cosgrove 2016 Economic utility and nutritional value of the Common wombat (*Vombatus ursinus*): Evaluating Australian Aboriginal hunting and butchery patterns. *Journal of Archaeological Science* 7: 751–763

Goff, M. 2009 Early post-mortem changes and stages of decomposition in exposed cadavers. *Experimental and Applied Archaeology* 49:21–36

Hill, A. 1979 Disarticulation and scattering of mammal skeletons. *Paleobiology* 5(3):261–327

Littleton, J. 2000 Taphonomic effects of erosion on deliberately buried bodies. *Journal of Archaeological Science* 27:5–18

Lyman, L. and G. Fox 1997 A critical review of bone weathering as an indication of bone assemblage formation. In W. Haglund and M. Sorg (eds), *Forensic Taphonomy: The Post- Mortem Fate of Human Remains*, pp. 223–324. London: CRC Press

Marden, K., M. Sorg and W. Haglund 2013 Taphonomy. In E. Di Gangi and M, Moore (eds), *Research Methods in Human Skeletal Biology*, pp.241–262. London: Elsevier

Menkhorst, P. 1996 *Mammals of Victoria: Distribution, Ecology and Conservation*. Melbourne, Vic.: Oxford University Press

O'Brien, C., S. Forbes, J. Meyer and I. Dadour 2007 A preliminary investigation into the scavenging activity on pig carcasses in Western Australia. *Forensic Science, Medicine and Pathology* 3(3):194–199

O'Connor, T. 2000 *The Archaeology of Animal Bones*. College Station, Texas: Texas A&M University Press

Reed, A. 2001 Disarticulation of kangaroo skeletons in semi-arid Australia. *Australian Journal of Zoology* 49: 615–63

Reitz, E. and E. Wing 2008 *Zooarchaeology* .(2nd edition). Cambridge: Cambridge University Press

Rodriguez, W. and W. Bass 1983 Insect activity and its relationship to decay rates of human cadavers in East Tennessee. *Journal of Forensic Sciences* 28: 836–852

Applications of XRD analysis in Australian archaeological contexts: introducing the Olympus TERRA portable XRD analyser

Alice Mora

Abstract

X-ray diffraction (XRD) analysis is routinely applied to identify the crystalline phases of a wide range of geological, archaeological, and faunal materials. In recent years, industries have focused on the development of XRD instruments that are increasingly transportable, cost- and time-effective. The quality of data output of portable XRDs is becoming comparable to that of the conventional benchtop XRD systems.

The Olympus TERRA portable XRD analyser features a small vibrating sample holder that requires negligible sample amounts (10–15 mg) in powder form. It is lightweight, battery-operated and can be connected to personal devices via wireless connectivity. Reliable results can be achieved in a short timeframe (5–15 mins). Materials can be quickly analysed on-site with minimal sample destruction. These characteristics make this portable XRD a powerful tool for characterising, identifying and sourcing materials from Australian archaeological contexts.

Introduction

X-ray diffraction (XRD) analysis has proven to be a powerful tool in archaeological studies. This technique is successfully applied to characterise unknown materials and helps archaeologists in reconstructing past human behaviours. Unfortunately, the traditional benchtop XRD systems require a 'significant' amount of material in powder form, extended scanning times and a good level of expertise. These make the application of XRD analysis to archaeological materials challenging, especially in the Australian context, where quarantine regulations and ethical codes of conduct are (for good reasons) in place.

In recent years, industries have developed portable XRD instruments that require minimal sample size, are comfortably transportable, and able to generate inexpensive, quick and reliable data. Among the several portable XRDs available on the market, the Department of Archaeology and History at La Trobe University has recently acquired the Olympus TERRA portable XRD analyser, whose favourable characteristics will be highlighted in this short paper. The potential applications of XRD analysis in routine archaeological investigations across the Australian landscape will be discussed thereafter, and they include studies aiming to reconstruct past procurement and processing of raw materials, identifying if and how a material may have been heated, or assessing diagenetic alteration of faunal remains.

Department of Archaeology and History,
La Trobe University, Bundoora, Vic. 3086

A.Mora@latrobe.edu.au

X-ray diffraction analysis

X-ray powder diffraction analysis is routinely applied to a wide spectrum of geological, archaeological, and faunal materials to identify their constituent crystalline phases (minerals), the presence of amorphous components (e.g. glasses), and the determination of their respective amounts. The rationale behind this technique is that a crystal presents a structure characterised by a distinctive three-dimensional periodic array of atoms, which can diffract X-rays. When the X-rays are focused onto the crystalline phases, they are scattered by the constituting atoms at specific diffraction angles, depending on the periodic nature of a crystalline structure, i.e. the distance between its constituting crystallographic planes (d-spacing). The scattered radiation is collected by a detector, processed, and displayed in a diffractogram. The position, intensity and shape of the diffraction peaks act as a fingerprint for identifying a specific crystal structure (Pecharsky and Zavalij 2005). Therefore, XRD analysis can distinguish between materials that are chemically identical because of the distinctive ordered arrangements of their atoms. A common example is the three distinct forms of silica (SiO_2): glass (amorphous), quartz and cristobalite (both crystalline); which are distinguishable through their diffraction patterns (Smith 1998).

The Olympus TERRA portable XRD analyser

Traditional X-ray diffraction systems have a complex and extensive setup, and their use requires a high level of expertise. In recent years, industries have focused on the development of XRD instruments that are increasingly transportable, can be operated after quick training, leading to less costly and time-consuming analyses (Nakai and Abe 2012). The quality of data output of these new portable XRDs is competitive with, if not comparable to that of the conventional benchtop XRD systems.

Among the several companies that have developed portable versions of XRDs, Olympus has placed into the market a very successful product: the 'Olympus TERRA portable XRD analyser' (**Figure 1**). This instrument is very light, weighing around 15 kg with four batteries. It is safely contained in a sturdy box and can be transported on-site within its trolley, making it ideal for use during geological and archaeological fieldwork, as well as in museum and quarantine-regulated collections. This instrument is battery-operated (each set of batteries lasts around 4 hours) and it has wireless connectivity to personal devices (either laptop, smartphone or tablet). The measurement is visualised in real time on the personal device and the output data can be subsequently downloaded. The sample preparation is quick and easy; samples are reduced in particles smaller than 150 μm (100 mesh screen) using the crushing and sieving tools included in the set. The Olympus TERRA pXRD analyser requires only 10-15 mg of sample to run reliable measurements, making the analysis minimally destructive (and feasible in contexts that it would not

Figure 1. The Olympus TERRA portable XRD analyser and the 'shaker'

normally be). Either bulk or selective sampling can be undertaken, including longitudinal and micro-area sampling.

Conventional XRD setups present a mobile configuration in which the components rotate relative to each other thanks to a goniometer, following Bragg-Brentano geometry. The sample (~ 300 mg) is grounded into a fine powder (<10 μm), homogenised, and appropriately pressed into the sample holder in order to avoid orientation effects. In contrast, in the Olympus TERRA portable XRD, the powder sample is inserted into one of the two sample chambers without any specific preparation thanks to the 'shaker'. This vibrating sample holder ensures that the crystals are randomly oriented by endless grain circulation. The new feature is possible because of the novel transmission geometry, which has first been developed in response to the challenging working conditions of the Mars Curiosity Rover and the limited dimensions of its XRD analyser (CheMin) (Downs and MSL Science Team 2015). In this type of configuration, the components are in a fixed position: the X-rays leave the tube (Cu or Co target), pass through a collimator, and collide into the sample, where they are diffracted by the array of grains onto a Charge-Coupled Device (CCD) detector. This allows the creation of an instrument of limited dimensions, easily transportable, which requires only minimal maintenance. Since the CCD camera can collect both diffraction and fluorescence data, the Olympus TERRA pXRD is at the same time an X-ray diffractometer and X-ray spectrometer (with an XRF energy range of 2.5 to 25 keV).

Another significant advantage is that the complete diffraction pattern of the sample is collected and displayed simultaneously (over the entire angular range of 5° to 55°) after the first exposure (~ 20 sec). In addition, the fluorescence data from the same sample is concurrently visualised in an XRF spectrum. This is adequate to quickly screen samples, such as understanding whether a known crystalline phase is present in the material, or to discriminate between two possible phases. Reliable data output can be achieved in less than 15 minutes, after approximately 50 exposures. More exposures will sharpen the diffraction peaks and reduce the background noise (**Figure 2**). The XRD data produced by the Olympus TERRA portable XRD analyser can be treated using two software packages: XPowder Software for Qualitative and Semi-Quantitative analysis, and Siroquant Software for Quantitative Rietveld analysis.

When using a conventional benchtop XRD, it takes around 10 minutes to quickly acquire the complete diffraction pattern because the sample is scanned at every possible angle. The resulting diffractogram will present a wider angular range (>55˚) and a slightly better detection limit (1-2 wt%) than that produced by a pXRD such as the Olympus TERRA. As outlined earlier, both the

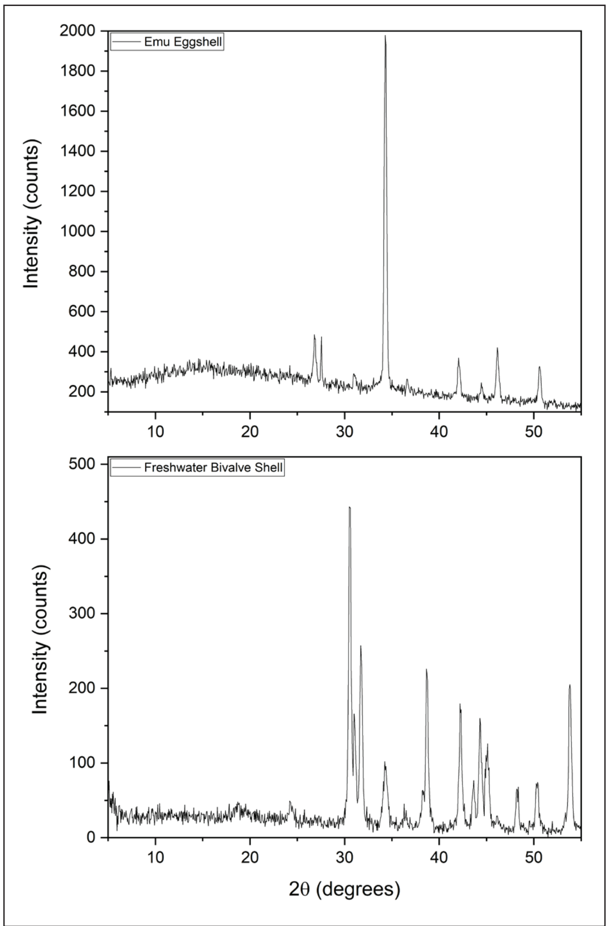


Figure 2. XRD diffractograms of emu (Dromaius novaehollandiae) eggshell (calcite) and freshwater bivalve (Alathyria jacksoni) shell (aragonite, calcite, quartz), using an Olympus TERRA pXRD analyser

benchtop and portable XRD systems present distinctive benefits and drawbacks, and ultimately the choice of using one of the two depends on several variables, including the research questions, available funds and time, level of expertise, and sampling constraints (e.g. sample preservation, sample location, regulations). As a rule of thumb, the portable XRD analyser would be efficient for a quick (on-site) screening of all the samples (with identification and quantification of all minerals), and for selecting the more complex mixtures that could be subsequently analysed via a benchtop XRD system.

XRD applications in Australian archaeological contexts

Broadly speaking, X-ray diffraction analysis identifies the mineralogical composition of materials, permitting an understanding of the conditions under which each material was formed and subsequently altered. XRD analysis presents a myriad of potential applications in Australian archaeological contexts, depending on specific research questions and type of samples, which may include faunal remains, lithic materials, ceramics, heat-retainers, ochres, and sediments.

Archaeofaunal remains such as fragments of bones, teeth, mollusc shell and eggshell are commonly found across the Australian landscape. The inorganic fraction of both bones and teeth is constituted by hydroxylapatite crystals. By studying the microstructural alterations of bone/tooth mineral crystallites, it may be possible to identify diagenetic and thermal processes that affected the faunal material (Piga et al. 2009; Rahmat et al. 2020; Rogers et al. 2010), which would help reconstructing ancient fire use and food processing (Solari et al. 2015; Van Hoesel et al. 2019), and/or post-mortem environmental conditions to which they were exposed (Stathopoulou et al. 2008; Trueman et al. 2004; Tütken et al. 2008).

Calcite, the inorganic fraction of avian eggshell, is also affected by heat-induced mineralogical changes, which are dependent on the temperature of heating (Engin et al. 2006; Macha et al. 2015; Naemchanthara et al. 2008; Tsuboi and Koga 2018). XRD analysis of mollusc shells and fish otoliths allows the identification of the different forms of calcium carbonate (aragonite and/or calcite) constituting their mineral fractions, which are indicative of the environmental conditions during the life of the animal and post-mortem. Environmental factors, such as chemical composition of water during shell formation, may affect the resulting shell mineralogy (Checa et al. 2007; Medaković et al. 2003). Moreover, mineralogical transition of aragonite into calcite may be later induced by heating as a result of food processing (Aldeias et al. 2019) or post-depositional thermal alteration (Milano and Nehrke 2018). The mineralogical characterization of the archaeofaunal remains is also a powerful tool for selecting well-preserved and reliable samples for DNA studies (Götherström et al. 2002), stable isotope analysis (Disspain et al. 2016; Munro et al. 2007), and radiocarbon dating (Long et al. 2018; Webb et al. 2007).

The determination of the mineralogical composition of lithic materials and earth-based pigments may help establish the provenance of raw materials by identifying the possible geological sources, and thus giving insight into procurement strategies and histories of transport and use (Corkill 2005; Dayet et al. 2016; Jercher et al. 1998; Trindade et al. 2010). Characterising the mineralogy of ochres may also solve attribution and authenticity issues of Indigenous artworks (Nel et al. 2010). The assessment of mineralogical changes in ceramics, heat-retainers, and other burnt clays allows for the reconstruction of their thermal history including the determination of firing events and maximum temperatures (Holakooei et al. 2014; Rasmussen et al. 2012). Clayey sediments and soils exposed to fire (hearths) undergo mineralogical alterations, which can be indicative of human occupation of the site and fire-related activities (Berna et al. 2007; Singh et al. 1991).

To conclude, the Olympus TERRA pXRD analyser may be a cost- and time-effective tool for characterizing, identifying, and sourcing (on-site and with minimal sample destruction) a range of archaeological materials that are routinely found in Australian contexts. Given its practicality, the use of a portable XRD could easily be implemented in routine archaeological investigations. If needed, more complex studies could subsequently be undertaken via a benchtop XRD system.

Acknowledgments

I would like to thank the anonymous reviewers for their helpful suggestions.

References

Aldeias, V., S. Gur-Arieh, R. Maria, P. Monteiro and P. Cura 2019 Shell we cook it? An experimental approach to the microarchaeological record of shellfish roasting. *Archaeological and Anthropological Sciences* 11(2):389–407

Berna, F, A. Behar, R. Shahack-Gross, J. Berg, E. Boaretto, A. Gilboa, I. Sharon, S. Shalev, S. Shilstein, N. Yahalom-Mack, J.R. Zorn, and S. Weiner 2007 Sediments exposed to high temperatures: Reconstructing pyrotechnological processes in Late Bronze and Iron Age Strata at Tel Dor (Israel). *Journal of Archaeological Science* 34(3):358–373

Checa, A.G., C. Jiménez-López, A. Rodríguez-Navarro and J.P. Machado 2007 Precipitation of aragonite by calcitic bivalves in Mg-enriched marine waters. *Marine Biology* 150(5):819–827

Corkill, T. 2005 Sourcing stone from the Sydney region: A hatchet job. *Australian Archaeology* 60(1):41–50

Dayet, L., F.-X. Le Bourdonnec, F. Daniel, G. Porraz and P.-J.Texier 2016 Ochre provenance and procurement strategies during the middle stone age at Diepkloof Rock Shelter, South Africa. *Archaeometry* 58(5):807–829

Disspain, M.C.F, S. Ulm, C. Izzo and B.M. Gillanders 2016 Do fish remains provide reliable palaeoenvironmental records? An examination of the effects of cooking on the morphology and chemistry of fish otoliths, vertebrae and scales. *Journal of Archaeological Science* 74:45–59

Downs, R.T. and MSL Science Team 2015 Determining mineralogy on Mars with the CheMin X-ray diffractometer. *Elements* 11(1):45–50

Engin, B., H. Demirtaş and M. Eken 2006 Temperature effects on egg shells investigated by XRD, IR and ESR techniques. *Radiation Physics and Chemistry* 75(2):268–277

Götherström, A., M.J. Collins, A. Angerbjörn and K. Lidén 2002 Bone preservation and DNA amplification. *Archaeometry* 44(3):395–404

Holakooei, P., U. Tessari, M. Verde and C. Vaccaro 2014 A new look at XRD patterns of archaeological ceramic bodies. *Journal of Thermal Analysis and Calorimetry* 118(1):165–176

Jercher, M., A. Pring, P.G. Jones and M.D. Raven 1998 Rietveld X-ray diffraction and X-ray fluorescence analysis of Australian Aboriginal ochres. *Archaeometry* 40(2):383–401

Long, K., R. Wood, I.S. Williams, J. Kalish, W. Shawcross, N. Stern and R. Grün 2018 Fish otolith microchemistry: Snapshots of lake conditions during early human occupation of Lake Mungo, Australia. *Quaternary International* 463:29–43

Macha, I.J., L.S. Ozyegin, F.N. Oktar and B. Ben-Nissan 2015 Conversion of ostrich eggshells (*Struthio camelus*) to calcium phosphates. *Journal of The Australian Ceramic Society* 51(1):125–133

Medaković, D., R. Slapnik, S. Popović and B. Gržeta 2003 Mineralogy of shells from two freshwater snails *Belgrandiella fontinalis* and *B. kuesteri*. *Comparative Biochemistry and Physiology Part A: Molecular & Integrative Physiology* 134(1):121–127

Milano, S. and G. Nehrke 2018 Microstructures in relation to temperature-induced aragonite-to-calcite transformation in the marine gastropod *Phorcus turbinatus*. *PloS one* 13(10):e0204577

Munro, L.E., F.J. Longstaffe and C.D. White 2007 Burning and boiling of modern deer bone: Effects on crystallinity and oxygen isotope composition of bioapatite phosphate. *Palaeogeography, Palaeoclimatology, Palaeoecology* 249(1–2):90–102

Naemchanthara, K., S. Meejoo, W. Onreabroy and P. Limsuwan 2008 Temperature effect on chicken egg shell investigated by XRD, TGA and FTIR. *Advanced Materials Research* 55–57:333–336

Nakai, I. and Y. Abe 2012 Portable X-ray powder diffractometer for the analysis of art and archaeological materials. *Applied Physics A* 106(2):279–293

Nel, P., P.A.. Lynch, J.S. Laird, H.M. Casey, L.J. Goodall, C.G. Ryan and R.J. Sloggett 2010 Elemental and mineralogical study of earth-based pigments using particle induced X-ray emission and X-ray diffraction. *Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment* 619(1–3):306–310

Pecharsky, V. and P. Zavalij 2005 Fundamentals of diffraction. In V. Pecharsky and P. Zavalij (eds), *Fundamentals of powder diffraction and structural characterization of materials,* pp. 99–260. USA: Springer Science+Business Media

Piga, G., T.J.U. Thompson, A. Malgosa and S. Enzo 2009 The potential of X-ray diffraction in the analysis of burned remains from forensic contexts. *Journal of Forensic Sciences* 54(3):534–539

Rahmat, R.A., M.A. Humphries, J.J. Austin, A.M.T. Linacre, M. Raven and P. Self 2020 Integrating spectrophotometric and XRD analyses in the investigation of burned dental remains. *Forensic Science International* 310:110236

Rasmussen, K.L., G.A. De La Fuente, A.D. Bond, K.K. Mathiesen and S.D. Vera 2012 Pottery firing temperatures: A new method for determining the firing temperature of ceramics and burnt clay. *Journal of Archaeological Science* 39(6):1705–1716

Rogers, K., S. Beckett, S. Kuhn, A. Chamberlain and J. Clement 2010 Contrasting the crystallinity indicators of heated and diagenetically altered bone mineral. *Palaeogeography, Palaeoclimatology, Palaeoecology* 296(1–2):125–129

Singh, B., S. O'Connor, P. Veth and R. Gilkes 1991 Detection of amorphous alumino-silicate by X-ray diffraction and chemical analysis to detect firing in archaeological sediments. *Archaeology in Oceania* 26(1):17–20

Smith, D.K. 1998 Opal, cristobalite, and tridymite: Noncrystallinity versus crystallinity, nomenclature of the silica minerals and bibliography. *Powder Diffraction* 13(1):2–19

Solari, A., D. Olivera, I. Gordillo, P. Bosch, G. Fetter, V.H. Lara and O. Novelo 2015 Cooked bones? Method and practice for identifying bones treated at low temperature. *International Journal of Osteoarchaeology* 25(4):426–440

Stathopoulou, E.T., V. Psycharis, G.D. Chryssikos, V. Gionis and G. Theodorou 2008 Bone diagenesis: New data from infrared spectroscopy and X-ray diffraction. *Palaeogeography, Palaeoclimatology, Palaeoecology* 266(3–4):168–174

Trindade, M.J., M.I. Dias, J. Coroado and F. Rocha 2010 Firing tests on clay-rich raw materials from the Algarve basin (southern Portugal): Study of mineral transformations with temperature. *Clays and clay minerals* 58(2):188–204

Trueman, C.N., A.K. Behrensmeyer, N. Tuross and S. Weiner 2004 Mineralogical and compositional changes in bones exposed on soil surfaces in Amboseli National Park, Kenya: Diagenetic mechanisms and the role of sediment pore fluids. *Journal of Archaeological Science* 31(6):721–739

Tsuboi, Y. and N. Koga 2018 Thermal decomposition of biomineralized calcium carbonate: Correlation between the thermal behavior and structural characteristics of avian eggshell. *ACS Sustainable Chemistry & Engineering* 6(4):5283–5295

Tütken, T., T.W. Vennemann and H.-U. Pfretzschner 2008 Early diagenesis of bone and tooth apatite in fluvial and marine settings: Constraints from combined oxygen isotope, nitrogen and REE analysis. *Palaeogeography, Palaeoclimatology, Palaeoecology* 266(3–4):254–268

Van Hoesel, A., F.H. Reidsma, B.J.H. van Os, L. Megens and F. Braadbaart 2019 Combusted bone: Physical and chemical changes of bone during laboratory simulated heating under oxidising conditions and their relevance for the study of ancient fire use. *Journal of Archaeological Science: Reports* 28:102033

Webb, G.E., G.J. Price, L.D. Nothdurft, L. Deer and L. Rintoul 2007 Cryptic meteoric diagenesis in freshwater bivalves: Implications for radiocarbon dating. *Geology* 35(9):803–806

Cultural heritage significance – not to be muted or trifled with

David Tutchener[1,2], Rebekah Kurpiel[3], Bradley Ward[2], Elizabeth Toohey[2], Dan Turnbull[2] and Robert Ogden[2]

Abstract

The Bunurong Land Council Aboriginal Corporation regards the establishment of cultural heritage significance as a crucial component of the study of Aboriginal cultural heritage and Aboriginal lifeways in Australia. How cultural heritage significance is assessed is particularly important within the context of cultural heritage management, where this information has the potential to influence decisions about heritage protection. The authors believe it is past time that Aboriginal groups drive how cultural heritage significance is produced within cultural heritage management. In order to achieve this, the Bunurong Land Council Aboriginal Corporation is developing a metric and guidelines for the assessment of cultural heritage significance to be used within their Registered Aboriginal Party area. This metric recognises the multi-facetted nature of cultural heritage significance, incorporating a range of significance criteria (including scientific values) within a broader framework that incorporates contemporary Aboriginal values in places within a broad cultural landscape.

