Late Quaternary human-environment interaction in Bunuba and Gooniyandi country, Western Australia

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Declaration

Unless otherwise acknowledged in the text, all work contained therein is the original research of the author.

Rose Hannah Whitau 2018

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Abstract

In north Western Australia, records of palaeoenvironmental change are scarce or under explored, particularly terrestrial archives that allow for comparison with the archaeological record and examination of human-environment interaction in the past. The extent to which these records reflect localised vegetation responses to climate fluctuations, and the manner in which people adapted to these changes in climate and vegetation, has yet to be investigated within the context of stratified archaeological inquiry. Analysis of archaeobotanical proxies excavated in association with other cultural remains provide the obvious evidential link to this issue; however, archaeobotany is rarely applied in Australian archaeology due to a lack of application of appropriate field techniques, limited reference collections, and the poor preservation of organic remains.

This research, which is part of the ARC Linkage Project: Lifeways of the First Australians, investigates human-environment interaction using archaeobotanical techniques at two sites in the Kimberley region of northern Western Australia: Riwi and Mount Behn rockshelter, during the late Quaternary. Located on the edge of the Great Sandy Desert in Gooniyandi country, Riwi has a discontinuous occupation sequence of about 45 ka, while Mount Behn rockshelter, located some 180 km northwest of Riwi in Bunuba country, has an occupation sequence of ~3 ka. Anthracology (wood charcoal), palynology (pollen and spores), and wood identification using X-ray microtomography are used alongside other research from the Lifeways Project to reconstruct vegetation, investigate human-environment interaction, and explore the taphonomy and representativeness of the different proxy data sets. The findings from each site are then located within a regional narrative of human-environment interaction.

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Chapter 1. Introduction

1.1 Rationale

The timing of Aboriginal arrival on the Australian continent is still an unresolved, contentious issue, with recent evidence from Madjedbebe rockshelter in northern Australia pushing the minimum age back to 65 ka cal. BP (Figure 1.1; Clarkson et al. 2017) (note that the majority of ages presented in this thesis are calibrated years before present, but only ka is given in the text). Whatever the minimum age, the distribution of Pleistocene sites with archaeological deposits over 40 ka, across a broad range of environments throughout Australia, attests to both the rapidity with which the continent was colonised, and the adaptability of the colonisers (Figure 1.1; Allen and O’Connell 2014; Balme 2013; Balme and O’Connor 2014; Balme et al. 2009; Hiscock and Wallis 2005; O’Connell and Allen 2015).

The last 65 ka spans an interglacial cycle, with the Last Glacial period occurring 30—18 ka (Reeves et al. 2013a, 2013b; Turney et al. 2006; Williams et al. 2009), many generations after the initial colonisation of Australia. The continent itself was much larger during the Last Glacial Maximum (LGM, 22—18ka), with the north Australian coastline extending some 100—600 km from its present location creating an extensive exposure of land connecting Australia and New Guinea, known as Sahul (Figure 1.1; de Deckker and Yokoyama 2009; Shennan and Milne 2003; Yokoyama et al. 2000, 2001). Climate shifts over the past 65 ka generated extensive environmental changes across the continent; expanding and contracting areas hospitable to human habitation, particularly within the arid zone, which extended into the modern semi-arid zone during arid phases, such as the Last Glacial period (Fitzsimmons et al. 2013; Hesse et al. 2004; Kershaw et al. 2003; Lampert and Hughes 1974; Williams et al. 2015b).

Numerous socio-ecological models have been applied by archaeologists to explain human occupation patterns and technological innovations over the past 65 ka. The paucity of archaeological evidence from the arid zone and its fringes during the LGM has been ascribed to a population contraction to ecological refugia during the onset of aridity, which resulted in less hospitable environments (Hiscock and Wallis 2005; McConnell and O’Connor 1997; O’Connor and Veth 2006; O’Connor et al. 1999; Przywolnik 2005; Smith 2013; Veth 1989, 1995; Veth et al. 2005; Williams et al. 2015b). Commencing around 18 ka, rapid sea level transgression during the deglacial period has been associated with the contraction of territorial boundaries and subsequent population pressure (David and Lourandos 1998; Lourandos and David 1998; Moore 2013; Mulvaney 2013; Smith 1992). A transitory arid phase around 5 ka has been correlated with an intensification of innovative technologies and the regionalisation of rock art styles in northern Australia (Attenbrow et al. 2009; Haberle and David 2004; Hiscock 1994; Mulvaney 2013; Rowland 1999; Ulm 2013; Veitch 1996; Williams et al. 2010; Williams et al. 2015a).

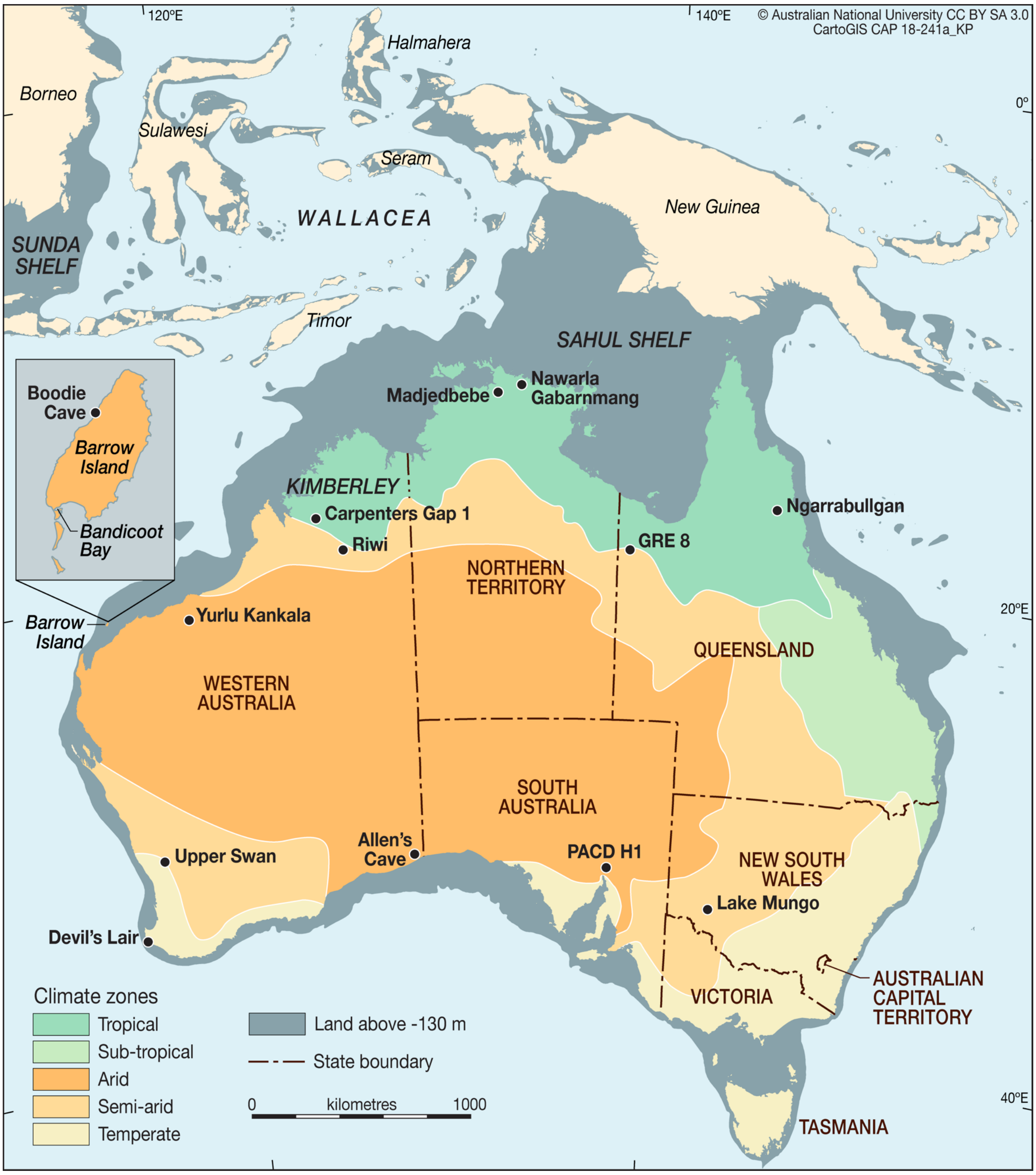


Figure 1.1 Modern Australia, with the Last Glacial coastline, climate zones, states, and sites with antiquity greater than 40 ka, adapted from Vannieuwenhuyse (2016: Fig. 1.1, 2), CAD CartoGIS, Australian National University

Despite the centrality of environmental factors in many socio-ecological models in Australian archaeology, most explications rely on the extrapolation of palaeo-environmental data from marine, coastal, or terrestrial contexts located at some spatio-temporal distance from the archaeological record in question. In north western Australia, for example, records of palaeoenvironmental change are scarce or under explored, particularly terrestrial archives that allow for comparison with the archaeological record and examination of human-environment interaction in the past. Analysis of archaeobotanical proxies excavated in association with other cultural remains provide the obvious evidential link to this issue; however, archaeobotany is rarely applied in Australian archaeology due to a lack of application of appropriate field techniques, limited reference collections, and the poor preservation of organic remains (Denham et al. 2009; Dotte et al. 2015).

Aside from reconstructing vegetation change and enabling the exploration of human occupation models, archaeobotanical analyses provide essential information on a resource indispensable to human subsistence: plants. Although the Australian archaeobotanical record is woefully under-researched, there is no doubt that plants would have played a leading role in the lifeways of Australia's Aboriginal people since the continent's colonisation some 65,000 years ago. Indeed, in contrast to the rock art galleries of Aurignacian and Magdalenian Europe (e.g. Hodgson and Helvenston 2006), and other hunter-gatherer contexts in North America (e.g. Hays-Gilpin 2013) and Africa (e.g. Mguni 2009), the rock art of northern Australia, and particularly the Kimberley region, includes a rich corpus of direct and indirect plant depictions, such as: grasses, trees, tubers; the imprinting of pigment-soaked plants; the anthropomorphism of plants; and plant-derived material culture (e.g. digging sticks, dilly bags, and hafted implements) (Veth et al. 2016).

The presence of food plants in the earliest Kimberley rock art, the recovery of edge-ground axe technology from ~44—49 ka contexts in the Kimberley (Hiscock et al. 2016), and the identification of starches from grindstones excavated from Madjedbebe, Australia's oldest archaeological site (Clarkson et al. 2017; Hayes 2015), clearly demonstrate a complex relationship between people and plants from the Pleistocene onwards. Attempts have been made to recognise this complexity by reviewing the traditional division of the Pleistocene continent of Sahul into the Melanesian, agricultural north, and the Aboriginal, hunter-gatherer south, with the application of theories such as domiculture (Hynes and Chase 1982), niche construction theory (e.g. Florin and Carah 2016), and ecoscaping (Ouzman et al. 2017). However, further archaeobotanical evidence from stratified contexts is necessary to test these hypotheses and develop our understanding of the relationships between people, plants, and climate throughout Australia's occupational history.

1.2 Research Project and Aims

This research is part of the Australian Research Council Linkage Project (LP100200415): Lifeways of the First Australians: the Art and Archaeology of the Oscar-Napier Ranges (henceforth Lifeways Project), which is led by Chief Investigators Profs Sue O'Connor (Australian National University) and Jane Balme (University of Western Australia), in partnership with the Kimberley Foundation, the Western Australian Museum, the Department of Sustainability, Water, Populations and Communities, and the Bunuba and Gooniyandi Aboriginal communities. The primary purpose of the Lifeways Project is to explore the art and archaeology of the Oscar-Napier Ranges, where the rockshelters and caves located within the vestiges of a Devonian limestone reef have provided exceptional conditions for the preservation of archaeological archives.

Beginning in 2011, the Lifeways Project has built upon the earlier work of O'Connor and Balme in the '90s (Balme 2000; O'Connor 1995, 1996, 1999a; O'Connor and Veth 1993; O'Connor and Sullivan 1994; O'Connor et al. 2008) by reinvestigating previously excavated sites (Carpenter's Gap 1, Carpenter's Gap 3, and Riwi), undertaking exploratory excavations at new sites (Djuru/Windjana Gorge Water Tank site, Moonggaroonggoo, and Mount Behn rockshelter), mapping the rock art of the southern Kimberley, and working closely with Bunuba and Gooniyandi elders, rangers, and corporations on community-driven initiatives. Various research has been completed under the aegis of the Lifeways Project, including two completed PhD theses that analyse the project's excavated stone tools (Maloney 2015) and micromorphological sequences (Vannieuwenhuyse 2016); one completed Honours thesis (Dilkes-Hall 2014) on the macrobotanical remains, which has developed into a PhD project (Dilkes-Hall, incomplete); and one PhD thesis on the rock art of the southern Kimberley (Fyfe, incomplete). This thesis draws on other researchers' work conducted from within the Lifeways Project, some of which is presented (not just referred to) in the results and discussion chapters, and is excluded from this introductory chapter for the sake of repetition.

This research investigates human-environment interaction using archaeobotanical techniques at two sites in the Kimberley region of northern Western Australia: Riwi and Mount Behn rockshelter, during the late Quaternary. Located on the edge of the Great Sandy Desert in Gooniyandi country, Riwi has a discontinuous occupation sequence of about 45 ka, while Mount Behn rockshelter, located some 180 km northwest of Riwi in Bunuba country, has an occupation sequence of ~3 ka. Two sites were selected from the Lifeways Project due to time constraints. Riwi was chosen for its deep time sequence, unique preservation of combustion features, and exceptional preservation of organics in the Holocene units. Mount Behn rockshelter was chosen as a comparison for Holocene occupation, with the site yielding the largest excavated point assemblage in the Kimberley region to date.

Anthracology (wood charcoal), palynology (pollen and spores), and wood identification using X-ray microtomography are used alongside other research from the Lifeways Project to reconstruct vegetation, investigate human-environment interaction, and explore the taphonomy and representativeness of the different proxy data sets. The findings from each site are then located within a regional narrative of human-environment interaction. The two main aims of this thesis are:

1. To explore late Quaternary human-environment interaction at two archaeological sites in Bunuba and Gooniyandi country, by:

a) Identifying taphonomic biases and assessing the representativeness of the analysed archaeobotanical assemblages, and
b) Reconstructing local vegetation change during site occupation using archaeobotanical analyses, and
c) Locating botanical resource exploitation and management within the archaeobotanical record, and

d) Correlating these results with broader climatic and environmental archives.
2. To develop the application of archaeobotanical analyses in Australia, by:
a) Applying appropriate, current archaeobotanical methods which are informed by a critical engagement with the literature, and
b) Producing reproducible research that develops the ways in which archaeobotanical analyses can be more readily applied to Australian archaeological contexts.

1.3 Defining the Kimberley Region

The Kimberley region is located within northern Western Australia between 14°S and 19°S latitude, and 123°E to 129°E longitude, spanning an area of over 421, 000 km^2, which is bordered by the Great Sandy and Tanami Deserts to the south and the Northern Territory border to the east (Figure 1.2), although the administrative and physiographic boundaries which define the Kimberley region vary between sources, contingent upon the methods used (Pepper and Keogh 2014). The following section provides a brief introduction into the geology, modern physiography, climate, biota, and bioregions of the Kimberley region. More detailed information specific to the areas surrounding Riwi and Mount Behn rockshelter are described in site descriptions given in Chapters 3, 4, and 6.

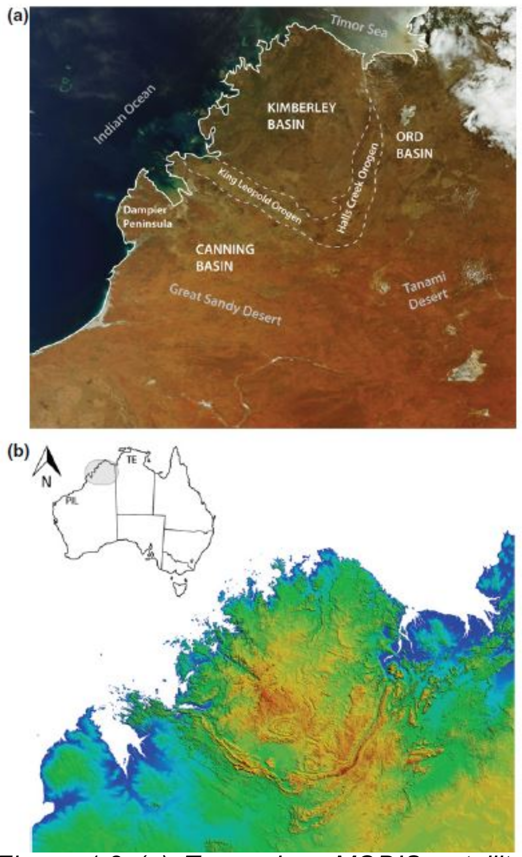


Figure 1.2 (a) True-colour MODIS satellite image (NASA) showing the Kimberley and surrounding areas; (b) Digital elevation model image showing the Kimberley and surrounding areas, red equates to areas of high elevation, and blue equates to areas of low elevation. The inset shows the location of the Kimberley (grey) with the Top End of the Northern Territory (TE) and the Pilbara (PIL). Copied directly from Pepper and Keogh (2014: Fig. 1, 1444).

Geologically, the Kimberley region is dominated by the Kimberley plateau or basin, the basal geology of which is comprised Paleoproterozoic and Proterozoic siliciclastic sedimentary rocks, mafic volcanic rocks, and intrusive dolerite (Tyler et al. 2012). The Kimberley basin is framed by the King Leopold Orogen to the south-west and the Halls Creek Orogen to the south-east (Figure 1.2a). The basal geology of both Orogens is comprised of Paleoproterozoic and Proterozoic gabbro, granite, volcanics, and metamorphics (Tyler et al. 2012). The Canning and Ord Basins border the orogenic belts to the south-west and south-east respectively. The Canning Basin is comprised of Paleozoic Ordovician to Cretaceaous sediments, including Devonian reef complexes which formed on the northern boundary with the King Leopold orogenic belt. The archaeological sites investigated in the Lifeways Project are all located within the vestiges of the Devonian reef complex. Formed within Devonian Pillara and Sadler limestone facies that are comprised of limestone, siltstone, and calcareous sandstone, Riwi is part of an extended karstic system which formed in the Early Permian glaciation from subglacial lakes and solution channels (Playford et al. 2009). The Mount Behn rockshelter is an outcrop of the central Napier Range, formed at the intersection of Napier formation Famennian marginal-slope limestone and Behn conglomerates of Devonian submarine-fan deposits (Playford et al. 2009).

The underlying geological structure and lithology of the Kimberley largely determines the region’s physiography in terms of topography and surface drainage systems. A sandstone-capped plateau, rising 40—854 m above sea level comprises the northern and central components of the Kimberley basin (Figure 1.3b, d; Boden and Given 1995). The western section of the basin, also known as the Prince Regent Plateau, is predominantly deeply dissected King Leopold Sandstone, with gently sloping exposures of basalt, and the eastern section, also known as the Karunjie Plateau, is less dissected Pentecost Sandstone, with sedimentary rocks forming frequent scarps and irregular mesas (Wende 1997). The rugged topography of the King Leopold and Halls Creek Orogens is typified by the steep, parallel ridges of the King Leopold and Durack Ranges in the south-west and south-east respectively (McKenzie et al. 2009).

Soil cover tends to be more extensive on the volcanic plains and thinner in the sandstone dominated areas, where bedrock, including basement strata, can be exposed from intense folding (McKenzie et al. 2009; Tille 2006; Wende 1997). The Fitzroy and Ord rivers form broad alluvial plains to the west and east of the Kimberley plateau, which contains the Isdell, Prince Regent, King Edward, Drysdale, and Pentecost river basins. The Kimberley region floods seasonally and is subject to tropical storms. The increases in water load have incised many of the rivers into the ranges and tablelands, creating extensive gorges and valleys.

The Kimberley region is situated within the seasonally dry Australian Monsoonal Tropics, where precipitation is dominated by the Australian summer monsoon and tropical cyclones, both of which are driven by the southward migration of the Inter-Tropical Convergence Zone (ITCZ) between December and March, with the amount of rainfall broadly decreasing in a south-east gradient towards the interior of the continent (Suppiah 1992). The monsoonal trough of the ITCZ separates the westerlies to the north and the trade winds to the south, with weaker monsoonal periods corresponding with a more northerly position of the monsoonal trough and stronger, more active monsoons with a more southerly ITCZ (Suppiah, 1992). Several climate drivers affect the strength of the Australian summer monsoon, including the Madden-Julian Oscillation (MJO) (Wheeler et al. 2009), the temperature of the Indo-Pacific Warm Pool (IPWP) (Huang and Mehta 2004), variability in sea surface temperatures (SSTs) (Taschetto et al. 2010), and the El Niño/Southern Oscillation (ENSO) (Risbey et al. 2009). The mean annual rainfall for the region is ~1000 mm per year, with more than 70% of rainfall occurring between January and March (Bureau of Meteorology, 2017). Temperature data from Fitzroy Crossing airport, which is roughly equidistant from Riwi and Mount Behn rockshelter and has been recorded daily since 1998, gives an annual average temperature of 36.1°C, with the lowest mean monthly temperature recorded for June (30.4°C), and the highest in November (40.8°C) (Bureau of Meteorology, 2017).

The tropical, semi-arid climate, coupled with the diverse landscape of the Kimberley region, support a highly endemic biota, with over 65 species of endemic fauna, over 300 species of endemic flora, and descriptions of new taxa published with each exploration into taxonomically unchartered areas (Pepper and Keogh 2014, and references therein). The Interim Biogeographic Regionalisation for Australia (IBRA) divides the Kimberley into two regions (Northern Kimberley, Central Kimberley), with an additional two regions overlapping with the eastern Northern Territory (Victoria Bonaparte and Ord Victoria Plain) (Figure 1.3c). These divisions are informed from detailed mapping, expanding on the original four phytogeographic districts identified by Beard (1979) for the Kimberley: the Gardner District to the north, Dampier and Hall Districts to the south, and the Fitzgerald District in the centre. Broadly speaking, the vegetation of the northern Kimberley is a savanna woodland of eucalypts, bloodwoods, and high-grasses, which grades into a low-tree steppe dominated by spinifex moving south, and pindan woodland to the west (Beard 1979). Pockets of monsoon rainforest persist in fire protected gorges and coastal areas, such as the Mitchell Plateau, Windjana Gorge National Park, and Purnululu National Park (McKenzie et al. 1991) and mangroves in certain coastal areas and rivers, such as in and around Broome and the Keep River region (Beard 1979).

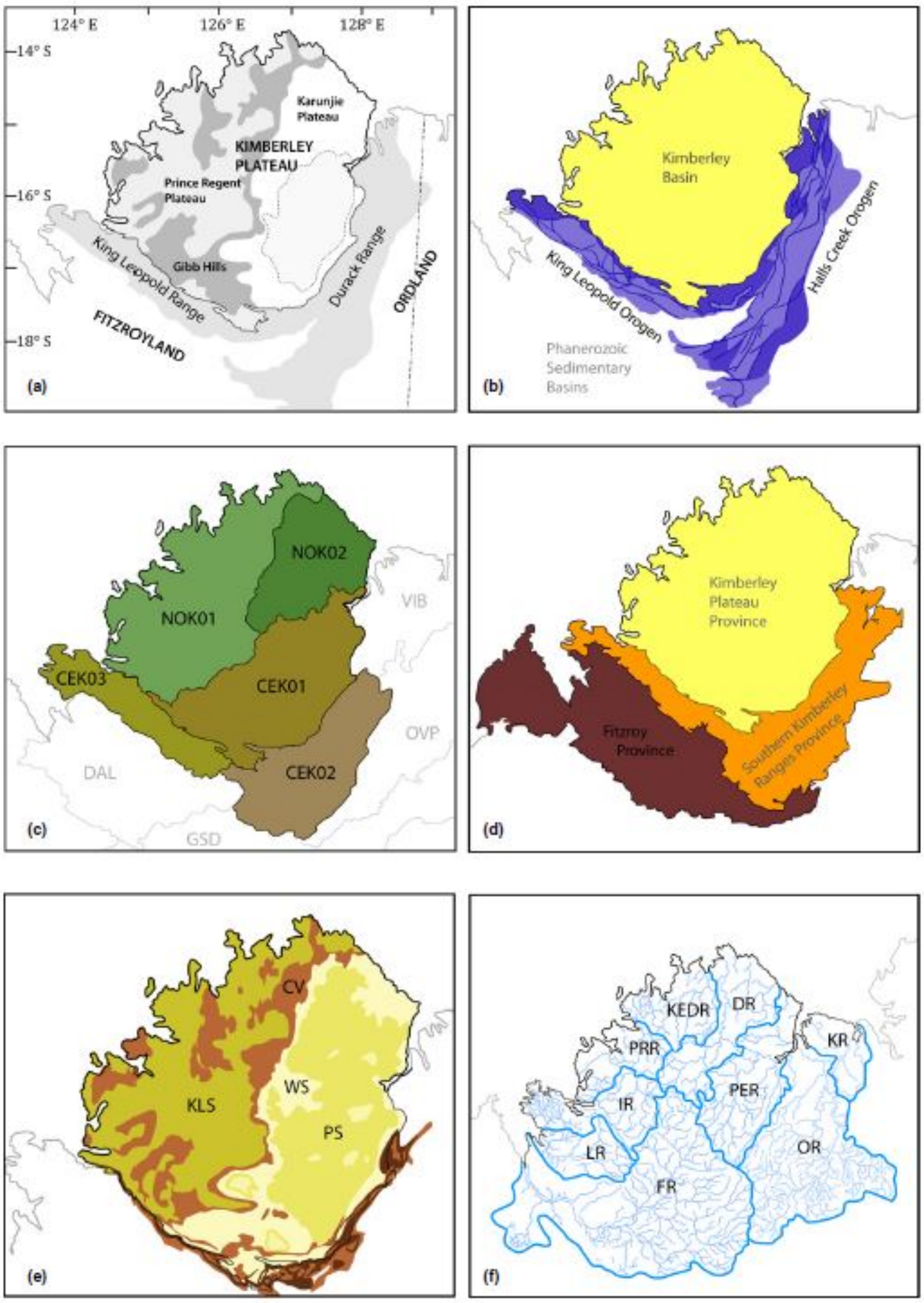


Figure 1.3 (a) Physiographical divisions of the Kimberley region. The dashed shape encloses the Durack River, Salmond River, and Bindoola Creek basins. The vertical dotted line represents the state border between Western Australia and the Northern Territory. (b) Tectonic units of the Kimberley. Coloured regions define the Kimberley region. (c) The boundaries of the two IBRA bioregions: North Kimberley (NOK) and Central Kimberley (CEK), with their subregions (NOK01-02 and CEK01—03). (d) Soil landscape provinces of the Kimberley. (e) Simplified geological map with rock units: PS (Pentecost Sandstone), WS (Warton Sandstone), KLS (King Leopold Sandstone) CV (Carson Volcanics). (f) Kimberley rivers and drainage basins: FR (Fitzroy River), LR (Lennard River, IR (Isdell River), PRR (Prince Regent River), KEDR (King Edward River), DR (Drysdale River), PER (Pentecost River), OR (Ord River), KR (Keep River). Figure taken directly from Pepper and Keogh (2014: Fig.2, 1446).

1.4 Palaeo-climate of the Kimberley Region

The climate systems and drivers which affect the Kimberley region operate on a much broader spatial scale than the region itself. This section summarises the palaeoclimate studies conducted within the broad zone of climatic influence affecting the Kimberley region, roughly between latitude East 105° to 140° and longitude South -5° to -30° (Figure 1.4). Temporally, this synthesis is bounded by human occupation of the continent, spanning the last 65 ka. This synthesis is not meant to be exhaustive, but rather, focuses on the most informative sequences in order to provide an essential palaeoclimate summary for exploring human-environment interaction in the Kimberley region.

1.4.1 Marine and coastal archives

Throughout the Quaternary, fluctuations in sea level are primarily the consequence of the expansion and retraction of ice sheets within glacial-interglacial cycles (Lambeck and Chappell 2001). The majority of available data pertaining to sea level fluctuations and the coastline migrations of northern Australia derives from geochemical, isotopic, microfossil analyses of marine records and geomorphological investigations of coastal ridges and estuarine deposits.

The most recent marine regression phase spans approximately 120 ka to 18 ka (Lambeck and Chappell 2001). Evidence from marine cores collected in the Bonaparte Gulf demonstrate that during this phase of marine regression, from approximately 60 ka to 32 ka, northern Australia's sea level oscillated between 50 and 90 m below present level, decreasing to 120 m below present level between 32 and 30 ka (Lambeck and Chappell 2001; Lambeck et al. 2002; Yokoyama et al. 2000; Yokoyama et al. 2001). This low stand persisted from 30 ka to 18 ka, with the height of the LGM (20.8—18.7 ka, Ishiwa et al. 2015) seeing the lowest sea level reaching close to 130 m below present level, with the palaeo-coastline reaching between 100 and 600 km out from the present coastline, creating an extensive exposure of land connecting Australia and New Guinea, known as Sahul (Figure 1.1; de Deckker and Yokoyama 2009; Shennan and Milne 2003; Yokoyama et al. 2000; Yokoyama et al. 2001). Novel landscapes, both coastal and inland, were produced by the recession of the coastline, such as the Bonaparte depression, an inner lagoon (Clarke and Ringis 2000; Ishiwa et

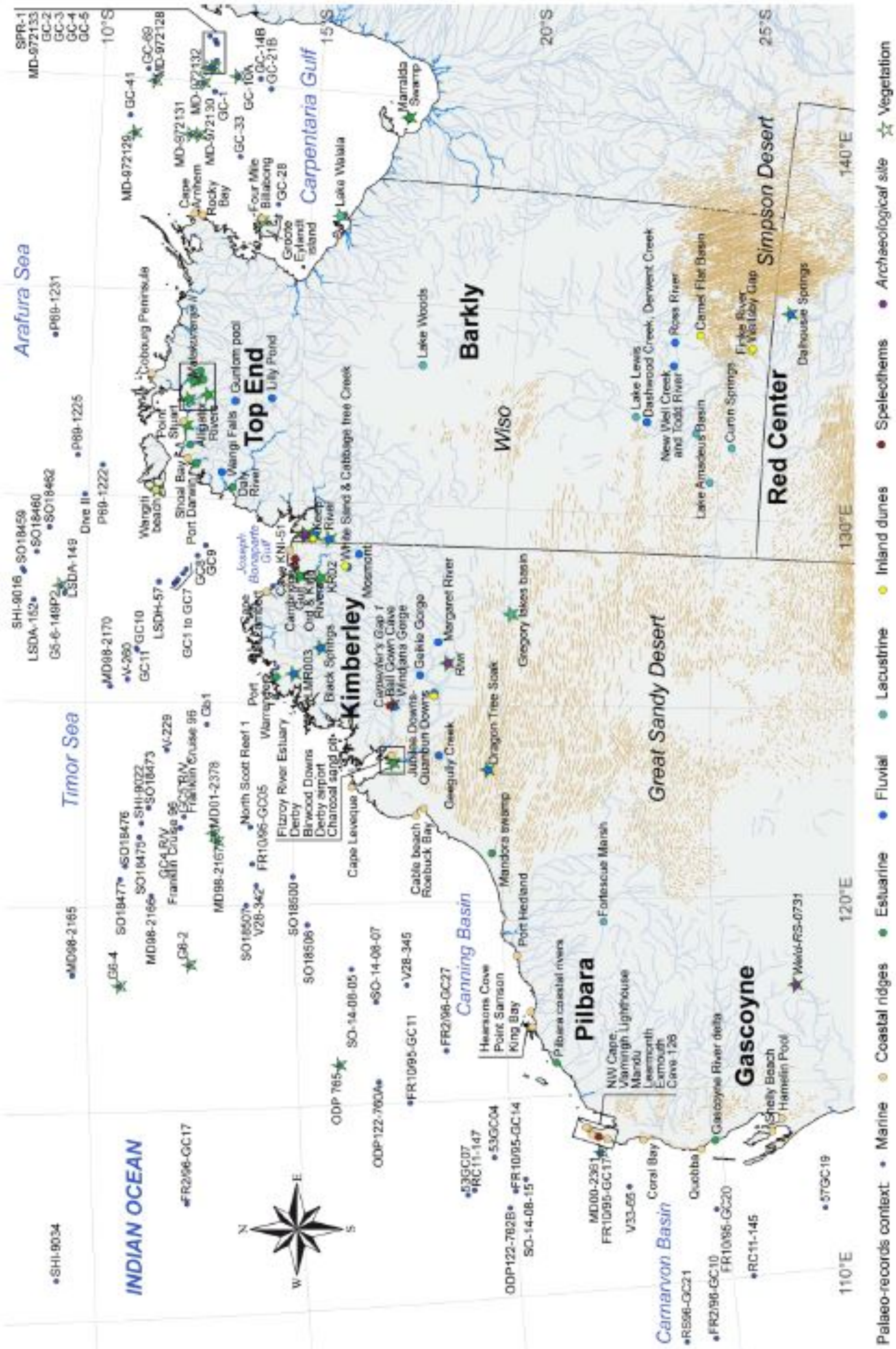


Figure 1.4 Palaeoenvironmental records of north west Australia, from Vannieuwenhuyse (2016: Fig. 2-12, 27).

al. 2015; van Andel et al. 1967; van Andel and Veevers 1967; Yokoyama et al. 2001), and palaeolakes like the Lake Carpentaria mega-lake phase from 42 ka to 12 ka (Chivas et al. 2001; Couapel et al. 2007; de Deckker et al. 1998; Devriendt 2011; Jones and Torgersen 1988; McCulloch et al. 1989; Reeves 2004; Reeves et al. 2007; Reeves et al. 2008; Torgersen et al. 1983; Torgersen et al. 1985; Torgersen et al. 1988; Yokoyama et al. 2001).

The marine transgression phase began around 18 ka, with deglaciation inducing a rapid sea level rise which markedly modified the north Australian coastline, with the Sahul continent conclusively dissolving into Australia and New Guinea by 10.4 ka, signaled by the return of inter-oceanic circulation within the Gulf of Carpentaria (Chivas et al. 2001; Reeves et al. 2008; Torgersen et al. 1988). Boulders and sand barriers formed along the northwest Australian coast by frequent, intense cyclones provides evidence for monsoon intensification during the mid- to late Holocene (Bryant 1992; Horne et al. 2014; Lees 1987, 1992a, 1992b, 2006; Lees and Clements 1987; Lees et al. 1990; Lees et al. 1992; Lees et al. 1995; Nott 2004, 2011; Nott and Bryant 2003; Scheffers et al. 2008). Modern sea level was attained by 7.4—6.5 ka (Griffiths et al. 2009; Lambeck et al. 2014; Lewis et al. 2013; Mohtadi et al. 2011; Stott et al. 2007; Wyrwoll and Valdes 2003; Xu et al. 2010), stabilizing, with some local differentiation, by around 1.4 ka (Lewis et al. 2013; Wyrwoll et al. 1995).

1.4.2 Terrestrial archives

The majority of inland archives within northwest Australia consist of coarsely dated records of aeolian, fluvial, and lacustrine deposition, with the key exception being the stable isotope records from speleothems collected from Ball Gown Cave and Cave KNI-51 in the Kimberley, and Cave C126 in the Pilbara (Figure 1.4; Denniston et al. 2013a, 2013b, 2013c).

Sedimentological and geomorphological studies of environments which are sensitive to moisture variability have enabled the broad reconstruction of certain climatic events in northern Western Australia. The modern playa systems of Australia's arid and semi-arid zones are the vestiges of mega lake systems such as Lake Amadeus (Chen et al. 1993), Lake Lewis (Chen 1997; English et al. 2001), the Gregory lakes catchment (Bowler et al. 2001), and Lake Woods

(Bowler et al. 1998; Hutton et al. 1984), which started to dry up as early as 1 Ma. Lakes Lewis and Amadeus in the arid zone were playa systems by 60 ka (Chen 1997; Chen and Barton 1991; Chen et al. 1990; Chen et al. 1995; English 2005; English et al. 2001), whereas Lakes Woods and Gregory in the semi-arid zone developed into semi-permanent lakes about 37—30 ka (Bowler et al. 2001; Bowler et al. 1998; Fitzsimmons et al. 2012). The Gregory lakes basin, which lies above the north-eastern margin of the Great Sandy Desert and below the monsoon shear line is the closest palaeo-lake to the Kimberley region (Figures 1.4, 1.5), and investigations of its strata are summarised below.

The modern Lake Gregory catchment covers over 65 000 km^2 and is comprised of five basins (Mulan, Bulbi, Yuenbi, Kurdu Kurdu and Rillyi Rillyi), which support a series of ephemeral lakes that range from fresh to brackish, and are connected by channels and floodplains. The Sturt and Djaluwon Creeks are the principal tributaries, flowing from north and south, respectively, with monsoonal precipitation accounting for 75-80% of the total annual rainfall, and monsoonal vigour determining lake levels in the catchment. Shoreline ridges, which are preserved above mean modern lake levels on the western periphery of the Lake Gregory system, reveal periods when the lakes were much deeper than at present, illustrating variation in monsoonal intensity and its southward penetration throughout the Late Quaternary (Bowler et al. 2001). Over the past 300 ka, TL ages of lacustral events preserved within shoreline ridges coincide with interglacial phases within marine isotope stages (MIS) 9, 7, and 5, while the development of longitudinal dune systems within the basin corresponds to glacial phases (MIS 8 and 6) of reduced monsoonal activity (Bowler et al. 2001). The lake system has been progressively regressing over the past 300 ka, with the last 'mega-lake' phase during MIS 5 (Bowler et al. 2001); however, pluvial deposits at Parnkurpirti Creek signify the extension of Lake Mulan ~50—40 ka (Veth et al. 2009). Following an inactive monsoon during the Last Glacial Maximum (LGM), radiocarbon dated lacustrine gastropods provide evidence for monsoon reactivation ~14 ka, a reactivation date which is further supported by a radiocarbon dated alluvial sequence in the Fitzroy basin (Wyrwoll and Miller 2001).

Fitzsimmons and colleagues (2012) developed a chronology of linear dune formation using optically stimulated luminescence (OSL) dating in conjunction with sedimentological and geomorphological analyses at two sites in the Lake Gregory catchment: Gidgee dune and Parnkupirti dune. While the resolution of the OSL chronology was too low to enable the detection of specific stages of dune activity, the authors use the OSL ages to approximate periods of increased aeolian activity, which they associate with cycles of relative aridity (Fitzsimmons et al. 2012). The Parnkupirti dune preserved the earliest phase of aeolian sedimentation, with the deposition of the dune's basal sediments dating to ~91.5 ka. Fitzsimmons and colleagues (2012) correlate this aeolian activity with rising aridity subsequent to the 'mega-lake' Gregory regression. Following the lake regression, sporadic dune reactivation ensued at both Gidgee and Parnkupirti between 35–11.5 ka, supporting other regional studies that suggest a weakened monsoon during the Last Glacial Maximum (LGM). At Gidgee dune there was a marked increase in sediment accumulation during the mid-Holocene, substantively greater than accumulation for the LGM, potentially indicating a distinct 'arid event'. Unfortunately, as Fitzsimmons and colleagues (2012) emphasise, there is currently not enough evidence to deduce whether this mid-Holocene "arid event" was more intense than the LGM, whether the event was operating at a local or regional scale, or if the marked sediment increase is an artefact of post-depositional processes.

The tropical north is largely devoid of dunes since the humid climate prevented their deposition even during LGM. A key exception to this is Wonnamarring, a solitary climbing dune of aeolian origin, located in the Carr Boyd Ranges, some 200 km north of the closest dune fields in the Great Sandy Desert (Figure 1.4; Wende et al. 1997). Wende et al. (1997) hand augered three sites along an east-west ridge of the climbing dune, in order to determine the stratigraphy and collect samples for thermoluminescence (TL) dating. The authors argue that orographically influenced local winds constructed the dune during relatively arid phases when vegetation cover in the valley (and the dune itself) was reduced (Wende et al. 1997). The lowest unit was deposited around 22 ka, and is directly overlain by 6 to 7 m of Holocene deposits spanning the last 6000 years, with the upper 3 to 4 m active within the last 500 years (Wende et al. 1997). Eight complementary TL dating samples were also taken from exposed alluvial sequences along the Cabbage Treek Creek bank, some 7km north-west of Wonnamarring, which indicate periods of enhanced fluvial activity and possible monsoon activation (Wende et al. 1997). The lower, fine-grained alluvial deposit yielded ages of 37.4 ± 6.1 and 37.0 ± 3.1 ka, and the upper sequence between 12.6 ± 1.0 and 5.3 ± 0.4 ka (Wende et al. 1997). At one of the sampling sites there is evidence for extensive overbank deposition during the early Holocene, and at another of the sampling sites there is evidence for significant fluvial activity in the mid-Holocene, ending at around 5 to 6 ka (Wende et al. 1997).

Published sedimentary sequences for the rest of the Kimberley region are restricted to the Holocene. Radiocarbon dated peat sequences from two swamps (Mandora Swamp and Dragon Tree Soak) and an alluvial deposit (Geegully Creek) on the western fringe of the Great Sandy Desert, reveal no significant break in deposition, indicating that hydrological conditions have remained relatively stable in the area in the past 6.5 ka (Figure 1.4; Wyrwoll et al. 1986; 1992). Wyrwoll et al. (1992) also argue, with caveats, that the lack of alluvial deposition during the early Holocene could indicate less surface water and more arid conditions during this time, at the southern limits of monsoonal influence.

These aeolian, fluvial, and lacustrine depositional sequences provide evidence for a dynamic terrestrial landscape during the late Quaternary in northern Western Australia. While the poor chronological control normally associated with geomorphological records is slowly decreasing with the application of OSL dating techniques, the records are still largely discontinuous, with limited temporal resolution. Additionally, sometimes these geomorphological records reflect local anomalies, rather than regional palaeoclimatic changes (e.g. Wyrwoll et al. 1992). Stable isotope profiles of speleothems can provide an archive of palaeoclimate change at much higher resolution (Hendy 1971); three such records are available for northern Western Australia (Denniston et al. 2013a, 2013b, 2013c, 2015).

Denniston et al. (2013a, 2013b, 2013c, 2015) have conducted stable isotope analyses on ^{230}Th dated stalagmites from three locations in northern Western Australia: cave C126 in Cape Range Peninsula in the Pilbara; Ball Gown Gave, close to Windjana Gorge National Park in the southern Kimberley region; and cave KNI-51 in the Ningbing Range in the eastern Kimberley (Figure 1.4). A stable oxygen isotope time series collated from six Ball Gown Cave stalagmites spans 40—31 ka and 27—8 ka (Denniston et al. 2013b). While the time series lacks the chronological control required to tie changes in $\delta^{18}O$ ratios to climatic events, the authors observe a variable, yet nonetheless active monsoon during the LGM (24—20ka), followed by pronounced shifts in the hydrologic regime between 16—13 ka (Denniston et al. 2013b). Fluctuations in stalagmite $\delta^{18}O$ values at Cave KNI-51 indicate an active monsoon between 7.5 and 4.5 ka, followed by an abrupt weakening of the monsoon around 4.2 ka, which is sustained until 1.2 ka, with a peak in aridity occurring between 1.5 and 1.2 ka (Denniston et al. 2013c). Wetter conditions, with evidence for small-scale variability, occur from 1.2 ka through to the present (Denniston et al. 2013c, 2015).

A more complex picture of palaeoclimate is offered by the cave C126 record, where combined stable oxygen and carbon profiles of stalagmites provide millennial-scale sensitivity that spans the LGM through to the mid-Holocene (Denniston et al. 2013a). The LGM is characterised by slow stalagmite growth, isotopically heavy $\delta^{18}O$ values, and average $\delta^{13}C$ values of -5‰; the deglaciation by faster stalagmite growth and lower $\delta^{18}O$ values from around 19 ka, with $\delta^{18}O$ ratios reaching a minimum between 17.5 and 16.0 ka, during which time $\delta^{13}C$ values stabilise. Denniston et al. (2013a) argue that the $\delta^{18}O$ minimum could be produced by a variety of factors, including an increase in rainfall from tropical cyclones; more numerous, stronger frontal systems; or enhanced monsoon activity caused by a southward penetration of the ITCZ. Regardless of which climate driver is responsible for the $\delta^{18}O$ minimum, the period between 17.5 and 16.0 ka seems to have been one of enhanced moisture in the region. The Holocene record is typified by rapid stalagmite growth and low $\delta^{18}O$ values, which reduce during the early Holocene and around 6.5 ka, shifts which probably reflect a more southerly ITCZ (Denniston et al. 2013a). Stable carbon isotope values decrease abruptly between 11 and 8 ka, suggesting an increase in plant cover, while unexpected low values around 6 ka could reflect more C_3 dominated vegetation following the high rainfall values of the early and mid-Holocene (Denniston et al. 2013a).

1.5 Reconstructing Vegetation in the Kimberley Region

The Kimberley region's high seasonality, in conjunction with a mean annual potential evapotranspiration of ~1900 mm per year (Bureau of Meteorology 2018) results in a water-limited environment. In this water-limited environment, water-bodies, the conventional archives of palaeo-environmental change, tend to be ephemeral and therefore the sediments are not consistently waterlogged and anaerobic, rendering the preservation of pollen, the classic proxy for vegetation change, unlikely. For example, in the East Kimberley, between the Ord and Victoria Rivers, Head and Fullagar (1992) sampled three swamps for pollen and charcoal analysis: Green Swamp, Coornamu Swamp, and Marralam Billabong (Figure 1.5). Marralam Billabong, which is a permanent water source, is nonetheless a poor pollen catchment as it is part of a drainage line in the wet season. Pollen recovered from the Green and Coornamu Swamp cores was highly eroded, which the authors attribute to habitually fluctuating water levels that did not entirely evaporate from about 2.1 ka at Coornamu and from about 1 ka at Green Swamp (Head and Fullagar 1992). The authors conclude that both aeolian deflation in the dry season and scouring during monsoonal flooding limits the number of suitable palynological catchments in the region (Head and Fullagar 1992).

The deposits of Carpenter's Gap 1 rockshelter (henceforth CG1) in the Oscar-Napier Range revealed exceptional botanic preservation, particularly within the Holocene units (Figure 1.5; Balme 2000; Dilkes-Hall 2014; McConnell 1997, 1998; McConnell and O'Connor 1998). Macrobotanic (McConnell 1997, 1998; McConnell and O'Connor 1998), anthracological (Edgar 2001; Frawley 2009; Frawley and O'Connor 2010), and phytolith (Wallis 2000, 2001) analyses were conducted at Carpenter's Gap 1 rockshelter. The anthracological analyses (Edgar 2001, Frawley 2009) are explored in Chapter 2 of this thesis. McConnell (McConnell 1997, 1998; McConnell and O'Connor 1998) analysed the macrobotanical record from Square A of the CG1 excavation, in which nearly 2500 plant fragments were recovered. There are several issues with the macrobotanic record, including over-identification of fragmented Poaceae and Cyperaceae stems (Wallis 2000), the misidentification of *Vitex* seeds as *Ampelocissus acetosa* (India Dilkes-Hall pers. comm.), and the association of certain plants with incorrect vegetation communities or water requirements

(Wallis 2000). In her interpretations, McConnell focuses (McConnell 1997; McConnell and O'Connor 1998) on reconstructing palaeoenvironmental changes throughout the occupational sequence, and while the known ethnobotanic uses of various plants are listed, human agency is not included in the discussion of the assemblage. Similarly, the explication of preservational issues is fragmentary and conflicting (cf. Wallis 2000). The following summarises the integrated macrobotanic and phytolith records presented by Wallis (2000, 2001), which acknowledges many of the issues inherent in the macrobotanic record. The phytoliths recovered from CG1 are mostly derived from macropod faeces, and as such, provide evidence for local vegetation change, rather than human exploitation of plants (Wallis 2000, 2001).

During Phase 1 (43—34 ka) of CG1's occupation, the presence of palm phytoliths, which are restricted to areas of higher rainfall, and occur rarely in the southern Kimberley (Beard 1979), monsoon rainforest taxa (seeds and phytoliths), which have a relatively high water requirement, and Cyperaceae remains (seeds, stems, phytoliths), reflect a higher rainfall regime (Wallis 2000, 2001). The Phase 2 (34—22 ka) phytolith record indicates a gradual decrease in water availability from Phase 1, with an increase in arid-adapted spinifex alongside a decline in wet-tolerant grasses and palms absent from midway through Phase 2. Wallis (2000, 2001) argues that the presence of Cyperaceae remains (seeds, stems, phytoliths) and monsoon rainforest taxa (phytoliths only) during this period indicates that in spite of this gradual aridification, there was still semi-permanent water available within relatively close proximity to the site.

The integrated archaeobotanical record from Phase 3, which encompasses the LGM, indicates both increased aridity, with spinifex dominating the phytoliths alongside the potential addition of the xerophytic *Eriachne* grass and Chenopodiaceae seeds appearing in the macrobotanics, and the persistence of water availability, with the presence of a small component of monsoon rainforest taxa (phytoliths and seeds) and the incorporation of diatoms and sponge spicules amongst the biogenic silica. Wallis (2000, 2001) argues that in accordance with regional palaeoclimatic archives, the LGM was a more arid phase, and that the increase in diatoms and sponge spicules, alongside the presence of monsoon rainforest taxa, signified that people were carrying water into the cave during the drier phase of the LGM. During CG1's final occupation phase in the Holocene, large quantities of monsoon rainforest taxa (phytoliths and seeds) indicate both higher rainfall and better preservation conditions (Wallis 2000, 2001). A more effective precipitation regime is supported by a reduction in spinifex phytoliths concurrent with an increase in wet-tolerant grass phytoliths.

With the exception of the archaeological sites Carpenter's Gap 1 rockshelter and Riwi cave, there are no analysed terrestrial archives of botanical remains older than ~15 ka in the Kimberley region. Marine cores offer a long record of regional vegetation change at broad, coarse timescales. For example, marine cores extracted from the Australian northwest shelf show an increase in Poaceae (grasses) and inferred aridification from the Cainozoic through to the terminal Pleistocene (Figure 1.4; Hope et al. 2004; Kawamura et al. 2006; Kershaw and van der Kaars 2012; Kershaw et al. 2006; Martin and McMinn 1994; van der Kaars 1991; van der Kaars et al. 2000; Wang et al. 1999). Pollen analysis of marine core FR10/95-GC17, extracted 60 km from the north-western tip of Australia, show a shift from Eucalypt woodland to Chenopod shrub land between ~40 and 37 ka on the neighbouring mainland, a shift which is argued as evidence for drier conditions (Figure 1.5; van der Kaars and de Deckker 2002). This aridity is intensified in the LGM, with low pollen concentrations reflecting an overall diminution of vegetation cover between 35 ka and 20 ka (Kawamura et al. 2006; Kershaw and van der Kaars 2012; van der Kaars 1991; van der Kaars and de Deckker 2002; van der Kaars et al. 2000). This trend is supported by stable carbon isotope analysis of bulk sediment samples from two augers collected in the Gregory lakes basin (Pack et al. 2003). The combined carbon isotope record illustrates a general regional trend towards aridity during the Quaternary; from less water stress during the C3 trees and shrubs phase to the more arid tolerant C4 grasses' phase, beginning around 30 ka (Pack et al. 2003).

The appearance of mangrove taxa in marine archives around 14 ka, peaking in the mid Holocene, reflects the "Big Swamp" phase of Australia's northern tropical coast (Kawamura et al. 2006; Kershaw and van der Kaars 2012; Kershaw et al. 2006; van der Kaars and de Deckker 2002); however, the vegetation and geomorphological history of these mangrove forests is better explained from coastal and alluvial archives. Along the northwest coast, particularly within the

Top End of the Northern Territory, large alluvial floodplains were superseded by extensive mangrove forests, linked to a sea level high stand of ~1.5 m above modern levels produced by enhanced precipitation, between 9.5 ka and 7.4 ka (Figure 1.4; Chappell 1993; Clark and Guppy 1988; Mulrennan and Woodroffe 1998; Murray et al. 1992; Nanson et al. 1993; Prebble et al. 2005; Reeves et al. 2013b; Wang and Chappell 2001; Wasson 1992; Wasson et al. 2010; Woodroffe 1990; Woodroffe et al. 1985; Woodroffe et al. 1987; Wyrwoll et al. 1995). The mangrove forests retreated to be replaced by flood plain wetlands and freshwater lagoons, from around 4 ka, due to more arid, unstable climate conditions (Clark and Guppy 1988; Fujiwara et al. 1985; Hope et al. 1985; Moss et al. 2015; Nanson et al. 1993; Prebble et al. 2005; Roberts 1991; Shulmeister 1992; Shulmeister and Lees 1995; Wasson 1992; Woodroffe et al. 1987), producing a range of landforms and erosive environments that are not conducive to the preservation of natural or cultural archives (Rowland 1999; Rowland and Ulm 2012; Ward et al. 2013).

In the Kimberley, this mid-Holocene high stand is visible in macrotidal barriers deposited in Broome (Figure 1.5; Lessa and Masselink 2006), but invisible within the sedimentary stratigraphies of King Sound (Figure 1.5; Jennings 1975) and Cambridge Gulf, with the geomorphological and pollen evidence from the latter illustrating an earlier mangrove phase from 9.5 ka to 7.5 ka (Figure 1.5; Proske 2016; Proske et al. 2014; Thom et al. 1975). Because of this variation, some authors have argued that hydro-isostatic adjustments and changes to sediment supply from enhanced precipitation are also responsible for the greater mangrove expansion; not just a sea level high stand (Chappell 1974; Jennings 1975; Lambeck and Nakada 1990; Proske 2016; Proske et al. 2014). At King River and Parry Lagoon in the Cambridge Gulf, mangroves contracted between 7.4 ka and 6.3 ka, with mangrove diversity decreasing after 6.3 ka, which was most likely caused by the stabilization of the sea level (Proske 2016; Proske et al. 2014). Hypersaline mudflats, indicative of drier conditions, also developed along the King River at this time (Proske 2016). An increase in effective precipitation around 1 ka produced the conditions in which the Parry Lagoon wetlands were established, some 600 years ago (Proske 2016).

Further inland, there are only three published pollen records from the region: a 300-year record from the Mitchell River floodplain (Connor et al. 2017); Dragon Tree Soak which spans the last 6.5 ka (Figure 1.5; Pederson 1983; Wyrwoll et al. 1992; Wyrwoll et al. 1986); and Black Springs which spans the last ~15 ka (Figure 1.5; Field et al. 2017; McGowan et al. 2012). A sediment core was collected from a small waterhole (MP 11A) on the Mitchell River floodplain, along with surface sediment samples (Connor et al. 2017). The core was dated using both ^{210}Pb and ^{14}C methods, producing an age-depth model that spans the last 300 years, with geomorphological and palynological analyses conducted on the sediments (Connor et al. 2017). The results show that vegetation around the site has changed substantially in the last 100 years since European contact: the pollen record shows a decrease in riparian and non-grassy savanna tree canopy and an increase in grasses, which is accompanied by geochemical and biological indicators for increased grazing, differential fire regimes, erosion, and eutrophication of the MP 11A waterbody (Connor et al. 2017). By contrast, at Dragon Tree Soak, the preliminary pollen record supports the geomorphological evidence that very little changed at the swamp in the last 6.5 ka (Pederson 1983; Wyrwoll et al. 1992; Wyrwoll et al. 1986).

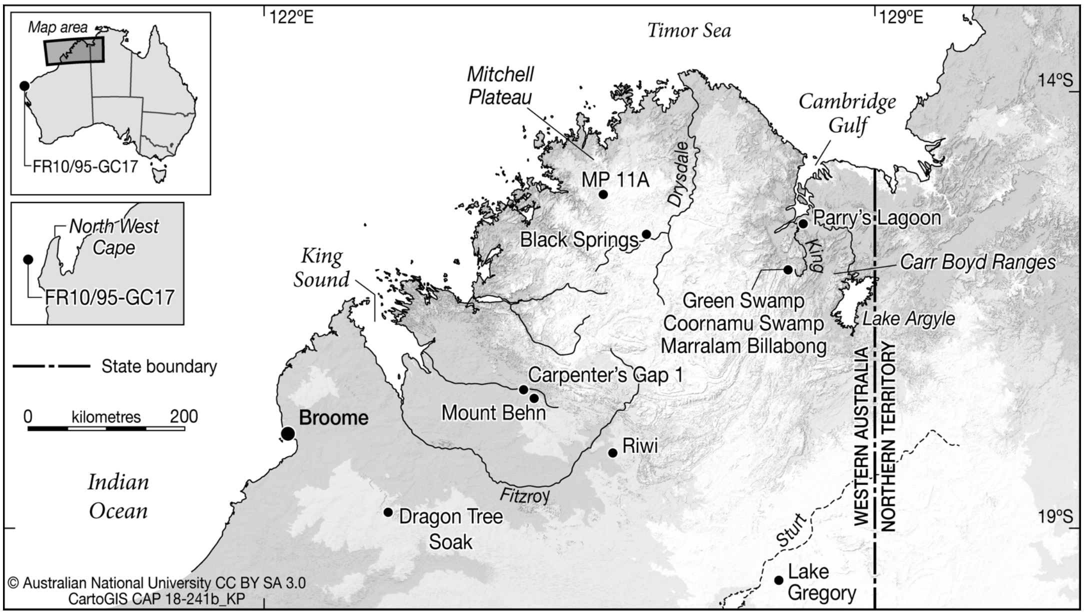


Figure 1.5 Palaeovegetation sites in the Kimberley region with inset of marine core FR10/95-GC17 off the Pilbara coast, CAD CartoGIS, Australian National University

Black Springs is an organic, minerotrophic peat mound spring located in the Kimberley's northwest (Field et al. 2017; McGowan et al. 2012). A 1.68 m long core spanning the last ~15 ka was subsampled for pollen, microcharcoal, loss on ignition (LOI), and humification analyses (Field et al. 2017), following the presentation of preliminary pollen results for the last ~6 ka (McGowan et al. 2012). Five surface pollen samples were also collected across four vegetation zones from the top of the mound to the savanna grassland (Field et al. 2017). Based on increases in both spring pollen taxa from ~14 ka and organic content from ~13 ka, the authors argue that precipitation increased within the northwest Kimberley from ~14 ka (Field et al. 2017). The early Holocene is characterised by rapid peat growth and an increase in spring vegetation cover, with organic content and spring surface wetness increasing from ~9.6 ka (Field et al. 2017). Pollen, LOI, and humification data suggest an active monsoon and stable conditions throughout the mid Holocene until ~5 ka (Field et al. 2017; McGowan et al. 2012). A sharp decline in organic content, increased aeolian sedimentation, a shift in vegetation with lower aquatic species, and the lowest humification values for the core illustrate the driest phase for the record between 2.6 and 1.3 ka (Field et al. 2017; McGowan et al. 2012). Humification data indicate a wet phase between 1.3 and 1.0 ka, followed by a drier phase between 1.0 and 0.5 ka, with modern conditions achieved in the last 550 years (Field et al. 2017).

1.6 People of the Kimberley Region

1.6.1 Aboriginal people in the Kimberley region today

The effects of European colonisation on the Aboriginal cultures of Australia were devastating. In the Kimberley region, pastoralism was introduced in the 1870s, drastically altering the socio-economic lifeways of the Indigenous peoples. The Kimberley is largely rugged and remote; however, which, combined with the relatively late introduction of permanent European settlement, enabled the maintenance of certain facets of the Aboriginal socio-cultural world, such as the adaptation of rock art practices (e.g. O'Connor et al. 2013), resistance to the European regime (e.g. Jandamarra, cf. Nicholson 1997) and the

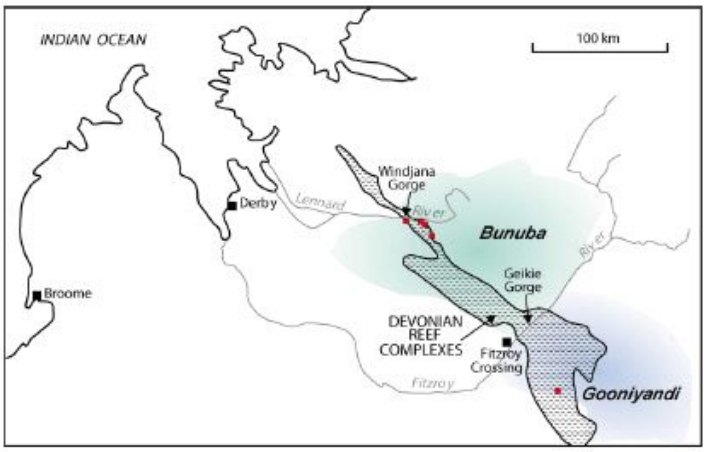


Figure 1.6 Bunuba and Gooniyandi language groups and location of Lifeways Project sites (in red), over the Devonian reef complex. Figure taken directly from Vannieuwenhuyse (2016, Fig. 2-18, 42).

retention of some languages. The Lifeways Project is located within the traditional lands of the Bunuba and Gooniyandi peoples, who differ from each other in language and cultural and artistic traditions (McGregor 1990). Figure 1.6 illustrates the broad territories of the Bunuba and Gooniyandi language groups (Horton 1996).

1.6.2 History of archaeological research in the Kimberley region

Western investigations of the rock art of the Kimberley region began in the early 19th century (Bradshaw 1982; Grey 1841), with these and subsequent researchers archiving the diverse corpus of pictographs (paintings, stencils, prints) and petroglyphs across the region (Akerman 2016; Brockman 1902; Crawford 1968; Elkin 1930; Mulvaney 2013; Playford 1960; Veth et al. 2016; Walsh 1994, 2000; Welch 1990, 1993a, 1993b). Four Australian Research Council Projects are currently underway that are dedicated to the dating of Kimberley and Northern Territory rock art through the application of AMS radiocarbon dating of pigment organics, mud-wasp nests, and oxalate-rich mineral crusts; OSL dating of mud-wasp nests; Uranium-Thorium dating of carbonates and sulphate-rich mineral crusts; and cosmogenic radionuclide dating of boulder scars (Veth et al. 2016). At the time of writing this thesis, the chronology of the Kimberley region's rock art is comprised of stylistic superimposition, examination of weathering, and a few key, occasionally controversial ages (Watchman 1987, 1993, 2000; Roberts et al. 1997; Aubert 2012).

Stratified archaeological inquiry did not commence in the Kimberley region until the 1970s, with the salvage excavation and survey of sites before the damming and flooding of the man-made Lake Argyle in the former Ord River valley (Figure 1.7; Dortch 1972, 1977; Dortch and Roberts 1996), and the investigation of sites in the southern Kimberley (Blundell 1974, 1975). Coastal archaeological research began in the Kimberley in the late 1980s (Figure 1.7; Table 1.1; O'Connor 1996, 1999a; O'Connor and Veth 1993; O'Connor and Sullivan 1994; Veitch 1996, 1999a, 1999b), followed by excavations in the southern Kimberley along the Oscar-Napier range in the 1990s and early 2000s, which uncovered the deep antiquity of human occupation in the region that extends back to 45—49 ka at Riwi, Carpenter's Gap 1, and the coastal site Widgingarri (Figure 1.7; Table 1.1;

Balme 2000; O'Connor 1995; O'Connor and Veth 2006). At around the same time, a Holocene rockshelter in the southern Kimberley (Figure 1.7; Table 1.1; Harrison 2000, 2002, 2004; Harrison and Frink 2000; Harrison et al. 2006) and more extensive excavations in the Keep River region in the north-eastern Kimberley were conducted (Figure 1.7; Table 1.1; Atchison et al. 2005; Fullagar et al. 1996; Galbraith et al. 1999; Head and Fullagar 1992, 1997; Roberts et al. 1999; Ward 2003, 2004; Ward and Larcombe 2003; Ward et al. 2005). More recently, the Australian Research Council funded two research projects to investigate the archaeology of the region, "Change and Continuity", led by June Ross and the late Mike Morwood in the northern Kimberley, and "Lifeways of the First Australians" in the southern Kimberley.

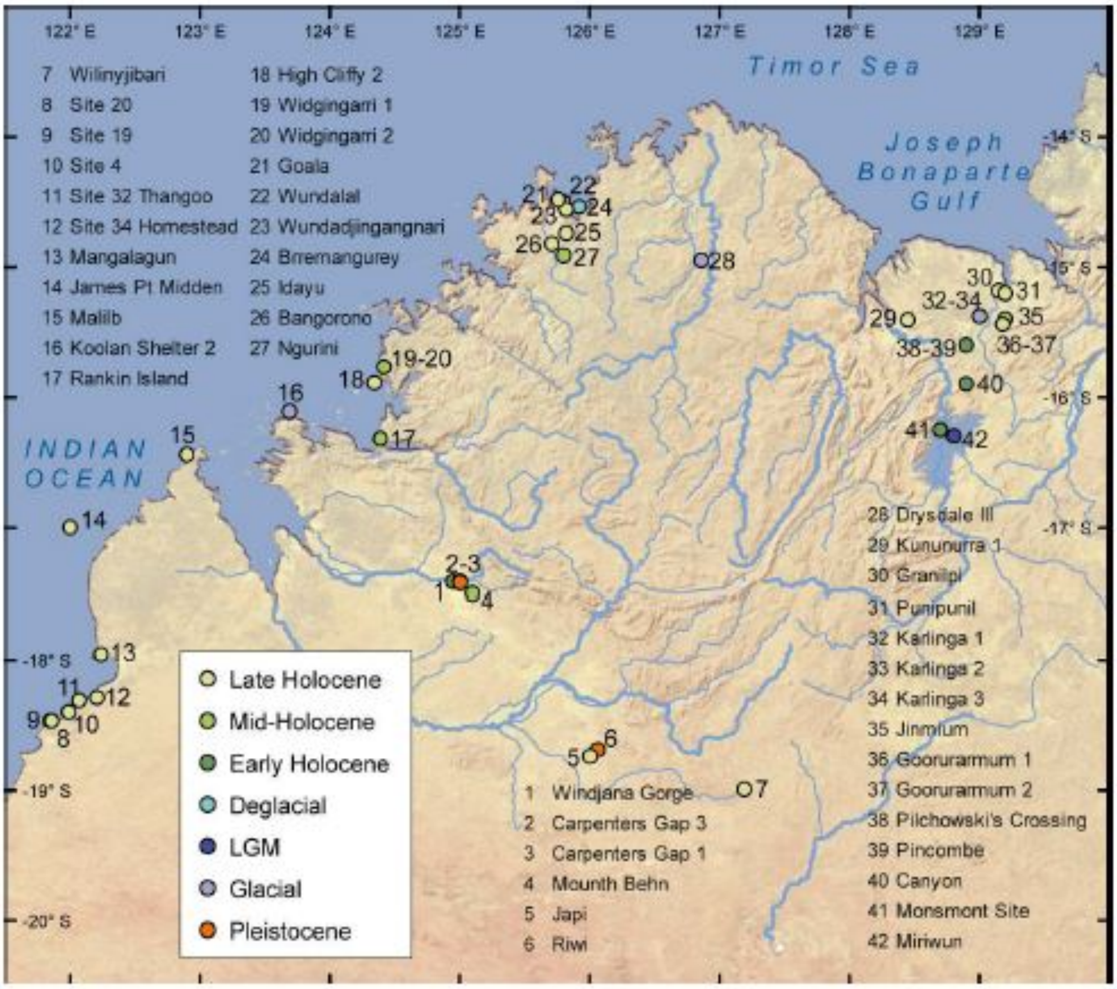


Figure 1.7 Location of archaeological excavation sites in the Kimberley region, taken directly from Vannieuwenhuyse (2016, Fig. 2-19, 45)

1.6.3 Summary of human occupation in the Kimberley region

The archaeological record of Pleistocene northern Australia is associated with highly mobile groups who were symbolically and technologically innovative

(Franklin and Habgood 2007; Habgood and Franklin 2008, 2010). For example, evidence for the world's oldest edge-ground stone tool technology was recovered from Carpenter's Gap 1 in the Kimberley, dated by association to 44—49 ka (Hiscock et al. 2016), with a later example dated by association to 33 ka recovered from the neighbouring Carpenter's Gap 3 (O'Connor et al. 2014). Balme and O'Connor (2014) maintain that edge-ground technologies afforded their users a suite of flexible applications, ideal for colonising new environments and exploiting novel resources. A complex relationship with plants is evident in both starches recovered from grinding implements elsewhere in northern Australia (Hayes 2015) and the suite of botanical motifs depicted in the rock art galleries of the Kimberley region (Veth et al. 2016).

