Australian Archaeology

ISSN: 0312-2417 (Print) 2470-0363 (Online) Journal homepage: www.tandfonline.com/journals/raaa20

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To cite this article: Lynley A. Wallis, Kim Vernon, Carney D. Matheson, Heather Burke, Christine Musgrave, Roseanne George, Samantha Lowdown, Cliff Callaghan, Sue Marsh, Salmia Yakub, Geraldine Jacobsen, Mia Dardengo & Keeley Wood (14 Aug 2026): An assemblage of resin-mounted macropod incisors from Quinkan Country, Cape York Peninsula, Queensland, Australian Archaeology, DOI: 10.1080/03122417.2026.2694015

To link to this article: https://doi.org/10.1080/03122417.2026.2694015

Published online: 14 Aug 2026.

AUSTRALIAN ARCHAEOLOGY
https://doi.org/10.1080/03122417.2026.2694015

ARTICLE

An assemblage of resin-mounted macropod incisors from Quinkan Country, Cape York Peninsula, Queensland

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ABSTRACT

This paper reports on the first identification of macropod incisor ornaments from a non-burial context in northeast Australia. While ethnographic museum collections demonstrate the vibrant traditional organic material culture of the Indigenous peoples of Australia, the vagaries of preservation mean such items are only rarely recovered archaeologically. The Late Holocene Windmill Way site in southeast Cape York Peninsula, Queensland, is one such remarkable exception. Amongst its diverse archaeological assemblage are 12 macropod incisors with balls of resin adhesive attached to their roots. The resin residues were analysed using Fourier transform infra-red spectroscopy (FTIR) and liquid chromatography mass spectrometry (LC-MS) chemical analyses, in conjunction with microscopy and some with AMS accelerator mass spectrometry radiocarbon dating. Results indicate that the resin predominately derives from *Xanthorrhoea* (grass tree), while AMS dating of two resin samples indicates the objects are 1,100–1,300 years old. The absence of non-resin residues and use-wear on the teeth suggests that they were not used for utilitarian tasks, such as cutting, scraping or drilling. Rather, the objects appear to have been components of an item of personal adornment, such as a necklace or headband, with the resin balls serving to fix the plant fibre string to the teeth. One fragment of cut hide and several plant fibres directly associated with the resin, together with the presence of hundreds of fragments of 2-ply plant fibre twine in the site, support the proposition that these artefacts may have been strung. Further support for this interpretation comes from motifs in the rock art of the nearby Biniirr National Park that depict strung objects of similar shape and size. The results demonstrate the value of FTIR and LC-MS analyses for resin identification, and highlight the need to carefully assess macropod incisors, even in the absence of obvious macroscopic signs of resin hafting.

ARTICLE HISTORY
Received 20 April 2026
Accepted 21 June 2026

KEYWORDS
FTIR; LC-MS; material culture; Late Holocene; personal adornment; macropod teeth; plant resins

Introduction

In Sahul, shell and bone ornaments have been reported from Late Pleistocene archaeological sites in Western Australia, including Riwi, Carpenters Gap 1, Mandu Mandu, Boodie Cave and Devils Lair (e.g. Balme 2000; Balme and O'Connor 2017, 2019; Balme et al. 2018; Dortch 1979a, 1979b; Hook et al. 2024; Langley et al. 2016; Morse 1993; O'Connor 1995), suggesting that personal ornamentation formed a component of the cultural toolkits of the earliest human arrivals. At the time of European invasion, similar items were also observed and documented in ethnohistorical records (e.g. Bassett-Smith 1894; Bates 1985; Bonnemains et al. 1988; Curr 1886, 1887; Dawson 1881; de Freycinet 2001:126; Hawkesworth et al. 1774; Parkinson 1773; Phillip 1789; Roth 1910; Smyth 1878:278). Animal teeth have been used in necklaces, chest pendants, circlets, headbands, forehead pendants and sidelock pendants (Figure 1; for Australian examples see Akerman 2010, 2018; Allen 1980:6; Hamlyn-Harris 1918:Plate VIII; Langley 2023:158–179, 195–196, 200–202, 203, 204; McCarthy 1953; Spencer and Gillen 1899:574; for international examples see Garrod 1932; Langley and O'Connor 2016; Leavesley 2007; Mene et al. 2025; Wei et al. 2016; Wenzhong 2025; Wickler 2001:209–211). These objects are well-represented in museum collections and continue to be made by Indigenous people in Australia today (e.g. Edmonds et al. 2020).

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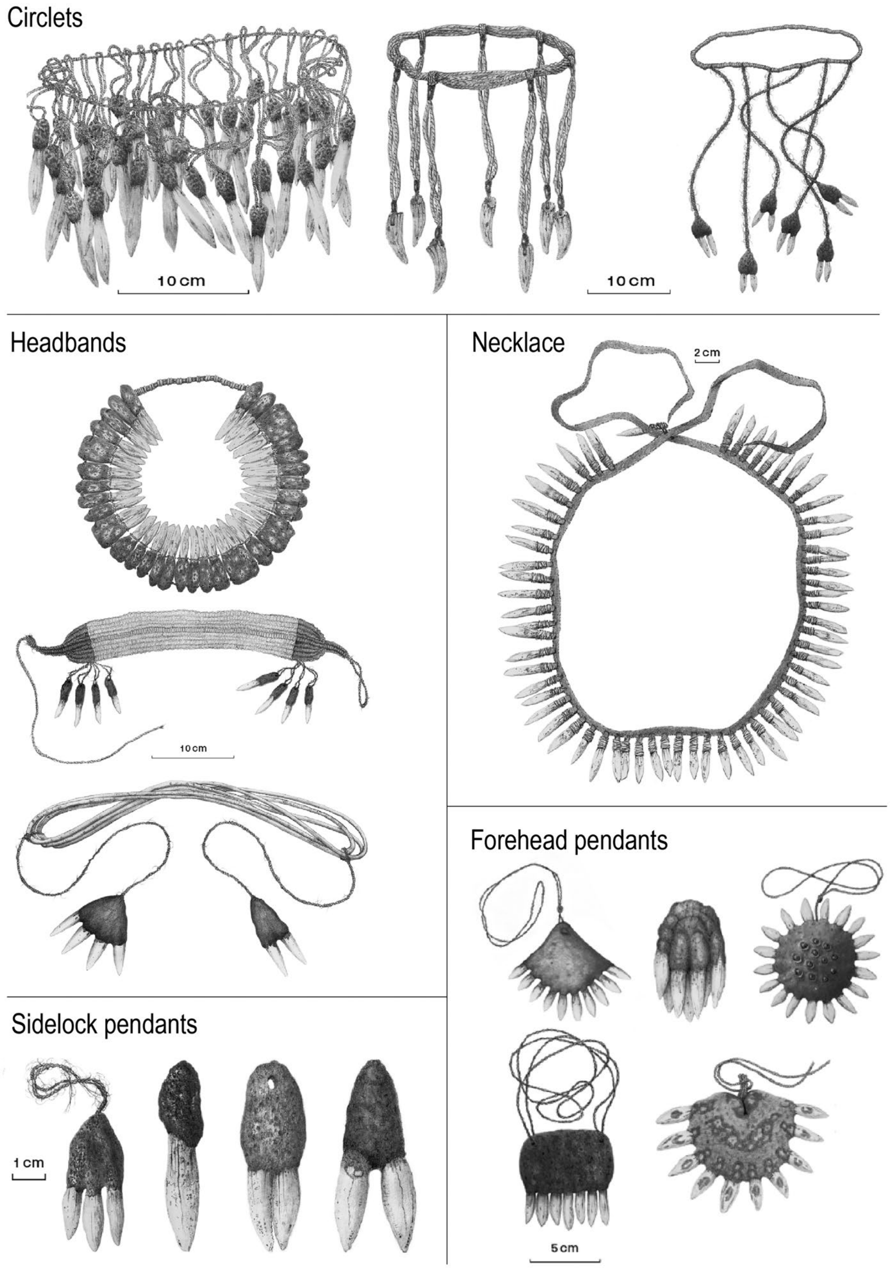

Figure 1. Illustrations of items of personal adornment in Australia incorporating macropod incisors (adapted from Langley 2023 with permission).

While personal ornaments from archaeological sites incorporate teeth from a variety of extant and extinct Australian animals, including Tasmanian devils, *Diprotodon*, sharks and crocodiles, teeth from macropods are inordinately represented (Balme and O'Connor 2019:182). In a recent review Balme and O'Connor (2019:186–187) suggested that the lustre and robusticity may have played a part and also speculated that the prestige associated with hunting such animals may have also been a factor, 'effectively communicating the social status of the wearer' (Balme and O'Connor 2019:187).