Introduction

'Heritage is the very stuff of social identity and to this extent can be regarded as a form of social action' (Byrne 2008:67).

This paper arises from the routine work of a Registered Aboriginal Party (RAP), the Bunurong Land Council Aboriginal Corporation (BLCAC), who are the decision-makers regarding the implementation of the *Aboriginal Heritage Act 2006* (Vic.), hereafter AHA, within the BLCAC RAP area in Victoria (**Figure 1**). The question that this paper would like to pose is: How does the AHA (including its amendments and associated regulations) and the Burra Charter articulate with cultural heritage management, specifically in how they assess cultural heritage significance in Victoria?

The AHA provides for the preparation of Cultural Heritage Management Plans (CHMPs) before the commencement of high-impact activities within areas of legislated cultural heritage sensitivity. As part of the CHMP process, archaeological investigations are required to determine the extent, nature and significance of Aboriginal cultural heritage within the activity area so that appropriate management conditions can be developed. In this context, there is a concerning trend for the significance of Aboriginal cultural heritage to be assessed in ways that are superficial or inadequate. An example of this includes the scientific values of an Aboriginal place being assessed as having a negative value (for example -2) on an internal rubric designed by a consultant. However, the same place is also considered by the BLCAC to be of very high cultural importance. According to the consultant, this results in the place being given a significance rating of low (or even extremely low) and CHMP conditions are then proposed based upon this analysis.

Furthermore, it is alarmingly common for the results of the significance assessment to bear no relation to the management conditions that are developed during the cultural heritage management process. Often, this may be influenced by the pressures of developers, the skill of the heritage advisor/archaeologist and budget constraints. At times, significance assessments driven by development construct a diametric paradigm between scientific and cultural significance, which reflects a fundamental misunderstanding of both the AHA and the Burra Charter. As a result, many places of cultural heritage significance are destroyed during the development process, often with only a token nod to the recording of cultural values. This form of assessment may be due to the heritage advisor/archaeologist (the author of the CHMP) not being comfortable or not having the skills to define what the cultural heritage significance of an Aboriginal place is. However, often this limitation is confused with only being able to assess the scientific significance of a place, rather than understanding that scientific significance forms part of the total cultural heritage significance of a place. In Victoria, there is also

[1] College of Humanities and Social Sciences, Flinders University, GPO Box 2100, Adelaide SA 5001
< david.tutchener @ flinders.edu.au >

[2] Bunurong Land Council Aboriginal Corporation, 16/395 Nepean Highway Frankston Vic. 3199

[3] Department of Archaeology and History, La Trobe University, Bundoora Vic. 3086

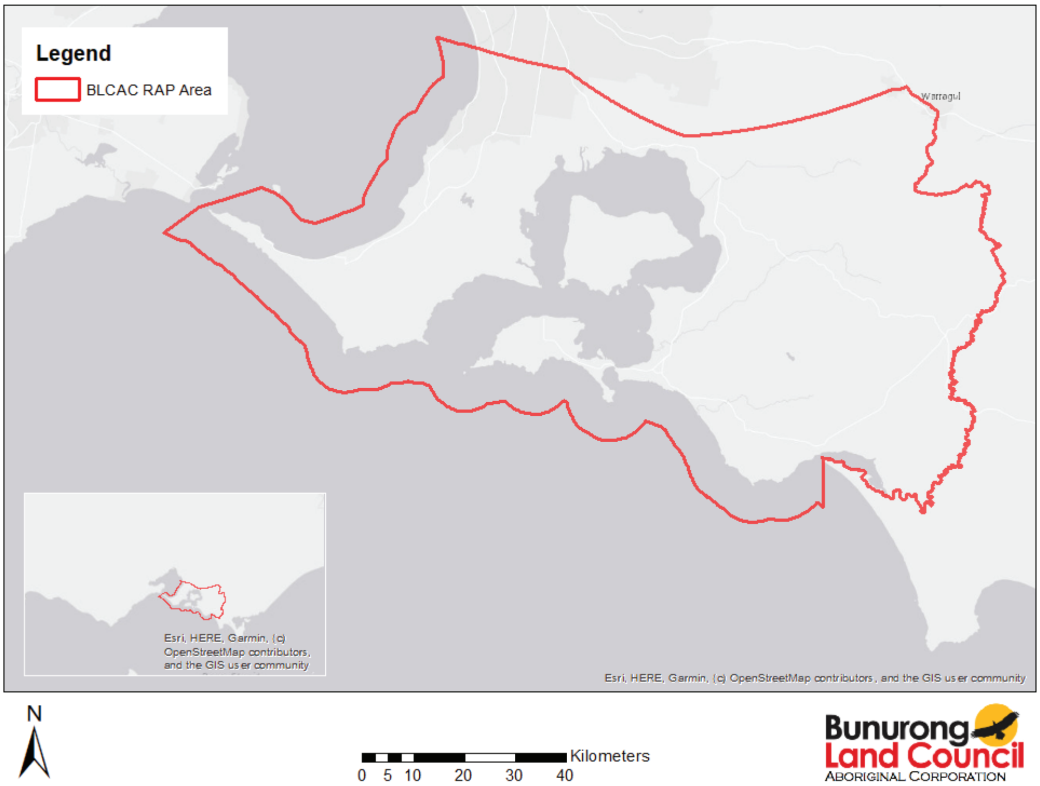


Figure 1. BLCAC current RAP area (August 2020)

currently no universal method for defining significance, which leads to numerous and varied approaches by practitioners. In order to remedy this shortfall, BLCAC is in the process of creating a metric to guide the assessment of cultural heritage significance within their RAP area, and we hope that this will encourage other RAPs to embark on the development of similar guidelines.

It seems that several factors lead to erroneous significance assessment within the cultural heritage management process. For example, places can be classified as low significance because they have not been understood or explored comprehensively. These errors become entrenched, and the effect is compounded when other newer places are assessed in reference to previous significance assessments for similar places. There is also a widespread reliance upon dated methodologies for the assessment of scientific significance (see Bowdler 1984). Perhaps most importantly, methods for the meaningful integration of scientific and other components of significance are currently lacking. It is common for heritage advisors/archaeologists to acknowledge that Traditional Owners consider all of their heritage to be highly significant but for these views to be summarily dismissed because 'it doesn't mean anything if everything is considered highly significant'. This approach typically results in a situation where only the scientific significance is considered to be important, authentic or valid.

We believe that now is an appropriate time to shift this paradigm within the heritage industry and reconsider how cultural heritage significance is assessed during the preparation of CHMPs. It is essential that scientific and other components of significance are accounted for during the process of significance assessment and that the management conditions developed for CHMPs reflect the results of the significance assessments they contain. We propose this reconsideration of significance assessment so that the cultural heritage management process can incorporate co-operative, accurate, comparative, consistent and functional approaches to cultural heritage management and conservation.

The main question posed in this paper needs to be addressed for several reasons, including:

1. The assessment of cultural heritage significance in Victoria within the cultural heritage management process can be misleading, or ill-informed, often leading to the destruction of places of significance; and
2. This question builds upon the intention of the AHA to empower Indigenous groups to have an active role in assessing and conserving their cultural heritage, rather than merely authorising its destruction.

In this paper, we discuss how cultural heritage significance is assessed in the Burra Charter and the AHA and suggest that a rubric is required to define how cultural heritage values will be defined in the BLCAC RAP area. The implementation of a rubric would address the above concerns and move the assessment of cultural heritage significance closer to the intention of both the AHA and the Burra Charter. By creating a rubric to define significance that is controlled by the RAP from within a decolonising agenda, a space is produced that can begin to overcome the significant power discrepancy that exists between RAPs, the government and developers.

Assessing Significance

There is a large body of work that relates to defining significance in cultural heritage management (also known as compliance, consulting or commercial archaeology) in Australia. This paper will not summarise all of this work, as it is previously discussed by several authors, most notably Brown (2008). However, some significant contributions in this area include work by Smith (2004:3) who argues that the assessment of significance through archaeology and cultural heritage management makes this practice a 'technology of government' which allows archaeologists to occupy a position of privilege when defining heritage values. This practice is problematic for the assessment of Aboriginal places and their associated social, cultural and heritage values.

Bowdler (1981, 1984) proposes a framework for assessing archaeological significance; she argues that archaeological significance should be assessed according to two categories: timely and specific research questions, and representativeness (Bowdler 1981:129). Secondly, Bowdler argues that 'archaeological significance is a mutable, even a transformational, quality, which changes as the subject changes' (Bowdler 1984:1). Importantly, this second aspect can be used to consider the cumulative impacts of development upon Aboriginal places; however, in practice, this is rarely done with any proficiency (Smith et al. 2019). Bowdler's (1984) work is still in frequent use within the cultural heritage management sector, however, as Brown (2008) argues, aspects of this work have not been applied correctly and therefore have become outdated.

Brown (2008) reconsiders Bowdler's body of work as it relates to cultural heritage management in New South Wales (NSW). When considering representativeness as an indicator of scientific significance Brown argues that this concept should be abandoned as its application has become 'sufficiently problematic' (Brown 2008:25) as heritage legislation provides comprehensive protection for all places, providing no incentive to assess its representativeness accurately. However, we would argue that although these places are officially protected, the reality of the compliance archaeology process is that sites are often destroyed as soon as they are discovered. Secondly, Brown (2008) argues that timely and specific research questions are not developed during the cultural heritage management process and that the actual research potential of a place holds little sway within regulatory frameworks. Importantly, Brown (2008) notes that Smith (2004:114–118) recognises that in practice research potential is often simply expressed in terms of whether a site is disturbed, rather than its actual potential.

The studies just reviewed discuss the nuances of understanding the scientific significance of a place. However, they do not discuss social and spiritual values and how to understand and interpret them within a heritage context. Byrne et al. (2001) broach this topic in an NSW context with a guide to understanding social significance within cultural heritage management. This discussion paper outlines how heritage practitioners currently define social significance and how social significance can be used as a tool for creating positive social change, mainly through the inclusion of Aboriginal people's perspectives into the assessment of places of significance.

Specific to Victoria, Freslov (1996) compiled a report that assessed the state of coastal archaeology and identified several issues, including how to assess the significance of coastal sites. Freslov (1996) notes that these significance assessments were largely based on the reporter's general knowledge of sites, and the reporter's knowledge of sites in the region, an excessively simplified system of point scoring for preservation, contents and representativeness and finally on the assumption that older sites are more significant than more recent sites. The first two issues have been largely addressed since the introduction of the AHA and a more formal Aboriginal heritage register (the Victorian Aboriginal Heritage Register, or VAHR). However, Freslov (1996:60) also notes that at worst, the last two points 'are open to abuse within the contract system and sites may be deemed less significant to satisfy an employer'. Crucially, Freslov identifies that the worst issue with significance assessment in Victoria is the failure to integrate and address Aboriginal cultural heritage significance in any meaningful way. This lack of meaningful engagement is an issue that Aboriginal groups still face daily, more than 20 years on from Freslov's report.

The Burra Charter and the *Aboriginal Heritage Act* 2006

The Australia ICOMOS Burra Charter (2013) was first developed in 1979 and has set a benchmark for the assessment of significance internationally. The Burra Charter has, to an extent, influenced much of the cultural heritage legislation in Australia, including in Victoria. The document has undergone several revisions; the current version was produced in 2013. There is a plethora of publications that discuss the use of the

Burra Charter, but often not considering its application to Aboriginal archaeology (Ireland 2004; Logan 2004; Waterton et al. 2006). Consequently, this paper is not the appropriate place to discuss this at length, however, it is essential to note that the Burra Charter outlines the following criteria for the assessment of cultural heritage significance in alphabetical order: aesthetic, historic, scientific, social and spiritual values. These criteria contribute equally to the nature of the cultural heritage significance of a place and cannot negate one another.

These assessment criteria are outlined in several practice notes and are designed as a practical guide to working with places that contain heritage values. The application of these criteria (often through a metric) allows for the production of accurate and inclusive statements of cultural heritage significance. The intention of the Burra Charter is clearly reflected in the AHA and much of the heritage legislation in Australia.

The purpose of the AHA is clearly outlined in its introduction and is included here as it is considered crucial to understanding its meaning within a decolonised context:

> *The main purposes of this Act are—*
>
> *(a) to provide for the protection of Aboriginal cultural heritage and Aboriginal intangible heritage in Victoria; and*
>
> *(b) to empower traditional owners as protectors of their cultural heritage on behalf of Aboriginal people and all other peoples; and*
>
> *(c) to strengthen the ongoing right to maintain the distinctive spiritual, cultural, material and economic relationship of traditional owners with the land and waters and other resources with which they have a connection under traditional laws and customs; and*
>
> *(d) to promote respect for Aboriginal cultural heritage, contributing to its protection as part of the common heritage of all peoples and to the sustainable development and management of land and of the environment* [*Aboriginal Heritage Act 2006* (Vic.)(1)(1)].

This comprehensive definition of the purpose of the AHA is integral to this discussion as it directly articulates with how the current cultural heritage management process in Victoria may improve through establishing and integrating how Aboriginal cultural heritage values are assessed. Whether or not the AHA currently addresses its purpose is another issue entirely, one that likely needs a full and open discussion at a later date. Importantly, the AHA establishes how, when and why CHMPs are produced and the role of RAPs. It defines the assessment of cultural heritage significance as being defined by several criteria: archaeological, anthropological, contemporary, historical, scientific, social or spiritual and significance in accordance with Aboriginal tradition [*Aboriginal Heritage Act 2006* (Vic.) (3)4)]. Very rarely are all of these values assessed within the cultural heritage management process, and consequently, cultural heritage significance is not assessed to its full potential, often leading to adverse outcomes for Aboriginal communities and the cultural heritage record. Crucially, the AHA promotes the involvement of the RAP in the assessment of their cultural heritage. Consequently, a metric for defining the cultural heritage significance of Aboriginal places that is produced and enforced by a RAP are required to address this structural inequality.

The proposed metric will be applied to archaeological places within the Bunurong cultural landscape that are located during research or commercial projects. It will include a number of criteria, including rarity in this context (e.g. on this landform), potential for protection into the future, scientific potential, educational/interpretation potential, associations with non-archaeological values and significance in accordance with Aboriginal tradition. These criteria will be discussed between the consultant and BLCAC. The results of this rubric will then go on to inform appropriate management conditions, preservation outcomes, interpretive strategies and will allow for a better comparison of different places within a geographic region.

Discussion

It is clear that even before the introduction of the AHA in 2006, as Freslov (1996) notes, Aboriginal cultural heritage significance was not assessed adequately in Victoria. This paper argues that this is still the case. Therefore, the intention of both the AHA and the Burra Charter is not currently being met within the cultural heritage management process. Often this is due to scientific and cultural significance values competing against one another. This fundamental misunderstanding must be addressed, as scientific values (or archaeological significance) and other relevant values all need to be incorporated into a broader assessment of cultural heritage significance.

Crucially, the general goodwill of the archaeological community cannot be underestimated, and BLCAC hopes to continue to work productively with developers, archaeologists and the government. As Bowdler (1984) notes, values change over time, and as identity and power politics change over time so too will the criteria for heritage assessment (Tutchener 2013). Consequently, any rubric proposed by BLCAC is not designed to be entirely static. However, it is hoped that this intention is understood in later iterations, and this allows for some consistency in how cultural heritage significance is defined, particularly in respect to the inclusion of

Aboriginal cultural heritage values.

What becomes evident throughout the cultural heritage management process is that there is still a large power discrepancy between RAPs and other organisations. To some extent, both the AHA and the Burra Charter attempt to bridge this divide and their impact can be seen in the assessment of cultural heritage significance in CHMPs. As Moon (2017) notes, there are parallels between the AHA and the *Native Title Act 1993* (Cwlth), where both sets of legislation assist in establishing Aboriginal organisations, however once established they are then not adequately supported by the government. In the case of RAPs this is still evident, as RAPs have often become a 'one-stop shop' for consultation purposes regarding all sorts of various matters. However, if RAPs are not resourced adequately for this broader role, this quickly becomes a burden on small community organisations. This power discrepancy is also clearly seen within the cultural heritage management process, where a developer has at hand considerable resources (human, financial and legal) that can assist in gaining their desired outcomes. Therefore, there is still a significant power disparity between Aboriginal organisations, developers and government departments (Tutchener 2015). It is our hope that through creating a significance assessment rubric that BLCAC can contribute to a positive change within the heritage sector and through the ability to control the assessment of their heritage BLCAC can regain a portion of power within this process. More broadly with the establishment of the First Peoples Assembly in Victoria and Treaty negotiations on the horizon, it is still possible that in some way, this power discrepancy will be corrected more substantially.

Conclusion

This paper has highlighted the need for a RAP-driven significance assessment rubric within the BLCAC area. The requirement for this originates from the inherent power differential between RAPs and sponsors within the cultural heritage management process. This paper suggests that this power imbalance can begin to be corrected by the introduction of a significance assessment rubric that creates a space for a RAP to decide the significance of their heritage and gain some control of this process. Both the Burra Charter and the AHA outline several criteria that can be adopted within this proposed rubric, and this is reflected in the work of many heritage consultants in Victoria. However, by formulating a rubric driven by the needs of the RAP, it is hoped that significance assessment will also become more standardised within the BLCAC RAP area, which may in turn produce greater conservation outcomes in the future.

References

Bowdler, S. 1981 Unconsidered trifles? Cultural resource management, environmental impact statements and archaeological research in New South Wales. *Australian Archaeology* 12:123–133

Bowdler, S. 1984 Archaeological significance as a mutable quality. In S. Sullivan and S. Bowdler (eds), *Site Surveys and Significance Assessment in Australian Archaeology: Proceedings of the 1981 Springwood Conference on Australian Prehistory*, pp.1–9. Canberra: Department of Prehistory, Research School of Pacific Studies, Australian National University

Brown, S. 2008 Mute or mutable? Archaeological significance, research and cultural heritage management in Australia. *Australian Archaeology* 67(1):19–30

Byrne, D. 2008 Heritage as social action. In G. J. Fairclough, R. Harrison, J. H. Jameson and J. Schofield (eds), *The Heritage Reader,* pp.149–173. London: Routledge

Byrne, D., H. Brayshaw and T. Ireland 2001 *Social Significance: A Discussion Paper*. Sydney: Research Unit, Cultural Heritage Division, NSW National Parks and Wildlife Service

Freslov, J. 1996 *Effective Strategies for the Management of Coastal Aboriginal Archaeological Sites and Places in Victoria*. Melbourne: Aboriginal Affairs Victoria

Ireland, T. 2004 The Burra Charter and historical archaeology: Reflections on the legacy of Port Arthur. *Historic Environment* 18(1):25–29

Logan, W. 2004 Voices from the periphery: The Burra Charter in context. *Historic Environment* 18(1): 2–8

Moon, J. 2017 Aboriginal cultural heritage legislation in Victoria, Australia: Leader or follower? *Excavations, Surveys and Heritage Management in Victoria* 6:51–56. Melbourne: La Trobe University

Smith, A., R. Kurpiel, S. Lawrence, J. Garvey, D. Turnbull and R. Ogden 2019 Assessment of cumulative impacts on Aboriginal cultural heritage on the Mornington Peninsula, Victoria: preliminary findings. *Excavations, Surveys and Heritage Management in Victoria* 8:71–76.