Pleistocene rock art of the Kimberley encompasses two styles: Pecked Cupules, which represent the earliest "colonising repertoire" and have recently yielded terminal Pleistocene ages (Green et al. 2015), and Irregular Infill Animal Style, of which South East Asian examples are dated to 36 ka (Aubert et al. 2014). These early rock art styles are associated with an open information exchange system, emerging territoriality, and the mapping of resources (Veth et al. 2016; Walsh 1994, 2000; Welch 1990, 1993, 2007). In terms of plant association, grinding hollows are found in association with 25% of the pecked cupules, and plant motifs are painted in association with 25% of Irregular Infill Animal sites (Figure 1.8; Veth et al. 2016). Grass imprints are possibly found in association with pecked cupules and in 38% of Irregular Infill Animal sites with plant motifs (Figure 1.8; Veth et al. 2016).

The Last Glacial period (30—18 ka), and particularly the LGM (22—18 ka), induced significant environmental changes across the Australian continent. A popular model, based on a diminution of archaeological evidence and sedimentation in arid Australian sites during this time, is a reduction in population density, with people becoming more sedentary and focussing on ecological refugia such as coastal zones and permanent inland water bodies (O'Connor and Veth 2006; Smith 2013; Veth 1989, 1995; Williams 2013; Williams et al. 2013; Williams et al. 2015a). Recent authors have recognised that diverse taphonomic factors have produced these depositional hiatuses (Hiscock and Wallis 2005; O'Connor and Veth 2006; Przywolnik 2005; Smith 2013; Smith et al. 2008;

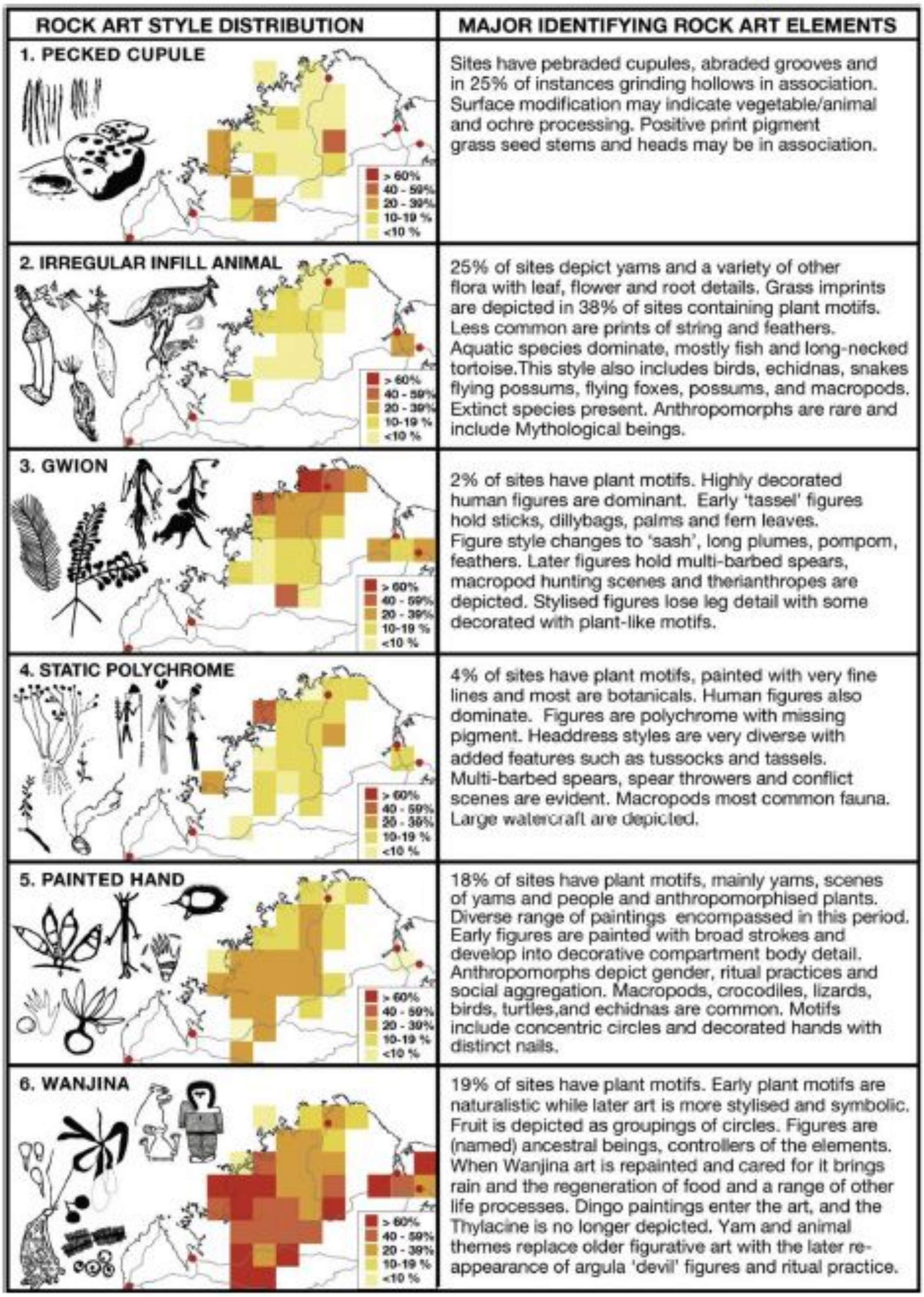
Williams et al. 2013, 2015b), but still define broad regional occupational patterns from small rockshelter excavations (cf. Langley et al. 2011) without geoarchaeological investigation of the chrono-stratigraphic sequence.

Table 1.1 List of archaeological excavation sites in the Kimberley with associated references, numbers refer to Figure 1.6, adapted from Vannieuwenhuyse (2016, Table 2-2, 47).

No	Site	Sources
1	Djuru/Windjana Gorge Water Tank Shelter	Maloney et al. 2016; O'Connor et al. 2008; Vannieuwenhuyse 2016
2	Carpenter's Gap 3	O'Connor et al. 2014; O'Connor and Veth 2006; Vannieuwenhuyse 2016; Vannieuwenhuyse et al. 2016
3	Carpenter's Gap 1	Edgar 2001; Frawley 2009; Frawley and O'Connor 2010; Langley et al. 2016; McConnell 1997, 1998; McConnell and O'Connor 1998; O'Connor 1995; Vannieuwenhuyse 2016; Vannieuwenhuyse et al. 2016; Wallis 2000, 2001
4	Mount Behn rockshelter	Maloney et al. 2017; Vannieuwenhuyse 2016; **Whitau et al. 2018, In Review (this thesis)**
5	Japi	Balme 2000
6	Riwi	Balme 2000; Balme and Morse 2006; Langley et al. 2016; Vannieuwenhuyse 2016; **Wood et al. 2016, Whitau et al. 2016a, 2016b, 2017, In Review (this thesis)**
7	Wilinyjibari	Harrison and Frink 2000
8	Site 20	O'Connor 1999b; O'Connor and Veth 1993; Veth 1995
9	Site 19	O'Connor 1999b; O'Connor and Veth 1993; Veth 1995
10	Site 4	O'Connor 1999b; O'Connor and Veth 1993; Veth 1995
11	Site 32 Thangoo	O'Connor 1999b; O'Connor and Veth 1993; Veth 1995
12	Site 34 Homestead	O'Connor 1999b; O'Connor and Veth 1993; Veth 1995
13	Mangalagun	O'Connor 1999b; O'Connor and Veth 1993; Veitch 1999a; Veth 1995
14	James Pt Midden	O'Connor 1999b; O'Connor and Veth 1993
15	Malilb	O'Connor 1999b; Smith 1987; Veth 1995
16	Koolan Shelter 2	O'Connor 1989, 1996, 1999a
17	Rankin Island	O'Connor et al. 2007
18	High Cliffy 2	O'Connor 1999a, 1999b; O'Connor and Sullivan 1994; Veth 1995
19	Widgingarri 1	O'Connor 1996, 1999a, 1999b
20	Widgingarri 2	O'Connor 1996, 1999a, 1999b
21	Goala	O'Connor 1999b; Veitch 1996, 1999a; Veth 1995
22	Wundalal	Veitch 1996; Veth 1995
23	Wundadjingangnari	Veitch 1996, 1999a, 1999b; Veth 1995
24	Brremangurey	Koppel et al. 2016; Szabo et al. 2015
25	Idayu	O'Connor 1999b; Veitch 1996; Veth 1995
26	Bangorono	Veitch 1996; Veth 1995
27	Ngurini	Veitch 1996; Veth 1995
28	Drysdale 3	Morwood and Hobbs 2000; O'Connor and Veth 2006
29	Kununurra 1	Dortch 1977; Veth 1995
30	Granilpi	Atchison 2009; Atchison et al. 2005
31	Punipunil	Atchison 2009; Atchison et al. 2005
32	Karlinga 1	Ward 2003, 2004; Ward et al. 2005; Ward et al. 2006
33	Karlinga 2	Ward 2003, 2004; Ward et al. 2005; Ward et al. 2006
34	Karlinga 3	Ward 2003, 2004; Ward et al. 2005; Ward et al. 2006
35	Jinmium	Atchison 2009; Atchison et al. 2005; Fullagar et al. 1996; Galbraith et al. 1999; Roberts et al. 1999; Ward et al. 2005; Ward et al. 2006
36	Goorurarmum 1	Ward 2003, 2004; Ward et al. 2005; Ward et al. 2006
37	Goorurarmum 2	Ward 2003, 2004; Ward et al. 2005; Ward et al. 2006

38	Pilchowski's Crossing	Bowdler and O'Connor 1991; Veth 1995; Ward et al. 2006
39	Pincombe	Bowdler and O'Connor 1991; Dortch 1977; Veth 1995; Ward et al. 2006
40	Canyon	Dortch 1977; Veth 1995; Ward et al. 2006
41	Monsmont Site	Dortch 1977; Dortch and Roberts 1996
42	Miriwun	Dortch 1977, 1986; Dortch and Roberts 1996

Figure 1.8 Distribution of the six major Kimberley rock art styles with characteristics of iconography, taken directly from Veth et al. (2016, Fig. 2, 3).



Vannieuwenhuyse (2016), combining her geoarchaeological analyses of five sites (Carpenter's Gap 1, 3; Djuru; Mount Behn rockshelter; Riwi) with a detailed reinvestigation of regional chrono-stratigraphic sequences, has convincingly demonstrated that there is no corroboration between these depositional hiatuses and site abandonment, supporting theories posited from elsewhere in Australia (Fanning et al. 2007; Holdaway et al. 2005; Hughes et al. 2014; Ward and Larcombe 2003). In Chapter 4, the combined anthracological and micromorphological analyses of an LGM hearth excavated from Riwi explores these issues in greater detail.

There appears to be minimal diversification of the stone tool kit from 49 ka through to the Pleistocene-Holocene transition, despite the vast tracts of land lost to sea level rise ~18 ka. Excavated faunal assemblages from Kimberley coastal sites; however, reveal the relationship between human economies and the Pleistocene-Holocene transition from inland to coastal environments with the commencement of the marine transgression phase (O'Connor 1996). In the northern Kimberley, the Gwion Gwion artistic tradition, a distinctive anthropomorphic style (Walsh 1994, 2000), might appear as early as 17 ka (Roberts et al. 1997), if the highly contended OSL age from a mud-wasp nest is indeed accurate. Gwion Gwion figures are not depicted in the southern Kimberley, but have a broad geographical range from the King Leopold Ranges across to the Northern Territory (Taçon et al. 1999) that may have been more expansive in the past, including areas now inundated by the Timor and Arafura Seas (Lewis 1988), which could represent an extensive, open information network system (Veth et al. 2016). While only 2% of Gwion Gwion figures are associated with plant motifs, the figures themselves are depicted with a diverse range of material culture, some of which, such as digging sticks, dilly bags, and fern leaves, are clearly plant-based (Figure 1.8; Veth et al. 2016).

The Australian archaeological record of the mid- to late Holocene is described as a period of intensification; characterised by increases in cultural discard, innovations in technologies, exploitation of novel resources, greater use of peripheral environments, and an accretion of evidence for long-distance exchange and external contact (e.g. Beaton 1982; Bowdler 1981; Cosgrove et al. 2007; David 2002; Flood 1980, 1999; Godwin 1997; Haberle et al. 2010;

Lourandos 1980, 1983, 1988, 1993, 1997). From fish traps to the proliferation of new stone tool types, these changes have been interpreted as responses to, and/or effects of: different site preservation, changing resource availability, population increase, and social change (cf. Ulm 2013 and references therein). Sedimentation in caves and rockshelters in northern Australia tends to be comprised of the slow accumulation of more natural inputs during the Pleistocene, shifting to more rapid sedimentation during the Holocene with more anthropogenic inputs (e.g. Atchison et al. 2005; Clarkson 2007; Jones 1985). While this sedimentation shift has been associated with changes in human occupation intensity (e.g. O'Connor et al. 1999), Vannieuwenhuyse (2016) clearly shows that this is not a linear relationship. This phenomenon is discussed in greater detail in Chapters 4 and 7 of this thesis.

The intensification of the mid- to late Holocene is often aligned to increased climatic variability and seasonal inconsistencies, with sustained changes trending towards aridification and inferred phases of resource abundance and depletion (Kershaw and van der Kaars 2012). For example, in northern Australia, reduction based analyses of stone tool assemblages have aligned changes in stone tool reduction strategies during the Holocene with adaptation to increasing aridity and inferred foraging risk (Clarkson 2002, 2007; Hiscock 1994, 2006; Hiscock and Veth 1991; Maloney et al. 2014; Maloney and O'Connor 2014; O'Connor et al. 2014). Direct percussion points are a highly adaptable technology that allows for the maintenance and recycling of tools, which first appear in the southern Kimberley between 5.6—5.3 ka at Carpenter's Gap 3 (Maloney et al. 2014; O'Connor et al. 2014), peaking in discard and reduction rates at Mount Behn rockshelter, between 2.8—1.8 ka, which Maloney et al. (2017) associate with the mid- to late Holocene arid phase commencing ~4 ka. Pressure-flaked points, unique to the Kimberley cultural record (appearing in the Northern Territory in the 1930s) and often termed "Kimberley Points" emerge in the last 1000 years, and are associated with the adoption of new projectile technologies around this time (Maloney et al. 2014).

The Holocene deposits of northern Australia tend to preserve organic remains better, which is particularly evident at both CG1 (McConnell 1997; McConnell and O'Connor 1998; Wallis 2000, 2001) and Riwi (Dilkes-Hall 2014; Chapters 3, 4, and 7 of this thesis). In the eastern Kimberley, Atchison et al. (2005) present macrobotanical analyses from three Holocene rockshelter sites: Jinmium, Granilpi, and Punipunil in the Keep River region, which is the only archaeobotanical investigation for the Kimberley other than the Carpenter's Gap 1 record and those conducted within the Lifeways Project. The authors found an abundance of charred and fragmented *Persoonia falcata* and *Buchanania obovata* seed remains from ~3.5 ka, which align with ethnographic records and modern Aboriginal practices of processing whole fruits into pastes and cakes (Atchison et al. 2005). After the arrival of pastoralism to the area, artefacts continue to be deposited at the rockshelters, but *P. falcata* and *B. obovata* seeds are absent (Atchison et al. 2005). Additionally, while *B. obovata* trees are abundant in the modern landscape, *P. falcata* trees are absent except for in areas where traditional Aboriginal landscape management practices have been re-established, clearly demonstrating the impact of such practices on the distribution of certain species (Atchison 2009).

Three styles of rock art are described in the Kimberley for the Holocene period: Static Polychrome, Painted Hand, and Wanjina (Figure 1.8). Certain attributes of the Static Polychrome style, which is associated to the early Holocene 14—9 ka, are shared across the Kimberley into western Arnhem Land, signifying long-distance exchange across a broad area (David et al. 2017; Lewis 1988). Like the Gwion Gwion figures, the Static Polychrome style is mostly anthropomorphic, depicted with a diverse suite of material culture, some of which, such as spearthrowers, are obviously plant-based. Only 4% of Static Polychrome figures are painted in association with plant motifs, whereas 18% of Painted Hand figures (9—5 ka) are associated with plants, which are predominantly yams and anthropomorphised plants. The Wanjina style, which appears in the last 5 ka, 19% of which is associated with plant motifs, is complex, with high stylistic heterogeneity possibly reflecting the marking of territorial boundaries (Veth et al. 2016).

1.7 Summary

The archaeological record of the Kimberley region, which, with the exception of several coastal shell middens (O'Connor 1999b; O'Connor and Veth 1993; Veitch 1996), is currently restricted to cave and rockshelter sites, extends back to 46—

49 ka at Riwi, Carpenter's Gap 1, and Widgingarri (O'Connor 1995; O'Connor and Veth 2006; O'Connor et al. 2014; Vannieuwenhuyse et al. 2016; Wood et al. 2016). The people who colonised this region arrived with a diverse tool kit, which they adapted across both space and time to exploit a diverse, fluctuating resource base. During the past 50 ka, the climate affecting the Kimberley region has undergone dramatic changes (summarised in Figure 1.9), with two major events, the LGM and its subsequent deglaciation, drastically affecting environments, vegetation, and people. The limiting factor for vegetation in the Kimberley region is effective precipitation, and the contraction and expansion of certain vegetation systems is tied to the strength and geographical range of the summer monsoon. While a broad synthesis of regional palaeo-climate patterns is available, our understanding of how vegetation and people adapted to these climate changes over the past 50 ka is restricted by the limited recovery of botanical remains from both palaeoenvironmental and archaeological archives. Responses of both plants and people to regional climatic events need to be explored at relevant, local spatio-temporal scales in order to understand human-environment interaction throughout the Kimberley's occupation history.

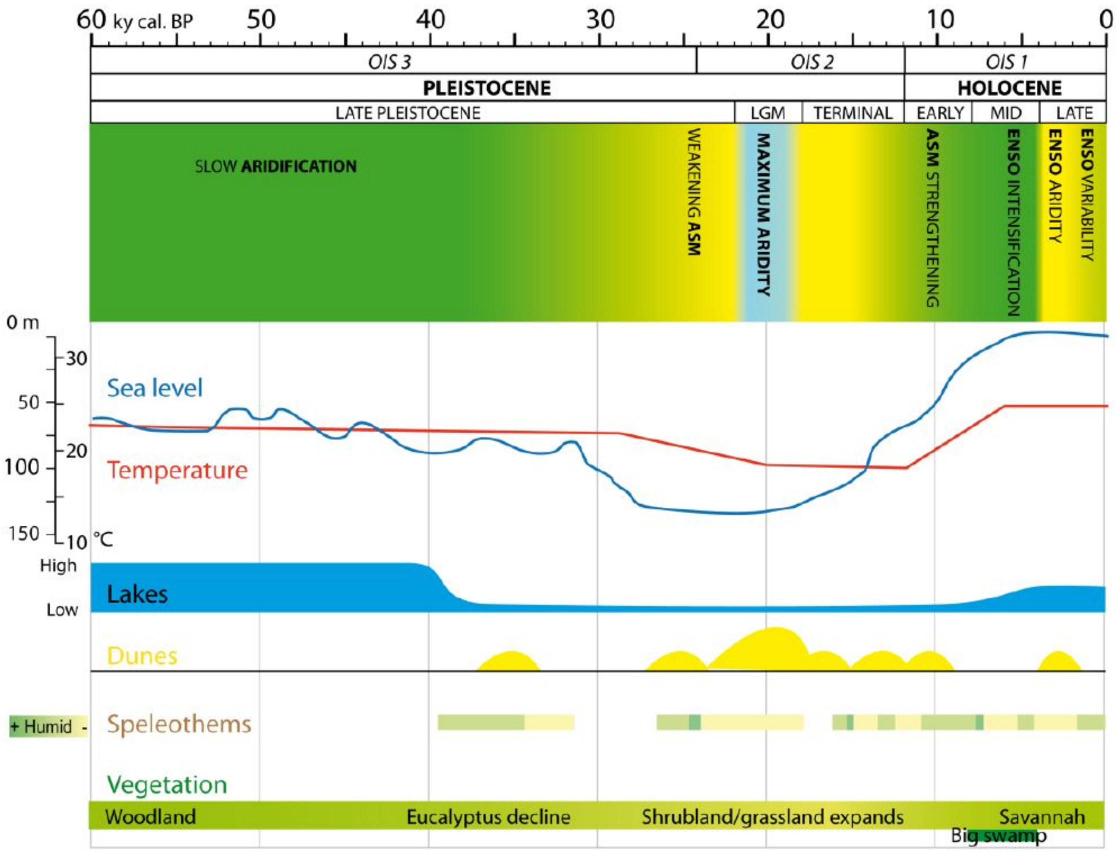


Figure 1.9 Main palaeoenvironmental data and palaeo-climate trends from north west Australia during the last 60 ka, taken directly from Vannieuwenhuyse (2016, Fig. 2-16, 41).

1.8 Thesis Structure

This thesis is a “Thesis by Compilation”, wherein the thesis is comprised of both chapters that have been submitted as independent research papers to peer-reviewed academic journals (Chapters 3—7), and an exegesis: Chapters 1, 2, and 8, which have not been submitted elsewhere. Following the ANU guidelines for “Thesis by Compilation” (Appendix A), Chapters 3—7 are styled and formatted in accordance with the requirements of the journal to which they are submitted, and signed authorship declarations detail the contribution of each author at the beginning of each of these chapters. Chapters 3—6 are published and Chapter 7 is under review. References cited within Chapters 1, 2, and 8 are presented in a single reference list after Chapter 8, before the appendices. All references cited within submitted chapters are listed at the end of each individual chapter.

Chapter 1 has introduced the rationale and aims for this thesis and provided background information on the Kimberley region. The two main aims of this thesis are (1) to explore late Quaternary human-environment interaction at two archaeological sites in Bunuba and Gooniyandi country, and (2) to develop the application of archaeobotanical analyses in Australia. This introductory chapter outlined the palaeo-environmental and archaeological investigations conducted in the region to date in order to provide essential context for the aims of this research, by establishing our current understanding of human-environment interaction in the region and identifying gaps in the literature. The rest of the chapter outlines the structure of the thesis and describes how the aims will be achieved.

Chapter 2 describes the methods used in this research and situates the selected methods within the Australian and International literature in order to identify key methodological issues and explicate the rationale for the application of these methods. In particular, the collation and creation of the Bunuba-Gooniyandi wood charcoal reference collection is described and the materials used as reference for pollen analysis are introduced. Sampling techniques in the field and laboratory are presented in greater detail than the submitted chapters. The key theoretical precepts of the anthracological discipline and its status in Australia are examined, alongside a brief review of the current state of archaeobotanical analysis in Australia, which is explored in order to provide the necessary context for the second thesis aim. Finally, novel methods, including the application of X-ray microtomography and the analysis of pollen from cave sediments are defined, but an attempt has been made to complement, rather than repeat the methods presented in Chapters 5 and 7.

Chapters 3 and 4 present the results of anthracological analyses conducted at Riwi. Chapter 3, **Wood charcoal analysis at Riwi cave, Gooniyandi country, Western Australia**, reconstructs Riwi's local woody vegetation throughout the site's occupation through analysis of charcoals excavated from non-combustion feature contexts, and compares this local reconstruction with broader palaeo-climatic and palaeo-environmental records. Chapter 4, **Home is Where the Hearth Is: Anthracological and Microstratigraphic Analyses of Pleistocene and Holocene Combustion Features, Riwi Cave (Kimberley, Western Australia)**, combines the anthracological and micromorphological analysis of Riwi's combustion features and compares these results with the non-combustion feature assemblages presented in Chapter 3, in order to infer changes in the technological use of fire, fuel resource management practices, and occupation intensity through time. The combined anthracological and micromorphological analyses enable the proposal of a typology of combustion feature types and a definition of their chronology, which have important archaeological and methodological implications for both Australian and International archaeology that are discussed at the end of the chapter.

Chapter 5, **X-ray computed microtomography and the identification of wood taxa selected for archaeological artefact manufacture: Rare examples from Australian contexts**, identifies the wood taxa used to produce two wooden implements recovered from Riwi: the negative component of a fire drill and an artefact fragment. While showcasing the archaeological application of X-ray microtomography, the chapter also draws on archaeobotanical analyses presented in Chapter 3 and Dilkes-Hall (2014) in order to show that the past inhabitants of Riwi selected certain woods for specific purposes at least within the last 1000 years of the site's occupation. In particular, the paper argues that wood from the genera *Grevillea* and *Hakea* were avoided as fuel as they were an important resource for tool making.

Chapter 6, **The curious case of Proteaceae: macrobotanical investigations at Mount Behn rockshelter, Bunuba country, Western Australia**, presents the results of anthracological and macrobotanic analyses conducted at Mount Behn rockshelter. Neither the wood charcoal nor macrobotanic records are representative of the local species richness, precluding both the reconstruction of local vegetation and an in depth exploration of resource management and use. Certain taxa are over-represented, in particular *Celtis* spp. endocarps and wood charcoal from the Proteaceae family. The taphonomy of seeds and wood charcoal is explored in depth, and a regional picture is drafted to explain the differential management of Proteaceae wood resources at Mount Behn rockshelter and Riwi.

Chapter 7, **Three archaeobotanical proxies, two archaeological sites: complexities of human-environment interaction in Bunuba and Gooniyandi country, Kimberley region, Western Australia**, presents the results of palynological analyses conducted on Holocene deposits at Mount Behn rockshelter and Riwi, alongside summaries of anthracological and macrobotanic analyses published elsewhere (Chapter 3, 4, 6, and Dilkes-Hall 2014). Pollen is poorly recovered from Riwi but well-preserved at Mount Behn rockshelter. In this chapter, the taphonomy and representativeness of each of the three proxies is explored in depth and the benefits of multi-proxy analysis discussed. The results are compared with broader palaeo-climatic and palaeo-environmental archives in order to provide a synthesis of human-environment interaction during the Holocene.

In the final chapter, Chapter 8, the major findings of this research are evaluated alongside the research aims presented in the introduction.

Chapter 2. Methods

2.1 Introduction

Multi-proxy archaeobotanical analyses are infrequently conducted in Australia, despite their obvious benefits: different proxies can capture a broader spectrum of botanic remains across divergent taphonomic pathways, providing a more comprehensive picture of human-environment interaction. This research aims to showcase how multi-proxy archaeobotanical research can be successfully adapted to different Australian archaeological contexts. Wood and pollen were selected as appropriate proxies due to their reproducibility: 1) wood charcoal is ubiquitous in the Australian archaeological record, and 2) the history of palynology in Australia has led to the development of reference material that spans most of the continent. Wood and pollen from archaeological deposits are complementary in that wood burned is an artefact of both human and environmental processes, whereas pollen provides a predominantly environmental signature. This thesis also includes the discussion of results from other archaeological subdisciplines conducted within the Lifeways Project, namely geoarchaeology (Chapters 4, 6, and 7) and carpology (Chapters 6 and 7). The collaborations between specialists working on the Lifeways Project has enabled a rigorous sampling strategy and comprehensive exploration of the material remains, which is discussed in depth in Chapters 4, 7, and 8.

Wood is a versatile resource that can be burned as fuel or manipulated to produce material artefacts of varying shape and purpose. An organic material which degrades easily, wood can only survive the rigours of the archaeological record via desiccation, waterlogging, mineralisation, and charring. Desiccated, waterlogged, and mineralised wood require specific, consistently anaerobic conditions (see Haneca et al. 2012; Rowell and Barbour, 1990 for detailed discussions of wood degradation processes), which while not uncommon, tend to be less global than the preservation of wood burned in hearths and other types of anthropogenic fireplaces. For example, various wooden utensils have been recovered from Acheulean deposits, such as a swamp context in Kalambo Falls in South Africa (Clark 1982) and Viking shipwrecks have been preserved in the Baltic Sea (Einarsson 1987; Fors and Björdal 2012). Whereas the total number of recovered wooden artefacts from the arid Australian continent is less than 100 fragments, the oldest of which was recovered from Wyrie Swamp and is associated with a date of 12.4—11.3 ka (Luebbers 1975; see summary in Chapter 5). Desiccated wood shavings and two wooden artefacts were recovered from Riwi: the negative end of a firedrill, or hearth stick, and the fragment of a wooden artefact.

Charred wood, or charcoal, is relatively inert and ubiquitous in the archaeological record. The systematic recovery of charcoal, the identification of its woody taxon, and its subsequent analysis within the context of human-environment interaction is a subdiscipline of archaeobotany, termed anthracology (Darvill 2008; Scheel-Ybert 2018). Anthracological analyses can be used to explore human-environment interaction in the past, since the identification of woody taxa recovered from archaeological contexts provides evidence for both the reconstruction of local woody vegetation and the management of fuel wood resources. In semi-arid and arid environments, such as the southern Kimberley region, water-bodies, the conventional archives of palaeo-environmental change, tend to be ephemeral. The sediments are not therefore consistently waterlogged and anaerobic, rendering the preservation of pollen, the classic proxy for vegetation change, unlikely. In these situations, anthracological assemblages can provide an invaluable alternative source of palaeo-environmental data Anthracological principles, which are discussed in depth in Section 2.2.1, form the foundations of this thesis, and the bulk of the analysis presented in the result chapters are concerned with the analysis of wood charcoal recovered from Mount Behn rockshelter and Riwi, particularly Chapters 3, 4, and 6.

Whatever the means of preservation, wood must be identified by the comparison of microscopic anatomical features from three planes within the xylem: transverse, tangential longitudinal, and radial longitudinal (Figure 2.1). With charcoal, it is very simple to section the wood by snapping the fragment with the hands or with the aid of a scalpel’s pressure (Leney and Casteel 1992), and to observe the anatomical features with a reflected lightfield/darkfield microscope and/or a Scanning Electron microscope (SEM). Uncharred wood is traditionally more complicated, requiring physical sectioning and thin section mounting in order to be observed with an SEM or Transmitted Light microscope (TEM). Alternatively, X-ray microtomography, which is non-destructive and expedient, can be utilised to explore wood’s internal anatomy, and this method, which is discussed in Chapter 5, was selected for the analysis of the two Riwi wooden artefacts.

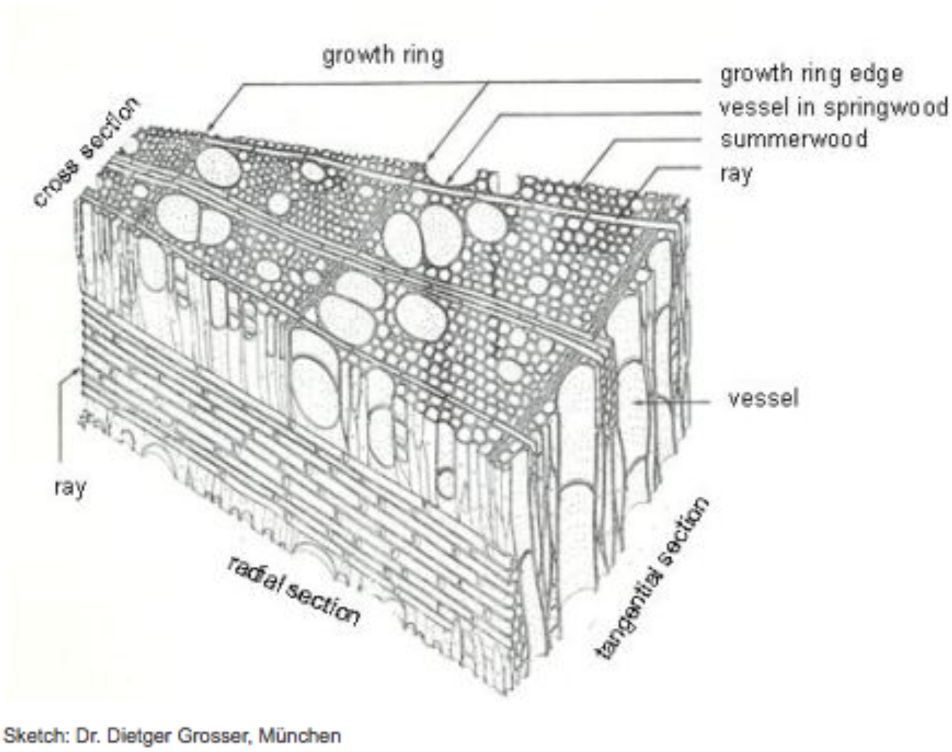


Figure 2.1 Transverse (cross section), radial longitudinal, and tangential longitudinal sections of hardwood secondary xylem, CAD Dietger Grosser (http://www.wolman.de/en/infocenter_wood/from_tree_to_wood/wood_properties/aufbau_der_laubhoelzer/index.php)

The microscopic features of archaeological wood internal anatomy need to be compared with those of living taxa. The identification of both charred and desiccated woody taxa undertaken here is made by comparison with the Bunuba-Gooniyandi reference materials, a collection of 71 taxa (Appendix D). A wood atlas presenting the anatomical descriptions of these taxa (Appendix D), was created by the author specifically for this thesis. The methods used to produce the Bunuba-Gooniyandi reference collection are outlined in Section 2.3.1, with the field notes appendixed (Appendix C).

Wood charcoal was initially selected to reconstruct local vegetation changes at the two sites; however, taphonomic biases, which are discussed in detail in Chapter 6, prevented the use of the Mount Behn anthracological record for vegetation reconstruction. An alternative archaeobotanical proxy was sought to address the research aims. Pollen was selected because of the author's prior knowledge and experience in palynological research, because pollen had preserved in the Mount Behn archaeological sediments, and because extensive reference materials are available that span most of the continent, so an additional reference collection did not need to be created. The Australasian Pollen and Spore Atlas <http://apsa.anu.edu.au/> is housed at the ANU in the Department of Archaeology and Natural History at the ANU, which manages both the online database and physical collections. Additionally, pollen is a suitable complement for wood charcoal analysis, capturing the non-wood producing plants such as the herbaceous taxa. Unlike wood charcoal from archaeological contexts, which is an artefact of both the local environment and human decision making processes, pollen tends to represent a more ecological signature, and so pollen cannot be used on its own to explore human behavior in an archaeological context. Each of these proxies has its own set of deposition, preservation, and ecological representation biases, with specific methodological tools and taphonomic analyses developed to better control these (see Nelle et al. 2010 and Chapter 7 for relevant discussion).

The following presents the tenets of anthracological methodology (Section 2.2.1), summarises the anthracological work conducted in Australia to date (Section 2.2.2), outlines the creation of the Bunuba-Gooniyandi wood charcoal reference collection (Section 2.3.1; see also Appendix C for target taxa list and field notebook), and the collation of relevant palynological reference material (Section 2.3.2). Excavation and laboratory methods are not duplicated here, but can be found for Riwi in Chapters 3 and 4, and for Mount Behn rockshelter in Chapter 5. Appendices D and E present images and descriptions of the wood charcoal and pollen reference collections respectively. The pollen reference collection is predominantly the cumulative work of the Archaeology and Natural History department at the Australian National University. While the author of this thesis has made contributions to this database for both this thesis and research assistant work, individual contributions are indistinguishable on the database. Appendices F and G present images of the archaeological wood charcoal and pollen types respectively.

2.2 Anthracology

2.2.1 Anthracological methodology

A sub-discipline of archaeobotany, anthracology is the systematic investigation of wood charcoal assemblages recovered from stratified contexts, which enables both the reconstruction of woody vegetation and the exploration of palaeoethnobotanical practices (Vernet 1973, 1992; Chabal 1992, Chabal et al. 1999). Commencing in Europe in the 1940s (Balout 1952; Couvert 1968, 1969a, 1969b; Godwin and Tansley 1941; Salysbury and Jane 1940), charcoal analysis developed rapidly as an archaeobotanical tool with the advent of reflected light microscopy, which greatly expedited the identification of wood charcoal taxa (Leney and Casteel 1975; Stieber 1967, 1969; Vernet 1972, 1973; Western 1971; Western et al. 1963). However, the discipline lacked a robust methodology until the rigorous and systematic research of the University of Montpellier in the early 1980s (Badal-Garcia 1992; Chabal 1982, 1988, 1990, 1992, 1994, 1997, 1991; Fabre 1996; Figueiral 1992; Figueiral and Willcox 1999; Grau Almero 1992; Heinz 1990; Heinz et el. 1992; Théry-Parisot 1998, 2001; Thiébault 1980, 2002; Vernet 1992). Wood charcoal analysis had been used to reconstruct woody vegetation since the first charcoal studies (e.g. Salysbury and Jane 1940), although this stirred much controversy (e.g. Godwin and Tansley 1941). It was mainly Lucie Chabal (1997) and then Isabelle Théry-Parisot and colleagues (see references below) who established and are continuously refining the methodological framework for achieving palaeoecological representativeness from anthracological assemblages, as discussed below in relation to sampling protocols.

Of course, the relationship between an anthracological diagram and past vegetation is not linear. There are many successive filters that can potentially affect the ecological representativeness of an anthracological diagram, which have been correlated to three phases of information transfer (Figure 2.2; Chabal et al. 1999; Théry-Parisot et al. 2010a). First, the transfer between past vegetation and the wood put to fire, either on-site in the case of bush fires, or off-site in the case of firewood collection for archaeological contexts. Second, the transfer between the wood put to fire and the charcoal assemblage recovered by excavation, from combustion, depositional, and post-depositional processes. Third, the transfer from excavation to analysis via sampling protocols. The third phase of information transfer can be controlled by a rigorous sampling methodology. The first two phases of information transfer must be explored through experiments and theoretical models (e.g. Asouti 2012; Chrzazvez et al. 2014; Dufraisse 2012, 2014; Goldstein and Shimada 2013; Paradis et al. 2013; Picornell-Gelabert et al. 2011; Salavert and Dufraisse 2014; Théry-Parisot et al. 2010a).

In archaeological contexts, the first phase of information transfer is the various socio-cultural factors which influence the decisions that people make in selecting, avoiding, randomly sampling, and managing fuel woods. The first theoretical model applied to the question of human practices is the Principle of Least Effort (PLE), which states that people collected fuel in proximity to the site, and that all species were collected in direct proportion to their occurrence within the environment (Chabal 1991; Prior and Price-Williams 1985; Shackleton and Prins 1992). As first pointed out by Shackleton and Prins (1992), PLE is an ecologically utilitarian paradigm that oversimplifies the complex interplay between a myriad of socio-ecological and economic factors that influence fuelwood management decisions. More nuanced models of fuel procurement have since been developed (e.g. Asouti and Austin 2005; Dufraisse 2011; Marston 2009; Picornell-Gelabert et al. 2011).

The natural and socio-cultural factors which affect firewood management practices can be divided into those which influence energetic needs (culture, settlement, and hearth function) and those which influence resource availability (environmental context, biomass, wood accessibility, and the properties of the available fuel) (Figure 2.3; Théry-Parisot et al. 2010a). The settlement, including factors such as duration of occupation, group and site size, will affect the required fuel load. The energetic needs of the group will be influenced by the group's culture and social organisation, for example, knowledge of wood resources and the technology used to collect fuel will influence the decisions that people make in selecting and avoiding certain taxa (e.g. Ramos et al. 2008), and ideological factors such as perceptions of the environment and taboos might cause the avoidance of certain taxa or vegetation communities (e.g. Byrne et al. 2013; Dotte-Sarout 2010; Dufraisse 2012, 2014; Henry et al. 2009; Lucena et al. 2007).

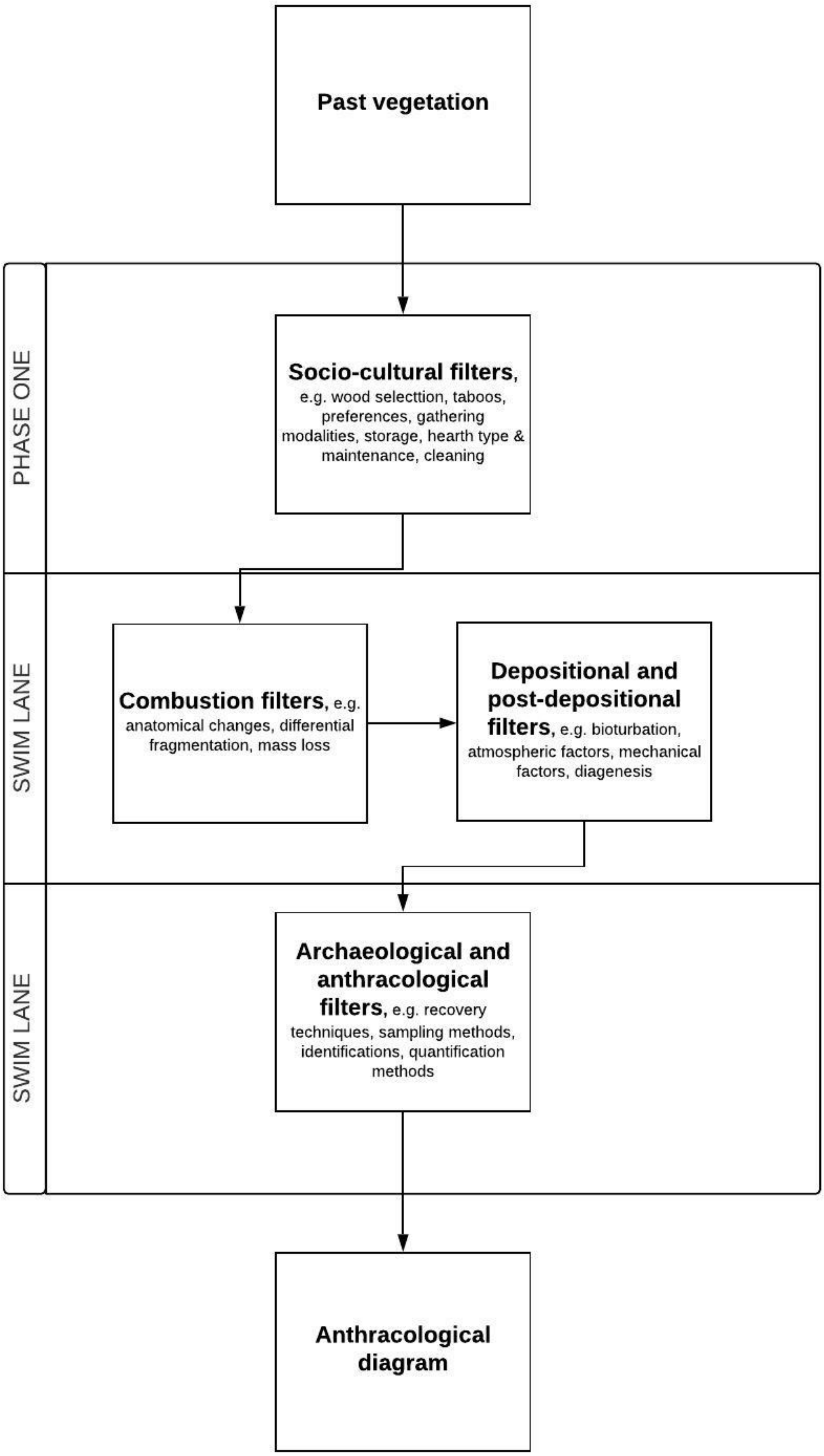


Figure 2.2 Three phases of information transfer acting on anthracological assemblages, adapted from Théry-Parisot et al. (2010a: Fig.1, 143).

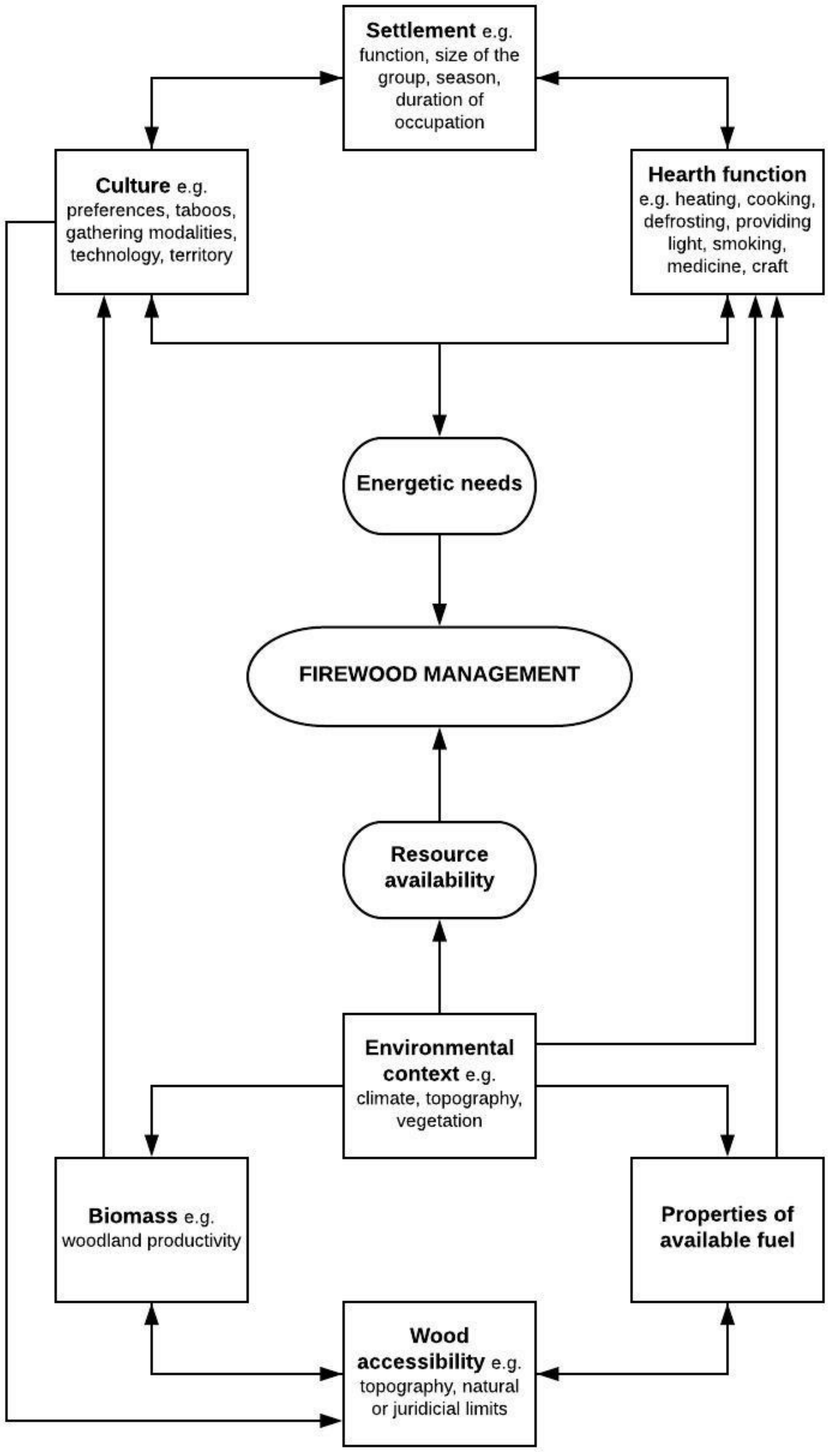


Figure 2.3 The natural and socio-cultural factors governing firewood management, adapted from Théry-Parisot et al. (2010a: Fig.4, 146).

The social organisation of the group, its subsistence practices, and how fuelwood collection fits in with other daily activities will affect the frequency and intensity of fuel wood collection (Asouti 2012; Dufraisse 2012; Dufraisse et al. 2007; Picornell-Gelabert et al. 2011; Salavert and Durfaisse 2014; Scheel-Ybert and

Dias 2007). The function of the fire (e.g. cooking, heating, medicine, craft production, funeral) for which the wood has been gathered also plays an integral role in the degree of selectivity of wood taxa, and in both the amount of wood required and the type of woods selected depending on various characteristics (e.g. smoke, smell, burning time, socio-cultural meanings, state of the wood) (Beauclair et al. 2009; Ford 1979; Huebert et al. 2010; Picornell-Gelabert et al. 2011; Ramos et al. 2008; Scheel-Ybert et al. 2014). In conjunction with the socio-cultural factors which influence a settlement's energy needs, resource availability is also affected by environmental context (such as climate change or people impacting/managing vegetation, e.g. Asouti and Kabukcu 2014; Dufraisse 2012), the availability and accessibility of the wood biomass (e.g. Asouti 2003; Deforce and Haneca 2015), and the properties of that available fuel, such as the wood's condition (cf. Dotte-Sarout 2010; Dufraisse 2012; Henry et al. 2009; Théry-Parisot 2002a, 2002b).

Once gathered, the wood put to fire is subjected to the second phase of information transfer, which can be divided into two successive processes: the combustion filter of the fire itself, and the depositional and post-depositional factors influencing the preservation of the archaeological assemblage. The combustion factors are comprised of heat source and wood property variables (Braadbaart and Poole 2008), which can alter the quantity of wood put to fire through mass loss and fragmentation (Loreau 1994; Rossen and Olsen 1985; Scott and Jones 1991; Vaughan and Nichols 1995). On a global scale, the wood structure of charcoal remains mostly unaffected by combustion processes, allowing for the anatomical elements within wood charcoal to be observed and compared to wood atlases. Combustion can cause some anatomical deformations, such as retraction, fusion, or cracks, which can prevent identification (see Chapter 6 for an in depth discussion; Beall et al. 1974; Jane 1956; Mac Ginnes et al. 1971; McParland et al. 2007; Metcalfe and Chalk 1950; Moore et al. 1974; Prior and Alvin 1983; Prior and Gasson 1993; Rossen and Olson 1985; Thinon 1992; Schweingrüber 1978; Zicherman 1981).

The Law of Fragmentation states that charcoal will fragment over time (during the various taphonomic processes) into a large number of small fragments and a smaller number of large fragments, and that fragmentation is driven by extrinsic factors, not the species of the wood (Chabal 1988, 1992). The extrinsic factors include combustion, depositional, and post-depositional factors which create fragmentation, since in anthracology the assemblage has been subjected to each of these processes. From a combustion perspective, recent experimental work by Chrzazvez et al. (2014) has demonstrated that the combustion processes that affect charcoal fragmentation are a bit more complex than the Law of Fragmentation allows, with both physical and potentially chemical properties of taxa influencing fragmentation rates, as well as charring conditions. Indeed, the varying and often conflicting results between different experiments testing the factors which affect fragmentation and mass loss during combustion (e.g. Loreau 1994; Rossen and Olsen 1985; Scott and Jones 1991; Théry-Parisot et al. 2010b; Vaughan and Nichols 1995) attest to the difficulty in reconstructing the taphonomic consequences of fire. Nevertheless, even if fire is an unpredictable taphonomic process, the representativeness of in situ bush fire charcoal assemblages (e.g. Blackford 2000; Enache and Cumming 2006; Gardner and Whitlock 2001; Lynch et al. 2004; Ohlson and Tryterud 2000; Scott et al. 2000; Thinon 1992) clearly shows that the societal filter is much more transformative than the combustion filter. The possible taxa-intrinsic factors affecting the representativeness of anthracological assemblages are also successfully addressed by the analysis of assemblages from long-term, synthetic deposits, which will tend to eradicate individual taphonomic characteristics of each taxon during each charring event (Chabal 1997; Chrzazvez et al. 2014; Dussol et al. 2017; Lancelotti et al. 2010).

The depositional and post-depositional factors that influence site formation processes and the preservation of all archaeological material, such as trampling, cleaning, bioturbation, sediment properties, and burial rates, also affect the integrity of anthracological assemblages (see summary in Théry-Parisot et al. 2010a:147—150). These factors are specific to the archaeological site in question, requiring systematic reference to the context of each archaeological stratum and feature. An in depth exploration of the taphonomic processes which have impacted the Riwi and Mount Behn rock shelter wood charcoal assemblages are described in detail in Chapters 3, 4, and 6.

The third and final phase of information transfer is the sampling and analysis of the charcoal assemblage. The anthracological sampling protocol was first established by Chabal (1997), who outlined three conditions that must be observed in order for an anthracological assemblage to be representative of woody vegetation in the past. First, charcoal samples must be derived from domestic contexts (also see Picornell-Gelabert 2011). This assumption is important because woods will be systematically selected for ritual or industry fires, and will not be representative of the broader vegetation community.

Second, charcoal samples must originate from contexts representative of long-term activities. These long-term contexts may be either heterogeneous deposits associated with a particular activity (e.g. kilns), for which meditated selection cannot be separated from indiscriminate sampling, or synthetic deposits comprised of the scattered charcoal in an archaeological stratum produced by long-term deposition and mixing. This condition is based on the premise that hearth features and concentrations of dense charcoal are episodic contexts that represent the primary refuse of the last few firing events, where areas of the surrounding landscape and vegetation communities might not have been visited for fuel wood, and/or the purpose of the hearth required the combustion of specific woods (Beauclair et al. 2009; Ford 1979; Huebert et al. 2010; Picornell-Gelabert et al. 2011; Ramos et al. 2008; Scheel-Ybert et al. 2014). By contrast, heterogenous and synthetic deposits, which were collected over a protracted length of time, are more likely to represent the taxonomic diversity and vegetation communities of the surrounding landscape (Badal et al. 2012; Chabal 1997; Chabal et al. 1999; Dufraisse 2012, 2014; Vita Finzi and Higgs 1970). Concentrated charcoal features should be analysed in conjunction with scattered contexts in order to tease out the socio-cultural factors that influence the creation of a charcoal assemblage at a site (Asouti and Austin 2005; Byrne et al. 2013; Carah 2016; Théry-Parisot et al. 2010a).

Third, a minimum of 200—400 identifiable charcoal fragments greater than 2 mm in size need to be sampled from each archaeological layer, acquired by systematic sampling of the sediments. The variation in fragment counts allows for differential species richness between regions. Where ecological diversity measures are known, it has been possible to define ecological representativeness, based on indices such as the Pareto Index produced by the Gini-Lorenz curve (Chabal et al. 1999; Delhon 2006; Nelle et al. 2013; Scheel-Ybert 2002), which varies from 200 fragments in temperate and Mediterranean climates to 400 fragments in the tropical zone. Where ecological diversity measures are not known, and/or to corroborate the results of diversity indices (which have their own inherent issues, cf. Colwell and Coddington 1994; Izsák and Papp 2000; Washington 1984), a saturation curve can define the point at which the identified assemblage represents the species richness of an area, by plotting the frequency of new taxa against the number of fragments analysed, and defining where the curve plateaus (Magurran 1988). These assessments, and anthracological analysis in general, are based on fragment counts rather than mass, because weighing is subject to more error, such as the precision of the scales when weighing smaller fragments, and identification requires the sectioning of the fragment, which modifies weight in a random way (Dotte-Sarout et al. 2015). Archaeological observations have also shown that relative proportions of mass and count are similar (Chabal et al. 1999; Huebert et al. 2010), and counting has the added benefit of being methodologically simpler.

The Law of Fragmentation over-simplifies the processes which affect the fragmentation of wood charcoal; however, the principle clearly elucidates that anthracological analysis must include a range of charcoal fragments of different sizes in order to represent the taxonomic richness of the assemblage (Chabal 1997; Chabal et al. 1999). When the entire anthracological assemblage from an archaeological unit is not being analysed, but sampled, a riffle-box is an ideal tool for ensuring the random inclusion of charcoal fragments of all sizes (Pearsall 2000). Additionally, since it is achievable to identify fragments down to 2 mm in non-tropical areas with comprehensive reference materials (e.g. Byrne et al. 2013; Delhon 2005; Dotte-Sarout 2010), excavation methods must be applied that allow for the systematic collection of charcoal fragments 2 mm in size and greater. For this reason, flotation and the sieving of sediments through nested screens is preferable to hand-picking of charcoals, which may incidentally integrate researcher bias (Pearsall 2000). It should be noted here that while a sample of sediment was floated at Mount Behn rockshelter, no flotation was conducted at Riwi due to both the preservation of organic materials by desiccation in the upper units, and the limited water supply in the area during the dry season.

2.2.2 Anthracology in Australia

The discipline of anthracology was developed as a systematic approach to wood charcoal remains in Europe, with the investigated assemblages excavated from sites in temperate Europe and the semi-arid Middle East. The expansion of anthracology into other continents and climatic zones has gained momentum over the past twenty years, led by the pioneering work of Scheel-Ybert and colleagues in the tropics of Brazil (Bachelet and Scheel-Ybert 2017; Beauclair et al. 2009; Scheel-Ybert 2000, 2001, 2002a, 2002b; Scheel-Ybert and Dias 2007; Scheel-Ybert et al. 2014). The difficulties of working with the diverse flora of the tropical zone have also been explored by Asouti and Fuller (2008) in South India, Thompson (1992) in Thailand, Dotte-Sarout (2010, 2016) and Huebert (2010, 2015, 2016) in the Pacific, and various researchers in Africa (Eichhorn 2007; Ekblom 2008; Ekblom et al. 2014; Hohn 2007; Hohn and Kahlheber 2008; Hohn and Neumann 2012; Kahlheber et al. 2014; Neumann et al. 1998; Schmidt 1997).

Table 2.1 Anthracological studies conducted at archaeological sites in Australia, with reference, number of charcoal samples identified, and number of taxa identified. For site locations, see Figure 2.4

Source	Site	Total fragments identified	Number of taxa identified
Boyd et al. 2000	Cape Byron Shell Midden	10	5
Burke 2004	Devil's Lair	131	9
Byrne et al. 2013; Taylor 2012	Weld Range	483	18
Carah 2010	Gledswood Shelter 1	135	10
Carah 2016	Madjedbebe	1965	20
Chae Byrne (pers. comm.)	Barrow Island, Serpent's Glen	--	--
Dolby 1995	Nunamira	25	6
Donoghue 1979	Toulkerrie Midden	21	10
Dortch 2004	Tunnel Cave	257	6
Edgar 2001	Carpenter's Gap 1	40	5
Fleur King (pers. comm.)	Sisters Creek Cave	--	--
Frawley 2009; Frawley and O'Connor 2010	Carpenter's Gap 1	179	43
Hudson 2013	Kalgan Hall	473	13
King 2015	Goddard Creek Open Site	200	37
Mackay-Dwyer 2011	Gordoly	247	10
Megaw 1966	Gymea Bay Rockshelter	--	12
Purssell 2012	Middle Park Station	373	13
Smith et al. 1995	Puritjarra	124	19
Whitau et al. 2018 (this thesis)	Riwi	2754	19
Whitau et al. 2016a, 2016b (this thesis)	Mount Behn rockshelter	614	17

Figure 2.4 Australia with climatic zones, LGM coastline, and archaeological sites with anthracological investigation (CAD: CartoGIS, Australian National University).

The first anthracological studies in Australia were undertaken in the 1960s (Donoghue 1979; Megaw 1966) and were contemporaneous with the pioneering stages of the discipline in Europe (Salisbury and Jane 1940; Godwin and Tansley 1941; Mormot 1955; Santa 1961; Couvert 1968, 1976). However, Australia has lagged in its application of the newer techniques and methods that have been developed elsewhere, in part because of the Anglo-Saxon focus of archaeology in Australia, as opposed to the former predominance of anthracological developments in European languages other than English, and in part because of the neglected application of archaeobotany in Australia in general (cf. Denham et al. 2009; Dotte-Sarout et al. 2015). Until recently, the corpus of anthracological analysis in Australia had comprised one Masters' thesis (Frawley 2009; Frawley and O'Connor 2010), a handful of publications (Boyd et al. 2000; Dortch 2004;

Smith et al. 1995), and a series of Honours dissertations (Carah 2010; Donoghue 1979; Dolby 1995; Edgar 2001; Hudson 2013; King 2015; Mackay-Dwyer 2011; Purssell 2012; Taylor 2012), with only two having been published (Burke 2004; Byrne et al. 2013). Consequently, anthracological research in Australia has been substantially restricted by both time and a lack of technical expertise, which has resulted in reduced sample sizes that have limited utility for archaeological and palaeoecological inquiry (Table 2.1, Figure 2.4; Dotte-Sarout et al. 2015).

More recently, anthracological analysis from Honours level research has tested the application of more rigorous anthracological principles to the Australian context (Taylor 2012; Byrne et al. 2013; Hudson 2013; King 2015). Four PhD theses have also been conducted or are currently away, including: this thesis; one completed thesis on the wood charcoal assemblages of combustion features from Madjedbebe in the Northern Territory (Figure 2.4; Carah 2017, and two theses in progress; one thesis currently underway in the Pilbara/Gascoyne region of Western Australia (Figure 2.4; Chae Byrne pers. comm.); and one other thesis in progress about Sisters Creek Cave in Tasmania (Figure 2.4; Fleur King pers. comm.). Both this PhD research (see chapters 3-7) and Carah's work (2016) have developed a rigorous, up-to-date anthracological methodology in Australia, with Carah establishing the first fuel wood management model for the region.

Anthracological research in Australia suffers from many of the factors which affect other archaeobotanical studies on the continent: poorly developed reference collections and poor on-site collection and recovery (Denham et al. 2009; Dotte-Sarout et al. 2015). Unlike other organic remains, poor preservation rendered by Australia's hostile depositional conditions cannot be as readily applied to charcoal in its relatively inert ubiquity. The lack of adequate reference material is a hindrance to the application of anthracology, but one that is being slowly rectified by work conducted at the University of Queensland, which provides online access to their archaeobotany collection (<http://uqarchaeologyreference.metadata.net/archaeobotany/list), and Australia's next generation of wood charcoal researchers sharing descriptions, photos, and physical specimens. It should be noted here that species level identification should not be automatically expected for Australian anthracology, since reference materials are still being collated, with the effects of environmental

factors on wood anatomy yet to be explored. Indeed, even certain European taxa that have been studied extensively cannot be secured to species level identification, such as Salicaceae (the *Acacia*, *Corymbia* and *Eucalyptus* genera are equivalent Australian examples). This restriction is unfortunate in the Australian context, where the majority of floristic diversity is found at the species level (Wheeler 1992), but necessary to prevent over-identification.

In terms of on-site collection and recovery, the application of anthracology has been impeded by four key issues (Denham et al. 2009; Dotte-Sarout et al. 2015). First, archaeobotanists have been often engaged post-excavation, which instigates and/or compounds the second issue, which is the application, or lack of, appropriate recovery techniques. Poor preservation of organic remains has often been cited in Australian archaeological site reports; however, the systematic recovery of macro-remains has been inadequately applied until recently (Denham et al. 2009; Fairbairn 2005). Third, excavations in Australia tend to be small, often consisting of typically 1 m^2 test pits, that are excavated by small teams, inhibiting the logistics of substantive archaeobotanical sampling (Langley et al. 2011). The fourth and final issue is an interpretive one that does not inhibit the application of archaeobotanical investigations, and that is the use of arbitrary excavation units or spits. Australian archaeologists tend to excavate by arbitrary units because visual differentiation is not observed within the sedimentary matrix, particularly when encountered within a small 1m^2 test pit. Additionally, sites with visible stratigraphy are often still excavated by excavation, rather than stratigraphic unit, and interpretations of archaeological remains are often described within these arbitrary units, instead of associating the material to the original deposition events (Ward et al. 2016). In the absence of a shift in excavation practice, this issue can be navigated post-excavation by careful association of excavation and stratigraphic units, and any material recovered from excavation units where sediments including more than one discrete deposit should be avoided.

Despite the geographical spread of anthracological research in Australia (Figure 2.4), little has been established in the way of sampling thresholds within the different climatic zones. Table 2.1 lists the number of fragments analysed in each anthracological investigation in Australia, which shows that eight studies have sampled less than 200 fragments. While the number of identified charcoal fragments totals 247 at Gordoly (Mackay-Dwyer 2011), 257 at Tunnel Cave (Dortch 2004), 373 at Middle Park Station (Purssell 2012), and 473 at Kalgan Hall (Hudson 2013) these fragments are spread over several archaeological units (five at Gordoly; three at Tunnel Cave and Middle Park Station; six at Kalgan Hall). At the Goddard open site in the Queensland tropics, 200 of 253 analysed charcoals were identified to varying levels of taxonomic significance from the most recent (~1.2 ka) archaeological unit (King 2015). Limited by time constraints and by stratigraphic and excavation units issues, King (2015) acknowledges that the sample size is still too small to accurately represent the diversity of the local tropical flora.

At Weld Range, which is subject to a semi-arid climate, 231 and 251 charcoal fragments were identified from two combustion features and associated scattered charcoal surrounding the first features, with saturation curves stabilising at 71 and 61 fragments respectively (Byrne et al. 2013; Taylor 2012). These saturation curves demonstrate that the taxonomic richness of the deposits was represented. Similarly, Carah (2016) analysed 14 hearths from Madjedbebe in order to explore wood selection strategies, rather than to reconstruct woody vegetation. One hearth (C3/4A) was sampled to 400 fragments, five hearths were sampled to 200 identifiable fragments, and 100% of the remaining six hearths (n = 25—121 identifiable fragments) were analysed (Carah 2016). Ten of the 14 hearths reach plateaux, which vary between one and 148 fragments (Carah 2016). Four hearths do not reach plateaux, two of which comprise the entire hearth assemblage (D3/21A and C1/43A were 100% sampled). The final taxon identified from the D2/21A hearth (n = 200), which was not encountered until specimen 195, was *Coelospermum* sp., a rare taxon which occurred once in the entire Madjedbebe assemblage (Carah 2016). The fourth hearth (E3/5A, n = 200), which was the most recent hearth with the most floristic diversity, was inadequately sampled to represent the richness of the assemblage (Carah 2016). With the exception of hearth E3/5A, the sampling effort was successful for the aims of the research, but is similar to all recent and current anthracological investigations in Australia, in that additional sampling, particularly of non-hearth contexts, will be required to establish clear regional sampling thresholds that represents the taxonomic richness of each area.

2.3 Reference collection

2.3.1 Wood charcoal reference collection

Identification of archaeological wood charcoal is conducted by comparing unknown archaeological charcoal with known plant specimens. Given that the present study was the first to apply systematic anthracology in the area, a physical collection, collected from modern vegetation growing near the site was essential (Pearsall 2000). Specimens collected for the comparative collection need to be representative of the species, and where possible, samples need to be collected from several plants, and from different parts of the plant (branch, root, bark and trunk), so that intra-specific variation is observable, and more archaeological samples might be identified to lower levels of taxonomic significance.

Before conducting fieldwork, a list of target taxa was created, using ethnographic sources (e.g. Crawford 1982; Paddy, Paddy & Smith 1985; Latz 1995) anthracological data (Frawley 2009; Frawley & O'Connor 2010), botanical survey information (e.g. Beard 1979; Wheeler 1992), and online vegetation mapping (<https://florabase.dpaw.wa.gov.au/>). Trees and shrubs with aforementioned firewood, construction, and other cultural uses, and the taxa identified in the Carpenter's Gap 1 assemblage (Frawley, 2009), were prioritised. An identification card was produced for each of the 63 species in the target taxa list, which included information regarding the identification (botanical pictures and descriptions), habit, habitat, and cultural uses of each taxon (Appendix C). These cards were printed in colour and bound in a notebook for use in the field, alongside Wheeler (1992), since there would be no botanist in attendance and access to Aboriginal Traditional Owners would be intermittent.