To date most archaeological finds of animal tooth beads and/or pendants in Australia derive from burial contexts, almost exclusively in south-eastern Australia (Figure 2a). Headbands of pierced kangaroo teeth with resin were found in a burial at Kow Swamp, NSW, dated to between 14,000 and 10,000 BP (Alan Thorne pers. comm. as cited in Dortch 1979b:43; Peter Brown pers. comm. as cited in Balme and O'Connor 2019:180), and also in a terminal Pleistocene-aged burial at Nacurrie, NSW (Brown 1989). The 7,000-year-old Lake Nitchie (NSW) burial of an adult male (Macintosh 1971; Macintosh et al. 1970) contained 178 *Sarcophilus harrisii* (Tasmanian devil) canine teeth, from at least 47 animals. Those teeth with intact roots showed pierced holes, indicating they had been suspended on a long necklace. Pardoe (1995:705) reported a similar necklace of Tasmanian devil canines in another burial on Walpolla Island, Victoria, also dating to ~7,000 BP. Some 327 pierced

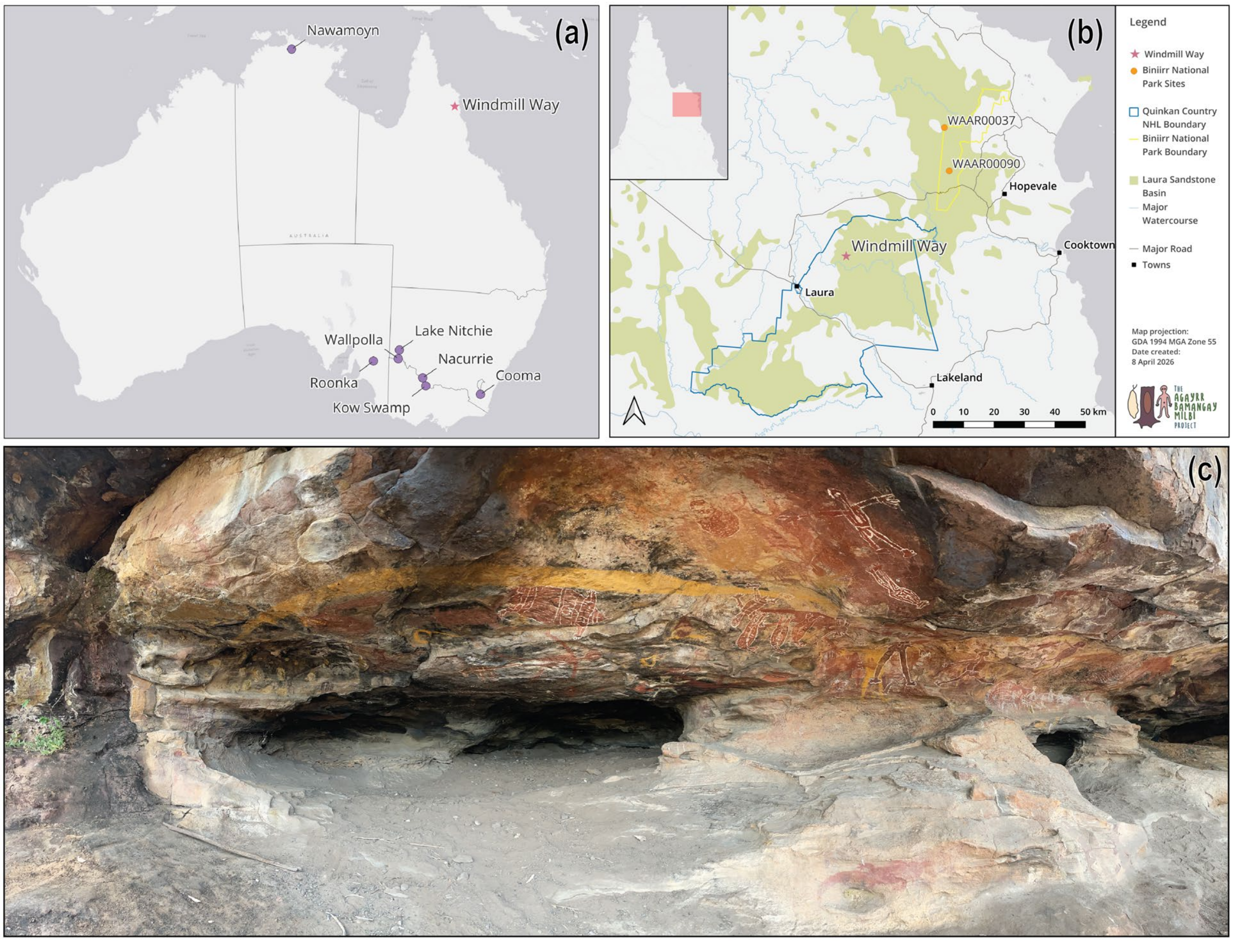

Figure 2. (a) Sites mentioned in the text; (b) detailed view of ABM study sites mentioned in the text; and (c) detailed view of the alcove in the Windmill Way site (photograph by Lynley Wallis).

incisors, from at least 126 macropods, were recovered scattered amongst the remains of a young male and older female buried some 7,000 years ago near Cooma, NSW (Feary 1996). Their burial context, coupled with polish observed on their lateral surfaces that could have formed 'as a result of sliding against each other', led Feary (1996:41) to suggest that they too once formed part of a necklace. Finally, at the cemetery at Roonka, along the Murray River in South Australia, a male's head was encircled by a fillet of notched wallaby teeth 'presumably in order to give additional purchase to a plaited or knotted binding' (Pretty 1977:305). A second band of wallaby incisors, possibly from another headband, was positioned across the man's left forearm (Pretty 1977:305).

In Sahul, outside of burial contexts, teeth convincingly demonstrated to be components of personal ornaments are extremely rare. One exception is an upper *Macropus antilopinus* incisor recovered during excavation at the Nawamoyn rockshelter in Arnhem Land, Northern Territory (NT) (Schrire 1982:127–128; White 1967:223). This item was pierced through the root, leading to its interpretation as a strung ornament. A second, unperforated macropod incisor at Nawamoyn was reported by Schrire (1982:128) as displaying 'an unusually high gloss on the lingual surface', tentatively suggesting that it too might have been used as ornamentation.

In this study we extend the known geographical range of archaeological macropod incisor ornaments to far north Queensland by reporting on 12 macropod teeth recovered from a non-burial context at the Late Holocene rockshelter site of Windmill Way, in southeast Cape York Peninsula (CYP) (Figures 2b and 2c). In this paper we describe the deployment of various analytical methods to better understand the age of these teeth and their means of production and function. Based on the presence of resin at the root ends of the incisors, the lack of evidence for damage attributable to use-wear, and the absence of use-related residues, as well as comparison with two rock art motifs from the nearby Biniirr National Park, we suggest that these objects were items of personal ornamentation. In doing so, we demonstrate (1) the need for archaeologists to carefully assess macropod incisors for signs of human use as ornaments, especially in the absence of piercing, obvious use-wear or macroscopic signs of resin hafting, as well as (2) the utility of FTIR analyses for resin identification.

The Windmill Way site

The Windmill Way rockshelter is located in the National Heritage-listed Quinkan Country on the southern side of a ridge of escarpment in the Laura Sandstone Basin in southeast CYP (Figure 2b). The site is surrounded by *Eucalypt* woodlands and grasslands, with grasstrees on the rocky slopes and Cooktown ironwoods in the deep sands along nearby watercourses (see Wallis et al. 2025 for full description of the environmental context of the site; see also Neldner et al. 1997, 2023). A wide variety of macropod and small mammal species occur in the local environment, dominated by agile wallabies (*Notamacropus agilis*), though their current abundance and distributions have been negatively impacted by habitat destruction since European incursion (Winter and Lethbridge 1995; personal observations of Traditional Owner co-authors).

The Windmill Way shelter measures 29 m in length and 4.6 m in width, with an uneven floor and several roughly circular alcoves along the rear wall. The northernmost of these alcoves, from which the assemblage discussed here was recovered, was not especially well suited for human occupation owing to the ceiling height being less than 1 m (see Figure 2c). The alcove was divided into six 1 m-wide strips (Squares A1–A6) spanning the full alcove width, and each strip excavated to bedrock. All excavated deposit was passed through nested 7 and 3 mm sieves on site. Cultural material from the larger sieve residue was initially sorted in the field, after which it was transported to Griffith University in Brisbane for further sorting by raw material type. The 3 mm sieve residue was retained in its entirety, with all sorting thereof undertaken in the laboratory.

Given the presence of pig hair throughout the shallow deposit and the general lack of sedimentary stratification, the sequence is clearly a disturbed palimpsest rather than a cleanly stratified deposit. The range and volume of material culture recovered (ochre, lithics, shell, bone, wood and plant fibre string) makes Windmill Way one of the largest and best-preserved assemblages in the region, despite its mixed nature (Wallis et al. 2025). As well as abundant human occupation refuse, the walls and ceiling of Windmill Way display a rich rock art assemblage, comprising painted, drawn and stencilled motifs in a wide array of colours (Figure 2c), as well as a single engraving of a macropod track pair. Several grinding patches are also present on exposed areas of the bedrock floor. Radiocarbon dating of various organic materials from the site have yielded age estimates from essentially modern through to 1,700–1,589 cal BP. Evidence that use of the shelter continued during the 'contact' period—which in this region dates from the mid-1870s following the discovery of gold on the Palmer River to the south (Cole 2004)—is provided by a piece of thick-gauge wire with a sharpened end, and a small fragment of coarsely-woven red fabric.

The presence of thousands of fragmented bones in Windmill Way (some retaining abundant dried flesh and many exhibiting spiral factures and evidence of gnawing) initially led to the interpretation that the faunal assemblage was largely non-artefactual and primarily associated with use of the site as a dingo den. The identification of a definite bone point and the observation of a discrete ball of resin adhering to the root of an isolated macropod tooth during excavation prompted an early reassessment of this interpretation. Accordingly, all tooth and jaw fragments were carefully inspected in the laboratory for macroscopic signs of resin. Ten teeth exhibited definite signs of resin, while a further two were identified as possible candidates. These 12 teeth form the focus of this present study.

Methods

For each of the 12 teeth, length, width and thickness measurements to the nearest 0.1 mm were recorded where possible (noting that the broken state of some items precluded some measurements being taken); weight was recorded to the nearest 0.001 g. Species identifications were made based on comparison with reference specimens held in the Queensland Museum, with particular attention given to dental wear patterns for different species.

