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A comparative study of early shell knife production using archaeological, experimental and ethnographic datasets: 46,000 years of *Melo* (Gastropoda: Volutidae) shell knife manufacture in northern Australia

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ABSTRACT

We investigate archaeological evidence for the early production of *Melo* (or commonly named 'baler') shell knives recovered from Late Pleistocene and Early Holocene deposits in Boodie Cave, Barrow Island. The site is in the Country of Thalanyji people in northwestern Western Australia. The oldest shell knife fragments were recovered from units dated to 46.2–42.6 ka, making this one of the oldest *Homo sapiens sapiens* shell tool technologies currently described. We situate this early and ongoing tradition of shell tool manufacture within recent discussions of the early development of shell industries from both Island Southeast Asia and globally. Although shell knives have been previously reported from Pilbara and Gulf of Carpentaria surface middens in northern Australia, systematic analysis of the manufacturing process and associated debris, and especially from pre-Holocene contexts, has not been previously conducted. This research explores the shell knife *chaîne opératoire* through the integration of three data sets derived from archaeology, ethnography, and experimental archaeology. This study highlights the significance of shell tool industries in the northwest of Australia, and globally, from the Pleistocene and into the Late Holocene in areas with limited access to hard rock geology where shell reduction represents a unique technological strategy.

1. Introduction

Excavations conducted in Boodie Cave on Barrow Island off northwest Western Australia (Fig. 1) between 2013 and 2015, on the lands of the Thalanyji people, have recovered numerous *Melo* specimens in the form of ovate-shaped erose-edged knives, broken knife fragments and previously undiagnostic debris. The *Melo* specimens are present in all stratigraphic units in the site dating between c. 46.2 and 6.5 ka. Boodie Cave was first occupied around 51.1–46.2 ka when it was a large plateau on a sand plain (Veth et al., 2017). The cave was abandoned in the Middle Holocene after Barrow Island formed, following rapid rising sea levels after the Last Glacial Maximum (LGM). Nine ovate-shaped shell knives manufactured on *Melo amphora* were identified in the upper units (SU3 and 4) of the site dating to between 6.5 ka and 10.2 ka. The knives were associated with a rich cultural layer that included shellfish remains, Scaphopod shell beads, turtle bones, diverse macropod remains and lithics (Veth et al., 2017). The Boodie Cave *Melo* assemblage provides an opportunity to explore early marine shell tool production from northern Australia and to contextualise this within chronologies of shell manufacture in Island Southeast Asia and internationally.

Modern humans appear to begin to use osseous and shell materials to make tools between c. 40 to 50 ka and this 'revolution' has been taken as a proxy of more complex social behaviour, with consensus that these new media have their own unique reduction properties (Henshilwood and Marean, 2003). New archaeological discoveries from both the northern hemisphere, Island Southeast Asia and Australia are consolidating our knowledge of the chronology and nature of early use of osseous and shell materials (Bailey et al., 2013; Klein and Bird, 2016; Langley et al., 2016; Langley and O'Connor, 2016; Marean, 2016; Szabó, 2008, 2013; Thomas, 2015; Will et al., 2016; Faulkner et al., 2021). Szabó et al. (2007) track the early occurrence of personal ornaments made from shell as a proxy of social and cognitive complexity, noting

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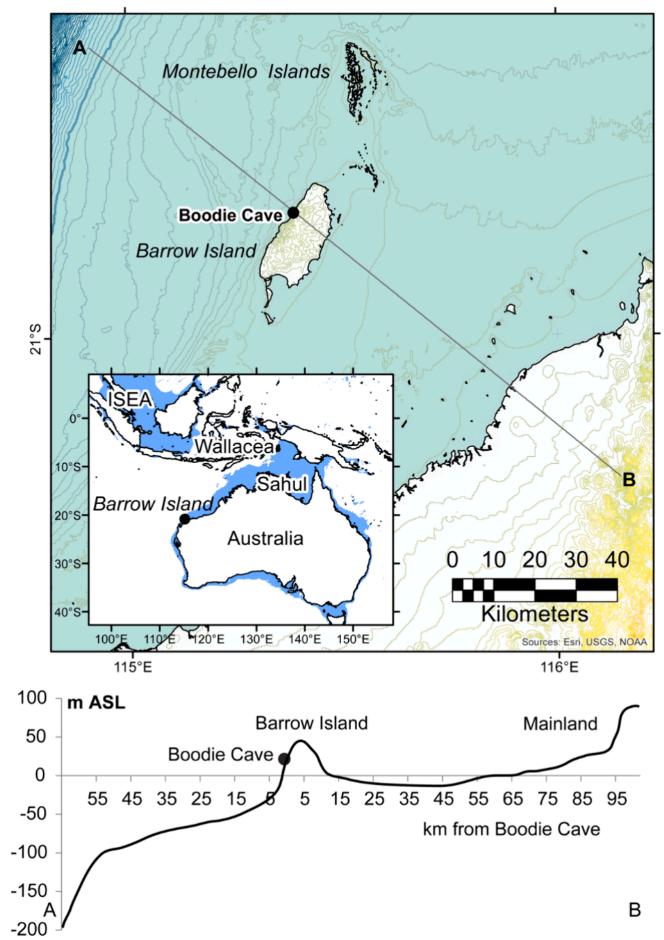

Fig. 1. Location of Barrow Island on the continental shelf (from Veth et al., 2017).

beads from Middle Stone Age sites in South Africa, ostrich bead manufacture from East Africa at 40 ka and from the eastern Mediterranean between 41 and 39 ka (see critique and rejection of claims for *H. erectus* tool manufacture in Szabó, 2013). With respect to shell implements, we note the case for the early use of *Callista chione* (brown venus clam) and *Glycymeris* (bittersweet clam) valves as 'scrapers' by Neanderthals at 13 sites across coastal Greece and Italy, dated between 115–50 ka (Douka and Spinapolice, 2012; Romagnoli et al., 2017) and worked limpet shells produced by modern humans from Altamira, Spain, dating from 25-17 ka (Cuenca-Solana et al., 2016).

However, globally there is a challenge in establishing a robust antiquity for shell tool manufacture through the presence of formal tools as well as the resultant debitage. Szabó et al. (2007) report a detailed study of shell artefacts from Golo Cave on Gebe Island, Island Southeast Asia dating from 32-28 ka. The authors conclude that human behavioural complexity might be more reliably inferred from the production of shell tools rather than those from lithics in this region:

> *The Golo shell artefact assemblage demonstrates that the important place of shell as a raw material has considerable antiquity. It further makes plain that shell is not necessarily perceived as an equivalent material to stone and that the intentions that lie behind the working of the two materials are neither similar in process nor coterminous* (Szabó et al., 2007: 714).

They stress the reliance on robust operculum blanks in a lithic-poor locality. The systematic use of robust shell and fashioning into identifiable implements is directly relevant to our case study. The northern Carnarvon bioregion, where Boodie Cave occurs, is comprised solely of limestone substrate with a plethora of the robust shellfish *Melo* available to manufacture knives. Before our current study, the Golo Island tools which were made on massive *Turbo marmoratus* (green turban snail) opercula, and *Scutellastra flexuosa* (star-shaped limpet) scrapers at ~30 ka were some of the earliest identified marine shell tools (as opposed to personal ornaments) crafted by *Homo sapiens sapiens* (Szabó et al., 2007; Szabó and Koppel, 2015). In the Australian context we note there are three worked *freshwater* mussel shellfish (Hyriidae), dated to between 40–30 ka, from the Lake Mungo Lunette site in western New South Wales, Australia (Weston et al., 2017).

This study contributes to this international research context in reporting the earliest known marine shell implements made by modern humans which continued until the Contact era in the northwest and until the 1960s in the Gulf of Carpentaria. This study has (a) characterised the *Melo* knives and debris recovered from the Boodie Cave excavations; (b) analysed the ethnographically collected erose-edged *Melo* knives from the Gulf of Carpentaria (Tindale, 1977); and (c) conducted archaeological experiments where erose-edged *Melo* knives were replicated to characterise the *chaîne opératoire*. All three data sets were then compared, and conclusions made regarding the *Melo* archaeological knives and debris from Boodie Cave.

2. Background

2.1. Boodie Cave: Archaeological context

Barrow Island is a large (202 km^2) limestone continental island located on the North West Shelf of Western Australia (Fig. 1). Its offshore position makes it ideally located to investigate past use by Aboriginal people of the now drowned and extensive arid coastal plains and to investigate the effects of a spatially fluctuating Pleistocene coastline. Barrow Island is in Thalanyji Country with Thalanyji people actively involved in managing and guiding research on cultural heritage sites on the island and mainland.

Boodie Cave is the largest of 20 stratified deposits identified on the west coast of Barrow Island with ~ 20 m^3 of cultural deposits excavated between 2013 and 2015. Archaeological deposits from Boodie Cave have provided evidence for some of the earliest use of marine resources by anatomically modern people outside of Africa and is one of the oldest sites with evidence for Aboriginal occupation from the western coast of Australia (Veth et al., 2017). An intensive dating program revealed that first occupation by Aboriginal people occurred ~ 51.1–46.2 ka, overlapping with some of the earliest dates for occupation of the arid zone of Australia. Marine resources are part of the dietary assemblages from initial occupation and continue to be transported to the cave through all periods of occupation, despite fluctuating sea levels and dramatic extensions of the coastal plain, until the island is abandoned around 6.5 ka. The changing quantities of marine fauna represented in the site through time reflect the varying distance of the cave from the contemporaneous shoreline (Veth et al., 2017). The dietary breadth of both arid zone terrestrial fauna and marine species increases after the LGM and significantly so by the Middle Holocene. The cave is abandoned by 6.5 ka when the island is located 60 km distant from the mainland coast.