Prior to fieldwork, Scientific or Other Prescribed Purposes Licences (SOPP), for the collection of flora for research purposes were obtained from the West Australian Department of Environment and Conservation, for Rose Whitau and Tim Maloney in 2013, and Rose Whitau and India Dilkes-Hall in 2014, in accordance with the Wildlife Conservation Act 1950, Section 23C Reg 56E(1)(b). A Regulation 4 Authority permit was also obtained for the collection of plant specimens from Windjana Gorge National Park in both 2013 and 2014. Plant press materials and field notebooks were donated by the Australian National Herbarium in Canberra.

Plant specimens were collected from the surrounding environs of the Mount Behn rockshelter, Carpenter's Gap 1 and 3 sites, and Windjana Gorge National Park in July 2013 and April 2014. In July 2013, a survey of Riwi's surrounding vegetation was conducted in conjunction with the wood reference material collection, the methods and results of which are presented in Chapter 3, Sections 3.2 and 4.1 respectively. During fieldwork in 2013, all woody taxa with fertile voucher material and the seasonally non-fertile species that were abundant or resembled descriptions within the target taxa list were sampled. From each plant sampled, two to three wood pieces were sawn from branches at least 2 cm in diameter, 10—15 cm in length, and at least 5 cm from where the branch joined the tree. Duplicate voucher material was collected where possible (and when space in the plant presses allowed), as requested by the Australian National Herbarium. Notes and photographs were taken and recorded in the field notebook provided by the Australian National Herbarium (Appendix C).

After field collection, voucher materials and wood samples were transported to the Australian National Herbarium following the quarantine protocols prescribed by Regulation 8(1) of the Conservation and Land Management Regulations 2002. Fertile material was vouchered by botanists at the Australian National Herbarium. Certain plant specimens, particularly those which the Australian National Herbarium had only a few examples, are now housed in the Herbarium, the official records of which can be accessed online, with permission, via the Integrated Botanical Information System (<https://www.anbg.gov.au/cgi-bin/anhsir>). The surplus voucher materials were destroyed once the taxonomic identification was confirmed by botanists from the Herbarium.

Once specimens were vouchered, the comparative charcoal collection was created from the gathered wood samples. Following Pearsall (2000), samples were wrapped in aluminium foil, placed in individual, labelled crucibles within whitewashed brick-layer's sand, and charred at 400˚C for 30—60 minutes (until smoke was no longer produced) in a muffle furnace at the Department of Archaeology and Natural History (ANH) at the Australian National University

(ANU). After charring, samples were organised into family groups and stored in the ANH Archaeobotany laboratory at the ANU, where the physical collection will remain (Figure 2.5). This collection was further supplemented by two wood samples from the Australian National Botanical Gardens (ANBG) in Canberra that were charred as per the process described above and 12 charcoal samples from the University of Western Australia's Department of Archaeology's Barrow Island, Pilbara, and Weld Range reference material (Byrne et al. 2013; Dotte and Byrne 2013; Taylor 2012).

Figure 2.5 Bunuba-Gooniyandi reference collection: storage (A and B), prepared slides (C). Photographs taken by Juliet Meyer.

The Bunuba-Gooniyandi reference collection comprises 66 species plus five taxa identified to genus level, totalling 71 taxa (Appendix D). These 71 taxa are from 33 genera and 22 family groups. Charcoal samples were snapped along the transverse, radial and longitudinal sections, with the aid of a scalpel where necessary, following Leney and Casteel (1975). Exposed sections were examined with an Olympus BH-2 reflected lightfield/darkfield microscope at magnifications of 20—500x, before closer examination of sub-elemental features, such as intervessel pits, and imaging with a JEOL JCM-6000 Neoscope Scanning Electron Microscope, in the ANH Department at the ANU. The anatomical features of a minimum of ten samples per taxon were described following the International Association of Wood Anatomists (IAWA) nomenclature (Wheeler et al. 1989), using a template (Figure 2.6) adapted from Dotte-Sarout's (2010) anthracological specimen form. Descriptions of each taxon, which were collated and entered into a Filemaker database, are presented in Appendix D, alongside

SEM images. Canonical examples of each taxon are also housed as a physical collection in the Archaeobotany laboratory at the ANH, ANU, with each section embedded in Bostik Blu-Tack on a microscope slide, for easy reference (Figure 2.5).

2.3.2 Palynological reference collection

The Australasian Pollen and Spore Atlas <http://apsa.anu.edu.au/> (APSA) is managed by the ANH Department at the ANU, where the physical material is housed. The APSA database is extensive, covering a broad range of vegetation communities across Australia, South East Asia, and the Pacific; therefore, an additional reference collection did not need to be created for the purposes of this thesis. A list of likely taxa was created, using botanical survey (e.g. Beard 1979; Wheeler 1992), and online vegetation mapping (<https://florabase.dpaw.wa.gov.au/>) data. Where images of taxa were not available on the APSA database, new images of the reference material were taken using the Zeiss Axiophot microscope and Zeiss Axiovision imaging software, and uploaded onto the APSA database. The completed reference list is presented in Appendix E.

Archaeological charcoal identification sheet

Site:		Square:		Quad:		Spit:		Sieve:		Mass (g):		No.:	
Type:													

	Transverse section		Longitudinal sections	
Vessels	Porosity/tracheid diameter		Perforation plates type	
	Vessel grouping		Helical thickenings	
	Vessel arrangement		Inter-vessel pits (arrangement, shape, size)	
	Angular outline of solitary pores			
	Tyloses			
Fibres	Fibres wall thickness		Helical thickenings	
			Fibre pits	
			Septate fibres present	
			Vascular-vasicentric tracheids	
			Parenchyma like fibres present	
Axial Parenchyma	Arrangement		Fusiform parenchyma cells	
			Axial parenchyma bands	
Rays	Aggregate rays		Rays height	
			Rays width	
			Rays cellular composition	
			Sheath cells	
			Tile cells	
			Storied structure	
Vessel-ray crossings			Vessel-rays pitting	
			Walls	

Notes:

Figure 2.6 Charcoal description template, adapted from Dotte-Sarout (2010)'s template

Chapter 3. Wood charcoal analysis at Riwi cave, Gooniyandi country, Western Australia

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Rose Whitau: developed the research question; undertook field work; created the reference collection; recorded and analysed the data; formulated the arguments in the manuscript; drafted the entire manuscript; edited and reviewed the manuscript.

Signed:

16/03/2018

Rose Whitau

Jane Balme: secured funding for the Lifeways Project; designed and managed fieldwork operations; edited and reviewed the manuscript.

Signed:

18/03/2018

Jane Balme

Sue O'Connor: secured funding for the Lifeways Project; designed and managed fieldwork operations; edited and reviewed the manuscript.

Signed:

18/03/2018

Sue O'Connor

Rachel Wood: produced the radiocarbon chronology for the site; edited and reviewed the manuscript.

Signed:

20/03/2018

Rachel Wood

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Wood charcoal analysis at Riwi cave, Gooniyandi country, Western Australia

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ABSTRACT

Wood charcoals excavated from archaeological sites provide a useful tool for palaeoenvironmental reconstruction, particularly in arid and semi-arid zones, where suitable catchments for palynological archives are often limited. Preservation of organic material in northern Australia is characteristically poor, and wood charcoal analysis provides a viable alternative to understand shifts in woody vegetation in the past. The analysis of charcoal from matrix contexts at Riwi cave, located in the southern Kimberley region of northern Western Australia, has allowed a reconstruction of the local woody vegetation during occupation over the last 45,000 years. The wood charcoal assemblage from the Holocene stratigraphic units reflects the composition of the modern vegetation, and illustrates that people were occupying the site during periods of relative humidity. The Pleistocene stratigraphic units show a shift in vegetation composition from *Eucalyptus* spp. to *Corymbia* sp. dominated savanna, with an understory of secondary shrub, associated with a Late MIS 3 arid event observed in both terrestrial and marine archives, suggesting that activities continued at Riwi during this arid event. Further anthracological analysis of other sites in the Kimberley will help to build a regional picture of woody vegetation change, and will further disentangle local and regional climatic signals, particularly in relation to phases of occupation.

1. Introduction

Preservation of organic material in monsoonal Australia is characteristically poor, and the geological stability of the ancient landscape limits the creation of depositional archives for analysis. The Kimberley region of north Western Australia has a particularly poorly preserved palaeoenvironmental archive. With the exception of archaeobotanical investigations conducted at Carpenter's Gap 1 (McConnell, 1997; Wallis, 2000; Frawley, 2009), palaeoenvironmental reconstruction of the Kimberley region has relied largely upon the dating of geomorphological sequences (e.g. Bowler, 1983; Wyrwoll et al., 1992; Fitzsimmons et al., 2012, 2013), or the isotopic profiling of stalagmites (Denniston et al., 2013a, 2013b, 2015), in conjunction with the extrapolation of palynological data from the Timor Sea (Kershaw and van der Kaars, 2012:240, Fig. 1) and the southern Pilbara (van der Kaars and de Deckker, 2002). While sites with better palynomorph preservation have been analysed more recently, including Black Springs (McGowan et al., 2012), the King River region (Proske et al., 2014), and the Mitchell Plateau (Simon Haberle pers. comm.), archives of fossil flora remain the exception, and not the norm.

Anthracology is the systematic analysis of archaeological wood charcoal assemblages from stratified contexts (Vernet, 1973, 1992; Chabal, 1992, Chabal et al., 1999). A subdiscipline of archaeobotany, anthracology, or wood charcoal analysis, enables the reconstruction and investigation of both palaeoenvironment and palaeoethnobotanical practice. Previous studies have identified the merits of anthracological analysis for palaeoenvironmental reconstruction (see reviews in Smart and Hoffman, 1988; Figueiral and Mosbrugger, 2000; Asouti and Austin, 2005; Dotte-Sarout et al., 2015). In arid environments, where pollen preservation is often poor, wood charcoals excavated from stratified archaeological contexts can provide the only reliable analogue for vegetation change (e.g. Willcox, 1999; Asouti and Hather, 2001; Höhn and Neumann, 2012; Cartwright, 2013; Jansen et al., 2013; Bachelet and Scheel-Ybert, 2015; Jude et al., 2016). Analyses of charcoals from archaeological deposits make

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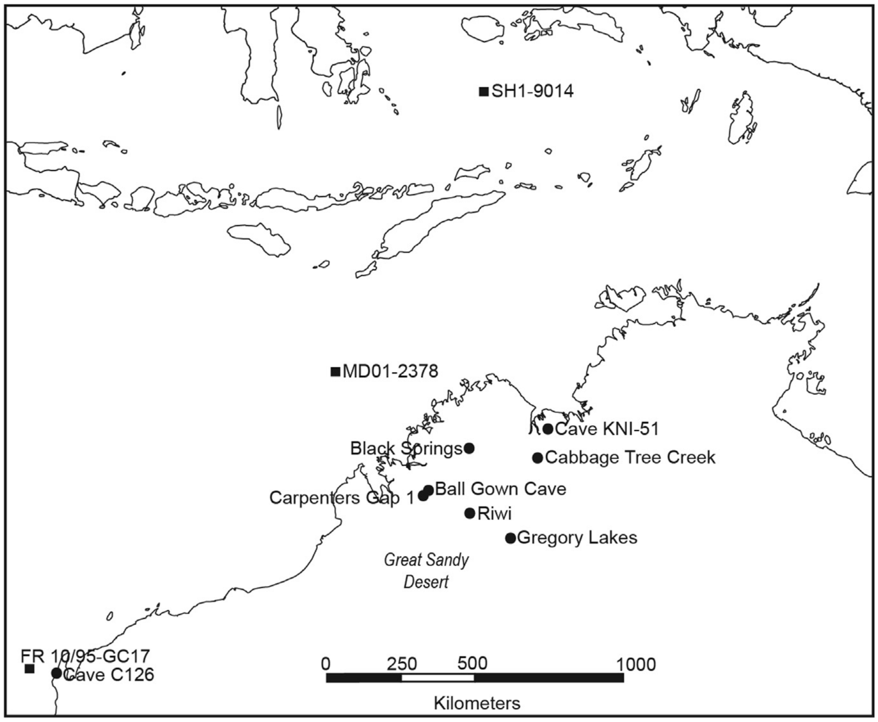

Fig. 1. Map of northern Western Australia with sites mentioned in the text.

possible a local-scale vegetation reconstruction that is more complex than regional palaeoclimate archives, and at a temporal scale that directly corresponds with prehistoric habitation (Asouti and Austin, 2005). Here we present results from wood charcoal analyses at Riwi, a limestone cave in the southern Kimberley region of Western Australia, on the edge of the Great Sandy Desert (Fig. 1), where excavations have revealed evidence of human occupation stretching back around 45,000 years (Wood et al., in press).

Despite the breadth of anthracological analyses conducted in Europe, South-West Asia, and South America, the application of anthracology in Australia is uncommon, with sampling thresholds largely untested (Dotte-Sarout et al., 2015). The first Australian anthracological studies were undertaken in the 1960s (Megaw, 1966; Donoghue, 1979), and were contemporaneous with the pioneering stages of the discipline in Europe (Salisbury and Jane, 1940; Godwin and Tansley, 1941; Momot, 1955; Santa, 1961; Couvert, 1968, 1976). However, Australia and wider Oceania have lagged in their application of the newer techniques and methods that have been developed elsewhere (see Théry-Parisot et al., 2010). With the exception of one Masters' thesis (Frawley, 2009; Frawley and O'Connor, 2010) and a handful of publications (Smith et al., 1995; Boyd et al., 2000; Dortch, 2004), the majority of anthracological applications in Australia have been undergraduate Honours dissertations (Donoghue, 1979; Dolby, 1995; Edgar, 2001; Carah, 2010; Mackay-Dwyer, 2011; Purssell, 2012), two of which have been published (Burke, 2004; Byrne et al., 2013). Consequently, anthracological research in Australia has been heavily constrained by both time and a lack of technical expertise, which has resulted in reduced sample sizes that have limited utility for archaeological and palaeoecological inquiry (Dotte-Sarout et al., 2015). In this paper we present results from one of the largest anthracological assemblages analysed in Australia to date.

2. Regional setting

2.1. Site description

Riwi is located within the Mimbi area of the country of the Gooniyandi Indigenous group, which is in the southern Kimberley region of Western Australia. Mimbi is defined by the Emanuel and Lawford Ranges to the west and east respectively (Fig. 2), both of which are composed of uplifted Devonian limestone reef. On the edge of the Great Sandy Desert, Mimbi has a semi-arid to subtropical climate, and is within the lower limits of the Australian Summer Monsoon, receiving approximately 500 mm of rainfall per annum (Bureau of Meteorology, 1996). Vegetation is largely delimited by effective precipitation during the wet season (October–May), geology, fire, and cattle-grazing, with diversity and abundance of woody vegetation decreasing in a southeast gradient towards the arid interior of the continent (Beard, 1979). Broad scale mapping of the region shows that the dominant vegetation type within the Mimbi area is sclerophyll, and grades between woodland savanna, steppe, and grassland (Beard et al., 2013). The vegetation associations and alliances for each of these units are flexible, and a number of species combinations with different upper and ground stories are possible (Perry, 1956; Beard, 1979).

A southwest-facing cave at the base of the Lawford Range, Riwi is comprised of two chambers. The main chamber is approximately 13 m deep and 7 m wide, with a high ceiling, while the chamber at the back of the cave is smaller, with a low ceiling that restricts movement (Fig. 2). Prehistoric rock art, including a boomerang and phytomorphs, decorate the cave walls. The mouth of the cave is littered with lithic artefacts. The site has outstanding botanical preservation, particularly in the Holocene deposits, with paper bark fragments, wood shavings, seeds, nuts, and fruits preserved by desiccation and carbonisation (Dilkes-Hall, 2014). Analysis of the faunal remains is yet to be conducted. A carpological study has revealed a predominance of dry rainforest taxa (Dilkes-Hall, 2014), particularly the fruits of wild bush plum (*Vitex* sp.).

3. Material and methods

3.1. Excavation methods and site chronology

A 1 m^2 test pit (Square 1) was excavated in 1999 (Balme, 2000) reaching bedrock at about 110 cm in one 25 cm^2 quadrant. In 2013, Square 1 was emptied and three additional 1 m^2 test pits (Squares 3, 4, and 5) were excavated, one of which, Square 4, was adjacent to the original test pit, forming a 2 × 1 m trench (Fig. 2). Each of the squares was excavated to bedrock at a maximum depth of 117 cm. All squares were excavated in arbitrary units of 2 cm, and in 50 cm horizontal quadrants, while some features were removed separately. All excavated materials were dry sieved through nested 5 mm and 1.5 mm mesh screens, and bulk sediment samples were collected from each excavation unit. Flotation was avoided because botanical remains were preserved by desiccation in the Holocene units.

Stratigraphic profiles for Squares 3 and 4 are illustrated in Figs. 3 and 4 respectively. Table 1 lists the excavation units (XU) sampled for this charcoal analysis in relation to their stratigraphic context, with associated radiocarbon chronology (Wood et al., in press). The majority of Pleistocene units (SU7–12) were deposited rapidly, between c. 46,000–30,000 cal BP. All Pleistocene deposits studied in this paper fall broadly within the terminal phase of Marine Isotope Stage (MIS) 3 (62–27 ka), before the onset of the Last Glacial Maximum (LGM). There is a clear boundary between the Pleistocene and Holocene units. Although small sections of discontinuous LGM deposits are preserved in Squares 1 and 3, these were excavated as separate features and were not studied as part of this paper (for further explication of the sampling strategy, see Section 3.3). The Holocene units represent two additional phases of site occupation; SU2 dates to around 7000 cal BP, and the youngest unit, SU1, spans between c. 1000 and 600 cal BP (Table 1).

Table 1
Riwi Squares 3 and 4: Relationship between stratigraphic units (SU) and excavation units (XU) studied here, with description and radiocarbon chronology of SU, dates were calibrated against SHCal13 (Hogg et al., 2013) in OxCal v.4.2 (Bronk Ramsey, 2009). Where a single charcoal fragment was dated more than once, the weighted average has been calibrated. Charcoal was pretreated using various methods by the different laboratories, including both ABA and ABOx-SC procedures Full details of sample context and pretreatment are given in (Wood et al., in press).

SU	XU		Lab.code	Material	Pretreatment	Radiocarbon age (BP)	Calibrated age (95.4% probability range, cal BP)
	Square 3	Square 4					
1	2B, 3C	2–3A, D; 4A, B, D	D-AMS 004068	Charcoal	ABA	816 ± 27	730–670
			D-AMS 004064	Charcoal	ABA	956 ± 29	915–760
			SANU-38220	Charcoal (*Corymbia* sp.)	ABA	18,930 ± 50	22,960–22,525
			SANU-43337	Wood (*Grevillea*/*Hakea* sp)	Holocellulose	670 ± 20	650–555
2	6C	7–8D	Wk 7605	Charcoal	ABA	5290 ± 60	6195–5905
			D-AMS 004069	Charcoal	ABA	6179 ± 29	7160–6935
			D-AMS 004065	Charcoal	ABA	6206 ± 37	7175–6935
			SANU-38223	Charcoal (*Corymbia* sp.)	ABA	6245 ± 30	7240–7000
			D-AMS 004063	Charcoal	ABA	6384 ± 32	7415–7170
			D-AMS004061	Charcoal	ABA	6250 ± 35	7245–7000
			D-AMS004062	Charcoal	ABA	6315 ± 32	7275–7025
			D-AMS004067	Charcoal	ABA	6452 ± 34	7420–7270
7	11A, C	11–12C, D; 13A	SANU-35916	Charcoal (Indeterminable)	ABOx-SC	29,720 ± 190	34,170–33,510
			D-AMS 004066	Charcoal	ABA	31,888 ± 153	36,155–35,345
			Wk 7606	Charcoal	ABA	31,860 ± 450	36,730–34,770
			SANU-35914	Charcoal (*Corymbia* sp.)	ABOx-SC	33,000 ± 280	37,830–36,480
			SANU-35921		ABOx-SC	33,270 ± 280	
			SANU-35924		ABA	32,910 ± 270	
			SANU-37707	Charcoal (Myrtaceae sp.)	ABOx-SC	34,450 ± 340	39,775–38,295
9	18–19A, D; 21–22A	–	SANU-35906	Charcoal (*Corymbia* sp.)	ABOx-SC	33,560 ± 300	38,610–36,855
			SANU-35919	Charcoal (Indeterminable)	ABOx-SC	34,000 ± 310	39,230–37,460
			SANU-35913	Charcoal (*Corymbia* sp.)	ABOx-SC	33,850 ± 300	38,960–37,205
10	25–26A, C, D;	18C; 19A, C;	SANU-37706	Charcoal (*Corymbia* sp.)	ABOx-SC	36,680 ± 420	41,970–40,400
	27–28C, D	20–21A, C, D; 22D; 23D	SANU-35918	Charcoal (*Corymbia* sp.)	ABOx-SC	33,340 ± 280	38,405–36,660
11	31B	26–29A, B; 30–31A	SANU-35910	Charcoal	ABOx-SC	29,840 ± 190	34,270–33,600
			SANU-35911	Charcoal (cf. *Corymbia* sp.)	ABOx-SC	41,520 ± 750	45,980–44,030
			SANU-35922		ABOx-SC	41,690 ± 760	
			ANUA13005	Charcoal	ABOx-SC	41,300 ± 1020	46,890–43,040
12	35 + all quads	35–39B; 40 + all quads	SANU-35909	Charcoal (*Corymbia* sp.)	ABOx-SC	41,590 ± 760	46,470–43,610
			SANU-35917	Charcoal (Indeterminable)	ABOx-SC	42,140 ± 810	46,000–44,060
			SANU-35925		ABA	41,050 ± 710	
			ANUA-13006	Charcoal	ABOx-SC	40,700 ± 1260	47,070–42,430

3.2. Vegetation survey methods

A survey of the site's surrounding vegetation was conducted in parallel with wood reference material collection in July 2013. Two 4 km transects were surveyed: Transect A within the valley floor directly in front of the site, Transect B along the plain behind the valley (Fig. 5). All woody taxa were surveyed within 20 m^2 quadrants at 50 m intervals along the valley floor, where the vegetation is mostly homogenous, and in 20 m intervals along the plain, which grades between spinifex (*Triodia* spp.) and bunch grasslands (*Chrysopogon* spp.), with pockets of low sclerophyll scrub-heath (*Acacia* spp., *Vachellia* spp.) colonising recently burnt areas. In conjunction with these two transects, the ephemeral watercourse that runs through the Riwi valley floor, and the limestone hills and outliers were also surveyed. Field identifications were based on a dominant taxa reference list collated from Beard (1979), Wheeler (1992), and the Atlas of Living Australia (www.ala.org.au). Members of the Mimbi community provided traditional ecological knowledge and Wheeler (1992) was also used in the field to aid

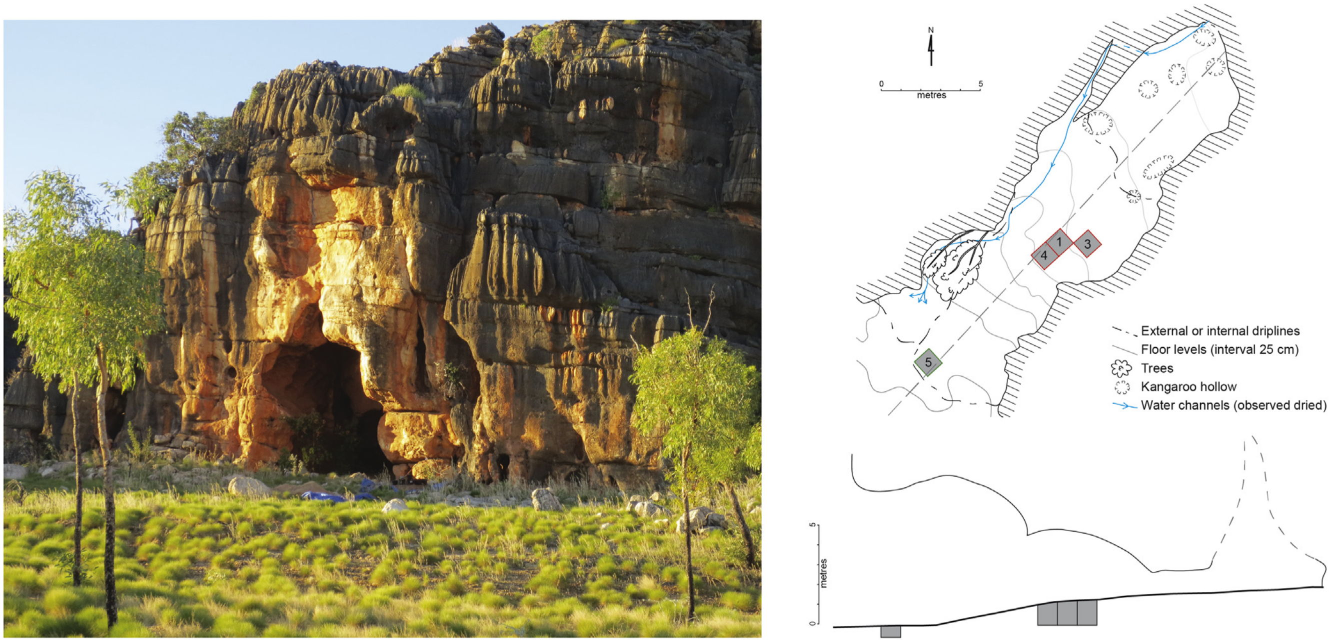

Fig. 2. Riwi cave entrance (left) and site plan (right).

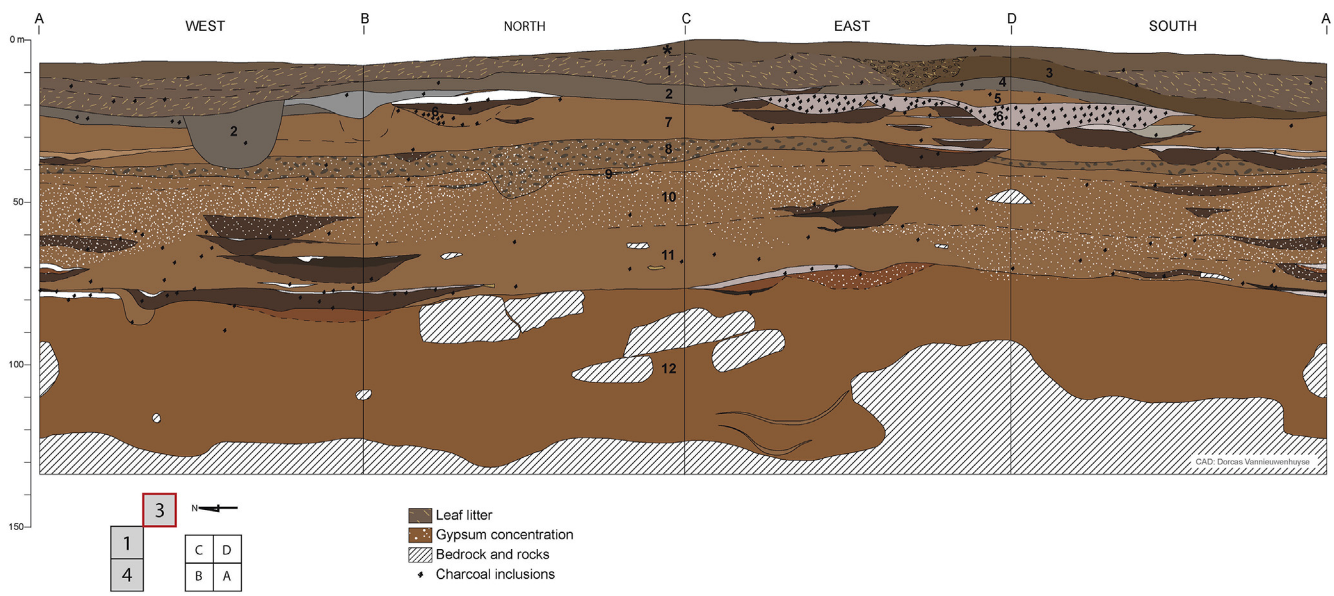

Fig. 3. Stratigraphic drawing of Riwi Square 3.

identification. Vouchers were collected and verified by botanists at the Commonwealth Scientific and Industrial Research Organisation (CSIRO) Herbarium in Canberra.

3.3. Laboratory methods

Wood charcoal deposits accumulated over an extended timeframe, such as scattered charcoals from matrix contexts, which are secondary refuse and represent prolonged patterns of use, must be analysed for valid palaeoenvironmental reconstruction, as opposed to episodic contexts such as hearths, which are primary refuse and represent the last firing event (Chabal, 1992; Chabal et al., 1999; Asouti and Austin, 2005). Hearth features, and SU6, which is comprised of densely packed hearths, were avoided for this investigation. Scattered charcoals from matrix contexts from Riwi excavation Squares 3 and 4 were sampled. By assessing the stratigraphic profile (Figs. 3 and 4), excavation unit depths, excavation notes, and microstratigraphy (Dorcas Vannieuwenhuyse pers. comm.) charcoals could be sampled from eight stratigraphic contexts, and any excavation units that were stratigraphically mixed were avoided (Table 1).

Following Leney and Casteel (1975), charcoals were identified by snapping fragments along the transverse, radial and tangential longitudinal sections, with the aid of a scalpel when necessary. Exposed sections were examined with an Olympus BH-2 reflected lightfield/darkfield microscope at magnifications of 20–500×, with certain fragments (such as rare or canonical type examples) selected for observation and imaging with a JEOL JCM-6000 Neoscope Scanning Electron Microscope (SEM). Quantification was conducted by count, rather than weight, following Chabal (1990, 1992) and

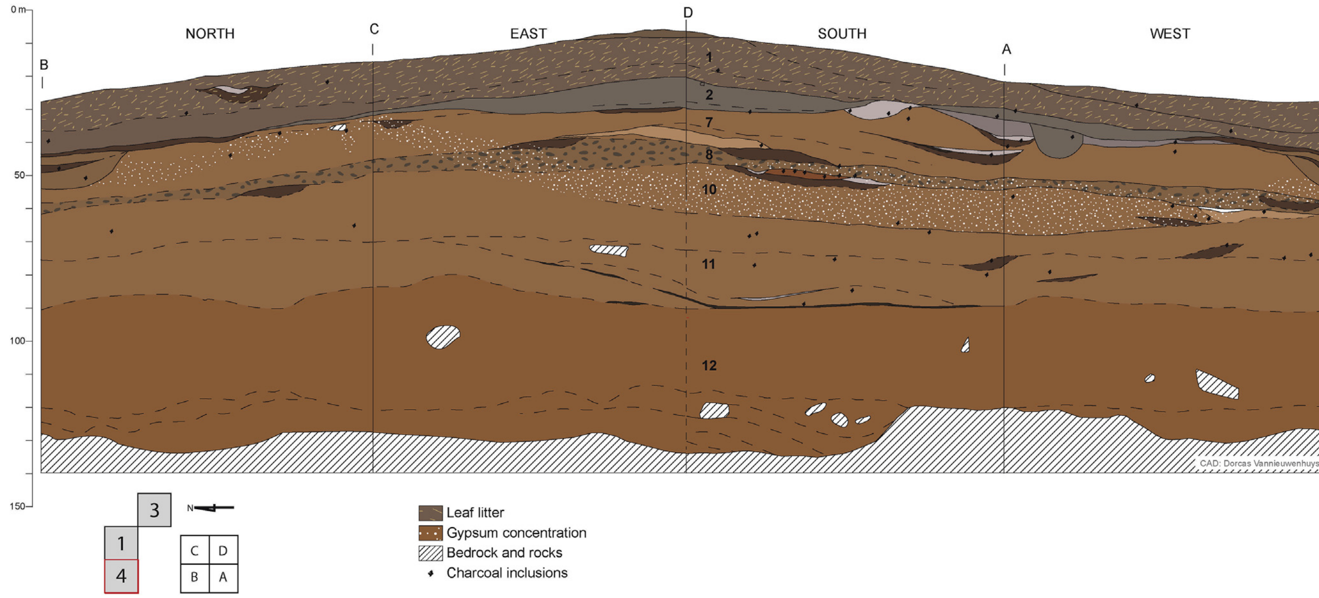

Fig. 4. Stratigraphic drawing of Riwi Square 4.

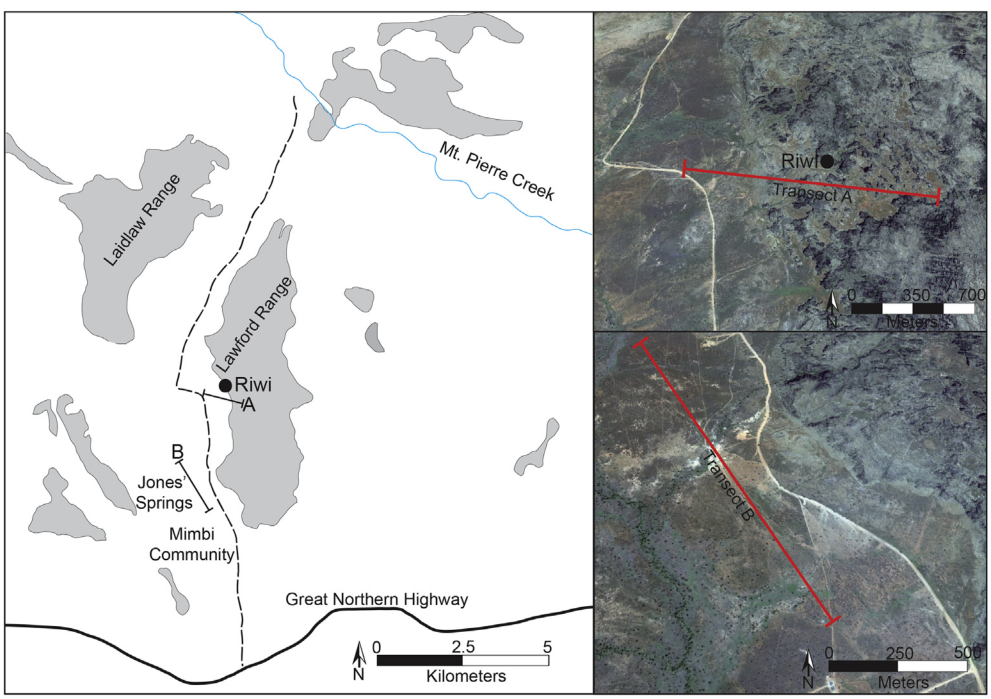

Fig. 5. Map of Mimbi area with vegetation transects A and B shown.

Théry-Parisot et al. (2010). Charcoal preservation was much better for the Holocene units than the Pleistocene and consequently the Holocene units were sub-sampled systematically: A minimum of 150 identifiable fragments from each sieve size (5 mm and 1.5 mm) was sampled for the two Holocene units: SU1 and SU2. A riffle-box was used to split the 5 mm and 1.5 mm samples to ensure an unbiased coverage of size differentiation within these sieve fractions. For each Pleistocene stratigraphic unit (SU7–12), all of the charcoal fragments greater than 2 mm were analysed.

The Bunuba-Gooniyandi reference collection (ANU), which was created for this project, and includes other sites within the Indigenous Bunuba people's lands, consists of 84 taxa collected over two successive field seasons (July 2013, April 2014), the latter, conducted in April 2014, was restricted to Windjana Gorge National Park (Fig. 1). Wood samples were prepared following Pearsall (1989), where samples were wrapped in heavy-duty aluminium foil and charred at 400 °C in a muffle furnace until smoke was no longer produced. This reference collection was further supplemented by an additional two wood samples from the Australian National Botanical Gardens and 12 physical charcoal samples from the University of Western Australia's reference material from the Weld Range and Barrow Island (Byrne et al., 2013; Dotte-Sarout and Byrne, 2013). Reference materials were examined with an Olympus BH-2 reflected lightfield/darkfield microscope at magnifications of 20–500×, and imaged with a JEOL JCM-6000 Neoscope Scanning Electron Microscope (SEM). The microscopic anatomy of each reference specimen was described following the IAWA list of features, and entered into a database following Dotte-Sarout's (2010) template. Wood identification keys including Hope (1998), Ilic (1991), and two online databases: Inside Wood (http://insidewood.lib.ncsu.edu/) and the University of Queensland Online Archaeology Collections (http://uqarchaeologyreference.metadata.net/archaeobotany/list) were also employed to aid identification.

4. Results

4.1. Modern vegetation

The broad scale physiognomic features for the Mimbi area (Beard et al., 2013) are further supplemented by the results of the July 2013 survey. Fig. 5 maps the survey path and vegetation communities across both 4 km transects; Transect A, which follows the ephemeral watercourse into the limestone hills; and Transect B, which extends into the plain beyond the Lawford Range. The Riwi valley floor vegetation is low tree-steppe: Hummock grassland (*Triodia bitextura*) with scattered bloodwood (*Corymbia dicromophloia*/*Corymbia opaca*), and snappy gum (*Eucalyptus brevifolia*), with frequent kapok bush (*Cochlospermum fraseri*) and helicopter tree (*Gyrocarpus americanus*). The ephemeral creek that runs through the valley floor supports pockets of riparian sedgeland, with red river gum (*Eucalyptus camaldulensis*) over mixed sedges. Beyond the limestone outliers that define the valley floor, the vegetation grades between spinifex and bunch grasslands, with pockets of low sclerophyll scrub-heath (*Vachellia suberosa*, *Acacia ampliceps*, *Acacia bivenosa*, *Flueggea virosa*) colonising recently burnt areas. It should also be noted that a *Mallotus nesophilus* tree grows within the front entrance of Riwi cave, and that the invasive weed *Calotropis procera* has successfully colonised the area.

The skeletal soils of the limestone range and outliers sustain, in order of decreasing abundance: *Gyrocarpus americanus*, *Ficus* spp. (*Ficus tinctoria* subsp. *tinctoria* and an unknown *Ficus* sp.), *Cochlospermum fraseri*, *Celtis philippensis*, *Dodonaea polyzyga*, *Flueggea virosa*, and *Grevillea* sp. With the exception of *Gyrocarpus americanus* and *Grevillea* sp., these Indo-Malayan plants are often associated with the dry rainforest of the Kimberley region, in particular, semi-deciduous vine thickets. Kimberley vine thicket communities are small, isolated pockets of dry rainforest that are thought to represent a once widespread palaeotropical flora (Gillison, 1987; McKenzie et al., 1991). The interaction of topography and disturbance by fire has played a pivotal role in the distribution and composition of these vine thicket patches, the species of which have economic importance to hunter–gatherer populations (Clayton-Greene and Beard, 1985; McKenzie et al., 1991), which are distributed predominantly within coastal areas or rocky outcrops, where ocean and/or topography can provide protection from fire. The closest recorded vine thickets to the Mimbi area are those found in the Windjana Gorge and Bungle Bungle National Parks (McKenzie, 1991; Wallis, 2000, 2001). While no pockets of vine thicket were observed within the limits of the July 2013 survey, dry rainforest taxa were observed in abundance across the limestone range and outliers, with certain taxa, such as *Flueggea virosa*, interspersed with savanna vegetation across the valley floor. Similar intermixing of rainforest and sclerophyll vegetation has been observed in Queensland (Gill, 1975; Webb et al., 1984; Fensham and Butler, 2004).

4.2. Anthracological assemblage

Across the eight SUs sampled, a total of 3142 charcoal fragments were analysed, 1594 fragments of which were positively identified to varying levels of taxonomic significance. A total of 19 taxa, including two family level identifications (Lamiaceae sp. and Myrtaceae sp.), were assigned from ten family groups. Where type-level identification could not be positively assigned for a specimen, it was described as indeterminate, whereas all charcoal fragments that could not be positively identified due to brittleness, vitrification, or were otherwise too degraded, were assigned indeterminable status. While Appendix 1.0 describes the archaeological charcoal types, several aspects of the nomenclature require explication here.

The *Corymbia* genus was only recently separated from *Eucalyptus* and granted monophyletic status (Hill and Johnson, 1995), the separation has gained further support from molecular phylogenetic, cladistical analyses (Parra-O et al., 2006; Ochieng et al., 2007; Ladiges et al., 2010). The microscopic features of the wood described in this study also support the monophyly of *Corymbia*, since intergeneric differentiation is achievable for Myrtaceae, but secure interspecific differentiation is currently unattainable. *Corymbia* sp. has variable axial parenchyma (lozenge aliform to bands one to three cells wide) and vessel arrangement (large clusters, strongly dendritic, to clusters of two more common in diagonal patterns). While this variability has been observed within fragments (Fig. 6A and B), the *Corymbia* sp. taxon could potentially include more than one species of *Corymbia*.

Conversely, the two *Eucalyptus* taxa, Types A and B (Fig. 6C and D), could potentially represent the same species, since the major elements of differentiation between the two types are porosity and abundance of axial parenchyma, which could reflect intra-specific variation relating to divergent environmental habits (Schweingruber et al., 2007; Carlquist, 2013). We have kept the two types separate for discussion when further anthracological investigations in Australia can better disentangle this relationship between environment and phenotypic expression. These two types are very distinctive when archetypal examples are viewed side by side but the high proportions of *Eucalyptus* indeterminate attest to the difficulties in teasing out diagnostic elements for this genus. This is not the case with the two *Ficus* sp. types; the distinction between the two is limited by fragment size and the longitudinal sectioning ability of the fragment. Species or confer-species level identifications have yet to be assigned to *Ficus* types because further reference analysis on interspecific variation need to be conducted for the region. Finally, it should be noted that most Lamiaceae types were only diagnostic to the family level because the fragments were produced from twiggy material (Fig. 6E and F).

Table 2 lists the positively identified taxa, with their relative frequencies for each SU, expressed in terms of absolute fragment counts and proportion of total identifiable fragments. The following describes the wood charcoal assemblages analysed from each of the SUs in relation to preservation factors at the site. The oldest layer, SU12, yielded the lowest quantity of charcoal; however, the charcoals which survived were comparatively well preserved, with 17 out of 32 fragments identifiable, creating the lowest percentage of indeterminable charcoal fragments amongst the Pleistocene units. The sandy sediment of SU12 includes abundant gravels from decaying bedrock and roof fall, which, combined with the comparative quality of the surviving charcoal, suggests that mechanical trampling may have played a leading role in the decomposition of the charcoal from this unit. There are not enough identifiable fragments within the SU11 and SU12 assemblages to constitute valid palaeo-environmental reconstructions; therefore, these data have been excluded from further analyses. The quality of charcoals preserved in SUs 8–11 was much lower than those from SU12, with higher proportions of very brittle, powdery charcoals, the microscopic features of which were often obscured by gypsum, particularly in SUs 8–10. In SU10 for example, of the 749 recovered charcoals, only 178 could be identified to varying levels of

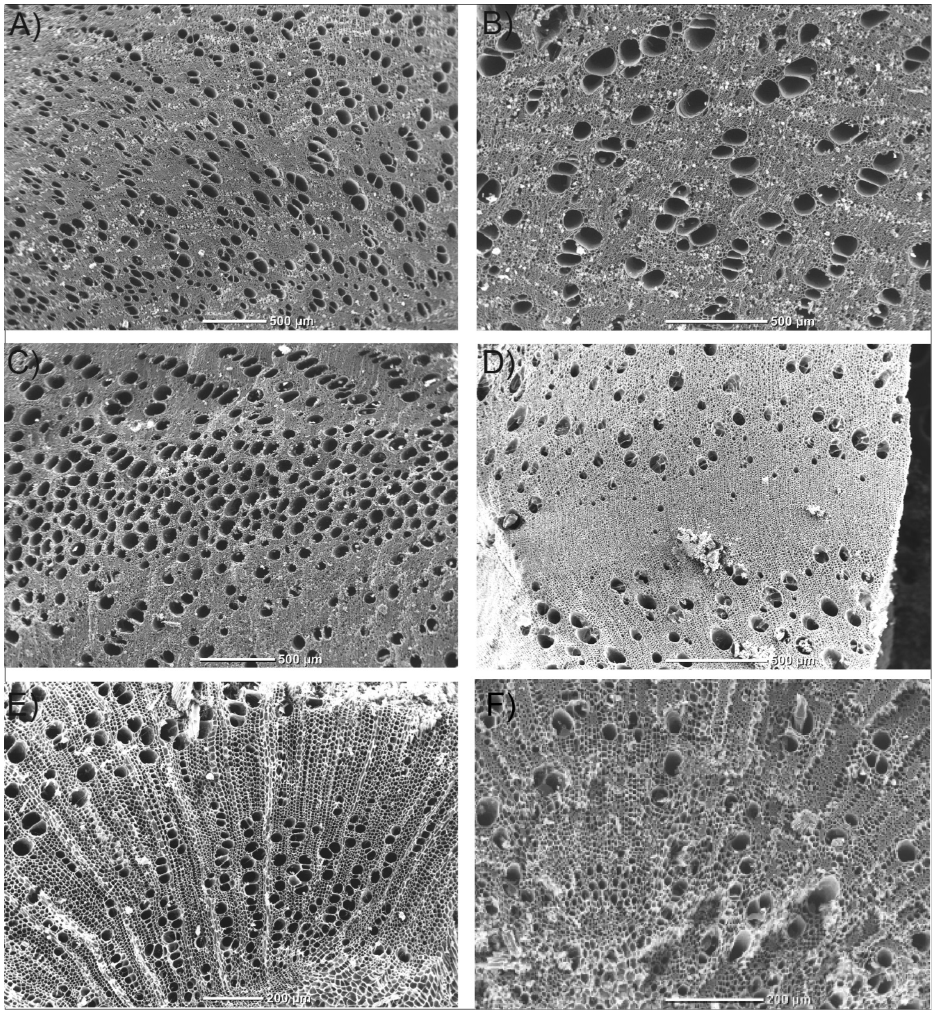

Fig. 6. A) *Corymbia* sp., transverse section, sample R4D7_52. B) *Corymbia* sp., transverse section, sample R4D8_39. C) *Eucalyptus* sp. Type A, transverse section, sample R3D8_22. D) *Eucalyptus* sp. Type B, transverse section, sample R3A15_31. E) Lamiaceae sp., twiggy material, transverse section, sample R4A42_1.5_01. F) Lamiaceae sp., twiggy material, transverse section, sample R3F1_4D1.5_07. All images were produced with the JEOL 6000 Desktop SEM (high vacuum, SEI, 15kv) in the Archaeology and Natural History Department at the Australian National University.

taxonomic significance. The presence of gypsum nodules in SUs 8–10 is indicative of an alternating wetting and drying of these sediments. Indeed, the excellent preservation of botanical remains by desiccation in the Holocene units is not replicated in the lower units. Charcoals from SU7 and the two Holocene layers were abundant and well-preserved, with the features of the majority of indeterminable charcoals from these units obscured by vitrification.

Table 2
List of taxa with relative frequencies for each SU expressed in absolute fragment counts (n) and proportion of total fragments analysed (Nt).

	SU1		SU2		SU7		SU8		SU9		SU10		SU11		SU12	
	n	% Nt	n	% Nt	n	% Nt	n	% Nt	n	% Nt	n	% Nt	n	% Nt	n	%Nt
Celtis sp.	3	0.6	23	5.6	11	2.1	0	0	0	0	0	0	0	0	0	0
Mallotus sp.	45	8.7	6	1.5	15	2.9	0	0	0	0	0	0	0	0	0	0
Bauhinia sp.	0	0	4	1.0	0	0	1	0.3	0	0	0	0	0	0	0	0
Erythrophleum sp.	22	4.2	5	1.2	77	14.7	22	5.6	7	1.9	4	0.5	2	1.4	0	0
Vachellia sp.	0	0	6	1.5	44	8.4	1	0.3	0	0	0	0	0	0	0	0
Vitex sp.	26	5.0	23	5.6	0	0	0	0	0	0	2	0.3	0	0	0	0
Lamiaceae sp.	6	1.2	9	2.2	2	0.4	0	0	0	0	1	0.1	0	0	6	18.8
Ficus sp. *Type A*	13	2.5	23	5.6	9	1.7	0	0	0	0	1	0.1	0	0	0	0
Ficus sp. *Type B*	8	1.5	6	1.5	0	0	1	0.3	0	0	0	0	0	0	0	0
Ficus indeterminate	0	0	2	0.5	1	0.2	0	0	0	0	0	0	1	0.7	0	0
Corymbia sp.	163	31.5	163	39.7	141	26.9	18	4.6	50	13.4	24	3.2	18	12.6	11	34.4
Eucalyptus sp. *Type A*	20	3.9	1	0.2	19	3.6	50	12.8	63	16.9	76	10.1	5	3.5	0	0
Eucalyptus sp. *Type B*	1	0.2	1	0.2	0	0	12	3.1	16	4.3	20	2.7	3	2.1	0	0
Eucalyptus indeterminate	5	1.0	1	0.2	7	1.3	38	9.7	20	5.4	32	4.3	5	3.5	0	0
Melaleuca sp.	18	3.5	22	5.4	6	1.1	6	1.5	5	1.3	7	0.9	1	0.4	0	0
Myrtaceae sp.	0	0	1	0.2	2	0.4	3	0.8	3	0.8	9	1.2	0	0	0	0

Table 2 (*continued*)

	SU1		SU2		SU7		SU8		SU9		SU10		SU11		SU12	
	n	% Nt	n	% Nt	n	% Nt	n	% Nt	n	% Nt	n	% Nt	n	% Nt	n	%Nt
Flueggea sp.	34	6.6	27	6.6	2	0.4	1	0.3	0	0	2	0.3	0	0	0	0
Grevillea/Hakea sp.	2	0.4	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Brucea sp.	7	1.4	5	1.2	5	1.0	4	1.0	1	0.3	0	0	0	0	0	0
Ni	373	72.0	328	79.8	341	65.1	157	40.1	165	44.2	178	23.8	35	24.5	17	53.1
Indeterminable	145	28.0	83	20.2	183	34.9	235	59.9	208	55.8	571	76.2	108	75.5	15	46.9
Nt	518	100	411	100	524	100	392	100	373	100	749	100	143	100	32	100

5. Discussion

5.1. Sampling procedures

Saturation or species-area curves are presented in Fig. 7 for the Holocene and Pleistocene units, with the exceptions of SU12 and SU11. The plateaux signify the number of fragments that need to be identified in order to sufficiently represent the diversity of the archaeological assemblage and evaluate the adequacy of the sampling strategy (Chabal et al., 1999; Scheel-Ybert, 2002; Lepofsky and Lertzman, 2005; Byrne et al., 2013; Dotte-Sarout et al., 2015). The SU1–2, SU7–10 assemblages reach plateaux; with the Holocene curves stabilising between 150 and 160 fragments, and the Pleistocene units stabilising by 130 fragments. These numbers of identifiable fragments per context are relatively small sample sizes when compared to tropical (400 fragments, see Scheel-Ybert, 2002; Dotte-Sarout et al., 2015) and even Mediterranean flora (200 fragments, see Chabal et al., 1999; Delhon, 2006). In addition to the saturation curve giving an indication of how well the assemblage represents the original deposits in terms of taxonomic diversity, Gini-Lorenz concentration curves were produced for SU1–SU10 (Fig. 8) to test the validity of the sample sizes in relation to diversity and frequency of taxa as compared to known measure for extant vegetation communities (cf. Chabal, 1992; Scheel-Ybert, 2002; Byrne et al., 2013; Dotte-Sarout et al., 2015). The Pareto Indices produced by the Gini-Lorenz curves range from 26:74 (SU7) to 29:71 (SU9), with a median ratio of 27:73 (SU2, SU8, SU10). On average then, 27% of the taxa from the assemblage comprise 73% of the individual fragments observed, the range of Scheel-Ybert (2002: 10)'s "normal" modal classes (c. 25:75). The ratio of 28:72 for SU1, where disintegration of charcoals is lower than the older units, shows that 300 fragments is the minimum number of identifiable fragments that need to be observed to represent the diversity of the assemblage. This is probably because despite the low diversity of woody taxa in the region, a high number of fragments (300–400) need to be sampled in order to adequately represent each of the vegetation units that people targeted for fuel wood (savanna, riparian, dry rainforest) (Fig. 7).

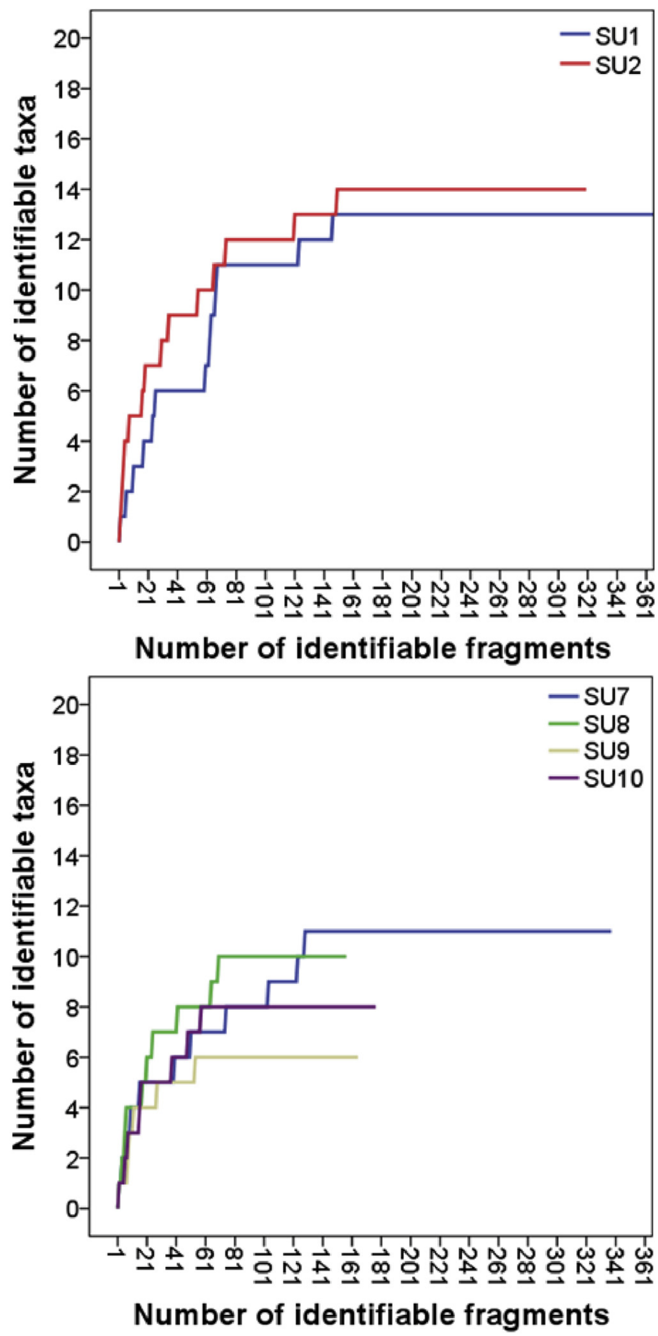

Fig. 7. Saturation curves of Riwi Holocene (top) and Pleistocene (bottom) units.

5.2. Cultural filters

Following the Principle of Least Effort (PLE), fuel wood is gathered in proportion to species availability and ease of collection (Shackleton and Prins, 1993); furthermore, fuel wood collection is often integrated within other economic occupations, such as hunting or food gathering (Asouti and Austin, 2005; Picornell Gelabert et al., 2011; Salavert and Dufraisse, 2014). Other Australian anthracological studies have shown that people favoured riparian contexts for gathering fuel, and have related these to the importance of water collection in arid to semi-arid environments (Smith et al., 1995; Frawley and O'Connor, 2010; Byrne et al., 2013). The only riparian taxon identified from the Riwi charcoal

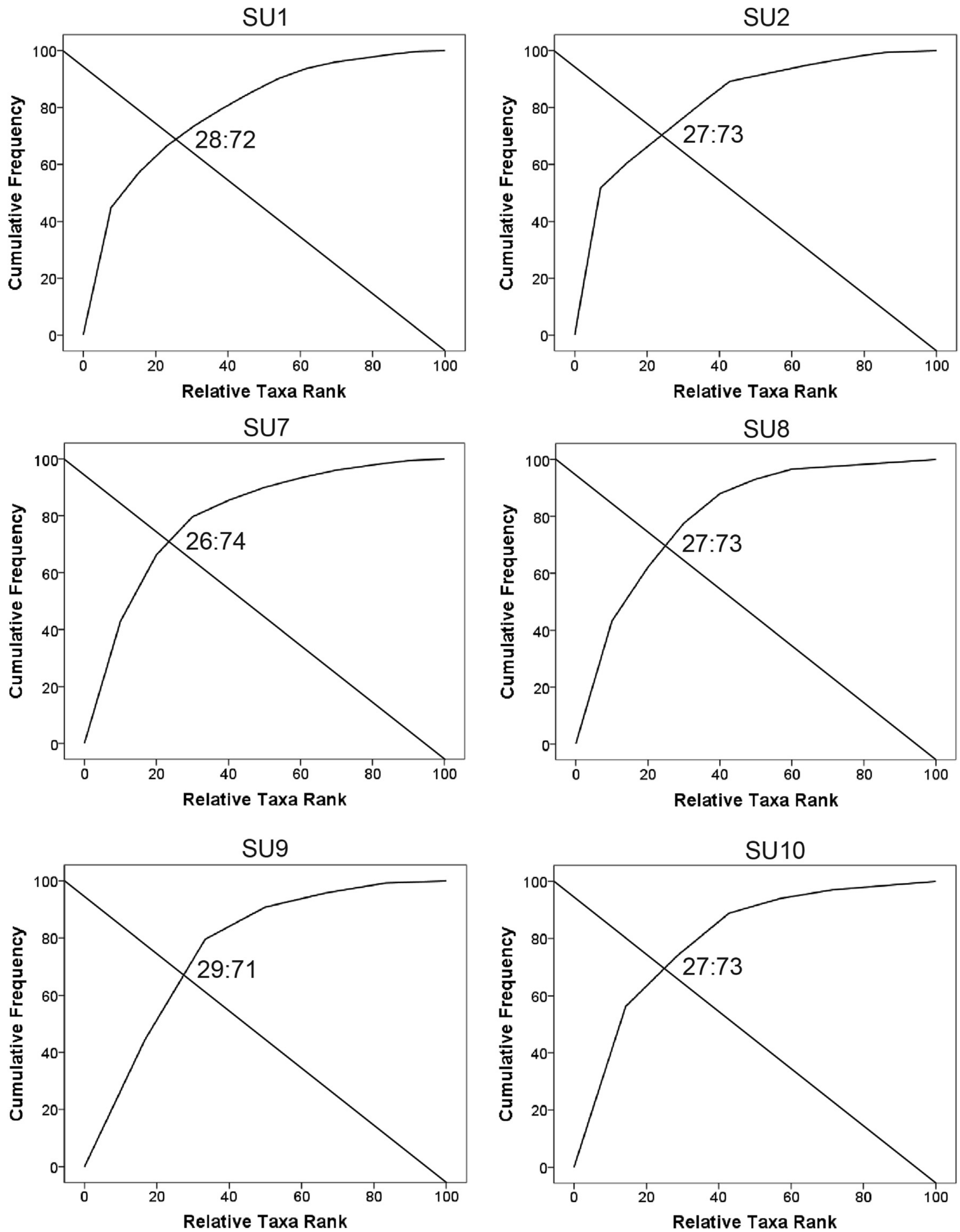

Fig. 8. Gini-Lorenz curves with Pareto Indices for SU1, SU2, SU7–10.

assemblage was *Melaleuca* sp., however, it is possible that one of (or both) of the *Eucalyptus* types are red river gum (*Eucalyptus camaldulensis*), which are a riparian species, and not one of the savanna eucalypts, such as snappy gum (*E. brevifolia*). Even if *Eucalyptus* spp. are included as part of a potential riparian element, other steppe/savanna taxa dominate the record (*Corymbia* sp., *Erythrophleum* sp., *Vachellia* sp., *Bauhinia* sp.), suggesting that people were targeting the valley floor and/or the plain for fuel wood. The overall dominance of *Corymbia* sp. reflects both the proportion of available *Corymbia* sp. in the environment and potentially that people were selecting it for fuel wood.

Dry rainforest taxa appear in the Pleistocene units, with the earliest recoveries of Lamiaceae, *Ficus* sp., *Flueggea* sp., and *Brucea* sp., occurring in SU12, SU11, SU10, and SU9 respectively, while *Celtis* sp. and *Mallotus* sp. both appear for the first time in SU7. The low abundance and diversity of dry rainforest taxa in the Pleistocene units could reflect the higher proportions of indeterminable taxa than the Holocene units, since these rarer elements would be expected to under fragment following the law of fragmentation, where abundant taxa over fragment and are over represented, while rarer taxa under fragment and are under represented (Vernet and Thiebault, 1987; Chabal, 1990, 1992; Chabal et al., 1999; Lancelotti et al., 2010; Théry-Parisot et al., 2010). The Holocene units, by contrast, have much higher proportions and diversity of dry rainforest taxa. These taxa produce important food sources for Indigenous people throughout the Kimberley (e.g. McConnell, 1997; Wallis, 2000, 2001; Dilkes-Hall, 2014). Indeed, the macrobotanical remains from Riwi also show a dominance of, or preference for, vine thicket species, particularly *Vitex glabrata*, and especially during the Holocene, although again this probably represents differential preservation (Dilkes-Hall, 2014).

Following the anthracological premise that domestic firewood collection is often embedded within other subsistence practices in Australia (see review in Dotte-Sarout et al., 2015), it is plausible that dry rainforest wood was collected for fuel during food collection. Dilkes-Hall (2014) argues that the dominance of these taxa in the macrobotanical record could signify both the existence and importance of vine thicket communities in the Mimbi area in the past. While this is certainly a plausible hypothesis, which could be supported by the increased abundance of dry rainforest taxa in the earliest Holocene unit, it is equally plausible that these highly vagile species survived independently, and not as a vine thicket association, within the protected areas of Mimbi's limestone hills. Since these taxa are economically important to Gooniyandi people today, the role of human agency in their survival is also worth considering, particularly in light of recent clado-linguistic and genetic analyses that explore the spread of boab (*Adansonia gregorii*) within the region (Rangan et al., 2015). It is worth noting here that the increase in *Mallotus* sp. in SU1 could reflect the fact that a *Mallotus nesophilus* tree now grows within the dripline of the cave. *M. nesophilus* is the only example of the *Mallotus* genus that is currently recorded in the region, and no other example of the tree was identified on survey. The ripe fruit of the tree is edible, and its growth within the cave could be an example of human dispersal, incidental or otherwise.

A hearth stick and a wooden artefact fragment were recovered from Riwi SU1, imaged using X-ray microtomography, and their wood types identified to Lamiaceae sp. and *Grevillea*/*Hakea* sp. respectively (Whitau et al., 2016). The hearth stick, which is the negative component of a two piece fire drill kit, is anatomically different from both the *Vitex* sp. and Lamiaceae sp. charcoal types. The anatomy of the wooden artefact fragment is also of a different type to Riwi's two *Grevillea*/*Hakea* sp. charcoals. Both wooden artefacts point to the selection of woods for specific purposes. The avoidance of Proteaceae wood as fuel is particularly interesting, since this has been noted in other anthracological studies within Western Australia's semi-arid to arid zone (Byrne et al., 2013; Dotte-Sarout and Byrne, 2013). In the Pilbara and Weld Range sites investigated by Byrne et al. (2013) and Dotte-Sarout and Byrne (2013), people avoided *Grevillea* species because these trees were large, and often anthropogenically scarred to mark the landscape. The *Grevillea* species, which grow around Riwi cave today, are small shrubs and unlike the Pilbara and Weld Range communities, are occasional to rare in distribution. If *Grevillea* species were typically shrubs and infrequently distributed during SU1 occupation, then it could be that the wood of this tree was avoided in order to manage the resource for artefact manufacture. Indeed, the woody taxa that comprise the modern vegetation are largely represented within the SU1 charcoal assemblage, with *Gyrocarpus americanus* and *Cochlospermum fraseri* the most conspicuous exceptions. *G. americanus* and *C. fraseri* are abundant throughout the modern vegetation communities within the site vicinity. While these taxa may have only recently colonised the valley floor, both are important economically to Gooniyandi people, the roots of *Cochlospermum fraseri* are eaten, and the bark of *Gyrocarpus americanus* is used to make containers or coolamon (Davis et al., 2011). The absence of *Gyrocarpus americanus* from the charcoal record is probably an example of avoidance, since the smoke of this species makes a very unpleasant pungent smell when burnt. The lack of *Cochlospermum* is probably a factor of preservation, with the unlignified parenchyma characteristic of the genus producing a less robust wood.

5.3. Palaeoenvironmental reconstruction

5.3.1. Pleistocene units

Fig. 9 provides a graphical representation of the anthracological data from Riwi, with taxa presented as proportions of the total number of fragments for each SU. Myrtaceae is the dominant family group across each of the SUs, with three genera (*Corymbia*, *Eucalyptus*, and *Melaleuca*) represented. *Eucalyptus* sp. Type A dominates the earlier Pleistocene units SU8, SU9, and SU10, with subsidiary components of both *Eucalyptus* sp. Type B and *Corymbia* sp. This relationship shifts during SU7, where *Corymbia* sp. increases and *Eucalyptus* spp. decrease in both abundance and diversity. *Corymbia* sp. remains the dominant charcoal type throughout the Holocene units. This suggests a change in species composition of the woody component of the savanna/steppe vegetation, from mixed *Eucalyptus* with subdominant *Corymbia*, to the modern composition of *Corymbia* with subdominant *Eucalyptus*. SU7 also sees an increase in *Erythrophleum* sp. and *Vachellia* sp., to proportions that are not replicated elsewhere in the record (22.6 and 12.9% respectively), suggesting a co-current increase in shrub cover.

The shift to *Corymbia* sp. dominance during SU7, coupled with an increase in shrub land, could be related to a change in water availability, and/or to a disturbance event such as fire. Water availability is the principal edaphic factor governing the distribution of Australia's eucalypts and their allies, and the interaction of topography and disturbance play a pivotal role in community composition and species distribution (e.g. Adams, 1996; Fensham et al., 2005, 2007; Allen et al., 2010). Although *Eucalyptus* and *Corymbia* species within the northern savanna regions are adapted to tolerate the dry season of the Australian summer monsoon, *Corymbia* are more likely to survive extended drought periods due to their deep root architecture and stomatal control (Rice et al., 2004; Fensham et al., 2005, 2014). The coincident increase of *Erythrophleum* sp. and *Vachellia* sp. further signals a vegetation shift. Species of the *Vachellia* genus tend to be associated with secondary shrublands, while the only *Erythrophleum* species that grows in the region is *E. chlorostachys*, or ironwood, a tree/shrub that grows in a wide variety of habitats and is capable of epicormic resprouting (Wheeler, 1992; Franklin et al., 2010). The major factors affecting ironwood growth and habit are light availability and/or competition (Woinarski et al., 2002), and indeed, at one particular site on Melville Island, ironwood responded to the clear-felling of the eucalypt overstory with a marked increase in sapling density (Fensham and Bowman, 1992).