Microscopy

Each object was examined and photographed using low powered stereoscopic microscopy and a high-powered Olympus DSX1000 microscope. The microscopic techniques employed included bright-field, dark-field, plane-polarised, oblique light, mixed light (dark and bright field), cross-polarised and differential interference contrast (DIC) microscopy. Use-wear, manufacturing marks and taphonomic alterations (or the absence thereof) were documented based on comparison with international (e.g. Bradfield 2015; Buc 2011; Fernandez-Jalvo and Andrews 2016; Fisher 1995; LeMoine 1994; Pal et al. 2020) and Australian studies (e.g. Langley et al. 2016; Theden-Ringl and Langley 2018). Though often difficult to distinguish owing to the naturally shiny appearance of tooth enamel, polish was defined as an area that appeared brighter and/or smoother than the surrounding material, formed through physical abrasion during contact with other materials (cf. Fullagar 1991; Hayden 1979; Kamminga 1982; Keeley 1980; Keeley and Toth 1981; Marreiros et al. 2020). Striations were defined as linear traces (scratches grooves or furrows) caused through mechanical abrasion (cf. Kamminga 1982; Keeley 1980; Keeley and Newcomer 1977; Semenov 1964).

Fourier transform infra-red spectroscopy

Fourier-transform infra-red spectroscopy (FTIR) uses infra-red light absorbance to undertake a chemical analysis of predominantly organic compounds and functional groups in resins (Monnier 2018). While it is possible to undertake direct microscope-based reflectance FTIR, such an approach proved non-feasible in this study, with a reliable FTIR spectrum not able to be generated owing to the dark surfaces of the resins. Instead, using a Perkin and Elmer Benchtop FTIR Spectrum 2 machine, we employed two other approaches to the FTIR analysis of the Windmill Way tooth resins:

1. Attenuated total reflectance (ATR) FTIR, whereby each tooth was applied directly to the crystal window of the Spectrum 2, secured using a clamp, and a spectrum produced. All objects excepting FAUN20048 and FAUN20056, which had limited macroscopic visual signs of resin, were analysed directly using this approach; and,
2. Dissolution of a sample from each tooth in a few microlitres of acetonitrile solvent, which was then applied directly to the crystal window of the same Spectrum 2 machine and allowed to dry. The spectra generated in this fashion did not have any carbon dioxide interference and generally produced excellent results. This technique was particularly useful for samples that had initially given poor results with the first approach, specifically FAUN20032, FAUN20033, FAUN20035, FAUN20037, FAUN 20038, FAUN20039, FAUN20048 and FAUN 20056.

FTIR results were compared with an archaeological reference collection of resins constructed by Matheson and McCollum (2014), supplemented by two *Xanthorrhoea* spp. specimens collected in 2024 from the ABM Project field area. As well as the resin samples themselves, control samples were taken from elsewhere on the teeth to assess the potential for background contaminants to produce false positive results.

The Spectrum 2 machine was cleaned, and a background standard run between every archaeological sample, to ensure no cross-contamination.

Liquid chromatography–mass spectrometry

Liquid chromatography-mass spectroscopy (LC-MS) allows for the identification of the chemical components of materials, and potentially the plant species from which resins were derived. Following FTIR analysis, the acetonitrile solvent extractions from each artefact were analysed using a Thermo Scientific Q Exactive Plus Orbitrap LC-MS with Xcalibur software to generate mass spectra. FreeStyle™ v1.8 software was used to resolve the peaks of the mass spectra. Compound Discoverer v3.2 software was used with mzCloud, ChemSpider, mzVault and MassList databases for chemical identification. Again, the archaeological results were compared with the Matheson and McCollum (2014) reference collection, supplemented by the two *Xanthorrhoea* spp. specimens from the ABM Project field area.

Radiocarbon dating

Two sub-samples of resin from the root ends of FAUN20038 and FAUN20039 were subject to accelerator mass spectrometry (AMS) radiocarbon dating at the Australian Nuclear Science and Technology Organisation (ANSTO). Sample pre-treatment involved an acid-base-acid treatment, washing thoroughly and drying at 60 °C, prior to sealed-tube combustion and graphitisation using Fe/H_2 reduction (Hua et al. 2001; Wilcken et al. 2015). The Southern Hemisphere Calibration Curve (SHCal20) was used for the calibration of age determinations using OxCal 4.4 (Bronk Ramsey 2009; Hogg et al. 2020).

Results

Morphology, use-wear and residues

In total, 12 teeth were analysed, ten with obvious resin balls still intact at their root ends, and two with trace macroscopic signs of staining at the root ends that were suspected of being resin remnants. The front 2 m of the Windmill Way alcove (Squares A1 and A2) did not contain any teeth; six were recovered from the deepest recess nearest the rear wall (Square A6); and the remainder from Squares A3, A4 and A5 in the middle of the alcove. Table 1 summarises the morphological characteristics of each tooth (see also Figure 3 lower row), while Figure 3 (upper and middle rows) shows photomicrographs of key features on a sample of teeth.

All 12 teeth were macropod mandibular incisors, two of which were broken (FAUN20032 and FAUN20038), and three others retained some form of damage not thought to be related to human use. Eleven could be confidently identified to species: two from *Onychogalea unguifera* (northern nail-tail wallaby); three from *Lagorchestes conspicillatus* (spectacled hare wallaby); and six from *Notamacropus agilis* (agile wallaby),

Table 1. Morphological characteristics of the teeth.

Artefact ID	XU	Status	Species	Thickness (mm)	Width (mm)	Length (mm)	Weight (g)	Use-wear Present	Potential Use Related Residues	Notes
FAUN20032 	A6	Broken	*Notamacropus agilis* (agile wallaby)	4.06	6.96	CND	0.65	Two parallel striations at tip on lingual and buccal surfaces	Small fragment of resin along one margin; starch near cementoenamel junction	Root end missing. Slightly asymmetrical tip. Some encrusted sediment on lingual surface. Darkly stained.
FAUN20033 	A6	Complete	*N. agilis* (agile wallaby)	3.9	6.95	39.04	0.98	Nil	Resin at root; plant fibre embedded in resin at root; starch grains near cementoenamel junction; lipid along one margin half-way along tooth	Bulk of resin detached from tooth root. A little encrusted sediment on lingual surface. Slightly asymmetrical tip.
FAUN20034 	A6	Complete	*Lagorchestes conspicillatus* (spectacled hare wallaby)	3.57	5.42	CND	0.45	Striations associated with chipped enamel	Resin at root	Both lingual and buccal surfaces have several very dark circular stains (microbial contamination?). Tip minimally worn but enamel on one side near tip is chipped. Enamel cracked.
FAUN20035 	A5	Complete	*N. agilis* (agile wallaby)	4.51	7.37	40.48	1.31	Minor striations at tip on buccal surface	Resin at root	Very slightly asymmetrical tip. Very well-preserved and intact. Possible caries near tip.
FAUN20036 	A5	Complete	*L. conspicillatus* (spectacled hare wallaby)	3.74	4.33	CND	0.41	Nil	Resin at root	Root end missing. Symmetrical tip. Some encrusted sediment on lingual surface.
FAUN20037 	A6	Complete	*N. agilis* (agile wallaby)	4.33	8.17	40.77	1.37	Minor striations on buccal surface; notched fracture at tip	Resin at root	Resin on lingual surface has broken away during lab handling. Slightly asymmetrical tip. Some physical damage. Some encrusted sediment on lingual surface.
FAUN20038 	A6	Broken	CND though likely to be *N. agilis* (agile wallaby)	CND	CND	CND	0.66	Nil	Resin at root; fragment of cut hide oriented obliquely through resin	Crown end missing. Thick layer of encrusted sediment, particularly on lingual surface.
FAUN20039 	A6	Complete	*N. agilis* (agile wallaby)	4.7	8.03	39.24	1.08	Nil	Limited resin at root; cellulose fibre embedded in resin at root; lipid on buccal surface	Minor encrusted sediment and staining on lingual surface. Symmetrical tip. Lateral chipping of enamel on one margin.
FAUN20048 	A4	Complete	*Onychogalea unguifera* (northern nail-tail wallaby)	3.01	4.97	31.2	0.478	Nil	Resin at root; cellulose fibre bundle spun in Z twist embedded in resin at root	Resin predominantly preserved on lingual surface. Very asymmetrical tip. Some light encrusted sediment on lingual surface. Notch on lateral margin (not associated with use-wear).
FAUN20049 	A4	Complete	*O. unguifera* (northern nail-tail wallaby)	2.72	4.37	29.8	0.339	Minor striations along margin on buccal surface	Limited resin at root; bundled cellulose fibres embedded in resin at root	Microscopic resin preserved at root end. Very asymmetrical tip. Very light encrusted sediment on lingual surface. Small fracture on incisal margin.
FAUN20050 	A4	Complete	*N. agilis* (agile wallaby)	4.16	7.84	38.95	1.051	Nil	Resin at root; cellulose fibres embedded in resin at root	Resin predominantly preserved at root end on the buccal surface. Sightly asymmetrical tip. Very light encrusted sediment on buccal surface, and thicker encrustation on lingual surface.
FAUN20056 	A3	Complete	*L. conspicillatus* (spectacled hare wallaby)	3.16	4.73	26.72	0.412	Nil	Limited resin at root	Slightly asymmetrical tip. Very light encrusted sediment on lingual surface.

CND = could not determine. Artefact IDs in grey are shown in more detail in Figure 3. Images taken under a combination of bright-field and/or dark-field light. Scale bar on each image measures 5 mm.