The marine invertebrate record at Boodie Cave includes the key economic taxa *Terebralia, Nerita* and *Turbo* (Fig. 3). Taxa used for ornaments and tools include Scaphopoda, *Terebralia, Melo* and *Tridacna*. Nine *Melo* knives and one knife fragment (Fig. 4) were recovered from Boodie Cave in squares E101, F101, G101 and C111 which are all

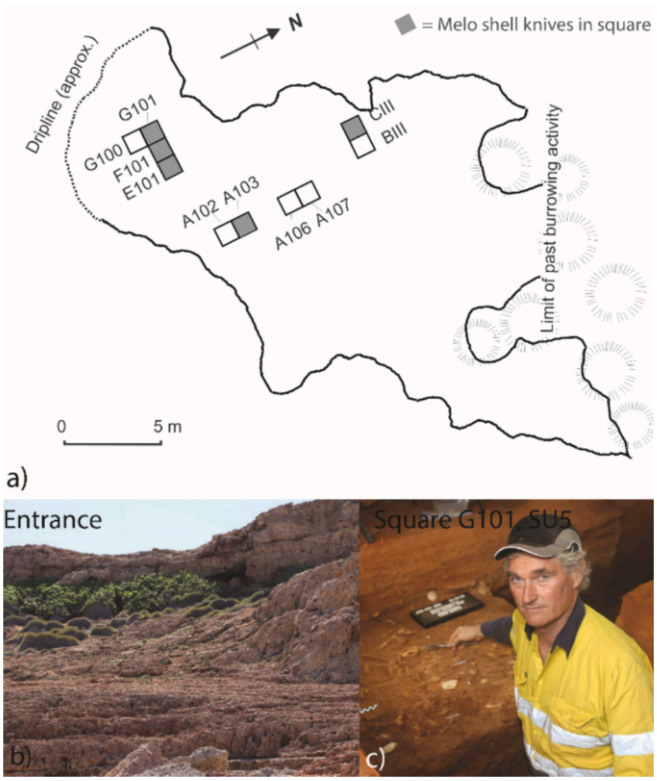

Fig. 2. (a) Plan of excavated squares (Image: BIAP); (b) Boodie Cave entrance (Image: Kane Ditchfield); (c) Peter Veth in front of living floor Square G101, SU5 (Image: Kane Ditchfield).

situated towards the front of the cave (Fig. 2a). Shell knife tips and bases also occur in these squares and in square A103.

Specimens of *Melo* from squares A103 and F101 were analysed as part of this technological study (Fig. 2). Square A103 contains *Melo* specimens in all SUs with ages spanning 46.2–6.5 ka. Square F101 contains a similar sequence with increased marine invertebrate taxa in the Early Holocene units. *Melo* specimens occur in all SUs for this square. The *Melo* knives and knife fragments are not edge-ground but have an erose-edge (or irregularly notched edge) on one and occasionally both margins. The knives often retain one or two of the mollusc's shoulder spines and some of the whorl suture (Fig. 4).

2.2. Melo shell knives

As documented in the ethnographic literature across northern Australia *Melo* shells were modified and then traded by Aboriginal people for use as water carriers, containers, saucepans, canoe bailers, spoons, knives, adzes, and as pendants and other ornaments (Haddon, 1901; Roth, 1910; Akerman, 1975, 1973; Schall, 1985; Bradley et al., 2006; Akerman and Stanton, 1994; Memmott, 2010; Best, 2012). *Melo* shell was often fractured and then edge-ground to make tools such as adzes and ornaments (Haddon, 1901; Akerman, 1975; Tindale, 1977). The mollusc was also eaten (Haddon, 1901; Meehan, 1982), with the Anbarra in Arnhem Land collecting them on 'king tides', eating the shellfish, and then using the retained shells as scoops and dishes, as do the Anbarra's neighbours the Yolŋu (Bentley James, pers. comm., 2024; James, 2016). The same collection times and strategy was also recorded by Bradley et al. (2006) for the Yanyuwa from the southern shore of the Gulf of Carpentaria. Further, the Yanyuwa dugong hunters have three names for baler shells based on shell size:

> *The term* rabu *is used for baler shells that could easily fit into the palm of the hand and were once used as cups and for the digging out of, and cleaning of, freshwater wells* (rawurrki/mabin). *The term* rabu *is also a generic term for baler shells. The* wirringkayi *baler was a larger shell favoured as a tool to bail out bark and dugout canoes, whilst the largest specimens, called* thalimbu, *were used as water carriers* (Bradley et al., 2006: 58).

Marine and freshwater mollusc taxa were used to make knives in the Kimberley, Gulf of Carpentaria and Cape York (Roth, 1910; Davidson, 1938; Akerman, 1975; McCarthy, 1976). The Bardi in the Kimberley used edge-ground *Melo* knives (Akerman, 1975) and ground-edge baler shell adzes and 'knives' were used as far south as the Nyangamarta territory on the southern end of the 80-Mile Beach in northwestern

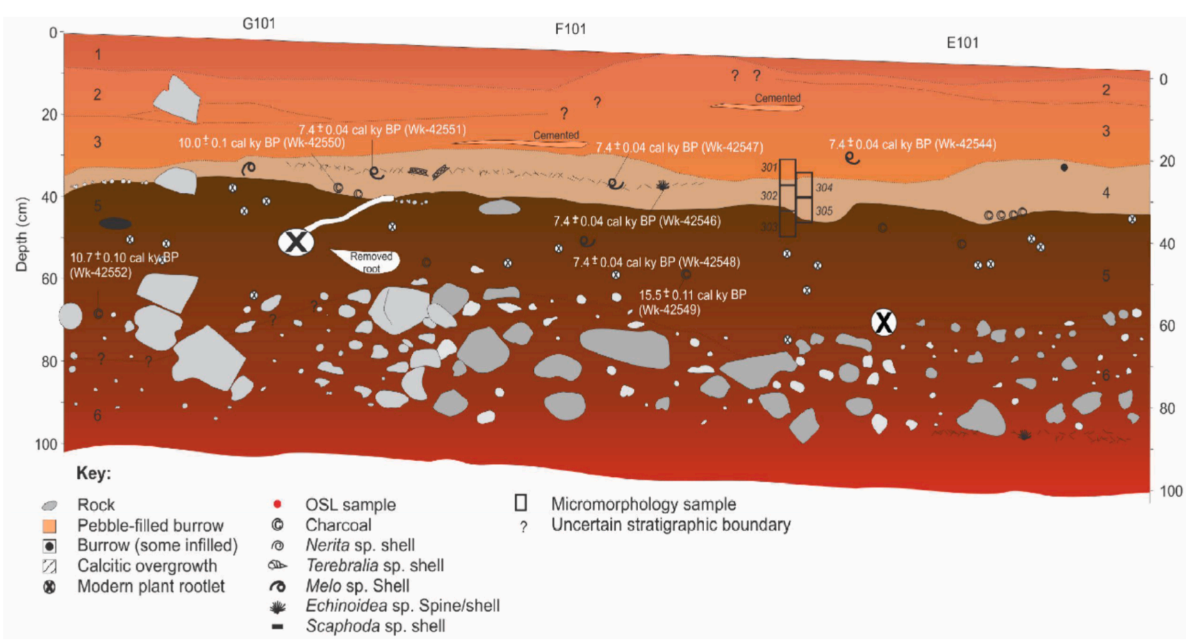

Fig. 3. Boodie Cave north face stratigraphic sequence for squares G101, F101 and E101 (Image: Ingrid Ward).

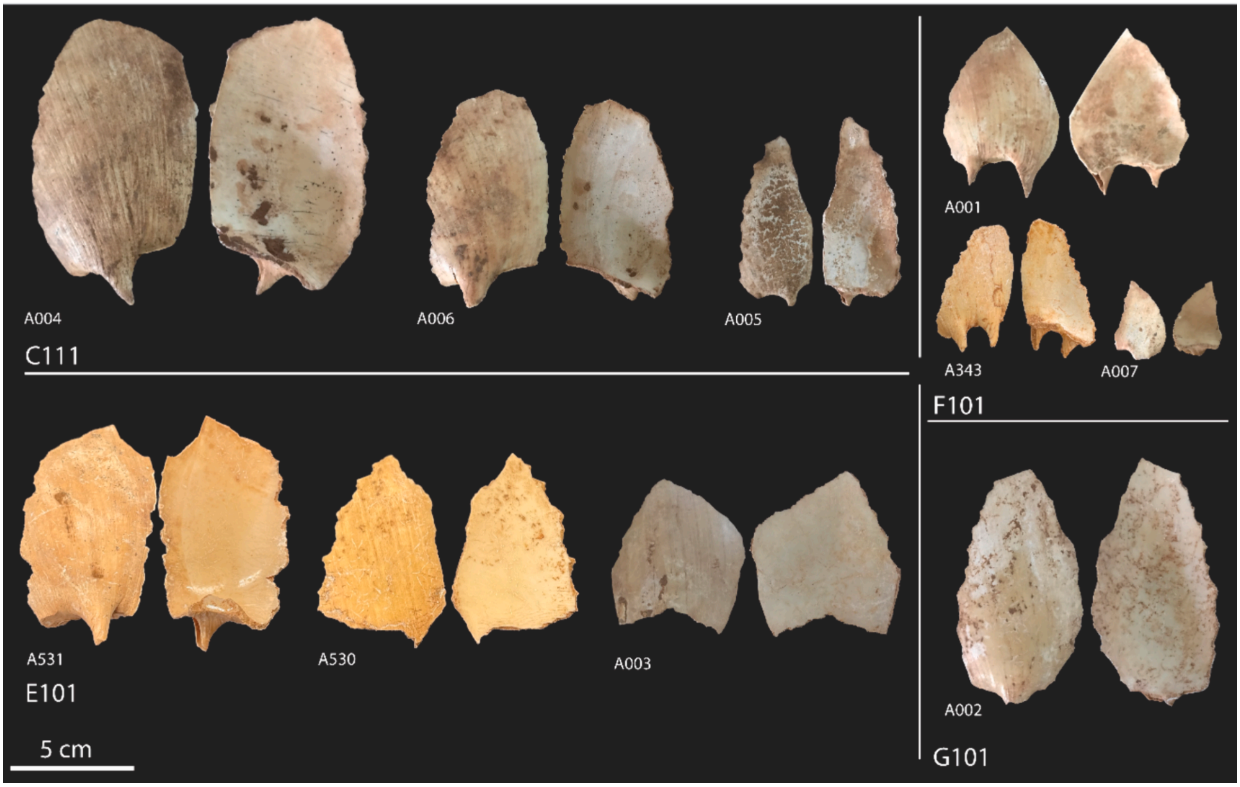

Fig. 4. *Melo* knives and knife fragments (dorsal and ventral view) from Boodie Cave (Image: Fiona Hook).

Australia. While it has not been tested, it appears to Kim Akerman that many of the implements observed from the southern area of distribution on Fig. 5 appear to have been ground from the external convex side of the shell rather than the internal side which is prevalent in the northern areas.

