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What was ground?: a functional analysis of grinding stones from Madjedbebe and Lake Mungo, Australia

Elspeth Hayes
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WHAT WAS GROUND?

A FUNCTIONAL ANALYSIS OF GRINDING STONES FROM MADJEDBEBE AND LAKE MUNGO, AUSTRALIA

A THESIS SUBMITTED IN FULFILMENT OF THE REQUIREMENTS FOR THE AWARD OF THE DEGREE

DOCTOR OF PHILOSOPHY

FROM THE

UNIVERSITY OF WOLLONGONG

By

ELSPETH HAYES

**CENTRE FOR ARCHAEOLOGICAL SCIENCE,
SCHOOL OF EARTH AND ENVIRONMENTAL SCIENCES**

2015

Declaration

I, Elspeth Hannah Hayes, declare that this thesis, submitted in fulfilment of the requirements for the award of Doctor of Philosophy, in the School of Earth and Environmental Sciences, University of Wollongong, is wholly my own work unless otherwise referenced or acknowledged. The document has not been submitted for qualifications at any other academic institution.

Elspeth H. Hayes

03 August 2015

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Abstract

This thesis addresses the use of grinding stones and fragments in Australia through an integrated use-wear and residue analysis of tools from two early occupation sites: Madjedbebe (MJB; formerly known as Malakunanja II), in northern Australia, and Lake Mungo, in western New South Wales. Grinding stones are ubiquitous in Australia and are present in some of the earliest human occupation sites of Sahul (the Pleistocene landmass comprising Australia and New Guinea), but our knowledge of grinding stones has been overshadowed by a general focus on flaked stone artefacts. Moreover, the function of grinding tools has mostly been inferred on the basis of morphology, and largely restricted to grass seed grinding, which is usually associated with deeply grooved, large sandstone dishes. Previous studies of grinding stones from the region have found little compelling evidence for seed grinding prior to the Pleistocene/Holocene boundary, in part because many grinding stones from Pleistocene contexts occur as fragments with no recurring form and no distinctive grinding grooves. Such tools are often referred to as “amorphous” grinding stones and their function is frequently assumed to be opportunistic, with little understanding of what materials were processed. However, functional analyses of Pleistocene grinding stones have rarely incorporated use-wear and residue analyses and therefore the function of these tools has remained relatively unexplored. Another issue associated with recognising Pleistocene grinding stones is that many are found on deflated and highly eroded surfaces and have been difficult to accurately provenance and date (for example, grinding stones recovered from Cuddie Springs and Lake Mungo). In this thesis, I report on a functional study of 91 grinding stones from MJB and 17 sandstone artefacts from Lake Mungo. Optically stimulated luminescence (OSL) and radiocarbon ages have suggested ages for these artefacts up to 45 ka for MJB and 14 – 25 ka for Lake Mungo. I analysed all specimens for diagnostic traces of use. My use-wear analysis involved the documentation of wear traces on the stone surface, as identified under multiple magnifications and lighting arrangements. The documented wear traces were compared with a use-wear reference library that was created with experimental and ethnographic grinding stones. Experimental specimens included 28 grinding tools made from one of five different sandstone materials used to grind and pound bone, wood, seeds, wheat, haematite and stone for varying amounts of time. The ethnographic tools included 12 arid zone upper stones (hand-stones) made of indurated sandstone and used for processing seeds. My residue analyses involved the removal of adhering material from the tool surface using one of two sampling methods: pipette extractions using multiple solvents, and ultra-sonication with distilled water. I examined removed material microscopically under transmitted light, and biological stains were applied to distinguish organic material. Non-visible residues and biomolecules were detected using a suite of biochemical tests to indicate the presence of fatty acids, proteins and carbohydrate compounds. Residue mixtures were further characterised with Gas Chromatography Mass Spectrometry (GC-MS) to identify specific biomolecules and compared to modern reference material.