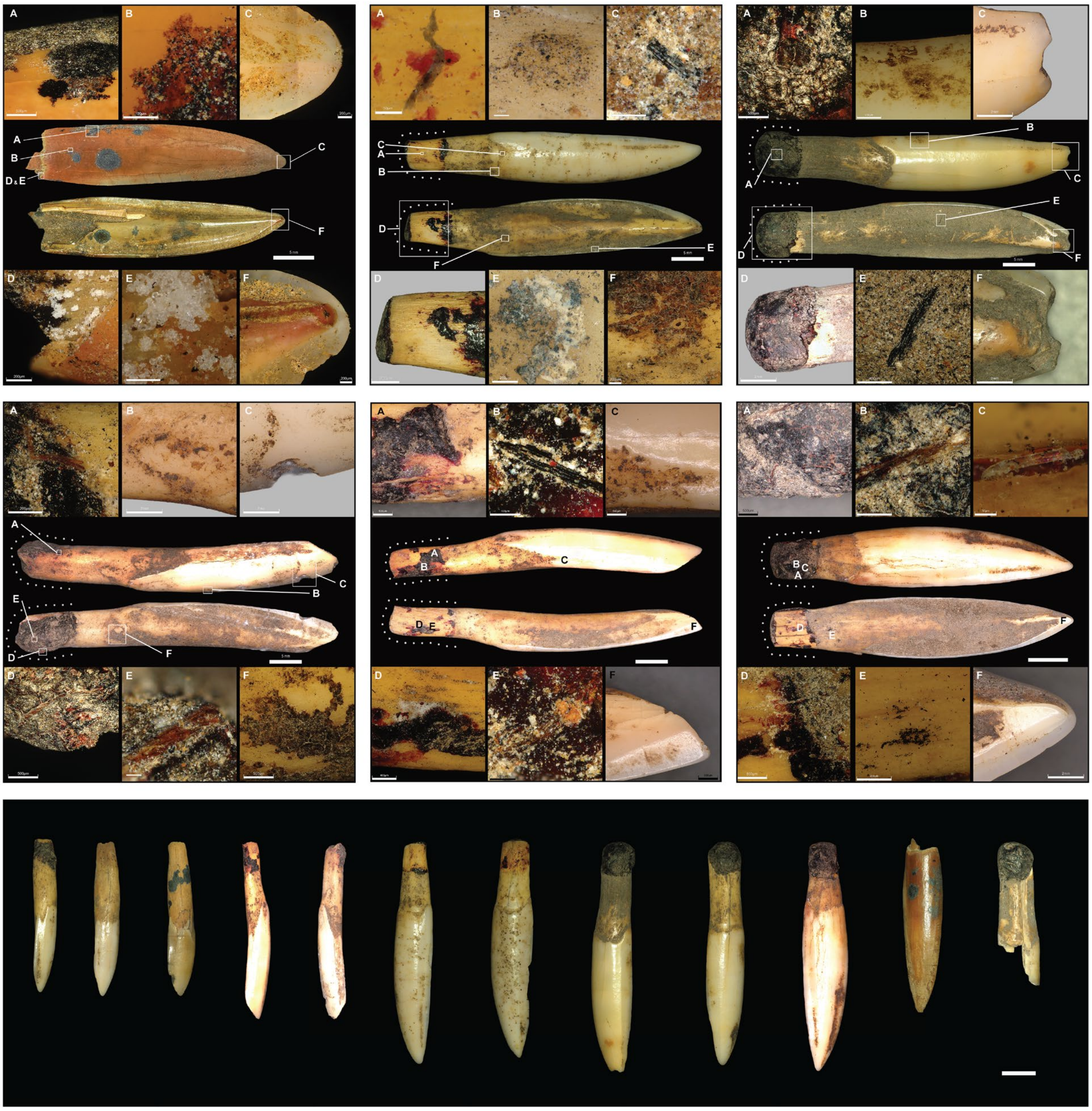

Figure 3. Photomicrographs of the Windmill Way specimens: (upper left) FAUN20032 (A, B) resin, (C) enamel tip striation on buccal surface, (D, E) starch grains, (F) enamel tip striation on lingual surface; (upper centre) FAUN20033 (A) cellulose fibre, (B, E) lipid, (C) starch, (D, F) resin; (upper right) FAUN20037 (A, B, D, E), (C) notched tip fracture buccal surface, (F) notched tip fracture lingual surface; (middle left) FAUN20048 (A, B, D, F) resin, (C) notched fracture buccal surface, (E) cellulose fibre bundle spun in a 'Z' twist; (middle centre) FAUN20049 (A, D) resin, (B, E) cellulose fibre bundle, (C) striations on buccal surface, (F) fractured enamel on incisal margin; and (middle right) FAUN20050 (A, D, E) resin, (B, C) cellulose fibre, (F) smooth margins of enamel tip. Dotted lines denote main extent of resin on the artefact; and lower row (from left to right) FAUN20036, FAUN20056, FAUN20034, FAUN20049, FAUN20048, FAUN20033, FAUN20039, FAUN20037, FAUN20035, FAUN20050, FAUN20032 and FAUN20038. Images taken under a combination of cross-polarised, brightfield and mixed (bright and darkfield) light sources.

the latter being the most abundant component of the large, mostly naturally accumulated faunal assemblage. The final tooth (FAUN20038) could not be identified to species owing to its broken state, though, based on its width, it is likely also to be from *N. agilis*. These three macropod species all fall in the small- to medium-size range and are common in the study area today, *N. agilis* especially so.

Some teeth exhibited considerable wear resulting from the natural grazing behaviour of the species, most notably the two *O. unguifera* teeth, while one displayed damage consistent with carious destruction (Table 1). None were perforated. Minor striations of indeterminate origin were observed on five teeth, although these cannot be confidently attributed to anthropogenic causes. Because incisors are naturally lustrous owing to the inherent qualities of the outer layer of enamel, polish was almost impossible to identify confidently; consequently, erring on the side of caution, no definite polish was observed.

In terms of residues, all teeth retained varying amounts of a generally heterogenous residue interpreted as non-cultural debris from the depositional environment. Ten preserved obvious and large amounts of resin at their root ends, while a further two had microscopic patches of resin at their roots, and many had microscopic patches of resin further along the body of the tooth towards the crown. The resin itself, where macroscopically abundant, was fashioned into very neat, small balls attached to the very tip of the roots, not extending more than 5 mm along the root shaft.

Other use-related residues were very limited. Five teeth were associated with plant cellulose fibres (FAUN20003, FAUN20039, FAUN20048, FAUN20049 and FAUN20050), four of which were oriented laterally in a manner consistent with a string attachment. Notably, FAUN0038 has a cut piece of organic material that passes obliquely through the resin ball (Figure 4). This material measures 0.5 × 0.6 mm in cross-section and protrudes 1.2 mm from the adhesive ball. It is consistent with microscopic physical characteristics of animal hide or skin (cf. Spangenberg et al. 2010). Its surface comprises a dark, well-meshed surface layer or 'crust', followed by a single layer of parallel collagen fibres (as indicated by the white arrows in Figure 4b). This is consistent with the 'grain' layer of epidermal cells in hide or skin. Beneath the grain layer is a 'corium' layer of collagen fibres. Micro-FTIR analysis was undertaken to further characterise this material. Collagen was identified, although evidence for processing of the hide into leather could not be confirmed via the non-destructive approach used.

Radiocarbon dating

As set out in Table 2, the two dated specimens returned similar radiocarbon ages of c. 1,170–1,290 cal BP.

Fourier transform infra-red spectroscopy analysis

Using the first FTIR approach, all samples produced results consistent with resin from a species of *Xanthorrhoea*, though on occasion the signal was of poor resolution (Table 3). Adoption of the second FTIR approach allowed us to refine the initial results to obtain stronger signals, confirming that resin samples taken from artefacts FAUN20033, FAUN20035, FAUN20036, FAUN20037, FAUN20038, FAUN20039, FAUN20048, FAUN20050 and FAUN20056 were specifically consistent with *X. johnsonii* resin. Figure 5 shows a selection of typical FTIR spectra, demonstrating typical results associated with *Xanthorrhoea* generally, *X. johnsonii* specifically, and negative *Xanthorrhoea* results.

Liquid chromatography–mass spectrometry results

The analysed resins produced spectra indicative of different compounds that varied across the archaeological

Table 2. Radiocarbon dates for resin on teeth from Windmill Way.

Lab. Code	Artefact Code	Material	^{14}C Age BP	Calibrated Age (95.4% probability) cal BP*
OZCA14	FAUN20039	Resin	1,350 ± 30	1,294–1,177 (95.4%)
OZCA15	FAUN20038	Resin	1,330 ± 30	1,285–1,175 (91.9%); 1,135–1,114 (3.5%)

Table 3. Summary of FTIR data for resins on teeth from Windmill Way.

	Artefact ID Code											
Species	FAUN20032	FAUN20033	FAUN20034	FAUN20035	FAUN20036	FAUN20037	FAUN20038	FAUN20039	FAUN20048	FAUN20049	FAUN20050	FAUN20056
Xanthorrhoea spp.	X	X	X	X	X	X	X	X	X	X	X	X
Xanthorrhoea johnsonii		X		X	X	X		X	X		X	X

X denotes presence.