Melo knives with erose margins, like those from Boodie Cave, have been described from the Gulf of Carpentaria in Queensland by anthropologists Tindale (1974, 1977), and Colliver and Woolston (1967), working with Kaiadilt and Lardil peoples (Figs. 6, 7) and by archaeologist Rosendahl (2012) on Mornington Island surface midden sites. The *Melo* knives were made initially by using a stone scraper or on oyster pick to fashion the blank. The erose-edge was created by wrapping the knife blank with a paperbark (*Melaleuca*) guard and using the maker's teeth to clamp and lever off a small section of shell, one at a time (Fig. 7). The fragments which are removed to create the erose-edge produce an edge with a $< 45^{\circ}$ bevel from the dorsal to ventral surfaces (Fig. 6, 7, 14). The base of the knives often retain the shoulder spines which are wrapped in paperbark (*Melaleuca*) to create a handle (Fig. 6a).

The Kaiadilt used these knives for butchering turtle and dugong and also for adzing wood and likely working softer timbers. Tindale observed that when the Kaiadilt used the knives to butcher turtle they were initially made as preforms, heated in hot sand and the edges notched and resharpened using the paper bark and teeth compression technique; this was repeated while the butchering occurred (Tindale, 1977; Colliver and Woolston, 1967). The need to rejuvenate the working edge suggests that the knives blunted quickly during use and required resharpening.

Tindale (1977) additionally made collections of *Melo* knives during his fieldwork, these comprising both the artefacts collected during their production, and those found on surface midden sites, in collaboration with the Kaiadilt community. Artefacts in these collections include shell knives, blanks, preforms, and reduction debris, which are now curated within the South Australian Museum.

Archaeological evidence on surface sites along the coastal regions of Pilbara and Kimberley have yielded artefacts made of worked *Melo* shell, such as water carriers, spoons, bowls, and ornaments as well as undiagnostic fragments. Most of these baler artefacts have been dated to within the last 2,000 years (Akerman, 1973, 1975; Przywolnik, 2003), although recent excavation work on eight open sites on Murujuga (Dampier Archipelago) has shown that *Melo* fragments are present in stratigraphic units dating from 9,530 cal BP to the recent past (McDonald et al., 2023c). From Murujuga there is one direct date on subsurface *Melo* shell with calibrated date range of 7,434–7,262 cal BP at Rosemary Island Central Valley, as well as a calibrated date range 390–2760 cal BP for a subsurface *Melo* shell specimen and dates from 46 surface shell specimens at Wadjuru Pool on Rosemary Island, which range in age from 500 to 1,500 cal BP (Supp. Info. Table 1; Berry, 2017; McDonald et al., 2023c; McDonald and Berry, 2017). The overall trend observed in the *Melo* shell weights from eight excavations on Murujuga is that there are low numbers in the Early Holocene units, such as at Rosemary Island Central Valley; however, by the Late Holocene and on the surface the weight of *Melo* shell is high and ranks as one of the most common species after the economic species *Tegillarca granosa* and *Terebralia* (McDonald et al., 2023a, 2023b, 2023c). The presence of the fragments is interpreted as use of *Melo* for water and food containers (McDonald et al., 2023a).

During heritage work for Thalanyji, *Melo* knife, knife fragments and knife manufacturing have been recorded by FH from the surface of shell scatter sites long the Ashburton coastline (Fig. 17). These sites were occupied by Aboriginal people between 5,993 cal BP and 513 cal BP (Hook, 2014; Veitch and Warren, 1992). These *Melo* fragments are similar in morphology to those found in Boodie Cave. Akerman (1975) described edge-ground *Melo* shell adzes and knives from the Kimberley coast which were hafted. Przywolnik (2003) describes *Melo* and *Tridacna* shell tools from shell midden sites in Cape Range on the Ningaloo coast. She details three *Melo* shell knives and one dish from three different midden sites. The knives are described as a long-curved section of shell with a thin edge and a thicker opposite edge. Use-wear is described as microchipping and splintering of the blade edge (Przywolnik, 2003). In a subsequent paper Akerman (2004) questioned whether the baler knives described by Przywolnik were cultural, raising

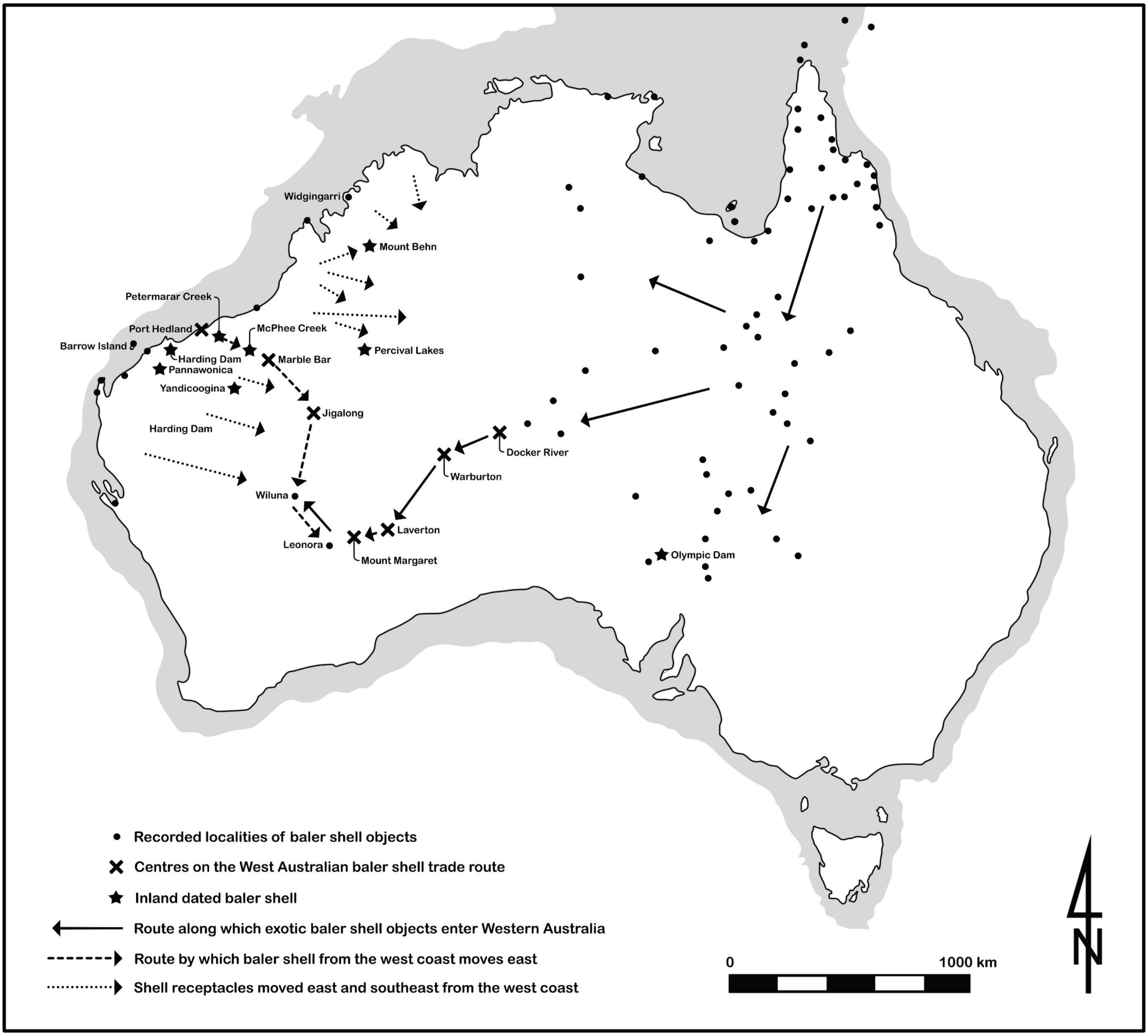

Fig. 5. Australian *Melo* shell trade networks (based on Akerman, 1975, 2023) and recorded location of baler shell objects (Image: Adam Black).

the possibility their edges were potentially the result of natural breakage and weathering. Morse (1993, 1996) also lists the presence of *Melo* shell dishes and pendants in surface midden sites at Cape Range. The pendants all have ground edges and are elongated oval in plan-view with a single pierced hole.

In the inland Pilbara, baler shell implements consistent with those reported on by Akerman (1975) were recorded on the surface of Watura Jurnti and in a Packsaddle Range site (Marsh et al., 2018). Smith and Veth (2004) reported on the dating of baler shell at Western Desert sites which indicated 'down-the-line' exchange of baler shell (*Melo*) into the heart of the Great Sandy Desert over 2,000 years ago and continuing up until the late 1800s. The dated samples were small pieces found on the surface of campsites (Kiriwirri, Kurtararra and Yurlpul) near Aboriginal wells and springs along the shores of the Percival Lakes (Smith and Veth, 2004). Surface *Melo* fragments were also found at nine places during the Canning Stock Route Project (Jo McDonald, pers. comm., 2023).

The major function of the shell traded into the interior of the continent was for display as pendants, with brilliant-white polished baler shell pendants still important in rainmaking ceremonies (Akerman, 1973). The archaeological specimens from the Percival Lakes are too small to determine their original function. However, given that this line of springs is said by the Martu people to be part of the *Jila* mythology associated with rainmaking, the archaeological specimens may well be pieces of worn-out pendants. Alternatively, it is possible that they are debris from the manufacture of pendants, which would account for their presence on general occupation sites, as Akerman (1973) has observed at Wiluna further south within the Western Desert. The presence of baler shell in Late Pleistocene deposits dated to 51.7–33.3 ka from Jansz Rockshelter at Cape Range (Przywolnik, 2002), 42.3–38.7 ka at Boodie Cave (Hook et al., in prep.), and 33.1–30.3 ka from Widgingarri Shelter 1 in the Kimberley (O'Connor, 1999; Norman et al., 2022) indicates the early utilitarian use of this taxa (Supp. Info. Table 1). *Melo* is common in archaeological sites in the Carnarvon bioregion with 44 specimens dated from the Late Pleistocene to the last 100 years. (Supp. Info. Table 1).