The 91 grinding stones from MJB were collected during the 2012 field season. The recovered specimens were made from sandstone (n = 80), quartzite (n = 8), mudstone (n = 2) and volcanic stone (n = 1). These specimens were most frequently from one of three pulses of activity: Pulse 1 (182 – 209 cm below surface (bs)); Pulse 2 (113 – 150 cm bs) and Pulse 3 (10 – 36 cm bs). Unpublished radiocarbon ages produced on charred botanical remains and gastropod shell from the 1989 and 2012 excavations gave bracketing ages of 28.6 – 35.8 ka cal BP (Pulse 1), 9.2 – 18.2 ka cal BP (Pulse 2), and 4.2 – 5.5 ka cal BP (Pulse 3). Of the analysed specimens, 16 had traces consistent with the processing of pigments, 52 had evidence for the processing of plants (including starchy plants and seeds) and four had evidence for the processing of animal tissue. Eleven specimens had traces that indicated the processing of multiple resources. Plant processing tools were identified in all three Pulses, but pigment processing tools were restricted to early Holocene and Pleistocene deposits.

The artefacts analysed from Lake Mungo included 17 sandstone pieces from the central part of the Mungo lunette during 2009 – 2011. A suite of OSL ages has provided bracketing age estimates for the stratigraphic units in which the artefacts were recovered. Ten artefacts are attributed to Unit E (~25 – 14 ka), and four artefacts are attributed to Unit F (~8 ka). Three artefacts from the Golgol lag were of unknown age. Use-wear indicates a likely seed grinding function for 14 of the artefacts. Use-related residues include starch, cellulose and other plant tissues.

Grinding stones are an important artefact class that appear to retain residues at least as commonly as flaked stone, and perhaps in greater abundance on the typically more porous surfaces. I argue that grinding stones provide a unique and vast bank of past resource-use that is only beginning to be fully exploited by archaeologists. The results of this study have provided confirmation of Pleistocene plant processing and seed grinding activities in Sahul, and have indicated a range of other on-site activities that fluctuate in importance through time. The results also indicate the value of employing an integrated approach to functional analysis that includes the examination of stone tool morphology and use-wear together with a forensic study of residues, including morphological, biochemical and other molecular approaches.

The determination of what was ground on stone provides a vast, mostly unexplored data bank with which we can evaluate and assess hypotheses based on other sources of evidence, such as flaked stones. Since grinding technology (like flaked stone technologies) spans most of human history, details of what was ground are likely to provide new insights into understanding behavioural adaptations associated with archaic and modern human evolution. Such insights may include the response of human populations to changing environmental conditions, landscapes and risk, as well as the cultural practices and the use of symbolic expressions.

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Chapter 1:

Introduction: Thesis and aims

1.1 Introduction

Determining the function of prehistoric artefacts is vital for reconstructing important technological, subsistence and other behavioural activities of past human societies. Stone artefacts found in context provide valuable insights into the origin and dispersals of various hominin groups, and, through use-wear and residue analysis, information regarding specific tasks, resource-use, and patterns of behaviour. Flaked stone artefacts, including cores and flakes, are the most common lithic artefacts identified in archaeological sites, and have provided the basis for numerous interpretations of past human technologies and associated cognitive capacities (e.g., Ambrose 2001, 2010; Lombard & Haidle 2012; Lombard & Phillipson 2010; Rots & Van Peer 2006; Wadley 2010; Wadley *et al.* 2009). Flaked artefacts are frequently identified in Australian archaeological sites, and are commonly made from materials such as quartz, silcrete, chert and quartzite, among others. The relatively few functional studies performed on these artefacts in Australia have indicated a range of tasks occurring throughout Australian prehistory (e.g., Akerman *et al.* 2002; Attenbrow *et al.* 2009; Fullagar 1986a, 2011; Fullagar & David 1997; Fullagar & Jones 2004; Hall *et al.* 1989; Hayden 1977; Hayes *et al.* 2014a; Kamminga 1977; Robertson 2005; Robertson *et al.* 2009).

A focus of this thesis is the study of ground stone artefacts, which I define as any stone that has been modified through abrasion and/or pounding. Grinding stones provide important information about past human activities (Table 1.1). However, ground stone artefacts are far less common in the archaeological record, and have received less attention than flaked stone artefacts. Ground stone artefacts include items that have been either intentionally modified to a specific form (i.e. *manufacture-ground*); or used to grind or process other materials (i.e. *use-ground*) (Odell 2004: 74-85). Manufacture-ground tools include both ornamental and utilitarian tools, including polished stone, vessels and beads, as well as ground-edge axes, adzes and bowls. Use-ground stones (hereafter referred to as “*grinding stones*”) include all utilised grinding dishes, portable hand stones, stone “files” (otherwise referred to as “*abraders*” or “*polishers*”—*cf.* Adams 1993: 64, 2002a: 143-5; and Hamon 2008: 1504) and large bedrock grinding patches. Functional analyses of these tools have provided details of past grinding activities, including the processing of edible plant and animal tissue, the preparation of hides and leather, the production and maintenance of various implements such as ground-edge axes, hatchets and blades, polished stone and ivory, bone points and shell hooks, and the processing of pigments, such as the grinding and mixing of ochre and haematite (see Table 1.1 for references). In this thesis, I argue that Australian grinding stones provide a rich and unique source of archaeological evidence for the utilisation of plant, animal and other resources, since initial colonisation.