Smith, L. 2004 *Archaeological theory and the politics of cultural heritage*. Oxfordshire: Routledge

Australia ICOMOS 2013 *The Burra Charter: The Australia ICOMOS Charter for Places of Cultural Significance*. Australia ICOMOS Incorporated

Tutchener, D. 2013 Collective identity and heritage: Ebb and flow at national and global levels. *Journal of Globalization Studies* 4(2): 96–103

Tutchener, D. 2015 Hard and soft power and the cultural heritage industry: An Australian example. *Nexus: The Canadian Student Journal of Anthropology* 23(1):1–12

Waterton, E., L. Smith and G. Campbell 2006 The utility of Discourse Analysis to Heritage Studies: The Burra Charter and social inclusion. *International Journal of Heritage Studies* 12(4):339–35

A second look at the Langlands Iron Foundry: the engine behind Marvellous Melbourne's phenomenal rise

Sarah Myers[1], Sarah Mirams[2] and Natalie Paynter[3]

Abstract

A recent archaeological investigation yielded extensive remains from Victoria's first Iron Foundry. As only a handful of industrial sites investigated in the CBD, these results are important to our understanding of the archaeology of Melbourne. Of broader import, the results reveal multiple phases of development at the foundry, seemingly mirroring the incredibly rapid development of Melbourne into an international city. In this paper we examine the results of the excavation considering their contribution to an important chapter in the story of Melbourne's industrial manufacturing history and the city's transformation from a pastoral outpost to a manufacturing powerhouse.

Introduction

In 2018, ArchLink Archaeologists and Heritage Advisors undertook an archaeological excavation located in the southwest corner of Melbourne's CBD. Located at 9–27 Downie Street (**Figure 1**), the site is identified on the Victorian Heritage Inventory as H7822-1835 and falls within the former grounds of the Langlands Iron Foundry. Langlands Iron Foundry famously assembled the first iron paddle steamer, the *Vesta* and made the first locomotive boiler in the colony. Only two other iron foundries have been investigated in the Melbourne CBD compared to the hundreds of residential and commercial sites that have been investigated over the past 20 years.

A previous investigation of the Langlands Foundry which yielded few features and no structures, was reported in the *International Journal of Historical Archaeology* (Myers et al. 2018). The significance of the former foundry site was recognised for its association with John Batman's garden, one of the earliest European settlers in Victoria. Located at 556–560 Flinders Street (**Figure 1**), the site is identified on the Victorian Heritage Inventory, H7822-1847, and also falls within the former grounds of the Langlands Iron Foundry. The Flinders Street site corresponded with the former yard area for the foundry while the Downie Street site corresponded with footprints for the foundry buildings.

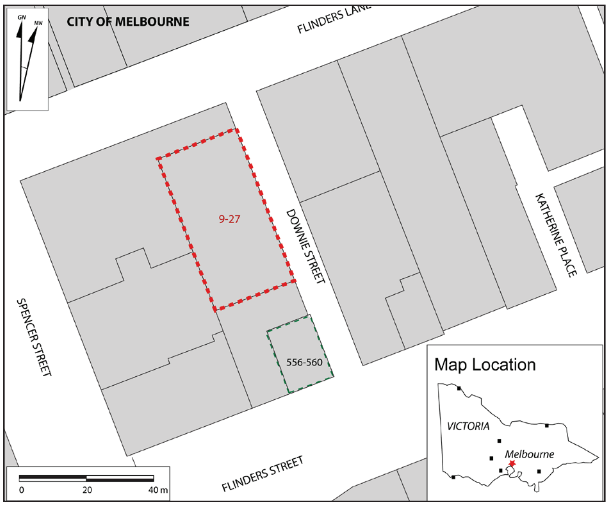


Figure 1. The location of the site at 9–27 Downie St (investigated in 2018/2019) and the site at 556–560 Flinders Street (investigated in 2015)

The footings found within the Downie Street site were well preserved beneath layers of iron waste fill. Accumulation deposits, features and artefacts were also uncovered relating to three distinct stratigraphic phases attributable to the occupation and development of the site by the Foundry. Though no structures or features relating to Batman's garden were found, some artefacts were considered potentially to be from this period. Across the stratigraphic phases, changes were noted in the architecture of the foundry buildings, the technological innovations of the various foundry installations and typological trends in the foundry tools and objects. These changes are considered to reflect and represent the rapid development of Melbourne during the 19th century.

Historical Background

Langlands Iron Foundry was established in 1842 by Scottish immigrants Robert Langlands and Thomas

[1] ArchLink Archaeologists and Heritage Advisors, PO Box 59, The Patch, Vic. 3792, sarah.myers@archlink.com.au

[2] School of Philosophical, Historical and International Studies, Monash University, Wellington Road, Clayton, Vic. 3800, pastandfuture@bigpond.com

[3] Consultant Archaeologist, Geelong, Vic. 3218, paynternatalie@yahoo.com.au

Fulton, just seven years after Melbourne was first settled in 1835. The allotment was previously part of John Batman's garden located to the east of 'Batman's Hill' as indicated on Hoddles 1837 plan (Myers and Mirams 2018:8). Unfortunately, there is little information about Robert Langlands in the historical records. We know that Fulton, however, was born in Dundee in 1813 and served an apprenticeship as a machine-maker before migrating to Port Phillip in partnership with Robert Langlands (Brereton 1972). Fulton left the partnership after only a few years and established another foundry several blocks to the east, Fultons Foundry. He was replaced by Robert Langland's brother, Henry Langlands who arrived in Victoria from Scotland in 1846.

Henry Langlands became an influential figure in Melbourne colonial society. He was active in politics, industry and philanthropy. In Scotland, Henry Langlands had supported the anti-slavery Reform Bill and Catholic Emancipation movement. In Melbourne he supported the anti-transportation movement and provided financial support to the hospital, the Benevolent Asylum, the Immigrants Aid Society, Temperance Movement and the Yarra Aboriginal Mission (*The Age* 23 June 1863:5). He was a member of the Colonial Reform Association which lobbied for democratic and land reform. He chaired a protest meeting in the aftermath of the Eureka Stockade that spurred on democratic reform in Victoria (Serle 1977:171).

Langlands and Fulton purchased Allotment 2 adjacent to Flinders Street and the Yarra River for their foundry. It was close to Queens and Coles wharves where goods were loaded and unloaded. The Customs House was a block away on Queens Street. This was the commercial end of town in the 1840s where local industries, warehouses and businesses associated with import, export and shipping were located (Lewis 1995:23).

Despite the 1840s depression, Robert Langlands and Thomas Fulton purchased the property on Flinders Street and began manufacturing items with just a foot-powered lathe to hand (Milner 1990). Between 1842 and 1852, Langlands repaired and manufactured a wide range of agricultural implements as well as drays, carriages, buggies, axle-boxes, wool-presses, ornamental ironwork, cast iron bells and beams (Milner 1990:6). By this time, Langlands had purchased the neighbouring allotments, Allotment 3 and 4 and expanded the Foundry as Melbourne's population grew. In 1839, Melbourne's population was estimated to be 4,000, with almost 6,000 Europeans living across the Port Phillip District. By 1851 the population of Melbourne had risen to between 23,000 and 26,000. Victoria's population was 77,354 (Serle 1977:382; Shaw 1996:85).

The gold rush had seen metal workers flocking to Victoria, many who set up their own businesses during the 1850s. Enoch Chambers opened up Melbourne's third foundry in Prahran in 1856 and by the early 1860s, dozens of engineering works, many specialising in particular products or working with different materials, were established across Melbourne (Churchward 2005). The scale of these foundries varied, some were set up in small factories producing domestic items such as kettles, lamps and tin cans.

Other Ironworks and Foundry studies

Other archaeological examples of Australian ironworks include the Fitzroy Ironworks in Mittagong excavated in 2005 (Godden Mackay Logan 2007). The Fitzroy Ironworks operated from 1848 to 1910, mining and smelting iron ore, as well as producing pig-iron in a blast furnace. They also cast iron and made coke. The Fitzroy Ironworks is described in *Australia's Age of Iron: History and Archaeology*, Jack and Cremin's early history of iron smelting in Australia which examines historic blast furnaces across the south eastern states including Lal Lal in Victoria and Lithgow in NSW (Jack and Cremin 1989).

Kristie Altenberg and R. Ian Jack's comparative study of a traditional Portuguese foundry and the Phoenix Foundry in Uralla, NSW, describes a modest family brass and iron casting foundry which began operation in 1898 and employed six people (Altenberg and Jack 1990:53). John Hyett's comparative study of the archaeology of a blacksmith shop in Strathbogie, which operated from 1889-1991, explored the building layout, tools and equipment used in a stand-alone blacksmith shop and compared it with international examples (Hyett 2002:92).

Casey and Lowe completed an investigation of the PN Russell & Co Engineering Works during a larger investigation of the Darling Quarter, (formerly Darling Walk), in Darling Harbour, Sydney (Casey and Lowe 2013). The Works operated at the site from 1859 to 1875. Limited excavations within the yard area of the Works revealed information regarding the operations and transportation within the foundry complex. The remains of a weighbridge, which weighed wagons of raw materials and end products was identified. Few industrial artefacts or foundry related objects were recovered.

Another foundry investigation in Melbourne's CBD was undertaken in 2016 by Qu.A.C. Archaeology and Heritage (Lane et al. 2018). The site, H7822-2042, was located at 229–241 Franklin Street, Melbourne and contained remains of the Soho Iron Foundry. The site contained the full extent of a working foundry that operated from the early 1860s until about 1914. During fieldwork some structural features were uncovered allowing interpretation of the layout and workings of the foundry. Bluestone blocks forming engine beds and timber beams associated with foundry machinery were excavated, while cuts, indentations and pits also indicated the location of foundry equipment (Lane et al. 2018:62). A flue network made of handmade bricks was revealed after removal of a thick layer of slag.

Two millstones were also excavated and the chimney stack location was revealed. Layers of black foundry sand with cuts suggested the location of the moulding shop (Lane et al. 2018:78). There were scarcely any complete iron tools recorded that were associated with foundry work (Lane et al. 2018:3). Metal was found across the site as heavily corroded concretions with tools embedded (Lane et al. 2018:116). The few artefacts included part of a small iron rake, an S-shaped open-ended spanner, and an iron pot. The lack of artefacts was attributed to the fact that foundry plant and equipment was sold off when the foundry ceased operation in 1913 (Lane et al. 2018:22–23).

Another small foundry, Rowden Bros in La Trobe Street, Melbourne, which specialised in tin and galvanised iron was excavated by Andrew Long and Associates during the Metro Rail project in 2018. The report for this investigation is still in preparation, however, the authors understand that the site yielded furnace features and many thousands of metal objects, possibly proving an important comparative assemblage.

Project Background

The previous investigation of the former Langlands Iron Foundry undertaken in 2014/2015, at 556–560 Flinders Street, Melbourne (see broken green outline in **Figure 1**) represented about 10% of the original foundry property. It happened to correspond with a yard area of the former foundry, so no structural evidence was uncovered during the archaeological excavations (Myers et al. 2015). Several significant features and deposits were identified, including a brick-lined well, extensive brick and gravel paving, barrels of black pitch, iron tools and many clay smoking pipes (Myers et al. 2018:86, 92). The finds revealed the need for hardstand areas and filling to combat the boggy nature of the land and frequent flooding events due to the proximity to the Yarra River. The finds also evoked scenes of a male-dominated industry, with the work crew finding time for a smoko in between the hard, hot, and dirty work of a foundryman. The investigation opened an important window into the former foundry, with research indicating it was the first established in Melbourne and Victoria, and potentially of high significance for its contribution to the growth of the Australian colonies. The massive quantities of ferrous waste that had been used to cover over and fill the site, made it clear there was also potential for extensive remains of the Langlands Iron Foundry preserved north of this allotment (Myers et al. 2018:84).

The more recent investigation of the Langlands foundry undertaken in 2018/2019, at 9–27 Downie Street, Melbourne (broken red line in **Figure 1**) was located just 10 m north of the previously investigated site. The site area represents about 25% of the original Langlands Foundry grounds corresponding with the central and western portions where the earliest foundry buildings would have been located. This portion incorporated part of the original allotment purchased by Langlands. One of the few historical maps available that show the Foundry, indicate that several buildings were situated on the Downie Street site by the 1850s (Bibbs 1856) (**Figure 2**).

Extensive remains of the Langlands Iron Foundry were uncovered during the investigation of H7822-1835, including partial footings of all the buildings marked on the Bibbs Plan (**Figure 2**). The footings, features and deposits revealed the site was subject to continuous change and improvements over time. There were upgrades to, and adaptations of most buildings and many features. Early burnt timber footings were replaced with brick-on-stone footings. An early brick-lined single flue that delivered air to a small furnace was upgraded with a more substantial iron pipe, double flue. This flue was subsequently upgraded again, along with the building it was attached to, by an even larger, iron pipe, tri-flue delivering air to a new building. The new building was shown on a Dove Fire Insurance Plan (Dove c.1879?). These developments were noted in the taphonomy and statigraphic phasing at the site. The findings illustrate the rapid development of the Langlands Iron Foundry into a manufacturing powerhouse mirroring the phenomenal rise of Melbourne.

Results by Phase

Six stratigraphic phases were identified during the investigation (**Table 1)**. Phases 2, 2a and 3 were those associated with the occupation of the property by Langlands Iron Foundry from 1842 to 1881. Historical documentary evidence helped to clarify specific dates for each of these phases. This paper focuses on the findings from Phases 2, 2a and 3, which relate to the establishment, consolidation and subsequent expansion of the Foundry.

Phase 1

Soon after the arrival of Europeans in the southern part of Australia, John Batman built a homestead on the hill to the west of the subject site overlooking the Yarra River. Batman utilized the low-lying land to the east of Batman's Hill, including the study area as a garden and for agriculture. He, his family and workers, would have walked over the land and tended the gardens. As such, it may be that some post contact artefacts found at the natural ground surface could be attributed to his period of ownership. One artefact found that stands out as possibly relating to this Phase is a portion of a Mouth harp (also known as a Jews harp) found pressed

Figure 2. (a) Portion of the Bibbs Plan, 1856 and (b) the Dove Plan, c.1875? (sic) showing the 9–27 Downie Street site H7922-1835

Phase	Type	Date	Phase significance
Phase 1	Contact period – Batman's Garden	1835–1842	High
Phase 2	Langlands Iron Foundry (establishment)	1842–1851	High
Phase 2a	Langlands Iron Foundry (consolidation)	1851–1878	High
Phase 3	Langlands Iron Foundry (expansion)	1878–1881	Medium
Phase 4	West End Brewery, Mundells Warehouse & other businesses	1881–1928	Medium
Phase 5	Demolition - Vacant Redbrick warehouse & garage	1928–1938 1938–present	Low

Table 1. Historical and stratigraphic phases

into basal sediments (Myers et al. in prep.). A similar instrument was found by Ochre Imprints during excavations near the corner of Swanston and Flinders Streets for the Metro railway development.

Phase 2

An historic plan showing the layout of the Foundry for Phase 2, prior to 1850, has not been located. But the archaeological and historical evidence indicates that shortly after establishment, the layout of buildings at the Foundry would have been similar to the layout shown on the Bibbs plan, 1856 (**Figure 2**). This was corroborated by archaeological evidence for footings from Phase 2 and 2a that were found to correspond with the building layout shown on the Bibbs plan.

Rates records indicate that by 1845 the Langlands Foundry already comprised 'three dwelling houses, steam engine, workshops, foundry loft, sheds and yard' (Melbourne 1845). By 1846 the *Port Phillip Gazette and Settlers Journal* described the Foundry as the largest in the Australian colonies having machinery with straps and screws 'clanging away' connected to various lathes. There was also a turning shop where the model maker was preparing patterns for casting (*Port Phillip Gazette and Settlers Journal* 7 January 1846:2).

Toward the end of the excavation, beneath one metre or more of fill deposits, evidence for this earliest period (Phase 2) was uncovered. Timber footings with the remains of intact wall frames were found (**Figure 3**). Some were blackened from fire. A soft organic deposit containing wood shavings and timber offcuts from lathe work was found between these footings, which were probably the remains of the turning shop and the activities that took place there.

Shipping records suggest Langlands imported building materials, specialist equipment and products needed for their manufacturing enterprise. Pig iron (the raw material needed for commercial production of iron) was initially imported as it was not until 1875 that the Lal Lal Iron Works and smelter was built (Jack and Cremin 1994:62, 63). In 1847, Langlands imported 20 tons of pig iron from Scotland along with 8 boxes and 15 bales of merchandise (*Sydney Chronicle* 4 November 1847:2). Langlands also imported 2,500 fire bricks, 6 sheets of lead, 114 bundles of bar iron, 19 bundles of sheet iron, 1 block of tin, 2 pairs of smiths bellows and 1 cask of clay (*Melbourne Times* 25 March 1843:2). Possibly the sheet iron was used for cladding and roofs on sheds. The fire bricks were most likely used for building furnaces. The ship *Nebudda* carried 261 deals and battens (used to build structural frames before they were clad with sheet iron) and 92 pieces of sawn wood for Langlands in 1849 (*The Argus* 10 September 1849:2).

Samples of timber offcuts (DW-00127) from Phase 2 deposits at the site were scientifically tested by Know Your Wood and identified as Larch (*Larix* spp.), a timber from the Northern hemisphere valued for its tough, waterproof, and durable qualities (Ilic 2020). Larch was used in the construction of small boats and may have been purchased by Langlands for maritime repairs and construction orders. A timber artefact (DW-00932) possibly part of a batten or finishing for the Phase 2 building in Area A was tested for its species type and identified as Baltic pine (Ilic 2020). Baltic pine was the most widely imported timber in 19th century Victoria (Lewis c.1986).

Langlands also used local materials. In 1848, 2600 pieces of colonial slate were reportedly purchased from a quarry 50 miles from Melbourne; they did not have to import timber roofing shingles from Tasmania (Port Phillip Patriot 23 October 1848:2). Furthermore, the stumps on which the imported deals and battens were erected were found to be local timber. A rounded stump (DW 10634) was tested and identified as White

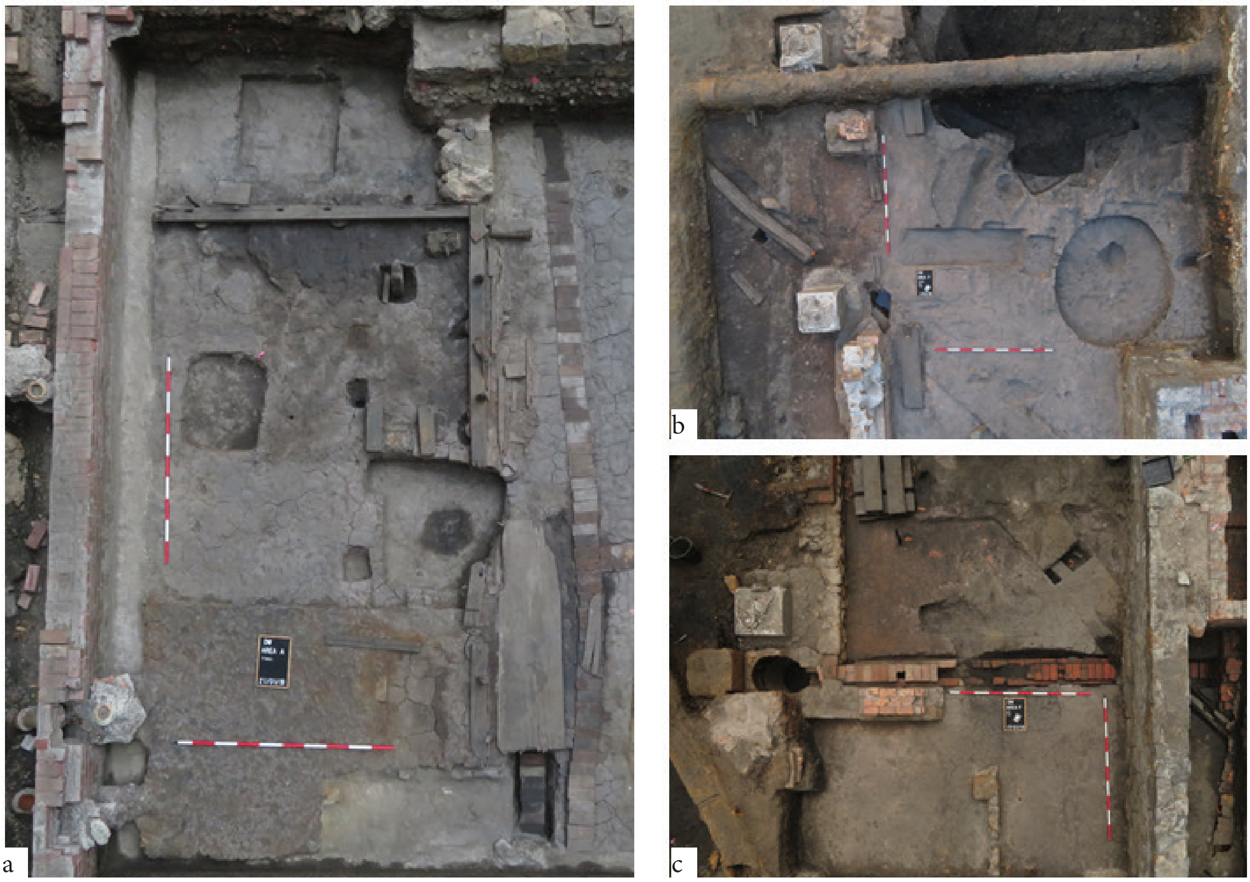


Figure 3. (a) the timber footings of what was likely the turning shop of Phase 2. (b, c) the brick-on-stone footings, brick-lined flue and cuts into the floor of what was likely the moulding room of Phase 2/2a. Later footings and features from Phase 3 (large stone footings and iron pipe that fed the tri-flue) and Phase 5 (concrete and redbrick footings and pylons) lie over and cut through the earlier phases

Stringybark (*Eucalyptus globoedia*), a local hardwood indigenous to the Melbourne area (Ilic 2020). A piece of worked timber (DW 00152), possibly a piece of flooring was identified as Southern Blue Gum (*Eucalyptus globulus*).