The radiocarbon chronology suggests that SU7 started to be deposited between c.38 000–35 000 cal BP. The apparent increase in aridity reflected in the charcoal at Riwi is broadly coincident with similar vegetation changes observed in the limited number of terrestrial and marine records that span this period in north Western Australia. Of these, palynological analyses of marine cores from the Pilbara coast, Timor Sea, and Banda basin provide the most detailed archives for late MIS 3 environmental conditions in northern Western Australia. Although the IMAGES core MD01-2378, collected 300 km from the north western coastline of Australia, is at too low a temporal

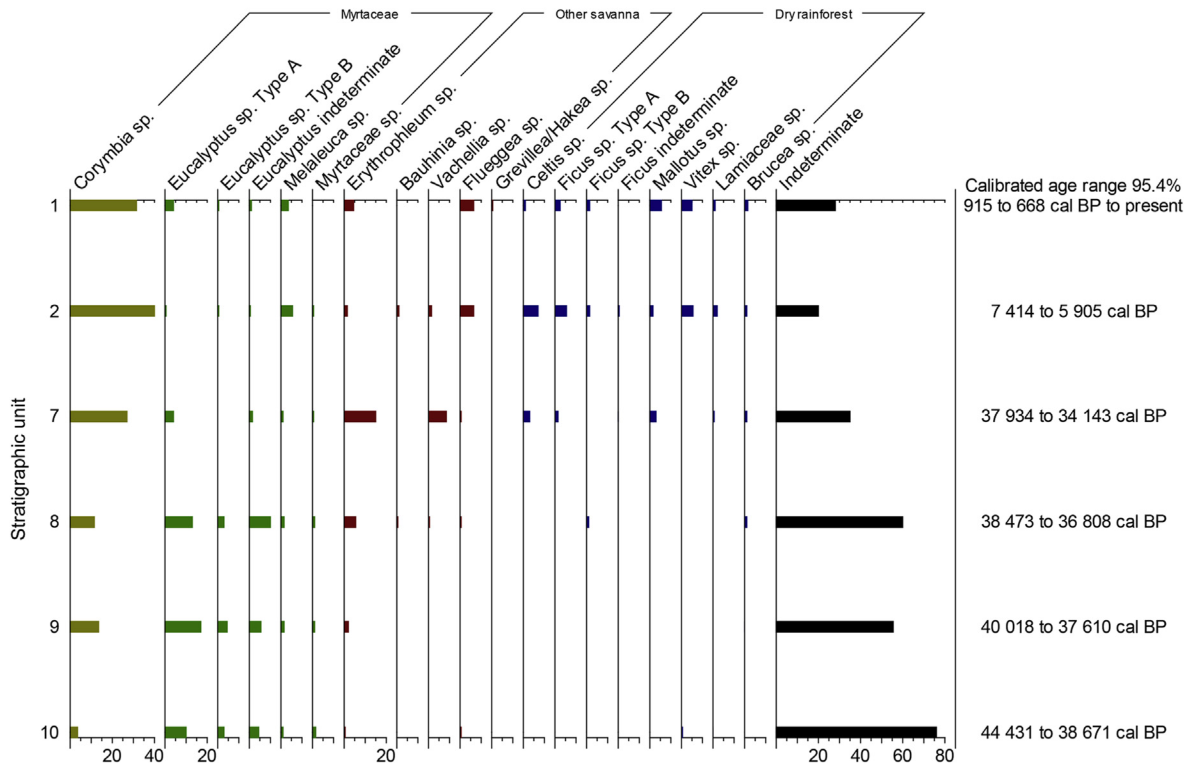

Fig. 9. Anthracological diagram, all data are presented as percentages of the total number of charcoal fragments analysed (Nt).

resolution to compare to Riwi (Kawamura et al., 2006), palynological analyses of marine core FR10/95-GC17, extracted 60 km from the north western tip of Western Australia, show a shift from Eucalypt woodland to Chenopod shrub land between ~40 and 37,000 on the neighbouring arid mainland. Climate transfer functions developed from marine core top samples along the northwest Australian coast (van der Kaars and de Deckker, 2003; van der Kaars et al., 2006) suggest that this reflects a decrease in summer rainfall (van der Kaars and de Deckker, 2002). A late MIS 3 vegetation change in north Western Australia finds further support from marine core SH1-9014, which was extracted from the Banda Basin (van der Kaars et al., 2000). Around 37,000, grass pollen increased relative to Eucalyptus, co-incident with a decrease in Dipterocarpaceae, the principal family group of the Indonesian rainforest (van der Kaars et al., 2000; Kershaw et al., 2003).

Unfortunately, few published terrestrial environmental records from north Western Australia span late MIS 3. Those that do, also suggest an increase in aridity shortly after 40,000. At the Lake Gregory catchment, the dating of palaeo-shoreline transformation ~37,000 indicates a regression from a high lake phase, with intermittent dune activity between ~35,000 and 11,500 suggesting more arid conditions, probably related to a weakened monsoon during the LGM (Wyrwoll and Miller, 2001; Veth et al., 2009; Fitzsimmons et al., 2013). Of particular interest is the formation of the Gidgee Dune, within the Gregory Lakes basin, where an Optically Stimulated Luminescence (OSL) sequence reveals the activation of linear dune formation between 35,200 ± 1400 and 34,000 ± 1500 (Fitzsimmons et al., 2012), which is coincident with Riwi SU7. A period of decreased fluvial activity follows the deposition of alluvium between 37,400 ± 6100 and 37,000 ± 3100 at Cabbage Tree Creek in the eastern Kimberley (Wende et al., 1997). The onset of aridity ~34,000 cal BP is also observed at Carpenter's Gap 1 rock shelter, with an increase in spinifex (*Triodia* spp.) macrobotanical and phytolith remains around this time, coupled with a disappearance of palm phytoliths in the latter part of the phase (Wallis, 2000, 2001; see Wallis, 2000: 309–327 for re-interpretation of McConnell's (1997) phases). The anthracological record from Riwi thus provides perhaps the strongest evidence in a terrestrial setting for the increase in aridity during this period suggested by the marine archives.

5.3.2. Holocene units

The SU2 charcoal assemblage, dating to around 7000 cal BP, is the most diverse unit, and this could reflect the relative humidity of the mid Holocene; however, this could also be an artefact of preservation. The SU2 charcoal assemblage shows a continued dominance of *Corymbia* sp., with very low abundance and diversity of *Eucalyptus* spp. (n = 3, 0.9%), and low proportions of *Bauhinia* sp. (n = 4, 1.2%) and *Vachellia* sp. (n = 6, 1.8%). The SU2 assemblage also includes considerable components of dry rainforest associated taxa: *Flueggea* sp. (n = 27, 8.2%), and 7.0% (n = 23) each of *Celtis* sp., *Vitex* sp., and *Ficus* sp. Type A. SU1, c. 1000 – 600cal BP, is broadly similar to SU2, and reflects the modern vegetation; *Corymbia* sp. dominates the woody taxa with a subsidiary component of *Eucalyptus* spp. No *Bauhinia* or *Vachellia* are present in SU1, which also parallels the modern valley floor composition, and the closest patch of this association occurs near Jones' Spring along Transect B (Fig. 5).

During the Holocene, occupation at Riwi cave can be correlated with periods of relative humidity, with phases of aridity associated with either site abandonment and/or stratigraphic absence. The mid-Holocene has been broadly characterised as a period of climatic warming and stabilisation, with increased fluvial activity peaking between ~10 and 6000 (Hesse et al., 2004; Fitzsimmons et al., 2013). Stable isotope profiles of U-series dated stalagmites from cave C126, Cape Range Peninsula (Denniston et al., 2013a); Ball Gown Cave, Napier Range

(Denniston et al., 2013b); and cave KNI-51, Ningbing Range (Fig. 1) (Denniston et al., 2015), provide unprecedented insight into palaeoclimatic patterns in the region. The C126 record reveals a general trend of low $\delta^{18}O$ values and rapid growth rates throughout the Holocene, with declining values during both the early Holocene and around 6500, which the authors attribute to a more southerly influence on the monsoon, and coupled with $\delta^{13}C$ minima at this time, increased monsoonal precipitation (Denniston et al., 2013a). This relatively humid period is followed by an arid phase, which is dated to between ~6 and 4000 with records of dune reactivation, coincident with site abandonment and/or stratigraphic absence at Riwi (Wyrwoll and Miller, 2001; Hesse et al., 2004; Fitzsimmons et al., 2007, 2012). Unlike the Pleistocene, Holocene inhabitation at Riwi was restricted to periods of relative humidity, with no evidence of sustained occupation during arid phases.

6. Conclusions

This paper presents the analysis of the largest anthracological assemblage in Australia at one of Australia's oldest archaeological sites, with over 3000 charcoal fragments examined from eight stratigraphic contexts that span some 45,000 years. Occupation at Riwi was discontinuous; the anthracological record supports an argument of site abandonment during arid phases within the Holocene, while occupation was sustained during an arid event in the Pleistocene. The vegetation shift observed in SU7 provides perhaps the strongest terrestrial evidence for the increase in aridity suggested by the marine archives. The dominance of steppe/savanna vegetation across the units is peculiar within the Australian anthracological record, where riparian taxa tend to be favoured for fuel consumption. Dry rainforest taxa, which were important economically, also comprise a minor proportion of the charcoal assemblage, lending support to the theory that Australia's prehistoric people were engaged with fuel collection during other subsistence activities. The selection of certain wood types for artefact manufacture, which do not appear in the anthracological record, illustrates that the past inhabitants of Riwi managed their wood resources for specific purposes, at least within the last 1000 years. Anthracological analysis of excavated features will help to elucidate the cultural filters and fuel procurement strategies used at the site.

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Appendix 1. Anatomical descriptions of archaeological wood charcoal types

Taxon	Porosity	Vessel elements	Fibres/tracheids	Axial parenchyma	Radial parenchyma
Celtis sp. Cannabaceae	Diffuse Growth boundary sometimes distinct	Radial groups 2–3 Diagonal patterns Bordered to scalariform, small to medium pits	Fibre walls thin	1 Confluent 2 Aliform/lozenge aliform 3 Vasicentric 4 Confluent to banded (2–4 cell wide bands) 5 Apotracheal aggregates	1–4 seriate Uniseriate parts as wide as multiseriate 2 to 25 cells long Ray cells heterogeneous, mixed Tile cells
Mallotus sp. Euphorbiaceae	Diffuse	Radial groups 2–6 Radial/diagonal Solitary pores angular outline Bordered, small pits	Fibre walls thick	1 Abundant apotracheal aggregates 2 Paratracheal aggregates 3 Wavy bands (1–3 cells wide)	Uni to tri seriate 7 to 35 + cells high Heterogenous Mixed Tile cells
Bauhinia sp. Fabaceae	Diffuse	2 pore size classes Clusters 2 (large) Radial groups (1 large, 2–6 smaller) Weak diagonal to tangential Simple, small pits	Fibre walls thick	1 Scalariform bands (2–4 cells wide) 2 Vasicentric 3 Winged aliform 4 Confluent Storied strands (2–4 cells long)	Uni to tri seriate 2 to 15 cells high Storied Heterogenous Procumbent body 1–2 rows upright/square
Erythrophleum sp. Fabaceae	Diffuse	Clusters 2–3 Weak tangential Bordered to scalariform, small pits	Fibre walls very thick	1 Lozenge aliform 2 Confluent 3 Short, wavy bands >4 cells 4 Diffuse apotracheal aggregates	Uni to 4 seriate 6 to 23 cells long
Vachellia sp. Fabaceae	Diffuse	Radial groups 2–4 (6) Radial/diagonal Bordered to scalariform, small pits	Fibre walls thick	1 Paratracheal confluent 2 Bands (2–7 cells wide) 3 Aliform/lozenge aliform Cells are quite blocky, form strands (2–4 cells long)	Uni to tri seriate 2 to 21 cells high Tile cells
Vitex sp. Lamiaceae	Diffuse Growth boundary sometimes distinct	Radial groups 2–3 Tangential bands Radial/diagonal lower density Bordered to scalariform, minute pits	Fibre walls thick	1 Scarce 2 Scanty paratracheal	1–4 seriate 6 to 40 cells high 2 sizes Tile cells Heterogenous Procumbent body, 2–4 rows of upright/square

(continued on next page)

(*continued*)

Taxon	Porosity	Vessel elements	Fibres/tracheids	Axial parenchyma	Radial parenchyma
Ficus sp. Type A Moraceae	Diffuse	Radial groups 2–4 Diagonal/radial Bordered to scalariform, small pits Simple plates	Fibre walls thick to very thick	1 Bands >4 cells (4–10) 2 Bands <4 cells (2–4) 3 Scanty paratracheal	Uni to 4 seriate 6 to 25 + cells high Heterogenous Procumbent body 1–3 rows upright/square Tile cells
Ficus sp. Type B Moraceae	Diffuse	Radial groups 2–5 Longer chains with 2 distinct pore sizes Diagonal/radial Abundant tyloses	Fibre walls very thick	1 Scalariform bands 6–12 cells wide Blocky cells, strands 6–12 cells long	Bi to 6 seriate 8 to 40 + cells high
Corymbia sp. Myrtaceae	Diffuse	Clusters 2–6 Dendritic to diagonal Tyloses abundant Vestured, minute/small pits Plates simple	Fibre walls thin to medium Distinctly bordered pits	1 Confluent 2 Winged aliform 3 Wavy bands (1–3 cells wide) Strands 2–4 cells long	Uni to biseriate 2 to 9 cells high Homogenous Procumbent
Eucalyptus sp. Type A Myrtaceae	Diffuse With abrupt change in pore density	Clusters 2 Strong diagonals Vestured, small/medium pits Plates simple	Fibre walls medium to thick Distinctly bordered pits	1 Abundant apotracheal aggregates 2 Paratracheal aggregates 3 Vasicentric	Uni to biseriate 2 to 9 cells high
Eucalyptus sp. Type B Myrtaceae	Semi-ring porous	Clusters 2–3 Diagonal Vestured, small/ medium pits Plates simple	Fibre walls medium	1 Scanty paratracheal 2 Diffuse apotracheal aggregates	Uni to biseriate 1 to 10 cells high
Melaleuca sp. Myrtaceae	Diffuse	Mostly solitary Diagonal to radial Vestured changeable pits	Fibre walls medium Distinctly bordered pits	1 Scarce apotracheal aggregates 2 Scanty paratracheal	Uni to biseriate 1 to 13 cells high
Flueggea sp. Phyllanthaceae	Diffuse	Radial chains 2–6 (8–12) Radial Bordered to scalariform, very minute pits	Fibre walls very thick	1 Abundant apotracheal aggregates 2 Paratracheal aggregates	Uni to tri seriate 3 to 23 cells high Tile cells
Grevillea/*Hakea* sp. Proteaceae	Diffuse	Clusters 2 Tangential (+weak diagonal), festooned Scalariform to bordered, minute pits Plates simple	Fibre walls thick to very thick Simple to minutely bordered pits	1 Festooned, confluent 2 Lozenge/winged aliform Fusiform parenchyma cells	Rays of 2 sizes Uni to triseriate, 4 to 13 cells high 10–14 seriate, 100 + cells high
Brucea sp. Simaroubaceae	Porous	Clusters 2–3 Diagonal/weak tangential Bordered to scalariform, minute pits Plates simple Consistently helical thickenings throughout	Fibre walls thin	1 Paratracheal aggregates 2 Apotracheal aggregates	Uni to tri seriate 2 to 15 cells high

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Chapter 4. Home is Where the Hearth Is: Anthracological and Microstratigraphic Analyses of Pleistocene and Holocene Combustion Features, Riwi Cave (Kimberley, Western Australia)

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Rose Whitau: developed the research question; undertook field work; created the reference collection; recorded and analysed the anthracological data; formulated the arguments in the manuscript; drafted the majority of the manuscript, including the Introduction, Site Description, Sampling, Anthracological Methods, Anthracological Results, Discussion, and Conclusions sections; edited and reviewed the manuscript.

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Home Is Where the Hearth Is: Anthracological and Microstratigraphic Analyses of Pleistocene and Holocene Combustion Features, Riwi Cave (Kimberley, Western Australia)

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Abstract The manipulation of fire is a technological act. The identification of the archaeological signatures of the controlled use of fire has important implications not only for the estimations of the origins and functions of the first fireplaces but also for our understanding of prehistoric technological development and resource use. At Riwi (Kimberley region, Western Australia), excavations over two field seasons have revealed a discontinuous occupation sequence over the past 45 ka, showing numerous, different combustion features interspersed within the deposit. Anthracological and micromorphological investigations at Riwi Cave indicate that the combustion features at the site can be categorised into three types: flat combustion features (type A), dug combustion features (type B) and thick accumulations of mixed combustion residues (type C). These provide evidence for two kinds of combustion practice: (i) fires lit directly on the ground and most likely not re-used and (ii) ground ovens, the latter appearing some 10,000 years after the first evidence for occupation of the site. A comparison of the wood species identified within these combustion features with those from equivalent scattered context levels, enables an exploration of the potential factors influencing wood selection and fire use through time at the site. A detailed

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understanding of the relationship between wood charcoal remains and archaeological context yields significant information on changes to environmental context and site occupation patterns over time.

Keywords Hearths · Combustion features · Anthracology · Micromorphology · Fuel wood management · Australian archaeology

Introduction

An essential component of the hunter-gatherer tool-kit, fire is a source of light, warmth, protection and an instrument for cooking, manufacturing equipment and altering the environment. The origins and functions of the first fireplaces have important implications for hominin evolution and form a key debate in Palaeolithic archaeology (*e.g.* Alperson-Afil and Goren-Inbar 2010; de Lumley 2006; Goudsblom 1986; Gowlett 2006; Gowlett and Wrangham 2013; James *et al.* 1989; Roebroeks and Villa 2011; Sandgathe *et al.* 2011; Wrangham 2009), with the first habitual, controlled uses of fire linked to increases in brain size and cognition (Brain 1981; Gowlett 2006; Pruetz and LaDuke 2010; Rolland 2004; Wrangham 2009) and the colonisation of the northern latitudes (Brace *et al.* 1987; Gowlett 2006; Oakley 1956; Preece *et al.* 2006; Rolland 2004; Stratus 1989; Weiner *et al.* 1998; Wrangham *et al.* 1999). Evidence for anthropogenic fire can be contextually variable and, in the case of the earliest examples, highly contentious (*e.g.* Berna *et al.* 2012; for a recent review on the evidence of human use and control of fire, see Goldberg *et al.* 2017; Stahlschmidt *et al.* 2015, pp. 181–183). The most unambiguous signature for the habitual, controlled use of fire is the structured hearth, with the earliest evidence found in Qesem Cave in Israel, dated approximately to 400 ka (Karkanas *et al.* 2007; Shahack-Gross *et al.* 2014).

The identification of the archaeological signatures of hearth-building processes has important implications not only for the estimation of the first controlled uses of fire but also for understanding of prehistoric technological development and resource use. A suite of techniques for both the macro- and micro- scale analyses of combustion structures are currently employed, ranging from the *in situ* description of hearth structures (*e.g.* Metcalfe and Heath 1990; Solé *et al.* 2013; Vaquero and Pastó 2001), to the physical and chemical analysis of charred components and sediments with the application of geophysical (*e.g.* Barbetti 1986; Bellomo 1991, 1993), geochemical (*e.g.* Karkanas *et al.* 2002; Rudner and Sumegi 2002), micromorphological (*e.g.* Mallol *et al.* 2013a; Mentzer 2014; Schiegl *et al.* 2004; Wattez 1992; *cf.* review in Aldeias 2017) and anthracological analyses (*e.g.* Beauclair *et al.* 2009; Henry and Théry-Parisot 2014; Scheel-Ybert *et al.* 2014; Vidal-Matutano 2016). The study presented in this paper combines the latter two approaches, anthracology and micromorphology, to explore building processes of hearths from an Australian Indigenous archaeological context.

Microstratigraphic investigations of combustion features can help document the anthropogenic activities associated with their formation and also assess their degree of preservation or alteration (Mallol *et al.* 2013a; Mentzer 2014; Wattez 1992), by identifying their components (Estévez *et al.* 2014; March *et al.* 2014; Mentzer 2014; Stiner *et al.* 1995; Wattez 1988; Weiner *et al.* 1995), deciphering whether they are intact or disturbed (Goldberg *et al.* 2009; Mallol *et al.* 2013a; Mentzer 2014; Miller and Sievers 2012; Miller *et al.* 2010), documenting how they have affected the substrate (Aldeias *et al.* 2016; Canti and Linford 2000; Mallol *et al.* 2013b) and to what extent they have been affected by post-depositional processes (Karkanas 2010; Karkanas *et al.* 2000; Karkanas *et al.* 2002; Mentzer 2014). Soil morphology experiments and ethnoarchaeological investigations have identified various characteristics of combustion features (Courty *et al.* 1989; Macphail *et al.* 2004; Mallol *et al.* 2007; Wattez 1992; Miller *et al.* 2013) that have been applied to archaeological contexts. These include distinguishing single from multiphase hearth use (Meignen *et al.* 1989, 2007), discriminating hearths from secondary ash dumps (Schiegl *et al.* 2003) and detecting burned stable layers (Macphail *et al.* 2004).

Anthracological investigations of wood charcoal assemblages follow the premise that hearth features and concentrations of dense charcoal are episodic archaeological contexts. They are the primary refuse of the last few firing events, whereas dispersed wood charcoal from scattered contexts are secondary refuse, potentially accrued over a more protracted period of time (Asouti and Austin 2005; Byrne *et al.* 2013; Chabal 1990, 1992; Chabal *et al.* 1999; Dotte-Sarout *et al.* 2015; Théry-Parisot *et al.* 2010). Where wood charcoal analyses are employed for palaeoenvironmental reconstruction, hearths and concentrated charcoal features must be avoided, and scattered charcoal from occupation contexts must be examined in order to represent the accumulation of multiple fuel wood collection events, so that more of the site's surrounding environment will be represented (Badal-García *et al.* 2012; Chabal *et al.* 1999; Dufraisse 2012, 2014; Théry-Parisot *et al.* 2010; Scheel-Ybert 2002). Concentrated features, such as charcoal lenses and hearths, should be analysed in conjunction with scattered contexts to tease out the cultural factors that influence the creation of a charcoal assemblage at a site (Asouti and Austin 2005; Byrne *et al.* 2013; Théry-Parisot *et al.* 2010). However, in spite of this premise which is essential to the discipline, very few anthracological studies have explicitly employed micro-scale techniques to define the combustion context of a site in order to understand combustion processes better (*e.g.* Allué *et al.* 2017; Damblon *et al.* 1996; Damblon and Haesaerts 2002; Vidal-Matutano 2016).

In the Australian archaeological context, various geoarchaeological and archaeological analyses have explored the formation and post-depositional alterations of hearth features at open sites, particularly at Sturt National Park in arid western New South Wales (Fig. 1; Fanning and Holdaway 2001; Fanning *et al.* 2008, 2009; Holdaway *et al.* 2017) and Olympic Dam in northeastern South Australia (Fig. 1; Sullivan *et al.* 2012; Sullivan and Hughes 2013). Analysis of sedimentary processes within Australian rock shelters has concentrated largely on preservation potential (Ward 2004; Ward and Larcombe 2003; Ward *et al.* 2006) and the vertical movement of artefacts (Allen and O'Connell 2003; Bird *et al.* 2002; Hiscock 1985, 1990). With the exception of micromorphological analyses conducted at Carpenters Gap 1 rockshelter (Fig. 1; Vannieuwenhuyse 2016; Vannieuwenhuyse *et al.* 2017), which revealed the presence of combustion features' rake-out zones in the Late Pleistocene and Holocene archaeological levels, few attempts have been made in Australian archaeology to understand how fireplaces were built, maintained and used by Indigenous hunter-gatherer populations. Similarly, very few anthracological investigations have been conducted in Australian contexts, although the number of statistically viable analyses is starting to improve (see Byrne *et al.* 2013; Carah 2010; Dotte-Sarout *et al.* 2015; King 2015; Whitau *et al.* 2016a).

In this paper, we present the results from combined anthracological and micromorphological analyses of combustion features at Riwi Cave in the southern Kimberley

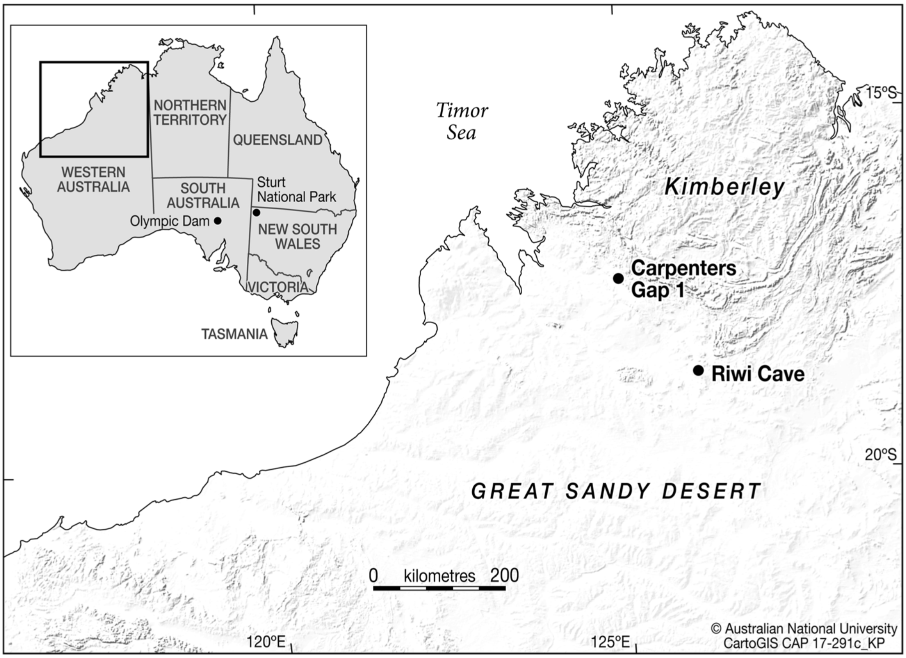

Fig. 1 Northern Western Australia with inset of Australia and sites mentioned in the text (CAD: CartoGIS, Australian National University)

region of northern Western Australia. At Riwi, excavations have revealed a discontinuous occupation sequence over the past 45 ka showing numerous different combustion features interspersed within the deposit (Balme 2000; Vannieuwenhuyse 2016; Whitau *et al.* 2016a; Wood *et al.* 2016). This sequence represents an exceptional opportunity to undertake a combined and detailed geo-anthracological analysis in order to explore the depositional and post-depositional factors that have affected the creation and preservation of hearths. We propose a typology of these features based on their sedimentological and anthracological characteristics. The wood species identified within the hearths are compared with the spectrum of charcoal identified from contemporaneous scattered contexts, which are more representative of the broad vegetation changes in the vicinity of the site (see anthracological analysis in Whitau *et al.* 2016a). The combined anthracological and micromorphological approaches enable an investigation of the possible factors influencing wood selection, fire-use and deep-time combustion features related practices in an Australian archaeological context.

Site Description, Context and Antiquity

Riwi Cave is located in the southern Kimberley region of Western Australia (Fig. 1), within the traditional lands of the Indigenous Gooniyandi people, on the northern edge of the Great Sandy Desert. Located in the South Lawford Range and formed within Devonian Pillara and Sadler limestone facies (Playford *et al.* 2009, p. 251), the cave is situated within a valley enclosed by low-range outcrops, through which an ephemeral creek flows during the wet season. Receiving a sub-tropical to semi-arid climate within the 500-mm isohyet of the Australian Summer Monsoon (Bureau of Meteorology 2015), the skeletal soils of the Riwi valley support a low tree steppe: hummock grassland (*Triodia bitextura*) with scattered bloodwood (*Corymbia dicromophloia/Corymbia opaca*) and snappy gum (*Eucalyptus brevifolia*). A variety of dry rainforest associated taxa, including *Celtis strychnoides*, *Dodonaea polyzyga* and *Flueggea virosa* grow along the limestone range and outliers (Whitau *et al.* 2016a). The cave is composed of two chambers, and a channel running through the north-west side of the front chamber, where a yellow ball flower tree (*Mallotus nesophilus*) grows, signifies water circulation in the cave during the wet season (for site review and plan, see Vannieuwenhuyse 2016; Wood *et al.* 2016; Whitau *et al.* 2016a). Vestigial evidence of past human occupation includes rock art on the cave walls and lithic artefacts scattered across the floor of the cave's entrance.

Riwi Cave was first excavated in 1999 (Balme 2000). In 2013, the original 1 m^2 test pit (square 1) was emptied and the excavation area expanded, with the addition of 2 × 1 m^2 test pits inside the cave (squares 3 and 4) and one 1 m^2 test pit at the entrance of the cave (square 5). All squares were taken to bedrock in 50 cm quadrants in arbitrary 2 cm units, reaching an approximate maximum depth of 115 cm in squares 1, 3 and 4 (Figs. 2 and 3). With the exception of certain features, which were removed separately, and bulk sediment samples, which were collected for each excavation unit, all excavated materials were sieved though nested 5 and 1.5 mm screens. Because the Holocene units were desiccated, flotation was avoided. A detailed description of both the cave and the excavation specifics can be found in Whitau *et al.* (2016a) and Wood *et al.* (2016).

A precise radiocarbon chronology, coupled with a detailed optically stimulated luminescence (OSL) chronology, provides one of the most accurately dated archaeological sequences in Australia (Wood *et al.* 2016). The two chronologies are largely consistent throughout the sequence, both identify earliest occupation of the site around 46.4–44.6 ka

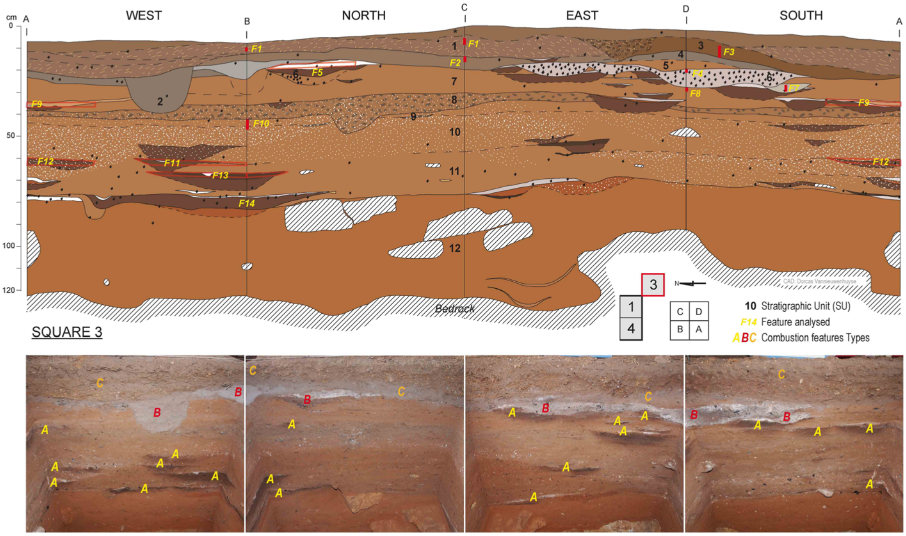

Fig. 2 Riwi square 3 section and photos showing the provenience of combustion features and scattered charcoal assemblages used for the anthracological analysis. Refer to text and Fig. 4 for combustion features typology (photos and CAD: Dorcas Vannieuwenhuyse)

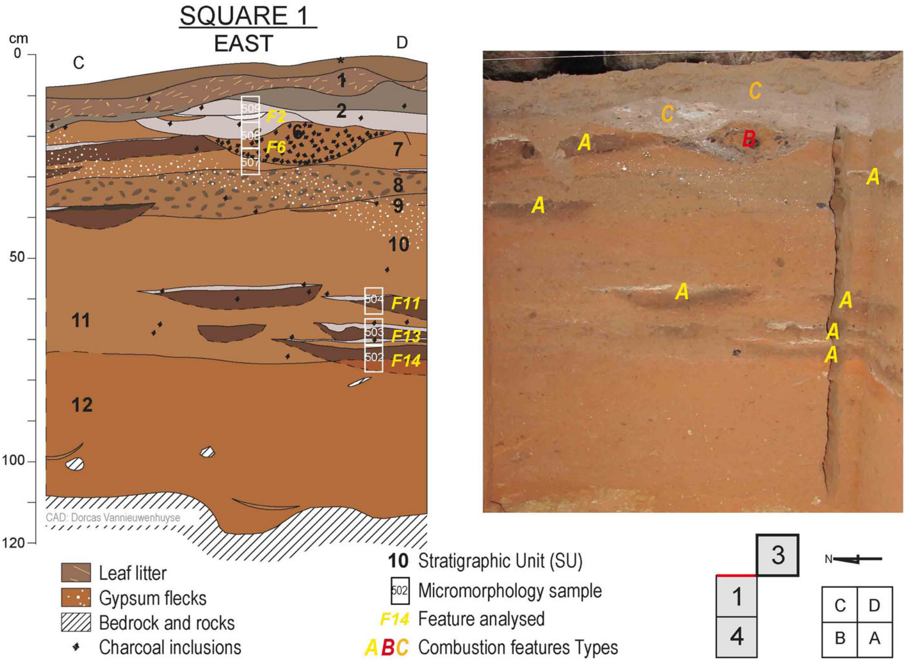

Fig. 3 Riwi square 1 sections and photos showing combustion features sampled for the micromorphological analysis. Refer to text and Fig. 4 for combustion features typology (photos and CAD: Dorcas Vannieuwenhuyse)

cal BP (95.4% probability range) at the top of SU12, and both confirm the presence of several chrono-stratigraphic hiatuses in the upper levels of the sequence (Vannieuwenhuyse 2016; Wood *et al.* 2016). The radiocarbon chronology was mainly based on charcoal sampled from the numerous combustion features interspersed within the Riwi archaeological levels (Figs. 2 and 3). Detailed information about the provenance and stratigraphic context of the dated charcoal was gathered by the geoarchaeological observations undertaken in the field. The anthracological analysis provided background information on charcoal wood species and the context of charcoal production (see Table 1). These data are usually limited or not available in the construction of radiocarbon chronologies in Australian archaeological contexts (Ward *et al.* 2016), which are often only based on the age of charcoal fragments with little reference to the context of that charcoal's production (Wood 2015; Wood *et al.* 2016). The limited reporting of these data is in spite of recent work conducted elsewhere that characterises the spatial relationship between charcoal and charred seeds selected for radiocarbon analysis and associated archaeological materials and features (Asscher *et al.* 2015; Boaretto 2015; Boaretto *et al.* 2009; Rebollo *et al.* 2011; Toffolo *et al.* 2012).

Materials and Methods

Sampling

The Riwi anthracological and micromorphological samples were collected from the July 2013 excavations and from the archaeological material recovered and sorted in the

Table 1 Combustion features from Riwi squares 1, 3 and 4 analysed for the study

Features—details							Radiocarbon dates associated				
Feature	Feature description	Type	SU	SQ	XU/ Quad	Microm sample	Lab. code	Sampling context	Wood species	Radiocarbon age	Modelled calibrated age range 2σ
F1-C	Brown grey layer (mix of very fine sand with abundant leaf litter, charcoal and ash)	C	1	3	2B, 3C		SANU-43337	From sieve	*Grevillea/Hakea* sp.	670 ± 20	655–555
F2-C	Grey-brown ashy layer with charcoal and few leaves	C	2	3	6C		SANU-39505	From sieve	*Corymbia* sp.	6385 ± 30	N/D
				1	D	*R509; R508 top*	D-AMS004061	From feature (wall)	Not determined	6250 ± 35	7245–7010
F3-A	Grey to black fine to very fine ash with abundant charcoal inclusions	A	3	3	4D, 5D		S-ANU38226	From feature (excavation)	*Corymbia* sp.	16,930 ± 50	20,620–20,040
							SANU-38814	From feature (excavation)	*Corymbia* sp.	16,850 ± 100	20,620–20,040
F4-B	Compact white ash with abundant charcoal inclusions in concave pit	B	6	3	6B		S-ANU35920	From feature (wall)	*Corymbia* sp.	30,110 ± 200	34,380–33,720
							D-AMS 004070	From feature (wall)	Not determined	30,154 ± 141	34,370–33,780
F5-B	Hearth with packed chunks of charcoal in large concave pit, interspaces filled by ashes, very sharp boundary with SU7	B	6	3	8D		SANU-39506	From feature (wall)	*Corymbia* sp.	29,050 ± 180	34,040–33,170
F6-B	Hearth with packed chunks of charcoal in large concave pit, interspaces filled by ashes, very sharp boundary with SU7	B	6	1	D	*R508 bottom, R507 top*	S-ANU35907	From feature (wall)	*Corymbia* sp.	29,790 ± 190	34,180–33,580
F7-B	Compact ash with a high density of burnt bone and charcoal in the southeast corner	B	7	3	10D						Between end of SU7 (36,040–34,130) and start of SU6 (34,920–33,850)
F8-A	Ashy sediment with charcoal inclusions, diffuse boundary with burnt red sediment	A	7	3	11D						Between end of SU7 (36,040–34,130) and start of SU6 (34,920–33,850)
F9-A		A	7	3	13A						

Table 1 (continued)

Features—details							Radiocarbon dates associated				
Feature	Feature description	Type	SU	SQ	XU/ Quad	Microm sample	Lab. code	Sampling context	Wood species	Radiocarbon age	Modelled calibrated age range 2σ
	Small hearth with burnt sand, ash and abundant charcoal										Between end of SU8 (38,130–36,010 and start of SU7 (37,670–35,590 37,934–35,807)
F10-A	Black, compact, fine sediment, with gypsum nodules (2–5 mm)	A	9/10	3	16B, 17B		S-ANU35919	From feature (wall)	Unidentifiable	34,000 ± 310	38,850–37,740
F11-A	Compact dark sediment with charcoal inclusions	A	10/11	3	23B						Between end of SU11 (45,080–42,110) and start of SU10 (44,060–40,490)
				1		*R504*					
F12-A	Well-defined black, compact sediment with charcoal inclusions and gypsum nodules (2–5 mm)	A	10/11	3	23A						Between end of SU11 (41,692–38,671) and start of SU10 (40,018–37,932)
F13-A	Well-defined black, compact sediment with charcoal inclusions and gypsum nodules (2–5 mm)	A	11	3	25B						Within SU11, between 45,420–43,900 and 45,080–42,110
				1		*R503*	ANUA-13005	From level (excavation)	Not determined	41,300 ± 1020	45,180–43,410
F14-A		A	11/12	1		*R502*	SANU-35909	From feature (wall)	*Corymbia* sp. (type R01)	41,590 ± 760	45,900–44,470

A short description is given for each feature with associated combustion features types, stratigraphic context (SU) and related excavation units (XU) from where anthracological (A) and micromorphological (M) samples were collected. When available, radiocarbon dates directly associated with the feature or same stratigraphic level are given. Radiocarbon dates are mentioned calibrated against SHCal13 (Hogg *et al.* 2013) in OxCal v.4.2 (Bronk Ramsey, 2009) following radiocarbon chronology done for the site by Wood *et al.* (2016)

laboratory. Twelve combustion features from Riwi square 3 were selected for anthracological analysis (Fig. 2) in conjunction with the analysis of scattered contexts from squares 3 and 4 presented in Whitau *et al.* (2016a). Six micromorphological samples targeting combustion features were extracted from the eastern sections of square 1 (Fig. 3). The proximity of the sampling and the similarities in type of combustion features observed between the two squares allows the comparison and incorporation of both anthracological and micromorphological results to build our analysis. Table 1 presents an overview of the different combustion features and scattered charcoal assemblages analysed for the study, their stratigraphic and sampling context, their typology and their antiquity. Radiocarbon ages follow those of Wood *et al.* (2016) and are given as modelled calibrated values calculated using OxCal 4.2, using SHCal13 or Marine13 calibration curves (Bronk Ramsey 2013; Ramsey and Lee 2013; Ramsey *et al.* 2013; Reimer *et al.* 2013).

Microstratigraphic Methods

Oriented micromorphological sediment samples were extracted using plaster bandages (Goldberg and Macphail 2003, 2005), which were then prepared following the standard fabrication processes for soil thin sections (Camuti and McGuire 1999; Courty *et al.* 1989; FitzPatrick 1984). Resin impregnation of these monoliths was undertaken at the geotechnical facilities of the School of Earth and Environment at the University of Western Australia. Small pre-cut chips (54 × 63 × 10 mm) were sent to Spectrum Petrographics (Vancouver, Washington, USA) for thin sectioning. Thin sections were digitally scanned for archival and publication purposes (Arpin *et al.* 2002; De Keyser 1999). Thin section observations and microphotography were carried out using a Nikon polarising petrographic microscope in the School of Earth and Environment at the University of Western Australia. Observations were made under different magnifications (×10, ×25, ×50, ×100, ×500) using both plane polarised (PPL) and cross polarised light (XPL). Descriptions follow the terminology standardised by Stoops *et al.* (2010). Identification and interpretation of components and pedofeatures are based on the available micromorphology literature (primarily Bullock *et al.* 1985; Courty *et al.* 1989; Goldberg and Macphail 2005; Stoops *et al.* 2010) and case studies as cited in the text.

Anthracological Methods

All anthracological analysis was conducted at the Department of Archaeology and Natural History at the Australian National University. Charcoal was identified by snapping fragments along the transverse, radial and tangential longitudinal sections, with the aid of a scalpel where necessary (following Leney and Casteel 1975). An Olympus BH-2 reflected lightfield/darkfield microscope was used to examine exposed sections at magnifications of ×20–500. Rare types and archetypal examples of taxa were selected for further observation and imaging with a JEOL JCM-6000 Neoscope scanning electron microscope (SEM). Following Chabal (1990, 1992) and Théry-Parisot *et al.* (2010), quantification was conducted by count, rather than weight. All of the charcoal fragments over 2 mm were examined from each feature (see feature list in Table 1), except F1-C and F2-C, which are Riwi's two Holocene stratigraphic units (SU1 and SU2 in Whitau *et al.* 2016a). F1-C and F2-C are composed of an accumulation of combustion features mixed with other natural inputs, wherein features could not be sampled separately due to their thin morphology and the palimpsest nature of their deposition. All of the excavated sediment from F1-C and F2-C was collected during excavation within squares 3 and 4, with all of the > 1.5 mm charcoal fragments transported to the laboratory for anthracological analysis. A minimum of 300 identifiable fragments was sampled for the Holocene units, and a riffle-box was used to split the samples to ensure an unbiased coverage of size differentiation.

Following Whitau *et al.* (2016a), charcoal fragments are described as indeterminate when type-level identification cannot be positively assigned and indeterminable where fragments cannot be positively identified due to degradation. Archaeological material was compared with the reference material housed at the Australian National University described by Whitau *et al.* (2016a). Wood identification keys including Hope (1998), Ilic (1991) and two online databases: Inside Wood (http://insidewood.lib.ncsu.edu/) and the University of Queensland Online Archaeology Collections (http://uqarchaeologyreference.metadata.net/archaeobotany/list) were also employed to aid identification.

Results

Based on excavation, sediment and anthracological observations, combustion features in the Riwi sequence have been grouped into three different types (Fig. 4; Table 1): flat combustion features (type A), dug combustion features (type B) and palimpsest of combustion features (type C). The features analysed in this study are numbered from top to bottom, with a suffix for the combustion feature type. For example, F1-C is the highest feature in the sequence and a type C combustion feature. The sedimentary and anthracological characteristics of each type of combustion feature are detailed and compared in the following sections. Each type, with the exception of F3-A, appears to be found in subsequent chronostratigraphical levels, as demonstrated by the site's sequence (Figs. 2 and 3).

Description of Combustion Features in Riwi Sequence

Interdisciplinary analyses conducted on the site have demonstrated that Riwi was occupied on a regular basis from 45 ka up to the European contact period, despite a visibly

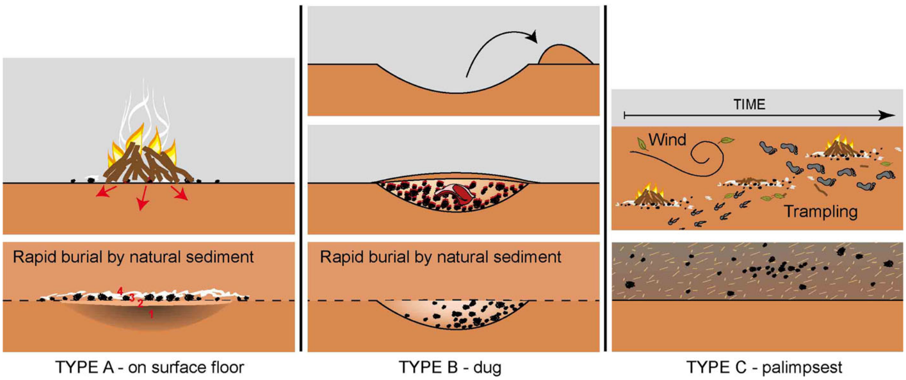

Fig. 4 Combustion feature types found in Riwi (modified from Vannieuwenhuyse 2016)

discontinuous stratigraphic record (Vannieuwenhuyse 2016; Wood *et al.* 2016). The combustion features comprise the main non-material evidence for anthropogenic inputs within the Riwi sequence, and as such, provide exceptional insights into past behaviours over time.

The Pleistocene layers (SU12 to SU5, from the bottom to approximately 20 cm below the surface) have an excellent integrity and reveal the presence of numerous flat combustion features (type A; F8 to F14) appearing at the top of SU12, approximately 40 cm from the bedrock (Figs. 2 and 3). Several dug combustion features (type B; F4 to F7) are visible at the top of the Pleistocene sequence and at the bottom of the Holocene layers. In most of the observed sections, a sharp disconformity places Holocene ash-rich deposit (type C; F1 and F2) directly above the orange Pleistocene layers dated to 34–31 ka. However, discrete episodes of sedimentation have been preserved in some places, in particular, SU3, which includes charcoal and hearths (F3-A) dated to the Last Glacial Maximum (LGM, two charcoal dated at 20620–20040 cal BP, see Table 1) and is only visible in the south-east corner of square 3 (Fig. 2, see also figures in Vannieuwenhuyse 2016; Wood *et al.* 2016). The Holocene layers (F1-C and F2-C) are dated to 7 ka and 0.8–0.7 ka and are mainly composed of an ash-rich accumulation (type C) that encompasses compacted combustion residues (ash, charcoal) and other vegetal organic remains. Preservation of organic material *via* desiccation within the Holocene layers is exceptional and includes seeds, fruit fragments, paperbark fragments (*Melaleuca* spp. bark that had and still has a myriad of uses across Aboriginal groups of Australia, *e.g.* Wynjorrotj *et al.* 2005; Yunupingu *et al.* 1995), wood shavings and two wooden artefact fragments (Dilkes-Hall 2014; Langley *et al.* 2016; Whitau *et al.* 2016b).

Microstratigraphic Results

The Riwi natural sequence is composed of a mix of geogenic, botanical and animal bone fragments in various proportions (detailed results of the Riwi archaeo-stratigraphical sequence geoarchaeological analysis and a full description of the micromorphological thin sections analysed can be found in Vannieuwenhuyse 2016). While the Pleistocene layers are predominantly composed of geogenic particles, giving the sediment a strong orange hue within which combustion features are easily distinguishable, the Holocene deposit is grey because of the predominant proportion of combusted botanical residues (Figs. 2 and 3). Across the five combustion features sampled for micromorphology (three type A: F11-A, F13-A, F14-A; one type B: F6-B; and one type C: F2-C, see Table 1; Fig. 3), the main combustion by-products observed are vegetal residues (phytoliths, ash, seeds, wood charcoal) and some animal bone fragments (Fig. 5), observed at various burning stages (partially burnt, charred, turned to ash) and in varying states of preservation (depending on syn- and post-depositional modifications, *e.g.* decomposition, alterations).

Anthracological Results

Across the features sampled (seven type A: F3-A, F8-A, F9-A, F10-A, F11-A, F12-A, F13-A; three type B: F4-B, F5-B, F7-B; and two type C: F1-C, F2-C, see Table 1; Fig. 2), a total of 2824 charcoal fragments were analysed, 1861 of which were positively identified to varying taxonomic ranks. Table 2 lists the positively identified taxa, with their relative frequencies for each feature expressed in terms of absolute fragment counts and the percentages of the total number of fragments analysed. A total of 19 taxa, including

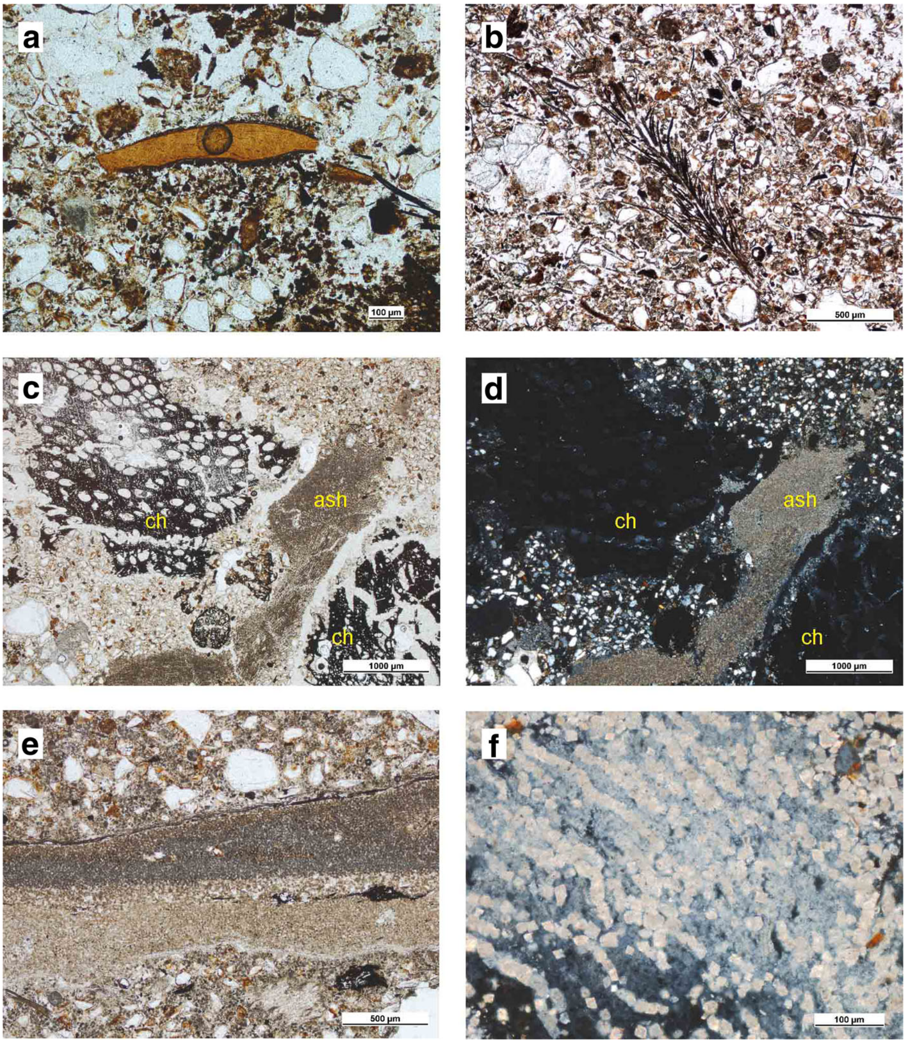

Fig. 5 Microphotographs of combustion by-products observed in Riwi thin sections (reproduced from Vannieuwenhuyse 2016). **a** Burnt bone displaying brownish colour (R515B, PPL, scale 100 μm); **b** inflorescence fragment charred by heat of combustion features and microcharcoals mixed in geogenic sediments (F14-A, thin section R502B, PPL, scale 500 μm); **c**, **d** charcoal fragments and ash particles, note the ash calcitic crystal (bright) high interference colours (F6-B, R507C, PPL and XPL, scale 1000 μm); **e** non-disturbed ashes showing colour variation from yellowish to grey and the presence of phytoliths in the outer parts (F2-C, R509A, PPL, scales 500 and 1000 μm); **f** articulated ash particles with typical prismatic shape at high magnification (F2-C, R508B, XPL, scale 100 μm)

two family level identifications (Lamiaceae sp. and Myrtaceae sp.), were determined from nine family groups. A full description of the archaeological charcoal types is presented in Whitau *et al.* (2016a, Appendix 1). Results are discussed in more detail in 'Types of Combustion Features—Micromorphological and Anthracological Characteristics'.

Saturation curves are presented in Fig. 6, which plot the number of identifiable charcoal fragments against the number of identifiable taxa for each feature. Each plateau indicates

Table 2 Anthracological results from Riwi square 3 for combustion features types A, B and C, expressed in both absolute fragment counts and as percentages of the total number of analysed fragments

Type	Context	Euphorbiaceae	Fabaceae			Lamiaceae		Moraceae			Myrtaceae	
		Mallotus sp.	*Bauhinia* sp.	*Erythrophleum* sp.	*Vachellia* sp.	*Vitex* sp.	Lamiaceae sp.	*Ficus* sp. type A	*Ficus* sp. type B	*Ficus* indeterminate	*Corymbia* sp.	*Eucalyptus* sp. type A
Absolute fragment counts												
C	F1-C	45	0	22	0	26	6	13	8	0	163	20
C	F2-C	6	4	5	6	23	9	23	6	2	163	1
A	F3-A	1	1	6	2	6	1	2	3	0	44	14
B	F4-B	3	7	21	3	9	2	7	4	0	138	13
B	F5-B	1	6	26	7	1	0	0	0	0	156	55
B	F7-B	0	6	22	2	0	4	1	0	0	163	34
A	F8-A	0	0	3	0	0	0	0	0	0	2	0
A	F9-A	0	2	92	28	3	8	0	0	0	12	7
A	F10-A	0	0	0	0	0	0	0	0	0	0	0
A	F11-A	0	0	0	0	0	0	0	0	0	0	1
A	F12-A	0	0	0	0	0	0	0	0	0	0	3
A	F13-A	0	0	0	0	0	0	0	0	0	1	1
Proportion of total number of analysed fragments												
C	F1-C	8.7	0.0	4.2	0.0	5.0	1.2	2.5	1.5	0.0	31.5	3.9
C	F2-C	1.5	1.0	1.2	1.5	5.6	2.2	5.6	1.5	0.5	39.7	0.2
A	F3-A	0.5	0.5	3.0	1.0	3.0	0.5	1.0	1.5	0.0	22.1	7.0
B	F4-B	0.7	1.6	4.8	0.7	2.1	0.5	1.6	0.9	0.0	31.4	3.0
B	F5-B	0.2	1.3	5.4	1.5	0.2	0.0	0.0	0.0	0.0	32.6	11.5
B	F7-B	0.0	1.3	4.6	0.4	0.0	0.8	0.2	0.0	0.0	34.0	7.1
A	F8-A	0.0	0.0	13.0	0.0	0.0	0.0	0.0	0.0	0.0	8.7	0.0
A	F9-A	0.0	0.9	39.8	12.1	1.3	3.5	0.0	0.0	0.0	5.2	3.0
A	F10-A	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Table 2 (continued)

Type	Context	Euphorbiaceae	Fabaceae			Lamiaceae		Moraceae			Myrtaceae	
		Mallotus sp.	*Bauhinia* sp.	*Erythrophleum* sp.	*Vachellia* sp.	*Vitex* sp.	Lamiaceae sp.	*Ficus* sp. type A	*Ficus* sp. type B	*Ficus* indeterminate	*Corymbia* sp.	*Eucalyptus* sp. type A
A	F11-A	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	6.7
A	F12-A	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	27.3
A	F13-A	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	7.7	7.7

Type	Myrtaceae				Phyllanthaceae	Proteaceae	Simaroubaceae	Ulmaceae	Number of Identifiable Fragments	Indeterminable	Total number of analysed fragments
	Eucaltptus sp. type B	*Eucalyptus* sp. indeterminate	*Melaleuca* sp.	Myrtaceae sp	*Flueggea* sp.	*Grevillea*/ *Hakea* sp.	*Brucea* sp.	*Celtis* sp.			
Absolute fragment counts											
C	1	5	18	0	34	2	7	3	373	145	518
C	1	1	22	1	27	0	5	23	328	83	411
A	1	0	0	0	3	0	17	0	101	98	199
B	1	3	7	0	22	0	10	10	260	179	439
B	18	11	25	3	2	0	3	3	317	162	479
B	19	20	8	5	4	0	16	5	309	170	479
A	0	0	0	0	1	0	0	0	6	17	23
A	0	2	2	1	0	0	0	1	158	73	231
A	0	0	0	0	0	0	0	0	0	6	6
A	0	1	1	0	0	0	0	0	3	12	15
A	0	0	0	1	0	0	0	0	4	7	11
A	0	0	0	0	0	0	0	0	2	11	13
Proportion of total number of analysed fragments											
C	0.2	1.0	3.5	0.0	6.6	0.4	1.4	0.6	72.0	28.0	100
C	0.2	0.2	5.4	0.2	6.6	0.0	1.2	5.6	79.8	20.2	100

Table 2 (continued)

Type	Myrtaceae				Phyllanthaceae	Proteaceae	Simaroubaceae	Ulmaceae	Number of Identifiable Fragments	Indeterminable	Total number of analysed fragments
	Eucaltptus sp. type B	*Eucalyptus* sp. indeterminate	*Melaleuca* sp.	Myrtaceae sp	*Flueggea* sp.	*Grevillea*/ *Hakea* sp.	*Brucea* sp.	*Celtis* sp.			
A	0.5	0.0	0.0	0.0	1.5	0.0	8.5	0.0	50.8	49.2	100
B	0.2	0.7	1.6	0.0	5.0	0.0	2.3	2.3	59.2	40.8	100
B	3.8	2.3	5.2	0.6	0.4	0.0	0.6	0.6	66.2	33.8	100
B	4.0	4.2	1.7	1.0	0.8	0.0	3.3	1.0	64.5	35.5	100
A	0.0	0.0	0.0	0.0	4.3	0.0	0.0	0.0	26.1	73.9	100
A	0.0	0.9	0.9	0.4	0.0	0.0	0.0	0.4	68.4	31.6	100
A	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0	100
A	0.0	6.7	6.7	0.0	0.0	0.0	0.0	0.0	20.0	80.0	100
A	0.0	0.0	0.0	9.1	0.0	0.0	0.0	0.0	36.4	63.6	100
A	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	15.4	84.6	100

Results for F1-C and F2-C (SU1 and SU2) are reproduced from Whitau *et al.* (2016a)

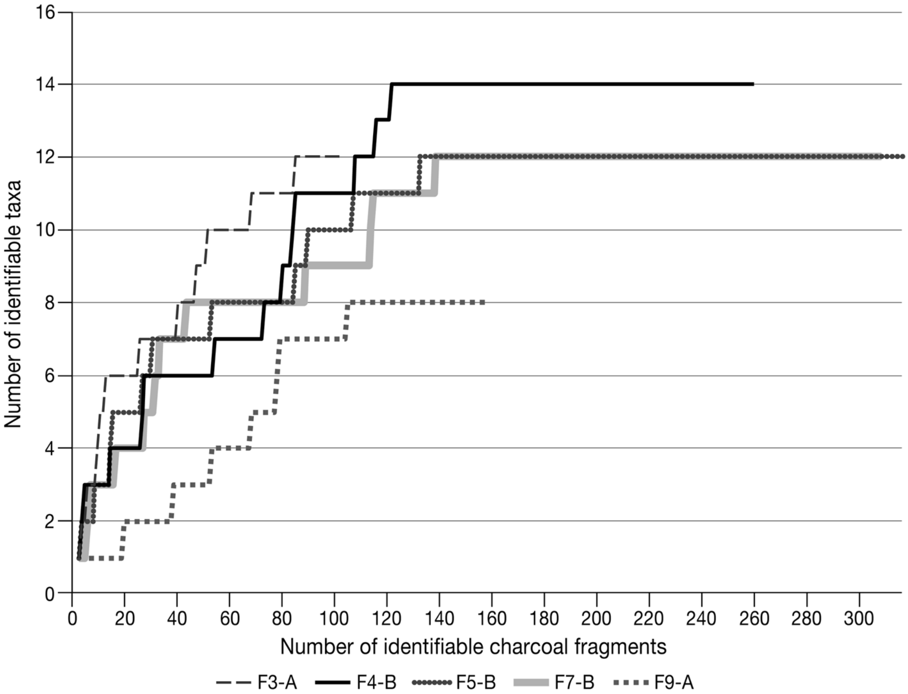

Fig. 6 Saturation curves for combustion features types A and B (CAD: CartoGIS, Australian National University)

the number of fragments that need to be identified in order for the diversity of the archaeological assemblage to be appropriately represented (Byrne *et al.* 2013; Chabal *et al.* 1999; Dotte-Sarout *et al.* 2015; Scheel-Ybert 2002). Across the 12 contexts analysed, seven saturation curves (F1-C, F2-C, F4-B, F5-B, F7-B, F8-A, F9-A) reach plateaux, illustrating that these contexts provide viable representations of the assemblage diversity. The F3-A, F10-A, F11-A, F12-A and F13-A curves do not stabilise. While the F10-A, F11-A, F12-A, F13-A, SU11 and SU12 assemblages comprise a total of 67 identifiable fragments and are excluded from 'Fuel Wood Management: Comparing Concentrated and Scattered Charcoal Contexts', the F3-A assemblage, with 101 identifiable fragments, is of a reasonable size, almost reaching the mean plateau point of the other viable sample sizes, and is cautiously included in comparisons with scattered contexts.

Types of Combustion Features—Micromorphological and Anthracological Characteristics

The following sections describe the sedimentary characteristics and wood charcoal assemblages identified for each of the combustion feature types.

Type a Flat Combustion Features (F3-A, F8-A, F9-A, F10-A, F11-A, F12-A, F13-A)

Abundant throughout the Pleistocene units dated from 45 to 34 ka (SU11 to SU7), type A combustion features are flat lenses that show a complex layering (Fig. 4). Four different microfacies were identified in type A combustion features (illustrated by micromorphological observations undertaken for F12-A and F13-A, Fig. 7, see also Appendix 1 for micromorphological descriptions of the microstratigraphic units and microfacies), with from bottom to top:

- (1) Dark brown layer (concave shapes visible in stratigraphy) composed of geogenic sands, with a high proportion of microcharcoal and carbonised vegetal particles (Fig. 7c).
- (2) Orange-pinkish layer composed of geogenic sands and ash particles (Fig. 7b).
- (3) Layer with charcoal chunks embedded within the geogenic sands (Fig. 7a).
- (4) Whitish layer (Fig. 7c) mostly composed of ash particles (pseudomorphs of plant calcium oxalate) and phytoliths that are often still in anatomic connection (articulated).

With the exception of F3-A and F9-A, charcoal preservation from each of the analysed type A features is very poor. The few charcoal recovered from F10-A, F11-A, F12-A and F13-A are soft and rounded, with all of the indeterminable fragments unable to be examined due to brittleness, disintegrating to ash particles and providing no clean sections. Of the 45

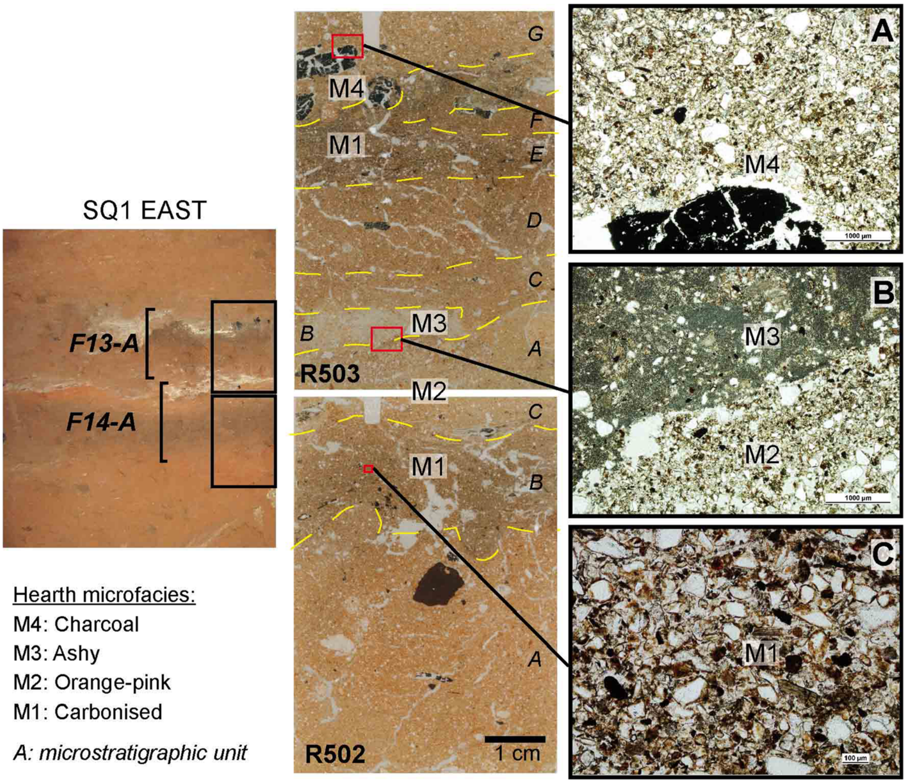

Fig. 7 Microfacies types in Pleistocene type A flat combustion features (modified from Vannieuwenhuyse 2016). Left, detailed view of flat combustion features F13-A and F14-A in Riwi square 1 eastern section showing location of micromorphological samples. Middle, scan of thin sections R502 and R503 with microstratigraphic units identified in each thin section, microphotos location and hearth microfacies types (M1 to M4). Right, microphotographs of type A flat combustion features microfacies types (numbering in reference to Fig. 4 and in-text description). **a** Top layer with charcoal fragments (microfacies 3) (F13-A, R503G, PPL, scale 1000 μm); **b** orange-pinkish (microfacies 2) and whitish layers (microfacies 4) (F14-A, R503A/B, PPL, scale 1000 μm); **c** dark carbonised organic-rich layer (microfacies 1) (F14-A, R502B, PPL, scale 100 μm)

charcoal recovered from across these four features, only 9 were identifiable, predominantly *Eucalyptus* sp. type A, and all of the Myrtaceae family. By contrast, in terms of both composition and preservation, the F8-A feature produced six identifiable fragments, three were identified *Erythrophleum* sp., two *Corymbia* sp. and one *Flueggea* sp., while eleven of the indeterminable fragments were too brittle and six were too vitrified.

The two type A features which produced reasonable anthracological assemblages are F9-A (N_i = 158) and F3-A (N_i = 101). F9-A, which is located at the bottom of SU7 (Fig. 2) is the only Riwi anthracological assemblage that is not dominated by Myrtaceae: *Erythrophleum* sp. (39.8%) dominates with subsidiary *Vachellia* sp. (12.1%), *Corymbia* sp. (5.2%) and *Eucalyptus* sp. (3.8%). F9-A is also anomalous in that it is the only Pleistocene unit to produce an assemblage with one individual taxon count (*Erythrophleum* sp., N_i = 92) that is higher than the indeterminable count (72 fragments) for that unit. Observed within SU3—a stratigraphic layer dated from the LGM timing (Table 1) that shows evidence of post-depositional bioturbation (Fig. 2)—F3-A is the youngest type A feature analysed and sits above the type B contexts developed in the next section. The dominant taxon for this unit is *Corymbia* sp., with subsidiary *Brucea* sp. and *Eucalyptus* sp. charcoal. Comprising 8.5% of the total charcoal examined within the F3-A unit, *Brucea* sp. charcoal were identified here in their highest proportion of the Riwi anthracological assemblage.

Type B Dug Combustion Features (F4-B, F5-B, F6-B, F7-B)

Around 34 ka, type B combustion features are observed in section (Figs. 2 and 3). These dug features sometimes cut through the flat combustion features immediately below, disturbing the orientation of particles (Fig. 8b). Type B combustion features contain large fragments of charcoal embedded within a fine matrix of geogenic sands and/or random oriented ash particles (Fig. 8a).