Food processing tools in the form of grinding stones have been documented in many sites around the world (Table 1.1), and are important for the reconstruction of past human diets, subsistence practices, human health, food availability and environmental pressures. Other behaviours that may be linked with the presence of grinding stones include: (1) responses to climate change and risk management (e.g., Hiscock 2008; Veth 1989); (2) environmental management and food availability (e.g., Adams 1994); (3) colonisation of previously uninhabited environmental zones or regions of limited food resources (e.g., Cosgrove *et al.* 2007; O'Connell & Hawkes 1981); (4) ritual practices (e.g., Dubreuil & Grosman 2009); (5) craft production (e.g., Baysal & Wright 2005; Delgado-Raack & Risch 2009; Ebeling & Rowan 2004; Rosenberg & Golani 2012); (6) household structure and organisation (e.g., Adams 1994; Baysal & Wright 2005; Hamon & Le Gall 2013; Weiss *et al.* 2008) and (7) the sexual division of labour (e.g., Baysal & Wright 2005; Delgado-Raack & Risch 2009; Hamon & Le Gall 2013).

Table 1.1: Archaeological examples of grinding stone function, identified through use-wear and residue analyses.

Grinding stone use		Reference(s)
Plant processing	Plant food processing	Adams 1988; Atchison & Fullagar 1998; Baysal & Wright 2005; Cosgrove 1996; Cosgrove <i>et al.</i> 2007; Fullagar & Field 1997; Fullagar <i>et al.</i> 2006, 2008, 2015; Field & Fullagar 1998; Field <i>et al.</i> 2009; Van Gijn & Verbaas 2009; Goren-Inbar <i>et al.</i> 2002; Liu <i>et al.</i> 2010a, 2010b; Nic Eoin 2012; Pearsall <i>et al.</i> 2004; Piperno <i>et al.</i> 2000, 2004; Revedin <i>et al.</i> 2010; Tao <i>et al.</i> 2011; De la Torre <i>et al.</i> 2013; Quigg <i>et al.</i> 2001; Van Peer <i>et al.</i> 2003; Verbaas & Van Gijn 2008; Weiss <i>et al.</i> 2008; Wright 1994.
	Processing of plant material for fibre	Fullagar & Wallis 2012.
Faunal processing	Animal food processing	Stephenson 2011; Quigg <i>et al.</i> 2001; Yohe <i>et al.</i> 1991.
	Preparation of hides and leather	Adams 1988, 1989a; Cristiani <i>et al.</i> 2012; Dubreuil & Grosman 2009.
	Polishing of bone, antler, shell and ivory	Attenbrow <i>et al.</i> 1998; Procopiou <i>et al.</i> 2011; Rosenberg & Golani 2012.
Processing of inorganic material	Preparation of stone material (polishing and manufacture)	Procopiou <i>et al.</i> 2011.
	Preparation of clay for pottery	Derricourt 1986.
	Preparation of pigments	Adams 1998; Cristiani <i>et al.</i> 2012; Henshilwood <i>et al.</i> 2011; Nic Eoin 2012; Van Peer <i>et al.</i> 2003.

Despite the great potential of grinding stone analyses to address and evaluate debates concerning behavioural complexity, studies of grinding tools have rarely been incorporated into archaeological investigations of hunter-gatherer behaviour and site usage. In Australia, if not elsewhere, this is in part due to the fact that ground-stone artefacts are rarely identified in archaeological contexts, and typically account for less than 0.3 per cent of the stone artefacts in archaeological assemblages (Edwards & O’Connell 1995; Gorecki *et al.* 1997: 145). Consequently, grinding implements can be expected to be absent or rare in small cultural assemblages (Gorecki *et al.* 1997; Hiscock & Wallis 2005: 42). This is particularly true for Pleistocene-aged sites, where lithics are rare and grinding stones are typically represented fragments that are mostly irregularly shaped with no distinctive recurring form (Smith 2004: 177). Consequently, grinding stones are relatively poor chronological markers in Australia until the late Holocene. The low typological variability and low quantity of ground stone artefacts in archaeological sites therefore render these artefacts less analytically attractive than other forms of lithic tools (Rowan & Ebeling 2008: 2). The study of Australian grinding stones has also been constrained by the limited application of available methodologies for evaluating tool function and the apparently distinct morphologies of grinding stones and associated fragments (Balme *et al.* 2001; Crowther & Haslam 2007; Hiscock & Clarkson 2000).