During the excavation brick-on-uncut stone footings from Phase 2 were also uncovered, built directly over basal clays. A brick-lined flue and barrel-lined chimney, connecting with a small forge (**Figure 3c**) was associated with one of these buildings. Criss-crossed timbers provided a machinery stand, possibly for a small crane. Between these footings was a deposit of grey foundry sand. Circular impressions were found cut into this deposit and the basal sediments. It was clear this building was the Foundry's earliest moulding room where molten iron was poured into moulds. The cuts in the ground indicate very large moulds were being cast (**Figure 3b**).

The base part of a furnace was also uncovered, constructed of handmade brick-on-stone, similar to other structures associated with Phase 2. The furnace was rectangular and divided into two halves: one side apparently functioning as an oven, and the other as a fire box. A laminated deposit of fine brick dust had collected in the second chamber perhaps because of the poor quality of the bricks used. In front of the firebox was the opening of an underground brick-lined, timber-topped, flue. The other end of this flue opened into a circular stone feature, possibly the base of another furnace, uncovered during the final monitoring stage of the investigation.

In the early years, working with these simple buildings and furnaces, Langlands prospered. The Foundry assembled Victoria's first iron paddle-steamer, the *Vesta*, from imported sections (Milner 1990:15). They also repaired and manufactured a wide range of agricultural implements as well as drays, carriages, buggies, wool presses, beams and street signs (Milner 1990:6).

There would have been great pressure to expand their operations, but in December 1850 an 'alarming fire' broke out in the Foundry yard and spread south towards Coles Wharf, igniting George Cole's sail loft and shop (*Port Phillip Gazette and Settlers Journal* 21 November 1850:2). The fire also ignited a barrel of gunpowder, which exploded and lit up the sky. According to Edmund Finn (1888:210), it could be seen from Flagstaff Hill. After the fire at the Foundry in 1850, Henry Langlands immediately applied to the Melbourne City Council under the *Melbourne Building Act* (1849) to make additions to his factory (Melbourne City Council 1850). These Notices of Intent to Build were required under the Act for any new building or major work but excluded privies and chimneys. Building regulations were introduced to Melbourne in 1849 to specify fireproof building materials to prevent 'mischiefs by fire' (Lewis 1995:39).

This fire marked the end of Phase 2, which was clear in the stratigraphic profile across several areas as a layer of charcoal over demolished structures. In other areas, fill layers, changes to structures and the addition of new structures heralded the onset of Phase 2a.

Phase 2a

In 1855, the property was mortgaged to William Downie for £1400, to raise money for the repairs and the new buildings (Officer of the Register General and the Office of Titles 1855).

In Phase 2a one of the burned-down workshop buildings (with the timber footings) was rebuilt, at least in part, with stone internal footings added. These overlie the charcoal layer, but within the same footprint as the underlying timber footings and the building marked on the Bibbs Plan. A second building (with timber footings) was removed altogether and capped with a bitumen pavement. A new building was added with brick-on-stone footings and internal timber supports that rested on timber base-plates. A sample of these (DW 10632) was identified as River Red Gum (*Eucalyptus camaldulensis*), a dense redwood highly prized for its durability and strength (Ilic 2020). Its use in this phase suggests a greater understanding of the potential of Australian timber species had been established by the gold rush.

The brick-on-stone moulding shop (shown in part in **Figures 3b, c**) was upgraded with a new, larger furnace powered by air delivered through iron pipe flues (**Figure 4**). The furnace was probably installed above the upright pipe flues. The change in flue type from brick-lined to iron-pipe represents an important change in technology at the site from manual to mechanised. A large stone machine-support was also added at this time, replacing or complementing the earlier timber version.

Artefacts found in association with this moulding room included an iron cauldron, graphitised ceramic crucible fragments and iron tools such as gaggers and pinchers (for lifting hot crucibles), files, crank handles and hooks (**Figure 5**).

Economic demand and population growth since the early years of the gold rush was phenomenal. In four months of 1852, a total of 609 ships docked in Hobsons Bay carrying 55,075 passengers, all hoping to find their fortune in Victoria. The frontier port town of Melbourne grew into one of the richest cities in the world. Waves of immigration saw the population increase from 77,345 in 1851 to 540,322 in 1861 (Serle 1977:382). The city and hinterland developed at break-neck speed as new settlements opened up where gold was discovered. The demand for equipment to extract the gold in the decade following the initial discoveries saw Langlands flourish. Langlands fabricated and imported mining equipment including steam engines, stamp batteries, quartz-crushing machines, pumping equipment and winding

Figure 4. Evidence of the upgraded furnace and flues in Phase 2a, found at northern end of the moulding room building which was constructed during Phase 2

gear (Weickhardt 1983:48). They also manufactured the first tubular boiler for the first locomotive in Victoria (Milner 1990:16) as well as boilers, dredging and railway equipment, pipes and saw-mills (Weickhardt 1983:47; Milner 1990:6).

This period also presented unique challenges for the business. When the news of the gold discoveries in Buninyong reached Melbourne in 1851 almost every able-bodied man left Melbourne and headed for the goldfields. Businesses and offices were deserted and ships in the Yarra were abandoned as crews left their posts and went inland (Serle 1977:21). It appeared that Langlands Foundry may have lost employees to the lure of the gold in the early gold rush also. Between August 1851 and 1852 positions were advertised regularly in the Melbourne papers for engineers, patternmakers, moulders, wheelwrights, carpenters, boilermakers and blacksmiths. The advertisements specified that Langlands required skilled workers only and would provide them with liberal wages (*The Argus* 10 May 1852:5, 20 April, 1852:12, 12 August 1852:5). Wages for skilled workers by 1853 had grown 5 or 6 times greater than in 1851.

By 1861, the Foundry had become increasingly mechanised, with steam-driven machines such as slotting, boring and planing machines for finishing and smoothing the metal. There was also a self-acting screw cutter, plate bending machine, friction hammer and a machine for cutting plates and bars. Some of the orders in 1861 included 600 tons of 14-inch pipe for the North Clunes Mining Company (*The Age* 14 December 1861:5). At this time, the foundry was described as 'one of the most extensive and important factories now in operation' (*The Age* 14 December 1861:5).

Langlands expanded in 1864, establishing a new foundry over the River at Southbank and consolidating the Flinders Street operation. The impetus for this move was a contract to build the caisson for the Alfred Graving Dock which required closer access to the port and specialised equipment (*The Argus* 8 February 1872:6). The Flinders Street and Flinders Lane frontages were subdivided and sold. The original foundry grounds had contracted by almost a third (Officer of the Register General and the Office of Titles 1864).

The wealth generated by gold, and the growth of regional cities and towns as well as an expanded population saw Victorian government and private enterprise invest in infrastructure projects such as housing, railways, water supplies, port facilities, as well as public building through the boom times of the 1870s and 1880s (Lewis 1995:60). As well as the Alfred Graving Dock, Langlands was also awarded the contract to manufacture bridge girders for the North Eastern Railway which ran from Melbourne to Albury (*The Age* 29 October 1870:3). It was a Victorian government contract to manufacture 200 wrought iron locomotive railway wheels for rolling stock in 1877 that was to see the Flinders Street Foundry site reshaped (*The Herald* 16 August 1878:3). Locomotive wheels until this time were imported. This was the first time they would be


DW 00346 - metal hand file


DW 00574 - crucible base


DW 00416 - metal gaggers


DW 00129 - turned wooden offcuts


DW 00113 - set of nested metal weights


DW 003493 - carriage bolt


DW 00599 - cast iron cauldron


DW 00413 - railway spikes

Figure 5. Artefacts collected from deposits associated with the turning shop and moulding rooms in Phase 2 and 2a

manufactured in Australia (*The Argus* 17 August 1878:5).

This contract would require new plant and equipment. The adaptations made to the moulding room in Phase 2a were likely done to allow for larger items to be made, but a larger building would be required to fulfill this contract. The end of Phase 2a at the site was marked by the demolition of all structures across the southern part of the site to make way for a new upgraded workshop building.

Phase 3

In 1878 Langlands submitted a building application to the Melbourne City Council (Melbourne City Council 1878). The Dove Fire Insurance Plan c. 1875? (sic) shows the site was completely reconfigured with fewer, much larger workshops (constructed of iron) and an extensive yard area (**Figure 2b**). These new buildings were oriented west to east across the site replacing the timber and iron buildings that were oriented north-south in the Bibbs Plan (**Figure 2**a).

The Dove Fire insurance plan is marked with a query '?' against the date 1875 which is hand-written on the plan. The date provided was probably a guess at the likely date it was produced. The evidence in the historic record (the building application) paired with the archaeological evidence, indicated that the Dove plan must have been produced in 1878 (not 1875 as indicated on the plan and in the SLV database).

The new plant took several months to be constructed and prepared. Special sheds were fitted out for the work. The process was reported in the Melbourne press. The reports described some of the equipment used in the manufacture of the wheels, including furnaces and hydraulic machines to press the iron into the moulds, a blast furnace, a hanging cupola furnace, steam hammers and double-turning lathes. The blast furnace was fed from three underground air pipes, the air sourced from a fan in another building, (*The Herald* 16 August 1878:3; *The Argus* 17 August 1878:5).

This description explains why the remains of a large furnace structure associated with Phase 3 of the Foundry, seemed strangely absent at the site during the excavation. If the furnaces were hanging above the ground, then on removal, they would have left no trace. Archaeologically, the new workshop building was represented by substantial, shaped, bluestone footings over a solid rubble base that cut through the older Phase 2 and 2a structures and deposits at the site, bedding in the basal sediments. Large, square-shaped bluestone crane mounts were also installed, tied together with metal pins. These were placed either side of a large, iron tank that was set into the ground (**Figure 7**).

Fewer small iron tools and timber moulds were found in Phase 3 deposits than had been found in Phases 2 and 2a. There were, however, more larger items found, including a large wrench DW-00408 and an industrial weight DW-08269 of approximately 28lb/ 12kg (**Figure 6**).

Substantial amounts of ferrous waste were dumped as fill around the new iron pipe tri-flue raising the ground level across the site. A circular feature was cut into, or formed from, compacted foundry sand. It had a central iron-ball shaped axle cut into the natural clays in the centre of the ring. A dislodged iron wheel that lay alongside the iron ball may have originally rested on the axle. These features likely formed the remains of equipment used to move iron ingot moulds or other vessels around while each was filled with molten iron. The presence of this ring feature (or industrial sized 'Lazy Susan') together with the pad footings for the cranes and the large new iron tri-flue were indicative of a new technology being used at the Foundry (**Figure 7**).

Incredibly, despite the huge investment made, Phase 3 lasted only 4 years. The new workshop building, furnace and flue system appeared to have been constructed to complete the one important contract

DW 00308 - large wrench / spanner

DW 08269 - calibrated bar weight

Figure 6. Artefacts collected from deposits associated with the new moulding workshops of Phase 3

Figure 7. Features associated with Phase 3. (a) an aerial view of the large iron tri-flue, (b) a portion of the foundry sand-ring impression with central axle, (c) the new workshop footing in section showing the deep rubble base and shaped stone coursing, (d) the intact machine (or crane) footing

for the railway wheels. The elements found in Phase 3 were like those required for the Bessemer process. The Bessemer process was an invention by Henry Bessemer that enabled the inexpensive production of steel, a more reliable product than cast iron (but was previously more expensive to produce). The process involved forcing air through the molten iron to remove impurities from the iron by oxidation. It is considered one of the most important developments in steel making between the 1850s and 1950s.

However, a newspaper article indicates that the Langlands did not adopt the Bessemer process until 1887 when they had already moved to another factory across the Yarra (*The Goulburn Herald* Tuesday 7 June 1887: 2). Indeed, according to the article, when they did 'attempt' to introduce Davy's Bessemer process in 1887, it was the first time any Bessemer Process had been introduced in any of the Australian colonies. Although the features uncovered were probably not part of a Bessemer process, the presence of similar technologies being installed and used at the Flinders Street site, suggests that Langlands were moving toward more efficient processes in steel making during this phase. Advances were stimulated by being awarded the large contracts. By upgrading production systems, Langlands were perhaps attempting to maintain their position at the forefront of the iron foundry industry in Australia.

In 1880, Langlands purchased the Fulton Foundry located in South Melbourne for £27,000. All plant from Flinders Street was removed to this second premises. South Melbourne was where many heavy engineering and timber yards had moved from the mid-nineteenth century (Priestly 1984:245). The amalgamation of Fultons and Langlands created one of the most complete ironworks in Victoria (*The Australasian Sketcher* 28 May 1881:3). At this time, Langlands was amongst the biggest factories in Victoria, employing 300 people across their two operations (Serle 1971:70). They continued to manufacture iron and steel goods to build Victoria, including the water pipes connecting Melbourne to the Yan Yean Reservoir and the Kew tram lines (*The Age* 22 June 1888:7; *The Daily Telegraph* 30 May 1884:4). In 1889, the population of 'Marvellous Melbourne' had grown to 445,000.

Conclusion

The most recent investigation of the former Langlands Iron Foundry uncovered extensive remains from the earliest days of the Foundry in the 1840s through to its final days in 1881. The artefact assemblage demonstrates this industrial character, with hundreds of metal objects, including many foundry tools. This site differs from other investigations of ironworks and foundries, which have typically yielded few artefacts. This assemblage can now be the comparative assemblage against which other foundry assemblages, yet to be recovered, can be compared. The assemblage will be housed at the Heritage Victoria's artefact laboratory.

The structural remnants of the Foundry included footings and industrial features made of wood, stone, brick and iron that were altered, adapted and reconstructed over three distinct phases (2, 2a and 3). This structural evidence together with historical information, accumulated deposits and material culture, has contributed to the interpretation of specific uses for each structure: the turning shop, moulding room, counting shop, pattern store, furnaces, flues and airpipes; as well as highlighted their adaptation, improvements and technological advances. It also pointed to a synchronistic development with the development of Melbourne, perhaps even a symbiotic relationship. An archival record including an extensive excavation report and photo database will be available through Heritage Victoria and the ArchLink website.

The findings from the excavation provide important insights into the development of the 19th century industrial manufacturing business, Langlands Iron Foundry. They reveal phenomenal change and adaptation of the business, to service the burgeoning population of Melbourne over the 39 years that Langlands occupied the site. Furthermore, they reveal the importance of this site to the story of Melbourne's industrial manufacturing history and the city's transformation from a pastoral outpost to a manufacturing powerhouse.

References

THE AGE 'Messrs Langlands' Foundry', 14 December 1861:5

THE AGE 'The late Henry Langlands, Esq', 23 June 1863:5

THE AGE 'Langland Foundry Company (Ltd)', 29 October 1870:3

THE AGE 'Contracts', 22 June 1888:7

Altenberg, K. and R. I. Jack 1990 The Living Archaeology of Work: A Traditional Foundry in Central Portugal *Australian Historic Archaeology* 8:51–62

THE ARGUS 'Shipping Intelligence', 10 September 1849:2

THE ARGUS 'Advertisements', 10 May 1852:5

THE ARGUS 'Advertisements', 20 April 1852:12

THE ARGUS 'Advertisements' 12 August 1852:5

THE ARGUS 'Langlands Foundry Company (Ltd.)', 8 February 1872:6

THE ARGUS 'The Manufacture of Railway Carriage Wheels', 17 August 1878:5

THE AUSTRALASIAN SKETCHER 1881 'Casting Operations at the Langlands Foundry', 28 May 1881:3

Bibbs c.1856 Plan of Melbourne, VPRS 8168/PO2 Unit 5391 Roll12, Public Records Office of Victoria

Brereton, R. 1972 Fulton, Thomas (1813–1859). In B. Nairn, G. Serle and R. Ward (eds), *Australian Dictionary of Biography* 4:225. Melbourne, Vic.: Melbourne University Press

Casey and Lowe Archaeology and Heritage Consultants 2013 Archaeological Investigation 2008-2010, Darling Quarter, Darling Harbour, Sydney. Retrieved 30 June 2020 from < http://www.caseyandlowe.com.au/wp-content/uploads/2009/04/Section-3.9-3.11-Results-of-Archaeological-Investigation-CONDENSED.pdf >

Churchward, M.S. 2005 Engineering. In A. Brown-May and S. Swain (eds), *The Encyclopedia of Melbourne*, pp. 236–238. Cambridge: Cambridge University Press

THE DAILY TELEGRAPH 'Contracts', 30 May 1884:4

Dove, H.P., c. 1875?. Plans of Melbourne. Melbourne: Trinity College, University of Melbourne Finn, E. 1888 *The Chronicles of Early Melbourne 1835-1852: Historical, Anecdotal and Personal* Melbourne, Vic.: Fergusson and Mitchell

Finn, E. 1888 *The Chronicles of Early Melbourne 1835-1852: Historical Anecdotal and Personal* Melbourne, Vic.: Fergusson and Mitchell

THE GOULBURN HERALD 1887 'The Bessemer Process', Tuesday 7 June 1887:2

Godden Mackay Logan 2007 Highlands Marketplace, Mittagong (Part of the Former Fitz Roy Iron Works): archaeological investigation report. Unpublished report prepared for Fabcot Pty Ltd

THE HERALD 1878 'Visit of Inspection' 16 August 1878, 3.

Hyett, J. 2002 Variation on a Theme: The Archaeology of an Australian blacksmith's shop *Australasian Historical Archaeology* (20):92–95

Ilic, J. 2020 Wood Identification Results. Technical letter report by Know Your Wood

Jack, I.R. and A. Cremin 1994 *Australia's Age of Iron: History and Archaeology*. South Melbourne, Vic.: Oxford University Press in association with Sydney University Press

Lane, S., A. Gilchrist and J. Porter 2018 229–241 Franklin Street, Melbourne (H7822-2042) Historical Archaeology Excavation Report. Unpublished report prepared for Iglu No. 301 Pty Ltd

Lewis. M. 1995 *Melbourne: The City's History and Development*. Melbourne, Vic.: City of Melbourne

Lewis. M. c.1896, Australian Architectural Index. Retrieved 29 August 2020 from < https://www.mileslewis.net/australian-architectural/ >

Melbourne 1845 Lonsdale Latrobe Gipps and Bourke Ward Rate Book, VPRS 5708/P01 Unit 8, Public Records Office of Victoria

Melbourne City Council 1850 Notice of Intention to Build. Miles Lewis Architectural Index, Registration No. 508. Retrieved 26 May 2020 from < http://www.mileslewis.net/australian-architectural.html >

Melbourne City Council 1878 Notice of Intention to Build. Miles Lewis Architectural Index, Registration No. 7886. Retrieved 26 May 2020 from < http://www.mileslewis.net/australian-architectural.html >

THE MELBOURNE TIMES 'Shipping Intelligence' 25 March 1843:2

Milner, P. 1990 *On the Langlands Foundry Company*. Melbourne, Vic.: Department of Mechanical and Manufacturing Engineering, University of Melbourne

Myers, S., Mirams, S. and T. Mallett 2015 Langlands Iron Foundry and Stookes Shipping Butchers (H7822-1847), 556–560 Flinders Street, Melbourne. Unpublished report prepared for Flinders Lodge

Myers, S. and S. Mirams 2018 9–27 Downie Street (H7822-1835) Archaeology Assessment and Consent Application Report. Unpublished report prepared for Little Projects Pty Ltd

Myers, S., S. Mirams and T. Mallett 2018 Langlands Iron Foundry, Flinders Street Melbourne. *International Journal of Historical Archaeology* 22:78–99

Myers, S., S. Mirams, J. Richmond, N. Paynter, K. Roddis, T. Mallett, N. Grguric, Z. Spielvogel and N. Stebbins in prep. Langlands Iron Foundry and The West End Brewery Stables (H7822-1835), 9-27 Downie Street, Melbourne: Historical Archaeology Excavation Report. Unpublished report prepared for Little Projects Pty Ltd

THE PORT PHILLIP GAZETTE AND SETTLERS JOURNAL 'The Port Phillip Foundry' 7 January 1846:2

THE PORT PHILLIP GAZETTE AND SETTLERS JOURNAL 'Alarming Fire' 21 November 1850:2

PORT PHILLIP PATRIOT 1848 'Domestic Intelligence' 23 October 1848:2

Priestley, S. 1984 *The Victorians: Making Their Mark*. Clayton, Vic.: Fairfax, Syme and Weldon Associates

Serle, G. 1971 *The Rush to be Rich: A History of the colony of Victoria 1883–1889* Melbourne, Vic.: Melbourne University Press

Serle, G. 1977 *The Golden Age: A History of the colony of Victoria 1851–1961* Melbourne, Vic.: Melbourne University Press

Shaw, A.G.L. 1996 *A History of the Port Phillip District: Victoria Before Separation.* Melbourne, Vic.:

Melbourne University Press

THE SYDNEY CHRONICLE 'Imports' 4 November 1847:2

Weickhardt, C.G.T. The first foundry. *Royal Historical Society of Victoria* 54(3):47–49

Going over old ground: modeling historical landscape change in Victoria using GIS

Greg Hil[1], Susan Lawrence[1] and Diana Smith[2]

Abstract

Historical land-use descriptions are an important aspect of cultural heritage management in Victoria. Determining prior uses of a landscape can help archaeologists to predict the presence and condition of prior ground surfaces during the planning stages of a cultural heritage assessment. Unfortunately, prior land-uses are almost universally considered through the lens of ground 'disturbance', which can limit the inferential potential of past activities. This is particularly true for the outcomes of industries such as mining and urbanisation. In this paper, we present a means of reframing prior land-uses by characterising and categorising their possible stratigraphic outcomes. This framework is paired with a GIS-based approach for comparing nineteenth century topographic maps with more recent records of elevation. The potential of this approach is highlighted by its presented use at Ballarat and Melbourne's Hoddle Grid (CBD), where significant increases and decreases in historical elevation levels are identified. When combined with the historical record, this form of modeling could provide archaeologists with a new means of considering historical land-uses as they relate to the current condition of the archaeological record.