The three type B features selected for wood charcoal analysis (F4-B, F5-B, F7-B) each have a relatively low percentage of indeterminable fragments, ranging from 33.8% for F5-B to 40.8% for F4-B. *Corymbia* sp. is the dominant taxon across the three type B features, with subsidiary *Eucalyptus* sp. and *Erythrophleum* sp. The feature F4-B, which has the lowest proportion of *Eucalyptus* sp. (3.9%) compared with F5-B and F7-B (17.6 and 15.3%, respectively), also has a higher proportion of *Flueggea* sp. (5.0%) than these other type B features, a proportion which is not duplicated in the other Pleistocene contexts.

Type C Palimpsest Combustion Features (F1-C, F2-C)

Type C features are only present in the Holocene deposits and are accumulations composed mainly of by-products of combustion (predominantly ash and charcoal), along with a mix of non-burnt vegetal parts and a minor proportion of geogenic sands (Fig. 9). The high proportion of combustion residues gives the Holocene deposits its grey colour (Figs. 2 and 3). Under a microscope, the microfacies show a very bright calcitic crystallic b-fabric as a result of the high proportion of ash particles (pseudomorphs of plant tissues) (Fig. 9b, d). These particles are found both in anatomic connection (Fig. 9c, d) and disturbed (Fig. 9a, b), which indicates some mixing in this level, resulting from maintenance activities such as reworking (cleaning rake-out of hearths but also human and animal trampling and turbation, see Fig. 4).

Yielding exceptional preservation of organics, Riwi's two excavated Holocene units, F1-C and F2-C, produced the lowest proportions of indeterminable charcoal of all analysed

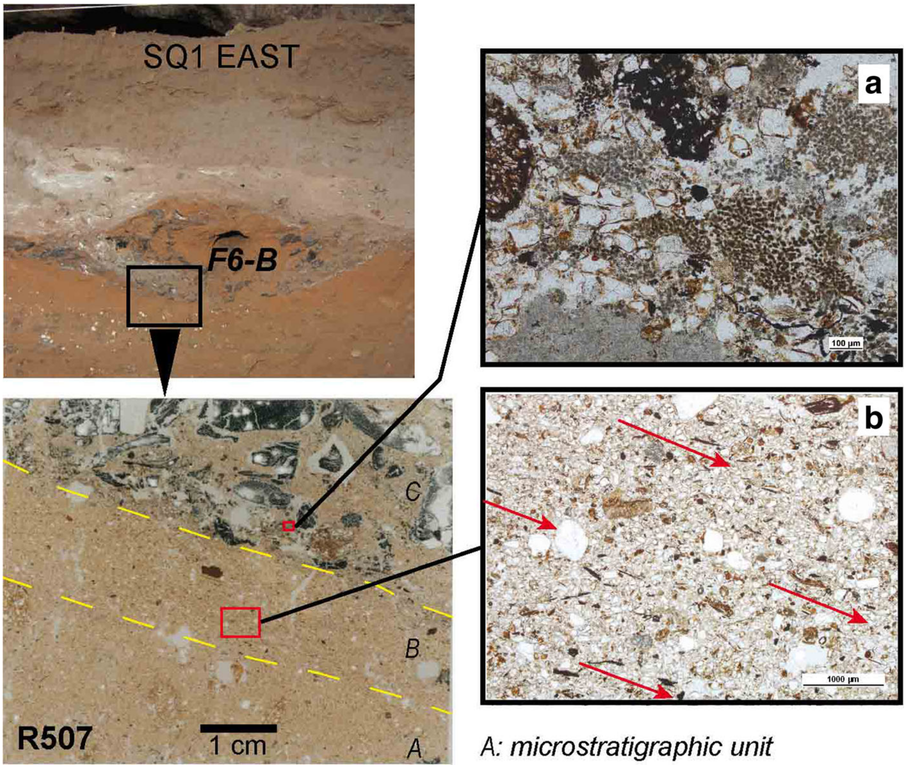

Fig. 8 Microfacies types in Pleistocene type B dug combustion features (modified from Vannieuwenhuyse 2016). Top left, detailed view of combustion feature F6-B in Riwi square 1 east section showing location of micromorphological sample. Bottom left, scan of thin section R507 showing the different microstratigraphic units identified. Right, microphotographs of two different microfacies identified. **a** Mixed charcoal fragments, ash particles and geogenic sands (R507C, PPL, scale 100 μm); **b** bedded organic particles below the combustion feature that could indicate digging, the particles being oriented in the same direction due to sloping (R507A, PPL, scale 1000 μm)

contexts (28.0 and 20.2%, respectively). Dominated by *Corymbia* sp. (39.7%), with subsidiary *Flueggea* sp. and other dry rainforest taxa, F2-C is the most diverse unit anthracologically (14 taxa). F1-C is broadly similar to F2-C; *Corymbia* sp. (31.5%) dominates with subsidiary *Mallotus* sp. (8.7%) and *Flueggea* sp. (6.6%). The high proportion of *Mallotus* sp. is not duplicated elsewhere in the Riwi anthracological record.

Discussion: Fire Management at Riwi Cave

The Building Processes of Combustion Features and Their Hypothetical Functions

Type A Flat Combustion Features (F3-A, F8-A, F9-A, F10-A, F11-A, F12-A, F13-A)

The micromorphological evidence demonstrates that the flat combustion features found in the Pleistocene layers were constructed in the same way, where the fire was lit

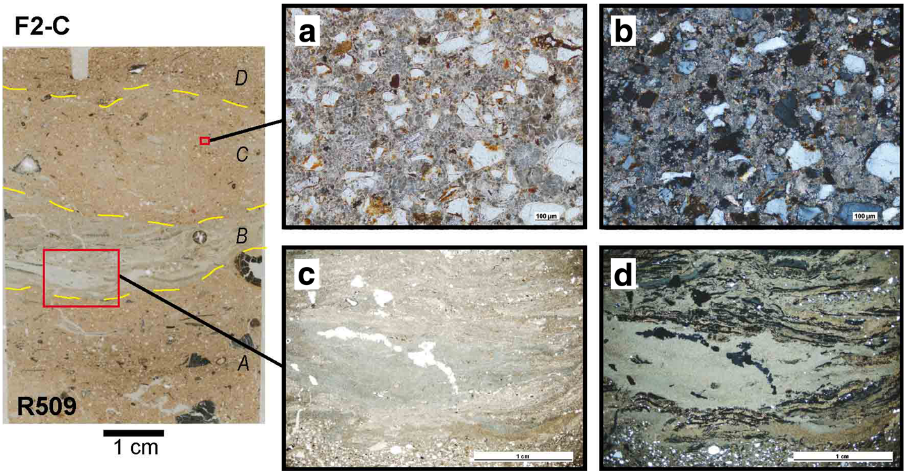

Fig. 9 Microfacies types in Holocene type C combustion feature (modified from Vannieuwenhuyse 2016). Left: thin section R509 sampled in SU2 (F2-C) showing microfacies identified. **a**, **b** Mixed facies of non-articulated ash particles and geogenic sands (PPL and XPL, scale 100 μm); **c**, **d** accumulation of non-disturbed ashes including calcitic crystal pseudomorphs of plant calcium oxalate (bright and white in XPL) and isotropic phytoliths (appear dark in XPL because optically isotropic) (PPL and XPL, scale 1 cm)

directly onto the ground surface (Fig. 4). The underlying substrate is affected by heat in two ways. The dark colour of the concave dark brown layer (1) is the result of the carbonisation of vegetal organics already present in the geogenic matrix. Their carbonisation was induced by the heat radiance from the fire lit on the ground surface above the sediments. The orange-pinkish layer (2) corresponds to the surface where the fire was lit and where temperatures were high enough to induce both the total combustion of organics already present in the sediment and the typical reddening of the sediment resulting from the oxidation of iron components (Aldeias *et al.* 2016; Canti and Linford 2000). In comparison with layer 1, the lighter hue of layer 2 is also a result of the presence of ash from the layers above.

The top of layers 1 and 2 are the remnants of a 'past occupation surface' where the fire was lit (as formulated by Mallol *et al.* 2013b), where people walked and lived in the cave at a certain time in the past. The layer with charcoal (3) corresponds to the combustion itself and contains big charcoal fragments and carbonised organics. Observation of the charcoal sampled for the anthracology analysis shows that they tend to be rounded and brittle in all of the analysed Pleistocene type A flat combustion features (with the exception of the two youngest features F3-A and F9-A). The poor preservation of the charcoal structure is mainly explained by the properties of the wood charcoal itself (differential preservation depending on species, use of wet or dry wood) as already suggested by Théry-Parisot *et al.* (2010). The top whitish layer (4) is composed of ash particles that are mostly still in anatomic connection. The anatomic connection of the ash particles indicates that the firing event was *in situ*, and that these structures were not used repeatedly (Mentzer 2014; Miller *et al.* 2010). The excellent preservation of these structures was permitted by a relatively rapid burial by aeolian natural sedimentation after each firing episode with evidence of only minor post-depositional processes, as demonstrated by the steady sediment deposition rate of Pleistocene levels (Wood *et al.* 2016) and the geoarchaeological analysis of the sequence (Vannieuwenhuyse

2016). Aeolian sedimentation, in conjunction with the post-depositional processes observed in the sequence, in particular the formation of pedogenic gypsum, points to relatively dry conditions over the Pleistocene period. Ash particles were not affected by dissolution, which indicates a relative dryness of the sequence through time (Vannieuwenhuyse 2016).

The fact that only few charcoal fragments are found in most type A combustion features (F8-A, F10-A, F11-A, F12-A, F13-A, see Table 2), and that the combustion by-products associated are mostly ash seems also to indicate that the wood burned in these contexts was mostly completely combusted. As such, this type of combustion feature probably indicates short lived activities or short visits to the cave, where the open air fire was left to burn until the fire died (*cf.* Chabal *et al.* 1999). Two type A features yielded more than 11 identifiable charcoal fragments: F3-A and F9-A (see saturation curves in Fig. 6). If the type A features represent short-lived, episodic combustion events, then these assemblages would be expected to have a lower diversity than their coincident scattered contexts, since the former are hypothesised to represent one or two fuel wood collection trips, the latter many (Asouti and Austin 2005; Byrne *et al.* 2013; Chabal 1990, 1992; Chabal *et al.* 1999; Dotte-Sarout *et al.* 2015; Théry-Parisot *et al.* 2010). The F9-A feature, which yielded 158 fragments of identifiable charcoal, has a low taxa diversity (8 taxa). This low diversity is coupled with the lowest proportion of indeterminable charcoal (31.6%) of any of the Pleistocene units, indicating that this low diversity is not an effect of taphonomic factors acting on the assemblage; supporting the hypothesis that the type A hearth structures are episodic archaeological contexts. The F3-A feature, which sits above the type B features in between the Pleistocene and Holocene sediments, is an exception to this pattern as it yields a relatively high number of identifiable fragments ($N_i = 101$) for a type A feature and a diverse assemblage (12 taxa). This feature is discussed in further detail in 'Fuel Wood Management: Comparing Concentrated and Scattered Charcoal Contexts' in relation to its context.

Altogether, the micromorphological and anthracological analyses of the type A features indicate that these could have been small open-air hearths typically used as single-firing episodes, for heating, lighting and cooking purposes during short term visits to the site, where the fire was left to burn until the fuel wood was totally combusted. The type A combustion features (excluding LGM F3-A that shows a different pattern and is discussed in further detail in 'Fuel Wood Management: Comparing Concentrated and Scattered Charcoal Contexts' in relation to its context) were all rapidly and successively buried by aeolian sedimentation (Vannieuwenhuyse 2016) over a period of 14,000 years (from the first occupation level dated around 45 ka to the top of SU5 around 31 ka), indicating that visitation to the site was episodic and recurrent over many generations.

Type B Dug Combustion Features (F4-B, F5-B, F6-B, F7-B)

The type B dug combustion features, which are found in the upper Pleistocene levels (SU7) and date to around 34 ka (Table 1; Wood *et al.* 2016), present completely different sedimentary characteristics to the flat type A combustion features. The type B features contain many more charcoal than the type A flat hearths (Table 1; Fig. 5c, d), indicating a more incomplete combustion process. At the micromorphological scale, the ash particles are generally not observed in anatomic connection, which indicates that the combustion residues have been displaced. Geogenic sand is intimately mixed with the combustion by-products (Fig. 8a) within the structures and could be related to the covering of the fire with sediment (Fig. 4). Baking food in ground ovens is a cooking practice frequently recorded ethnographically amongst some Aboriginal groups (*e.g.* Gould 1968; Harney 1951) and was experienced by one of the authors (RW) during her fieldwork with Gooniyandi traditional owners. The sedimentary facies observed in the structure reflect an earth oven functioning, from the scraping preparation step to the abandonment of the structure in a disrupted state. Indeed, if the type B features were used as cooking pits, which were covered with earth as a ground oven, both the restricted exposure to oxygen and the extinction of the fire at the expected cooking time might explain why combustion of the fuel was incomplete (Antal and Grønli 2003). Such conditions would typically produce larger, more solid charcoal than the type A hearths, which were exposed to oxygen and left to burn until resulting in complete combustion of the wood. Similar dense and dug features have been interpreted as possible cooking pits in Holocene and terminal Pleistocene layers of rockshelter excavations in western and central Australia (Byrne *et al.* 2013; Smith *et al.* 1995), but here, our interpretation is supported by both micromorphological and anthracological lines of evidence.

Type C Palimpsest of Combustion Features (F1-C, F2-C)

The Holocene layers are mainly composed of a compact ash-rich deposit, which represents a palimpsest of *in situ* fire places and secondary contexts of ash accumulations (hearth rake-out and ash dumps) in conjunction with material evidence for diverse activities taking place in the cave (botanical remains and artefacts). Often individual features are difficult to distinguish but remnants of types A and B combustion features were both observed throughout these levels. This absence of clear layering is also observed at the microscale, with most of the particles in the Holocene deposits observed in random patterns, with both fresh and carbonised organic matter mixed with geogenic sands and vegetal organic debris, fresh or carbonised (Fig. 9a, b). These observations confirm that intense processes such as trampling, mixing and bioturbation due to the presence of humans and animals in the cave have disturbed the primary organisation of the upper levels of the deposit (Fig. 4).

Based on the microstratigraphic and anthracological analyses as well as archaeological material evidence from the site (Balme 2000; Vannieuwenhuyse 2016; Whitau *et al.* 2016a, b; Wood *et al.* 2016), the Holocene units seem to reflect a more consistent occupation at Riwi than the earlier Pleistocene layers. In other Aboriginal archaeological sites around Australia, the Mid- to Late Holocene is often described as a period of intensification, with various interpretations of changes observed in the archaeological record extrapolated from single site contexts to encompass regional and pan-continental spatio-temporal narratives (see summaries in Langley *et al.* 2011; Ulm 2013). In the Kimberley region, increased abundance in charcoal and lithic artefacts has been argued to signify a more intense occupation during the Holocene (*e.g.* Dortch and Roberts 1996; O'Connor 1995, 1999; Veitch 1996). In terms of lithic artefacts, recent reduction-based analyses (*e.g.* Maloney and O'Connor 2014; Maloney *et al.* 2014) have demonstrated that peaks in lithic artefact discard directly correlate to distinct technological innovations, in line with observations of other assemblages in northern Australia (*e.g.* Clarkson 2008).

Fuel Wood Management: Comparing Concentrated and Scattered Charcoal Contexts

Table 3 and Fig. 10 present the anthracological results from seven combustion features (F1-C, F2-C, F3-A, F4-B, F5-B, F7-B and F9-A) alongside the stratigraphic contexts SU7, SU8, SU9 and SU10 (reproduced from Whitau *et al.* 2016a) in relation to vegetation type, where taxa have been grouped into five categories: bloodwood/eucalypt savanna, non-eucalypt savanna, dry rainforest, riparian and indeterminable (Fig. 11). Bloodwood/eucalypt savanna is comprised of all the Myrtaceae except for *Melaleuca* sp., which is the sole charcoal type in the riparian category (*e.g.* Fig 11f). Non-eucalypt savanna is composed of those arid-adapted, sclerophyll taxa that colonise the valley floor (*e.g.* Fig. 11g), and the dry rainforest taxa, traditionally associated with monsoonal vine thicket, are those which inhabit the limestone range and outliers (Fig. 11b). The dry rainforest component is comprised of Indo-Malayan taxa, which vary considerably at the family level, in comparison with the deep-time Australian flora (as represented by the other vegetation types) that comprise low familial and high species-level diversity. The dry rainforest taxa are important economically to hunter-gatherer populations (Dilkes-Hall 2014; Whitau *et al.* 2016a).

In Whitau *et al.* (2016a), we argue that firewood was predominantly collected from the valley floor throughout the occupation sequence (Fig. 11a), where the open vegetation would have allowed for easy collection in close proximity to the cave, following the Principle of Least Effort (Shackleton and Prins 1993). Across all features, with the exception of F9-A, firewood was most commonly collected from the bloodwood/eucalypt savanna species of the valley floor (Fig. 11a, f), which was dominated by *Eucalyptus* species, until the time of SU7 deposition, when the vegetation shifted to *Corymbia* sp. dominance, coupled with an increase in shrubby, non-eucalypt savanna taxa (*Erythrophleum* sp. and *Vachellia* sp.) (Fig. 11g) (Whitau *et al.* 2016a). From SU7 onwards, *Corymbia* sp. maintains its dominance in the anthracological record throughout type B and the anomalous F3-A feature until the Early Holocene. The F1-C and F2-C Holocene units reveal that Riwi's highest charcoal diversity (13 and 14 taxa respectively, see Table 1) is mostly created by larger proportions of dry rainforest taxa and might reflect a different firewood collection strategy, with more fuel collected from the dry rainforest taxa of the limestone outcrops (Fig. 11b). This higher charcoal diversity could also be the result of better preservation of dry rainforest taxa in the upper units of the sequence. The latter seems likely to have been a significant contributing factor, with the exceptional organic preservation of the Holocene units producing the lowest proportions of indeterminable charcoal (F1-C = 28.0% and F2-C = 20.2%, Table 2).

At Riwi, F9-A is the sole context where non-eucalypt savanna taxa dominate the anthracological assemblage, in this case principally represented by *Erythrophleum* sp. (Fig. 11g). Even the nine charcoal identified from the F10-A, F11-A, F12-A and F13-A, type A features are all Myrtaceae (Fig. 11c, f) and predominantly *Eucalyptus* sp., which reflects, albeit with very poor assemblage numbers, the composition of the Pleistocene units (SU8–SU10) in which these features were located. The F9-A hearth

Table 3 Anthracological results expressed in percentages of number of analysed fragments from combustion features F1-C, F2-C, F3-A, F4-B, F5-B, F7-B and F9-A compared with those of scattered contexts SU7, SU8, SU9 and SU10; the latter (and F1-C and F2-C) reproduced from Whitau *et al.* (2016a)

Type	Feature	Bloodwood/eucalypt savanna						Non-eucalypt savannah					Dry rainforest	
		Corymbia sp.	*Eucalyptus* sp. Type A	*Eucaltptus* sp. Type B	*Eucalyptus* sp. Indeterminate	Myrtaceae sp	**Total bloodwood/ eucalypt savanna**	*Bauhinia* sp.	*Erythrophleum* sp.	*Vachellia* sp.	*Grevillea*/ *Hakea* sp.	Total non-eucalypt savanna	*Celtis sp.*	*Mallotus sp.*
C	F1-C	31.5	3.9	0.2	1	0	36.6	0	4.2	0	0.4	13.9	0.6	8.7
C	F2-C	39.7	0.2	0.2	0.2	0.2	40.5	1	1.2	1.5	0	10.8	5.6	1.5
A	F3-A	22.1	7	0.5	0	0	29.6	0.5	3	1	0	5	0	0.5
B	F4-B	31.4	3	0.2	0.7	0	35.3	1.6	4.9	0.7	0	10.2	2.3	0.7
B	F5-B	32.6	11.5	3.8	2.3	0.6	50.8	1.3	5.4	1.5	0	9	0.6	0.2
B	F7-B	34	7.1	4	4.2	1	50.3	1.3	4.6	0.4	0	7.3	1	0
A	F9-A	5.2	3	0	0.8	0.4	9.4	0.8	39.8	12.1	0	53.1	0.4	0
SU	SU7	26.9	3.6	0	1.3	0.4	32.2	0	14.7	8.4	0	28.1	2.1	2.9
SU	SU8	4.6	12.8	3.1	9.7	0.8	31	0.3	5.6	0.3	0	6.2	0	0
SU	SU9	13.4	16.9	4.3	5.4	0.8	40.8	0	1.9	0	0	1.9	0	0
SU	SU10	3.2	10.1	2.7	4.3	1.2	21.5	0	0.5	0	0	0.5	0	0

Type	Dry rainforest								Riparian	Indeterminable
	Vitex sp.	Lamiaceae sp.	*Ficus* sp. Type A	*Ficus* sp. Type B	*Ficus* indeterminate	*Flueggea* sp.	*Brucea* sp.	Total dry rainforest	*Melaleuca* sp.	
C	5	1.2	2.5	1.5	0	6.6	1.4	27.5	3.5	27.8
C	5.6	2.2	5.6	1.5	0.5	6.6	1.2	30.3	5.4	20.1
A	3	0.5	1	1.5	0	1.5	8.5	16.5	0	49.4
B	2.1	0.5	1.6	1	0	5	2.3	15.5	1.6	40.4
B	0.2	0	0	0	0	0.4	0.6	2	5.2	33.8

Table 3 (continued)

Type	Dry rainforest								Riparian	Indeterminable
	Vitex sp.	Lamiaceae sp.	*Ficus* sp. Type A	*Ficus* sp. Type B	*Ficus* indeterminate	*Fluggea* sp.	*Brucea* sp.	Total dry rainforest	*Melaleuca* sp.	
B	0	0.8	0.2	0	0	0.8	3.3	6.1	1.7	35.6
A	1.2	3.5	0	0	0	0	0	5.1	0.8	32
SU	0	0.4	1.7	0	0.2	0.4	1	8.7	1.1	34.9
SU	0	0	0	0.3	0	0.3	1	1.6	1.5	59.7
SU	0	0	0	0	0	0	0.3	0.3	1.3	55.7
SU	0.3	0.1	0.1	0	0	0.3	0	0.8	0.9	76.3

is positioned at the limit between SU8 and SU7, where a shift in taxa ranks is visible (Fig. 10). SU7 shows an increase in *Corymbia* sp., while *Eucalyptus* sp. types decrease in both abundance and diversity, and *Erythrophleum* sp. and *Vachellia* sp. increase to proportions that are not replicated elsewhere amongst the scattered charcoal assemblages (Whitau *et al.* 2016a). The fuel wood that comprises the F9-A anthracological assemblage was collected before or during the ecological shift observed in the SU7 assemblage, and it is interesting to note that the dominance of *Erythrophleum* in the feature clearly echoes the taxonomic composition shift represented in SU7 (Fig. 10). F9-A is a type A hearth structure, which was not re-used and so the dominance of *Erythrophleum* sp. is most likely an effect of a single firing episode. It could be that *Erythrophleum* sp. was collected in relation to its increased availability in the surrounding landscape where non-eucalypt savanna newly dominated or that it was specifically targeted as a fuel wood, without these hypotheses needing be mutually exclusive.

The *Erythrophleum* genus is composed of some eight (Ross 1998) or nine (Dunlop *et al.* 1995) taxa, one of which, *Erythrophleum chlorostachys* or ironwood, is endemic to Australia, where it grows from northeastern Queensland to the Kimberley region of Western Australia. Aboriginal groups in Queensland and the Northern Territory are recorded using ironwood in a variety of ways: an infusion of the bark is used to treat stomach pains, root infusions for cuts and leaf infusions for scabies; smoke from the wood and leaves is used to relieve constipation and smoke from the bark to produce sterility in women; resin from the roots is an adhesive and gum from the bark is edible and produces a red dye; and the wood is

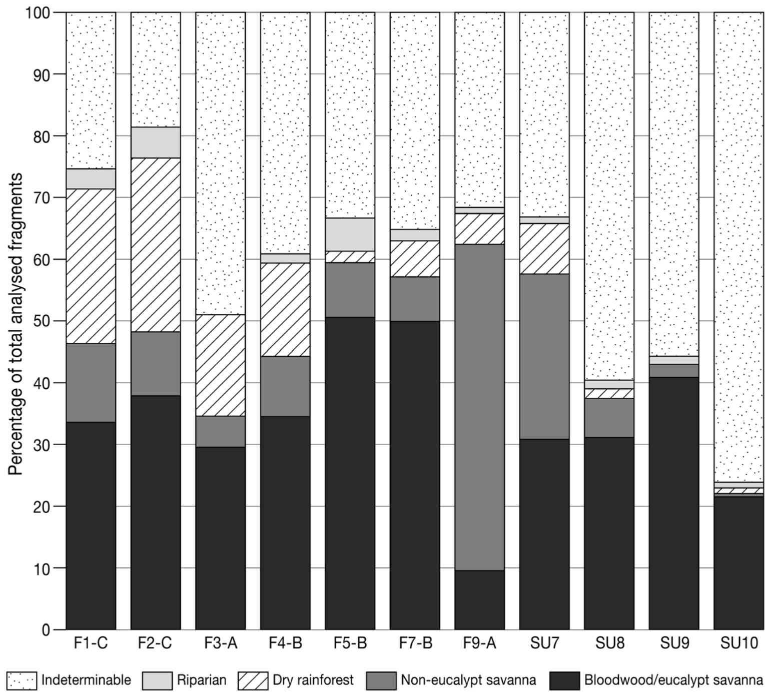

Fig. 10 Comparison of wood charcoal assemblage composition between combustion features types A, B and C, and the Riwi scattered contexts presented in Whitau *et al.* (2016a) (CAD: CartoGIS, Australian National University)

used for carvings, spears, music and cooking sticks (Brock 1988; Dunlop *et al.* 1995; Woinarski *et al.* 2002). While there are no ethnographic accounts of ironwood use in the Kimberley region, at the very least, ironwood is one of the densest of Australia's native timbers (1200 kg/m^3) (Boland *et al.* 1984; Woinarski *et al.* 2002) and might provide a different type of fire from the bloodwood/eucalypt species.

The flora represented in the type B features are broadly comparable with those in SU7 in terms of taxonomic diversity, relative frequency and rank of taxa, which is contrary to the expectation that combustion events have low taxonomic diversity, since they represent the last few firing events (Chabal *et al.* 1999; Dotte-Sarout *et al.* 2015; Théry-Parisot *et al.* 2010). The more likely explanation for the similarity between SU7 and the type B dug features (Fig. 10) is that both were used several times and the assemblages represent multiple collecting trips (Whitau *et al.* 2016a). Indeed, F5-B is a series of densely packed combustion features showing concave pits, ash and abundant charcoal; therefore, it securely represents several firing episodes. Such an explanation would also make sense with the proposed identification of these features as ground or earth ovens, with features being re-used several times during an occupation period. Moreover, the voluntary cessation of the combustion process involved in earth oven cooking is an additional factor for a better representation of the original fuel wood taxonomic diversity in comparison with open-air hearth features.

Between the types B and C features sits the F3-A type A hearth. Unlike the other type A contexts, F3-A has a high diversity (12 taxa) in addition to a high proportion of indeterminable charcoal (49.2%) (Table 3). Bloodwood savanna dominates the assemblage, with the high proportion of dry rainforest taxa comprised largely of *Brucea* sp.

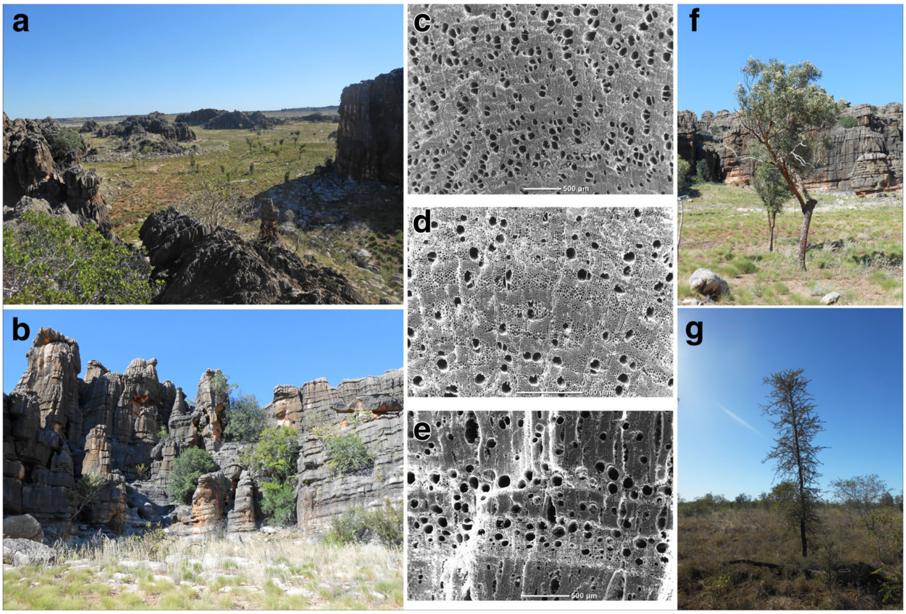

Fig. 11 Vegetation types and their common charcoals. Left, low tree steppe of the Riwi valley floor (**a**), dry rainforest taxa colonise the limestone outcrop (b); centre, reference SEM images of *Corymbia dampieri* (**c**), *Vachellia suberosa* (**d**), *Brucea javanica*; right: *Corymbia* sp. (**f**) and *Vachellia suberosa* (**g**) (photos and SEM by R. Whitau)

(8.5%) (Figs. 10 and 11e). The sole species of the genus endemic to Australia, *Brucea javanica* prefers secondary forest, sandy dunes and limestone rock. Generally growing as a small shrub or tree, *B. javanica* produces edible roots and fruit that can aid in the treatment of dysentery and fever (Kulip and Wong 1995). Its relatively high abundance in F3-A is not readily explicable and could relate to socio-environmental changes affected by the LGM. The position of the F3-A hearth shows that type A hearth structures continued to be built after the appearance of type B hearths in the record.

While the individual features of the type C units are more difficult to distinguish, both types A and B combustion structures were produced during this time, which is characterised by an increased taxonomic diversity and representation of dry rainforest taxa (Fig. 11b) in the archaeobotanical record, including non-woody remains (Dilkes-Hall 2014; Whitau *et al.* 2016a).

All anthracologically analysed contexts from Riwi cave show that firewood was typically collected from the valley floor and, with the exception of F9-A, bloodwood/eucalypt savanna taxa were the favoured fuels, supporting arguments presented by Whitau *et al.* (2016a). The shift in taxon dominance from eucalypt to bloodwood observed in the scattered contexts, which is likely associated to environmental changes at around 34 ka (Whitau *et al.* 2016a), is reflected in the composition of all the features analysed in this paper.

Methodological and Archaeological Implications

The study presented here clearly supports important taphonomic studies (*e.g.* Dussol *et al.* 2017; Théry-Parisot *et al.* 2010) in showing that the factors affecting charcoal preservation are complex. Table 4 summarises the anthracological and micromorphological data alongside a summary of the discussion presented above. Fires which were lit directly on the ground surface, like the type A hearth structures, are far less likely to produce quantifiable charcoal within the structure itself, as the direct exposure to oxygen will often combust the fuel entirely. Increase in charcoal abundance in itself should not then necessarily be correlated with an intensification of occupation (Ward *et al.* 2016), as the prevalent type of combustion structure, its formation and length of use as well as its degree of preservation must also be considered. Similarly, changes in deposition dynamics (*e.g.* deficit of natural sedimentation) can lead to the creation of palimpsest type deposits in archaeological sequences (Bailey and Galanidou 2009; Mallol and Mentzer 2015; Vannieuwenhuyse 2016). At Riwi, the changes observed between combustion features, the increased abundance of charcoal dense features within F1-C and F2-C and the high trampling of surface deposits all point towards a change in site use during the deposition of the Holocene units, where occupation of the cave was intensified in terms of the number of site visits, coupled with a reduction of time between visits and lesser accumulation of natural inputs as pointed out in several Australian archaeological studies (*cf.* Ulm 2013; Ward 2004; Vannieuwenhuyse *et al.* 2017).

This study also signifies the importance of understanding site formation processes; as already stated by several Australian researchers (Holdaway *et al.* 2008; Langley *et al.* 2011; Vannieuwenhuyse *et al.* 2017; Ward and Larcombe 2003; Ward *et al.* 2016). The exceptional preservation of flat type A hearths in Riwi provide an archaeological case study for how heating can impact underlying sediments in this type of fine sand substrate, in the Riwi example: several centimetres below the surface where the

Table 4 Summary of anthracological and micromorphological results

	Type A Flat combustion features	Type B Dug combustion features	Type C Palimpsest
Combustion feature description	Four different microfacies were identified in type A combustion features (Fig. 7, see Appendix 1.0), with from bottom to top: (1) Dark brown layer (concave shapes visible in stratigraphy) composed of geogenic sands, with a high proportion of microcharcoal and carbonised vegetal particles (Fig. 7c). (2) Orange-pinkish layer composed of geogenic sands and ash particles (Fig. 7b). (3) Layer with charcoal chunks embedded within the geogenic sands (Fig. 7a). (4) Whitish layer (Fig. 7c) mostly composed of ash particles (pseudomorphs of plant calcium oxalate) and phytoliths that are often still in anatomic connection (articulated).	Type B combustion features are characterised by the digging of a pit or depression where the fire was lit and frequently reused. These dug features sometimes cut through the flat combustion features immediately below, disturbing the orientation of particles (Fig. 8b). Type B combustion features contain large fragments of charcoal embedded within a fine matrix of geogenic sands and/or random oriented ash particles (Fig. 8a).	Type C features are accumulations composed mainly of by-products of combustion (predominantly ash and charcoal), along with a mix of non-burnt vegetal parts and a minor proportion of geogenic sands (Fig. 9). The high proportion of combustion residues gives the Holocene deposits its grey colour (Figs. 2 and 3). Under the microscope, the microfacies show a very bright calcitic crystallic b-fabric as a result of the high proportion of ash particles (pseudomorphs of plant tissues) (Fig. 9b, d). These particles are found both in anatomic connection (Fig. 9c, d) and disturbed (Fig. 9a, b) which indicates some mixing in this level.
Hypothesised function	Small, open-air, single-use hearths which were lit directly onto the ground surface and used for heating, lighting, or cooking purposes during short term visits to the site.	Earth or ground ovens which were constructed by digging a pit or depression into the substrate. A fire was lit within the depression and subsequently buried during a hypothesised underground cooking process.	A palimpsest of numerous type A and B features coupled with an increase of combustion residues resulting from maintenance activities such as reworking (cleaning rake-out of hearths but also human and animal trampling and turbation, see Fig. 4).
Economy of wood	The charcoal within the type A combustion features is mostly completely combusted with the exception of the F3-A and F9-A assemblages. F9-A is the only anthracological sample from Riwi Cave which was not dominated by	The taxonomic diversity of the type B dug features is similar to the associated scattered contexts and might indicate re-use of the combustion features. The dominance of bloodwood savanna taxa indicates that firewood was collected predominantly from	The savanna taxa of the valley floor continue to be well represented alongside a higher proportion of dry rainforest taxa, which indicates a potentially more extensive use of the surrounding landscape and its various ecological niches.

Table 4 (continued)

	Type A Flat combustion features	Type B Dug combustion features	Type C Palimpsest
	bloodwood/eucalypt; the dominance of *Erythrophleum* sp., coupled with the low diversity of F9-A taxa, is indicative of a single firing episode. Taxa were collected predominantly from the valley floor as per the associated scattered Pleistocene contexts.	the valley floor, with a minor presence of dry rainforest taxa, which are associated with the limestone outcrop.	
Inference of hunter gatherer strategies	Occupation was intermittent from 47 to 34 ka, with enough time between site visits to allow for these flat, open-air, single-use hearths to be covered by natural, rapid aeolian deposition.	More frequent and/or longer occupation at the site during this time (c. 34 ka).	Frequent occupation of longer duration during the Holocene sequence producing a palimpsest of archaeological deposition, which forms this type C secondary context.

fire was lit. This depth of effect has several implications in how to sample such features and how to interpret the archaeological material (botanical remains, bones, lithic artefacts, ochre pigments, but also sediment samples for luminescence dating) from the affected underlying substrate, as already pointed out by microstratigraphic experimental studies by Aldeias *et al.* (2016) and Mallol *et al.* (2013b).

Conclusions

Starting 45 ka years ago and for over 14,000 years, Pleistocene occupation at Riwi was intermittent and potentially episodic. The cave would be visited for short periods: a fire lit directly on the ground (type A), fuelled by wood collected from the eucalypt savanna of the valley floor, and abandoned, with these hearth structures most likely not re-used. Occupation was intermittent, with enough time between site visits to allow for these flat, open-air, single use hearths to be covered by natural, rapid aeolian deposition.

From around 34 ka to the onset of the LGM, a new combustion feature (type B) is observed, which potentially reflects a different type of occupation at the site. Instead of lighting the fire directly on the ground, the fire was lit in a dug pit, covered with earth during combustion and extinguished prior to the completion of the combustion process; in a pattern similar to a ground oven. The anthracological composition of these type B structures is most similar to the scattered context of SU7, demonstrating the collection of fuel wood from the bloodwood-dominated savanna newly established on the valley floor. The taxonomic diversity of the type B dug features might illustrate that these ground ovens were re-used multiple times and potentially signify more frequent and/or longer occupation at the site during this time.

Type A and B combustion features continued to be produced during the LGM and through to the Holocene, when the site seems to have been visited more frequently. Change in deposition patterns and higher frequency of occupation produced a palimpsest of archaeological deposition, which forms the type C secondary contexts. This period also records an increase in use of vegetation resources located in the dry rainforest areas. The savanna taxa of the valley floor continue to be well represented, indicating a potentially more extensive use of the surrounding landscape in its various ecological niches. This aligns with an intensification of occupation, where intensification refers to an increase in the number of site visits and the duration of these visits.

Combined anthracological and micromorphological analyses of combustion features at Riwi have allowed us to propose a typology of features, to define the chronology of their appearance in the record and to document changes in site occupation patterns and landscape use over time. Our results show that interpretations of anthracological spectra should be adapted to the type of combustion structure recovered; the relationship between charcoal preservation and context is far too complex to warrant the direct association of charcoal abundance with intensification of site use and/or population increase.

Future experimental studies which explore both hearth building processes and fuel wood selection strategies using traditional Aboriginal methods will enable a deeper understanding of how fire was manipulated in the past and strengthen the functional interpretation of the different types of combustion features identified in our study. Precise and multiproxy studies allow a few tangible glimpses into the lives of a site's past inhabitants, building a home 'where the hearth is'.

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Chapter 5. X-ray computed microtomography and the identification of wood taxa selected for archaeological artefact manufacture: Rare examples from Australian contexts

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Rose Whitau: developed the research question; undertook field work; supervised the X-ray microtomography scan and analysed the tomograms; formulated the arguments in the manuscript; drafted the entire manuscript, except for the use wear analysis descriptions in sections 7.1 and 7.2; edited and reviewed the manuscript.

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Rose Whitau

India Ella Dilkes-Hall: undertook field work; sorted all excavation materials; reviewed the relevant archaeological literature regarding wooden artefact recovery and ethnobotanical literature regarding traditional Aboriginal uses for Proteaceae and Lamiaceae woods; formulated and refined arguments in the manuscript; edited and reviewed the manuscript.

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Emilie Dotte-Sarout: assisted with the laboratory work; suggested the application of X-ray microtomography; formulated and refined arguments in the manuscript; edited and reviewed the manuscript.

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Emilie Dotte-Sarout

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X-ray computed microtomography and the identification of wood taxa selected for archaeological artefact manufacture: Rare examples from Australian contexts

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ABSTRACT

Wooden artefacts are seldom recovered from Australian archaeological contexts, limiting our understanding of an important component of past Indigenous socio-economic systems. When recovered, the taxa used for construction are very rarely identified, and when undertaken, taxonomic identifications are generally unsubstantiated. For wood taxa to be identified, the microscopic elements of the xylem structure need to be observed and described from three planes. Conventional microscopy methods require physical sectioning, which is a complex, time-consuming process, whereas X-ray computed microtomography is non-invasive and expeditious. Here we describe the use of X-ray microtomography to identify the material of two wooden implements, the negative component of a fire drill and an artefact fragment, both recovered from Riwi cave in the southern Kimberley of Western Australia. By drawing on archaeobotanical analyses conducted at Riwi cave (wood charcoal and other macrobotanical remains), we are able to illustrate that the past inhabitants of Riwi selected certain woods for specific purposes within the last 1000 years of occupation at the site.

1. Introduction

The limited preservation of botanical materials in Australian archaeological contexts, coupled with the slow development of conversant archaeobotanical techniques, has hindered our understanding of plant use in prehistoric lifeways (Beck et al., 1989; Denham et al., 2009). When compared to other regions of the world, the recovery of wooden artefacts from Australian archaeological sites is especially rare, and where excavated, taxonomic identification is seldom conducted. However, the identification of a wood taxon has the potential to inform on wood selection criteria, the functional properties of the raw material (e.g. density, bending strength), and provide an additional line of evidence for examining adaptive strategies and technological developments employed in the past. While the traditional methods of wood taxon identification are destructive and laborious, X-ray microtomography is non-invasive and expeditious. Here we use X-ray microtomography to identify the taxa of two artefacts, the negative component of a fire drill and the tip of a wooden artefact, both recovered from Riwi cave, which is located in the south central Kimberley of Western Australia (Fig. 1). The benefits and disadvantages of this technique are reviewed in relation to our current understanding of wooden artefact manufacture within the Australian context. By drawing on archaeobotanical analyses conducted at Riwi cave (wood charcoal and other macrobotanical remains), we are able to depict a more nuanced picture of plant exploitation at this site.

2. Identification of wood taxa

For wood taxa to be identified, the microscopic elements of the xylem structure need to be observed and described from three planes: transverse, tangential longitudinal, and radial longitudinal. Conventional microscopy methods require physical sectioning and thin section mounting, which is a complex, time-consuming process (Jansen et al., 1998), that essentially applies “a two-dimensional tool to a three-dimensional problem” (Brodersen, 2013: 409). Additionally, physical sectioning, which can result in breakage, might not always be appropriate, particularly when working with cultural artefacts. For example, during the initial stages of this project, permission was obtained from the Mimbi community to sample the Riwi wooden artefact fragment for direct dating and the creation of sections for scanning electron

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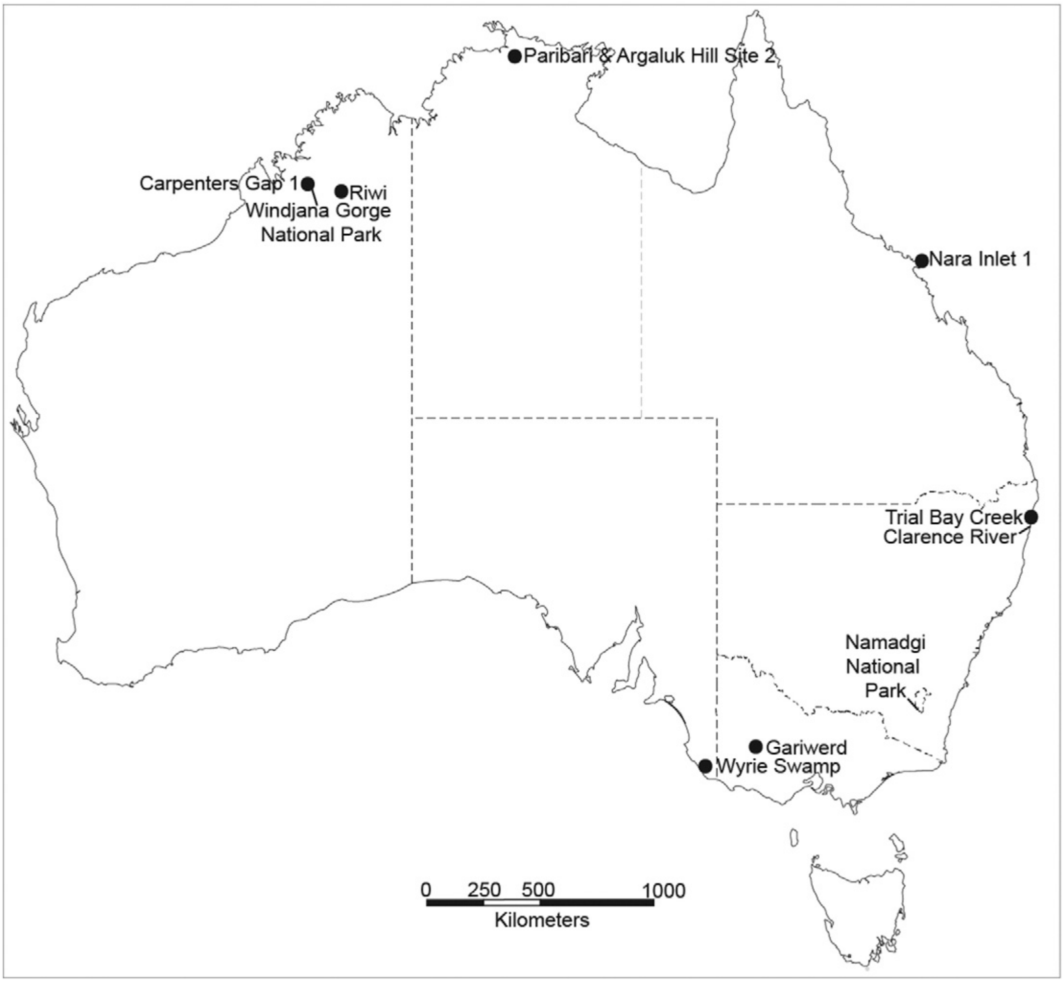

Fig. 1. Map of Australia with sites mentioned in the text.

microscopy (SEM). During the sampling process the entire artefact snapped longitudinally in half, a common risk during the sampling of desiccated wood. This result required a specific restoration process and the definition of a new strategy that would allow for the identification of the wood without further risking the integrity of the artefact, for which X-ray computed microtomography was selected.

X-ray computed microtomography (μCT) utilises radiographic projections, in conjunction with appropriate software, to reconstruct a sequence of non-destructive views (2D and 3D) ad infinitum. The apparatus is conceptually analogous to medical tomography but differs in that the sample rotates while the X-ray source and detector remain fixed. Across a range of rotation angles, the X-ray camera logs 2D radiographic data, data which are then manipulated by volume rendering software to create 3D constructs of the sample's internal structures. The sample's attenuation of the X-rays creates contrast in the μCT image, where lower absorption of the X-rays results in darker voxels and higher absorption of the X-rays results in lighter voxels. Carbon-based plant tissue absorbs X-rays well, and contrasts readily with the air within the vessel, tracheid, or fibre elements, and surrounding the sample (Brodersen, 2013: 412–413). Resolution, measured in voxels, is inversely proportionate to the field of view, and developments in μCT technologies have enabled sub-micrometre magnifications (Brodersen, 2013; Van den Bulcke et al., 2009).

The X-ray μCT technique has been applied to a variety of disciplines, including geosciences (Cnudde et al., 2006); animal physiology (Westneat et al., 2008); plant physiology (e.g. Danjon and Reubens, 2008; Lombi et al., 2011; Steppe et al., 2004); and soil science (Oliviera et al., 2012). Its current applications in archaeological research include the characterisation of pottery fabric (Kahl and Ramminger, 2012); material identification of ivory, bone, and antler artefacts (Reiche et al., 2011); preservation of collagen in bone (Beck et al., 2012); mapping of mineral contamination within charcoal fragments (Bird et al., 2008), and identification of wood type employed in the construction of wooden artefacts (Bugani et al., 2009; Haneca et al., 2012; Mizuno et al., 2010; Stelzner and Million, 2015; Tuniz et al., 2012).

3. The recovery of wooden artefacts from Australian archaeological contexts

Unlike charcoal, which is relatively inert, uncharred wood is subject to the post-depositional processes that affect organic materials. To prevent degradation, burial environments must be anaerobic, and consistently so (see Haneca et al., 2012; Rowell and Barbour, 1990 for discussion of wood degradation processes). Australian archaeological deposits suffer low sedimentation rates, high insect and microbial activity, and the alternation of wetting and drying of sediments in the monsoonal north. These factors, in conjunction with the predominance of small "test-pit" sized excavations, combine to decrease the likelihood of wooden artefact recovery and the preservation of botanical remains in general (Denham et al., 2009; Langley et al., 2011). In Australian archaeological contexts, the most common means by which wood preserves is desiccation, with only three recorded examples of wood preserved in waterlogged conditions from Clarence River, Trial Bay Creek, (McBryde, 1977) and Wyrie Swamp (Luebbers, 1978). The wooden artefacts from Wyrie Swamp are the oldest on the continent, with radiocarbon dated peat samples placing the deposit to within 12,398 to 11,270 cal BP 95.4% (ANU-1292) and 10,375 to 9628 cal BP 95.4% (ANU-1293) (Luebbers, 1975: 39). The next oldest wooden artefact, a wooden bi-point from Nara Inlet 1, Whitsunday Islands, is associated with a 2151 to 1894 cal BP 95.4% (Beta 28188) stratigraphic unit (Barker, 1989). All other wooden artefacts recovered from Australian contexts are dated either directly or by association to within the last 1000 years (Argue et al., 2001; Blundell, 1975: 419; Cane, 1984: 183; Clarke, 1985, 1987; David, 1992; David and Dagg, 1993; Flood and Tresize, 1981; Gunn, 2009; McBryde, 1977; McConnell, 1997: 83; O'Connor, 1999: 80, 82; Rosenfeld et al., 1981: 29; Schrire, 1982). While the recovery of wooden artefacts from Australian archaeological contexts is restricted to the Holocene, paperbark fragments and woodshavings recovered from the Carpenter's Gap 1 rockshelter, Western Australia, provide evidence of woodworking in the Pleistocene (O'Connor, 1995).

Not only are wooden artefacts rarely recovered from Australian archaeological contexts, when they are recovered, the woody taxa used to produce these artefacts are not usually identified (Blundell, 1975: 419; Cane, 1984: 183; Clarke, 1985, 1987; David, 1992; David and Dagg, 1993; Flood and Tresize, 1981; McConnell, 1997: 83; O'Connor, 1999: 80, 82; Rosenfeld et al., 1981: 29). Furthermore, when taxonomic identification is undertaken, it is generally unsubstantiated in the literature. Eleven wooden implements were recovered from the top level of the Paribari midden, Arnhem Land (Schrire, 1982: 63–65). The taxa used to produce eight of these artefacts are identified: three to family level, one to genus, and five to species, all without description of methods or reference material (Schrire, 1982: 64). A hafted adze was recovered from Argaluk Hill, site 2, at Oenpelli (now Gunbalanya) located in western Arnhem Land. While the handle and resin source were both identified by Setzler and McCarthy (1950) as ironwood (*Erythrophleum chlorostachys*), the authors do not describe the method for taxonomic identification and, although the artefact was recovered during excavation, no chronology was attempted for the site (Attenbrow, 2008: 493; Setzler and McCarthy, 1950). Dredging activities at Clarence River, New South Wales, exposed one boomerang, which was directly dated to 281 to 157 cal BP 95.4% (GaK-1299) (McBryde, 1977: 161). While the boomerang was attributed to the *Planchonella* genus of the Sapotaceae family, no methods are described for this identification (McBryde, 1977: 161). In Gariwerd (the Jardwadjali/Djab Wurrung name for the Grampian Ranges), Western Victoria, two bark slabs and twenty eight wooden peg-like artefacts were collected in 1983 from a painted rock shelter (Gunn, 2009: 23). The two slabs exhibit multiple cutmarks made with a steel implement, a product of their removal from the tree, and while the slabs are identified as stringybark, the methods of identification are not described (Gunn, 2009: 24).

There are only two examples of wooden artefacts from Australian archaeological contexts that are identified by accredited wood anatomists (Argue et al., 2001; Luebbers, 1978). First, excavations of basal peat deposits at Wyrie Swamp, South Australia, uncovered 29 wooden artefacts, including barbed and non-barbed spears, boomerangs, digging sticks, and a number of wooden artefacts of unidentified function (Luebbers, 1975: 39). The wood of one partial boomerang was identified by the Forest Products Laboratory at CSIRO as *Casuarina stricta* (now *Allocasuarina verticillata*) and directly dated with an age range of 11,104 to 10,250 cal BP 95.4% (ANU-1490) (Luebbers, 1978: 127, 134). Second, a digging stick recovered from the base of an overhang in Namadgi National Park, in the Australian Capital Territory was sampled for AMS dating and wood species identification (Argue, 1995; Argue et al., 2001: 41). The artefact has an age of 317 to 45 cal BP 95.4% (NZA-10301) and a taxonomic identification of *Acacia* sp. was assigned to the artefact by CSIRO (Argue et al., 2001: 41). While accredited wood anatomists identified the woody taxa in both of these examples, no methods or reference materials are described.

4. Description of the study area, site, and wooden artefacts

Riwi is a southwest facing cave located in the Mimbi area of Gooniyandi country in the south central Kimberley region of Western Australia (Fig. 1). The cave is situated at the bottom of the Lawford Range, which is comprised of Devonian limestone reef. On the edge of the Great Sandy Desert, Riwi is within the southern limits of the Australian Summer monsoon, receiving 500 mm of rainfall per annum, most of which falls within the wet season (November to April) (Bureau of Meteorology, 1996: 44). Broad scale mapping of the region shows that the dominant vegetation type within the Mimbi area is sclerophyll, and grades between woodland savanna, steppe, and grassland (Beard, 1979).

The walls and most surfaces within the cave are painted or incised with art. A 1 m^2 test pit was excavated in 1999 (Balme, 2000), and in 2013, three additional test pits were added, one of which, Square 4, created a 2 × 1 m trench with the original test pit (Fig. 2). Each of the squares was excavated to bedrock in arbitrary units of 20 mm, and in 500 mm horizontal quadrants, while features were removed separately. All excavated materials were dry sieved through nested 5 mm and 1.5 mm mesh screens, and bulk sediment samples were collected from each excavation unit. No flotation was conducted due to the limited water supply in the Mimbi area during the dry season. Cultural materials recovered from both excavation seasons include stone artefacts,

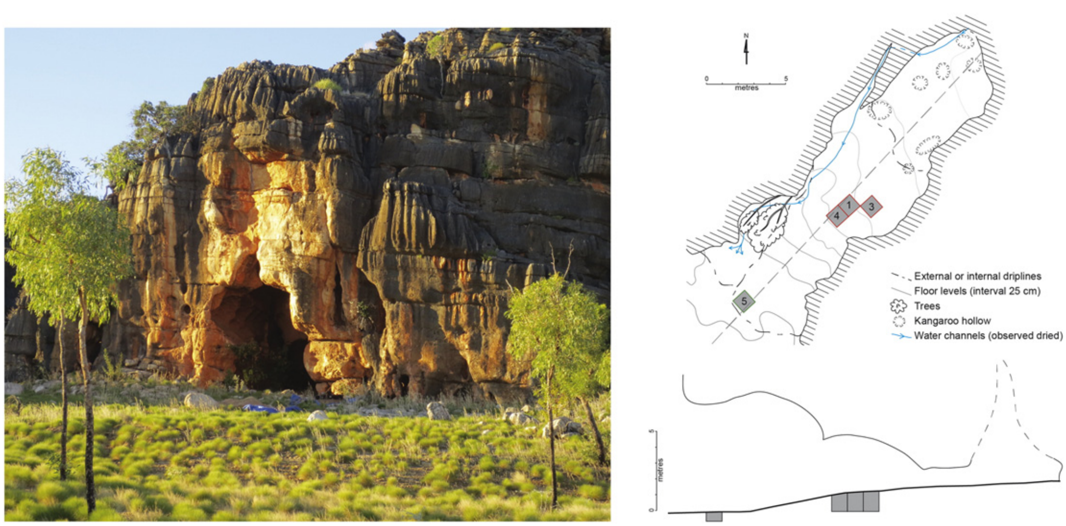

Fig. 2. Riwi cave (left) and excavation site plan (right).

faunal remains, charcoal, freshwater shellfish remains, emu eggshell, ochre, string, scaphopod beads, and uncharred macrobotanical remains. Exceptional botanical preservation at Riwi cave is generated by the dry, anaerobic, and alkaline sediments of the limestone cave.

Wooden artefacts recovered from Riwi include the fragment of a wooden implement, the negative component of a firedrill, and wood shavings associated with the production of wooden artefacts (Fig. 3). The fragment of the wooden artefact displays numerous signs of working, including cut marks, polish, and evidence for its intentional removal from a larger artefact. It is 23.9 mm in length, 23.4 mm in width, 10.1 mm in thickness, and weighs 2.44 g. The negative component of the firedrill, which is 47.1 mm long and 7.6 mm wide, has an incomplete drilling cup. The diameter of the complete drilling cup would have been approximately 11 mm. Davidson (1947) records the fire-drill as a two piece tool-kit consisting of two thin rods of wood, one the hearth stick (negative) and the other the drill (positive). The hearth stick is made from a softer wood than the drill, which is pressed into the drilling cup of the hearth stick and rotated quickly between the palms of the hands (Akerman, 1998: 10). The fragment recovered from Riwi is the hearth stick.

5. Materials and methods

5.1. Dating

The wooden fragment was recovered from Square 3, excavation unit 8C. Because this excavation unit is a mixture of stratigraphic units 1 and 2, the artefact was sampled for radiocarbon dating. The fragment was shaved with a scalpel on the proximal end; first to remove peripheral material; and second to obtain a sample (10.4 mg) for analysis. Radiocarbon analysis was undertaken by the Australian National University's (ANU) radiocarbon laboratory using the single stage accelerator mass spectrometry (AMS) method (Fallon et al., 2010). The calibrated age range is 651 to 557 cal BP 95.4% (S-ANU43337), calculated with the SHCal13 curve (Hogg et al., 2013) in OxCal version 4.2 (Bronk Ramsey, 2009).

The hearth stick, which was recovered from Square 4, excavation unit 6, is too fragile for sampling, and is dated only by association, within the age range of stratigraphic unit 1 (915 to 668 cal BP to recent). Table 1 presents the radiocarbon chronology for the Holocene units of the site, while Table 2 lists each of the wooden artefacts, including quantifications of wood shavings, with their associated stratigraphic units and radiocarbon chronology. Wood shavings were weighed and each individual fragment, or the number of individual specimens (NISP), was counted.

5.2. X-ray microtomography

The X-ray Computer Tomography laboratory, operated by the Department of Applied Maths at the Australian National University (ANU), scanned both wooden artefacts. A small cube (6 mm^3) of the distal fragment, which was initially removed with a razor blade for examination by SEM, was placed in the X-ray μCT chamber, whereas the entire hearth stick was inserted, and only the drilling cup section was rendered (Fig. 5d). Both samples were rested on silicon plugs, enclosed within glass tubes, and individually mounted on the precision rotation stage during the scanning process. A range of parameters was explored to find the optimal scanning conditions (80 keV and 75 μA). Both 3D volumes comprised 3600 scans, collected with a double helix trajectory. The X-ray detector is a 16-bit, scintillator-coupled 3040 × 3040 pixel CCD camera mounted on a linear rail. The entire apparatus sits on top of custom-built vibration isolators for stability. The radiographic data were translated with the ANU Supercomputer facility, and rendered with Drishti software.

Fig. 3. A) Wooden artefact fragment; B) hearth stick; C) examples of wood shavings from Square 4, excavation unit 7B. All photographs were taken with a Canon EOS 400D digital camera.

Table 1
Riwi Squares 3 and 4: radiocarbon chronology of the Holocene stratigraphic units (SUs). Dates were calibrated against SHCal13 (Hogg et al., 2013) in OxCal v.4.2 (Bronk Ramsey, 2009).

SU	SU description	Lab. code	Material	Radiocarbon age	Calibrated age range 2σ
1	Grey-brown (7.5YR4/3; 10YR7/6) fine sand with abundant leaf litter, rich in charcoals and ashes, clear boundary with SU2; mud nests, insect cocoons, and several concave kangaroo hollows observed	D-AMS 004068	Charcoal	816 ± 27	732–668
		D-AMS 004064	Charcoal	956 ± 29	915–760
2	Grey-brown (7.5YR4/4; 7.5YR4/6) ashy fine sand with leaves and charcoals, very sharp boundary with Pleistocene layers	Wk 7605	Charcoal	5290 ± 60	6195–5905
		D-AMS 004069	Charcoal	6179 ± 29	7162–6935
		D-AMS 004065	Charcoal	6206 ± 37	7175–6936
		S-ANU38223	Charcoal	6245 ± 30	7243–6998
		D-AMS 004063	Charcoal	6384 ± 32	7414–7170

5.3. Wood identification

Taxonomic identification is conducted by comparing an unknown sample's wood anatomy with the anatomy of known, botanist-vouchered reference materials. The Bunuba-Gooniyandi reference collection (ANU), which was created for anthracological research led by Whitau, consists of 84 taxa collected over two successive field seasons (July 2013, April 2014). Vouchers of fertile material were identified by, and lodged with, Brendan Lepschi and his team at the CSIRO Herbarium in Canberra. Wood samples were prepared following Pearsall (1989: 128–133). The Bunuba-Gooniyandi reference collection was further supplemented by an additional two wood samples from the Australian National Botanical Gardens and 12 physical charcoal samples from Chae Byrne's Weld Range and Barrow Island reference collections at the University of Western Australia. Wood identification keys including Hope (1998); Ilic (1991), and two online databases: Inside Wood (http://insidewood.lib.ncsu.edu/) and the University of Queensland Online Archaeology Collections (http://uqarchaeologyreference.metadata.net/archaeobotany/list) were also used to aid identification. Wood anatomy is described following the IAWA nomenclature and characteristics (Wheeler et al., 1989).

6. Results

6.1. Wooden artefact fragment

The X-ray scan of the wooden artefact fragment obtained a resolution of 3.0 μm. Slices of transverse, tangential and radial longitudinal views, translated with volume rendering software (Drishti), are presented in Figs. 4A–C. The artefact is produced on wood which is semi ring-porous. Transverse views show that the vessel elements are clustered tangentially in groups of two to three with longer chains common when vessels are smaller in size. The fibre walls are thick to very thick, and axial parenchyma is unilateral, often winged aliform, sometimes lozenge aliform, and always confluent. The axial parenchyma and vessel groups are festooned. The longitudinal sections show rays of two sizes: uniseriate rays one to seven cells high, and 12 to 23 seriate rays, 30 to 69 cells high. Aggregate rays were also observed. The resolution attained by the scan (3.0 μm) was too low to describe sub-elemental features, such as intervessel pitting.

The anatomy of the distal fragment is characteristic of the Proteaceae family, and more particularly, the *Grevillea* and *Hakea* genera. The Bunuba-Gooniyandi charcoal reference collection includes eight examples of *Grevillea* and *Hakea* species, and anatomical comparisons were aided with the various databases and literature listed in Section 5.3. *Grevillea* and *Hakea* share a lot of anatomical traits, such as clusters of pores which are tangentially arranged; festooned, confluent axial parenchyma; aggregate rays; bordered to scalariform intervessel pits, simple perforation plates; and often rays of two sizes (Figs. 4F–H). However, distinguishing between the two genera is more difficult with the presence and absence of traits shared across both genera. There are currently 42 identified species and subspecies of *Grevillea*, and four species of *Hakea* (*H. arborescens*, *H. chordophylla*, *H. lorea*, and *H. macrocarpa*) in the Kimberley region (http://florabase.dpaw.wa.gov.au/). During the 2013 vegetation survey and reference material collection, four species of *Grevillea* were collected within 50 km of Riwi cave: *G. pyramidalis*, *G. refracta*, *G. wickhamii*, and an unknown *Grevillea* sp. While no *Hakea* species were collected, the survey was by no means exhaustive, and only plants producing fertile voucher material were collected; *Hakea* should not, therefore be ruled out on these grounds. The wood artefact fragment is therefore identified as *Grevillea*/*Hakea* sp.

Of interest, three fragments of one individual *Grevillea* sp. fruit were recovered from Square 4, excavation unit 8B, which is mixed between stratigraphic units 1 and 2. Of the 4627 charcoal fragments analysed from this site, only two fragments were positively identified from the Proteaceae family (Table 3). While both of these examples (Figs. 4D, E) are *Grevillea*/*Hakea* sp., they are not of the same type as the wooden artefact, since the charcoal examples are diffuse-porous, with vessels in weak tangential to diagonal arrangement, and rays of two types: uni- to triseriate, four to 13 cells high; and ten to 14 seriate, over 100 cells high. Both of these fragments were recovered from the 1.5 mm sieve fraction of stratigraphic unit 1.

6.2. Hearth stick

The X-ray scan of the hearth stick obtained a resolution of 3.7 μm. The drill cup is formed directly on the pith, the softest part of the stem. Slices of transverse, tangential longitudinal, and radial longitudinal views, rendered with the Drishti software are presented in Figs. 5A–C. Transverse views show that the wood is diffuse-porous, with vessel clusters of two most common, while longer chains of three to four vessels occur occasionally, arranged in radial to diagonal patterns. Fibre walls are thin, and axial parenchyma is scarce. The longitudinal views show uni- to triseriate rays, two to 30 cells high. Ray cells are heterogenous in composition, of mixed shape, but this could also be related to the proximity of the xylem to the pith (Wheeler et al., 1989: 291). The end cells of all rays are tapered. Perforation plates are simple, and sub-

Table 2
Weights and number of identified specimens (NISP) for wood shavings and wooden artefacts presented by excavation unit, with associated stratigraphic units and calibrated age ranges (2σ).

Square	Stratigraphic unit	Excavation unit	Calibrated age range (2σ)	Material	Weight (g)	NISP
3	1	2B	732–668 cal BP	Wood shavings	0.02	1
3	1	8C	651–557 cal BP	Wooden artefact fragment	2.44	1
4	1	1D, 2A–D, 3A–D, 4A–D, 5B–D, 6B, 6C, 7B	732–668 cal BP	Wood shavings	3.09	282
4	1	6B	732–668 cal BP	Hearth stick	0.29	1
4	2	7A, 7D, 8A, 8C, 8D, 9A–C	7414–5905 cal BP	Wood shavings	3.22	165

elemental features are unobservable at the available resolution (3.7 μm).