The dates for the Percival Lakes sites show that, for over the last 2,000 years, baler shell has been exchanged or traded into the heart of the Great Sandy Desert, > 400 km from the nearest potential coastal

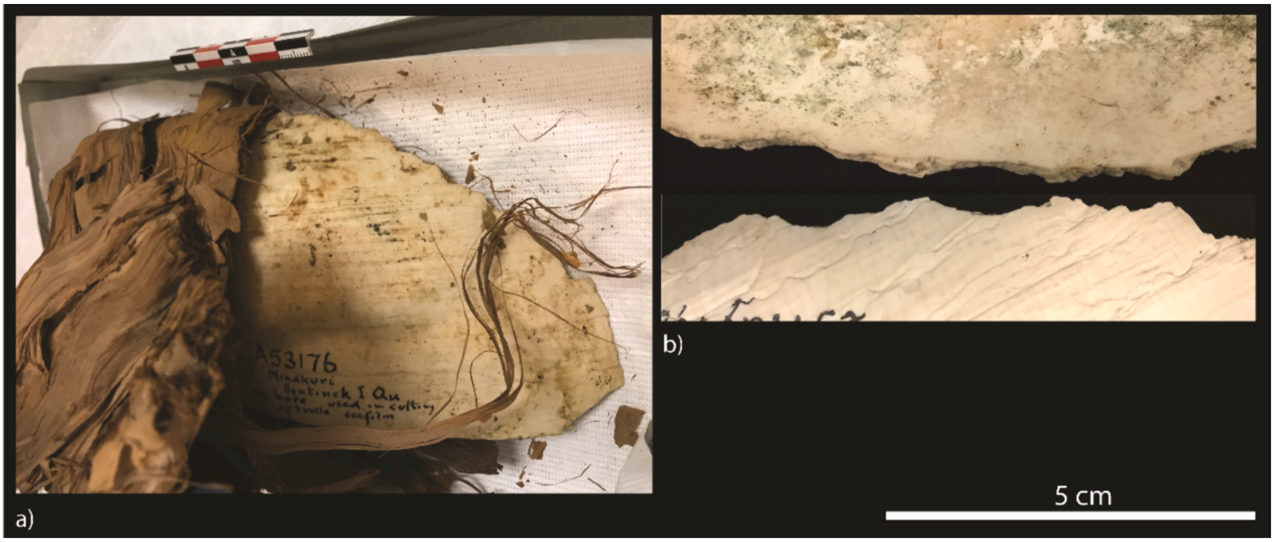

Fig. 6. (a) *Melo* knife with paper bark handle (A.53176); and (b) dorsal and ventral close up of erose knife edge (A.53169). Both collected by Norman Tindale held in South Australian Museum (Images: Fiona Hook).

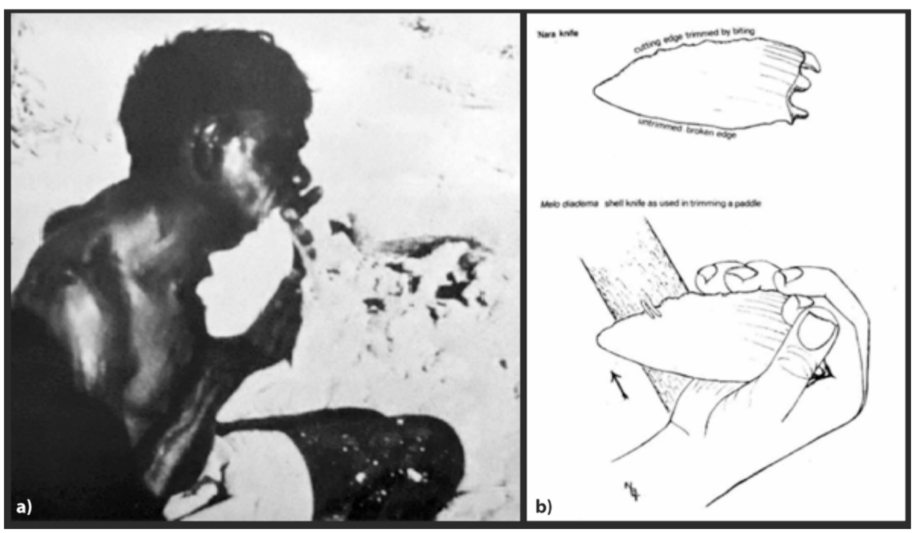

Fig. 7. (a) Kaiadilt man creating erose-edge of a *Melo amphora* knife; (b) drawing by anthropologist Norman Tindale of a *Melo amphora* shell knife and its use as a woodworking adze (from Tindale, 1977: 262-263).

source of these shellfish. These results imply the existence of a long-distance exchange system from at least this date, although more data are required to determine the parameters and characteristics of this system. These observations raise the possibility that shell was carried and traded from Pleistocene coastlines for over 40 km to Boodie Cave for use in utilitarian and possibly other functions. The exciting possibility of long-distance exchange of baler, pearl, and other shells from early in the occupation of the northwest, and plausibly from 40,000 BP is raised, with a site on Koolan Island having pearl shell dated to before 20,000 years ago (O'Connor, 1999).

3. Materials and methods

3.1. *Melo* macro- and microstructure

The genus *Melo*, belonging to the family Volutidae, is a genus of marine gastropod molluscs that are known for their exceptionally large size. The ovate shells are so large that they have been commonly referred to as 'bailer' or 'baler' shells, owing to their past use in bailing out canoes (Haddon, 1901; Bradley et al., 2006). In northwestern Australia there are four species of *Melo*: *M. amphora*, *M. ashmorensis*, *M. umbilicatus* and *M. peterstimpsoni*; with *M. amphora* the only taxa that occurs in Western Australia through to Queensland, including Papua New Guinea (Morrison and Wells, 2005). *M. amphora* can grow up to 52.4 cm in length (Fig. 8). *Melo* shell macrostructures include a spindle-shaped, elongated shell with a smooth or spirally ridged surface and a distinctive aperture with thickened and often flared lips. *M. ashmorensis, M. umbilicatus* and *M. peterstimpsoni* have very low shoulder spines, only measuring 2–8 mm, that are not longer than the spire and have no spine near the aperture. In contrast *M. amphora* have long shoulder spines, between 10–40 mm, with the longest spine nearest the aperture (Fig. 8). On the Mohs scale *Melo* registered ~ 5, making it extremely hard, and almost like a stainless-steel knife (Ward et al., 2019).

Mollusc shells comprise up to five superposed layers composed of foliated calcite and aragonite crystals (Almagro et al., 2016; Ward et al., 2019). Although the microstructure of *Melo* has not received systematic study, three other species in the same Volutidae family (two of which are extinct), have been described. They comprise crossed-lamellar / fibrous

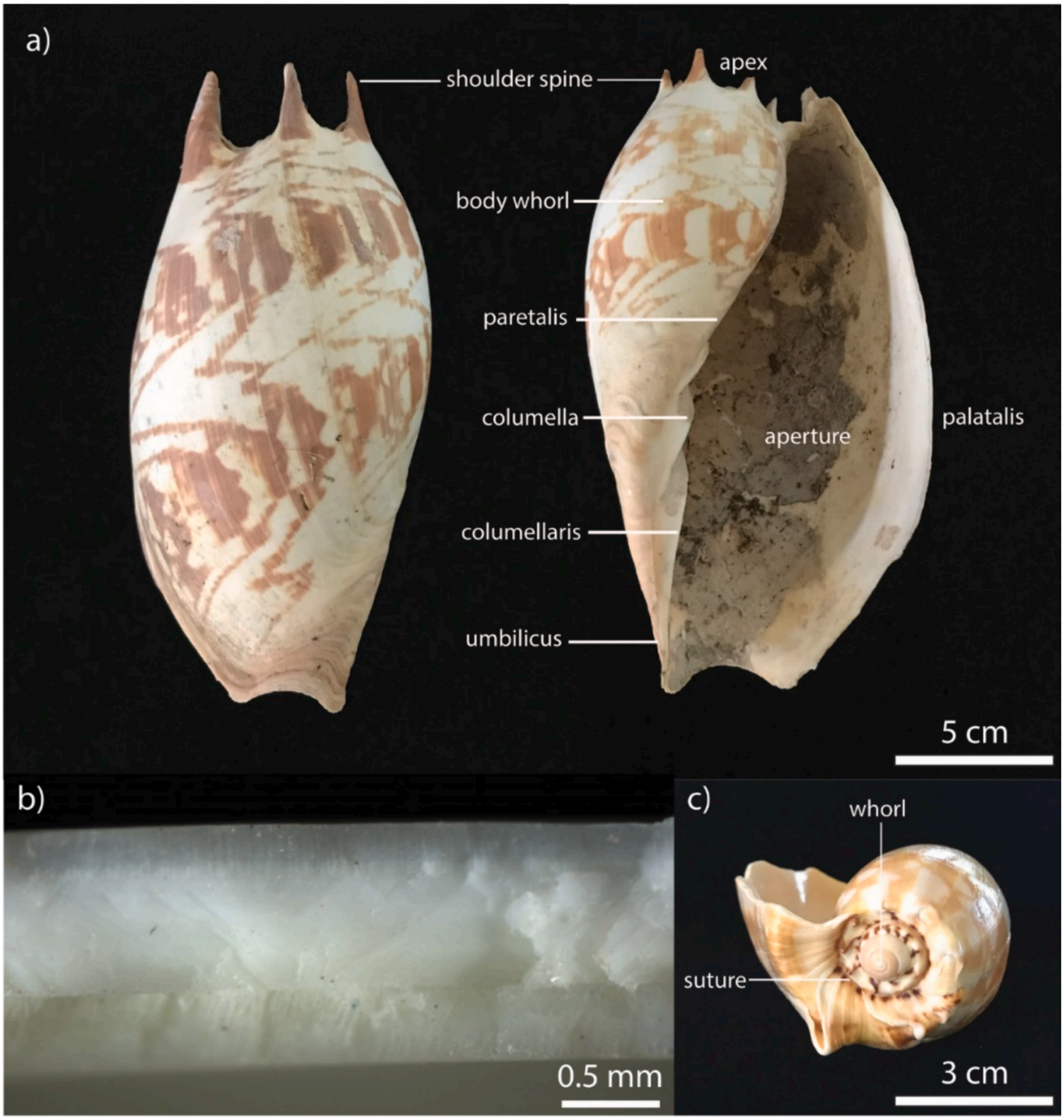

Fig. 8. (a) and (c) *Melo amphora* macrostructure (Image: Fiona Hook); (b) microstructure showing crossed-lamellar structure (Image: Richard Fullagar).

crossed-lamellar (both perpendicular and parallel), prismatic and spherulitic prismatic microstructures (Pietsch et al., 2021). The prismatic microstructure is made of first-order prisms that are parallel. The spherulitic prismatic microstructure is created by first-order prisms with second-order prisms that extend outwards. The crossed-lamellar microstructure is made up of third-order prisms that are often twinned aragonite crystals arranged into second-order lathes as sheets or bundles. The first-order lamellae lying next to each other consist of second-order lathes that have an opposing orientation, usually at an angle of 70° to 90° (Pietsch et al., 2021). This crossed-lamellar microstructure of *Melo* makes the shell very strong, having evolved to withstand predator attack and being crushed on a rocky reef during storm events (Fig. 8). The unique cross-lamellate structure directly influences how the shell can be broken and utilised as a raw material for tools and ornaments (Szabó, 2008, 2013).