Introduction

The nineteenth century was a formative period for much of Victoria's contemporary cultural landscape. From the 1830s, industries such as mining, forestry, and agriculture, combined with urbanisation to reshape Victoria's surface into something akin to the landscape we recognise today. As the state continues to be transformed it is now often the task of archaeologists to interpret how those prior landform changes relate to the archaeological record. And, whilst it may be tempting to assume that activities like historical mining or urban development were uniformly disturbing to cultural heritage, subsurface testing has often found this to be untrue. The movement of large quantities of earth associated with many forms of nineteenth century industry sometimes resulted in the burying and thus protection of prior ground surfaces. This has become particularly apparent in the context of urban fill deposits and gold mining sludge. Examples of the former include urban areas that have been artificially raised through imported earth and the latter a form of gold mining tailings that have been redeposited through fluvial processes (Lane and Gilchrist 2019; Lawrence and Davies 2014). If the presence of these types of landform changes can be anticipated prior to works, this could save time and resources, whilst producing better outcomes for uncovered cultural heritage. In this paper we present a means to model, visualise, and ultimately interpret some of those changes to the landscape through the use of nineteenth century topographic maps and GIS. This project is part of ongoing PhD research jointly funded by Aboriginal Victoria and La Trobe University and associated with the ARC-funded Rivers of Gold project.

Landscape change and Victorian archaeology

Humans have been shaping Victoria's landscape for at least 30,000 years (Canning and Thiele 2010). Prior to the 1830s, the main driver of that change was Aboriginal land management, settlement, and subsistence. European invasion and the industrial activities it transplanted represented a stark turning point. The continent's first hooved animals devoured grasslands and compacted topsoils underfoot (Paterson 2018:5). Entire hillslopes were rapidly denuded of trees, and by the 1850s, inland regions were being ripped open in search of gold (Lawrence and Davies 2018). It has been estimated that in the nineteenth century alone, 800 million cubic metres of sediment were mobilised by Victorian gold miners (equivalent to over 300 Great Pyramids of Giza!) (Davies et al. 2018a, 2018b). The landscape was also remodelled across the colony's emerging urban centres in order to better accommodate European settlement. Near Melbourne, wetlands were filled in, Batmans Hill was levelled, and the Yarra River was redirected and channelised (Giblett 2016; Presland 2008, 2014; Victorian Low-Lands Commission 1873). These large-scale transformations were of course joined by the incremental activities of the wider

[1] Department of Archaeology and History, La Trobe University, Melbourne, Vic. 3086, g.hil@latrobe.edu.au

[2] Aboriginal Victoria, Department of Premier & Cabinet, Bendigo, Vic. 3550

public, including the ploughing of fields, the digging of cellars, and through the continuous rhythm of building construction, renovation, and demolition.

Given the myriad ways that nineteenth century Victorians shaped the landscape the 'land-use history' section of a Cultural Heritage Management Plan (CHMP) (an investigatory report in Aboriginal cultural heritage management that considers Aboriginal cultural heritage, prior land-uses of an area, and provides contingencies in case Aboriginal cultural heritage is discovered) can only ever scratch the surface of activities that may have taken place in any given area. One of the challenges faced by archaeologists is relating descriptions of land-use to site formation, particularly in the absence of subsurface testing. In Aboriginal cultural heritage management this often results in an implicit association of land-use to degrees of 'disturbance'. This is not unexpected given the primary purpose of most 'desktop assessments' (the preliminary stage of CHMPs) is to determine the necessity for more in-depth archaeological investigation.

Victoria is not unique in its struggle to integrate near-endless forms of landscape change into a standardised planning framework. The British Geological Survey (BGS) has long recognised the need to include anthropogenic deposits into their maps and models of urban stratigraphy (Ford et al. 2014:60). Recognising that geology's most fundamental rules are rarely applicable to anthropogenic deposits, the BGS instead developed a system of classification based on morphogenetics. That is, defining artificial ground by *how* it is formed rather than what it is formed *of*; behaviour rather than composition. What they created was the Classification Scheme of Artificial Ground (McMillan and Powell 1999; Ford et al. 2010). In this system, all forms of anthropogenic landscape change can be split into five categories (**Table 1**).

With minor adjustments, such as relabelling made ground as 'remade ground' to acknowledge pre-colonial land management, changing the ground surface from which forms of artificial ground relate from 'natural ground surface' to 'pre-colonial ground surface', and more accurately referring to 'disturbed ground' as 'collapsed ground', this system is well-suited to Victorian archaeological contexts. Rather than replacing traditional stratigraphic approaches, the BGS system, as used here, instead relates the stratigraphic outcomes of land-uses to former pre-colonial ground surfaces. The approach can be thought of as a means to characterise and categorise the stratigraphic outcomes of anthropogenic activities on landscape-based scales.

Reframing anthropogenic landscape change (land-use) in terms of its physical outcomes could provide increased clarity during planning stages of development. For instance, if a prior land-use activity may have resulted in 'remade ground', development proponents could have increased forewarning about the possibility of nineteenth century structural remains or in situ Aboriginal cultural heritage in their activity area. The converse is also true in cases of 'worked ground'. As areas of excavation are often associated with locally redeposited material, this approach could potentially identify artificial ground patterning across a landscape. However, for such a system to be of value during planning stages, archaeologists need a means of determining the outcomes of historical land-use *prior* to subsurface investigations. Identifying the possible presence or absence of artificial ground and/or prior ground surfaces through non-invasive methods is achievable through methods such as historical research, Ground Penetrating Radar (GPR), and, as we present in this paper, through the use of topographic maps and GIS.

Methods: modeling volumetric landscape change with GIS

The BGS's classification scheme, as used here, categorises artificial landscape change in terms that are relative to pre-colonial ground surfaces. However, this definition is

BGS Category	Definition
Made Ground	Areas where the ground is known to have been deposited by man on the former, natural ground surface: road, rail, reservoir and screening embankments; flood defences; spoil (waste) heaps; coastal reclamation fill; offshore dumping grounds; constructional fill
Worked Ground	Areas where the ground is known to have been cut away (excavated) by people: quarries, pits, rail and road cuttings, cut-away landscaping, dredged channels
Infilled Ground	Areas where the ground has been cut away (excavated) and then had artificial ground (fill) deposited: partly or wholly back-filled workings such as pits, quarries, opencast sites; landfill sites (except sites where material is dumped or spread over the natural ground surface)
Landscaped Ground	Areas where the original surface has been extensively remodelled, but where it is impractical or impossible to separately delineate areas of worked (excavated) ground and made ground
Disturbed Ground	Areas of surface and near-surface mineral workings where ill-defined excavations, areas of man-induced subsidence caused by the workings and spoil are complexly associated with each other, for example collapsed bell pits and shallow mine workings

Table 1. BGS Classifications and definitions (taken verbatim from McMillan and Powell 1999: 4)

easily adapted to refer to later, historical ground surfaces if required. If an alluvial flat, for example, remains largely unmodified by post-colonial industry until 1860, when it is blanketed by gold mining sludge, it remains 'remade ground' until it is 'worked' deeper than that layer of sludge. In order for it to become 'worked ground' the area must be excavated until 'natural' (a culturally sterile basal horizon) has been uniformly reached. This process is simplified when it is reframed in terms of numerical elevation change. The hypothetical 1860 sludge event increased the elevation at the exampled location by a quantifiable amount. The elevation of a given ground surface can be raised, decreased, or left the same (unless it is reduced then later increased by the same amount). Therefore, to model landscape change, the elevation of a given ground surface must be compared to a later ground surface at the same location. This can be achieved through the comparison of historical Digital Elevation Models (DEMs) produced from nineteenth century topographic maps in GIS. Two case study areas that demonstrate this application are Ballarat and Melbourne's Hoddle Grid (the City of Melbourne's central business district) (**Figure 1**). The prior and later ground surfaces at those two locations date to 1858 and 2012 (Ballarat) and 1853 and 1895 (Hoddle Grid). The dates are dictated by the availability of nineteenth century elevation data for each study area.

First, high resolution digital scans of each historical topographic map were retrieved from online databases and georeferenced within ArcGIS Pro (Version 2.4.1). The georeferencing process aligns each historical map to its real-world location through user-defined control points. In this instance those control points consisted of well-defined street corners and building footprints, which were aligned to LiDAR or modern cadastral maps of each study area. The use of LiDAR to georeference John Phillips' 1858 map of Ballarat was pertinent, as the same LiDAR was later used for surface-to-surface comparisons. Next, all forms of elevation information contained within each historical map (contour lines or survey benchmarks) were manually mouse-traced within ArcGIS Pro. This process, known as vectorisation, allows that elevation data to be integrated into mapping algorithms. Phillips' 1858 map of Ballarat depicts elevation solely through the use of contour lines (intervals of five feet/1.524 m), whereas Clement Hodgkinson's 1853 plan of the Hoddle Grid depicts elevation through contour lines (intervals of four feet/1.219 m) and through 212 elevation benchmarks. From here, Esri's ArcGIS Pro interpolation algorithms were used to create DEMs of both Ballarat and the Hoddle Grid from 1858 and 1853 respectively. The outcome of these steps was the creation of three-dimensional models that can be referred to as each area's 'prior ground surface'.

To quantify elevation change through time a second DEM was created for each study area. For Ballarat, this 'later ground surface' took the form of LiDAR imagery collected of the township in 2012. For Melbourne's Hoddle Grid, a mosaic was created from 22 Melbourne Metropolitan Board of Works (MMBW) plans created

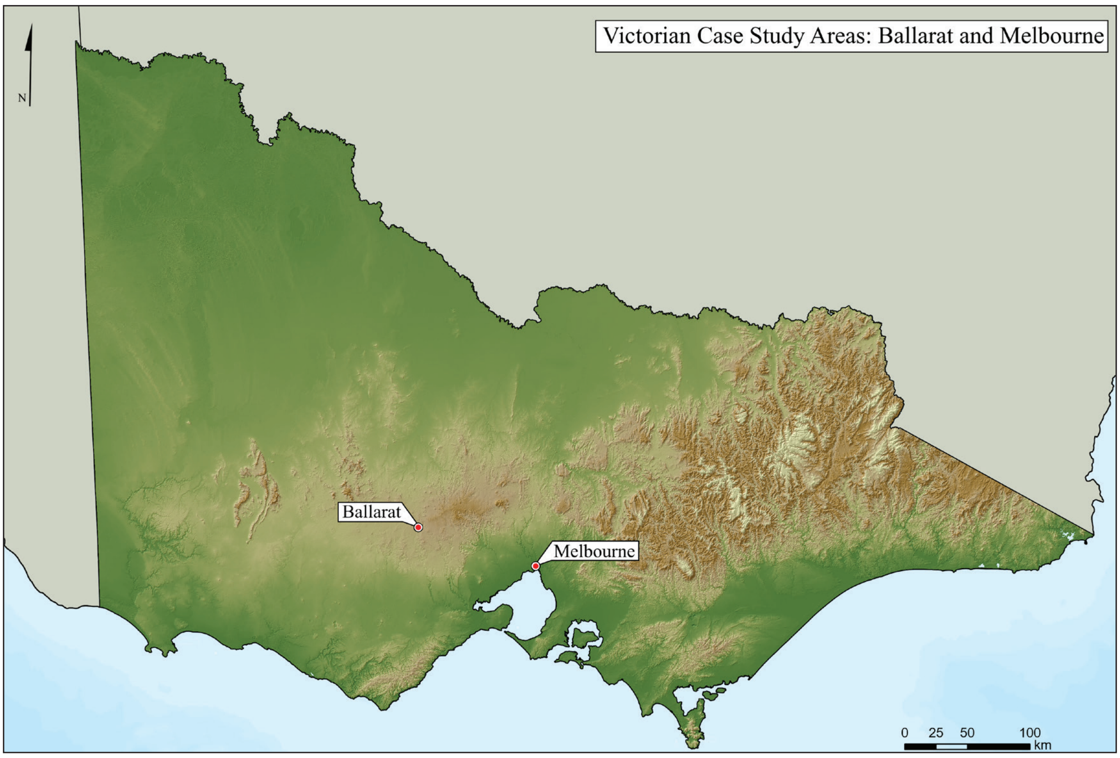


Figure 1. The location of the two Victorian case study areas: Ballarat and Melbourne

in 1895. These plans represent elevation through a combined 11,212 elevation benchmarks. Each 1895 plan also depicts building and cellar footprints, which often contained elevation values. All footprints containing an elevation value were vectorised into polygon shapefiles. This step allowed the elevation values of the 5,404 cellars and buildings to be represented within the 1895 DEM without being averaged against the surrounding landscape.

The final step of the analysis was to calculate the difference in elevation between the historical DEMs. For this, ArcGIS Pro's 'raster calculator' was used. This step produced a new DEM comprised of the differences between the two historical models. So, if one hypothetical area within the Hoddle Grid was four metres above sea level in 1853 and seven metres above sea level in 1895 the value of the new DEM at that location would be three metres (as the area increased by three metres in elevation). Conversely, if an area became lower by 1895, this produced a negative elevation value. These height differences were then classified by colour and then superimposed onto georeferenced historical maps to identify possible sources of elevation change (e.g. land-use).

Results

The historical landscape-change modeling identified widespread changes in elevation across both case study areas. **Figure 2** provides a colourised example of this landscape change in Ballarat. As indicated in the legend, red to orange represents areas that decreased in elevation between 1858 and 2012, whereas green to darker green represent areas of increase (with yellow representing areas within a metre of change). The map highlights how Ballarat's sludge channel (constructed in the early 1860s) cut into the late-1850s ground surface. Also, note the filling in of the waterway across the middle of the map. Along the centre right, parts of Main Street are now two metres higher than their late-1850s levels. These changes in elevation along Main Street are supported by local historical sources (Bate 1978:101; Spielvogel 1981:20).

Our landscape change modeling also revealed innumerable changes in elevation across Melbourne's Hoddle Grid. An example of this landscape change, and possible occurrences of remade or infilled ground, are shown in **Figure 3**. Areas showing an increase in elevation within the figure (increasing from light to dark green) appear to align-well with recent excavations and

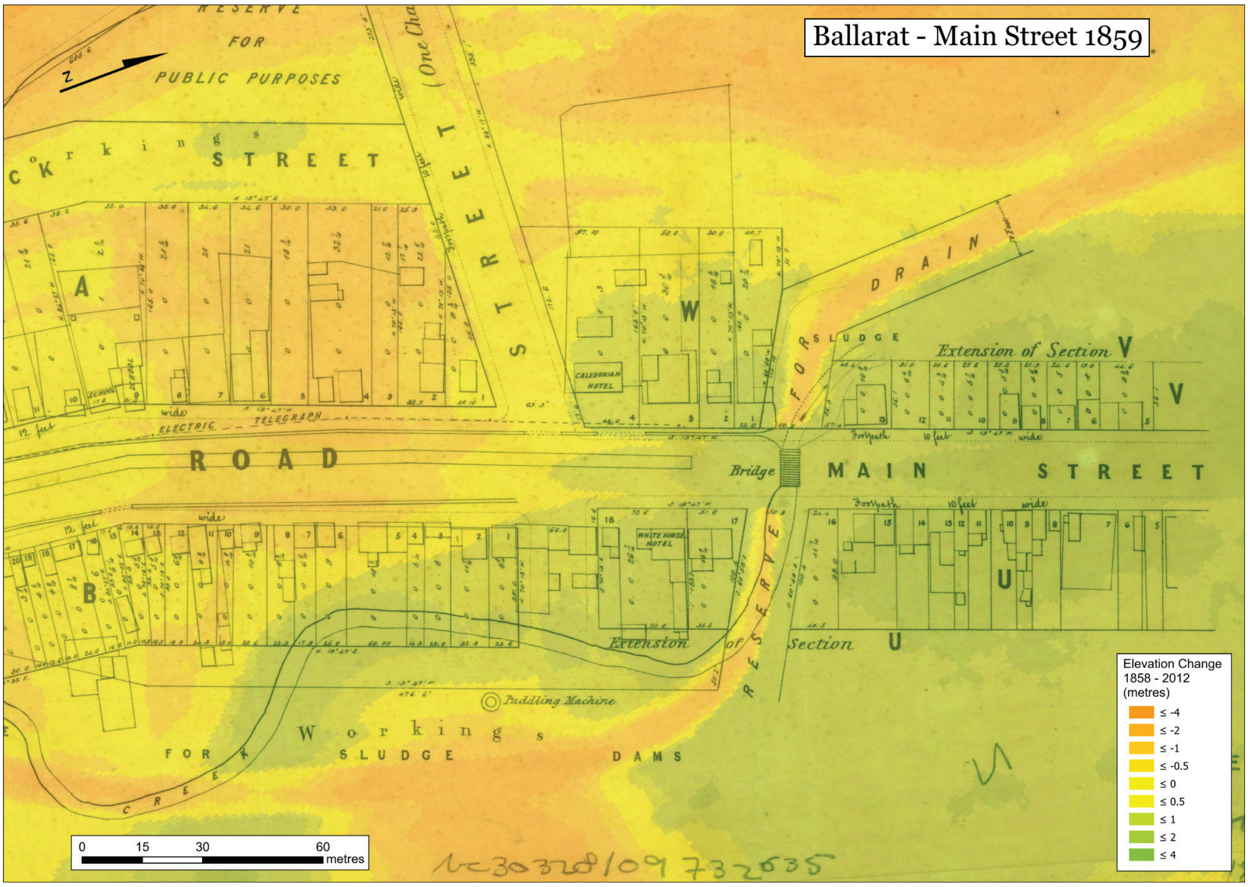


Figure 2. Elevation change modeling (1858-2012) at Ballarat overlying 1859 map of Main Street (Carruthers 1895—full map citation in references)

the findings of the 'Heritage in Ruins' report regarding the Grid's urban fill deposits (Lane and Gilchrist 2019; Negus Cleary et al. 2019). These fill events correspond to Acts of Parliament passed in the 1850s, which required landowners to raise the ground surface of their property if requested by City Council (Lane and Gilchrist 2019). This was partially a response to a deadly typhoid epidemic, attributed to standing pools of stagnant water, which plagued Melbourne throughout the nineteenth century (Dingle and Rasmussen 1991). In some cases, built structures were buried beneath upwards of two metres of imported earth. The area marked in red in **Figure 3** provides an example of an area where structural remains were discovered at those significant depths (Negus Cleary et al. 2019). Examples of public work 'fill orders' gazetted in local newspapers are also shown within the figure. Other forms of landscape change, not depicted in **Figure 3**, include the removal of Batmans Hill, which was levelled during the 1860s, as well as numerous cellars depicted in the 1895 MMBW plans (Presland 2008). The cellars provide many probable examples of 'worked ground' across the Grid—areas that are much less likely to retain pre-colonial ground surfaces. There also appears to be some spatial patterning in terms of areas that increased in elevation. In some cases, larger areas of increase (remade or infilled ground) correspond to parts of the Grid that are low-lying in relation to their surroundings. Altogether, our elevation change modeling, sheds significant light on the anthropogenic use of both Melbourne and Ballarat's landscapes during the nineteenth century.