The anatomy of the hearth stick is characteristic of the Lamiaceae family. Six Lamiaceae genera are identified within the Kimberley, three of which tend to produce secondary xylem (the other three are herbaceous): *Clerodendrum*, *Premna*, and *Vitex* (http://florabase.dpaw.wa.gov.au/). No Lamiaceae were identified within the Riwi site vicinity during the July 2013 field season, probably because the family tends to flower and fruit during the end of the wet season. Samples of *C. tomentosa* (Fig. 5F), *V. glabrata* (Figs. 5G, H), and an unknown *Vitex* sp. were collected during the April 2014 field season from Windjana Gorge National Park. The limited reference collection makes robust identification difficult for this family. Table 3 details the major anatomical features exhibited by the three genera. These anatomical features are very similar across the

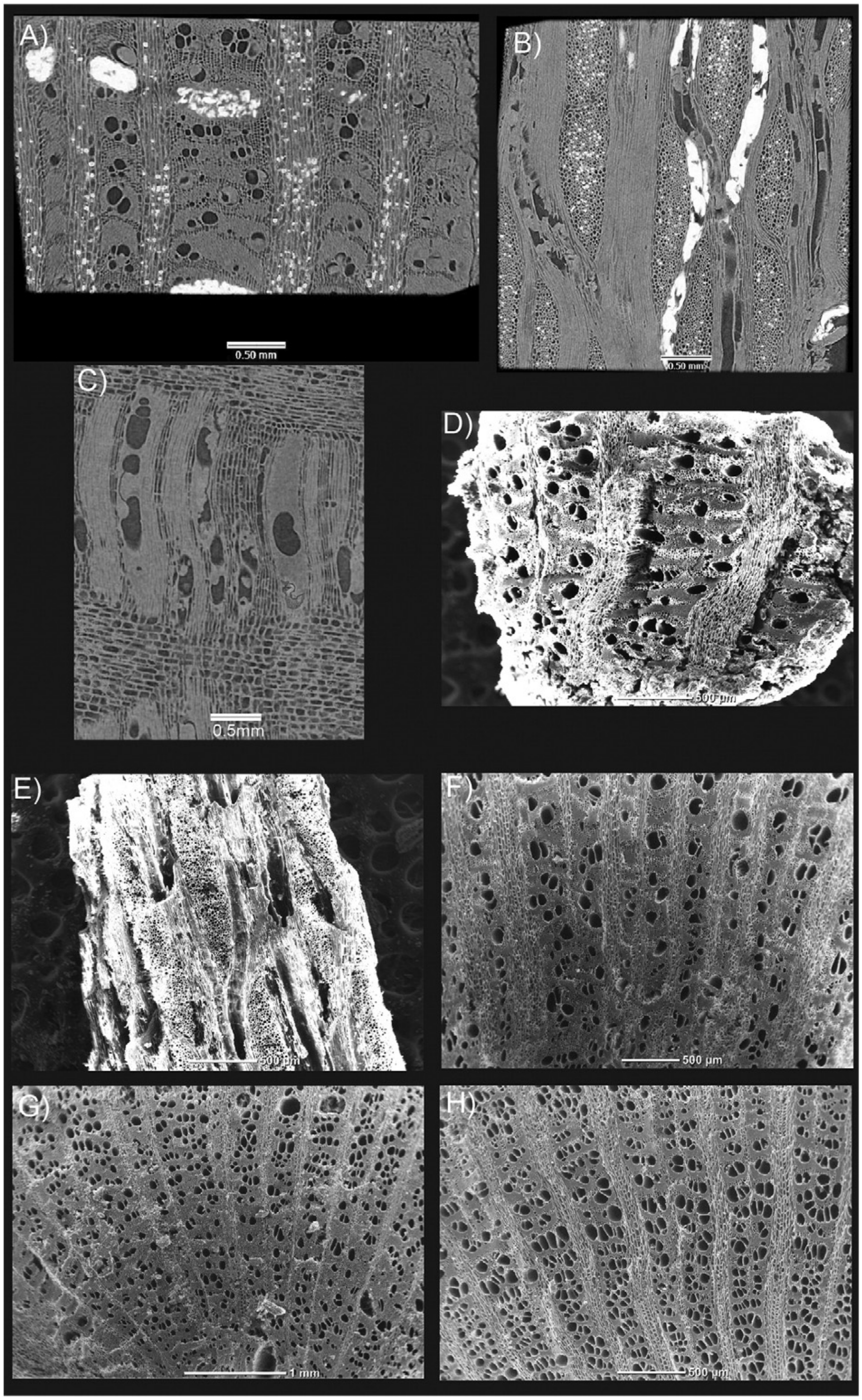

Fig. 4. A) Wooden artefact fragment, transverse section; B) wooden artefact fragment, tangential longitudinal section; C) wooden artefact fragment, radial longitudinal section; D) archaeological wood charcoal *Grevillea*/*Hakea* type, sample R4A206, transverse section; E) archaeological wood charcoal *Grevillea*/*Hakea* type, sample R4A206, tangential longitudinal section; F) reference wood charcoal, *Grevillea* sp., sample BG09, transverse section; G) reference wood charcoal, *Grevillea refracta*, sample BG25, transverse section; H) reference wood charcoal, *Hakea arborescens*, sample BG37, transverse section. 4A–C were scanned with the X-ray detector 16-bit, scintillator-coupled 3040 × 3040 pixel CCD camera and rendered with Drishti software. 4D–H were produced with the JEOL 6000 Desktop SEM (high vacuum, SEI, 15 kv).

Table 3
Summary of major wood anatomy features for the *Clerodendrum*, *Premna*, and *Vitex* genera.

Genus	Vessel elements	Fibres	Axial parenchyma	Radial parenchyma
Clerodendrum sp.	• Growth ring boundaries distinct • Semi-ring to diffuse porous • Vessels in clusters (2 to 3), arranged in diagonal patterns • Simple perforation plates • Intervessel pits alternate, polygonal	• Fibres thin to thick walled • Fibres with simple to minutely bordered pits • Septate and non-septate fibres present	• Scanty paratracheal • Diffuse in aggregates • Two cells per strand	• Ray width one to three cells • Large rays commonly four to ten seriate • Body ray cells procumbent with one to two-four rows of upright and/or square marginal cells
Premna sp.	• Growth ring boundaries distinct • Semi-ring to diffuse porous • Vessels in clusters (2 to 4), arranged in diagonal patterns • Simple perforation plates • Intervessel pits alternate, polygonal	• Fibres thin to thick walled • Fibres with simple to minutely bordered pits • Septate and non-septate fibres present	• Scanty paratracheal • Marginal or in seemingly marginal bands • Two to four cells per strand	• Ray width one to three cells • Large rays commonly four to ten seriate • Body ray cells procumbent with one to two-four rows of upright and/or square marginal cells
Vitex sp.	• Growth ring boundaries distinct • Semi-ring to diffuse porous • Vessels in clusters (2 to 3), arranged in diagonal patterns • Simple perforation plates • Intervessel pits bordered	• Fibres thin to thick walled • Fibres with simple to minutely bordered pits • Septate and non-septate fibres present	• Scanty paratracheal • Vasicentric • Two to four cells per strand	• Ray width one to three cells • Large rays commonly four to ten seriate • Body ray cells procumbent with one to two-four rows of upright and/or square marginal cells

three genera, with axial parenchyma serving as the main distinguishing factor (see Table 3). While species from all three genera can exhibit narrow (one to three cells wide), marginal bands of axial parenchyma, these bands consistently occur within the *Premna* genus. For this reason we think that the fire drill is unlikely to be *Premna*, but since this is based on the available literature (Section 5.3) with limited physical reference material, we leave the level of identification to the family group. The hearth stick is identified as Lamiaceae sp.

Vitex sp. and Lamiaceae sp. occur throughout the charcoal record (Table 3), and these types differ in anatomical structure from the hearth stick. The *Vitex* charcoal type (Fig. 5D) is diffuse-porous, but growth boundaries are distinct through changes in pore abundance and fibre wall width. Vessels are common in radial groups of two to three, forming narrow tangential bands in areas of high vessel density, with radial to diagonal patterns in areas of lower vessel density. Fibre walls are medium to thick in thickness, and axial parenchyma is scarce, visible occasionally in a scanty paratracheal arrangement. Intervessel pits are bordered in shape, with borders between pits occasionally connecting across the vessel in groups of two to four pits. Vessel-ray pits are scalariform. Both septate and non-septate fibres are present, but the absence of the unlignified septa could be an effect of the charring and post-depositional processes. Rays are uni- to six seriate, ranging from six to 40 cells high, with abundant tile cells. The Lamiaceae family group consists of charcoals produced from twiggy material; and are most likely the juvenile wood of the *Vitex* genus (Fig. 5E). *V. glabrata* is the most abundant taxon within the carpological record in terms of both minimum number of individuals (MNI) and number of identified specimens (NISP) (Table 4). No other Lamiaceae genera were identified from either the charcoal or macrobotanical records (see Table 5).

7. Discussion

7.1. Wooden artefact fragment

The rarity of *Grevillea*/*Hakea* spp. fragments in the charcoal and macrobotanical records potentially illustrates an example of the past inhabitants of Riwi selecting different woods for different purposes. Avoidance of Proteaceae wood for fuel use has been noted in previous anthracological studies in semi-arid Western Australia (Byrne et al., 2013; Dotte-Sarout and Byrne, 2013). While ethnographic literature is available for Aboriginal groups throughout the Kimberley region, a CSIRO calendar is the only written source of Gooniyandi plant use (Davis et al., 2011). The calendar provides information on food resources and seasonal indicators for resource availability and does not extend to plants used for the production of material culture (Davis et al., 2011). For this reason ethnographic literature from surrounding Aboriginal groups was investigated with particular reference to wooden tool manufacture and wood selection. The Aboriginal hunter-gatherers of Australia select, and have selected, a variety of different woods for the manufacture of specific artefacts, and a complete list of taxa is beyond the scope of this paper, so the Proteaceae family was targeted for the artefact fragment, the Lamiaceae family for the hearth stick. The Kija people of the southeast Kimberley prefer four species for the production of boomerangs, spears, spear shafts, and woomera: *G. miniata*, *G. pyramidalis*, *G. striata*, and *G. wickhamii* (Scarlett, 1985: 22; Wightman, 2003: 56–57). *H. arborescens* is also selected for the construction of boomerangs and fighting clubs by both the Kija and Jaru Aboriginal groups (Scarlett, 1985: 22; Wightman, 2003: 58). The Bardi people of the Dampierland Peninsula specifically select *G. striata*, *H. arborescens*, and *H. macrocarpa* for the manufacture of boomerangs (Kenneally et al., 1996: 19; Paddy et al., 1993: 22; Smith and Kalotas, 1985: 334, 344). While no ethnobotanical literature currently exists for the Gooniyandi people, other groups in the Kimberley region are documented selecting wood from the *Grevillea* and *Hakea* genera for artefact manufacture, and in particular, the production of wooden artefacts that require balance and aerodynamism, such as boomerangs, spears, spear shafts, and woomera.

While the density and mechanical properties of a wood will inform its suitability for specific artefact manufacture, these properties are poorly reported in the ethnographic records, limiting our understanding of wood selection. Kamminga (1988) forms the major exception, listing the air dried densities of various woods in relation to their recorded uses. However, no other mechanical properties are mentioned, and the list is incomplete, for example, of the seven *Grevillea*/*Hakea* species listed, densities are only given for *G. striata* and *H. leucoptera* (880 kg/m^3 each), while no densities are listed for all six of the *Clerodendum* and *Premna* species (Kamminga, 1988: 45–46). Similarly, modern manuals on the technological properties of Australian woods tend to focus on commercial timbers, with *G. robusta* and *V. cofassus* serving as the sole representatives of the genera in question (Bolza and Kloot, 1963;

Fig. 5. A) Hearth stick, transverse section; B) hearth stick, tangential longitudinal section; C) hearth stick, radial longitudinal section; D) archaeological wood charcoal *Vitex* sp. type, sample R4D702, transverse section; E) archaeological wood charcoal Lamiaceae sp. type, sample R4A42_1.5_01, transverse section; F) reference wood charcoal, *Clerodendrum tomentosum*, sample BG75, transverse section; G) reference wood charcoal, *Vitex glabrata*, sample BG78, transverse section; H) reference wood charcoal, *Vitex glabrata*, sample BG78, tangential longitudinal section. 4A–C were scanned with the X-ray detector 16-bit, scintillator-coupled 3040 × 3040 pixel CCD camera and rendered with Drishti software. 4D–H were produced with the JEOL 6000 Desktop SEM (high vacuum, SEI, 15 kv).

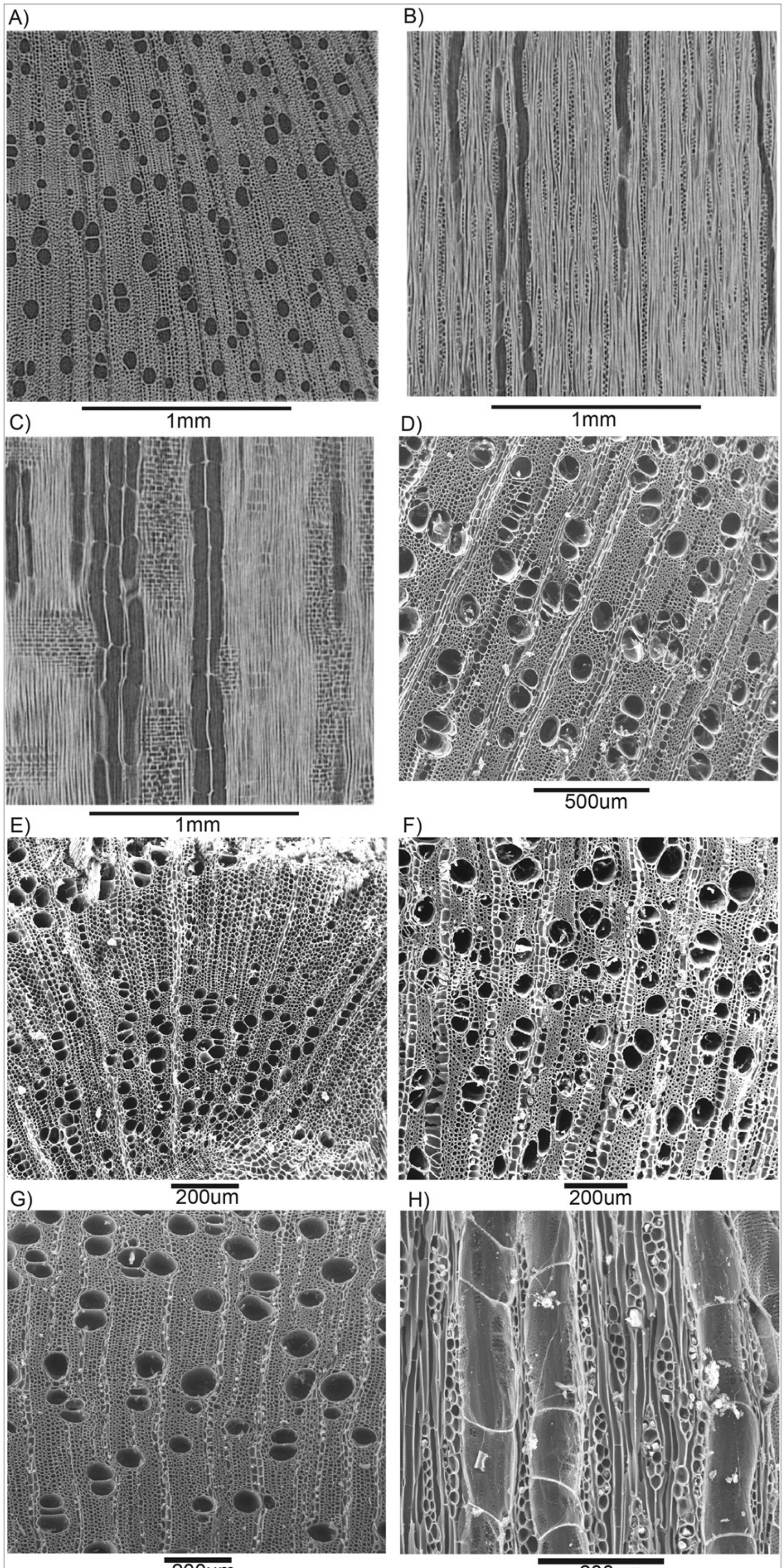
A)
B)
1mm
1mm
C)
D)
1mm
500um
E)
F)
200um
200um
G)
H)
200um
200um

Table 4
Frequencies of Lamiaceae and Proteaceae wood charcoal within each stratigraphic unit (SU), expressed in terms of both absolute fragment counts (n) and proportion of total identifiable fragments (Ni).

	SU1		SU2		SU7		SU10		SU12	
	n	%	n	%	N	%	n	%	n	%
Lamiaceae										
Vitex sp.	26	7.0	23	7.0	0	0	2	1.1	0	0
Lamiaceae sp.	6	1.6	9	2.7	2	0.6	1	0.6	6	35.3
Proteaceae										
Grevillea/*Hakea* sp.	2	0.5	0	0	0	0	0	0	0	0

Bootle, 2005; Keating and Bolza, 1982); preventing a detailed discussion of the technological properties of the woods selected for the manufacture of the Riwi wooden artefacts.

In conjunction with wood type, we observed three key features that lead us to hypothesise that the fragment constitutes the extremity of an artefact intended for aerial use. First, the artefact has been planed with a lithic edge, exposing tangential longitudinal sections. This planing action would produce wood shavings (Fig. 3c; Clarke, 1987: 141). Second, crushing along the distal tip could be the result of repetitive impacts with another surface, such as the ground. Third, the proximal end displays numerous cut marks, which terminate in a splinter fracture, indicating that the fragment was intentionally removed via flexion, after the tip was weakened by cutting. Because such a large section was intentionally removed, for example, in comparison to wood shavings (see Table 2 for comparative weights), we argue that weight and balance were important properties for the original implement. This hypothesis is supported by the wood type since *Grevillea* and *Hakea* genera are selected for the production of aerial implements by Aboriginal groups in the Kimberley region. We aim to test this hypothesis with further consultation with Gooniyandi people, and comparison with wooden implements housed in museum and private collections from the region.

7.2. Hearth stick

The three non-herbaceous Lamiaceae taxa (*C. tomentosum*, *P. acuminata*, *V. glabrata*) found in the Kimberley region are not sclerophyllic, like the Proteaceae of the region, but are associated with the dry rainforest of the Kimberley, in particular, semi-deciduous vine thickets. Kimberley vine thicket communities are small, isolated pockets of dry rainforest that are thought to represent a once widespread palaeotropical flora (Gillison, 1987; McKenzie, 1991). The interaction of topography and disturbance by fire has played a pivotal role in the distribution and composition of these vine thicket patches (Clayton-Greene and Beard, 1985; McKenzie, 1991), which are distributed predominantly within coastal areas or rocky outcrops, where ocean and/or topography can provide protection from fire. The closest recorded vine thickets to the Mimbi area are those found in the Windjana Gorge and Bungle Bungle National Parks (McKenzie, 1991; Wallis, 2000, 2001). While no pockets of vine thicket were observed within the limits of the July 2013 survey, dry rainforest taxa were observed in abundance across the limestone range and outliers. No Lamiaceae species were collected from the Mimbi area, but the abundance of *Vitex* sp. wood charcoal and *V. glabrata* fruits in the Holocene archaeological units indicate that this genus grew within walking distance of the site during the last 1000 years.

Dry, pithy stems of genera belonging to the Lamiaceae family are commonly used as hearth sticks across northern Australia (Clarke, 2012: 120–121). *Clerodendrum* and *Vitex* are cited occasionally in the available ethnographic literature (Clarke, 2012: 120; Wightman, 2003: 45, 148); however, the most commonly cited genus is *Premna*, with the species *P. acuminata*, common name the “firestick tree” often cited with reference to fire making tools (Crawford, 1982; Kenneally et al., 1996: 196; Scarlett, 1985; Smith and Kalotas, 1985; Wightman, 2003). The use of *P. acuminata* stems to make firesticks using the drilling method is documented for the Kija, Jaru, and Bardi groups across the Kimberley region (Crawford, 1982: 34; Scarlett, 1985: 23; Smith and Kalotas, 1985: 384; Wightman, 2003: 66). Although we are unable to identify the hearth stick material to lower than family level, the fact that this Lamiaceae sp. type is different from the *Vitex* sp. and Lamiaceae sp. charcoal types is further evidence of different woody taxa being selected for different purposes, at least within the last 1000 years of occupation at the site.

7.3. The X-ray μCT process

The X-ray μCT process is an efficient and non-destructive method for imaging the internal structure of opaque objects. The main limitation of the technique is resolution, which is inversely proportional to sample width. While certain μCT systems are capable of 1 μm resolution, this is only possible with submillimetre sample sizes (Bird et al., 2008: 2700). For the two Riwi artefacts, the highest spatial resolution attainable was 3.0 μm; therefore, all elements below 3.0 μm, such as intervessel pitting, could not be observed. These features are important diagnostic markers which could have enabled a higher level of identification, particularly for the hearth stick, had the available reference material, in terms of both the physical collections and the literature, been more extensive. Identification of wood taxa is a function of both resolution and reference material; therefore, while SEM images would have enabled a more detailed description of both artefacts, the limited reference material would have hindered further diagnosis.

The main advantage of the X-ray μCT process is the fact that it is non-invasive and could be used to determine the woody taxa of artefacts for which physical sectioning is not culturally appropriate, such as those artefacts which are precious to descendant populations and/or housed in museum collections. However, the dimensions of the object and the size of the X-ray apparatus' chamber are limiting factors. For example, the X-ray Computer Tomography laboratory at the ANU is capable of scanning objects with a maximum width of 100 mm. Once inside the chamber, smaller area(s) of the object can be selected for scanning at high resolution. The examination of several areas within wooden material is ideal given the centripetal disintegration of woody tissues (Florian, 1990: 5), and the application of other techniques, such as dendrochronological analyses (cf. Stelzner and Million, 2015).

8. Conclusions

Two wooden objects from Riwi, a distal fragment of a wooden artefact and a hearth stick, were both analysed with X-ray computed microtomography. The Riwi wooden artefacts were compared to reference material: the distal fragment is identified as *Grevillea*/*Hakea* sp., the hearth stick as Lamiaceae sp. We argue that the fragment was purposefully removed in order to alter the appearance or behaviour of the object from which it originated, which we hypothesise was intended for aerial use. The paucity of Proteaceae remains in both the wood charcoal and macrobotanical records, already observed in previous Western Australia anthracological studies, shows that the past inhabitants of Riwi were avoiding *Grevillea*/*Hakea* as a fuel wood, and selecting it for the manufacture of particular artefacts. The hearth stick was produced on a Lamiaceae sp. type which differs from the *Vitex* sp. and Lamiaceae sp. types recovered from the archaeological wood charcoal record. The identification of the material used to produce the two Riwi wooden artefacts has enabled us to illustrate that the past inhabitants of Riwi selected certain woods for specific purposes within the last 1000 years of occupation at the site.

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Table 5
Frequencies of Lamiaceae fruits recovered within each stratigraphic unit (SU)*, expressed in terms of both minimum number of individuals (MNI) and number of identified specimens (NISP).

	SU1		SU2		SU7		SU10	
	MNI	NISP	MNI	NISP	MNI	NISP	MNI	NISP
Lamiaceae								
Vitex glabrata	167	228	22	19	10	13	2	2

*Note that only Quad B was sampled for macrobotanical analyses.
Adapted from Dilkes-Hall, 2014.

Applied Maths (ANU) scanned the artefacts and rendered the images and models. Rachel Wood sampled and dated the wooden artefact fragment. Dorcas Vannieuwenhuyse produced the site plan in Fig. 2. This research was funded by the ARC Linkage Grant LP100200415, with contributions from the Kimberley Foundation Australia and the Department of Sustainability, Water, Populations and Communities. We would like to thank Tim Maloney for his comments on earlier versions of this paper, and two anonymous reviewers for their insightful comments.

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Chapter 6. The curious case of Proteaceae: macrobotanical investigations at Mount Behn rockshelter, Bunuba country, Western Australia

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Rose Whitau: developed the research question; undertook field work; recorded and analysed the anthracological data; formulated the arguments in the manuscript; drafted the entire manuscript, except for the carpological methods and results sections; edited and reviewed the manuscript.

Signed:

16/03/18

Rose Whitau

India Ella Dilkes-Hall: undertook field work; recorded and analysed the carpological data; formulated and refined arguments in the manuscript; drafted the carpological methods and results sections; edited and reviewed the manuscript.

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Dorcas Vanniewenhuyse: undertook field work; recorded and analysed the carpological data; formulated and refined arguments in the manuscript, particularly in regards to site formation processes and taphonomy; edited and reviewed the manuscript.

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ARTICLE

The curious case of Proteaceae: macrobotanical investigations at Mount Behn rockshelter, Bunuba country, Western Australia

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ABSTRACT
Macrobotanical analyses, which offer important information about human-environment interactions of the past, are underdeveloped in Australia due to limited reference materials, poor preservation of organic remains and inadequate field sampling strategies. Wood, seeds, fibres and resin provide invaluable information on diet, technology and human-environment interaction. When excavated from stratified archaeological deposits, macrobotanical remains enable analysis at a scale that is spatio-temporally linked with human occupation, unlike broad-scale palaeo-environmental records, which defy correlation with short-time human responses. Identification and analyses of wood charcoal and seeds from Mount Behn rockshelter, Bunuba country, in the southern Kimberley region of Western Australia, where the largest stone point assemblage for the region was excavated. Neither the anthracological nor carpological records reflect the taxon richness of vegetation communities of the modern vegetation, precluding both palaeo-environmental reconstruction and in-depth exploration of resource management and use. Certain taxa are over-represented in the anthracological and carpological records, in particular, Proteaceae wood charcoal and *Celtis* spp. endocarps, and we explore how anthracological and carpological spectra are artefacts of preservation, with particular reference to other macrobotanical research that has been conducted in the Kimberley region and Western Australia.

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Introduction

Mount Behn rockshelter yielded the largest assemblage of the retouched stone artefacts known as points excavated from the Kimberley region to date (Maloney et al. 2017). Applying technological criteria and morphological analyses to the Mount Behn unifacial and bifacial point assemblages, Maloney et al. (2017) present the first substantial demonstration of a point reduction continuum in the Kimberley, akin to those observed in the Northern Territory and Queensland (Clarkson 2002, 2007; Hiscock 1994, 2006). Maloney et al. (2017) argue that the majority of points were discarded during the deposition of SU3 and SU4, between 3,815–3,575 cal. BP (ANU-33031) and 1,835–1,710 cal. BP (ANU-46907), a period which they associate with an El Niño-Southern Oscillation (ENSO) phase of aridity and inferred foraging risk, between approximately 2,400 and 1,200 cal. BP (Conroy et al. 2008; Denniston et al. 2013; Donders et al. 2007, 2008; Field et al. 2017; Gagan et al. 2004; McGowan et al. 2012; Moy et al. 2002; Rein et al. 2005; Rodbell et al. 1999; Schulmeister 1999). This view aligns with other reduction based analyses of stone tool assemblages in Northern Australia, which have linked changes in stone tool reduction strategies with adaptation to increases in aridity and inferred foraging risk (Clarkson 2002, 2007; Hiscock 1994, 2006; Hiscock and Attenbrow 2002; Hiscock and Veth 1991; Maloney et al. 2014; Maloney and O'Connor 2014; O'Connor et al. 2014).

The lack of detailed palaeoenvironmental data available from the area does not allow for a precise correlation of human-environment interaction. For example, the 2,400 and 1,200 cal. BP arid phase is based on palaeoclimate records located at some distance from Mount Behn rockshelter, with the closest palaeoenvironmental archive, Black Springs, some 230 km northeast of the site and offering a local, rather than regional vegetation reconstruction (Figure 1; Field et al. 2017; McGowan et al. 2012). The obvious solution to this issue is to reconstruct the local vegetation from the archaeobotanical remains recovered from Mount Behn rockshelter and explore human-environment interaction throughout the site's occupation.

Of the suite of botanical fossils that can be obtained from archaeological contexts, macrobotanical

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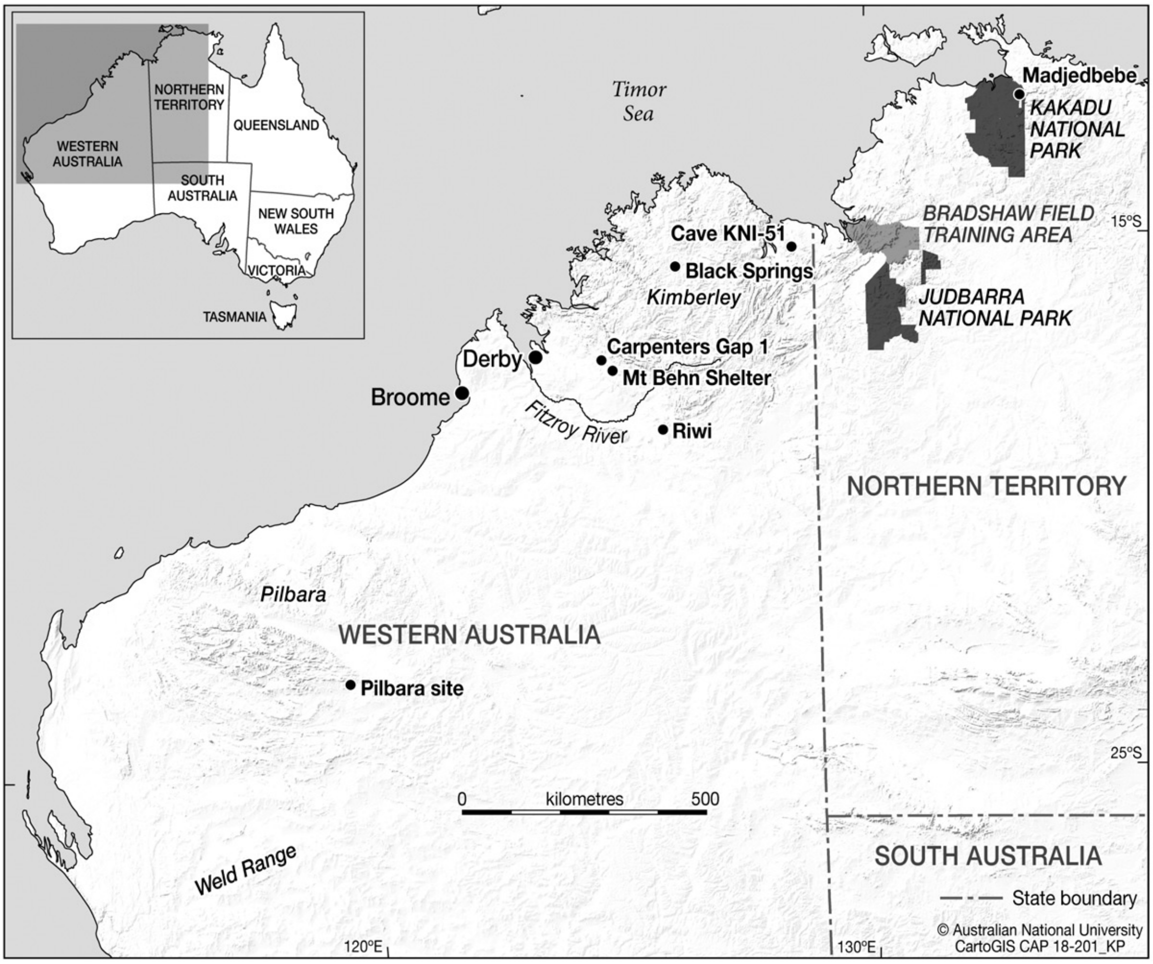

Figure 1. Western Australia with sites mentioned in the text and inset of Australia, including Black Springs (Field et al. 2017); Cave KNI-51 (Denniston et al. 2013); Carpenters Gap 1 (Frawley 2009); Madjedbebe (Carah 2016); and Riwi (Whitau et al 2016a). Note that precise coordinates cannot be provided for the Pilbara (Dotte-Sarout and Byrne 2013) and Weld Range (Byrne et al. 2013) sites due to confidentiality agreements (figure produced by CartoGIS, Australian National University).

remains offer the most unambiguous signature of human manipulation. Wood, seeds, fibres and resin provide invaluable information on diet, technology and human-environment interaction. When excavated from stratified archaeological deposits, macrobotanical remains enable analysis at a scale that is spatio-temporally linked with human occupation, unlike broad-scale palaeoenvironmental records, which defy correlation with short-time human responses (Holdaway et al. 2010). However, macrobotanical remains are organic and perishable and so their survival depends on an array of taphonomic factors. The most common mode of preservation is through carbonisation via charring, whether direct (e.g. wood for fuel), or indirect (e.g. seeds in the sediment are burned, or waste is thrown on a fire). Depending on the context, the anaerobic conditions provided by waterlogged or desiccated sediments are more or less likely to offer the opportunity for organic remains to preserve, or certain types of macrobotanical remains might mineralize through the absorption of certain compounds from certain types of sediments (Pearsall 2015).

In Australia, analyses of macrobotanical remains have enabled exploration of resource use and management, landscape use, diet and mobility patterns, in the tropical regions of the Northern Territory and Queensland (Carah 2016; Clarke 1989; Cosgrove et al. 2007, Ferrier and Cosgrove 2012); the tropical Kimberley (Atchison 2009; Atchison et al. 2005; Dilkes-Hall 2014; McConnell and O'Connor 1997; Whitau et al. 2016a, 2016b), and semi-arid New South Wales (Fullagar et al. 2008). However, these studies are rare, as macrobotanical research remains under-developed in Australia. Indeed, since Denham et al.'s (2009) summary of archaeobotanical work conducted in Sahul, only a handful of macrobotanical studies have been conducted on the Australian continent, including five published works (Byrne et al. 2013; Dotte-Sarout et al. 2015; Ferrier and Cosgrove 2012; Whitau et al. 2016a, 2017), and three unpublished theses (Carah 2016; Dilkes-Hall 2014; Florin 2014).

Some Australian archaeological contexts do not allow botanic remains to be well preserved (cf. Denham et al. 2009; Dotte-Sarout et al. 2015); for example, the alternate wetting and drying of the monsoonal north does not favour the production of anaerobic environments, and the complex sedimentation processes observed within rockshelters, the most commonly excavated context in Australia (Williams et al. 2014), limit the creation of suitable deposits. Poor preservation is not the limiting factor of macrobotanical research; wood charcoal is one of the most ubiquitous archaeological remains, and yet its potential as an indicator for human-environment interaction is only beginning to be explored in Australia (cf. Dotte-Sarout et al. 2015). Inadequate field sampling strategies and the lack of reference materials continue to hinder the application of archaeobotanical techniques.

The purpose of this paper is to test Maloney et al. (2017)'s foraging risk hypothesis, by exploring human-environment interaction at Mount Behn rockshelter throughout its occupation sequence, and comparing local-scale vegetation reconstruction at the site with broader palaeoenvironmental and palaeoclimatic records. Wood charcoal and carpological assemblages are chosen specifically for this purpose, the first because wood charcoal is an appropriate proxy for vegetation reconstruction (Asouti and Austin 2005; Dotte-Sarout et al. 2015), the latter because other macrobotanical remains reveal the best direct evidence for human manipulation of plant resources (Pearsall 2015). Like all archaeological remains, macrobotanic assemblages are artefacts of preservation, and so the taphonomy and representativeness of each assemblage need to be considered for vegetation reconstructions and assessments of human-environment interaction to be valid. An essential aim of this paper, then, is to explore the taphonomy and representativeness of two archaeobotanical assemblages recovered from Mount Behn rockshelter (wood charcoal and seeds/fruits). This aim is particularly important for Australian archaeology, where poor preservation of botanical remains is often cited, but is not necessarily the limiting factor for the application of archaeobotanical analyses, when appropriate recovery techniques, such as flotation, are not regularly applied in the field, and archaeobotanists are often not engaged in the fieldwork process (Denham et al. 2009).

Study site

Mount Behn rockshelter is an outcrop of the central Napier Range within the traditional lands of the Aboriginal Bunuba people, in the southern Kimberley region of Northern Western Australia, located some 100 km from the current coastline (Figure 1). Situated within the tropical zone, the rockshelter receives an average of 700 mm of rainfall per annum, most of which falls within the wet season (October–May) of the Australian summer monsoon (Bureau of Meteorology 2015). The rockshelter, which is formed at the intersection of Behn conglomerates and Napier limestone (Playford et al. 2009), sits some 10 m above a plain at the top of a 15° talus slope (Figure 2). Approximately 40 m in length, between 2 and 10 m in depth and 2 m in height with a deep overhang, the rockshelter's ceiling and walls are almost entirely covered in rock art, which is both stylistically diverse and profusely superimposed. Soot also extensively covers the lower part of the ceiling. The surface of the shelter is littered with lithic artefacts including grinding stones, and a collection of lithic artefacts is also housed in a bower bird nest at the front of the cave.

A white fig (*Ficus virens*) grows within the shelter, while various trees and shrubs, including boab (*Adansonia gregorii*), *Vitex* sp., *Celtis strychnoides*, waterbush (*Myoporum montanum*), and white currant (*Flueggea virosa*) grow underneath the overhang, obscuring the view to the shelter from below (Figure 2). The limestone outcrop supports a sparse steppe of spinifex (*Triodia bitextura*), with boabs and other low trees such as kurrajong (*Brachychiton viscidulus*), kapok bush (*Cochlospermum fraseri*) and bloodwoods (*Corymbia* sp.). This steppe grades into greybox/cabbage gum (*Eucalyptus tectifica*/*Corymbia grandifolia*) savanna woodland with high ribbon grass (annual *Sorghum* sp.) and subsidiary *Corymbia cadophora*, *Hakea arborescens*, *Grevillea* sp. and *Acacia* sp. across the plain below. An ephemeral creek adjacent to the rockshelter supports riparian vegetation dominated by paperbarks (*Melaleuca* sp.) and sedges.

Figure 2. Mount Behn rockshelter outcrop (photographs and photograph montage by Dorcas Vannieuwenhuyse).

Methods

Site chronostratigraphic sequence and excavation methods

In 2012, a 2 × 1 m trench (Squares 1 and 2) was excavated near the central back wall of Mount Behn rockshelter (Figures 3 and 4; Maloney et al. 2017; Vannieuwenhuyse 2016). While Square 1 was excavated to bedrock at a depth of 70 cm, Square 2 was excavated until sterile deposits were reached at a depth of 50 cm. Seven stratigraphic units (SU) were identified in the field (Figure 4). The upper part of the sequence, SU5 to SU1, from c.40 to 50 cm below to the surface of the deposit and dated to the late Holocene, are archaeologically rich with recovered material including lithic artefacts, animal bone fragments, plant remains, charcoal, freshwater shell, scaphopod beads and fragments of painted wall. The boundary between the sterile lower deposit and the archaeologically rich deposits of the upper sequence are clear in some parts of the exposed stratigraphy and diffuse in others. SU5, for example, was created by the mixing of SU6 and SU4. Boundaries within the upper part of the sequence were also diffuse and difficult to differentiate. SU2 is a discontinuous rocky layer that only appears in the northern and western sections of the trench. The main occupation layers are SU4, SU3 and SU1. Several flat combustion features interpreted as hearths are interspersed throughout SU4–SU1.

Radiocarbon ages were obtained from seed, charcoal and the marine shell of which scaphopod beads are composed (Maloney et al. 2017; Vannieuwenhuyse 2016). Based solely on the charcoal chronology, the SU4 and SU3 age is bracketed between 3,815–3,575 cal. BP (ANU-33031) and 1,835–1,710 cal. BP (ANU-46907) and SU1 between 439–146 cal. BP and recent times (ANU-32631, ANU-46909). The marine shell ages are older than those of the charcoal, with the oldest radiocarbon age of 5,531–5,304 cal. BP (ANU-33033) determined from a bead recovered from SU5. Beads from the SU1 deposit were directly dated to 3,799–3,550 cal (ANU-33107) and 2,739–2,211 cal. BP (ANU-32510) (Balme and O'Connor 2017). The disparities between the marine and charcoal chronologies are most likely a combination of post-depositional perturbation of deposit and spatio-temporal distances between the acquisition of the scaphopod material, its varying cultural consumption (as discussed in Balme and O'Connor 2017), and burial at Mount Behn rockshelter, which is over 100 km from the current coastline (Figure 1).

Each square was excavated in 2 cm vertical spits × 50 cm horizontal quadrants. The deposit was dry-sieved through nested 5 and 1.5 mm mesh screens, except for a sediment sample of 2–3 L from Square 2 Quadrant C, within each vertical excavation unit (XU), which was bucket-floated, the heavy residue of which was wet sieved, on site. A bulk sediment sample was collected from each vertical XU in both squares for laboratory analyses. Flat hearths, which had laterally diffuse boundaries, are more obvious in section than they were during excavation and were

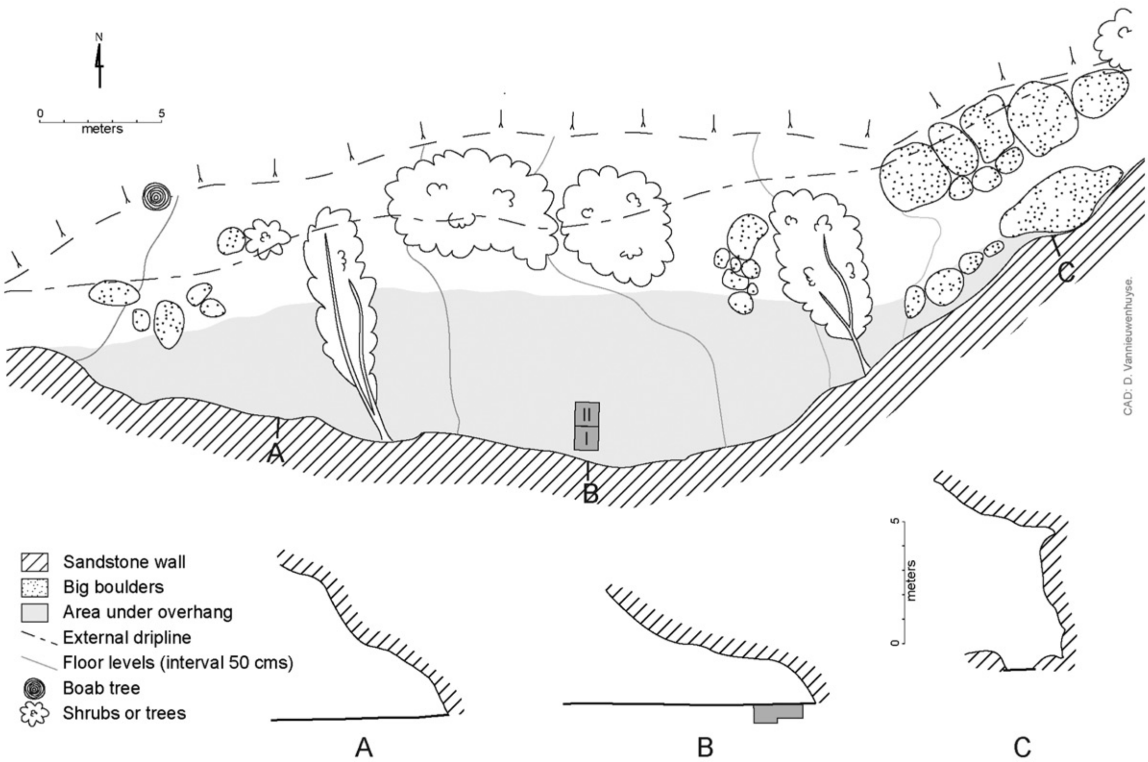

Figure 3. Mount Behn shelter plan showing the location of the excavation squares and shelter sections from western, central and eastern areas (topographic survey and CAD by Dorcas Vannieuwenhuyse).

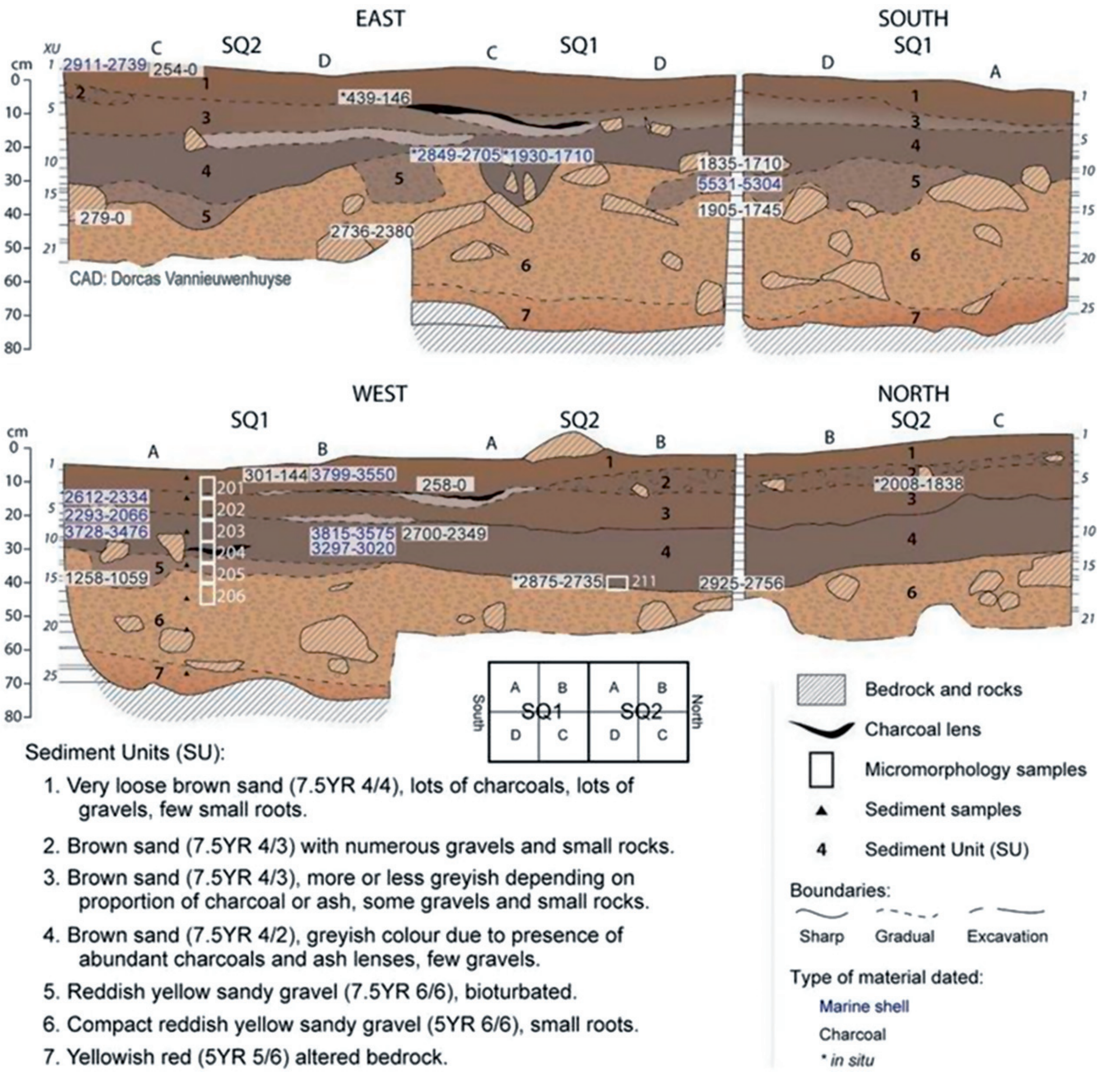

Figure 4. Mt Behn Squares 1 and 2 showing **dated** stratigraphic sections with descriptions of SUs and the location of micromorphological and sediment samples. (CAD by Dorcas Vannieuwenhuyse).

not removed separately. No off-site pits were dug due to time constraints.

Laboratory methods

Anthracological methods

By assessing the stratigraphic profile (Figure 4), XU depths and excavation notes, charcoals could be sampled from each of the stratigraphic contexts, and any XU that were stratigraphically mixed were avoided (Table 1). All of the charcoal fragments greater than 2 mm^2 were analysed from SU5–1, including both the flot and heavy residue from the floated sample. Charcoals were identified by snapping fragments along the transverse, radial and tangential longitudinal sections, with the aid of a scalpel where necessary (Leney and Casteel 1975). Exposed sections were examined with an Olympus BH-2 reflected lightfield/darkfield microscope (Japan) at magnifications of 20–500×, with rare or type examples selected for observation and imaging with a JEOL JCM-6000 Neoscope Scanning Electron Microscope (SEM) (Japan). Quantification was conducted by count, rather than weight, following Chabal (1990, 1992) and Théry-Parisot et al. (2010).

The Bunuba-Gooniyandi reference collection (ANU), which was created for this project, and includes Riwi cave, a Pleistocene archaeological site located within Gooniyandi people's lands (Figure 1; Balme 2000), consists of 84 taxa collected over two successive field seasons (July 2013, April 2014); and two wood samples from the Australian National Botanical Gardens (Whitau et al. 2016a). Following Pearsall (2015), wood samples were wrapped in aluminium foil and charred at 400°C in a muffle furnace until smoke was no longer produced. This

Table 1. Stratigraphic units (SU) and Excavation Units (XU) from which anthracological and carpological materials were collected, XU that were sampled for flotation are in bold.

		XU					
SU	Description	Square I	Square II	Lab.code	Material	Radiocarbon age (BP)	Calibrated age (95.4% probability range, cal BP)
1	Very loose brown sand (7.5YR 4/4), lots of charcoals, lots of gravels, few small roots	–	2B, **2C**	ANU 46912 ANU 46909 ANU 32631	Charcoal Charcoal Charcoal	108 ± 26 224 ± 25 265 ± 35	254–0 301–144 439–146
2	Brown sand (7.4YR 4/3) with numerous gravels and small rocks	–	4B				
3	Brown sand (7.5YR 4/3), more or less greyish depending on proportion of charcoal or ash, some gravels and small rocks	2A, 2C	**5C**, 6B, **6C**, 7B	ANU 32509	Seed	2,020 ± 34	2,008–1,838
4	Brown sand (7.5YR 4/2), greyish colour due to abundant charcoals and ash lenses, few gravels	6D, 7A, 7D, 8A, 8D, 9A,	11A, 11B, **11C**, 12A, 12B, **12C**, 13A, 13B	ANU 32507 ANU 46907 ANU 32513 ANU 32632 ANU 32512	*Celtis* seed Charcoal Charcoal Charcoal Charcoal	1,955 ± 30 1,884 ± 26 2,460 ± 35 2,775 ± 35 2,715 ± 45	1,930–1,747 1,835–1,710 2,700–2,349 2,925–2,756 2,875–2,734

Associated radiocarbon dates are calibrated against SHCal13 (Hogg et al. 2013) in OxCal v.4.2 (Bronk Ramsey 2009) following the radiocarbon chronology presented in Maloney et al. (2017) and Vannieuwenhuyse (2016).

reference collection was further supplemented by an additional 12 charcoal samples from the University of Western Australia's Weld Range and Barrow Island reference material (Byrne et al. 2013; Dotte-Sarout and Byrne 2013; Taylor 2012). All reference materials were examined with the microscopes described above. The microscopic anatomy of each reference specimen was described following the IAWA list of features, and entered into a database following Dotte-Sarout's (2010) template. Wood identification keys including Hope (1998), Ilic (1991) and two online databases: Inside Wood <http://insidewood.lib.ncsu.edu/> and the University of Queensland Online Archaeology Collections <http://uqarchaeologyreference.metadata.net/archaeobotany/list> were also employed to aid identification. Where type-level identification could not be positively assigned to a charcoal fragment, it was described as indeterminate. All charcoal fragments that could not be positively identified due to brittleness, vitrification or because they were otherwise too degraded, were assigned indeterminable status with a brief description of why identification was not possible. Vitrified wood has a refringent, glass-like appearance that is produced by the fusion and homogenisation of the anatomical structures of the charcoal (McParland et al. 2010).

Carpological methods

All carpological remains were analysed from all recovered contexts (5 and 1.5 mm sieves, flot, heavy residue from flotation). Carpological materials from the Mount Behn excavation were hand sorted in the University of Western Australia laboratory under a 10× magnification lamp. Categories based on macroscopic morphological characteristics were employed and each specimen was described following guidelines provided by the University of Queensland's key criteria,[1] which include shape, surface texture and dimension. The reference collection used to identify carpological material was built from field collections (Dilkes-Hall 2014), previously collected specimens (McConnell 1998) and duplicate vouchered botanical material (Crawford 1982; Smith and Kalotas 1985) housed at the Western Australian Museum. Carpological materials were grouped into burnt/unburnt, and whole/fragmented categories and quantification was conducted by counting the number of individual specimens (NISP).

Results

Anthracological results

Across the four SUs sampled, a total of 1,513 charcoal fragments were analysed. Of these, 614 fragments were positively identified to varying levels of taxonomic significance. Appendix 1 presents anatomical descriptions of each taxon. A total of 17 taxa, including four unknown types and two family level identifications (Lamiaceae sp. and Myrtaceae sp.), were assigned from eight family groups. Table 2 and Figure 5 show the positively identified taxa, with their relative frequencies for each SU, expressed in terms of absolute fragment counts and proportion of total fragments. Table 3 lists taxa in three broad identification groups (indeterminable, *Grevillea*/*Hakea* sp., and all other taxa) in relation to their preservation status, in terms of both number and percentage of total fragments for each SU.

The SU1 assemblage has the highest taxon richness (14 taxa), followed by SU3 and SU4 (both with 10 taxa), while SU2 has the lowest taxon richness,

[1]<http://uqarchaeologyreference.metadata.net/archaeobotany/contribute>

Table 2. Wood charcoal taxa by SU in number of fragments (*n*) and percentage of total fragments (%)

IDENTIFICATION		SU1		SU2		SU3		SU3	
FAMILY	TAXON	*n*	%	*n*	%	*n*	%	*n*	%
COMBRETACEAE	*Terminalia* sp	25	4.8	1	2.4	8	2.2	6	1.0
FABACEAE	*Acacia* sp.	23	4.4	0	0	12	3.4	4	0.7
	Bauhinia sp.	8	1.5	0	0	0	0.0	4	0.7
HERNANDIACEAE	*Gyrocarpus* sp.	1	0.2	0	0	1	0.3	0	0
LAMIACEAE	*Clerodendrum/Vitex* sp.	9	1.7	0	0	2	0.6	1	0.2
	Lamiaceae sp.	9	1.7	2	4.9	1	0.3	2	0.3
MORACEAE	*Ficus* sp.	4	0.8	0	0	3	0.8	1	0.2
MYRTACEAE	*Corymbia* sp.	3	0.6	0	0	5	1.4	2	0.3
	Eucalyptus sp.	58	11.2	1	2.4	24	6.7	2	0.3
	Melaleuca sp.	8	1.5	0	0	19	5.3	9	1.5
	Myrtaceae sp.	9	1.7	0	0	8	2.2	2	0.3
PHYLLANTHACEAE	*Flueggea* sp.	1	0.2	0	0	0	0.0	0	0
PROTEACEAE	*Grevillea/Hakea* sp.	132	25.4	24	58.5	78	21.9	94	15.8
UNKNOWN	Type 2	3	0.6	0	0	1	0.3	0	0
	Type 8	1	0.2	0	0	0	0.0	0	0
	Type 14	1	0.2	0	0	0	0.0	0	0
	Type 15	0	0	0	0	0	0.0	2	0.3
INDETERMINABLE		225	43.3	13	31.7	194	54.5	467	78.4
TOTAL		520	100.0	41	100.0	356	100.0	596	100.0

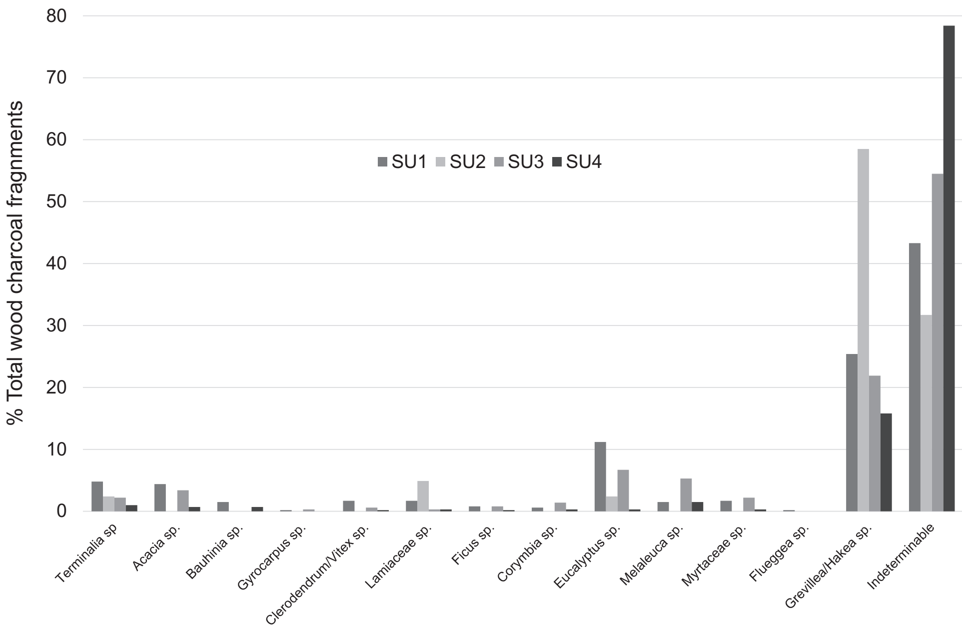

Figure 5. Wood charcoal taxa by SU.

with only four taxa represented (Table 2, Figure 5). SU2 has the lowest proportion of indeterminable charcoals (31.7%), followed by SU1 (43.3%), SU3 (54.5%) and SU4 (78.4%). SU2 and SU4 have the highest proportions of vitrified charcoals (87.8% and 88.9%, respectively), while SU1 has the lowest (61.5%) (Table 3). *Grevillea/Hakea* sp., a type which includes two indistinguishable Proteaceae genera (cf. Whitau et al. 2016b:540) that are considered paraphyletic (Weston and Barker 2006), is the dominant charcoal type across all SU. *Eucalyptus* sp. is the second most dominant taxon after *Grevillea/Hakea* sp. in the SU1 and SU3 assemblages (11.2% and 6.7%, respectively), which are broadly similar units with subsidiary *Acacia* sp., *Melaleuca* sp., and *Terminalia* sp. SU2 is an anomalous unit, comprised of only 41 charcoals, 24 of which were *Grevillea/Hakea sp.*, with two fragments of Lamiaceae sp., and one fragment each of *Terminalia* sp. and *Eucalyptus* sp. SU4, the oldest unit, with the highest proportion of indeterminable charcoals (78.4%), has low proportions of non *Grevillea/Hakea* sp. woody taxa, with only *Melaleuca* sp. and *Terminalia* sp. represented by counts of larger than five fragments (Table 2).

Carpological results

All of the carpological remains recovered were seeds and fruits, so in the following discussion, we replace the term 'carpological remains' with 'seeds and fruits'. A total of 203 seeds and fruits, which includes dry sieved and floated light and heavy

Table 3. Preservation of wood charcoal fragments by SU given in both number of fragments (*n*) and percentage for total assemblage (%) across three groups: indeterminable, *Grevillea/Hakea* sp., and all other taxa.

		SU1		SU2		SU3		SU4	
IDENTIFICATION	PRESERVATION	*n*	%	*n*	%	*n*	%	*n*	%
INDETERMINABLE	Vitrified	186	82.7	13	100.0	166	85.6	424	90.8
	Vitrified with radial cracks	12	5.3	0	0	16	8.2	16	3.4
	Root/knot wood	6	2.7	0	0	3	1.5	5	1.1
	Brittle	21	9.3	0	0	9	4.6	22	4.7
	TOTAL	225	100.0	13	100.0	194	100.0	467	100.0
GREVILLEA/HAKEA SP.	Vitrified	65	49.2	2	8.3	31	39.7	37	39.4
	Vitrified with radial cracks	52	39.4	21	87.5	38	48.7	53	56.4
	Non-vitrified	15	11.4	1	4.2	8	10.3	4	4.3
	Non-vitrified with radial cracks	0	0.0	0	0.0	1	1.3	0	0.0
	TOTAL	132	100.0	24	100.0	78	100.0	94	100.0
ALL OTHER TAXA	Partly vitrified	5	3.1	0	0	5	6.0	0	0
	Non-vitrified	155	95.1	4	100.0	76	90.5	35	100.0
	Non-vitrified with radial cracks	3	1.8	0	0	3	3.6	0	0
	TOTAL	163	100.0	4	100.0	84	100.0	35	100.0
TOTAL NON-VITRIFIED		200	38.5	5	12.2	100	28.1	66	11.1
TOTAL VITRIFIED		320	61.5	36	87.8	256	71.9	530	88.9

Table 4. Seeds per SU for each recovery type: SQ I and SQ II dry-sieved materials, and SQ II flot.

FAMILY	TAXON	SU1	SU2	SU3	SU4
SQI					
ULMACEAE	*Celtis* spp.	0	0	2	4
TOTAL		0	0	2	4
SQII					
MELIACEAE	*Melia azedarach*	0	1	0	0
MORACEAE	*Ficus* sp.	0	0	0	1
ULMACEAE	*Celtis* spp.	2	2	2	6
INDETERMINABLE		0	0	3	0
TOTAL		2	3	5	7
Flot SQII QC					
LAMIACEAE	*Vitex* cf. *glabrata*	3	0	1	0
MALVACEAE	*Triumfetta* sp.	0	0	1	0
SOLANACEAE	*Solanum* spp.	2	0	1	0
ULMACEAE	*Celtis* spp.	0	0	5	1
VITACEAE	*Ampelocissus acetosa*	3	0	0	0
	Cissus cf. *adnata*	0	0	1	0
INDETERMINABLE		2	0	0	0
TOTAL		10	0	9	1

Table 5. Seeds per SU from each recovery context, expressed in both fragment counts (*n*) and percentage of total assemblage (%).

IDENTIFICATION		SU1		SU2		SU3		SU4	
FAMILY	TAXON	N	%	*n*	%	*n*	%	*n*	%
LAMIACEAE	*Vitex* cf. *glabrata*	3	25.0	0	0	1	6.3	0	0
MALVACEAE	*Triumfetta* sp.	0	0.0	0	0	1	6.3	0	0
MELIACEAE	*Melia azedarach*	0	0.0	1	33.3	0	0	0	0
MORACEAE	*Ficus* sp.	0	0.0	0	0	0	0	1	9.1
SOLANACEAE	*Solanum* spp.	2	16.7	0	0	1	6.3	0	0
ULMACEAE	*Celtis* spp.	2	16.7	2	66.7	9	56.3	10	90.9
VITACEAE	*Ampelocissus acetosa*	3	25.0	0	0	0	0	0	0
	Cissus cf. *adnata*	0	0.0	0	0	1	6.3	0	0
INDETERMINABLE		2	16.7	0	0	3	18.8	0	0
TOTAL		12	100.0	3	100.0	16	100.0	11	100.0

fractions, were recovered from Mount Behn, 43 of which can be coordinated in secure stratigraphic contexts (Table 4, Table 5, Figure 6). Flotation proved beneficial and revealed five new taxa, belonging to four families, not recovered by sieve at the site, *Ampelocissus acetosa*, *Cissus* cf. *adnata*, *Solanum* spp., *Triumfetta* sp. and *Vitex* cf. *glabrata*. Sieved remains, which are less diverse than the flot assemblages, are attributed to three families: Meliaceae, Moraceae and Ulmaceae. Overall, the most common taxon recovered is *Celtis* spp., the number of which increases with depth. Various *Celtis* species have been identified in the Kimberley, in particular *C. australiensis*, *C. philippensis* and *C. strychnoides* (Guymer 2013; Wheeler 1992). *C. australiensis* is no longer a current taxon name and so the *Celtis* spp. in this paper refers to *Celtis* endocarps which could be either *C. philippensis* or *C. strychnoides*. Minor contributions include: *Ampelocissus acetosa*, *Cissus* cf. *adnata*, *Cleome* cf. *viscosa*, *Ficus* sp., *Melia azedarach*, *Solanum* spp., *Triumfetta* sp. and *Vitex* cf. *glabrata*. The seeds and fruits show no signs of carbonisation. SU3 is the most taxon rich unit (five taxa), followed by SU1 (four taxa), while the SU2 and SU4 assemblages are comprised of two taxa each (*Celtis* spp. with *Melia azedarach* and *Ficus* sp., respectively).

Discussion

Archaeobotanical taphonomy at Mount Behn rockshelter

Wood charcoal vitrification, radial cracks and taphonomy

Vitrification is the process by which plant tissues fuse during combustion. When these anatomical elements fuse together, the charcoal or wood is more likely to survive in the archaeological record because there is less surface area available to biodegrade. By the same token, these fused anatomical features are obscure, rendering identification unlikely. Vitrified wood charcoal fragments ($n = 1142/1513$, 75.5%) dominate the Mount Behn anthracological record.

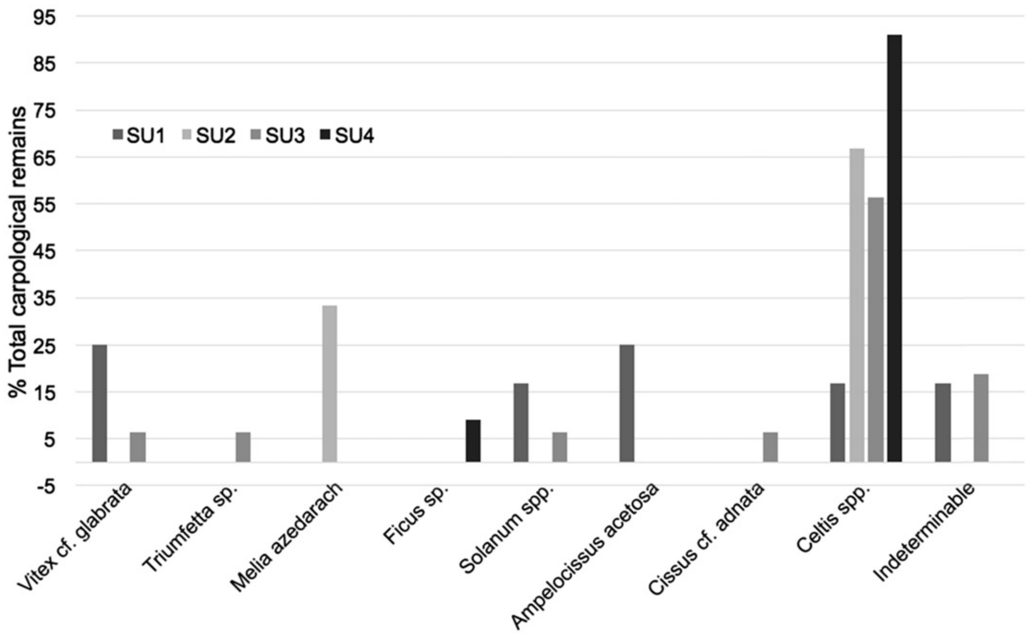

Figure 6. Mount Behn rockshelter showing percentage of identified seed types in SUs 1–4.

At Mount Behn rockshelter, where preservation of botanics (and organics in general) is poor, it makes sense that the anthracological assemblage would be mostly comprised of vitrified charcoals that are more likely to survive post-depositional processes.

The degree of vitrification, which can vary within an individual sample, may range from low brilliance-refractiveness, where certain anatomical structures may still be visible, to a completely fused, refractive mass (Marguerie and Hunot 2007). The factors that produce vitrification in wood charcoal, which is different from the pressurised transformation of lignocellulosic tissues to vitrinite in coal petrology (Kaelin et al. 2006), are poorly understood. Researchers have put forward various hypotheses to explain the vitrification process, including the combustion of wood at high temperatures (Fabre 1996; Prior and Alvin 1983; Thinon 1992), burning of green wood (Scheel-Ybert 1998; Talon 1997; Thinon 1992), re-charring (Fabre 1996), the transformation of resin (McParland et al. 2010), a high silica content within wood, and rapid cooling of charcoal with quenching (for the last two causes see JISCmail Archaeobotany online discussion group, cited in McParland et al. 2010:2679). McParland et al. (2010) examined both archaeological and laboratory-experimental wood charcoal assemblages, and demonstrated that neither high temperatures nor burning of green wood were the sole factors behind the phenomenon of vitrification. It seems likely that several factors, which might occur before, during and after combustion, must act collectively on an assemblage to produce vitrified charcoals. Experimentation in both the laboratory and field is necessary to shed further light on the conditions that produce vitrification in wood charcoal, in conjunction with detailed reporting of archaeological contexts where vitrified assemblages have been recovered.