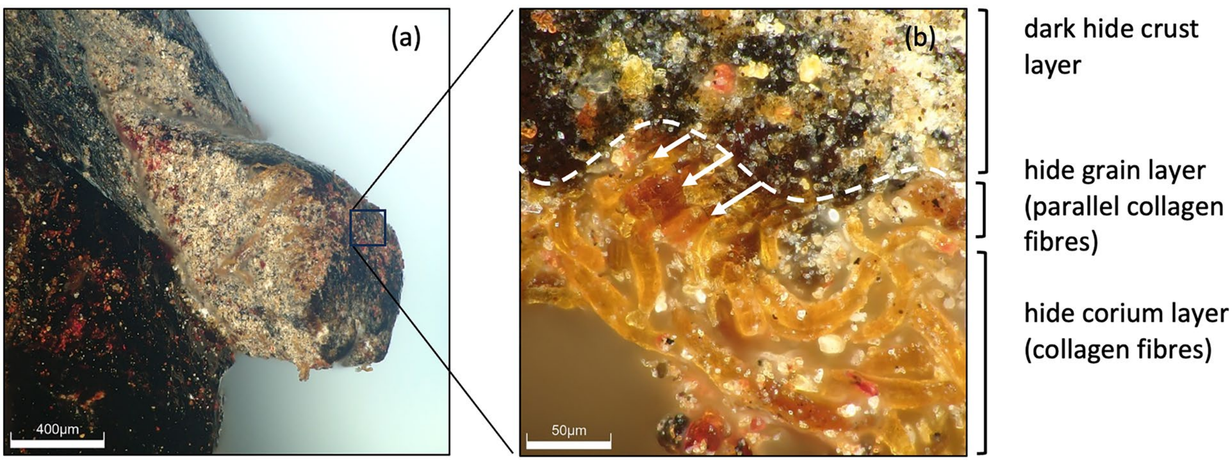

Figure 4. The fragment of hide observed in FAUN20038: (a) view showing the fragment of cut animal hide/skin protruding from the adhesive resin ball; and (b) detailed view showing the hide surface crust, the 'grain' layer of parallel collagen fibres and the hide corium layer (photographed under compensated mixed brightfield and darkfield lighting).

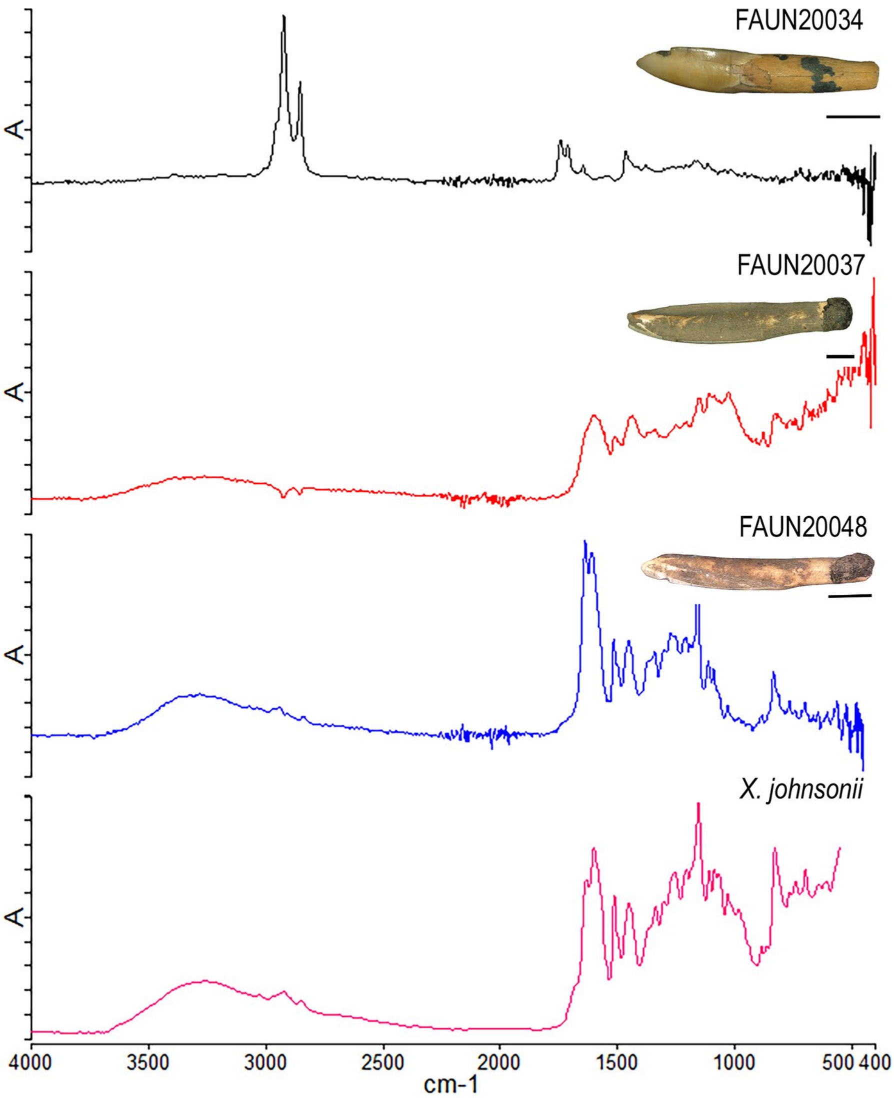

Figure 5. FTIR absorbance spectra: (black) FAUN20034 area of chipped enamel, with peaks inconsistent with resin; (red) FAUN20037 with peaks consistent with *Xanthorrhoea* spp. resin; (blue) FAUN20048 with peaks consistent with *X. johnsonii*; and (pink) comparative reference sample of *X. johnsonii*.

samples. Table 4 summarises the compounds associated with *Xanthorrhoea* spp. and *Erythrophleum chlorostachys* resins identified in the resin samples extracted from the Windmill Way incisors.

All 12 incisors exhibited chemical compounds consistent with grass tree (*Xanthorrhoea*) resin, as summarised in Table 4 (see also Figure 6 upper). In addition to either (a) a very low quantity; or (b) a very degraded amount of *Xanthorrhoea* resin, artefact FAUN20049 also had compounds consistent with the resin of *E. chlorostachys* (Figure 6 lower). The presence of two plant resin types may indicate that the artefact was re-used or repaired, or alternatively that the adhesive was intentionally produced as a composite of two resin sources.

Discussion

Despite the abundance of organic raw materials used in Indigenous material culture, the representation of such objects in Australian archaeological contexts is limited. Even at sites on CYP with good organic preservation, such as Yam Camp (Morwood and Dagg 1995) on Jowalbinna Station (in southern Quinkan Country), humanly crafted organic artefacts are uncommon: amongst abundant bones and teeth of 13 species recovered from Yam Camp, only one fragment from a ground bone point was identified. Wallis et al. (2025) previously reported on the unprecedented preservation conditions that allowed more than 500 pieces of plant fibre string to be preserved at the site of Windmill Way. This discovery of a series of macropod incisors, some with resin-encased root ends, is further testimony to the unusual preservation conditions at Windmill Way, allowing another, rare glimpse into organic material culture in the pre-contact period.

Resin species identification

The use of various plant-based 'cementing' substances (aka mastics, hafting substances, resins, wax, gum,

Table 4. The chemical compounds identified using LC-MS in each sample, compared against *X. johnsonii* and *E. chlorostachys* resin references samples (based on Matheson unpub. data).

Characteristic Compounds in Resins Identified with LC-MS	*X. johnsonii* resin	*E. chlorostachys* resin	FAUN20032	FAUN20033	FAUN20034	FAUN20035	FAUN20036	FAUN20037	FAUN20038	FAUN20039	FAUN20048	FAUN20049	FAUN20050	FAUN20056
benzoic acid	X			X		X		X	X		X		X	X
cinnamic acid	X		X		X	X		X	X					
p-coumaric acid	X	X	X			X	X	X	X	X		X	X	X
chrysophanic acid	X						X							
p-methoxy-cinnamic acid	X		X	X	X	X	X	X	X			X	X	X
hydroxybenzoic acid	X				X									
vanillin	X		X	X	X	X	X	X	X	X		X	X	X
p-hydroxybenzaldehyde	X		X		Y	Y		Y	Y					
pinocembrin	X	X	X	X	X	X	X	X	X	X	X	X	X	X
sakuranetin	X		X	X	X	X	X	X	X	X	X	X	X	X
cassaidine		X										X		

X denotes presence.

adhesive etc.) was ubiquitous across Indigenous Australia (e.g. Aiston 1929; Cribb and Cribb 1982; Maiden 1889). Many of these substances have been chemically characterised by Matheson and McCollum (2014). For CYP, Roth (1898:23–25, 1904:11–14) is the key source of information on preferred plant species and processes of resin-manufacturing techniques. Unfortunately, while other ethnographers, including Thomson (1936, 1939), McConnel (1953), and Hale and Tindale (1933) illustrated hafted objects from the region, they provided little detail of their manufacture.

Roth (1898, 1904) noted three gums were especially used across CYP, derived either from the roots of beefwood (*Grevillea striata*) or ironwood (*E. chlorostachys*), or from grass trees (*Xanthorrhoea* spp.). For beefwood and ironwood, short lengths of the roots from young trees are dug and cut out, heated over a fire and the sticky bark scraped off with a sharp stone (Roth 1898:23). Roth described such materials then being kneaded and moulded when hot, and often adding some form of temper, such as ash or fibrous plant matter to increase their melting temperature, reduce their brittleness and improve their adhesive qualities. Roth (1898:24–25) observed that grass tree resin does not require any processing, occurring naturally as lumps amongst the roots or at the base of the plant, already suitable for heating and use. An experimental study by Parr (1999) demonstrated that grass tree resin becomes brittle with repeated episodes of heating, suggesting that its capacity for re-use is limited.