3.2. Experimental program

The experimental study was designed to:

1. Assess the feasibility and efficiency of producing shell knives and the production time;
2. Delineate and categorise the distinct reduction stages involved in the knife manufacturing process;
3. Characterise the reduction techniques employed in crafting the knives; and,
4. Assess the efficacy of the knives for both butchering and woodworking applications.

The study involved the replicative manufacture of eight knives from complete *Melo amphora* and use-wear studies on two of these knives.

In October 2018 Kim Akerman, assisted by Fiona Hook and Richard Fullagar, made seven knives using the ethnographically observed techniques described by Tindale (1974) and Colliver and Woolston (1967)

Table 1
Attributes recorded on whole and partial erose-edge *Melo* knives.

Tool Size and Shape	Shell Elements Present	Edge Modification
Maximum Length	Columella	Edge Modification
Distal Width	Umbilicus	Modification Direction
Proximal Width	Whorl	Right Margin Modification
Midpoint Width	Apex	Left Margin Modification
Right Midpoint Thickness	Shoulder Spines	Proximal Modification
Left Midpoint Thickness	Aperture	Length of Modification – Right Margin
Number of Sides	Suture	Length of Modification – Left Margin
	Palatalis	Length of Modification – Proximal
	Paretalis	Right – Number of Notches
	Columellaris	Left – Number of Notches
	Number of Shoulder Spines	Proximal – Number of Notches
	Shoulder Spine State	Notch – Width
		Notch – Depth

(Fig. 11). The knives were made from juvenile *Melo amphora* which had been collected by a commercial shell collector from Port Hedland in northwest Australia.

Two knives (E004 and E008) were selected to complete the butchery (Fig. 12) and woodworking experiments (Fig. 13). Kim Akerman, Fiona Hook and Richard Fullagar all participated in the butchery of pork ribs. Two butchery experiments were conducted, one without sand, and the other with sand added to the pork ribs, to simulate butchery of an animal on a beach as observed by Tindale. The shoulder spines of the knife were wrapped in paperbark to replicate the traditional handle. Kim Akerman carried out the adzing of a greenwood tree (*Prunus*), directed by historic photographs and drawing (Fig. 7b) by Tindale (1977) of a Kaiadilt man making a canoe paddle from a mangrove branch (a softwood). The use-wear analysis is ongoing and will be reported in a separate paper.

The stages of reduction of the experimental knives, and the butchery/woodworking process, were recorded with still photography and videography. Material from each stage of the reduction sequence was collected from a large drop-sheet for characterisation in the laboratory. Each specimen's attributes were recorded using the methods detailed below.

3.3. Historical collections

With support from the Kaiadilt Aboriginal Corporation, in October 2018 Fiona Hook and Sean Ulm visited the South Australian Museum (SAM) to view the shell knives collected by Norman Tindale between 1960 and 1963 (Fig. 6, 7, 14). The SAM was able to locate 11 of the 46 specimens Tindale had collected (SAM Accession numbers: 53168; 53169; 53170; 53171; 53172; 53173; 53176; 53177; 53178; 53179; and 53180). Each specimen was photographed, and its attributes recorded using the methods detailed below.

3.4. Comparing the archaeological, historical, and ethnographic knives

The *Melo* specimens from Boodie Cave, the SAM collection and those manufactured in the replicative experiments, were categorised into three types: Tools, Tool fragments and Debris.

Shell macrostructure terms follow Vermeij (1995) and Claassen (1998) and are shown in Fig. 8. A range of attributes were systematically recorded on the tools, with the ventral surface facing forward and the proximal end at the base (Table 1, Fig. 9). Tool fragments had the following recorded: number of angle changes as viewed from the dorsal surface (greater than 45°); length; width; thickness, shell features, erose notch width and depth, where present. For debris these attributes were recorded: number of angle changes as viewed from the dorsal surface (greater than 45°); length; and width.

All measurements were made using Mitutoyo (CD-6″ CX) digital callipers with the jaws covered in a layer of rubber (Tool Magic) to prevent artefact damage. Each tool, tool fragment and a sample of debris from the Boodie Cave samples was imaged using a Canon digital SLR camera / iPhone 11 Pro.

4. Results

4.1. Experimental dataset

The first objective of the experimental investigation was to assess the feasibility and efficiency of crafting shell knives, particularly in terms of the manufacturing process and time requirements. Leveraging the expert proficiency of Kim Akerman, the manufacturing process demonstrated remarkable ease and efficiency. Each knife was successfully fashioned in less than 2 minutes, underscoring the expedient nature of their production. These findings suggest that the manufacture of shell knives was fast and efficient once the underlying principles governing the fracturing patterns of the shell were understood.

The second and third objectives of the study were to determine the *chaîne opératoire* to characterise the reduction debris from the manufacture process. Based on the findings from the experimental production of *Melo* knives, the *chaîne opératoire* encompasses three phases. The initial phase involves the delineation and detachment of the knife blank from a complete *Melo* shell. The first step in this phase involves perforating the shell along the parletalis, extending from the umbilicus to the collmellaris, utilising a small pointed hammerstone (Fig. 10). This operation effectively separates the blank from the remainder of the shell, yielding a substantial quantity of debris consisting of variously sized fragments, encompassing small sherds, larger pieces, as well as the contiguous umbilicus, columella, body whorl, and axis. The average number of the fragments generated during this phase is 84, with dimensions ranging from 1 mm to 40 cm, with a median size of 2 cm. The average thickness of these fragments was 1.43 mm. Fragment morphology typically appears irregular, with the number of angles per fragment varying from two to 10, with a median of four (refer to Fig. 10, 18).

The second phase entails the shaping of the blank through a levering technique to fracture the edge and modify the knife blank into an ovate shape. In the experimental procedures, a pair of pliers and paperbark were utilised to create an ovate-shaped blank. Kaiadilt men in the 1960s used their teeth and a paperbark protective layer, however, for modern safety requirements pliers were used instead. This stage resulted in the production of smaller fragments, with a median count of 18 per knife and dimensions spanning from 1 mm to 9 mm. The shapes of these fragments are generally trapezoidal in plan view (four angles) (Fig. 10).

The final stage of the *chaîne opératoire* involves the addition of erose notches, which form the functional cutting edge of the shell implement. This task was executed using a pair of pliers in conjunction with the paperbark wedge. This process yielded smaller fragments, with a median count of seven, ranging in size from 1 cm to 5 cm. Most of these shell fragments had an oval (<3 angles) morphology (Fig. 10, 18).

The experimental *Melo* knives represent the largest specimens under investigation in this comparative study. They exhibit a median length of

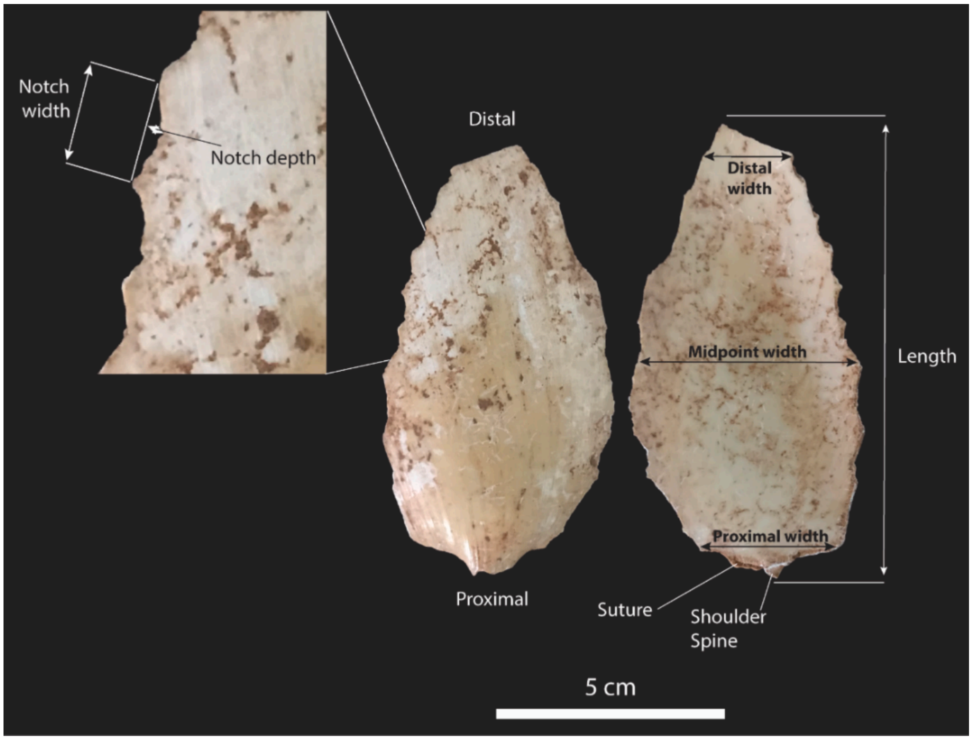

Fig. 9. *Melo* erose-edge knife measurements (Image: Fiona Hook).

144.6 mm, a proximal width of 56.2 mm, a distal width of 26.7 mm, and a midpoint width of 69.4 mm (Fig. 11). The right margin of these knives possesses a median thickness of 1.5 mm. Furthermore, these knives display an average of 7.5 erose notches, with each notch measuring approximately 10.3 mm in length and exhibiting a depth of approximately 2.1 mm.

The final aim of the experimental work was to determine the effectiveness of using the knives for butchery and woodworking. One knife (E004) was selected to butcher meat, in this case pork belly as turtle and dugong are protected species in Australia. One knife (E008) was selected to conduct the woodworking experiment.

The *Melo* knife was extremely effective in cutting the pork skin and meat into pieces. The knife was held perpendicular to the meat with the ventral surface of the knife facing the user. The meat was cut effectively with a sawing motion (Fig. 12). The butchery which was carried out without sand produced very little wear on the knife edge, however by contrast, with the addition of sand the knife edge was blunted after 5 min of cutting.