Conclusion

Our modeling has the potential to provide invaluable information about historical land-use across urban areas. Its results are a reminder of the ubiquity of nineteenth century industrial landscape change in our contemporary cultural landscape. Rather than being idiosyncratic examples, Ballarat and the Hoddle Grid's 'fill events' are likely to have taken place across much of developed Victoria whether through gold mining, urbanisation, or through the cumulative nature of human agency. Terms such as 'remade', 'worked', or 'infilled' ground could provide an effective means of categorising many different forms of landscape change. For buried Aboriginal cultural heritage, the archaeological

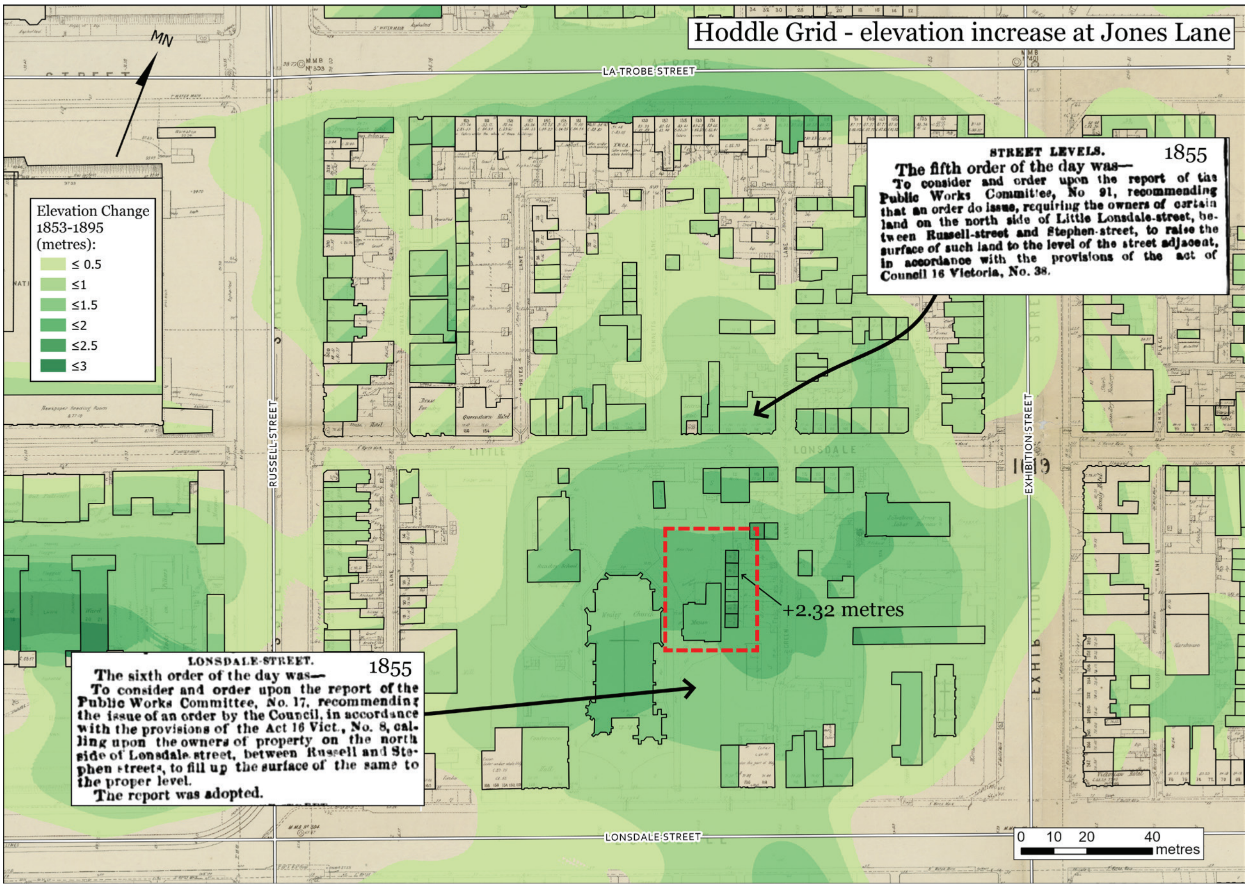


*Figure 3. Elevation increases greater than 0.25 m (1853 to 1895) at Jones Lane/Wesleyan Precinct (Hoddle Grid), overlying 1895 MMBW map, with relevant newspaper articles (*The Argus*, 20th February 1855;* The Argus*, 16th October 1855). The rectangle marked in red provides the approximate location where structural remains were uncovered during a 2017 excavation at Jones Lane*

implications for the presence of a mineshaft is really no different than a deep cellar, or a swimming pool (worked ground). An urban fill deposit has many of the same implications as gold mining sludge (remade/infilled ground). Together, these terms could provide increased clarity, while improving our ability to relate historical landform changes to the archaeological record. From a management perspective, this modeling could enable the production of new predictive models. These could allow cultural heritage resources to be refocused to areas with an increased likelihood of retaining pre-colonial ground surfaces. Whilst this could enable future discoveries to be made, it could also provide the opportunity to preserve archaeological fabric through avoidance. This paper has been a preliminary output of ongoing PhD research and these ideas and the GIS modeling will be the subject of future works (watch this space).

Acknowledgements

We would like to acknowledge Aboriginal peoples, the Traditional Custodians of Ballarat and Melbourne. This paper is a part of ongoing PhD research at La Trobe University and is taking place in accordance with the conditions set forth in Cultural Heritage Permit F20/102. This research is also part of the broader Rivers of Gold project jointly funded by La Trobe University, Aboriginal Victoria, and the Australian Research Council. The authors would also like to acknowledge valuable discussions with Jeremy Smith (Heritage Victoria), Michelle Negus Cleary (Dr Vincent Clark & Associates) and David Thomas (Aboriginal Victoria) and thank our anonymous reviewers for their detailed and insightful comments.

References

THE ARGUS ‘City Council’, Tuesday 20 February 1855:5

THE ARGUS ‘City Council’, Tuesday 16 October 1855:5

Bate, W. 1978 *Lucky City: The First Generation at Ballarat, 1851-1901*. Carlton South, Vic: Melbourne University Press

Canning, S. and F. Thiele 2010 Indigenous cultural heritage and history within the metropolitan Melbourne investigation area. Unpublished report to the Victorian Environmental Assessment Council

Carruthers, J. 1859 Town Lots, Ballarat East (Plank Road). Retrieved 3 October 2019 from < https://trove.nla.gov.au/version/31574733 >

Davies, P., S. Lawrence, J. Turnbull, I. Rutherfurd, J. Grove, E. Silvester, D. Baldwin and M. Macklin 2018a Reconstruction of historical riverine sediment production on the goldfields of Victoria, Australia. *Anthropocene* 21:1–15

Davies, P., S. Lawrence, J. Turnbull, I. Rutherfurd, J. Grove, E. Silvester, D. Baldwin and M. Macklin 2018b Bucket dredging in south-eastern Australia, 1899-1958. *Australasian Mining History*, 16:59–74

Dingle, A.E. and C. Rasmussen 1991. *Vital Connections: Melbourne and its Board of Works, 1891-1991*. Melbourne, Vic.: McPhee Gribble

Ford, J., H. Kessler, A. Cooper, S.J. Price, and A.J. Humpage 2010 An enhanced classification for artificial ground. British Geological Survey Open Report, OR/10/036

Ford, J., S.J. Price, A. Cooper and C.N. Waters 2014 An assessment of lithostratigraphy for anthropogenic deposits. *Geological Society*, *London, Special Publications* 395(1):55–89

Giblett, R. 2016 Lost and found wetlands of Melbourne. *Victorian Historical Journal* 87(1):135–156

Hodgkinson, C. 1853 Contour Plan of Melbourne, PROV VPRS 8168/P05 (MELBRL-15-1)

Lane, S. and A. Gilchrist 2019 Heritage in ruins: An investigation into Melbourne’s ‘buried blocks.’ Unpublished report to the Heritage Council Victoria (project PR180502)

Lawrence, S. and P. Davies 2014 The sludge question: the regulation of mine tailings in nineteenth-century Victoria. *Environment and History* 20:385–410

Lawrence, S. and P. Davies 2018 Archaeology and the Anthropocene in the study of settler Australia. In MAT de Souza and D. Menezes (eds), *Historical Archaeology and Environment*, pp. 229–251. Cham: Springer International Publishing

McMillan, A.A. and J.H. Powell 1999 BGS rock classification scheme. Volume 4, classification of artificial (man-made) ground and natural superficial deposits: Applications to geological maps and datasets in the UK. British Geological Survey Research Report, RR 99–04

Melbourne and Metropolitan Board of Works 1895 Melbourne and Metropolitan Board of Works detail plan. 1019. City of Melbourne, Melbourne

Negus Cleary, M., N. Bajzelj, J. Scibilla and M. Haas 2019 Beneath the clay: the mid-nineteenth century raising of street and property levels in Jones Lane and Little Lonsdale Street, Melbourne. *Excavations, Surveys and Heritage Management in Victoria* 8:17–28

Paterson, A. 2018 Once were foragers: the archaeology of agrarian Australia and the fate of Aboriginal land management. *Quaternary International* 489:4–16

Phillips, J. 1858 Geological Survey of Victoria: Ballarat. Department of Public Lands, Melbourne

Presland, G. 2008 *The Place for a Village: How Nature has Shaped the City of Melbourne*. Melbourne, Vic.: Museum of Victoria

Presland, G. 2014 A boggy question: differing views of wetlands in 19th century Melbourne. *The Victorian Naturalist* 131(4):96–105

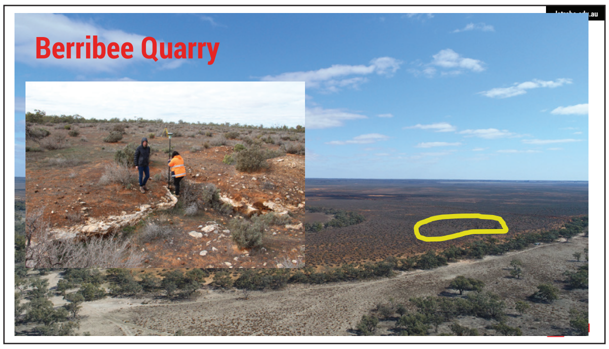
Spielvogel, N.F. 1981 *Spielvogel Papers: Volume Two*. P.G. Mansfield (ed.), Ballarat, Vic.: Ballarat Historical Society

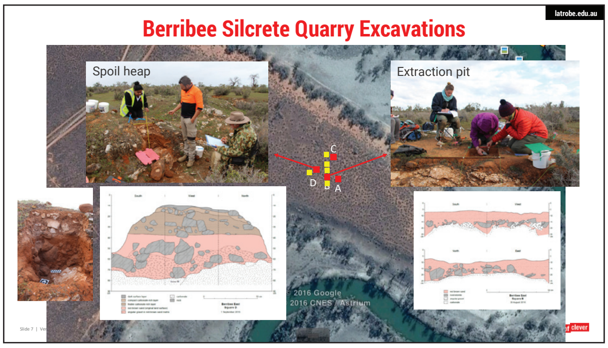
Victorian Low-Lands Commission, 1873 *Low-Lands Commission: Progress Report*. Melbourne, Vic.: John Ferres, Government Printer

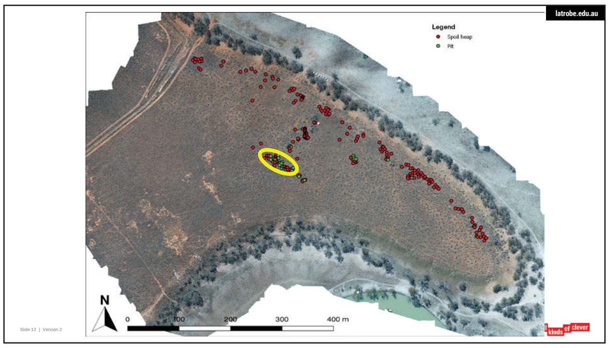
An update on research at Berribee Quarry: a dated silcrete extraction site in the Central Murray River Valley of northwestern Victoria

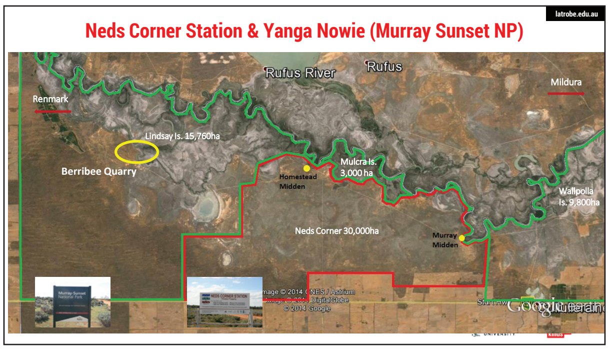
Jillian Garvey (La Trobe University)
Rebekah Kurpiel (La Trobe University)
Nathan Jankowski (ARC Centre of Excellence for Australian Biodiversity and Heritage, University of Wollongong)
Zenobia Jacobs (ARC Centre of Excellence for Australian Biodiversity and Heritage, University of Wollongong)
Paul Penzo-Kajewsk (La Trobe University)
Darren Perry (First People of the Millewa-Mallee Aboriginal Corporation)
Uncle Tinawin Wilson (First People of the Millewa-Mallee Aboriginal Corporation)
Bengi Salvi (University of Melbourne)
Austen Graham (Melbourne Water)
Emmy Frost (La Trobe University)

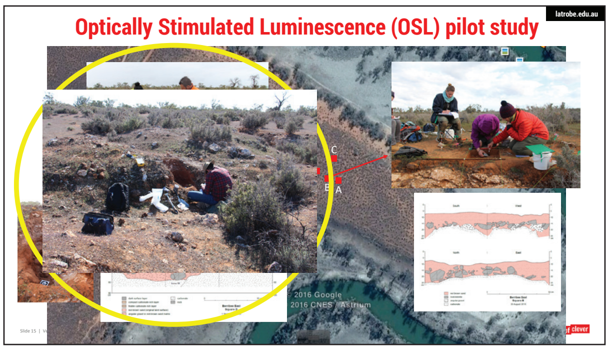
Berribee Quarry, on Ngintait Country, near the Lindsay River in the central Murray River Valley of northwestern Victoria, was a source of relatively high-quality silcrete for Aboriginal people. Initially described by Mark Grist, Berribee appears to be the only source of tool stone in the region. This source is unusual in that it is a subsurface deposit of silcrete that has been accessed via extraction pits rather than collected from an outcrop or other exposed source. This paper outlines recent fieldwork results, which are part of ongoing research as part of the ARC funded Neds Corner Archaeology Project. This research aims to understand the activities that were undertaken at Berribee Quarry, as well as the distribution and use of the material that people transported away from it. Recent drone and foot surveys of the quarry indicate that it comprises a complex series of extraction pits and spoil heaps distributed over an area of approximately 12 ha. Recently obtained Optically Stimulated Luminescence (OSL) age estimates derived from one of the quarry spoil heaps indicate that Berribee Quarry was used by Aboriginal people long before European arrival, and Traditional Owner accounts indicate that it was used up until the relatively recent past.











Therry (Munro Site) and Elizabeth Street excavations: Site formation along the former Williams Creek, Melbourne CBD’

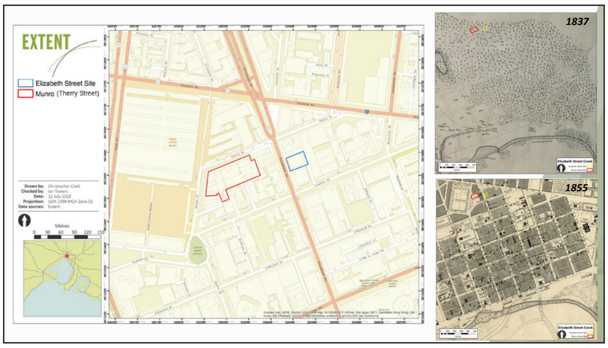
Christopher Clark (Extent Heritage)
Sarah Janson (Extent Heritage)

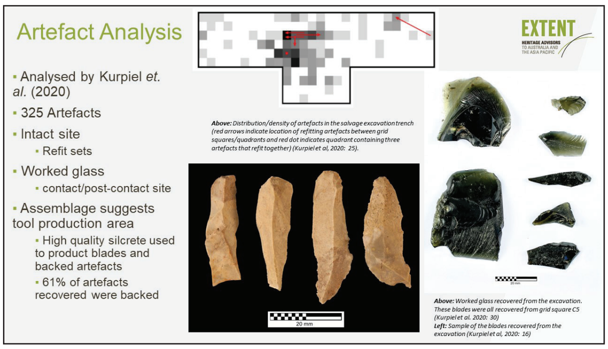
With contributions from:
Rebekah Kurpiel (La Trobe University)
Caroline Spry (La Trobe University)
Paul Penzo-Kajewski (La Trobe University)
Brandon Kerrigan (La Trobe University)
Caroline Hawker (La Trobe University)
Birgitta Stephenson (In the Groove Analysis)
Patrick Moss (University of Queensland)
Sam Player (Geoprospection)

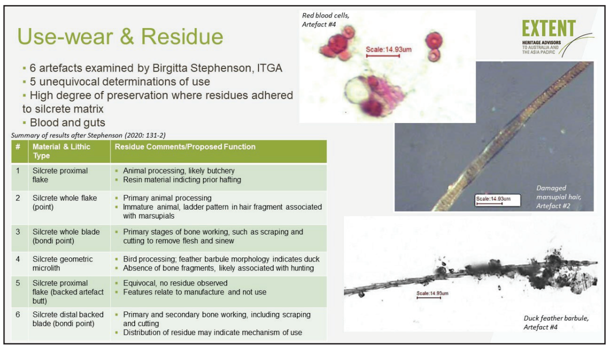
European colonisation of the area that is now Melbourne’s CBD dramatically modified a landscape that was intensively occupied and used by Aboriginal people. The establishment of Hoddle’s Grid in 1837 required levelling of hills, filling of wetlands and removal of waterways to achieve the planned rectangular shape of the fledgling city. One such waterway significantly amended to facilitate the city’s development was Williams Creek, which flowed approximately along the alignment of the current Elizabeth Street. This modification consequently accentuated major flooding events in the area, requiring further works, including under a Melbourne Council edict, to raise the street level of Melbourne during the mid-nineteenth century.

Two major projects recently undertaken by Extent Heritage have revealed archaeological evidence associated with the original Williams Creek and uncovered contact period Aboriginal cultural deposits preserved by the results of the nineteenth century Council edict. This presentation will discuss excavations at the historical Munro site (adjacent to Queen Victoria Market) which revealed a profile of the original Williams Street Creek underneath the foundations of early twentieth century shops, and, nearby, excavations at 478-488 Elizabeth Street in which a highly intact Aboriginal site was uncovered, preserved within pre-contact topsoil immediately below imported clay.

Radiocarbon dating, pollen and artefact analysis from these excavations have generated data that illustrates the changing environmental characteristics of Melbourne in this period, including evidence of changes in vegetation and increased erosion and of Aboriginal fire regimes. From this evidence, we can further our understanding of the impacts of the early settlement, both for Aboriginal people and Europeans, as they dealt with the consequences of the manipulation of the landscape. Analysis of the Munro and Elizabeth Street sites can be used to ask how the impacts of settlement and key historic events in the city’s development have affected both the formation and preservation of archaeological sites in the Melbourne CBD.





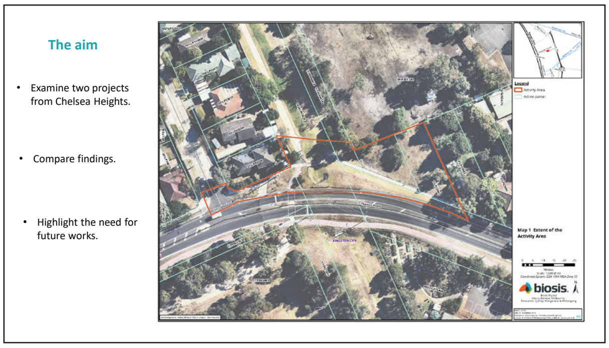


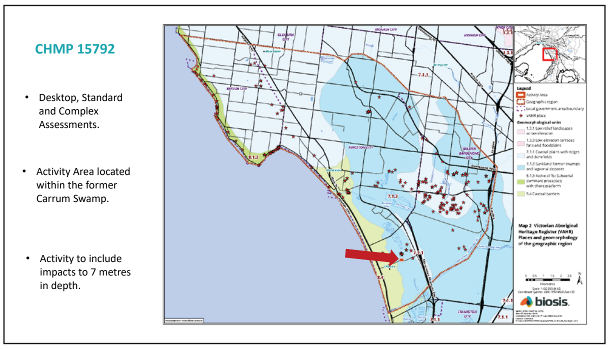
Dating the Sunklands; a complex picture

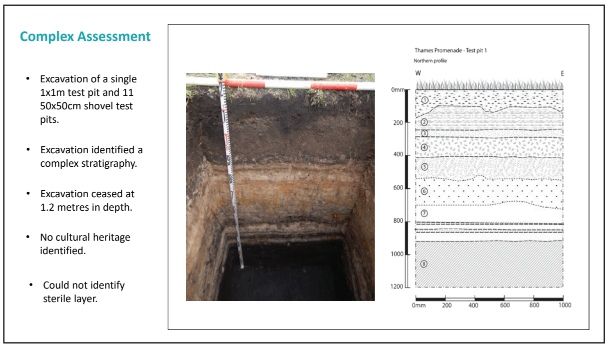
Martin Lawler (Biosis)
Aaron Dalla-Vecchia (Biosis)
Jim Wheeler (Extent Heritage)

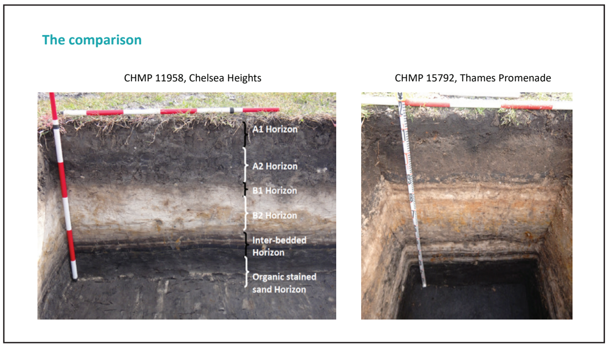
During CHMP 15792 assessment, Biosis carried out excavations at Thames Promenade, Chelsea Heights. The excavations were on the same landform as Aboriginal places identified during CHMP 11958 (conducted by Extent Heritage) at First Avenue, Chelsea Heights, 400 m to the southeast.