The chemical characterisation of the balls of resins on the Windmill Way teeth demonstrates that they predominantly derive from *Xanthorrhoea* spp., and often *X. johnsonii*, with one instance of *E. chlorostachys*. These findings agree with known ethnohistoric accounts. During stone artefact making sessions conducted in 2022 as part of the ABM Project, several Traditional Owners, including Troy Michaels, were well-versed in the modes of procurement and processing of beefwood and ironwood resins, demonstrating the means of their processing and use in the same fashion as described by Roth (1898) more than a century ago.

Viability of FTIR analysis for characterisation of resins

FTIR has been shown elsewhere to be extremely useful in the characterisation of Australian native resins in archaeological materials (e.g. Matheson and McCollum 2014). The challenge of achieving direct contact at an appropriate pressure for successful ATR-FTIR analysis of teeth in the current analysis was resolved by adopting a solution-based approach, whereby some of the potential resin on the tooth was dissolved in solution, extracted, applied to the ATR crystal and allowed to dry before attempting analysis. This approach allowed most of the residues to be characterised to at least genus level and is clearly an excellent means of effectively identifying the species of plants used for resins in Australian contexts.

Given that two of the Windmill Way teeth had limited macroscopically obvious signs of resin yet produced positive results for resin at their roots using these highly sensitive analytical techniques, it is possible that other macropod incisors in the assemblage might also harbour positive traces of resin. It is apparent that once the bulk of the resin haft detaches from the tooth's surface, few macroscopic signs remain to indicate its former presence, Locard's principle of exchange[1] notwithstanding. As such, further assessment is underway to

[1]Locard's (1920) principle, which forms the basis of much forensic science and archaeological residue analysis, is essentially that when two objects come into contact there will be some degree of exchange of materials between them.

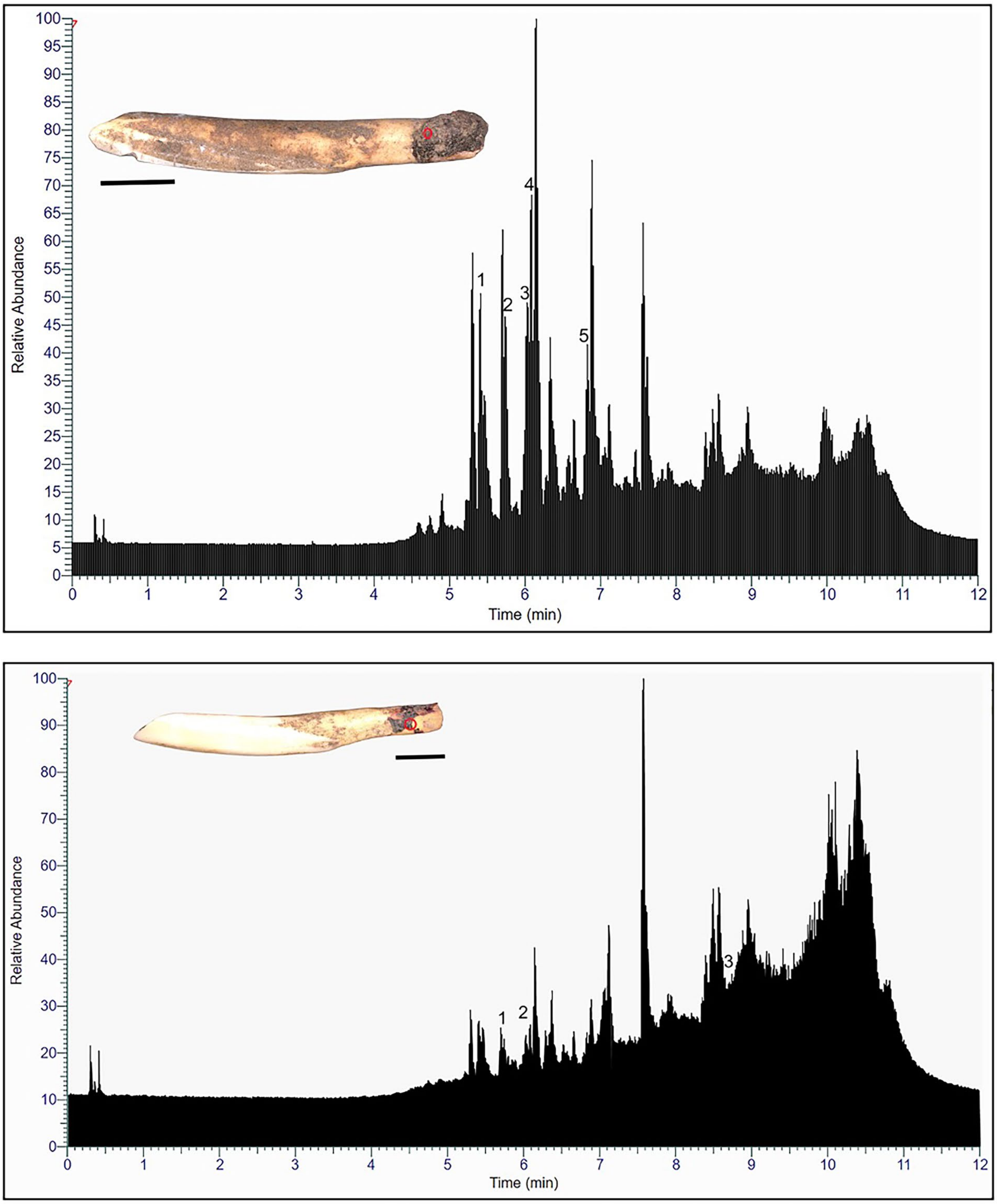

Figure 6. LCMS chromatograph of resin residue solvents from two Windmill Way incisors. The red circles indicate the locations of the solvent removal of residues: (upper) FAUN00248, whereby the numbered peaks indicate the compounds identified that are found in *Xanthorrhoea* spp. resin ([1] coumaric acid, [2] benzoic acid, [3] pinocembrin, [4] sakurnetin, and [5] vanillin); and (lower) FAUN20049, whereby the numbered peaks indicate the compounds identified that are found in *Xanthorrhoea* spp. ([1] sakuranetin and [2] pinocembrin) and *E. chlorostachys* resin ([3] cassaidine). Scale bar on both images is 5 mm.

ascertain if other Windmill Way incisors might retain trace amounts of resin at their root ends.

Utilitarian tools

Teeth from a variety of animal species were routinely incorporated into utilitarian tools used for scraping and engraving (McCarthy 1967:88); Figure 7 illustrates some such tools from the CYP region as collected and described by Roth (1898, 1904; see also McConnel 1953: Plate x, Figure o).

Roth (1904:21; see also Khan 2003:56) noted that the lower jaw of an agile wallaby was commonly used as a scraper or chisel without modification,

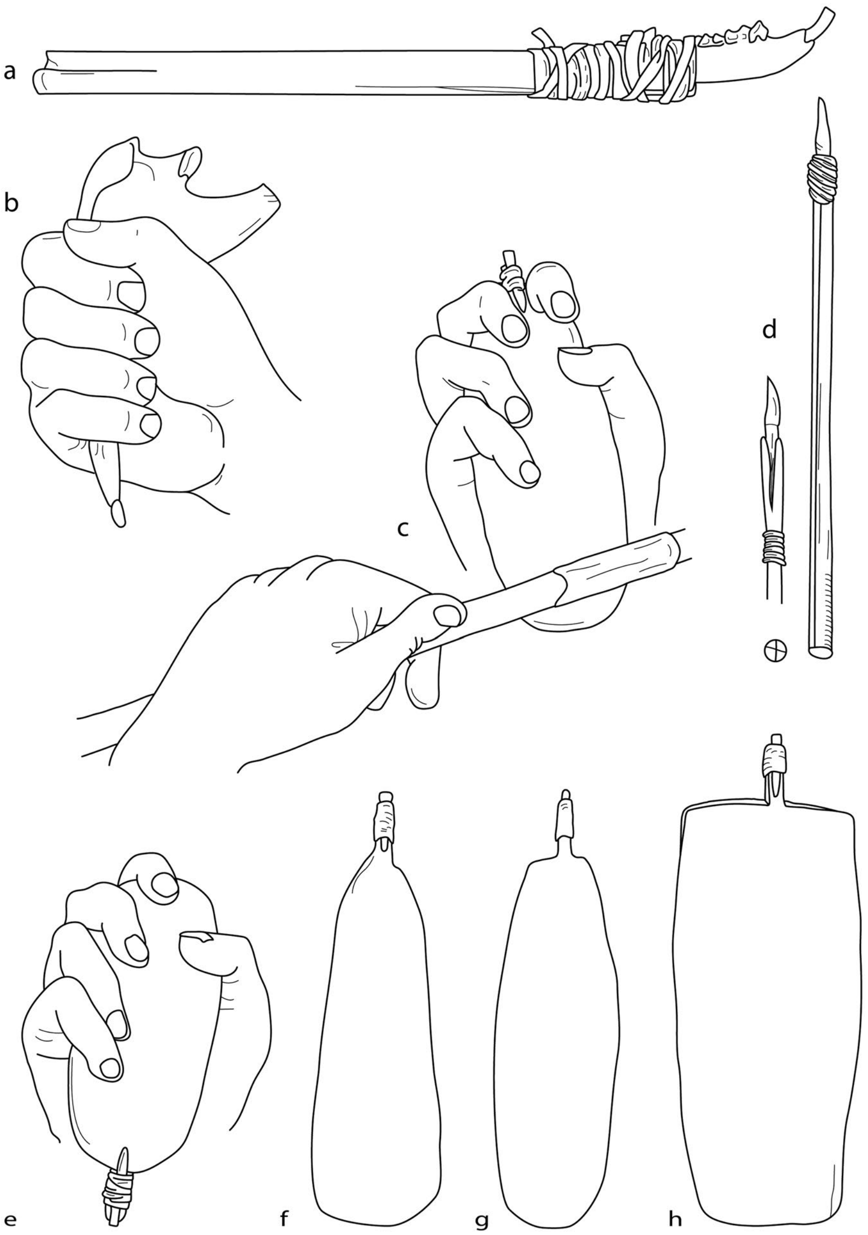

Figure 7. Utilitarian artefacts featuring macropod teeth: (a) hafted macropod mandible with deliberately broken incisor; (b) unmodified macropod mandible in hand; (c) resin smoother with incisor tip in use for smoothing resin showing nature of use; (d) macropod incisor tipped drill; (e) resin smoother in hand; and (f–h) resin smoothers (redrawn from Roth 1898, 1904).