The knife edge proved very effective as an adze in shaving bark, cambium, and xylem from a *Prunus* specimen. The knife was held with the ventral surface facing away from the body with the bevelled edge of the erose-edge shaving the wood (Fig. 13). The edge damage produced using the knife as an adze shows angular fragmentation during initial use which is itself a resharpening action. This angular fragmentation along the utilised margin forms a microscopically jagged edge (Fig. 13d, ii), due to the shell structure and develops until the margin is worn back to a naturally rounded growth feature of the shell (Fig. 13d, i). Most fractures from use create sharp jagged edges, but we occasionally observed a ‘rounded’ portion (the dotted line ii in Fig. 13d) created by a naturally rounded plane under the overlapping suture. There are no traces of use along this natural rounded fracture plane. We attribute the feature to the cross-lamellar nature of microstructure where the growth line has formed under the suture; that is, the junction between slightly overlapping growth lines. The naturally rounded growth feature can subsequently be fractured and sharpened by adzing hard material (i.e. self-sharpening), hard hammer blows or by pressure flaking (e.g. by using teeth to remove sections).

4.2. Historical dataset

Our review of Tindale’s historic collections revealed specimens that resembled small bowls or ‘spoons’, as these were not plausibly knives they were excluded from this study. Six specimens that were like the Boodie Cave knives were systematically measured; with one additional specimen not measured as it was still wrapped in its original bark handle (Fig. 6).

Two fragments of baler produced and collected from these original manufacturing events were also in the collection, as well as the tip of a knife fragment. Interestingly the knife tip fragment resembles a fragment of *Melo* from Boodie Cave dated to 46 ka (Fig. 15).

The *Melo* knives collected by Tindale from Bentinck Island are larger than the Boodie Cave specimens and smaller than the experimentally made knives (Fig. 14). They have a median length of 125.7 mm, a proximal width of 55 mm, a midpoint width of 67 mm and a distal width of 32.5 mm. The right margin has a median thickness of 1.3 mm and the length of 2.33 mm. The knives have an average of 5.6 erose notches with each notch averaging 10.3 mm in length and 2.1 mm in depth.

4.3. Boodie Cave dataset

Nine whole knives were recovered from five of the 10 excavated squares at Boodie Cave, with broken knife fragments and undiagnostic fragments found throughout the deposit from all 10 squares. The shell knives were recovered from five squares (A103, C111, E101, F101, G101; Fig. 2a), within the upper three stratigraphic units which are dated to 10.5–6.5 ka (Fig. 3). One hundred and fifty-three larger baler shell fragments were plotted *in-situ* during the excavations, with 1,992 *Melo* specimens recovered from squares A102, A103, E101, F101, G101 and G100 during systematic sorting of 4 mm and 2 mm fractions. For this current study, 430 *Melo* specimens from Square F101, 90 specimens from Square A103, and the knives from Squares C111, E101, F101, G101 were analysed. In comparison the lithic numbers are higher than the

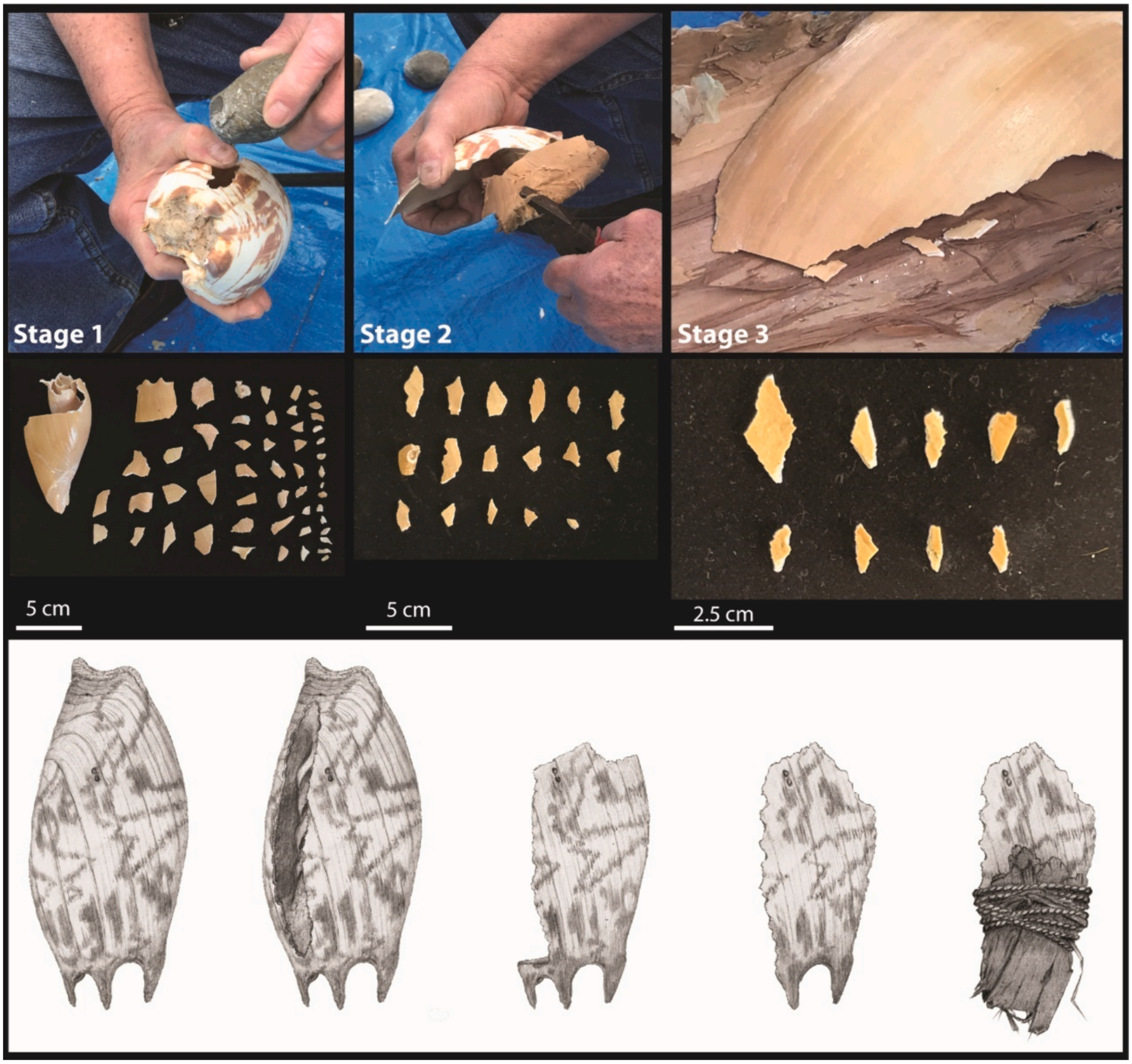

Fig. 10. *Melo* knife *chaîne opératoire* (Images: Fiona Hook, Adam Black).

Melo specimens, however, they follow the same patterning with lower numbers in SU6-7 and a substantial peak by SU5 with a slight decrease in SU1-3 (Ditchfield, 2018).

The earliest clearly modified *Melo* specimen occurs in a level dated by OSL to 46.2 ka (A103, SU7) (Fig. 15). It should be noted that at this time the Pleistocene coastline was located approximately 20 km to the northwest of Boodie Cave (Veth et al., 2017). Given that long-distance transport of baler shell occurred during the Late Holocene along the Pilbara coast into the Western Desert for a distance of over 400 km, the recovery of baler shell in this unit is quite plausible.

The *Melo* knives from Boodie Cave have a median length of 58.9 mm, a proximal width of 34.6 mm, a midpoint width of 40.8 mm and a distal width of 13.3 mm (Table 2). They are thus substantially smaller than the Bentinck Island knives. They have the characteristic ovate shape often with shoulder spines intact. The right margin has a median thickness of 0.9 mm and the left of 1.3 mm. The knives have an average of 5.6 erose notches, with each notch averaging 7.8 mm in length and 1.4 mm in depth.

The erose-edge on the knives and the knife fragments all have their notches initiated from the dorsal to ventral surface creating a bevel of < 45°. This creates a cutting edge, where the harder dorsal surface of the shell protrudes over the slightly softer crossed-lamellar interior of the shell.

In square A103, there are 89 *Melo* fragments which include undiagnostic specimens and one knife fragment. These specimens were recovered from SU2 to SU7, which date from 46.7 to 7 ka cal BP. Most fragments were recovered from SU3 and 4, comprising 38% and 21% of the *Melo* assemblage by frequency. The mean thickness of the nine *Melo* knives from Boodie Cave is 0.9 mm for the left margin and 1.4 mm for the right (ventral surface facing up; Table 2). The median thickness of the *Melo* fragments in A103 is 1.5 mm ($\sigma = 0.6692$). The mean size of the undiagnostic specimens is 3 cm with most fragments having four edges; trapezoid shaped fragments were thus the most common. Square F101 contained 420 undiagnostic *Melo* specimens and two small knives. The undiagnostic specimens occur in SU1, and SU3 to SU6, with 92 % occurring in SU4 and SU5. The two knives were recovered from SU4. Like the pattern noted in Square A103, the median thickness of the *Melo* fragments from Square F101 was 1.31 mm ($\sigma = 0.56628$) with the mean size of undiagnostic specimens in F101 also 3 cm. Similarly, these fragments exhibit four edges with the trapezoid shape being the most common.