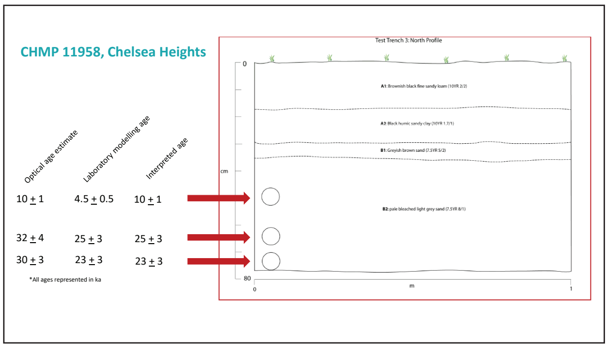
Due to the sandy nature of the deposit, it was not considered to safe to proceed with controlled excavation beyond 1.2 m in depth without shoring. No cultural heritage material or an archaeological sterile deposit was identified to this depth. In conjunction with stakeholders, an alternative investigation methodology was developed which utilised boreholes (Tonkin and Taylor) for stratigraphic recording (Peter Mitchell), AMS (Direct AMS) and OSL (Griffith University) dating to 7.1 m. The purpose of this methodology was to determine an archaeological sterile deposit whilst also providing insight into the geomorphology of the area. The three AMS samples provided Holocene dates, while the two OSL samples provided Pleistocene dates in excess of 100 ka BP, despite these samples being taken from deposits that were anticipated to provide a chronological sequence. The two data sets cannot be easily reconciled, however the data provided as part of both CHMP 11958 and CHMP 15792 provides an insight into the complex stratigraphic nature of the former swamp area. The results of CHMP 15792 will be presented here, along with a discussion of ongoing considerations when working in the Port Phillip Bay Sunklands.

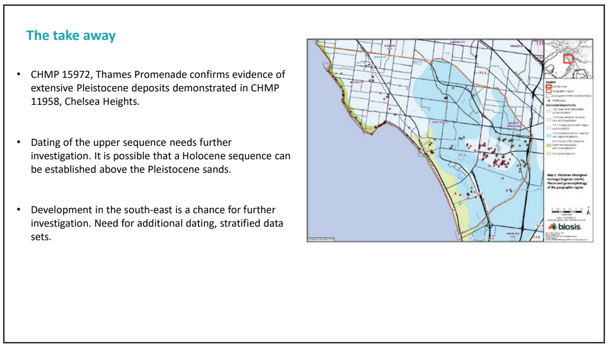










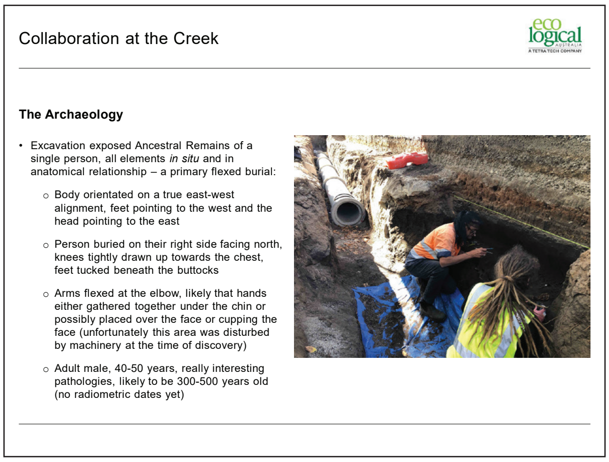


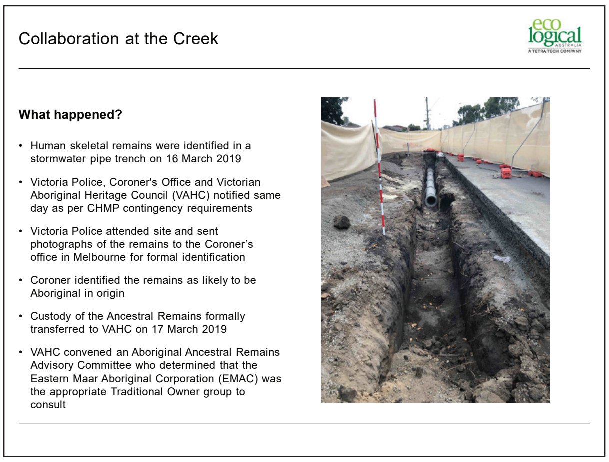
Collaboration at the Creek: the Barongarook Creek Bridge Burial, Colac, Victoria

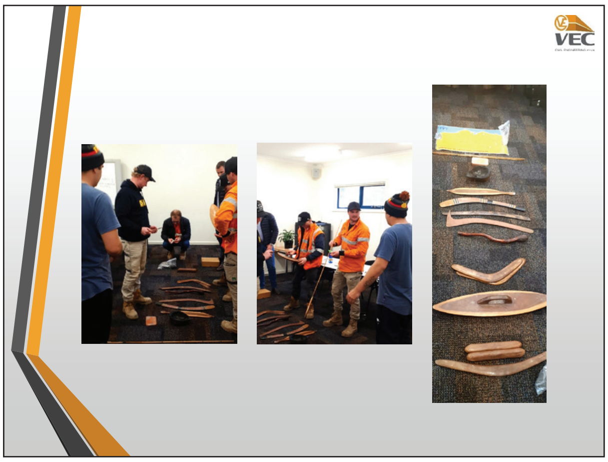
Michael Green (Eco Logical Australia)
Craig Edwards (Eastern Maar Aboriginal Corporation)
Owen Cavanough (VEC Civil Engineering
Matt Grigg (Major Road Projects Victoria)

This paper describes the circumstances of discovery and subsequent investigation of Aboriginal ancestral remains identified below an existing roadway during works for the construction of a new bridge crossing over Barongarook Creek in Colac, south-west Victoria. The paper focuses on the processes that were required during initial reporting of the discovery, the resolution of jurisdictional matters and identification of relevant stakeholders, and the steps that were followed during consultation and subsequent decision-making as to whether the ancestral remains should be left in situ or removed and repatriated at a later date.

Critical to the successful resolution of these matters was the seamless implementation of reporting processes required by Aboriginal Victoria under relevant provisions of the Aboriginal Heritage Act 2006 (Vic), the provision of clear advice from the Victorian Aboriginal Heritage Council regarding the identification of relevant Traditional Owner groups, and a willingness by the project manager (Major Road Projects Victoria), the Traditional Owners (Eastern Maar Aboriginal Corporation) and the constructor (VEC Civil Engineering) to work collaboratively in order to achieve an outcome that met all stakeholders' needs.



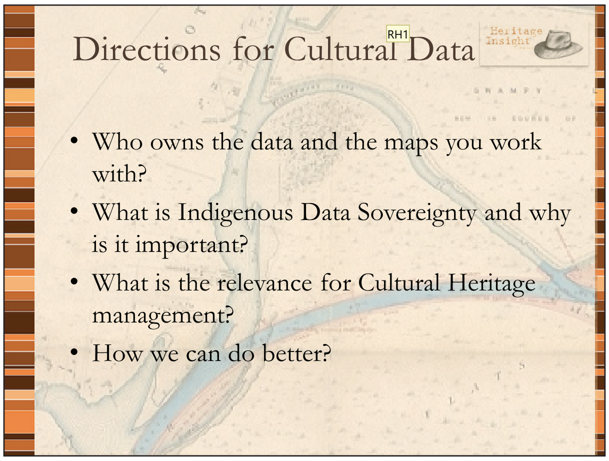


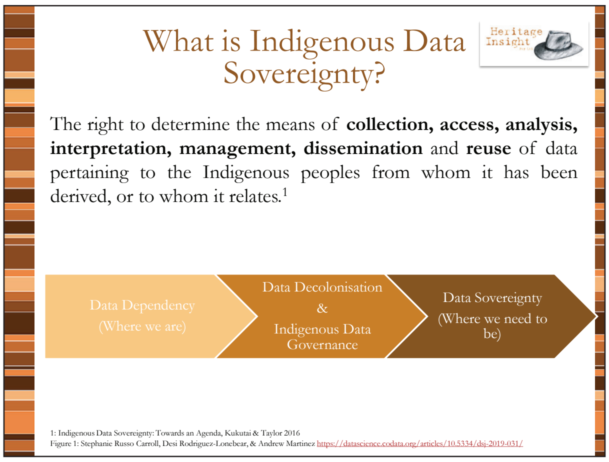


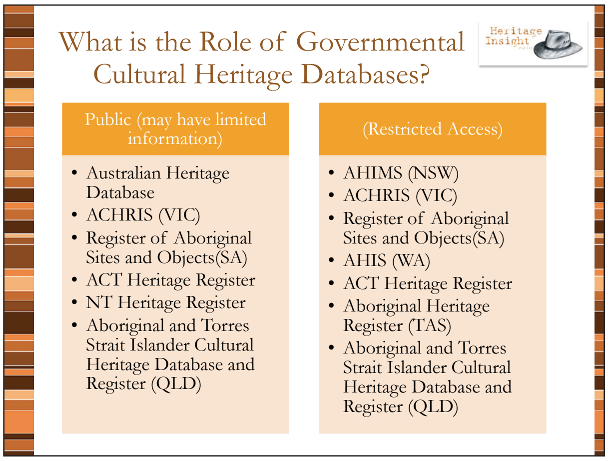
Indigenous data sovereignty

Fiona McConachie (RMIT; Wurundjeri Woi Wurrung Cultural Heritage Aboriginal Corporation),
Renee McAlister (Heritage Insight Pty Ltd)

Protecting cultural knowledge data as digital information is one important part of an information management system. Another, often overlooked, part of the management of cultural data is the information and data in maps. As digital data gathering becomes more sophisticated and spatial data collection increases in accuracy it is important to consider the implications of spatial data use on maps as it applies to Traditional Owner Data Sovereignty. The accessibility of maps containing cultural places, knowledge, and values has concerning implications for Traditional Owners and the quest for Indigenous Data Sovereignty. In this presentation we look at the creation, use, and distribution of maps containing cultural information, as well as discuss some of the legal and ethical discussions for people involved with consulting.



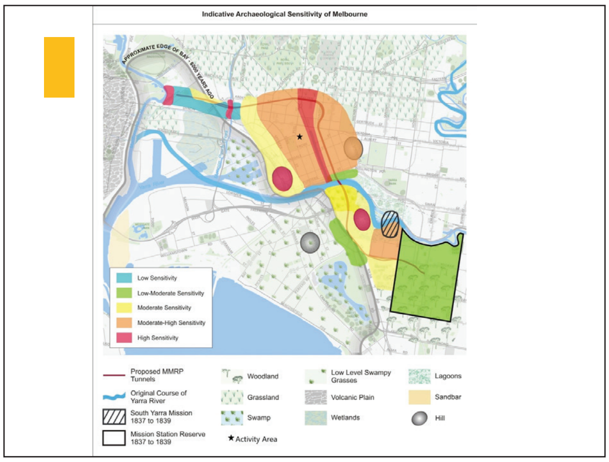


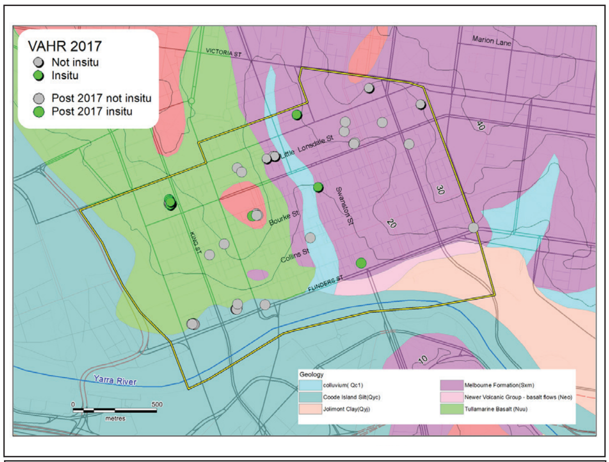


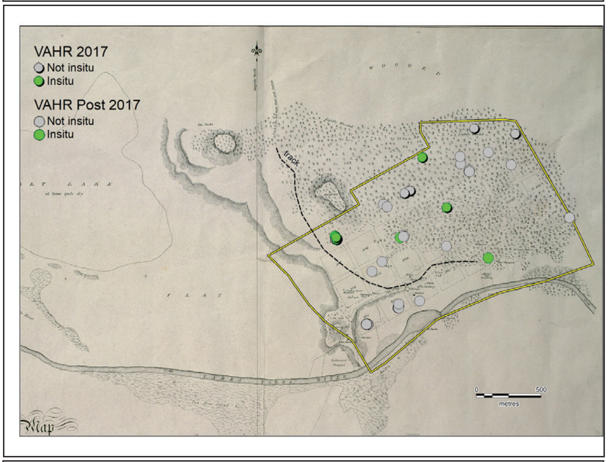
Hoddle Grid Heritage Review: pre-contact archaeology

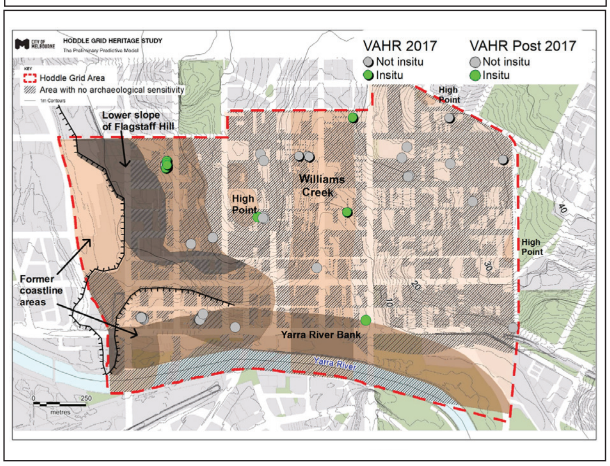
Petra Schell (Ochre Imprints)

This paper presents the outcomes of an analysis of the pre-contact Aboriginal archaeology across the Hoddle Grid study area, prepared for the Hoddle Grid Heritage Review commissioned by City of Melbourne. The project considered prior land and water forms, vegetation and other factors that influenced Aboriginal land uses and activities over time in the Hoddle Grid. This information is then related to the evidence that has been uncovered through recent archaeological excavations. The result is a spatial model designed to predict the likelihood of uncovering evidence of pre-contact Aboriginal sites within the Hoddle Grid area. Recommendations are made on how to increase the assessment and management of Aboriginal cultural heritage ahead of redevelopment in the Hoddle Grid study area.









Hoddle Grid Heritage Review: contemporary Aboriginal connections

Chris Johnston (Context; La Trobe University)

Over the last two years, the City of Melbourne's Hoddle Grid Heritage Review has shaped a new approach to heritage studies, expanding the scope to include the Aboriginal landscape – pre-contact and contemporary. The City of Melbourne's aim was to start considering all aspects of the City's cultural heritage – Aboriginal, colonial, contemporary, community, tangible and intangible. A challenging scope.

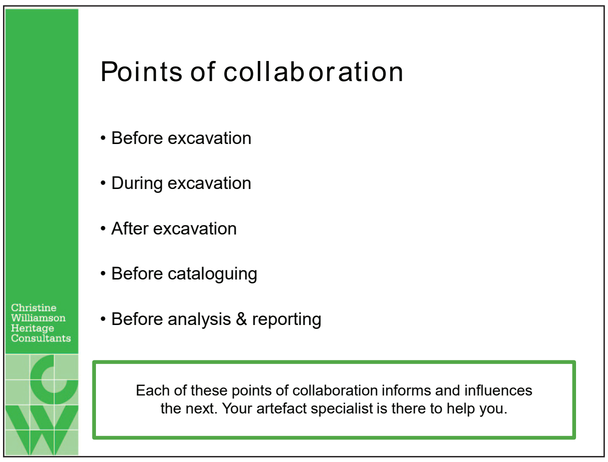
The Aboriginal cultural landscape of the central city is both archaeological and contemporary: the Hoddle Grid Heritage Review sought to address both.

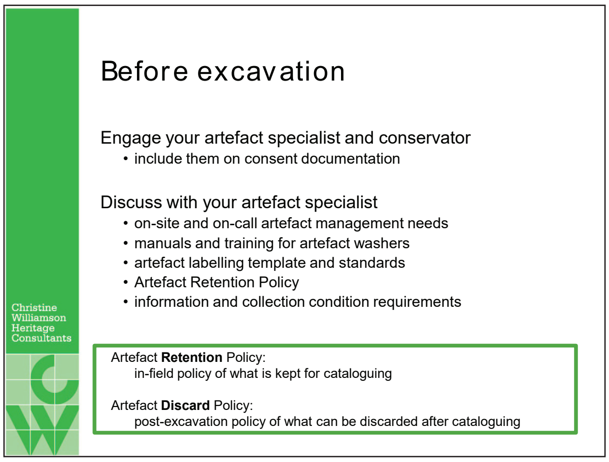
Aboriginal people have multiple connections with the central city, traditional and contemporary. City of Melbourne policies seek to recognise these connections. In this project, the project team worked with the three Traditional Owner organisations recognised by the City of Melbourne to document contemporary values for fifteen places, some already on heritage registers for their architecture and history, and others not. This work was underpinned by a thematic history, and an extensive list of places. Seeking greater recognition of Aboriginal perspectives and values in heritage studies and listings is an important, but challenging outcome.

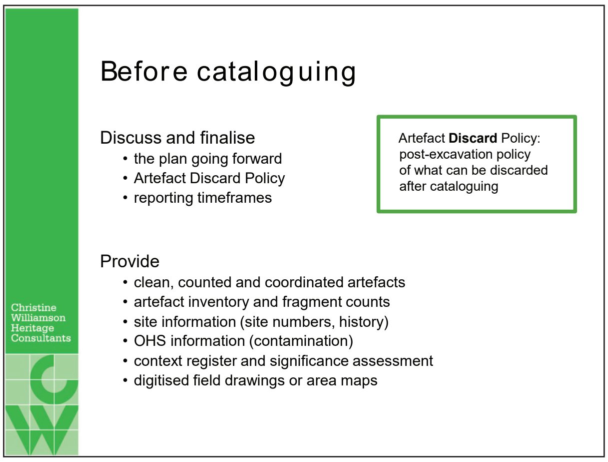
2020 vision: historic artefact management in a new decade

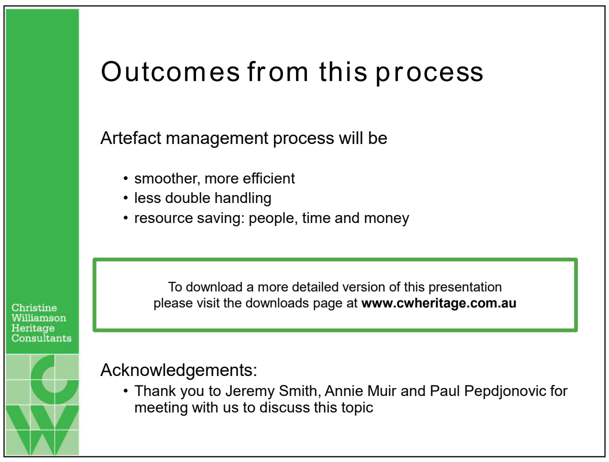
Bronwyn Woff (Christine Williamson Heritage Consultants)
Christine Williamson (Christine Williamson Heritage Consultants)

Over our combined 28 years of managing historic artefact collections, we have recently seen a change in the relationship between archaeologists and artefacts. As Heritage Victoria promotes more rigorous guidelines on requirements for site and artefact management, we note that in Victoria the focus is shifting towards planning artefact management procedures prior to excavation, with greater involvement of specialists occurring at all stages of the process. As artefact specialists we embrace this new more inclusive and integrated approach, and as this shift continues to gather momentum we wish to take stock of current methods and explore opportunities for improvement. In this paper we will outline a suite of processes aimed at improving the efficiency of artefact management, cataloguing and analysis. These suggested changes will benefit consultants, clients and artefact specialists alike in terms of time and cost efficiencies and collection interpretation outcomes.