whereby the incisor (prepared with fire and pressure) was left in situ, with the mandible itself serving as the handle. Sometimes the mandible was coated with resin to increase the comfort level of the user (see also Hale and Tindale 1933:105, their Figures 122 and 123; see also Bennett 1834:245). Pickering (1980) reproduced photographs of such a mandible taken by Donald Thomson in the 1920s and 1930s on CYP which show the broken incisor being used to craft bone points. Further afield, the Cooma burial (NSW) containing pierced macropod teeth mentioned earlier also included at least six kangaroo mandibles with intact (i.e. the roots of the teeth are still embedded in the jaw) incisors whose crown is snapped (Cohen 1993:54). These appear identical to the scraping tools described by Roth (1904; see also Khan 2003).

In some cases, tools involved a single macropod tooth hafted into a wooden handle. At Princess Charlotte Bay (~130 km north of Windmill Way), Hale and Tindale (1933: Figure 120) depicted 'resin smoothers' used in spear production, noting that they possessed 'a small spike at one end; to this projection the incisor tooth of a wallaby is fixed, to be used as a graver, scraper, or cutter' (Hale and Tindale 1933:104). Similar objects were also collected from Aurukun, near the tip of CYP (Allen 1980:84), and comparable examples are held in

Roth's collections in the Queensland Museum and Australian Museum.

Roth (1904:21; see also Khan 2003:56) noted:

> The kangaroo tooth scraper … of practically the whole Northern [Cape York] Peninsula, is in the form of a flat leaf-and-stalk shaped piece of 'iron-wood': one side of the 'leaf' is generally rough, either left so and made so with gum-cement, the other smooth, the tooth being attached to the 'stalk' on the latter side. The tooth … a kangaroo's lower incisor, is fixed with gut, or fibre-twine, and cement: its tip has been previously put into the edge of a flame and broken off abruptly by well-directed and graduate pressure, so as to give a sharp cutting edge to the enamel. The implement … is employed for sharpening spear-tips, and, in some spears, for cutting the groove into which the barb is fixed.

Akerman (2010:135) noted that the heated and snapped incisor dentine of incisor teeth is 'eminently suitable for the engraving of hardwoods, bone, soft schistose stone and pearlshell'. Bailey (1977:136) described the recovery of several wallaby incisors from an excavated shell mound at Kwamter, Weipa, which had been 'artificially split to form a cutting edge'. He argued these corresponded to the 'kangaroo teeth scrapers' described by Roth (1904).

Kangaroo tooth 'drills' were another common functional artefact (Langley 2023:96). In southeast CYP, Roth (1904:24–25; see also Khan 2004:48) described,

> The tooth drill … made with an incisor, from any of the larger species of kangaroo, which is stuck into a short handle, and fixed in position with twine and cement … The exact method of fixation consists in splitting (with shell) the extremity of the handle into four, by means of two cuts at right-angles, tying a piece of string around some little distance beyond, to prevent the splits from extending … and inserting the base of the tooth in the double wedge so produced …: the extremity of the handle is next firmly wound round with strong twine, and covered with 'ironwood' cement, while the string beyond, which, of course, is no longer required after once the resin has set, is finally removed. It is with this tool that the holes in the spear thrower (for fixing the peg) are drilled, as also the holes in the constituent pieces of shell forming the necklaces.

Further detail on the use of such composite artefacts included the observation that they were 'put into use by twirling with the flat of the hand … exactly after the manner of a vertical fire stick' (Roth 1898:29). Thomson (1936:74) likewise reported wallaby and kangaroo incisors being used 'as drills for fine work'. Roth (1901:9) also described such drills being used to strip the outer cortex from the septum of *Livistona australis* palm leaves when manufacturing fibre at Princess Charlotte Bay.

While it is therefore possible that the Windmill Way finds were components of functional, secular tools as described above, we reject this hypothesis for several reasons. The artefacts show no evidence of deliberate snapping and lack residues or use-wear patterns associated with such utilitarian functions. Rather, their overall form, the specific form of the resin mount and the absence of functional, tool-related use-wear suggest that they were more likely to have formed part of some type of personal adornment.

Personal ornaments

While macropod tooth ornaments were common elsewhere in Australia, there are few indications that strung macropod tooth headbands or necklaces were common (or even known) across CYP. Headbands and necklaces are represented in museum collections from the west, though not east, CYP, mostly featuring shell beads (Langley 2023: Tables 6.1, 6.4 and 6.8). Circlets, forehead pendants and sidelock pendants such as were common elsewhere in Australia are not known in museum collections from either west or east CYP (Langley 2023: Tables 6.3, 6.5 and 6.6). Of note, while Roth (1910:25–26) described macropod tooth ornaments from elsewhere in Queensland, and many different types of items of personal adornment across CYP, nowhere did he mention the use of macropod teeth in personal ornaments in CYP, where shells seem to have been the bead or pendant of choice. Similarly, although Thomson collected more than 20 necklaces from CYP, none incorporated macropod teeth; instead, all featured shells (Allen 2008). Likewise, the Queensland Museum holds a robust ethnographic collection of material items collected from the Laura region, including numerous necklaces, none of which include macropod teeth.

If the Windmill Way teeth formed components of personal ornaments, the absence of drilled perforations in the root ends indicates that they were not strung in the fashion of the *Sarcophilus* teeth in the Lake Nitchie or Cooma burial necklaces. One mounting method described by Langley (2023:201) involves 'a short strip of leather … folded over the root, and sinew or twine is then wrapped over the tooth and leather strip to bind it together. The shorter leather strip is passed through a small hole punctured in the larger collar strip' (see also Smyth 1878 [1972]:278 and Spencer and Gillen 1904:694). The presence of a single fragment of hide embedded in the resin ball on FAUN20038 is possibly indicative of this technique, although it is equivocal and not apparent across all Windmill Way specimens.

Langley (2023:202) described a second common mounting method in which 'each tooth is again individually set, but this time into resin, and then attached to the main band of fibre string'; this corresponds to the method most frequently observed in museum examples (Figure 1). Langley (2023) did not specify how the resin was applied in such instances, but inspection of photographs of museum objects show it typically extends halfway down the tooth in a somewhat rough, flattened form. In contrast, the resin on the Windmill Way teeth occurs as neat, discrete small balls, carefully and precisely pressed and smoothed into place at only the extreme root end of each tooth. Further, there are no clear impressions of string in the resin on the Windmill Way teeth, such as might be expected in the commonly described form of mounting. Nevertheless, beyond the fragment of hide, five teeth did show limited evidence of cellulose fibres in association with the resin, suggesting that some form of plant string mount was likely used for the Windmill Way assemblage.

The mounting method in an unprovenanced necklace from 'Australia' in the Pitt Rivers Museum, reproduced here as Figure 8, we consider better fits the Windmill Way specimens. In this instance the resin is mounted as discrete balls which serve as 'stopping devices' to prevent the twisted two-ply string used to secure each tooth in place from slipping off the teeth in the direction of the root end (the increasing width of each tooth body prevents the string slipping in the other direction). We suggest, on the basis of the morphological similarities, that this was the probable method of mounting for most of the Windmill Way teeth. It is worth noting, however, that we have been unable to locate other museum examples with a similar mounting technique, pointing to its apparent rarity. This could also be a geographically constrained technique, thus it is unfortunate that the sole museum example showing use of this method is unprovenanced.

It is not possible to know whether the 12 Windmill Way teeth are components of multiple objects or derive from a single object, nor, if the latter, whether that object was curated over a long, multi-generational period, as suggested by Macintosh (1971:60) for the Lake Nitchie necklace. However, the similar morphologies (i.e. small, neat, rounded balls at the root ends) and singular chemistries confirming all were *Xanthorrhoea* resin (except for FAUN20049, which also showed *E. chlorostachys* resin), suggest a common production process. Although the sample size is small, the near identical radiocarbon ages obtained for the resin on both FAUN20038 and FAUN20039 suggest that these two teeth at least are likely to derive from a single object.

While the teeth may represent trade items introduced from a distance, there is no specific evidence to support this interpretation. We prefer to favour the most parsimonious explanation: that the artefacts are of local origin. While the animal and plant species involved have wide ranges across northern Australia, the fact that (i) all three animal species are found in the immediate environs of the site (see below), as are (ii) the plant species from which the resins derive, speaks circumstantially to the mounted teeth being local rather than exotic items.