Based on the reduction patterns observed from the experimental archaeology, as described above, the undiagnostic fragments from A103 and F101 clearly match fragments from experimental stages 2 and 3 of

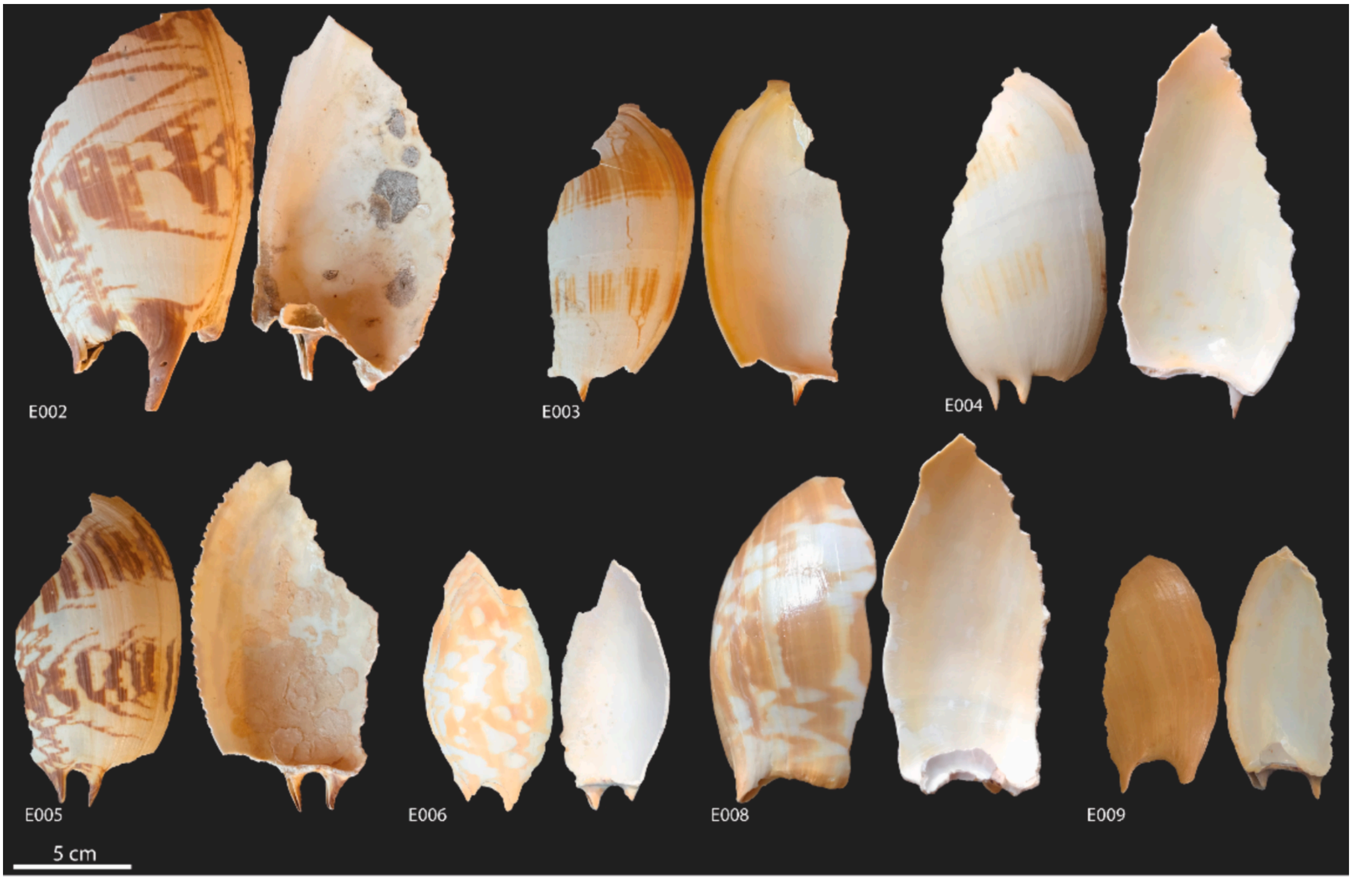

Fig. 11. *Melo* knives from experimental work (Image: Fiona Hook).

Fig. 12. Butchery experiment: (a) cutting the pork ribs; (b) knife edge after cutting the pork; (c) microscopy of knife edge after cutting pork without sand; (d) rounded knife edge after cutting pork with sand (Images: Fiona Hook, Richard Fullagar).

Fig. 13. Woodworking experiment: (a) using a *Melo* knife to adze *Prunus* wood; (b) wood shavings from adzing; (c) baler shell knife edge prior to use; (d) baler knife shell edge after use, showing jagged edge-fractures from use (i) and the natural shell growth feature (ii). The rounded edge of natural shell growth features should be carefully distinguished from edge-rounding caused by use (Images: Fiona Hook, Richard Fullagar).

the *chaîne opératoire*. For all fragments in Square F101 that are less than 1.35 mm thick (n = 230), the mean size is 2 cm, and the mean number of angles is four. For Square A103 there are 39 fragments that are less than 1.34 mm thick. Their mean size is 3 cm and mean number of angles is also four. The correspondence in these metrics of shell thickness and number of angles strongly suggests that most undiagnostic fragments in squares A103 and F101 are the result of *Melo* knife manufacture and use. Future work will focus on taphonomic agents that may be responsible for other breakage patterns and the remaining fragments.

An ongoing program of use-wear studies is occurring on both shell and lithic artefacts from Boodie Cave and will be reported elsewhere.

5. Discussion

Based on our inferences from the experimental archaeological results, the makers of the *Melo* (baler) knives at Boodie Cave relied on the natural morphology of the initially intact shell blanks. The manufacturing process firstly involved the selective removal of specific parts of the shell; secondly, shaping the preform knife blank; and thirdly, creating the cutting edge. The knives were all made from juvenile *Melo* shellfish, and most likely from *Melo amphora*, given the presence of a long shoulder spines at the aperture/spire margin on eight of the nine whole knives examined.

The knives are not ground in an adze-like fashion, as has been recorded to the north in the Kimberley (Akerman, 1975), but instead have an erose (irregularly notched) edge on one working margin. The knives have repeated characteristics which distinguishes them from shellfish with natural breakages. The first modifications begin from the *Melo* aperture (removing the columella, or body whorl) with the shoulder spines and portions of the umbilicus left to create a handle. They are generally ovate-shaped and the erose working edge occurs on the right margin (ventral surface facing upwards). This right edge is thicker than the left lateral margin which usually comprises the outer lip of the shell, which is thin and often weathered. The erose-edges observed on both the knives and knife fragments exhibits a consistent pattern, whereby the notches are initiated from the dorsal to ventral surfaces, resulting in the creation of a cutting edge with a bevel angle measuring less than 45°.

Fig. 14. *Melo* knife, knife fragment and debris (dorsal and ventral view) from Bentinck Island (Image: Fiona Hook).

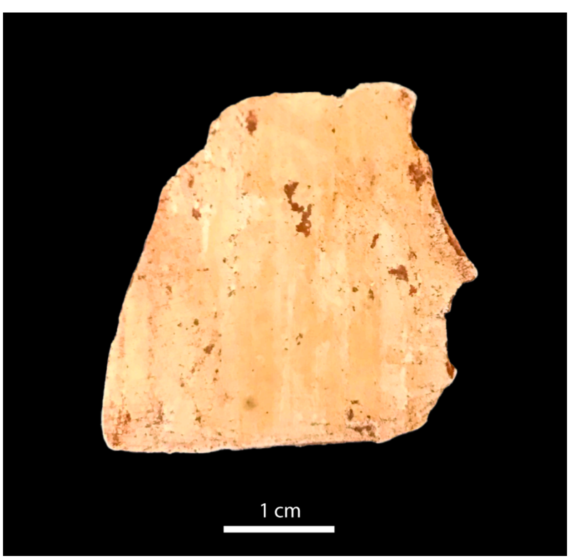

Fig. 15. *Melo* knife fragment from Boodie Cave, Square A103, SU7 (Image: Fiona Hook).

The knives from Bentinck Island made in the 1960s, and collected off the surface of middens by Tindale, share all the same features described from the Barrow Island knives. The Barrow Island knives, however, are smaller than the Bentinck Island shell knives. It is not possible to determine at this stage whether this is a factor of cultural choice, or instead shell species selection. It may be that on Barrow Island the shell knife makers selected younger *Melo amphora* to manufacture their knives. It may also be that the Barrow Island knives had different functions than the Bentinck Island examples.

Undiagnostic *Melo* fragments are a common feature of archaeological sites across the north of Australia. Our literature review of archaeomalacology analyses from the northwest of Australia did not locate any detailed analyses of *Melo* fragments. It is likely that part of the reason for this lack of previous analysis has been the lack of recognition of diagnostic features associated with the manufacturing process. For example, Berry (2017; McDonald and Berry, 2017) measured the maximum spire length of 176 surface collected *Melo* fragments from Wadjuru Pool on Rosemary Island. The measured specimens all had intact spires and apertures. The average maximum measurement across the spire and aperture[1] of the shells was 7.6 cm ranging between 2 cm and 18 cm. The spire to aperture width of a 40 cm long adult *Melo amphora* shell is 23 cm, suggesting that at Wadjuru Pool juveniles were preferentially selected by Aboriginal people. McDonald et al. (2023c) suggest that the *Melo amphora* shells were being used as water carriers as some of the shells from Wadjuru Pool were intact. If the *Melo* shells have an average apex-aperture width of 7.9 cm the *Melo* shell total length would be ∼ 16 cm long (Fig. 16). Shells of this size would only hold 90 ml of water, which is less than a standard drink. This suggests that these *Melo* shells are not water carriers but may represent cups for drinking from soaks (Bradley et al., 2006). Several *Melo* shells observed on the surface of Wadjuru Pool were fragmentary, and all *Melo* specimens from the eight archaeological excavations were also fragments. Given the utilitarian and ornamental multi-purpose use of *Melo* by Aboriginal people, additional work on the Murujuga *Melo* specimens from these excavations is

[1] Berry (2017) describes the maximum measurement of the shell perpendicular with the aperture as the 'length'.

Table 2
Boodie Cave – *Melo* shell knife metrics (mm).

Knife code	SQ	XU / SU	Length	Tool proximal width	Tool midpoint width	Tool distal width	Right midpoint thickness	Left midpoint thickness
A001	F101	407 / 4	53.3	34.9	38.6	12.6	0.9	1.1
A002	G101	534 / 3	54.5	41.9	50.4	11.3	1.2	1.3
A003	E101	606 / 4	90.8	30.0	46.0	19.1	0.7	1.5
A004	C111	108 / 3	111.4	47.7	62.7	46.3	1.4	1.8
A005	C111	115 / 3	66.0	23.8	26.8	10.1	1.1	1.3
A006	C111	108 / 3	79.5	38.3	44.2	26.5	0.5	1.4
A007	C111	108 / 3	29.9	18.2	14.7	3.9	0.9	1.0
A343	F101	407 / 4	58.9	24.6	12.0	25.1	0.4	1.4
A531	E101	604 / 3	16.4	34.6	40.8	13.3	0.7	1.8

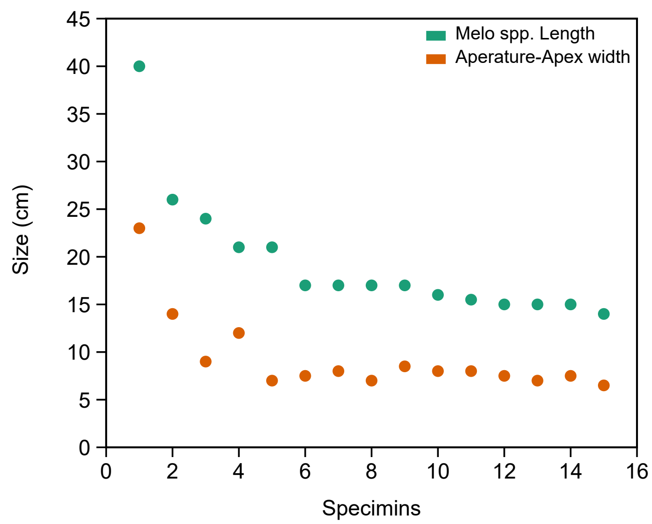

Fig. 16. Whole *Melo amphora* size measurements (specimens 1–3 are adults; 4–15 are juvenile).

warranted. The experimental data presented here can hopefully aid in this analysis.