The *Grevillea*/*Hakea* sp. charcoal type, which is very distinctive with its broad rays and festooned axial parenchyma, was often distinguishable despite vitrification (Figure 8(A,D)). Because the *Grevillea*/*Hakea* sp. charcoals were identifiable, despite vitrification, the higher proportion of *Grevillea*/*Hakea* sp. charcoals compared with other taxa is certainly an artefact of preservation. Other taxa were less distinguishable because of vitrification, with limited exceptions where vitrification was only partial on the fragment (Figure 8(B,C,E,F)).

Radial cracks (Figure 8(D)) were observed in the majority of vitrified *Grevillea/Hakea* sp. charcoals, in several non-vitrified Lamiaceae sp. twigs, but not the other indeterminable charcoals. The frequency of radial cracking, which is not uncommon in wood charcoal, is contingent on the density and size of the wood's rays, the proximity to the pith, the wood's moisture content prior to charring, and the temperature of combustion (Marguerie and Hunot 2007:1421; Prior and Alvin 1983; Théry-Parisot 2001; Théry-Parisot and Henry 2012). The broad, dense rays of *Grevillea/Hakea* sp. charcoals increase the likelihood of radial cracking, which is often associated with vitrification (Marguerie and Hunot 2007). The cracking of non-vitrified Lamiaceae sp. twigs, which have much narrower rays than the *Grevillea/Hakea* sp. charcoals, could be related to the dampness of the wood, or temperature of the fire when charred. Further experiments on these features would need to be conducted on Lamiaceae taxa in order to understand the combustion patterns of these woods in particular.

Figure 7. (A) *Celtis* spp. endocarps; (B) *Vitex* cf. *glabrata* drupes; (C) *Ficus* sp. fruit; (D) *Triumfetta* sp. Fruit; (E) *Cissus* cf. *adnata* seed; (F) *Solanum* sp. seed. All images taken by India Ella Dilkes-Hall using a Leica M205C stereomicroscope, with Leica Application Suite Version 3.8.5.

Seed and fruit taphonomy

The carpological assemblage indicates a decrease of preservation of botanical materials with depth, the exception being *Celtis* spp., of which ten endocarps were recovered from SU4 (Table 5), which could reflect an intrusion of more recent material. *Celtis phillipensis* and *Celtis strychnoides* are widespread tropical shrub-tree species that grow across Northern Australia and are frequently concentrated within vine thicket communities (Kenneally et al. 1996; Wheeler 1992). *Celtis* spp. produce fleshy drupes with hard, stony endocarps, from January to May coinciding with the mid to late wet season (Kenneally et al. 1996). There are few references in the ethnographic literature for the use of *Celtis* species by Aboriginal groups, with only one reference for the Kimberley region from the Bardi people, who eat the ripe fruit raw (Smith and Kalotas 1985). While *Celtis* endocarps are commonly recovered from archaeological sites in the Kimberley region, the high proportions in the Mount Behn record are unlikely to be linked to subsistence strategies.

The stony *Celtis* endocarps are globose with reticulate surface patterning, and are often recovered from archaeological contexts (Figure 7A; O'Connor et al. 2014; Sievers 2006; Wang et al. 1997). The robust *Celtis* sp. endocarp not only takes on atmospheric carbon (Wang et al. 1997) but is also subject to recrystallisation in a diagenesis similar to that observed in shells and coral, which increases their preservation potential (Messager et al. 2010; O'Connor et al. 2014). The calcium carbonate enrichment process of *Celtis*

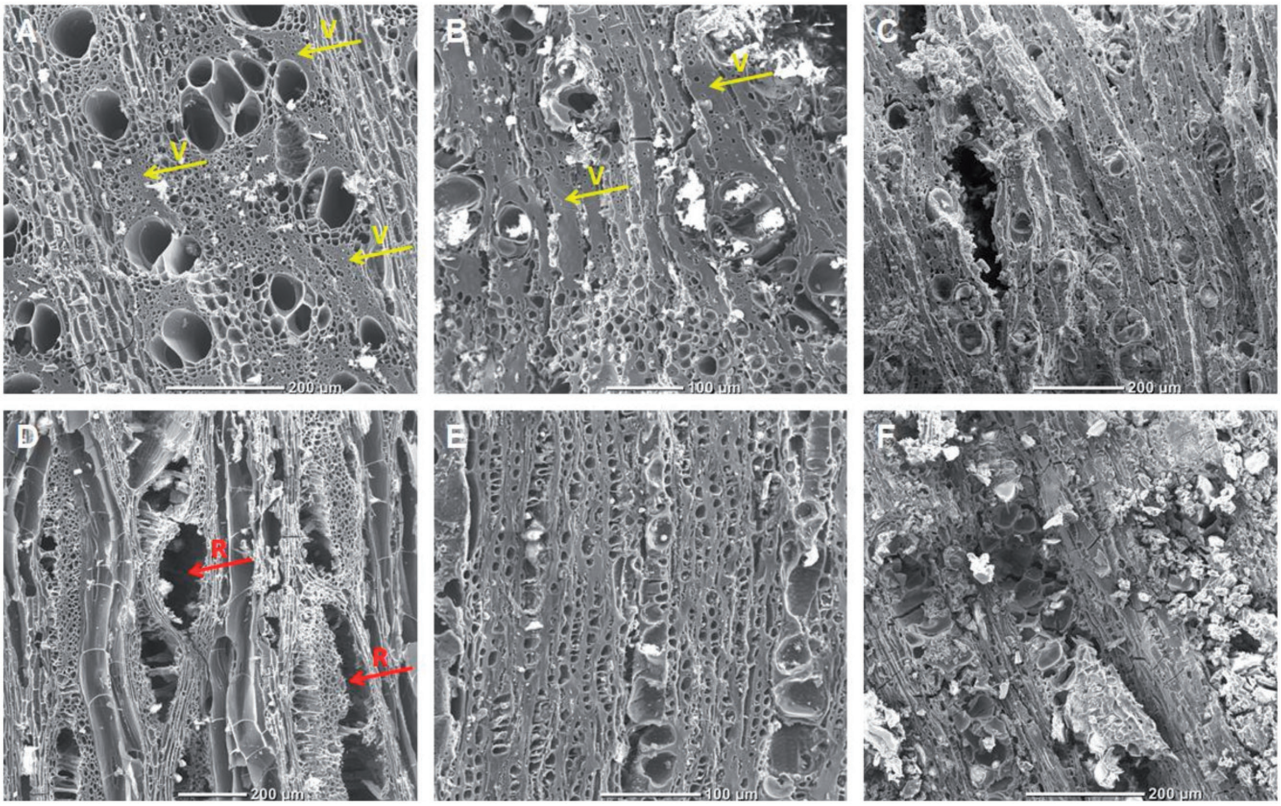

Figure 8. *Grevillea/Hakea* sp. type with vitrified fibres, examples of which are depicted with arrows, transverse section (A), tangential longitudinal section with radial cracks, examples of which are depicted with arrows (D); indeterminable charcoal with fibres that are more vitrified than (A), depicted with arrows, more transverse section (B), tangential longitudinal section (E); indeterminable charcoal mostly vitrified, transverse section (C), tangential longitudinal section (F) (all images of archaeological charcoals from Mount Behn rockshelter, scanned by Rose Whitau using the JEOL JCM-6000 Neoscope Scanning Electron Microscope (SEM) at the Archaeology and Natural History Department, Australian National University)

endocarps echoes the development of secondary carbonates observed around some bones at the microscopic level within the Mount Behn microstratigraphic sequence (Vannieuwenhuyse 2016) and demonstrates a certain degree of wetting/drying of the Mount Behn sequence at some time in the past or over a seasonal rhythm. Intense weathering and deposition of calcium carbonate flow layers are observed over the walls of the rockshelter and illustrate seasonal water infiltration.

Other taphonomic considerations

Aside from the fracturing produced by mechanical trampling, wood charcoal diagenesis at Mount Behn rockshelter is largely an effect of pre-depositional factors, while the preservation of seeds and fruits appears to be more affected by post-depositional processes. The fact that preservation of seeds diminishes with increasing depth is a normal evolution of the organic matter within stratigraphic profiles, especially when there is evidence of bioturbation as in the Mount Behn sequence. Interestingly, differential preservation between types of botanic remains was also observed at the microscopic level in the micromorphological assessment of the sequence (Vannieuwenhuyse 2016). For example, no macropod coprolite fragments (formed of organic matter) were visible in thin section, which is unexpected, particularly since macropod excrement and hollows were observed on the surface of the deposit. These particles are represented in the sequences of other sites of the region such as Carpenter's Gap 1 and Riwi, which are located within similar limestone environments (Vannieuwenhuyse 2016; Vannieuwenhuyse et al. 2017). Similarly, phytoliths, although composed of silica and therefore more robust than carbon based plant remains, were not observed in Mount Behn micromorphological thin sections (Vannieuwenhuyse 2016). This latter example could be explained either by the absence of primary deposition of such particles (absence of taxa producing phytoliths) or other taphonomic factors affecting their preservation over time.

Sample richness and representativeness

The taxon richness of the modern vegetation was not represented in either the wood charcoal or seed and fruit assemblages. At Mt Behn, 17 taxa from eight families (wood charcoal) and eight taxa from seven families (seeds) were identified at Mount Behn rockshelter, whereas at Riwi, which is some 300 km southeast of Mount Behn rockshelter, bordering the Great Sandy Desert, supporting a much lower species richness of modern vegetation, 19 taxa from 10 families (wood charcoal) and 34 taxa from 17 families (seeds and other floristics) were identified (Figure 1; Dilkes-Hall 2014; Whitau et al. 2016a, 2017). At Mt Behn rockshelter, SU1, the youngest unit, which has the lowest proportion of vitrified charcoals, has the highest taxon richness. SU4, which has the highest proportion of both vitrified and indeterminable charcoals, still has a relatively high taxon richness, suggesting that the taxa that are represented would have been in higher proportions within the original assemblage of fuel wood.

The dominant taxa from the wood charcoal and seed assemblages are *Grevillea/Hakea* and *Celtis* spp., respectively. Neither *Grevillea* nor *Hakea* species, which produce woody seed pods, were recovered in the seed record and *Celtis* sp. was not recovered in the anthracological record. *Grevillea* and *Hakea* are widespread genera on the Australian continent, with a high proportion of species level diversity, which range from small shrubs to tall trees, and occupy a vast tract of habitat types. The prevalence of *Celtis* spp. is most likely to be due to the inclusion of more recent material or an artefact of preservation, with mineralization producing a less degradable endocarp. In addition, the abundance of *Celtis* could be an effect of modern or prehistoric environmental seed rain from the natural accumulation of seeds in the shelter given that *Celtis* often grows on limestone outcrops (Minnis 1981), and indeed several *C. strychnoides* trees and shrubs currently occupy the entrance to Mount Behn rockshelter.

The dominance of *Grevillea/Hakea* sp. wood charcoal in the Mount Behn rockshelter anthracological assemblage is an artefact of positive preservation. The characteristics of Proteaceae anatomy, compared to other woods common to Northern Australia, are distinctive even when the wood charcoal is vitrified, and are thus more likely to be identified than other taxa. Table 3 shows that if the vitrified *Grevillea/Hakea* sp. charcoals were, like 98.8% ($n = 829/839$) of the other vitrified charcoals, indeterminable, the proportions of *Grevillea/Hakea* sp. would be low, forming a subsidiary component after *Eucalyptus* sp. in SU1, SU3, and SU4, while only one fragment of non-vitrified *Grevillea/Hakea* sp. was recovered from SU2. Indeed, if vitrified *Grevillea/Hakea* sp. charcoals are removed from the equation, *Melaleuca* sp. becomes the dominant taxon for SU4, *Eucalyptus* sp. for SU3 and SU1, while two fragments of Lamiaceae sp. would comprise the dominant component of the smaller SU2 assemblage. Therefore, while *Grevillea/Hakea* sp. charcoals dominate the wood charcoal record, if other vitrified charcoals were able to be identified, it is likely that *Grevillea/Hakea* sp. charcoals would form a subsidiary component across the assemblages.

People, climate, and vegetation at Mount Behn rockshelter

In terms of the broader climate signal, the stable isotope profile of the KNI-51 speleothem shows an abrupt weakening of the monsoon around 4.2 ka, which is sustained until 1.2 ka, with a peak in aridity occurring between 1.5 and 1.2 ka (Denniston et al. 2013). At Black Springs, a sharp decline in organic content, increased aeolian sedimentation, a shift in vegetation with lower aquatic species, and the lowest humification values for the core illustrate the driest phase for the record between 2.6 and 1.3 ka (Field et al. 2017; McGowan et al. 2012). According to other records therefore, SU4–SU3 (2825–1750 cal BP) was deposited during a period of relative aridity. By contrast, SU1 (439–0 cal BP) was deposited during wetter conditions, with evidence for small-scale variability, occurring from within the last millennium through to the present (Denniston et al. 2013; Field et al. 2017; Proske 2016).

Unfortunately, the taxon richness of the modern vegetation is not represented in the anthracological record at Mount Behn rockshelter, precluding the application of wood charcoal for palaeoenvironmental reconstruction (Asouti and Austin 2005; Dotte-Sarout et al. 2015). However, the wood charcoal and seed results show that different habitats were exploited throughout the site's occupation: the eucalypt savanna of the valley floor, the dry rainforest taxa of the limestone escarpment, and riparian vegetation are each represented throughout time. The major exception is the SU2 assemblage, which is further limited by the low volume of the SU. The low number of recovered remains prevents examination of the preference for each of these landscape types and how these preferences might have changed alongside the adaptation of vegetation communities to climate change over time. However, the fact that each vegetation type is represented is not insignificant, and illustrates that localised vegetation communities and the people who exploit them might not have been affected to the extent suggested by the aridity suggested by the broader climate signal. Indeed, the fact that people continued to exploit each landscape type during a climatically arid phase could indicate that the area surrounding Mount Behn rockshelter was a refugium during this period (2,825–1,750 cal BP).

Resource management: the curious case of Proteaceae

While few anthracological investigations have been conducted in Australia (cf. Dotte-Sarout et al. 2015), the handful that have been conducted in Western Australia (Byrne et al. 2013; Dotte-Sarout and Byrne

Figure 9. (A) *Grevillea/Hakea* sp. artefact fragment from Riwi Cave; (B) Wood shavings from Riwi Cave; (C) Boomerang stencil from Mount Behn rockshelter (A and B photographs taken by Michelle C. Langley and reproduced from Whitau et al. 2016b; C photograph taken by Jane Fyfe).

2013; Frawley 2009; Whitau et al. 2016a), with the exception of Frawley (2009), show that *Grevillea/Hakea* sp. woods were avoided for fuel use. In Weld Range *Grevillea* sp. trees are frequently distributed, growing as tall trees, which today are reserved for carving wooden tools and avoided for fuel as the wood does not burn well (Byrne et al. 2013). Zero fragments of *Grevillea/Hakea* sp. were identified from the Weld Range anthracological assemblage (Byrne et al. 2013). At Riwi Cave in the southern Kimberley, southeast of Mount Behn rockshelter, only two fragments of 3,142 analysed charcoals were identified as *Grevillea/Hakea* sp. (Whitau et al. 2016a). However, a 600-year-old wooden artefact fragment, imaged using X-ray microtomography, was identified as *Grevillea/Hakea* sp. (Figure 9(A); Whitau et al. 2016b). *Grevillea/Hakea* taxa, which grow as short shrubs on the Riwi limestone outcrops, are infrequently distributed amongst the modern vegetation. The low occurrence of recovered *Grevillea/Hakea* sp. charcoals, combined with the selection of the wood for artefact manufacture, can be argued to be an example of both specific site collection and resource management at Riwi, since the infrequently distributed shrub might have been avoided for fuel wood if it was a valuable resource for wooden artefact manufacture (Whitau et al. 2016a, 2016b). In the Pilbara, where *Grevillea* and *Hakea* species tend to grow as short shrubs, zero Proteaceae fragments were also recovered in the anthracological assemblages (Dotte-Sarout and Byrne 2013). At Carpenter's Gap 1 rockshelter, located 40 km northwest of Mount Behn, Frawley (2009) was surprised to find an abundance of Proteaceae charcoals because beefwood (*Grevillea* sp.) is cited as a poor fuel wood, which burns quickly and does not retain its heat. The total number of Proteaceae identified is 46 fragments, with 18 occurring in the Holocene units (Frawley 2009).

While the dominance of *Grevillea/Hakea* sp. charcoals within Mount Behn anthracological assemblage is readily explained as an outcome of uneven preservation and identification bias, its abundance relative to other Western Australian investigations merits some discussion. To summarise the above, arguments for *Grevillea/Hakea* sp. avoidance have included resource management for the production of wooden artefacts and its poor fuel capability.

At Carpenter's Gap 1, while no wooden artefacts were recovered, wood shavings, very similar to those found at Riwi, were recovered throughout the deposit (Figure 9(B)). No wooden artefacts or wood shavings were recovered from Mount Behn rockshelter, an anticipated probability given both the poor botanic preservation at the shelter and the limited recovery of wooden artefacts in Australia in general (cf. Whitau et al. 2016b). However, plant-based technologies are painted and stencilled on the shelter walls, including several stencils of boomerangs and an axe, which at the very least indicates the presence of such technologies at the site (Figure 9(C)). The evidence for woodworking is certainly less definitive at Mount Behn rockshelter than Carpenter's Gap 1 or Riwi; however, it is worth noting that wood tends to be worked when green, and green wood, particularly a resinous wood like those produced within the *Grevillea* and *Hakea* genera, is more likely to both vitrify and radially crack (Marguerie and Hunot 2007). The abundance of vitrified, radially cracked *Grevillea/Hakea* sp. charcoals could represent the incidental by-products of artefact manufacture. Finally, it is possible that in areas of higher taxon richness of woody taxa, there is no need to be selective with wood resources, which would explain why Proteaceae was recovered at both Carpenter's Gap 1 and Mount Behn rockshelters, which have a higher density and species richness of woody taxa than other sites mentioned here.

Outside of Western Australia, in the Northern Territory's tropical Kakadu region, anthracalogical analysis was conducted on 14 hearths excavated from the Madjedbebe archaeological site (Figure 1; Carah 2016). Taxa from open eucalypt woodland and monsoon vine forest dominate the anthracological assemblages, with minor contributions of *Grevillea/Banksia* shrubland averaging 3.84% frequency across the seven hearths in which this taxon appears (Carah 2016). *Grevillea/Banksia* wood charcoal was recovered from all the late Holocene hearths with the exception of one (C4/9A); from three late Holocene/LGM hearths (D2/21A, E3/20A, E4/22A); and was not recovered at all from any of the pre LGM hearths at Madjedbebe (Carah 2016). The hearths of the late Holocene have the highest taxon richness of the Madjedbebe anthracological assemblages both individually and collectively, and the E4/22A hearth has the highest taxon richness of the Pleistocene hearths. This supports the hypothesis presented here that, unsurprisingly, in areas of higher taxon richness of woody taxa, there is less need to be selective with wood resources, than areas of lower taxon richness, such as Riwi. Indeed, Jones et al. (2011) note that *Grevillea striata* is used in the Bradshaw and Judbarra parks area of Northern Territory for both carving and fuel.

However, the D2/21A and E3/20A hearths, alongside the other early Holocene/LGM hearths, have a lower overall taxon richness than the pre LGM group, and yet the frequency of *Grevillea/Banksia* wood charcoal is the highest for this unit (9.70%) (Carah 2016). Carah (2016) argues that the increase of this taxon during this time could be a reflection of environmental changes following the end of the LGM and the re-activation of the summer monsoon, and that the low incidence of *Grevillea/Banksia* shrubland in the older units compared to its presence in all four of the most recent hearths could suggest that this vegetation type was limited in distribution in the local environment during the Pleistocene. Carah (2016) further argues that because the *Grevillea/Banksia* community grows in poorly drained depressions, this limited distribution could indicate lower precipitation during the Pleistocene, and an increase in freshwater availability in the late Holocene, with the latter point supported by the Madjedbebe pollen record.

Conclusions

While the limited survival of macrobotanical remains at Mount Behn rockshelter did not allow for a valid palaeoenvironmental reconstruction, nor a direct testing of Maloney et al.'s (2017) foraging hypothesis, the recovered materials did show that various habitats (savanna, riverbanks, limestone outcrops) were exploited throughout the site's occupation sequence. The fact that each vegetation type is represented illustrates that localised vegetation communities and the people who exploited them might not have been affected to the extent suggested by the broader climate. The relationship between people, plants, and climate change needs to be explored at relevant scales, a point to be considered when inferring foraging risks extrapolated from a palaeoclimate record located at some spatio-temporal distance from the site under discussion.

The wood charcoal, seed, and fruit remains from Mount Behn rockshelter, like any archaeological assemblage, are artefacts of preservation; pre- and post-depositional factors have favoured the preservation of Proteaceae wood charcoal and *Celtis* endocarps, respectively. The complex factors that control the preservation of botanic remains ought to be borne in mind when interpreting all archaeobotanical assemblages, which the Mount Behn macrobotanical analyses clearly demonstrate. We are also beginning to see how exploitation of plant resources varies between archaeological sites, in comparison with other archaeobotanical records that are slowly being built up across the northern region of

Australia. If regional reference collections continue to be expanded, and field techniques adopted such as the simple bucket flotation used here, even poorly preserved plant assemblages, such as those recovered from Mount Behn rockshelter, will contribute to our understanding of human-environment interaction.

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Appendix 1

Anatomical descriptions of archaeological wood charcoal types.

Taxon	Porosity	Vessel elements	Fibres/tracheids	Axial parenchyma	Radial parenchyma
Terminalia sp. COMBRETACEAE	Diffuse	Clusters 2–3 Weak tangential to diagonal Bordered to scalariform small pits	Fibre walls very thick	Paratracheal confluent Lozenge aliform Short bands (2–4 cells wide) Apotracheal aggregates	Uni to 4- seriate 6–23 cells high
Acacia sp. FABACEAE	Diffuse	Clusters 2–3 Weak tangential to diagonal Vestured pits	Fibre walls thick	Lozenge aliform Confluent Winged aliform Vasicentric	Uni to bi seriate 2–20 cells high Heterogenous
Bauhinia sp. FABACEAE	Diffuse	2 pore size classes Clusters 2 (large) Radial groups (1 large, 2–6 smaller) Weak diagonal to tangential Simple, small pits	Fibre walls thick	Scalariform bands (2–4 cells wide) Vasicentric Winged aliform Confluent Storied strands (2-4 cells long)	Uni to tri seriate 2–15 cells high Storied Heterogenous Procumbent body 1–2 rows upright/square
Gyrocarpus sp. HERNANDIACEAE	Diffuse	Clusters 2–3 Diagonal/weak tangential Bordered to scalariform, minute pits Plates simple	Fibre walls very thin	Paratracheal aggregates Apotracheal aggregates	Uni to tri seriate 2–15 cells high
Clerodendrum/Vitex sp. LAMIACEAE	Diffuse, growth boundary sometimes distinct	Radial groups 2–3 Tangential bands Radial/diagonal lower density Bordered to scalariform, minute pits	Fibre walls thick	Scarce Scanty paratracheal	1–4 seriate 6–40 cells high 2 sizes Tile cells Heterogenous Procumbent body, 2–4 rows of upright/square
Ficus sp. MORACEAE	Diffuse	Radial groups 2–4 Diagonal/radial Bordered to scalariform, small pits Simple plates	Fibre walls thick to very thick	Bands >4 cells (4–10) Bands <4 cells (2–4) Scanty paratracheal	Uni to 4- seriate 6–25+ cells high Heterogenous Procumbent body 1–3 rows upright/square Tile cells
Corymbia sp. MYRTACEAE	Diffuse	Clusters 2–6 Dendritic to diagonal Tyloses abundant Vestured, minute/small pits Plates simple	Fibre walls thin to medium Distinctly bordered pits	Confluent Winged aliform Wavy bands (1–3 cells wide) Strands 2–4 cells long	Uni to biseriate 2–9 cells high Homogenous Procumbent
Eucalyptus sp. MYRTACEAE	Diffuse, with abrupt change in pore density	Clusters 2 Strong diagonals Vestured, small/medium pits Plates simple	Fibre walls medium to thick Distinctly bordered pits	Abundant apotracheal aggregates Paratracheal aggregates Vasicentric	Uni to biseriate 2 to 10 cells high
Melaleuca sp. MYRTACEAE	Diffuse	Mostly solitary Diagonal to radial Vestured changeable pits	Fibre walls medium Distinctly bordered pits	Scarce apotracheal aggregates Scanty paratracheal	Uni to biseriate 1–13 cells high
Flueggea sp. PHYLLANTHACEAE	Diffuse	Radial chains 2–6 (8–12) Radial Bordered to scalariform, very minute pits	Fibre walls very thick	Abundant apotracheal aggregates Paratracheal aggregates	Uni to tri seriate 3–23 cells high Tile cells
Grevillea/Hakea sp. PROTEACEAE	Diffuse	Clusters 2 Tangential (+weak diagonal), festooned Scalariform to bordered, minute pits Plates simple	Fibre walls thick to very thick Simple to minutely bordered pits	Festooned, confluent Lozenge/winged aliform Fusiform parenchyma cells	Rays of 2 sizes Uni to triseriate, 4–13 cells high 10–14 seriate, 100+ cells high

Chapter 7. Three archaeobotanical proxies, two archaeological sites: complexities of human-environment interaction in Bunuba and Gooniyandi country, Kimberley region, Western Australia

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Rose Whitau: developed the research question; undertook field work; prepared the Mount Behn palynological samples; recorded and analysed the anthracological data for both sites and the palynological data for Mount Behn rockshelter; formulated the arguments in the manuscript; drafted the entire manuscript, except for the Riwi pollen methods and results sections; edited and reviewed the manuscript.
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Rose Whitau

Cassandra Rowe: recorded and analysed the palynological samples for Riwi; formulated and refined arguments in the manuscript; drafted the Riwi pollen methods and results sections; edited and reviewed the manuscript.
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11/04/2018

Cassandra Rowe

Janelle Stevenson: managed the laboratory work in preparing the palynological slides for Riwi and Mount Behn rockshelter; formulated and refined arguments in the manuscript; edited and reviewed the manuscript.
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Janelle Stevenson

India Dilkes-Hall: undertook field work; recorded and analysed the carpological data; edited and reviewed the manuscript.

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Dorcas Vannieuwenhuyse: undertook fieldwork; formulated and refined arguments in the manuscript, particularly in regards to site formation processes and taphonomy; edited and reviewed the manuscript.

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Title

Three archaeobotanical proxies, two archaeological sites: complexities of human-environment interaction in Bunuba and Gooniyandi country, Kimberley region, Western Australia

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Abstract

In north western Australia, records of palaeoenvironmental change are scarce or under explored. This scarcity is particularly so for terrestrial archives that allow for comparison with the archaeological record and examination of human-environment interaction in the past. Here we present the results from macrobotanical (wood charcoal, seeds, and other floristics) and palynological (pollen and spores) analyses conducted on Holocene deposits at two archaeological sites in the Kimberley region of Western Australia: Mount Behn rockshelter, and Riwi. The Holocene units of Riwi offer excellent preservation of macrobotanical materials, and SU1, which was deposited during the last 1,000 years, yielded rare organic materials such as string, wood shavings, and wooden artefacts. By contrast, organic preservation at the Mount Behn rockshelter is very poor, the richness of the vegetation is not represented in the macrobotanical record, and certain taxa are over-represented due to preservation and identification biases. This scenario is the complete opposite for pollen, which is poorly recovered at Riwi and well preserved at Mount Behn rockshelter. We explore the taphonomy and representativeness of the wood charcoal, seeds, and pollen in order to draw a comprehensive picture of vegetation change and human-environment interaction at both sites. We argue that high proportions of riparian taxa within the assemblage indicate that the area around Mount Behn was a refugium during a phase of regional aridity between 2825—1750 cal BP. At Riwi, we show that the abundance and richness of monsoon rainforest taxa during the Holocene is a combined effect of relative humidity and the economic decisions of past inhabitants, particularly between 915—670 cal BP.

Key Words
Cave palynology; multi-proxy archaeobotanical analysis; human-environment interaction; Australian Aboriginal archaeology; hunter-gatherer archaeology

1.0 Introduction

The Australian archaeological record of the mid- to late Holocene is described as a period of intensification; characterised by increases in cultural discard, innovations in technologies, exploitation of novel resources, greater use of peripheral environments, and an accretion of evidence for long-distance exchange and external contact (e.g. Beaton 1982; Bowdler 1981; Cosgrove et al. 2007; David 2002; Flood 1980, 1999; Godwin 1997; Haberle et al. 2010; Lourandos 1980, 1983, 1988, 1993, 1997). From fish traps to the proliferation of new stone tool types, these changes have been interpreted as responses to, and/or effects of: different site preservation, changing resource availability, population increase, and social change (cf. Ulm 2013 and references therein). The intensification of the mid- to late Holocene is often aligned to increased climatic variability and seasonal inconsistencies, with sustained changes trending towards aridification and inferred phases of resource abundance and depletion (Kershaw and van der Kaars 2012). For example, in northern Australia, reduction based analyses of stone tool assemblages have aligned changes in stone tool reduction strategies with adaptation to increasing aridity and inferred foraging risk (e.g. Clarkson 2002, 2007; Hiscock 1994, 2006; Hiscock and Veth 1991; Maloney et al. 2014; Maloney and O'Connor 2014; O'Connor et al. 2014).

The Holocene is currently described by divergent palaeoenvironmental changes across the Australian continent (e.g. Fitzsimmons et al. 2013; Leonard et al. 2016; Magee et al. 2004). In north western Australia, archives of palaeoenvironmental change are scarce or largely unexplored, particularly terrestrial archives that allow for comparison with the archaeological record and examination of human-environment interaction in the past. In terms of palaeoclimate, there are a handful of partial, coarsely-dated records of aeolian dune formation and fluvial deposition, summarised in Fitzsimmons et al. (2013), and the stable isotope profile of the KNI-51 speleothem (Denniston et al. 2013). In terms of vegetation, pollen analysis of two cores in the north-eastern Kimberley has allowed for investigation of coastal dynamics and mangrove response to sea level changes (Figure 1; Proske 2016; Proske et al. 2014). Additionally, the pollen profile of a core from Black Springs (Figure 1; Field et al. 2017; McGowan et al. 2013), has provided evidence for environmental changes of a mound spring in relation to broader climate signals. Geochemical and palynological analyses conducted on a contiguous sedimentary record from the Mitchell Plateau provide unprecedented insight into vegetation change over the last 200 years, with particular reference to European impact (Connor et al. 2017). The extent to which these records reflect localised vegetation responses to climate fluctuations, and the manner in which people adapted to these changes in climate and vegetation, has yet to be explored within the context of stratified archaeological inquiry.

Analyses of archaeobotanical proxies excavated in association with other cultural remains provide the obvious evidential link to explore localised human and environmental responses to climatic changes. Archaeological sites represent fragments of the human past and have the potential to contain not only artefacts but subfossil organic remains (e.g. Clarkson and Wallis 2003; Dotte et al. 2015; Rowe and Kershaw 2008; Wallis 2001) that can yield palaeoenvironmental results, when unobtainable from more traditional sources such as lakes and swamps (Dimbleby 1985; Rowe and Kershaw 2008). However, archaeobotany is rarely applied in Australian archaeology for a variety of reasons, including a lack of application of appropriate field techniques and limited reference collections (Denham et al. 2009; Dotte et al. 2015).

By contrast, palynological research is well-established in Australia, and extensive reference materials are available that span most of the continent (e.g. the Australasian Pollen and Spore Atlas <http://apsa.anu.edu.au/>). Analysis of pollen from cave and rockshelter sites; however, is less established in Australia, although there are some early examples of pollen analysis from cave sites including Martin's (1973) work on cave sediments from the Nullarbor and Hope's (1978) work on sediments from Cave Bay on Hunter Island, Tasmania. Outside of Australia, the factors which affect the palynological records of cave deposits have been explored experimentally and in archaeological contexts. A number of studies over the past thirty years have employed cave palynology to reconstruct palaeoenvironments, provide insights into human-environment interaction, and establish climate sequences in relation to cultural activities, particularly where suitable catchments for palynological sampling are limited (e.g. Burney and Burney 1993; Davis 1990, 1994; Gale et al. 1993; Carrión et al. 1998, 1999; Horowitz 1992; Hunt et al. 2011; de Porras et al. 2011; Edwards et al. 2015).

In this paper, we present the results from palynological analyses conducted on Holocene deposits at two archaeological sites in the Kimberley region of Western Australia: Mount Behn rockshelter and Riwi cave (Figure 1). We compare the two palynological data sets with previously published macrobotanical (wood charcoal, seeds, and other floristics) results from each of these sites (Dilkes-Hall 2014; Whitau et al. 2016a, 2016b, 2017, 2018). We explore the taphonomy and representativeness of wood charcoal, seeds, and pollen in order to draw a comprehensive picture of vegetation change and human-environment interaction at both sites. Collectively these archaeobotanical analyses have the capacity to test the archaeobotanical potential of pollen, to demonstrate the palaeoenvironmental potential of archaeological sites, and to assess the applicability of regional climatic reconstructions at the local-scale.

Figure 1 about here

1.1 Study area

The Kimberley region is located in northern Western Australia, within the seasonally dry Australian Monsoonal Tropics (AMT) (Figure 1). The majority of rainfall is received during the wet season, which occurs October—May, with the amount of rainfall decreasing in a south-east gradient towards the interior of the continent. Geologically, the Kimberley region is defined by the King Leopold Orogen to the south west and the Halls Creek Orogen to the south-east, together forming a tectonic chevron forming the southern end of the Kimberley plateau (Griffin & Myers 1988). The diverse landscape of the Kimberley region supports a highly endemic biota (Connor et al. 2017; Pepper and Keogh 2014).

1.1.1 The Mount Behn rockshelter

The Mount Behn rockshelter is an outcrop of the central Napier Range formed at the intersection of Napier limestone and Behn conglomerates (Playford et al. 2009), located within the traditional lands of the Bunuba people on Leopold Downs Station, and within the IBRA's Central Kimberley sub-region (Figure 1, Figure 2). Receiving approximately 800 mm of rainfall per annum, the surrounding vegetation is relatively diverse and comprised of several different vegetation communities, including: greybox/cabbage gum (*Eucalyptus tectifica*/*Corymbia grandifolia*) savanna woodland with high ribbon grass (annual *Sorghum* sp.) along the plain; paperbarks (*Melaleuca* spp.) with sedges on the ephemeral creek bank; and spinifex (*Triodia bitextura*) steppe with mixed savanna and monsoon rainforest taxa across the limestone outcrop. A white fig (*Ficus virens*) grows within the shelter, while various trees and shrubs, including boab (*Adansonia gregorii*), black plum (*Vitex* spp.), hackberry (*Celtis strychnoides*), waterbush (*Myoporum montanum*), and white currant (*Flueggea virosa*) grow underneath the overhang, obscuring the view to the shelter from below (Figure 2).

Figures 2 and 3 about here
Table 1 about here

In 2012, a 2 x 1 m^2 trench was excavated to bedrock in one square and until sterile deposits were reached in the other (Figure 2, 3). Seven stratigraphic units (SU) were identified (Maloney et al. 2017; Vannieuwenhuyse 2016), the bottom two of which (SU7 and SU6), are comprised of decomposed bedrock. SU5 is a post-depositional mix of SU6 and SU4, and the upper four units (SU4—1) are archaeologically rich (high proportion of anthropogenic inputs), with diffuse boundaries, and evidence for two phases of occupation from 2925 to 1750 cal BP (SU4—SU3) and from 440 cal BP to present (SU2—SU1) (Table 1, Figure 3). The rich lithic record (54,294 lithics) is dominated by a fine-grained crystal quartz, and is the largest excavated assemblage of stone points from the Kimberley region (Maloney et al. 2017). Botanic preservation was relatively poor at the site, with *Grevillea*/*Hakea* sp. and *Celtis* spp. proportionally over-represented in the macrobotanical assemblages for pre- and post-depositional reasons respectively: *Grevillea*/*Hakea* sp. charcoals were easier to identify than other taxa within the mostly vitrified assemblage, and biomineralised *Celtis* spp. endocarps proved more robust than other seeds and fruits (Whitau et al. 2018). Stylistically diverse rock art is densely superimposed on the rockshelter's ceiling and walls.

1.1.2 Riwi

Riwi is a south-facing limestone cave at the base of the Lawford Range, located within Gooniyandi traditional lands and the IBRA Southern Kimberley Interzone, on the edge of the Great Sandy Desert (Figure 1, Figure 4). Receiving approximately 800 mm of rainfall per annum, the surrounding vegetation is less diverse than that of Mount Behn and is comprised predominantly of hummock grasslands of spinifex (*Triodia bitextura*) with a scattered upper story of low *Corymbia*/*Eucalyptus* sp. trees. The limestone hills surrounding Riwi support monsoon rainforest taxa, and a small riparian community of paperbarks (*Melaleuca* spp.) and sedges occupy the banks of the ephemeral creek.

Figures 4 and 5 about here
Table 2 about here

A 1 m^2 test pit was excavated in Riwi in 1999 (Balme 2000). In 2013, the original Riwi test pit was re-opened and extended to a 2 x 2 m excavation, with an additional 1 m^2 test pit opened at the front of the cave (Figure 4, 5). The Riwi deposits, which were excavated to bedrock (max depth 117 cm), show a complex stratigraphy and evidence for intermittent occupation spanning some 47 ka (Wood et al. 2016), with anthracological (wood charcoal) and micromorphological data showing an alteration in site use through changing combustion features throughout the Pleistocene deposits (Figure 5, Vannieuwenhuyse 2016; Whitau et al. 2017). While the Pleistocene deposits are predominantly comprised of natural geogenic inputs with in situ anthropogenic features, the Riwi Holocene deposits are essentially palimpsests of occupation (Vannieuwenhuyse 2016; Whitau et al. 2017), with two phases spanning 7415—5905 cal BP and 915—670 cal BP respectively (Table 2, Wood et al. 2016). The Holocene units of Riwi offer excellent preservation of macrobotanical materials, and SU1, which was deposited during the last 1,000 years, yielded rare organic materials such as string, wood shavings, and wooden artefacts (Dilkes-Hall 2014; Langley et al. 2016; Whitau et al. 2016a, 2016b, 2017). The diverse macrobotanical remains recovered from the Riwi Holocene deposits are discussed in greater detail in Sections 4.2 and 4.3.

2.0 Materials and Methods

Bulk sediment samples were collected from each excavation unit during both the Riwi and Mount Behn excavations. Sediment samples were selected for pollen sampling: sixteen excavation units from Riwi from the Square 1 profile recovered during the 1999 excavations (Balme 2000), and each excavation unit which yielded anthropogenic material was sampled from the Mount Behn rockshelter, Square 2, Quadrant A (southwest corner). Tables 1 and 2 and Figures 4 and 5 show where these samples were taken from in relation to each site's stratigraphic units. Five gram subsamples of these bulk sediment samples were processed for palynological analysis in the Department of Archaeology and Natural History, at the Australian National University. A simple five-step procedure was undertaken to concentrate the pollen:

1) the addition of a *Lycopodium* spike (20,848 spores) for quantification of the sedimentary pollen
2) disaggregation and dispersal of sample in 5% sodiumpyrophosphate (calgon)
3) cleaning of sample through a 125 µm sieve
4) density separation of the <125 um fraction using Lithium-sodium-polytungstate heavy liquid (specific gravity 2.0)
5) the staining of the organic float with Safranin and mounting in glycerol.

Concentrations of microcharcoal were very high for the Mount Behn samples and very low for the Riwi samples. Microcharcoal was not quantified because the charcoal signature would not be indicative of landscape fire but is more likely to be a result of the fragmentation of charcoal associated with the occupation of the cave. The Mount Behn pollen/spore identifications were carried out at the Archaeology and Natural History Department at the Australian National University (ANU) and the Riwi pollen/spore identifications were carried out at the School of Geography and Environmental Science at Monash University. Regionally appropriate reference collections were provided by the

Department of Archaeology and Natural History (ANU) and the School of Geography and Environmental Science (Monash).

3.0 Results

3.1 Mount Behn rockshelter pollen results

The Mount Behn rockshelter pollen results are presented in Table 3. Total pollen concentrations decline down the profile: 158,471 grains/cm^3 (SU1), 64,193 grains/cm^3 (SU3), and 26,750 grains/cm^3 (SU4). A total of 40 palynological types were identified to varying levels of taxonomic significance, including five unknowns and three undifferentiated groups (Fabaceae Undiff., Lamiaceae Undiff., and Myrtaceae Undiff.). The dominant family group across all SUs was Myrtaceae, with high proportions of Poaceae, *Ficus* (Moraceae), Amaranthaceae, and Cyperaceae. The Amaranthaceae and Myrtaceae genera are summed in Table 3 for ease of comparison.

Table 3 about here

A total of 24 taxa, including one unknown type and three undifferentiated groups, were identified from the SU4 pollen counts. The dominant family groups are Myrtaceae (30.0%), Cyperaceae (21.0%), Poaceae (13.0%), and Amaranthaceae (9.2%). The dominant genera are *Eucalyptus*-*Corymbia* Types (7.1%), *Ficus* (7.1%) *Lophostemon* Type A (4.0%), Chenopod (5.7%), and *Euphorbia* Type (3.6%). *Celtis* sp. (2.5%), *Blumea* Type (2.3%), *Sesbania* (1.7%), Meliaceae (1.7%), *Cheilanthes* (1.5%), *Premna* Type (1.5%) *Triumfetta* (1.3%), and Unknown Type 2 (1.1%), are the only other taxa with proportions greater than 1.0%, the remaining four taxa total 2.4%.

A total of 36 taxa, including four unknown types and two undifferentiated groups were identified from the SU3 pollen analysis. To a greater degree than SU4, SU3 is also dominated by Myrtaceae, with the family comprising 39.5% of the total pollen sum. The other dominant family groups are Cyperaceae (15.2%), Poaceae (10.8%), and Amaranthaceae (7.9%). The dominant genera are the *Eucalyptus*-*Corymbia* Types (14.7%), *Ficus* (5.4%), *Euphorbia* Type (4.2%), and *Celtis* (3.2%). *Triumfetta* (2.5%), *Premna* Type (1.8%), Unknown Type 2 (1.7%), and *Cheilanthes* (1.1%) are the only other taxa with proportions greater than 1.0%, the remaining 20 taxa total 5.8% of the total pollen sum.

The most species rich unit with 34 taxa, including four unknown types and two undifferentiated groups, the SU1 pollen assemblage is dominated by Myrtaceae, which as a family, account for 63% of the total pollen sum, double the proportion of SU4. The other dominant family group is Poaceae (12.4%), while proportions of Amaranthaceae (5.8%) and Cyperaceae (3.8%) are reduced in comparison to SU3 and SU4. *Eucalyptus*-*Corymbia* Type A is the dominant taxon (32.2%), with the total *Eucalyptus*-*Corymbia* Type sum accounting for 43.2%, the other dominant genera are *Lophostemon* Types (17.6%), *Ficus* 6.3%, and Cyperaceae 3.8%. Unknown Type 2 (2.1%) and *Euphorbia* Type (1.2%) are the only other taxa with proportions greater than 1.0%, the remaining 21 taxa total 5.5% of the total pollen sum.

3.2 Riwi pollen results

Total pollen concentrations decline down the profile much more dramatically for Riwi than Mount Behn rockshelter. The concentration from the Riwi SU1 samples reached 205,930 grains/cm^3; however, the vast majority of these grains were indeterminable due to their etched and contorted condition. Six pollen taxa (Myrtaceae undiff., Acanthaceae, Fabaceae undiff., *Trichodesma*, Asteraceae, and Poaceae) were identifiable from SU7, and three pollen taxa (Acanthaceae, Fabaceae undiff. and *Trichodesma*) from SU10. Pollen is absent from all other analysed stratigraphic units.

Table 4 lists the pollen types identified, in a presence/absence format for the SU1 unit. A total of 26 taxa were identified (predominantly to genus). Frequent family groups include Myrtaceae, Fabaceae, and Euphorbiaceae. Poaceae, Asteraceae, Amaranthaceae, Goodeniaceae, and Acanthaceae taxa are also recorded. Plant habit and habitat affiliations are diverse, ranging from canopy to sub-canopy trees and/or shrubs (ten taxa), herbaceous forms (14 taxa), grasses and lianas (one taxon each). Pollen records such as *Eucalyptus*-*Corymbia*, *Erythrina*, and *Acacia* reflect open sclerophyll environments, whereas *Mallotus* and *Claoxylon* (both Euphorbiaceae) can be incorporated into monsoonal forest and/or vine thicket communities.

Table 4 about here

4.0 Discussion

4.1 Palynomorph deposition at Mount Behn rockshelter and Riwi

Pollen transportation, deposition, and accumulation processes within cave contexts are complex. Cave architecture, including aspect (e.g. Weinstein 1983), number and size of entrances and air circulation patterns (e.g. Coles et al. 1989; Coles and Gilbertson 1994; Simpson and Hunt 2009); the occurrence and properties of vegetation at the cave entrance (Coles and Gilbertson 1994; de Porras et al. 2011; Coles et al. 1989); fluvial inputs (e.g. Coles et al. 1989; Genty et al. 2001); and animal and human inputs (e.g. Bottema 1975; Bright and Davis 1982; Davis and Anderson 1987; Coles et al. 1989; Hunt and Rushworth 2005; Fiacconi and Hunt 2015), influence the mechanisms by which pollen accumulates and is preserved.

The SU4—1 layers of the Mount Behn rockshelter are highly anthropogenic, but these sediments are a mixture of diverse geogenic and biogenic components (Vannieuwenhuyse, 2016). In terms of cave architecture, although currently obscured by vegetation, Mount Behn rockshelter is open across the extent of its length, and while the excavation squares are some 5 m from the external dripline, water was observed dripping from the rockshelter ceiling and walls during the 2012 field season (Figure 2). The depositional dynamics of Riwi's Holocene sediments are predominantly anthropogenic, with limited natural inputs, obscuring the palaeoenvironmental signal in comparison with the Pleistocene layers underneath, which are predominantly aeolian (Vannieuwenhuyse, 2016; Whitau et al. 2017). An abundance of leaf litter in the Holocene units, particularly SU1, attests to aeolian activity during this time; however, even if the sediments are predominantly anthropogenic. The Riwi cave entrance is high and wide, exposing most of the front chamber; however, the excavation squares are tucked slightly behind the eastern wall, where they are also out of the way of the ephemeral water channel that runs along the western side of the cave (Figure 3).

The occurrence of vegetation at the shelter entrance affects the pollen accumulated within a cave context (Coles and Gilbertson 1994; de Porras et al.2011; Coles et al. 1989). At Riwi, a *Mallotus nesophilus* tree grows within the cave itself, and at Mount Behn rockshelter, a white fig (*Ficus virens*) grows within the shelter, while various trees and shrubs, including boab (*Adansonia gregorii*), *Vitex* sp., *Celtis strychnoides*, waterbush (*Myoporum montanum*), and white currant (*Flueggea virosa*) grow across the shelter entrance. With the exception of waterbush at Mount Behn rockshelter, all shrubs and trees that were identified within the shelters and/or entrances are present within the pollen spectra.

Pollen dispersal mechanisms also play a significant role within depositional dynamics. In comparison to their abundance within floral inventories, rainforest associated taxa are often under-represented in palynological records, because they tend to be entomophilous, producing lower amounts of pollen than wind pollinated taxa, such as herbs and grasses (Burn et al. 2010; Rowe 2012; Kershaw and Strickland 1980). Indeed, in pollen records from Australian savanna environments the herbaceous understory tends to be better represented through a combination of broader pollen dispersal range and greater biomass than the often scanty tree canopy (Kershaw and Strickland 1990). Proportions of monsoon rainforest taxa are low across all proxies at Mount Behn rockshelter. At Riwi, where macrobotanical preservation is better, proportions of monsoon rainforest taxa are higher within wood charcoal and seed assemblages, but low for pollen. For example, seeds, other plant parts, wood (charred and desiccated), string, and bark were recovered from Riwi's Holocene units, reflecting the richness of the modern vegetation and providing evidence for human-environment interaction in the past, while only enough pollen was recovered to note presence/absence of taxa.

4.2 Palynomorph taphonomy at Mount Behn rockshelter and Riwi

The obvious benefit of conducting multi-proxy archaeobotanical analysis is that the different taphonomic pathways capture a broader spectrum of botanic remains, clarifying identifications, and narrowing the spatial distribution of plant taxa records. Multi-proxy archaeobotanical analysis enables a more comprehensive picture of human-environment interaction, nuanced by a deeper understanding of taphonomic process, clearly demonstrated in Tables 5 and 6, which summarise the three proxy data sets from Mount Behn rockshelter and Riwi. At both sites, herbs and smaller shrubs, such as Poaceae and Cyperaceae, which do not produce wood and are absent from the wood charcoal record, are represented in both the pollen and seed data.

Tables 5 and 6 about here

The Holocene units of Riwi offer excellent preservation of botanic materials, with string, wooden artefacts, and an abundance of macrobotanical materials recovered (Dilkes-Hall 2014; Whitau et al. 2016a, 2016b, 2018). By contrast, botanic preservation at the Mount Behn rockhelter is very poor, with the richness of the vegetation not represented in either the wood charcoal or seed records, since certain taxa are proportionally over-represented due to preservation and identification biases (Whitau et al. 2018). In addition, phytoliths, which are comprised of organic silica, were observed in abundance throughout the Riwi microstratigraphy but were absent throughout the Mount

Behn microstratigraphy (Vannieuwenhuyse 2016). The preservation of pollen deteriorates with depth at both Riwi and Mount Behn rockshelter, but is much better preserved in the upper units of Mount Behn than Riwi. The following discusses the potential reasons for this differential preservation.

Pollen preservation requires anaerobic, acidic, reducing (not oxidizing), unburnt sediments, with limited mechanical trampling and biological agents, such as fungi, bacteria, earthworms, and millipedes (Bennett and Willis 2001). Mechanical trampling of the deposit by animals and humans can damage pollen; the exine surfaces can become abraded by soil particles, which eventually leads to the destruction of grains. A loss of sculpturing detail can make damaged grains more difficult to identify, and abraded pollen is more susceptible to destruction by fungi and bacteria (Bennett and Willis 2001). Evidence of trampling (visible by the random organisation at the microscale of mixed fresh and carbonised organic matter with geogenic sands) as well as numerous insect channels and macropod hollows were identified in the upper part of the Riwi stratigraphy (top of SU2 and SU1) pointing to intense post-depositional perturbation in the top of the deposit (Vannieuwenhuyse, 2016; Whitau et al., 2017: Figs 9A, 9B). The Mount Behn deposits also show evidence for post-depositional mixing. The high level of fragmentation of charcoals is probably related to trampling (animal or human) and enhanced by the coarse texture of the deposit. The presence of soil fauna galleries (such as termites and ant lions) visible at a microscale (mainly observed at the SU6/SU5/SU4 transitions) points to post-depositional mixing (Vannieuwenhuyse 2016). Since both sites have evidence for mechanical trampling, and the botanical remains at Riwi are well preserved in spite of this, it seems unlikely that bioturbation is the primary cause for Riwi’s poor palynomorph preservation.

Pollen is destroyed by burning. The Riwi Holocene ash-rich deposit is composed of a complex layering of numerous in situ combustion features and secondary contexts of hearth rake-out and ash dumps (Vannieuwenhuyse 2016; Whitau et al. 2017), which implies the pollen that was deposited in these layers was burned at some point or at least exposed to heat. Combustion features were observed throughout the anthropogenic layers (SU4—1) of the Mount Behn sequence; however, these are less abundant and interspersed with the sequence and their edges sometimes hard to define amongst the gravelly sediment of the Mount Behn deposits. At both sites, it is possible that heat or charring has altered or destroyed pollen grains, but given that there are abundant botanical remains (seeds, other floristics, and wooden artefacts) preserved by desiccation within these layers at Riwi, it seems unlikely that post-depositional burning would be the main reason for the poor palynomorph preservation in the upper part of the Riwi sequence.

The pH of sediments affects palynomorph preservation. In general, pollen preservation is enhanced in acidic soils, and considerably less biological activity occurs in acidic in comparison with alkaline conditions. Pearsall (2015), for example, illustrates a drop in quantity of pollen preserved in sediments with a pH >6.0. Bryant et al. (1994) (having conducted a transect pollen study along the United States-Mexico border) found less than half of fossil samples had pollen sufficiently preserved to identify and count. The soils in this arid region were alkaline, ranging in pH from 6.0 to 8.5 and greater. The pH of excavated Riwi sediments span 7.5 to 9.5 with the Holocene levels being very alkaline (average of 9) because of the high content of calcitic ash (Vannieuwenhuyse 2016), which could account for the poorer preservation of pollen at the site. The Mount Behn sediments are also alkaline, with an average of 8.5 for sterile layers and spanning 8 to 9.5 in archaeological layers (Vannieuwenhuyse 2016), probably also due to the higher concentration of calcitic ash in these levels. Interestingly, palynomorphs have preserved quite well in spite of this alkalinity in the Mount Behn upper sequence.

Any chemical weathering, most of the time triggered by change in soil moisture content, can affect pollen preservation. At both sites, evidence of chemical post-depositional processes was identified in the stratigraphy (Vannieuwenhuyse 2016). When oxygen reacts with rock minerals (especially iron), damaging oxides, hydroxides, and haematite (the principal ore of iron) forms (Pearsall 2015; Whittow 2000). These oxides and hydroxides might certainly account for the very limited preservation of pollen in the red iron-rich sediments of Riwi's Pleistocene deposits and Mount Behn's lowest units (SU6—7), which are largely comprised of decomposing bedrock. Alternating episodes of soil wetting and drying will also weaken grain exines (Bennett and Willis 2001), which would also account for the paucity of palynomorph preservation in the Riwi Pleistocene units, throughout which the formation of gypsum nodules attests to the post-depositional phases of sediment wetting and drying (Vannieuwenhuyse 2016). Chemical weathering accounts for the poorer preservation of pollen within the lower units at both sites; however, it is unlikely that changes in sediment moisture content have affected pollen preservation within the Holocene units of Riwi, since the majority of recovered macrobotanical remains were preserved by desiccation (Dilkes-Hall 2014; Whitau et al. 2016b).

Pollen preservation declines with depth at both sites, and it seems likely that the absence of pollen within Riwi's lower stratigraphic units is an effect of chemical weathering produced by changes to sediment moisture content through time. The differential preservation during the Holocene between the two sites is less readily explicable. Other organics have preserved exceptionally well at Riwi, particularly compared to Mount Behn rockshelter, which makes the poor preservation of Riwi's pollen more anomalous. The concentration of pollen grains within the Riwi Holocene SU1 unit (205,930 grains/cm^3) is within the same order of magnitude as Mount Behn rockshelter's SU1 unit (158,471 grains/cm^3). We propose that while more pollen was potentially deposited at Riwi during the Holocene than Mount Behn rockshelter, the mode of sediment deposition (predominantly animal and human vectors, rather than aeolian), produced a highly abraded, largely indeterminable pollen assemblage, with better preserved pollen deposited along with the abundant leaf litter in SU1.

4.3 A regional narrative of human-environment interaction

<u>4.3.1 Riwi: SU2 (7415—5905 cal BP) and SU1 (915—670 cal BP)</u>

Located some 300 km southeast of Mount Behn rockshelter on the edge of the Great Sandy Desert, Riwi's surrounding vegetation is less species rich than that of Mount Behn, comprised predominantly of hummock grasslands of spinifex (*Triodia bitextura*) with a scattered upper story of low *Corymbia*/*Eucalyptus* sp. trees. Monsoon rainforest taxa pocket the limestone hills and intermix with savanna taxa in fire-protected areas, and the banks of an ephemeral creek support a small riparian community of paperbarks (*Melaleuca* spp.) and sedges. Each of these vegetation systems is visible in the archaeobotanical record, including the scanty pollen archive, which reveals the presence of several taxa that are currently invisible in the macrobotanical archives, from several families including Acanthaceae, Amaranthaceae, Euphorbiaceae, and Goodeniaceae (Table 4). Figure 6 compares the wood charcoal and seed records between Riwi's two Holocene stratigraphic units.

Figure 6 about here

Riwi's oldest Holocene unit, SU2, was deposited between 7415—5905 cal BP, and is the most anthracologically and carpologically diverse stratigraphic unit (Dilkes-Hall 2014; Whitau et al. 2016a; Wood et al. 2016). The predominant wood selected for fuel was *Corymbia* sp., which would have been collected from the valley floor (Whitau et al. 2016a). The seed and other floristic results show that monsoon rainforest taxa were favoured economically, with *Vitex* (black plum) accounting for half of the assemblage (Dilkes-Hall 2014). There is a hiatus of deposition between SU2 and SU1, with evidence for occupation at Riwi re-commencing between 915—670 cal BP (Wood et al. 2016). *Corymbia* sp. continues to be the predominant wood collected for fuel, with the diversity and proportions of *Eucalyptus* sp. taxa increasing at the expense of non-eucalypt savanna. This decrease in non-eucalypt savanna is also observed in the seed record, with *Acacia* Type A pods decreasing in number from 159 (SU2) to seven (SU1) (Dilkes-Hall 2014). The richness of monsoon rainforest taxa increases between the two units, with shifts in composition: *Vitex* and *Cynanchum* decrease, *Ficus* and *Celtis* are similar in proportion, and *Mallotus* increases between the SU2 and SU1 units.

A *Mallotus nesophilus* tree grows within Riwi cave, and was the only *Mallotus* species identified during the 2013 survey. The consumption of *Mallotus nesophilus* fruit is detailed by ethnobotanic sources (Smith and Kalotas 1985; Wightman 2003), and we have direct evidence that wood was burned at Riwi (Table 6; Whitau et al. 2016a). It is proposed that people were collecting *Mallotus* fruits and wood from patches of monsoon forest that were growing within the area and bringing them to Riwi for consumption, resulting in the establishment of a tree within the cave entrance (cf. Florin and Carah 2017; Hynes and Chase 1982). The deposition of the seed could be incidental or intentional, with *Mallotus* providing the most pertinent example at Riwi. Other taxa of economic importance, such as *Solanum*, which is present in both seed and pollen records, could also be incidentally or intentionally introduced by human activities at the site.

4.3.2 Mount Behn rockshelter: SU4—SU3 (2825—1750 cal BP), SU1 (440—0 cal BP)

At Mount Behn rockshelter, neither the wood charcoal nor seed remains reflect the richness or abundance of vegetation communities of the modern vegetation, and Proteaceae wood charcoal and *Celtis* spp. endocarps are over-represented in the anthracological and seed records respectively (Whitau et al. 2018). In Whitau et al. (2018), we argue that the high proportions of Proteaceae wood charcoal are an effect of identification bias, since the *Grevillea*/*Hakea* wood type can still be identified in spite of vitrification. Vitrification is a process by which the cells of the wood fuse together obscuring the anatomical features. We show that if the vitrified *Grevillea*/*Hakea* sp. charcoals were, like the majority of other vitrified charcoals, indeterminable, the proportions of

Grevillea/*Hakea* sp. would be low, forming a subsidiary component after *Eucalyptus* sp. in SU1, SU3, and SU4 (Whitau et al. 2018: Table 3).

Pollen, on the other hand, was preserved well, and reflects the modern vegetation: a savanna of eucalypt and grasses, with non-eucalypt savanna, monsoon rainforest, and riparian components. Figure 7 compares the pollen and wood charcoal records across the three stratigraphic units. The pollen record shows a shift in vegetation associations between SU4 (2825—1750 cal BP) and SU1 (440—0 cal BP). SU3, which overlaps chronologically with SU4 (2825—1750 cal BP), sits somewhere between SU4 and SU1, illustrating that the change between the two units was gradual. The SU4 (2825—1750 cal BP) pollen shows an open, grassy environment, with a high proportion on xerophytic shrubs and sedges, while SU1 (440—0 cal BP) is dominated by eucalypts, more mesophytic, rather than xerophytic shrubs, and less grasses and sedges. The SU1 (440—0 cal BP) increase in eucalypt dominance is reflected in the wood charcoal record, although as cautioned elsewhere, this could be an effect of preservational bias.

Figure 7 about here

4.3.3 Comparison with broader palaeoclimate signals

The relationship between the archaeobotanical remains and regional climatic signals is of course not linear. Various depositional, taphonomic, and human processes which could have impacted the archaeobotanical records at both sites have already been discussed in depth. Taking these caveats into consideration, we compare the archaeobotanical data with broader palaeoclimate signals in order to explore vegetation change, and how people might have adapted to these vegetation changes during occupation phases at each site. Occupation at both Mount Behn rockshelter and Riwi was intermittent; or at least, evidence for occupation at the sites is not constant. Across the two sites, Holocene deposits cover discrete periods of time: 7415—5905 cal BP (Riwi SU2), 2825—1750 cal BP (Mount Behn SU4—SU3), 915—670 cal BP (Riwi SU1), and 440—0 cal BP (Mount Behn SU1).

With the exception of Mount Behn rockshelter's SU4—3, which spans 2825—1750 cal BP, all of the Holocene materials at Riwi and Mount Behn rockshelter were deposited during regional phases of active summer monsoon and relative humidity. Fluctuations in stalagmite ∂_{18}O values at Cave KNI-51 in the central Kimberley indicate an active monsoon between 7.5 and 4.5 ka (Denniston et al. 2013). Pollen, loss on ignition (LOI) and humification data from Black Springs, some 230 km north of Riwi, suggest an active monsoon throughout the mid Holocene until ~ 5 ka (Field et al. 2017). The KNI-51 record shows an abrupt weakening of the monsoon around 4.2 ka, which is sustained until 1.2 ka, with a peak in aridity occurring between 1.5 and 1.2 ka (Denniston et al. 2013). At Black Springs, a sharp decline in organic content, increased aeolian sedimentation, a shift in vegetation with lower aquatic species, and the lowest humification values for the core illustrate the driest phase for the record between 2.6 and 1.3 ka (Field et al. 2017; McGowan et al. 2012). Wetter conditions, with evidence for small-scale variability, occur from 1.2 ka through to the present (Denniston et al. 2013; Field 2017; Proske 2016; Rowe 2012; Stevenson et al. 2015), broadly aligning with the re-commencement of Riwi's

Holocene occupation from 915—670 cal BP, and continuing throughout the deposition of Mount Behn rockshelter's SU1 (440—0 cal BP).

Holocene occupation at Riwi between 7415—5905 cal BP (SU2) and 915—670 cal BP (SU1) is synchronous with broader regional phases of relative humidity. The abundance and richness of monsoon rainforest taxa between 7415—5905 cal BP, increasing between 915—670 cal BP, could be a reflection of wetter conditions, with the monsoon rainforest restricted to protected limestone areas during more arid periods with increased fire risk, and expanding to the valley floor in periods of relative humidity. If the monsoon rainforest was able to expand during phases of relative humidity, a more extensive habitat range might have been able to support the past occupants more consistently, for a greater length of time. Indeed, we argue elsewhere that the Riwi Holocene units reflect more consistent occupation of longer duration than the earlier Pleistocene layers (Vannieuwenhuyse 2016; Whitau et al. 2016a; Whitau et al. 2017; Wood et al. 2016).

Human selection processes, favouring certain taxa for consumption, would play an important role in the abundance of monsoon rainforest taxa within the archaeobotanical record, particularly in regards to the seed assemblage (Dilkes-Hall 2014). The importance of *Vitex* fruits is not just evident within its high proportions of the Riwi assemblage, but also its abundance within the rock art record of the Kimberley region (Veth et al. 2016), although unfortunately absent from the Riwi rock art assemblage. Humans could also have incidentally or intentionally disseminated certain taxa of economic importance, such as *Mallotus* and *Solanum* species. Of course, the higher taxon richness of wood and seeds in the Riwi Holocene units is undoubtedly in part the result of better preservation of monsoon rainforest taxa in the upper units of the sequence, particularly since the exceptional macrobotanical preservation of the Holocene units produced the lowest proportions of indeterminable charcoal (Whitau et al. 2016a). The abundance of monsoon rainforest taxa within the Riwi Holocene units is therefore a combination of suitable preservation conditions, human selection processes, and the palaeoclimatic conditions which allow for the extension of this vegetation system.

According to other palaeoclimatic records, SU4—SU3 at Mount Behn rockshelter was deposited during a period of relative aridity (2825—1750 cal BP). The more open, xerophytic pollen record of SU4 is suggestive of more arid conditions than SU1, which would require an increase in relative humidity in order to support a denser tree canopy. By contrast, SU1 (440—0 cal BP) was deposited during wetter conditions. If 2825—1750 cal BP was an arid phase in north Western Australia, the high proportions of riparian taxa within the SU4—SU3 units are anomalous. At Carpenter's Gap 1, Wallis (2001) argued that an increase in diatoms, sponge spicules, and Cyperaceae remains, signified that people were carrying water into the cave during the drier phase of the Last Glacial Maximum. The presence of malacofauna within the Mount Behn rockshelter deposit certainly confirms the exploitation of riparian resources by people (Maloney et al. 2017), so it is proposed that the ephemeral creek adjacent to the rockshelter was a refugium during 2825—1750 cal BP. Maloney et al. (2017) argue that the majority of stone points were discarded during this arid phase (SU4—3: 2825—1750 cal BP), indicating that people were adapting their technologies to the inferred foraging risk, which parallels similar arguments regarding other lithic assemblages from elsewhere in northern Australia (e.g. Clarkson 2002, 2007; Hiscock 1994, 2006; Hiscock and Veth 1991; Maloney et al. 2014; Maloney and O'Connor 2014; O'Connor et al. 2014).

5.0 Conclusions

The archaeobotanical records of Riwi and Mount Behn rockshelter reveal the presence of distinct vegetation systems including: savanna steppe/woodland dominated by *Eucalyptus*/*Corymbia*, but not to the exclusion of other taxa; a diverse herbaceous/shrubby understory; a monsoon rainforest component; and a riparian/sedge zone. We argue that high proportions of riparian taxa indicate that the area around Mount Behn was a refugium during a phase of regional aridity between 2825—1750 cal BP. At Riwi we show that the abundance and richness of monsoon rainforest taxa during the Holocene is a combined effect of local moisture availability, as shown by both the regional archives and the Riwi sequence, and human activities, particularly between 915—670 cal BP.

Preservation of organic remains and limited reference collections are often cited as inhibitors to archaeobotanical research in Australia. Pollen research has been undertaken in Australia for decades, and there are many resources and reference collections available to palynologists. While reference collections in other archaeobotanical fields are constructed, this unique study has effectively demonstrated how pollen analysis can inform our understanding of vegetation change and human-environment interaction.

While here restricted to the Holocene, the benefits of multi-proxy analysis cannot be overstated. Pollen analysis, when combined with wood charcoal research, enables the construction of past environments. The analysis of macrobotanical remains, particularly seeds and other floristics, is the strongest indicator of human-plant interaction, and when combined with charcoal and pollen spectra, enables a more complex analysis and detailed interpretation of the relationships between people and their environment.

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Figure 1. Kimberley region with sites mentioned in the text, biogeographic subregions, monsoon isoheyts (Bureau of Meterology 2017), and an inset of Australia (CAD by CartoGIS, Australian National University).