We cannot know whether people directly hunted the animals from which the Windmill Way teeth

Figure 8. A necklace of 40 macropod teeth with balls of resin similar to those seen at Windmill Way (Pitt Rivers Museum object identifier: RS289222_PRM1950.10.67; reproduced with permission).

derive, or whether they simply scavenged them from the dingo predation that was occurring at the site. Given Windmill Way contains thousands of non-humanly modified spirally fractured and gnawed bones and teeth, the most parsimonious explanation is that the incisors were selected from the large faunal assemblage available in the shallow sediments. The dingo-accumulated faunal assemblage certainly contains many fragmented agile, nail-tail and spectacled hare wallaby remains, providing a readily available source for the incisors. Of course, it is also possible the teeth were taken from the jaws of humanly-killed animals, in which case they might have had other ceremonial or symbolic meanings, but in the absence of evidence to indicate such hunting, we cannot speculate further thereon.

Rock art depictions

One final line of evidence of relevance to the use of macropod incisors in items of personal adornment in CYP derives from rock art.

Stencils of what are argued to be macropod necklaces appear in Arnhem Land, NT (Chaloupka 1993, as cited in Langley 2023:201), and there are likely shell pendant stencils in Carnarvon Gorge, QLD (Beaton and Walsh 1977; Quinnell 1976). Similarly, though less convincingly, Welch (1996) claimed that Gwion Gwion paintings (in the Kimberley region of WA) of anthropomorphs included neck ornaments composed of regularly spaced elements, interpreted as strings of possible macropod incisors (see also Walsh 1988). Welch (1996:108) also interpreted a type of hair pendant in the paintings—called a *widja*—in which the 'lower incisor teeth of the slain kangaroo were attached with gum to the successful hunter's hair'.

More convincing painted depictions of personal ornaments incorporating macropod incisors are found in two rockshelters in Biniirr National Park, in CYP, approximately 45–50 km northeast of Windmill Way, recorded during the ABM Project. The first motif depicts the head of an anthropomorph wearing apparent ceremonial regalia, including a headdress and nose pin. A thin horizontal line across the forehead is bisected by a parallel series of vertical, elongated objects that likely represent macropod incisors (Figure 9 upper row). The second painted motif appears to depict a necklace of teeth; although it is not associated with an anthropomorph

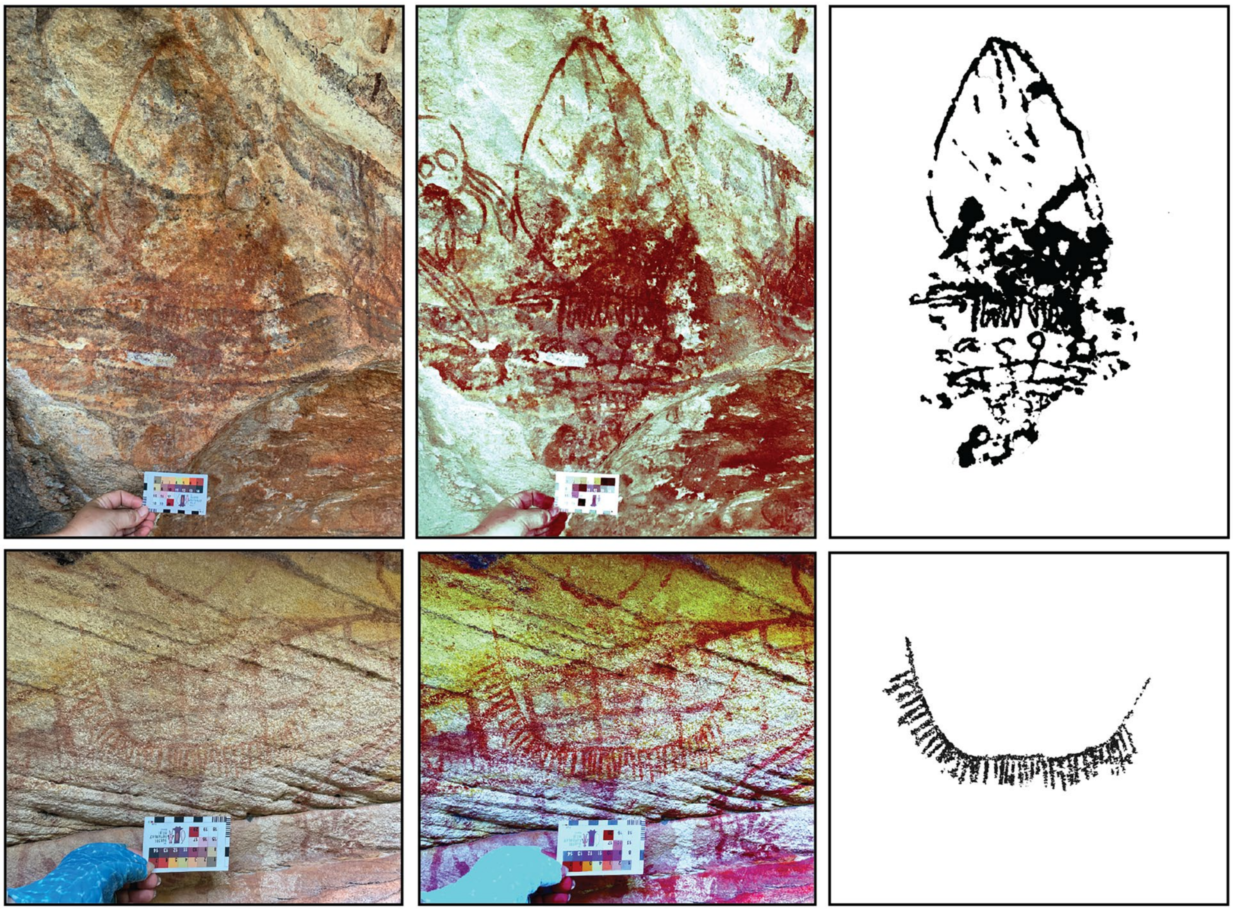

Figure 9. Rock art motifs from Biniirr National Park with possible macropod tooth incisor ornaments: (upper row) a possible headband from WAAR00037 and (lower row) a possible necklace from WAAR00090. Images on the left are the original images, in the centre are Dstretch versions, and on the right are extracts of the colour-matched pigment only.

and thus might alternatively represent a tassel string belt (Figure 9 lower row); the former explanation is preferred as the 'strings' are substantially shorter than those seen on ethnographic examples of such belts.

Conclusion

Macropod teeth suspended as ornaments using a combination of resin and perishable plant fibre string have not been previously documented from archaeological sites in Queensland, with comparable examples documented from burial contexts in southeastern Australia and museum specimens from the northwest of Australia. Based on detailed macro- and micro-analysis of 12 macropod incisors from the Windmill Way site, we consider it most likely that these teeth were components of a necklace or headband. As such, these objects are an extremely rare Late Holocene example of personal ornamentation recovered from a non-burial archaeological context in Australia. The direct dating of the resin is also insightful, as comparable ornaments from burial contexts have been dated indirectly from the age of the burial rather than the objects themselves. The successful FTIR and LCMS chemical characterisation of the resin, including on incisors lacking any macroscopically visibly obvious residue, is notable and supports Balme and O'Connor's (2019) call for further analysis of macropod teeth and other potential beads or pendants from archaeological contexts.

Acknowledgements

We dedicate this paper to our friend and colleague Tim Maloney, as a tangible embodiment of the kind of community-focused research that he championed. Tim was regularly in the lab with us during sorting as we identified additional resin-mounted teeth and shared equally in our excitement. The Olympus DSX1000 microscope on which the initial analysis of the teeth was completed was funded through an internal Griffith University Infrastructure grant awarded to Tim in 2020, for which we are eternally grateful. We especially appreciated his delightful quirks (such as insisting on having a steak for lunch, once a week at Sammy G's, while forbidding anyone to join him), willingness for a chat about all things archaeological, hunting or trivia-related especially, and the general enthusiasm for life that he brought to our small corner of the Nathan campus. He is greatly missed.

This research was undertaken as part of the ARC Linkage project 'Aboriginal Rock Art and Cultural Heritage Management in the Sandstone Country of Southeast Cape York Peninsula' (LP190100194), known as the Agayrr Bamangay Milbi (ABM) Project. It was conducted with approval from the Human Research Ethics Committee, Griffith University, Project No. 2020/219.

Non-Indigenous team members are especially grateful to the Laura Land and Sea Rangers, Elders of the Ang-Gnarra Aboriginal Corporation and members of the Laura Cultural Heritage Body. Co-authors and community Elders Christine Musgrave and Roseanne George participated in the site excavation and are cultural advisors to the Laura Land and Sea Rangers; Sue Marsh is the Laura Ranger Co-ordinator who, along with former rangers Sam Lowdown and Cliff Callaghan, also participated in the excavation. We thank all those who assisted with the subsequent sorting of the excavated materials.

Heather Jantezki, the Collection Manager of Mammals and Birds at the Queensland Museum, generously undertook the species identifications of the teeth. We are thankful to members of the Waarnthuurr-iin Aboriginal Corporation (especially Maude Olbar and Kegan Olbar) for granting permission to include images of the rock art motifs from Biniirr National Park. Michelle Langley generously granted permission to produce illustrations of macropod incisor ornaments from her excellent book on bone and tooth material culture in Australia.

We acknowledge financial support from the Australian Government for the Centre for Accelerator Science at ANSTO through the National Collaborative Research Infrastructure Strategy for the provision of radiocarbon dates (ANSTO grant number AP17758). Finally, we thank the referees and Mirani Litster for their insightful comments, which helped refine this paper.

Disclosure statement

No potential conflict of interest was reported by the author(s).

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