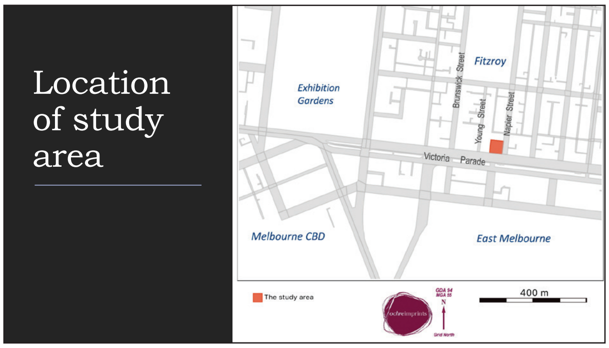


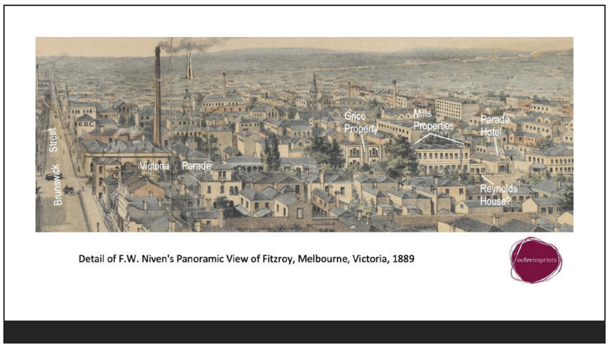


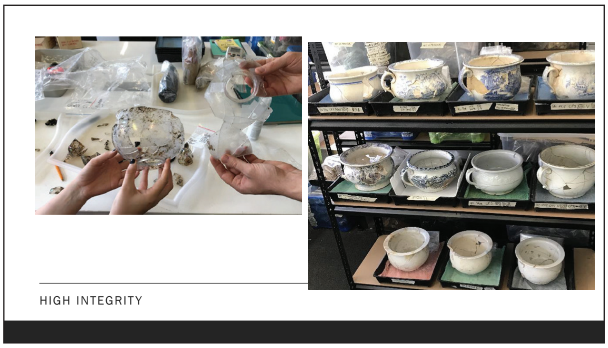
Trashed or treasure: a domestic assemblage from Fitzroy c1860-1880

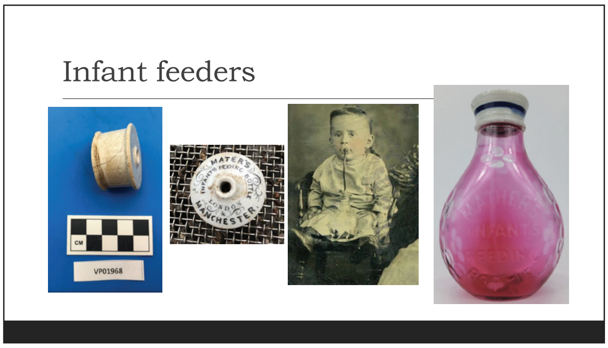
Jennifer Porter (Ochre Imprints)
Sharon Lane (Ochre Imprints)

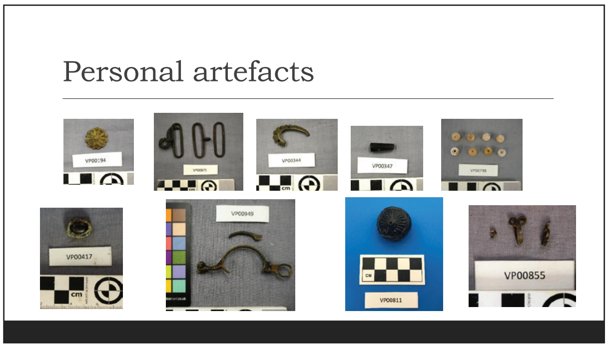
When archaeological structures are largely absent, and cesspits the only features deep enough to survive demolition, we rely on historical research and artefact analysis to tell the story. In this case the artefacts from two relatively intact cesspits revealed consumer choices and lifestyle of the well-to-do residing in inner suburban Fitzroy just after the gold rush. With Fitzroy and other inner suburbs undergoing rapid transformations, rich insights into the past derived from such assemblages are being destroyed beneath high rise developments.











The trouble with MNI – comparing assemblages across Chinese diaspora sites in Australasia

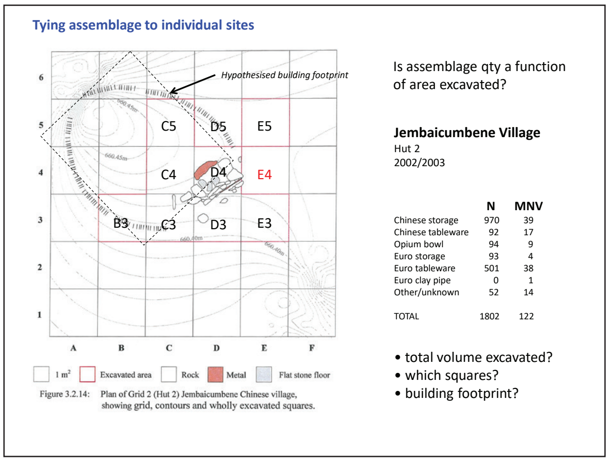
Paul Macgregor (The Uncovered Past Institute)
Melissa Tsafkas (The Uncovered Past Institute)

Two seasons of fieldwork have now been completed at the Harrietville Chinese Mining Village in northeast Victoria. It is a rural settlement site with evidence of domestic and economic activity, dating from ca 1860 to 1909. When comparing this site with other Chinese rural settlement sites around Australasia, it is useful to look at the different assemblages associated with building structures. The sites which are most relevant include: excavations of gold mining sites in Otago (Ritchie) from 1978 to 1985, excavations at Atherton Chinatown, Queensland (Grimwade and others) from the 1980s to 2015, the excavations at Butcher's Gully and Loddon Flats (Stanin), central Victoria from 2001 to 2003, the Chinese fish-curing site at Port Albert (Bowen) in Victoria in 2005, and mining settlements in south-eastern NSW (Smith) from 1996 to 2006.

In some cases, sub-surface sampling has prioritised features, with sampling that focuses on determining the horizontal extent of a structure but leaves large amounts of area unexcavated, and the artefacts as a byproduct. The MNI reported is then perhaps not a true reflection of the potential vessel count that may remain still buried. Volume of excavation is another issue. Smith and Ritchie, for instance, each had 30+ sites which were excavated, generating tens of thousands of fragments. As both excavations were also PhD projects, the amount of time for MNI analysis was constrained. So both focused on weight methodologies, and aggregating assemblage data across several sites. The reporting for each excavation also varied in how much data was provided regarding trench size per building site, and volume of soil excavated. In some cases, aggregate MNI for multiple sites, grouped together, masked the MNI count per individual habitation.

With the Harrietville excavations so far, we have excavated a smaller number of habitations (n = 2), and with more area excavated as a proportion of habitation size. We have also taken more time to study the form of each fragment. We developed MNI not just on, say, base or rim counts for vessels, but also carefully sorting by fine gradations of glass colour (for bottles), glaze colour (for ceramic jars) and curvature of fragments.

With different approaches to MNI methodology, it is difficult to consider the relative preponderance of particular vessel types between our excavations and others' excavations, to understand what that means, and generate interpretations from MNI counts. As a result, this paper will argue that it would be useful for historical archaeologists to think more carefully about why MNI is useful, consider methodologies that can be more valuable for comparing assemblages from different sites, and develop a standard framework to enable better comparative analysis in the future.



A crowd-funded aviation archaeology survey

Meaghan L. Aitchison
Leah Byrne
Talia Green
James Kightly
Daniel J. Leahy

At the Victorian Archaeology Colloquium 2019 a paper discussed a Second World War Brewster Buffalo aircraft wreck located on Mount Stanley in north east Victoria. The paper proved to be the catalyst that brought together a number of like-minded archaeologists from two states who wanted to see an archaeological survey conducted at the wreck site. This paper will present the results of the crowd-funded archaeological survey of the Buffalo wreck that took place in March 2019. Despite large portions of the wreck being salvaged over the years, much can still be learned from artefacts remaining at the site regarding the aircraft, its crash, and its involvement in the wider conflict. The survey identified a significant number of artefacts remaining at the site and has resulted in the wreck being listed on the Victorian Heritage Inventory.

2015 Reconnaissance Survey

Left: Artefact scatter located at the Mount Stanley Buffalo wreck site (photo by Daniel J. Leahy, 2015)
Right: Terrain and vegetation at the Mount Stanley Buffalo wreck site (photo by Daniel J. Leahy, 2015)

2019 Crowd Funding

- Raised over $700 from 9 to 27 February 2019.

gofundme

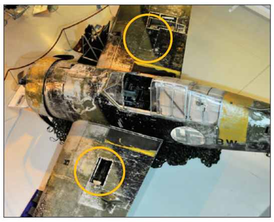
The Brewster Buffalo

- American built single-engine, single-seat fighter aircraft.
- 509 built
  - 92 intended for the ML-KNIL.
  - 21 diverted to Australia after the surrender of Java (17 delivered to the RAAF).

Early war advertisement for the Brewster Buffalo (via James Kightly)

Sources: Baugher 2001; Leahy 2019a; Maas 1987; Wilson 1998:30.

2019 Archaeological Survey



Left: Ammunition bay panel located at the Mount Stanley wreck site (photo by James Kightly, 2019)
Right: The sole surviving Brewster Buffalo, with ammunition bays in wings circled (photo by Matti Sartenada via Dave Brown)

The Mount Stanley Buffalo

- Crashed in poor weather on the morning of 1 July 1942 during a flight between Laverton and Wagga Wagga.
- Wreck located by 1st Constable William John Miller that morning.

Map showing the location of the Buffalo wreck in relation to airfields at Laverton and Wagga Wagga (image by Daniel J. Leahy, 2019)

Sources: Leahy 2019a; Miller 1942; NAA 1960; Wood 1942.

Results & Output

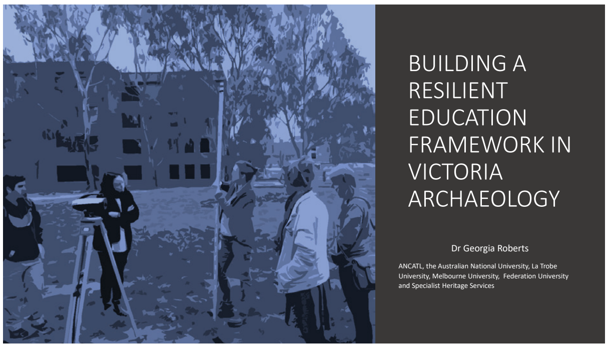
- Site listed on the Vic. Heritage Inventory and protected under the Heritage Act 2017.
- Academic conferences and lectures.
- Non-academic output (e.g. *Flightpath* article).

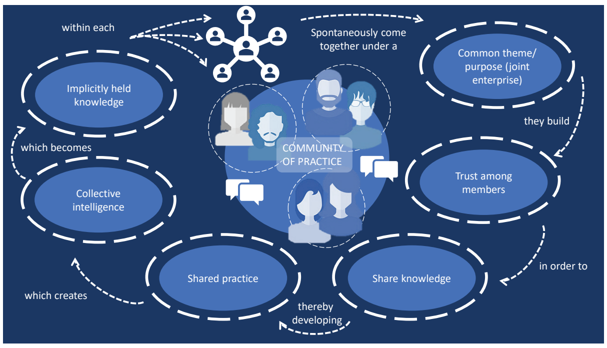
Flightpath Vol. 31, No. 2 (Nov 2019-Jan 2020)

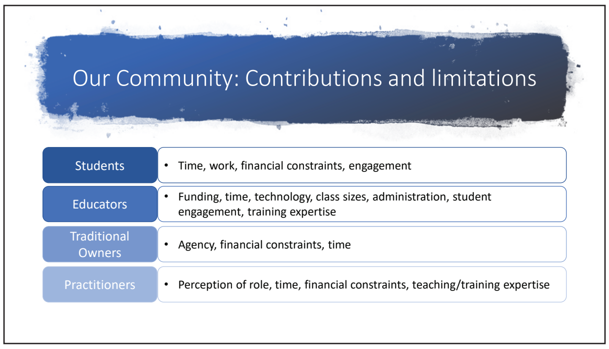
Building a resilient education framework in Victoria archaeology

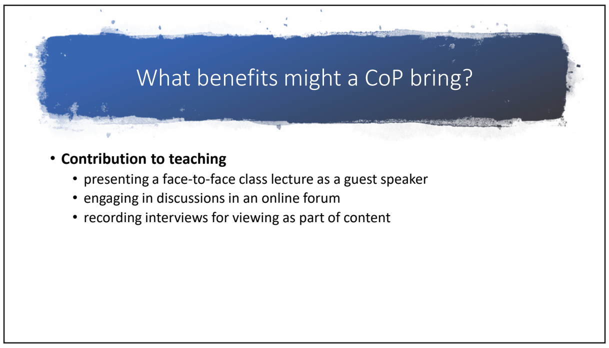
Georgia L. Roberts (Australian National Committee for Archaeology Teaching and Learning; Australian National University; Federation University; La Trobe University; Melbourne University)

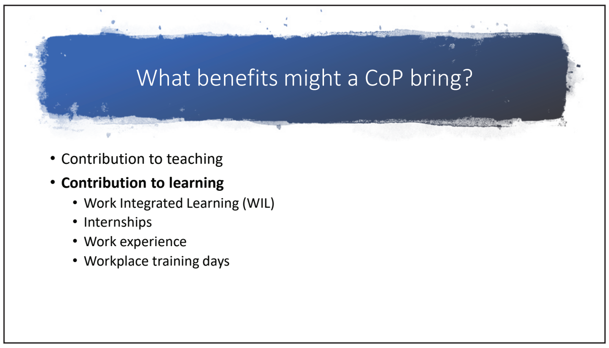
The teaching and learning of archaeology has become increasingly problematic. Teachers are faced with significantly decreased resources and capacities for content delivery within their classrooms while students are juggling study with work and a myriad of other commitments. The acquisition of practical skills is an excellent example of this issue which has been widely discussed over the last few months, particularity in conjunction with the launch of the Australian Archaeology Skills Passport. This paper will explore some of the opportunities for the Victorian archaeological community to build a more robust and resilient education framework in order to meet the current and future needs of the discipline.

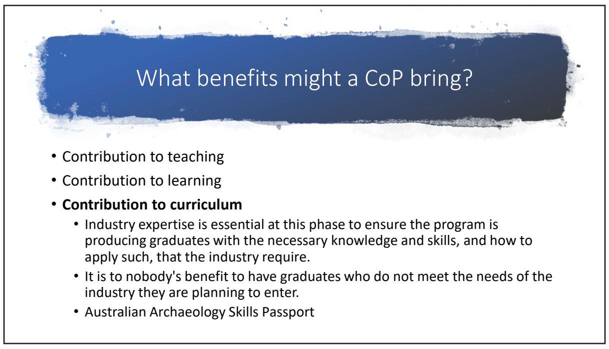








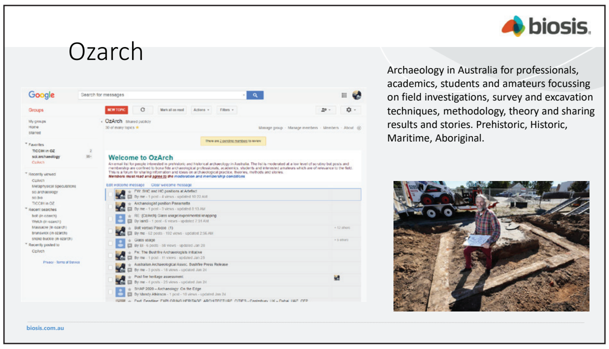


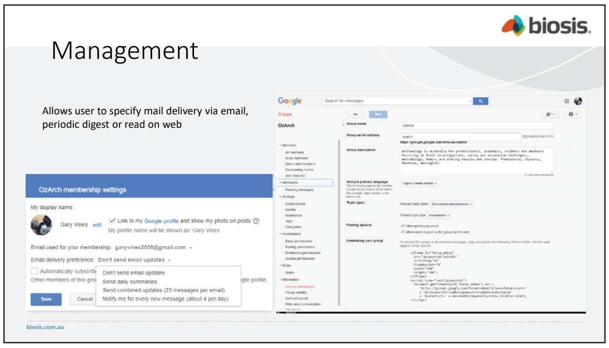


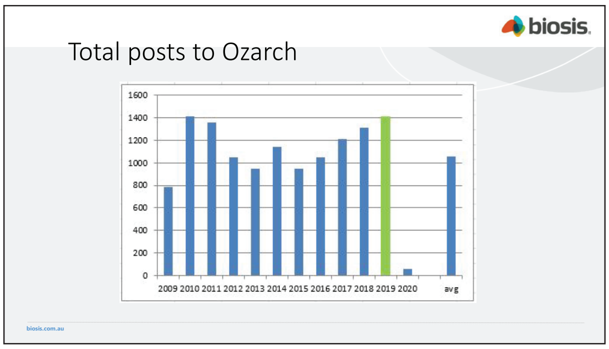
Ten years of OzArch

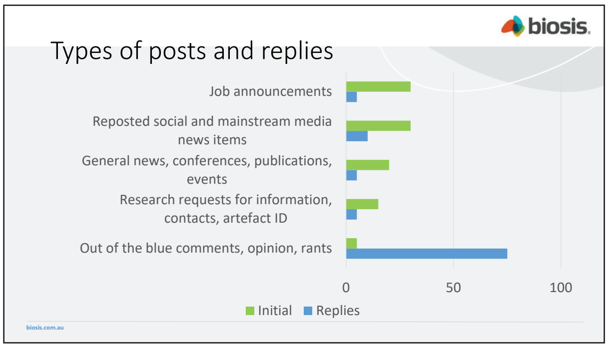
Gary Vines (Biosis)

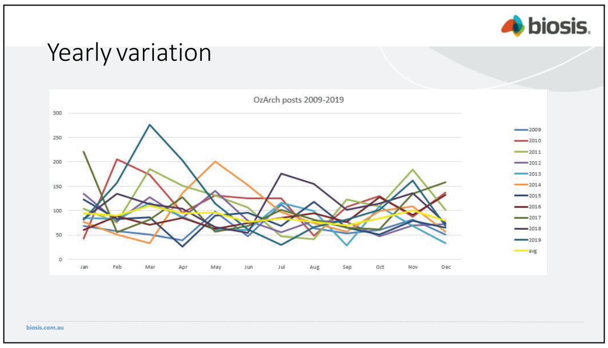
The internet provides wonderful opportunities for collaboration and exchange of information. Archaeology was an early adopter of electronic communications. However, while some countries have dozens of email discussion groups and rooms related to archaeology (over 70 in Britain for example), Australia has been fairly limited. OzArch was set up to replace the defunct AusArch list run by Peter Hiscock from ANU 10 years ago. OzArch has gradually grown in number of members but may be caught in a relevance impasse preventing it from being more widely used or diverse in its applications. This brief talk considers the development and use of OzArch in the last decade and its future possibilities.

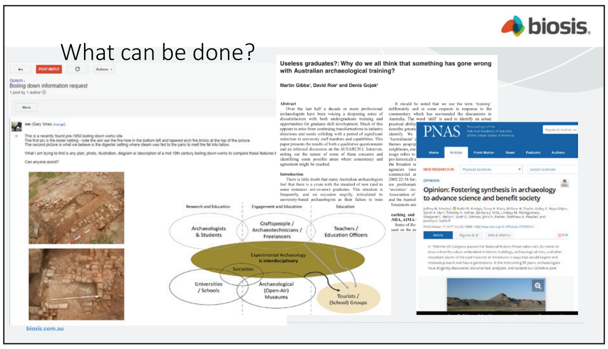












10 years of Aboriginal cultural heritage management training: outcomes and prospects

Maddy Maitri (La Trobe University)
Christina Pavlides (Aboriginal Victoria)

The Certificate IV in Aboriginal Cultural Heritage Management has been funded by Aboriginal Victoria and delivered by La Trobe University for the past ten years. This paper summarises some of the key outcomes for our Aboriginal graduates and considers Aboriginal cultural heritage management training in current and future educational and professional contexts.

Trainers and presenters

- 209 individual presenters from 50 organisations and consultancies.
- 60% (126) Indigenous

- Traditional owners
- Registered Aboriginal Parties
- Aboriginal community, educational and tourism organisations
- Aboriginal Victoria
- La Trobe and other Universities
- Consultants from archaeology and other disciplines
- Land managers
- Local councils…

Aims of the training program

- strengthen capacity of Aboriginal Victorians in relation to cultural heritage management and legislative compliance
- offer an accredited qualification that provides **accessible*** formal education and training in CHM
- support a pathway to higher education in archaeology and CHM for Aboriginal people
- *participants are supported with accommodation and transport costs in order to attend*

Outcomes – Intangible benefits

- empowerment
- community connection
- confidence
- cooperation
- research partnerships
- goals and directions

Our graduates

- 174 graduates out of 190 enrolments
  = 92% completion rate
  (c.f. 28% for VIC VET)
- men 61%, women 39%
- ages 18-65, average age 38
- 75% of graduates are linked to a RAP by association
- 25% of graduates are from non-RAP areas
- 90% of graduates are Victorian Traditional Owners

Prospects

- Strong demand – waiting list
- State government committed over $2 million funding for another four years – 60 positions
- Target non-RAP areas of Victoria
- Make delivery more flexible
- Customised training, skills sets, microcredentials
- Support Aboriginal aspirations to transition to heritage advisor status – archaeology or other degrees