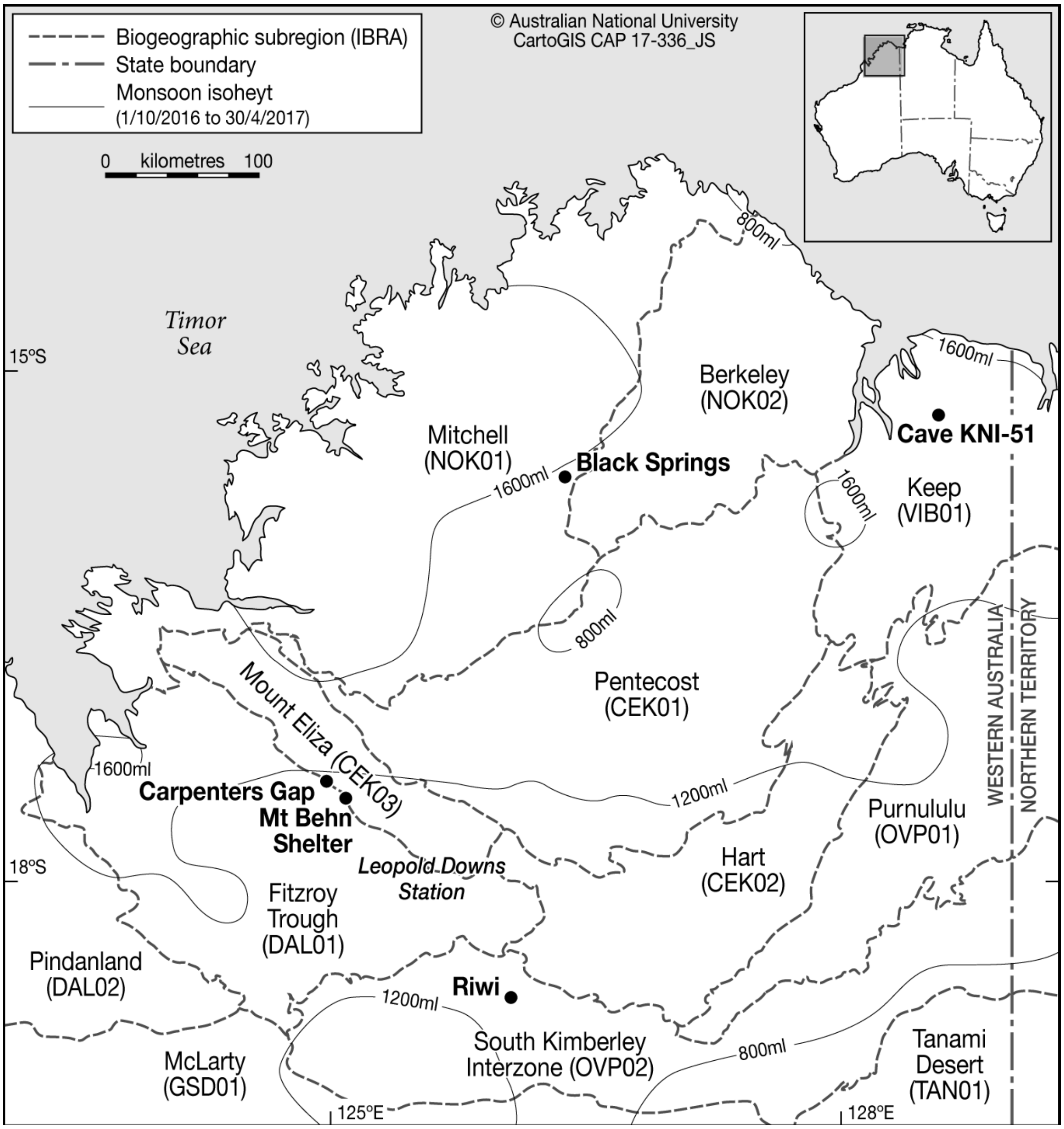

Figure 2. Mount Behn rockshelter outcrop and shelter plan showing the location of the excavation squares and shelter sections from western, central and eastern areas (photographs, photograph montage, topographic survey, and CAD by Dorcas Vannieuwenhuyse, reproduced from Whitau et al. 2018).

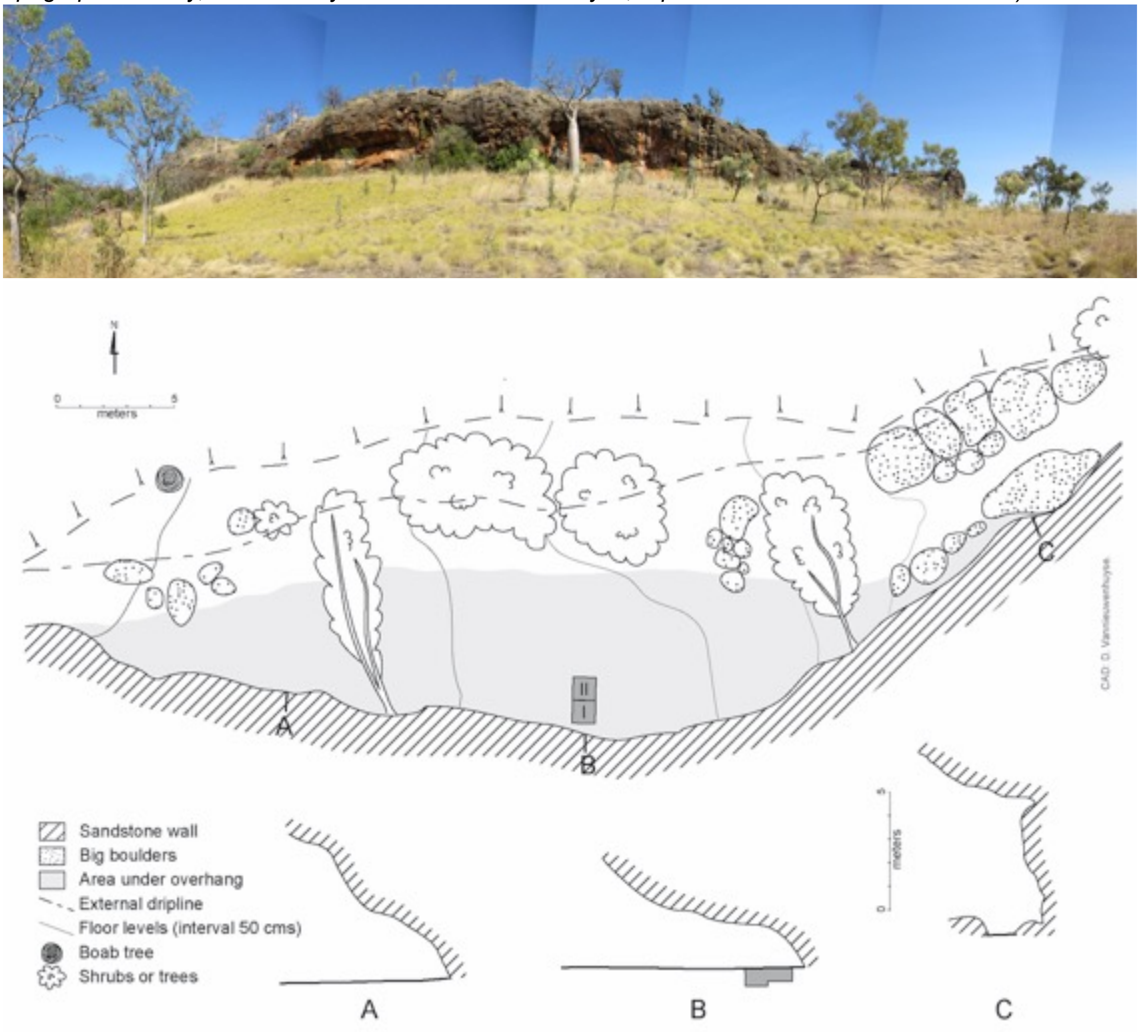

Figure 3. Riwi Cave entrance and site plan (photograph by India Dilkes-Hall, site plan CAD produced by Dorcas Vannieuwenhuyse, figure reproduced from Whitau et al. 2016a)

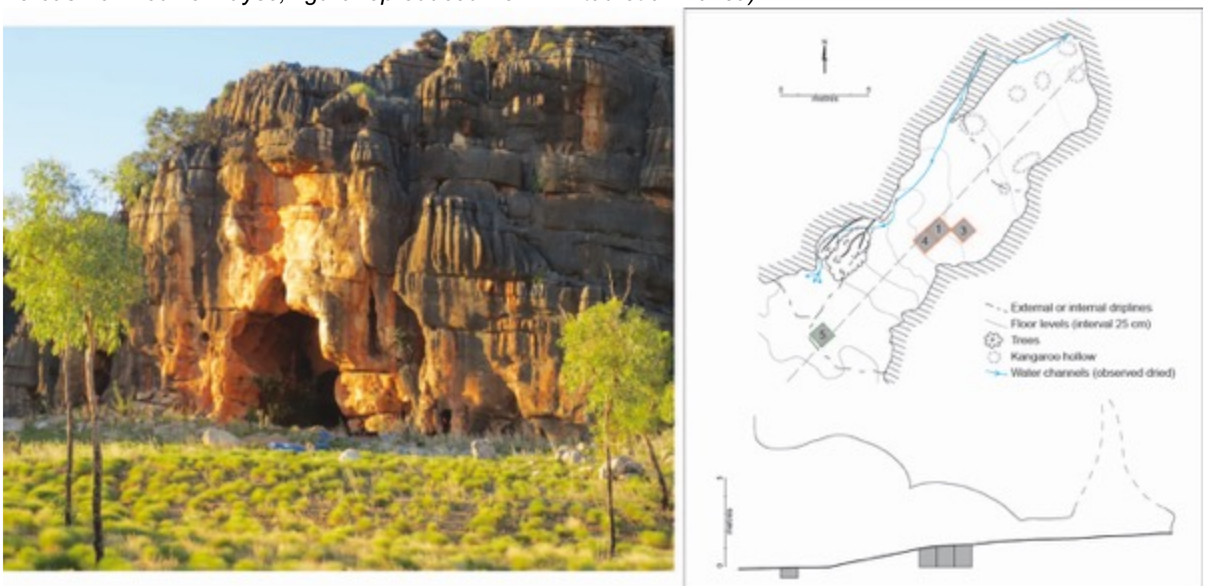

Figure 4. Mount Behn Squares 1 and 2 stratigraphic sections with descriptions of stratigraphic units and the location of pollen samples. (CAD by Dorcas Vannieuwenhuyse, reproduced from Whitau et al. 2018)

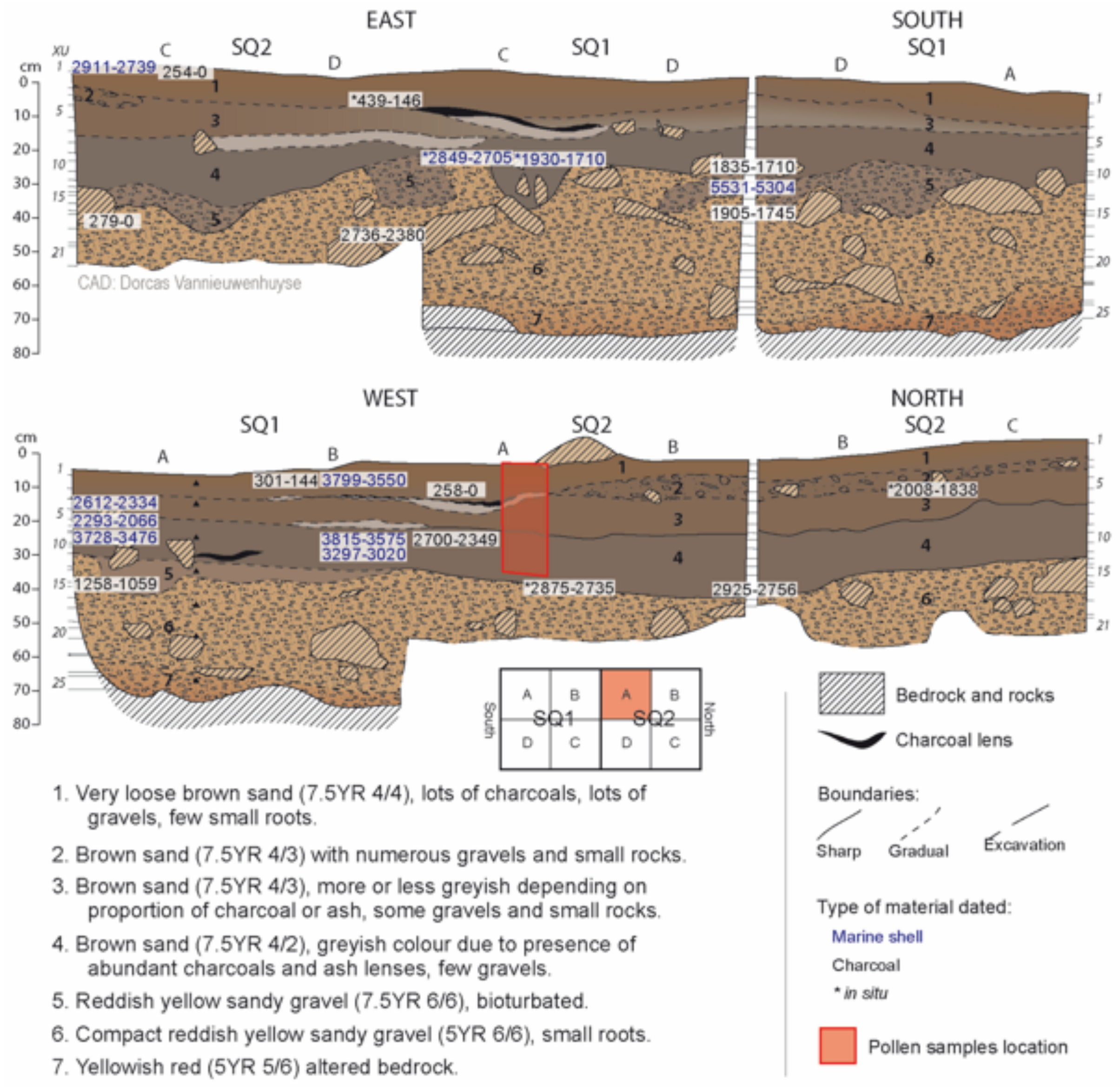

Figure 5. Riwi Square 1 stratigraphic section with the location of the pollen samples demarcated. Note that SU3—5 were not recovered from Square 1 (CAD by Dorcas Vannieuwenhuyse)

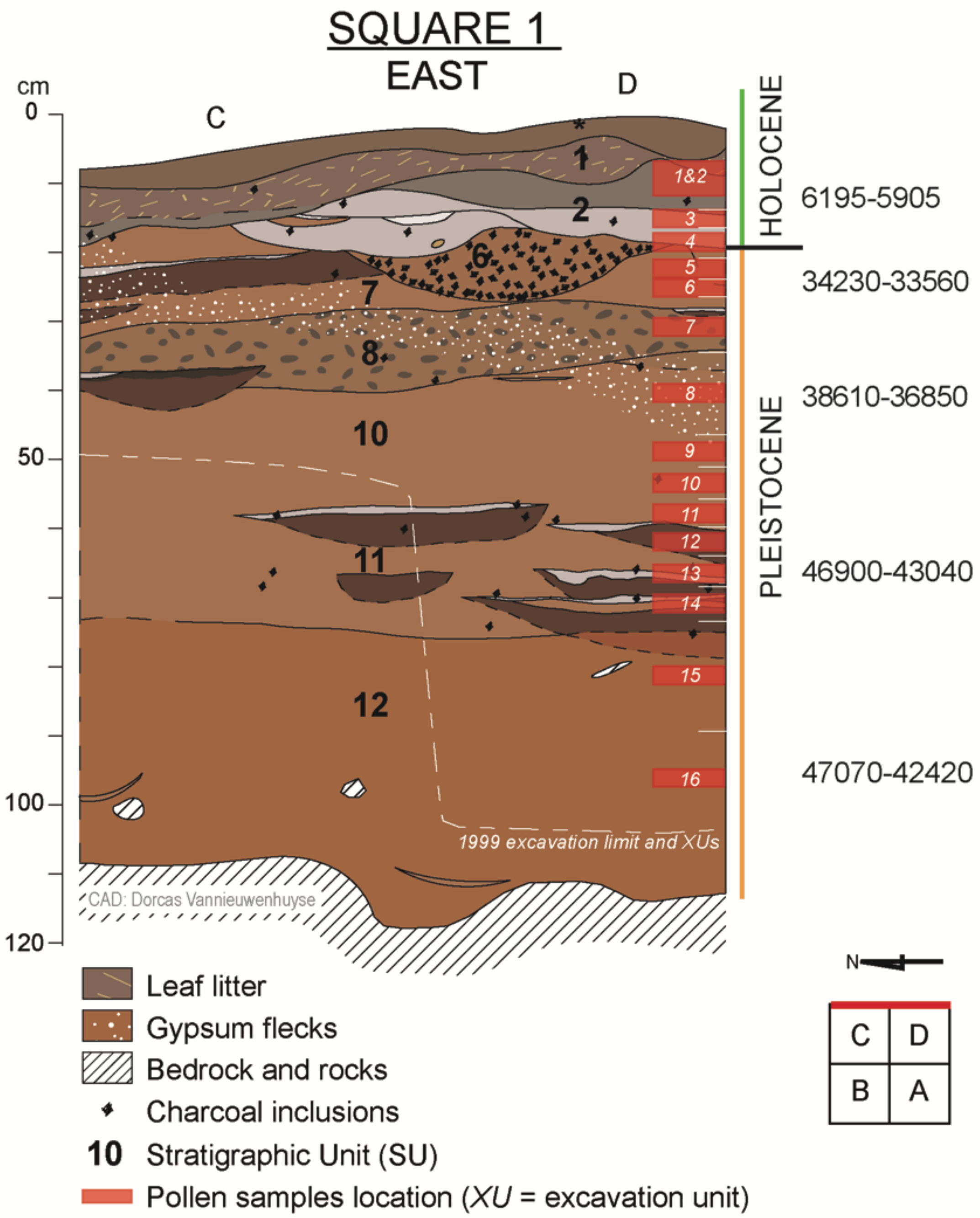

Figure 6 Riwi anthracological and carpological results by vegetation association for SU1 and SU2

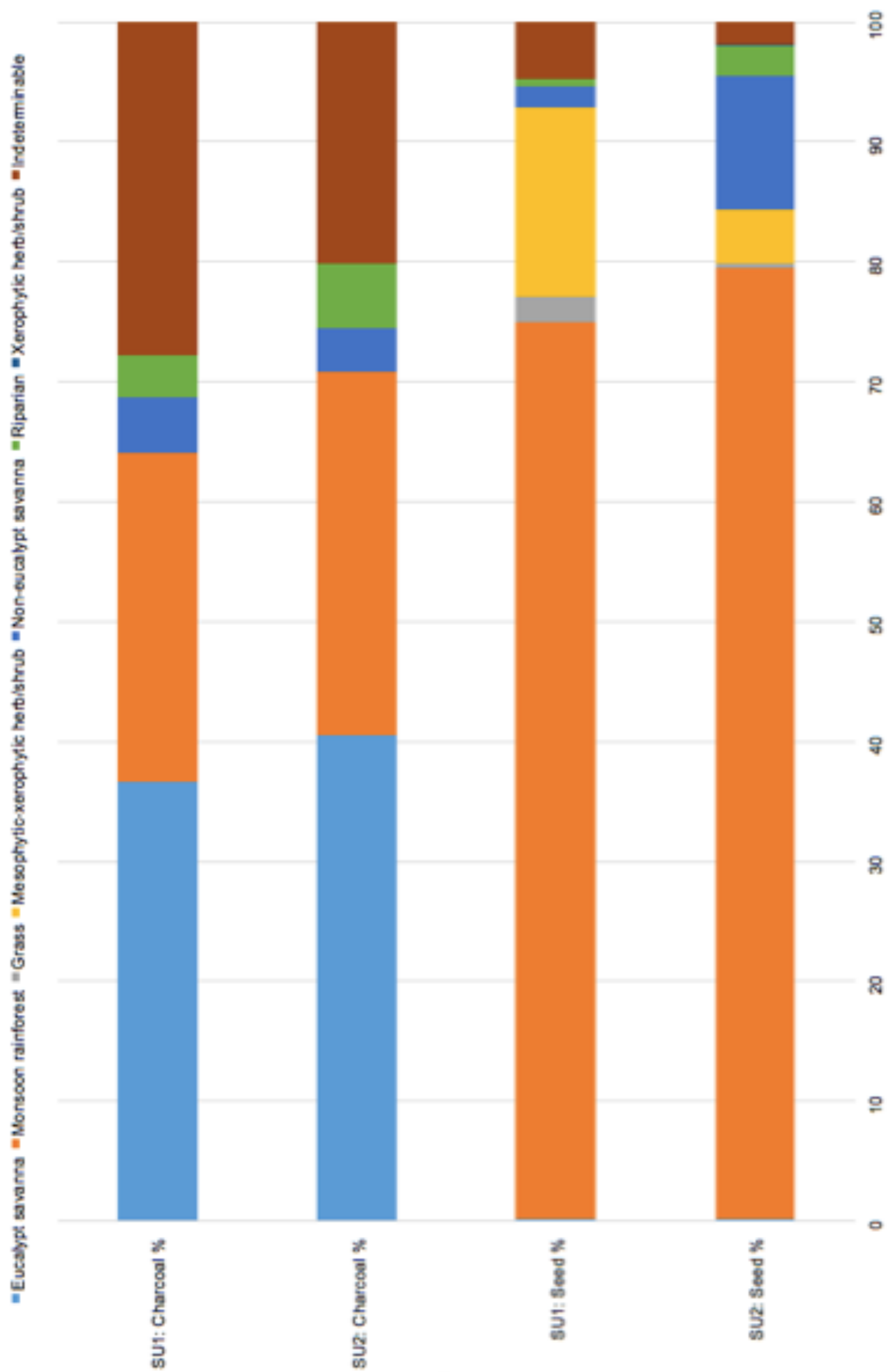

Figure 7 Mount Behn anthracological and palynological results by vegetation association for SU1, SU3, and SU4

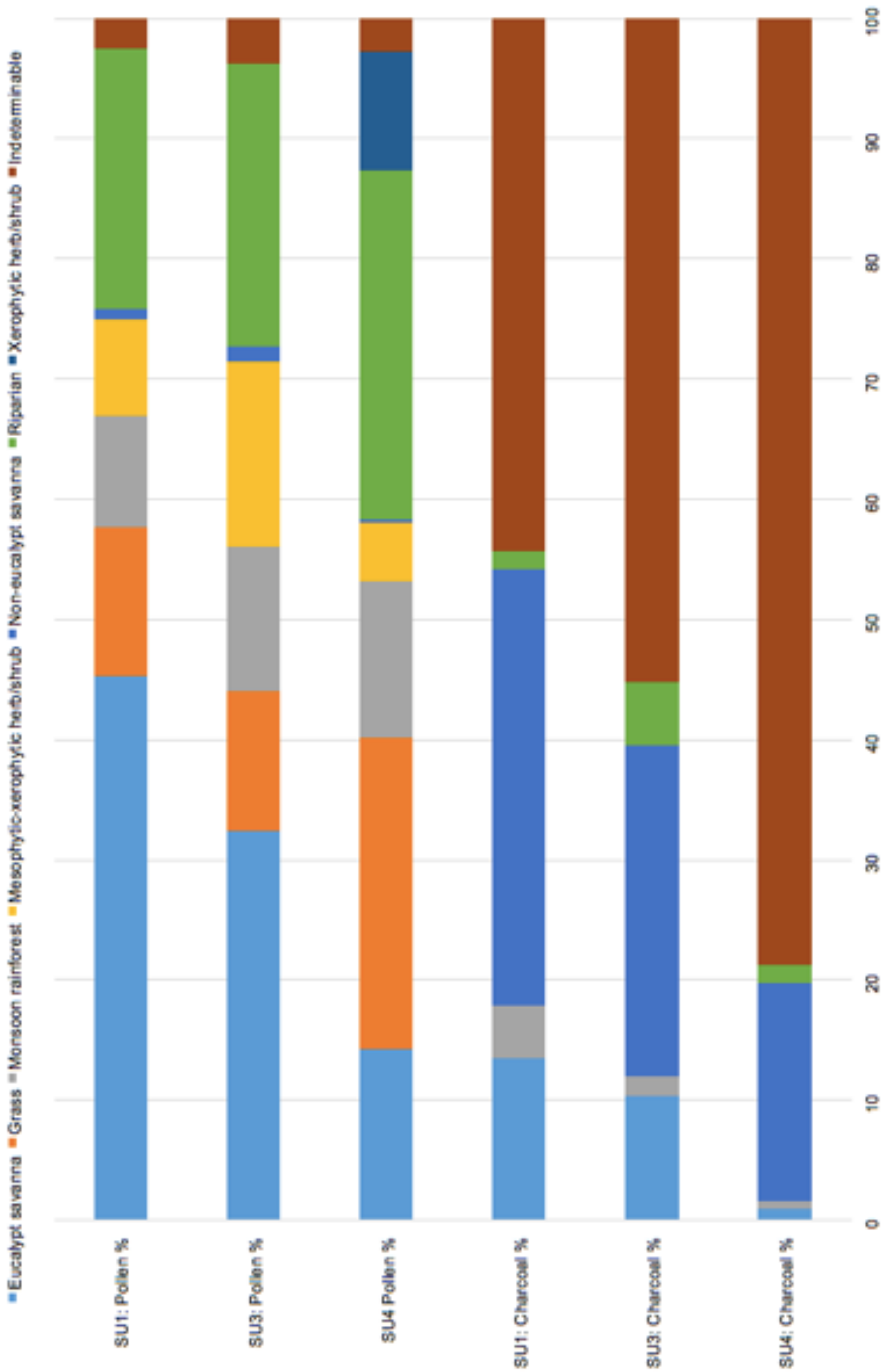

Table 1 Mount Behn rockshelter stratigraphic units (SU) with related excavation units (XU) from where palynological materials were collected. Radiocarbon dates are mentioned calibrated against SHCal13 (Hogg et al., 2013) in OxCal v.4.2 (Bronk Ramsey, 2009) following the radiocarbon chronology presented in Maloney et al. (2017) and Vannieuwenhuyse (2016). Table modified from Whitau et al. 2018.

SU	Description	XU Square II	Lab.code	Material	Radiocarbon age (BP)	Calibrated age (95.4% probability range, cal BP)
1	Very loose brown sand (7.5YR 4/4), lots of charcoals, lots of gravels, few small roots	1A, 2A, 3A	ANU 46912	Charcoal	108 ± 26	254—0
			ANU 46909	Charcoal	224 ± 25	301—144
			ANU 32631	Charcoal	265 ± 35	439—146
3	Brown sand (7.5YR 4/3), more or less greyish depending on proportion of charcoal or ash, some gravels and small rocks	4A, 5A, 6A, 7A	ANU 32509	Seed	2020 ± 34	2008—1838
4	Brown sand (7.5YR 4/2), greyish colour due to abundant charcoals and ash lenses, few gravels	8A, 9A, 10A	ANU 32507	*Celtis* seed	1955 ± 30	1930—1747
			ANU 46907	Charcoal	1884 ± 26	1835—1710
			ANU 32513	Charcoal	2460 ± 35	2700—2349
			ANU 32632	Charcoal	2775 ± 35	2925—2756
			ANU 32512	Charcoal	2715 ± 45	2875—2734

Table 2 A short description is given for each Holocene stratigraphy unit with related Excavation Units (XU) from where pollen samples were collected. Radiocarbon dates directly associated with the feature or same stratigraphic level are given. Radiocarbon dates are mentioned calibrated against SHCal13 (Hogg et al., 2013) in OxCal v.4.2 (Bronk Ramsey, 2009) following radiocarbon chronology done for the site by Wood et al. (2016). Table modified from Whitau et al. 2016a.

SU	Description	XU Square 1	Lab.code	Material	Radiocarbon age (BP)	Calibrated age (95.4% probability range, cal BP)
1	Brown grey layer (mix of very fine sand with abundant leaf litter, charcoal and ash)	1, 2	SANU-43337	Wood (*Grevillea*/*Hakea* sp.)	670 ± 20	650—555
			D-AMS 004068	Charcoal	816 ± 27	730—670
			D-AMS 004064	Charcoal	956 ± 29	915—760
2	Grey-brown ashy layer with charcoal and few leaves	3, 4	Wk 7605	Charcoal	5290 ± 60	6195—5905
			D-AMS 004069	Charcoal	6179 ± 29	7160—6935
			D-AMS 004065	Charcoal	6206 ± 37	7175—6935
			SANU-38223	Charcoal (*Corymbia* sp.)	6245 ± 30	7240—7000
			D-AMS 004063	Charcoal	6384 ± 32	7275—7025
			D-AMS 004067	Charcoal	6452 ± 34	7420—7270
7	Reddish, slightly greyish fine sand with dark brown aggregates of various sizes, variable presence of gypsum nodules (2—5 mm)	5, 6	SANU-35916	Charcoal (Indeterminable)	29,720 ± 190	34,170—33,510
			D-AMS 004066	Charcoal	31,888 ± 153	36,155—35,345
			Wk 7606	Charcoal	33,000 ± 280	36,730—34,770
			SANU-35914	Charcoal (*Corymbia* sp.)	33,270 ± 280	37,830—36,480
8	Yellowish-grey concave lenses of fine sand rich in organic matter, variable presence of gypsum nodules (2—5 mm)	7	--	--	--	--
9	Reddish very fine sand, scattered charcoals, numerous gypsum nodules (2—5 mm)	--	SANU-35906	Charcoal (*Corymbia* sp.)	33,560 ± 300	38.610—36,855
			SANU-35919	Charcoal (Indeterminable)	34,000 ± 310	39,230—37,460
			SANU-35913	Charcoal (*Corymbia* sp.)	38,850 ± 300	38,960—37,205
10	Reddish very fine	8—10	SANU-35918	Charcoal (*Corymbia* sp.)	33,340 ± 280	38,405—36,660

	sand, scattered charcoals, no gypsum nodules in Sq1		SANU-37706	Charcoal (*Corymbia* sp.)	36,680 ± 420	41,970—40,400
11	Reddish very fine sand, presence of anthropogenic features (hearths)	11—14	SANU-35910	Charcoal	29,840 ± 190	34,270—33,600
			SANU-35911	Charcoal (*Corymbia* sp.)	41,520 ± 750	45,980—44,030
12		15, 16	ANUA-13006	Charcoal	40,700 ± 1260	47,070—42,430
			SANU-35909	Charcoal (*Corymbia* sp.)	41,590 ± 760	46,470—43,610
			SANU-35917	Charcoal (Indeterminable)	42,140 ± 810	46,000—44,060

Table 3 Mount Behn rockshelter pollen results, expressed as percentages of total pollen sum, excluding damaged grains

	SU 1	SU 3	SU 4
Eucalyptus-Corymbia Type A	21.2	6.2	1.9
Myrtaceae Indet	13.2	17.7	18.9
Lophostemon Type A	10.8	6.7	4.0
Eucalyptus-Corymbia Type B	6.3	3.6	2.9
Lophostemon Type B	6.8	0.5	0.0
Eucalyptus-Corymbia Type C	4.6	4.9	2.3
Total Myrtaceae	**63.0**	**39.5**	**30.0**
Poaceae	11.7	11.6	13.0
ScabratePoaceae	0.7	0.0	0.0
Total Poaceae	**12.4**	**11.6**	**13.0**
Ficus	**6.3**	**5.4**	**7.1**
Chenopod	4.4	3.9	5.7
Ptilotus	1.1	3.4	2.7
Gomphrena	0.3	0.6	0.8
Total Chenopods	**5.8**	**7.9**	**9.2**
Total Cyperaceae	**3.8**	**15.2**	**21.0**
UnknownType2	2.1	1.7	1.1
EuphorbiaType	1.2	4.2	3.6
Meliaceae	0.7	0.5	1.7
Triumfetta	0.7	2.5	1.3
Celtis	0.6	3.2	2.5
PremnaType	0.6	1.8	1.5
Dodonaea	0.5	0.4	0.0
Acacia	0.3	0.2	0.0
CapparisType	0.3	0.5	0.6
Cochlospermum	0.3	0.1	0.0
Abutilon	0.2	0.1	0.0
BlumeaType	0.2	0.9	2.3
FabaceaeUndiff	0.2	0.1	0.2
Proteaceae	0.2	0.2	0.0
UnknownType17	0.1	0.0	0.0
Atalaya	0.1	0.2	0.0
Flueggea	0.1	0.1	0.0
Trichodesma	0.1	0.1	0.0
TriletePsilate	0.1	0.0	0.0
UnknownType13	0.1	0.1	0.0
UnknownType16	0.1	0.1	0.0
Adansonia	0.0	0.6	0.0
Cheilanthes	0.0	1.1	1.5
LamiaceaeUndiff	0.0	0.0	0.8
Portulaca	0.0	0.6	0.8
Sesbania	0.0	0.3	1.7
UnknownType18	0.0	0.5	0.0

Table 4 Riwi pollen results

	SU1
Myrtaceae (*Eucalytpus-Corymbia* type)	P
Myrtaceae (undiff.)	P
Erythrina (Fabaceae)	P
Acacia (Mimosaceae)	P
Celtis (Ulmaceae)	P
Dodonaea (Sapindaceae)	P
Euphorbiaceae (*Mallotus* type)	P
Euphorbiaceae (undiff.)	P
Euphorbiaceae (*Claoxylon* type)	P
Myrtaceae (*Calytix* type)	P
Acanthaceae	P
Amaranthaceae	P
Fabaceae (*Cassia* type)	P
Fabaceae (*Crotalaria* type)	P
Goodeniaceae	P
Tinospora (Menispermaceae)	P
Euphorbiaceae (*Euphorbia* type)	P
Fabaceae (undiff.)	P
Malvaceae (*Abutilon* type)	P
Solanaceae (*Solanum* type)	P
Spermacoce (Rubiaceae)	P
Trichodesma (Boraginaceae)	P
Asteraceae	P
Poaceae	P
Rubiaceae (*Dentella* type)	P
Tribulus (Zygophyllaceae)	P

Table 5 Mount Behn rockshelter, anthracological, carpological, and palynological data

Association	Taxon	Family	SU1 Pollen %	SU1 Seed n	SU1 Charcoal %	SU3 Pollen %	SU3 Seed n	SU3 Charcoal %	SU4 Pollen %	SU4 Seed n	SU4 Charcoal %
Bloodwood/eucalypt savanna	*Corymbia sp.*	Myrtaceae			0.6			1.4			0.3
Bloodwood/eucalypt savanna	*Eucalyptus sp.*	Myrtaceae			11.2			6.7			0.3
Bloodwood/eucalypt savanna	*Eucalyptus*/*Corymbia* sp.	Myrtaceae	32.1		1.7	14.6		2.2	7.1		0.3
Bloodwood/eucalypt savanna	Myrtaceae sp.	Myrtaceae	13.2			17.7			18.9		
Dry rainforest	*Capparis* Type	Capparaceae	0.3			0.5			0.6		
Dry rainforest	*Clerodendrum/Vitex sp.*	Lamiaceae			1.7			0.6			0.2
Dry rainforest	Lamiaceae Undiff.	Lamiaceae			1.7			0.3	0.8		0.3
Dry rainforest	*Premna* Type	Lamiaceae	0.6			1.8			1.5		
Dry rainforest	*Vitex cf. glabrata*	Lamiaceae		3			1				
Dry rainforest	*Melia azedarach*	Meliaceae									
Dry rainforest	Meliaceae	Meliaceae	0.7			0.5			1.7		
Dry rainforest	*Ficus*	Moraceae	6.3		0.8	5.4		0.8	7.1	1	0.2
Dry rainforest	*Flueggea*	Phyllanthaceae	0.1		0.2	0.1					
Dry rainforest	*Atalaya*	Sapindaceae	0.1			0.2					
Dry rainforest	*Dodonaea*	Sapindaceae	0.5			0.4					
Dry rainforest	*Celtis strychnoides*	Ulmaceae	0.6	2		3.2	9		2.5	10	
Dry rainforest	*Ampelocissus acetosa*	Vitaceae		3							
Dry rainforest	*Cissus cf. adnata*	Vitaceae					1				
Fern	Cheilanthes					1.1			1.4		
Fern	Trilete Psilate		0.1								
Grass	Poaceae	Poaceae	12.4			11.6			13.0		
Grass	Scabrate Poaceae	Poaceae	0.7								
Mesophytic shrub	*Triumfetta*	Malvaceae	0.7			2.5	1		1.3		
Mesophytic-xerophytic herb/shrub	*Trichodesma*	Boraginaceae	0.1			0.1					
Mesophytic-xerophytic herb/shrub	*Euphorbia*Type	Euphorbiaceae	1.2			4.2			3.6		
Mesophytic-xerophytic herb/shrub	*Abutilon*	Malvaceae	0.2			0.1					
Mesophytic-xerophytic herb/shrub	*Solanum sp.*	Solanaceae		2			1				

Non-eucalypt savanna	*Cochlospermum*	Bixaceae	0.3		0.1			
Non-eucalypt savanna	*Terminalia* sp.	Combretaceae		4.8		2.2		1
Non-eucalypt savanna	*Acacia* sp.	Fabaceae	0.3	4.4	0.2	3.4		0.7
Non-eucalypt savanna	*Bauhinia cunninghamii*	Fabaceae		1.5				0.7
Non-eucalypt savanna	Fabaceae Undiff.	Fabaceae	0.2		0.1		0.2	
Non-eucalypt savanna	*Gyrocarpus sp.*	Hernandiaceae		0.2				
Non-eucalypt savanna	*Adansonia*	Malvaceae			0.6			
Non-eucalypt savanna	*Grevillea/Hakea sp.*	Proteaceae	0.2	25.4	0.2	21.9		15.8
Riparian	*Blumea*Type	Asteraceae	0.2		0.9		2.3	
Riparian	Cyperaceae	Cyperaceae	3.6		15.2		21.0	
Riparian	*Sesbania*	Fabaceae			0.3		1.6	
Riparian	Lophostemon Type A	Myrtaceae	10.8		6.7		4.0	
Riparian	Lophostemon Type B	Myrtaceae	6.8		0.5			
Riparian	*Melaleuca sp.*	Myrtaceae		1.5		5.3		1.5
Xerophytic herb	*Portulaca*	Portulacaceae			0.6		0.8	
Xerophytic herb/shrub	Chenopod	Amaranthaceae	4.4		3.9		5.7	
Xerophytic herb/shrub	*Gomphrena*	Amaranthaceae	0.3		0.6		0.8	
Xerophytic herb/shrub	*Ptilotus*	Amaranthaceae	1.1		3.4		2.7	

Table 6 Riwi Cave, anthracological, carpological, and palynological data

Association	Taxon	Family	Pollen	SU1		SU2	
				Seed %	Charcoal %	Seed %	Charcoal %
Bloodwood/eucalypt savanna	*Calytrix* type	Myrtaceae	P				
Bloodwood/eucalypt savanna	*Corymbia* sp.	Myrtaceae			31.5		39.7
Bloodwood/eucalypt savanna	*Eucalyptus* sp.	Myrtaceae			5.1		0.6
Bloodwood/eucalypt savanna	*Eucalyptus/Corymbia* sp. (bloodwood gall)	Myrtaceae	P	0.1			
Bloodwood/eucalypt savanna	*Eucalyptus/Corymbia* sp. (operculum)	Myrtaceae		0.1		0.1	
Bloodwood/eucalypt savanna	*Eucalyptus/Corymbia* sp. (whole capsule)	Myrtaceae				0.1	
Bloodwood/eucalypt savanna	Myrtaceae sp.	Myrtaceae	P				0.2
Monsoon rainforest	Acanthaceae	Acanthaceae	P				
Monsoon rainforest	*Cynanchum* sp.	Apocynaceae		3.5		19.5	
Monsoon rainforest	*Marsdenia* sp.	Apocynaceae		0.2			
Monsoon rainforest	cf. *Cucumis*	Cucurbitaceae		0.1		0.1	
Monsoon rainforest	*Mallotus* cf. *dispersus* (flowers)	Euphorbiaceae	P	22.3		0.2	
Monsoon rainforest	Mallotus sp.	Euphorbiaceae		2.3	8.7	0.1	1.5
Monsoon rainforest	Lamiaceae sp.	Lamiaceae			1.2		2.2
Monsoon rainforest	*Premna acuminata*	Lamiaceae		3.9		0.1	
Monsoon rainforest	Vitex sp.	Lamiaceae		28.4	5	50.3	5.6
Monsoon rainforest	Tinospora	Menispermaceae	P				
Monsoon rainforest	*Ficus* sp. (achenes)	Moraceae		0.3			
Monsoon rainforest	*Ficus* spp.	Moraceae		9.5	4.0	7.8	7.6
Monsoon rainforest	*Ficus* spp. (stipule)	Moraceae		0.2			
Monsoon rainforest	Flueggea sp.	Phyllanthaceae		0.8	6.6		6.6
Monsoon rainforest	*Dodonaea* sp.	Sapindaceae	P				
Monsoon rainforest	Brucea sp.	Simaroubaceae			1.4		1.2
Monsoon rainforest	*Celtis strychnoides*	Ulmaceae	P	2.9	0.6	1.2	5.6
Monsoon rainforest	*Ampelocissus acetosa*	Vitaceae		0.3			
Monsoon rainforest	cf. *Cissus* sp.	Vitaceae		0.1			
Grass	Poaceae	Poaceae	P	x		x	

Grass	*Triodia* cf. *pungens* (spikelets/lemma)	Poaceae		x		x	
Grass	*Triodia* spp. (rootlets/leaves)	Poaceae		2.1		0.3	
Mesophytic-xerophytic herb/shrub	Asteraceae	Asteraceae	P	1.8			
Mesophytic-xerophytic herb/shrub	*Trichodesma zeylanicum*	Boraginaceae	P	3.5			
Mesophytic-xerophytic herb/shrub	Claoxylon type	Euphorbiaceae	P				
Mesophytic-xerophytic herb/shrub	Euphorbia type	Euphorbiaceae	P				
Mesophytic-xerophytic herb/shrub	Euphorbiaceae	Euphorbiaceae	P				
Mesophytic-xerophytic herb/shrub	Crotalaria type	Fabaceae	P				
Mesophytic-xerophytic herb/shrub	*Senna* sp. (pod)	Fabaceae	P	0.5		0.2	
Mesophytic-xerophytic herb/shrub	Goodeniaceae	Goodeniaceae	P				
Mesophytic-xerophytic herb/shrub	*Abutilon* cf. *hannii*	Malvaceae	P	x		X	
Mesophytic-xerophytic herb/shrub	cf. *Grewia retusifolia*	Malvaceae		8.7		3.7	
Mesophytic-xerophytic herb/shrub	*Sida* sp.	Malvaceae		1.0		0.5	
Mesophytic-xerophytic herb/shrub	Dentella type	Myrtaceae	P				
Mesophytic-xerophytic herb/shrub	Spermacoce	Rubiaceae	P				
Mesophytic-xerophytic herb/shrub	*Solanum* sp. (seed)	Solanaceae	P			0.1	
Mesophytic-xerophytic herb/shrub	*Solanum* sp. (stem)	Solanaceae		0.3			
Non-eucalypt savanna	*Terminalia* sp. Type A	Combretaceae		0.7		0.4	
Non-eucalypt savanna	*Terminalia* sp. Type B	Combretaceae				0.1	
Non-eucalypt savanna	*Acacia* sp. (pod) Type A	Fabaceae	P	0.6		9.2	
Non-eucalypt savanna	*Acacia* sp. (pod) Type B	Fabaceae		0.2		1.2	
Non-eucalypt savanna	*Acacia* sp. (pod) Type C	Fabaceae		0.1			
Non-eucalypt savanna	*Bauhinia cunninghamii*	Fabaceae					1
Non-eucalypt savanna	cf. *Acacia* sp. (seed)	Fabaceae		0.1		0.3	
Non-eucalypt savanna	*Erythrina* sp.	Fabaceae	P				
Non-eucalypt savanna	*Erythrophleum* sp.	Fabaceae			4.2		1.2
Non-eucalypt savanna	Fabaceae	Fabaceae	P				
Non-eucalypt savanna	*Vachellia* sp.	Fabaceae					1.5

Non-eucalypt savanna	*Grevillea/Hakea* sp.	Proteaceae			0.4		
Riparian	Cyperaceae (stem)	Cyperaceae		0.3			
Riparian	*Cyperus bulbosus* (tunic)	Cyperaceae		0.3		2.5	
Riparian	Melaleuca sp.	Myrtaceae			3.5		5.4
Xerophytic herb/shrub	Amaranthaceae	Amaranthaceae	P				
Xerophytic herb/shrub	*Tribulus terrestris*	Zygophyllaceae	P			0.1	

Chapter 8. Conclusions

The two overarching aims of this thesis are to explore late Quaternary human-environment interaction at two archaeological sites in Bunuba and Gooniyandi country and to develop the application of archaeobotanical analyses in Australia. The following synthesises the discussions presented in Chapters 3—7 in line with the thesis aims, focusing first on the archaeobotanical methods developed in this research, before exploring human-environment interaction in the Kimberley region during the late Quaternary. The chapter concludes with a discussion of potential future directions for archaeobotanical research in Australia.

8.1 Developing the application of archaeobotanical analyses in Australia

One of the central aims of this thesis is to develop the application of archaeobotanical analyses in Australia, through two subsidiary aims. The first subsidiary aim is to apply appropriate, current archaeobotanical methods at Riwi and Mount Behn rockshelter that are informed by a critical engagement with the literature. The second subsidiary aim is to produce reproducible research that develops the ways in which archaeobotanical analyses can be more readily applied to Australian archaeological contexts. Because the discussions relevant to each of these subsidiary aims overlap, conclusive statements are presented concomitantly.

This research is the second submitted PhD thesis on Australian archaeological wood charcoal. Chapters 3, 4, and 6 present the largest anthracological assemblages investigated in Australia to date, with 6,778 charcoal fragments analysed across the two sites, 3,368 of which were identified to varying levels of taxonomic significance from 11 family groups. Each archaeological context was closely examined, and a diligent approach taken to ensure the representativeness of each archaeobotanical assemblage. Riwi and Mount Behn rockshelter were both excavated by arbitrary units or spits, with certain features (predominantly hearths) removed whole. At both Riwi and Mount Behn rockshelter, excavations and archaeobotanical sampling methods were developed in collaboration with the Lifeways Project geoarchaeologist, Dorcas Vannieuwenhuyse, who analysed the site formation processes of each site in her thesis (Vannieuwenhuyse 2016). The benefits of collaboration with a geoarchaeologist cannot be overstated, here enabling the complex assessment of each archaeological context, its formation, and potential taphonomic biases, as discussed in detail in Chapters 4, 6, and 7. Through collaboration with the Lifeways Project geoarchaeologist, excavation and stratigraphic units were carefully associated, and any material recovered from excavation units where sediments included more than one discrete deposit were avoided. This approach enabled the successful collation of archaeobotanical assemblages from secure stratigraphic contexts. The main limitation of this approach is that some materials could not be used as they were excavated in units with more than one discrete deposit.

The representativeness of wood charcoal assemblages was tested at each site. At Riwi, saturation curves (Chapter 3) show that stratigraphic units 1, 2, and 7—10 reach plateau, indicating that the sample size is large enough to represent the taxon richness of each archaeological assemblage. Saturation curves do not reach plateau for stratigraphic units 11 and 12, precluding these contexts from palaeoenvironmental reconstruction. At Mount Behn rockshelter, charcoals are poorly preserved alongside other macrobotanical remains (Chapter 6), preventing the reconstruction of woodland vegetation from the anthracological assemblage. The taphonomy of seeds, pollen, and wood charcoal is explored in depth in Chapters 6 and 7, providing ground work for further taphonomic studies in Australian contexts, an additional archaeological example of wood charcoal vitrification processes, and the first comprehensive assessment of pollen recovered from an archaeological site. Pollen preservation is much better at Mount Behn rockshelter than Riwi, presenting a viable alternative assemblage to wood charcoal for vegetation reconstruction (Chapter 7).

Chapters 3 and 4 present the results of anthracological analyses conducted at Riwi, which offer the first anthracological investigation in Australia that examines both scattered and concentrated archaeological contexts. Chapter 4 combines the anthracological and micromorphological analysis of Riwi's combustion features and compares these results with the non-combustion feature assemblages presented in Chapter 3, in order to infer changes in the technological use of fire, fuel resource management practices, and occupation intensity through time. This research supports the premise that certain hearth features, such as the type A structures, are episodic archaeological contexts which represent the last few firing events (e.g. Beauclair et al. 2009; Ford 1979; Huebert et al. 2010; Picornell-Gelabert et al. 2011; Ramos et al. 2008; Scheel-Ybert et al. 2014), whereas scattered, synthetic deposits are more likely to represent the diversity of the surrounding vegetation (Badal et al. 2012; Chabal 1997; Chabal et al. 1999; Dufraisse 2012, 2014; Vita Finzi and Higgs 1970). Additionally, the type B combustion features, which were re-used, provide an example of a heterogenous deposit associated with a particular activity from a hunter-gatherer context.

The combined anthracological and micromorphological analyses presented in Chapter 4 have important methodological and archaeological implications. The findings support other taphonomic studies (e.g. Dussol et al. 2017; Théry-Parisot et al. 2010a) in showing that the factors affecting charcoal preservation are complex, while illustrating the importance of understanding site formation processes (Holdaway et al. 2008; Langley et al. 2011; Vannieuwenhuyse et al. 2016; Ward and Larcombe 2003; Ward et al. 2016). Fires which were lit directly on the ground surface, like the type A hearth structures, are far less likely to produce quantifiable charcoal within the structure itself, as the direct exposure to oxygen can completely combust the fuel. An increase in charcoal abundance should not then be correlated with an intensification of occupation, as suggested by Ward et al. (2016), since the prevalent type of combustion structure, its formation, duration of use, and degree of preservation must all be considered. The exceptional preservation of the type A hearths also provide an archaeological case study for how heating can affect the underlying sediments, which reaches several centimetres below the location of the fire in the Riwi example. This depth of effect has several implications in how to sample such features and how to interpret the archaeological material (botanical remains, bones, lithic artefacts, ochre pigments, also sediment samples for luminescence dating) from the affected underlying substrate (cf. Aldeias et al. 2016; Mallol et al. 2013).

Chapter 5 identifies the wood taxa used to produce two wooden implements recovered from Riwi: the negative component of a fire drill and an artefact fragment. The paper showcases the archaeological application of X-ray microtomography. An efficient and non-destructive method for imaging the internal structure of opaque objects, the main advantage of the X-ray microtomography process is the fact that it is non-invasive and could be used to determine the woody taxa of artefacts for which physical sectioning is not culturally appropriate, such as those artefacts which are precious to descendant populations and/or housed in museum collections. The main limitations of the technique are resolution and the dimensions of the object in relation to the X-ray apparatus' chamber. Once inside the chamber, smaller area(s) of the object can be selected for scanning at a resolution inversely proportional to the sample width. The examination of several areas within wooden material is ideal given the centripetal disintegration of woody tissues (Florian, 1990), and the application of other techniques, such as dendrochronological analyses (Stezner and Million 2015). In Australia, where wooden artefacts are rarely recovered from archaeological contexts and are precious in both their paucity and to descendent populations, X-ray microtomography provides an excellent, non-invasive technique for wood identification. When coupled with other archaeobotanical analyses from the same archaeological context, the identification of an artefact's woody taxon has the capacity to inform selection processes, landscape use, and resource management strategies.

As discussed in Chapter 2, the application of archaeobotany has been impeded by six key issues: a lack of reference collections, the engagement of archaeobotanists post excavation, the lack of appropriate recovery techniques, the small scale of Australian excavations, the excavation of sites by arbitrary units, and the poor preservation of organic remains (Denham et al. 2009; Dotte-Sarout et al. 2015; Fairbairn 2005; Langley et al. 2011). Both myself and a macrobotanic specialist (India Dilkes-Hall) have been engaged in the Lifeways Project since the first excavation season. The sampling methodology used in this research, which navigated the use of arbitrary excavation units, has already been discussed above. Poor preservation of organic remains has often been cited in Australian archaeological site reports; however, the systematic recovery of macro-remains has been inadequately applied until recently (Denham et al. 2009; Fairbairn 2005). The Mount Behn case study shows that, if field techniques such as simple bucket flotation are adopted, even poorly preserved assemblages such as those recovered from Mount Behn rockshelter will contribute to our understanding of human-environment interaction.

In terms of reference material, the Bunuba-Gooniyandi wood charcoal reference collection, which is housed in the Archaeology and Natural History department (Appendix D), will be made available online for others to use in the future, alongside the archaeological charcoal descriptions and images (Appendix F). In arid and semi-arid Australia, even within the tropical Kimberley, genus-level diversity is low, so it is less work to build representative reference collections than in tropical rainforest environments. Anthracology is therefore very feasible in Australia's arid and semi-arid zones, where permanent water bodies, the traditional source of palaeo-vegetation proxies, are rare. Additionally, Chapter 7 clearly demonstrates how pollen can be deposited and preserved in rockshelter contexts, providing useful information regarding the local vegetation during the site's occupation. Conveniently, extensive palynological reference collections already exist for most of Australia's vegetation systems, so the lack of reference material will not hinder the application of palynology to Australia's archaeological contexts in the future.

8.2 Human environment interaction in the Kimberley region during the late Quaternary

The first aim of this thesis is to explore late Quaternary human-environment interaction at two archaeological sites in Bunuba and Gooniyandi country, through four subsidiary aims. The first of these subsidiary aims is to identify taphonomic biases and assess the representativeness of the analysed archaeobotanical assemblages. This aim has been already discussed in Section 8.1. The second subsidiary aim is to reconstruct local vegetation change during site occupation using archaeobotanical analyses at each of the two sites. Local vegetation was reconstructed at Riwi using wood charcoal and at Mount Behn rockshelter using pollen. At Riwi, with the exception of one type A hearth, Myrtaceae is the dominant family group across each of analysed units, with the *Corymbia*, *Eucalyptus*, and *Melaleuca* genera represented (Chapters 3 and 4). *Eucalyptus* sp. Type A dominates the earlier Pleistocene units SU8—SU10 (~42—36.9 ka), with subsidiary components of both *Eucalyptus* sp. Type B and *Corymbia* sp (Chapter 3). This relationship shifts during SU7 (~38—35 ka), when *Corymbia* sp. increases and *Eucalyptus* spp. decrease in both abundance and diversity. SU7 also sees an increase in *Erythrophleum* sp. and *Vachellia* sp., suggesting a co-current increase in shrub cover. These shifts imply a change in species composition of the woody component of the savanna/steppe vegetation, from mixed *Eucalyptus* with subdominant *Corymbia*, to the modern composition of *Corymbia* with subdominant *Eucalyptus*. *Corymbia* sp. remains the dominant charcoal type throughout the Holocene units, which are the most taxon rich contexts, including a significant dry rainforest component.

At Mount Behn rockshelter, the pollen record reflects the modern vegetation: a savanna of eucalypt and grasses, with non-eucalypt savanna, dry rainforest, and riparian components (Chapter 7). The pollen record shows a shift in vegetation associations between SU4 (2.8—1.8 ka) and SU1 (0.4—0 ka). SU3 (2.0—1.8 ka), which overlaps chronologically with SU4, sits somewhere between SU4 and SU1, illustrating that the change between the two units was gradual. The SU4 pollen shows an open, grassy environment, with a high proportion on xerophytic shrubs and sedges, while SU1 is dominated by eucalypts, more mesophytic, rather than xerophytic shrubs, and less grasses and sedges. The SU1 increase in *Eucalyptus* dominance is reflected in the wood charcoal record although this could be an effect of preservation bias.

The third subsidiary aim is to locate botanical resource exploitation and management within the archaeobotanical record. At Riwi, combined anthracological and micromorphological analyses of combustion features allowed the construction of a typology of features and the documentation of changes in site occupation patterns and landscape use over time (Chapter 4). Beginning around 45 ka and continuing for over 14,000 years, Pleistocene occupation at Riwi was intermittent. The cave would be visited for short periods, a fire would be lit directly on the ground (type A), fueled by wood collected from the *Eucalyptus* savanna, and abandoned, with enough time between site visits to allow for these flat, open-air, single use hearths to be covered by rapid aeolian deposition. From around 34 ka to the onset of the LGM, the type B combustion feature, or ground oven, appears in the Riwi archaeological record. The wood charcoal composition of these features is most similar to the scattered context of SU7, demonstrating that people were collecting fuel from the newly established *Corymbia* steppe within the valley floor. The taxon richness of the type B features also indicates that these structures might have been re-used multiple times, potentially signifying a more frequent and/or longer occupation at the site during this time.

From the LGM through to the Holocene, both A and B hearth types were built. The Holocene units are comprised of a palimpsest of archaeological deposition (type C secondary contexts), signaling both a change in deposition patterns and a higher intensity of occupation, where intensification refers to an increase in the number of site visits and the duration of these visits (Chapters 4 and 7). The Riwi Holocene anthracological record is dominated by the savanna taxa of the valley floor, alongside an increase in abundance of dry rainforest taxa, indicating a potentially more extensive use of the surrounding landscape and its various ecological niches; aligning with a more intensive occupation pattern. The growth of a *Mallotus nesophilus* tree, which is not found elsewhere in the modern landscape, within Riwi cave could be an example of incidental or intentional seed dispersal by Riwi's past inhabitants (Chapters 3 and 7).

Not only were people exploiting the landscape surrounding Riwi more extensively during the Holocene, and possibly influencing the range of certain taxa, but they were managing the local wood resources. Two wooden objects from Riwi, analysed with X-ray computed microtomography, were identified via comparison with the Bunuba-Gooniyandi reference material. The distal fragment was identified as *Grevillea*/*Hakea* sp., a taxon which only appears twice in the entire Riwi anthracological record. The hearth stick was identified as Lamiaceae sp., of a type that differs from the other Lamiaceae wood charcoals recovered from the anthracological record. The low occurrence of the two artefact wood types in the wood charcoal assemblage illustrates that the past inhabitants of Riwi were selecting certain woods for specific purposes within the last 1000 years of occupation at the site.

At Mount Behn rockshelter, the poor survival of macrobotanical remains did not allow for a valid palaeo-environmental reconstruction, but the recovered materials did show that various habitats, including the savanna of the valley floor, riparian vegetation, and the dry rainforest of the limestone outcrops, were exploited throughout the site's occupation sequence (Chapter 6). The Mount Behn wood charcoal assemblage was mostly vitrified, with the *Grevillea*/*Hakea* sp. charcoal type distinguishable despite vitrification. The dominance of *Grevillea*/*Hakea* sp. charcoals within the Mount Behn anthracological assemblage is readily explained as an outcome of uneven preservation and identification bias; however, the relative abundance of the taxon in comparison to other Western Australian anthracological studies is anomalous. The abundance of vitrified, radially cracked *Grevillea*/*Hakea* sp. charcoal could represent the incidental by-products of artefact manufacture. No wooden artefacts or wood shavings were recovered from Mount Behn rockshelter, but plant-based technologies are painted and stencilled on the shelter walls, including several stencils of boomerangs and an axe, which at the very least indicates the presence of such technologies at the site. The evidence for woodworking is certainly less definitive at Mount Behn rockshelter than Riwi, where woodshavings were also recovered; however, wood tends to be worked when green, and green wood, particularly a resinous wood like those produced within the *Grevillea* and *Hakea* genera, is more likely to both vitrify and radially crack (Marguerie and Hunot 2007). Additionally, it is possible that in areas of higher taxon richness of woody taxa, there is no need to be selective with wood resources, which would explain why Proteaceae was recovered at Carpenter's Gap 1, Madjedbebe, and Mount Behn rockshelters, which have a higher density and species richness of woody taxa than other sites from more arid Western Australia, such as Riwi.

The fourth subsidiary aim is to correlate the results from this research with broader climatic and environmental archives. At Riwi, the shift to *Corymbia* sp. dominance during SU7 (~38—35 ka), coupled with an increase in shrubland, is most likely related to a change in water availability, caused by a more arid climate. This apparent increase in aridity is broadly coincident with changes observed in other regional marine and terrestrial archives. Palynological analysis of marine core FR10/95-GC17, which was collected some 60 km from the north west Pilbara coast, shows a shift from eucalypt woodland to chenopod shrub land between ~40 and 37 ka on the neighbouring mainland (Kershaw and van der Kaars 2012). Pollen analysis of marine core SH1-9014, which was collected from the Banda Basin, shows an increase in grass pollen around 37 ka relative to a decline in both *Eucalyptus* and Dipterocarpaceae, the latter is a principal family group of the Indonesian rainforest (Kershaw et al. 2003; van der Kaars et al. 2000). At the Lake Gregory basin, the dating of palaeo-shoreline transformation ~37 ka indicated a regression from a high lake phase, with intermittent dune activity between ~35 and 11.5 ka suggesting more arid conditions, probably related to a weakened monsoon during the Last Glacial period (Fitzsimmons et al. 2012, 2013; Veth et al. 2009; Wyrwoll and Miller 2001). At Cabbage Tree Creek in the eastern Kimberley, a period of decreased fluvial activity follows the deposition of aeolian sediments between 37.4 and 37 ka (Wende et al. 1997). The onset of aridity ~34 ka is also observed at Carpenter's Gap 1, with an increase in spinifex (*Triodia* spp.) macrobotanical and phytolith remains (Wallis 2000, 2001). The anthracological record from Riwi potentially provides the strongest terrestrial evidence for this pre-glacial onset of aridity and its effects on local vegetation. People continued to occupy Riwi throughout this increase in aridity, adapting their use of the cave and its landscape with the introduction of the type B hearth feature around 34 ka. In the Holocene; however, people were occupying the site during periods of relative humidity (Chapters 3 and 7).

With the exception of Mount Behn rockshelter's SU4—3 (2.8—1.8 ka), all of the Holocene materials at Riwi and Mount Behn rockshelter were deposited during regional phases of active summer monsoon and relative humidity (Chapter 7). Fluctuations in stalagmite $\partial_{18}O$ values at Cave KNI-51 in the central Kimberley indicate an active monsoon between 7.5 and 4.5 ka (Denniston et al. 2013c). Pollen, loss on ignition (LOI) and humification data from Black Springs, suggest an active monsoon throughout the mid Holocene until ~ 5 ka (Field et al. 2017). The KNI-51 record shows an abrupt weakening of the monsoon around 4.2 ka, which is sustained until 1.2 ka, with a peak in aridity occurring between 1.5 and 1.2 ka (Denniston et al. 2013c). At Black Springs, a sharp decline in organic content, increased aeolian sedimentation, a shift in vegetation with lower aquatic species, and the lowest humification values for the core illustrate the driest phase for the record between 2.6 and 1.3 ka (Field et al. 2017; McGowan et al. 2012). Wetter conditions, with evidence for small-scale variability, occur from 1.2 ka through to the present (Denniston et al. 2013c; Field 2017; Proske 2016).

Holocene occupation at Riwi between 7.4—5.9 ka (SU2) and 0.9—0.7 ka (SU1) is synchronous with broader regional phases of relative humidity. The abundance and richness of dry rainforest taxa between 7.4—5.9 ka, increasing between 0.9—0.7 ka, could be a reflection of wetter conditions, with the dry rainforest taxa restricted to protected limestone areas during more arid periods with increased fire risk, and expanding to the valley floor in periods of relative humidity. If the dry rainforest was able to expand during phases of relative humidity, a more extensive habitat range might have been able to support the past occupants more consistently, for a greater length of time, reflecting a more consistent occupation of longer duration than the earlier Pleistocene layers (Chapter 4).

Human selection processes, favouring certain taxa for consumption, would play an important role in the abundance of dry rainforest taxa within the archaeobotanical record, particularly in regards to the seed assemblage (Chapter 7; Dilkes-Hall 2014). The importance of *Vitex* fruits is not just evident within its high proportions of the Riwi assemblage, but also its abundance within the rock art record of the Kimberley region (Veth et al. 2016), although unfortunately absent from the Riwi cave rock art assemblage. Humans could also have incidentally or intentionally disseminated certain taxa of economic importance, such as *Mallotus* and *Solanum* species. Of course, the higher taxon richness of wood and seeds in the Riwi Holocene units is undoubtedly in part the result of better preservation of plant remains in the upper units of the sequence, particularly since the Holocene units produced the lowest proportions of indeterminable charcoal (Chapter 3). The abundance of dry rainforest taxa within the Riwi Holocene units is therefore a combination of suitable preservation conditions, human selection processes, and the palaeoclimatic conditions that allow for the extension of this vegetation system.

According to other palaeoclimatic records listed above, SU4—SU3 at Mount Behn rockshelter was deposited during a period of relative aridity (2.8—1.8 ka). The more open, xerophytic pollen record of SU4 suggests more arid conditions than SU1, which would require an increase in relative humidity in order to support a denser tree canopy. By contrast, SU1 (0.4—0 ka) was deposited during wetter conditions. If 2.8—1.8 ka was an arid phase in north Western Australia, the high proportions of riparian taxa within the SU4—SU3 units are anomalous. The presence of malacofauna within the Mount Behn rockshelter deposit confirms the exploitation of riparian resources by people (Maloney et al. 2017), so it is proposed that the ephemeral creek adjacent to the rockshelter was a refugium during 2.8—1.8 ka. Maloney et al. (2017) argue that the majority of stone points were discarded during this arid phase, indicating that people were adapting their technologies to the inferred foraging risk, which parallels similar arguments regarding other lithic assemblages from elsewhere in northern Australia (e.g. Clarkson 2002, 2007; Hiscock 1994, 2006; Hiscock and Veth 1991; Maloney et al. 2014; Maloney and O'Connor 2014; O'Connor et al. 2014).

The central aim of this thesis is to explore late Quaternary human-environment interaction at two archaeological sites in Bunuba and Gooniyandi country, through four subsidiary aims, which have been addressed. This research has used several archaeobotanical tools to investigate and compare human-environment interaction at Mount Behn rockshelter and Riwi in Bunuba and Gooniyandi country. Wood charcoal and pollen analyses have enabled the reconstruction of local vegetation, and the changes observed in these vegetation communities through time have been correlated to broader palaeoenvironmental archives. The exploitation of plants by people has been investigated with multi-proxy archaeobotanical analyses alongside micromorphological investigation, which have revealed resource management strategies, changes in landscape use over time, and the potential effect of people on the spread of certain taxa, whether incidental or intentional. Multi-proxy, multi-methods research is infrequently applied in Australian archaeology. This research explicitly outlines how the application of diverse methods can assist in overcoming some of the regular challenges faced by archaeologists in Australia, such as preservational inequity in tropical contexts (e.g. Clarkson et al. 2017).

8.3 Future directions

This thesis showcases the potential of archaeobotanical research in Australia, highlighting what can be achieved with a flexible approach and an interdisciplinary team. Experimental work was beyond the scope of this thesis, but Chapter 6 highlights the opportunities for future work in Australian anthracology, particularly in terms of vitrification and radial cracking processes. In the future, the development of reference collections ought to include the investigation of anatomical features within wood that reflect particular environmental conditions. This is particularly important since adaptations to more arid or humid climates might be more informative than the Linnaean classification of species, when reconstructing vegetation systems. For example, the trees of a dominant genus from an analysed wood charcoal record, such as *Corymbia* or *Eucalyptus* in the southern Kimberley, could be sampled in various environmental settings (ephemeral versus permanent river bank, limestone outcrop), and differences within the secondary xylem observed. Further experimental work that explores Aboriginal hearth building and wood working practices alongside Traditional Owners will greatly benefit the development of archaeobotanical research in Australia. Many ethnographic collections of Aboriginal wooden implements are housed in Australia's museums, and these too could provide a source of information surrounding plant use and resource management at the time of European contact. This thesis supports arguments that relationships between Aboriginal Australians and plants are complex, providing evidence for resource management strategies and changing landscape use over time. However, more systematic archaeobotanical investigations are required before more nuanced socio-ecological models can be effectively developed, particularly those which assess how changes in climate affected mobility patterns and access to plant resources.

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