The experimental work has illuminated the *chaîne opératoire* and expected archaeological signature if *Melo* knives were being used and made in archaeological sites. Fragments of *Melo* that are trapezoid or elliptical in shape, and which are smaller than 3 cm, are most likely the result of knife manufacture, notching, use, and edge maintenance (Fig. 10, 18). These features, when combined with the presence of larger fragments of contiguous umbilicus, columella, body whorl, and detached outer lips, may all provide consistent evidence for knife blank manufacture. One of the limitations of the experimental study is that it focused solely on the manufacture of knives. *Melo* was also used by Aboriginal people for the manufacture of pendants, which may have used the same outer lip of the juvenile *Melo.* These pendants were mostly edge-ground; however, it is possible that the initial shaping was done using similar techniques to stage 2 of the knife blank manufacture. Further work is required to characterise the production mode of pendants and associated use-wear.

Several of the undiagnostic *Melo* fragments recovered from Boodie Cave are also thicker than expected from knife manufacture debitage. Larger adult *Melo* shells were used by Aboriginal people as water carriers where the columella was removed to create an open dish, which have been recorded on coastal sites in Thalanyji Country (Fig. 17). This was usually achieved by burying the shell in the sand with the parietals exposed and then a fire being lit over the top to crack the exposed shell portion (McCarthy, 1957; Lamilami, 1974; Poignant and Poignant, 1996; Bradley et al., 2006). This portion was then removed along with the columella. The resultant debitage from making these dishes has not been documented in detail, however, given the usually large size of adult *Melo* shells (up to 50 cm long), the fragments are substantially thicker than those produced when making a knife from juveniles. In square

Fig. 17. *Melo* knife and water carrier/bowl from a coastal midden in Thalanyji Country (Images: Fiona Hook).

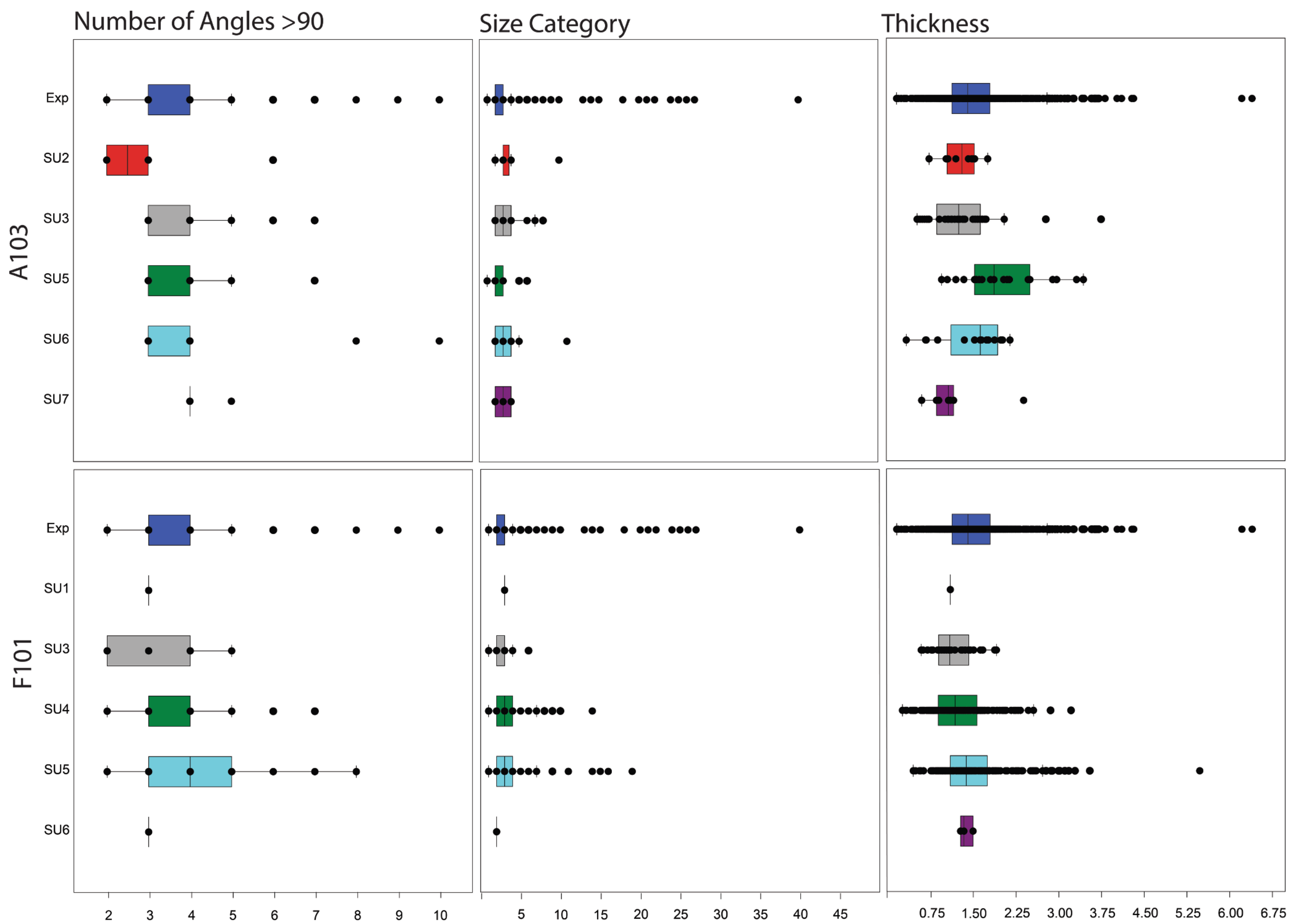

Fig. 18. Number of angles, size class and thickness of *Melo* debris specimens from the experimental dataset (row 1) and archaeological data from A103 SU 2—7 (top); and F101 SU1-6 (bottom).

A103 seven fragments are between 2.5 mm and 3.8 mm thick, while in F101 there are 19 fragments are between 2.5 mm and 5.5 mm thick. One possibility is that the thicker pieces derive from broken water carriers. As shown in Fig. 18, the experimental assemblage has several outliers in terms of thickness when compared to the results from A103 and F101. However, there is greater variability (outliers) from fragments produced from the experimental work. Only square A103 SU5 registers slightly thicker pieces that might match the size category and number of angles on the larger water container blanks. Further experimental work is required to understand these differences.

6. Conclusion

We provide evidence for the manufacture and use of *Melo* knives in Thalanyji country, north-west Australia, spanning 46,200 years. By identifying and dating both shell tools and the by-products generated from their manufacture this research provides one of the best case studies in the world for the long-term development and sustained use of a particular type of shell tool, in this case *Melo* knives. That this technology has an antiquity of 46.2–42.6 ka make this one of the oldest shell tool technologies developed by *Homo sapiens*. Previously, the oldest identified shell tools used by modern humans was from Golo Cave dated to 32–28 ka (Szabó et al., 2007; Szabó and Koppel, 2015).

Further, this is first time in Australian archaeology that *Melo* from a Late Pleistocene context has had a function identified using a technological analysis. *Melo* shell is the oldest direct dated marine invertebrate in Australia, with dates of 42.3–38.7 ka at Boodie Cave and ~ 36–34 ka at Janz Cave on Cape Range (Przywolnik, 2002) with undiagnostic *Melo* fragments ubiquitous in most northern Western Australian coastal archaeological sites (Bowdler, 1990; Morse, 1993; O'Connor, 1999; Veth et al., 2007; Berry, 2017; McDonald et al., 2023a, 2023b, 2023c). In most cases, *Melo* specimens have been assumed to be from water-carriers based on ethnographic evidence (e.g. Morse, 1993; McDonald et al., 2023c). In no cases have technological analyses been conducted on *Melo* specimens apart from Przywolnik's (2003) analysis, which has had its interpretation and conclusions questioned (Akerman, 2004). This study, therefore, demonstrates that additional technological studies of *Melo* artefact types are required to identify additional *Melo* tools in archaeological sites.

We believe that modified shell artefacts represent a significant but often under-described component, of northwest Australian tool industries. Taphonomic considerations will always play a crucial role in distinguishing between shell artefacts and naturally occurring breakage and future research on this theme is proposed. Understanding the role of shell artefacts in wider economic and social systems involves discerning between uses, such as water carriers, and the existence of shell artefact industries with distinct stages of procurement, manufacture, and use. The combined analysis presented here using experimental, ethnographic, and archaeological investigations has yielded valuable insights into *Melo* shell artefact production and utilisation from northwestern Australia. This work needs to be replicated for all other types of *Melo* artefacts, in order to develop a more nuanced understanding of this shell species and its importance in both the secular and sacred economy of Aboriginal people.

Melo shell knives exemplify an enduring industry within the northern Carnarvon bioregion, with archaeological excavations at Boodie Cave yielding many *Melo* knives, hundreds of larger shell fragments, and thousands of fragments of reduction debris, comparable in scale to silicified limestone debris from lithic reduction in the same units (Ditchfield, 2018). We conclude that such a wealth of material offers researchers a novel window into past marine resource utilisation and associated butchery and processing activities. Future research in northern Australian sites can profitably examine shell assemblages for shell blank reduction and tool manufacture, using both experimental and archaeological lenses. We conclude that past reliance on robust shellfish such as *Melo* for tools, in provinces lacking hard rock geology, will be more universal in northern Australia than currently acknowledged.

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CRediT authorship contribution statement

Fiona Hook: Writing – review & editing, Writing – original draft, Visualization, Validation, Resources, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Sean Ulm:** Writing – review & editing, Resources, Methodology, Conceptualization. **Kim Akerman:** Writing – review & editing, Methodology. **Richard Fullagar:** Writing – review & editing, Methodology. **Peter Veth:** Writing – review & editing, Resources, Methodology.

Declaration of competing interest

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

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Appendix A. Supplementary material

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jaa.2024.101614.

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