1.2 Functions of Australian grinding stones

Grinding stones are found ethnographically throughout Australia and are used for a diverse range of functions (Table 1.2). Previous studies of Australian grinding stones typically involved investigations of tool-stone and morphology as likely indicators of tool function, with only a few select studies incorporating use-wear and residue analysis. Smith (1985, 1988, 1989b, 2004) has described four morphological grinding stone varieties in Australia (see Section 2.4.1.1) that are known ethnographically for grinding and pounding seeds. These tools are described as being “heavily and repetitively used” with “well-worn surfaces and well-defined discrete wear patterns”, often showing “signs of maintenance, attempts to re-use or rejuvenate the implement, and probably also evidence of deliberate manufacture” (Gorecki *et al.* 1997: 141, see Smith 1986: 32), used primarily (if not exclusively) for the processing of seeds. According to Smith, the presence of these distinctive grinding tools in arid zone sites from ~3 ka, represents the onset of a seed grinding economy in which the grinding of seeds was a required adaptation for survival in Australia’s arid zone. Smith argued that the apparent scarcity or absence of these tools in the early Holocene and late Pleistocene contexts of Australia represents the limited occurrence of seed grinding activities

and the spatial and temporal variability in the importance of seed grinding economies (Smith 2004, 2015).

Other authors, such as Gorecki *et al.* (1997), have critiqued the utility of Smith's morphological/functional typologies and challenged the proposition that the systematic use of seeds only occurred by the mid to late Holocene. The authors draw attention to the limited number of grinding stones recovered from stratified contexts as well as the general lack of functional studies performed on these tools. Similarly, Veth and O'Connor (1996) also questioned whether amorphous grinding stones and formal seed grinding tools were variants of the same implement. Fullagar *et al.* (2008: 160) suggested that investigating the function and use of grinding stones requires the development of methodologies which can document artefact life histories including manufacture, use and recycling of the grinding stone.

Of the limited number of sites in which grinding stones are identified, most are fragments restricted to late Holocene deposits. Only sixteen Pleistocene-aged sites in Australia contain grinding stones (Figure 1.1), but these are generally considered to be expedient tools since they typically display a low degree of modification, and are not shaped for a specific purpose (Smith 1985: 29; 1986: 32). Although morphologically distinct seed grinding tools have been identified in Pleistocene deposits at Cuddie Springs (Fullagar *et al.* 2008), there is still some concern as to the stratigraphic integrity of the sediments in which the pieces were derived (see section 2.4.1.1). Smith (2013: 83-86) has argued that many of these specimens were reworked Holocene materials and thus do not provide evidence for seed grinding in the Pleistocene.

In this thesis, I present my analysis of 118 grinding tools from two Australian Pleistocene archaeological sites that each have a high degree of stratigraphic integrity, to show that seed grinding (among other tasks) was an important activity during the Pleistocene and early Holocene, and that evidence for seed processing is not unique to late Holocene archaeological deposits. Based on my analysis, I argue that morphology alone is not a reliable indicator of tool function. Rather, I suggest that tool stone morphology is related to the availability of stone material and distance to particular resources, which had been modified by changing environmental conditions.

1.3 Madjedbebe and Lake Mungo

Excavations at Madjedbebe (formerly known as Malakunanja II, hereafter referred to as MJB), northern Australia, have yielded the presence of grinding technologies spanning 50 – 60

thousand years (ka) (Clarkson *et al.* 2015; Roberts *et al.* 1998a). I argue that the occurrence of ground stone artefacts in the lowest artefact bearing occupational level of this site indicates that grinding stones were likely elements of the colonising toolkit, and that grinding technologies were a significant part of the cultural repertoire of the First Australians. Evidence for grinding at MJB is indicated not only by the presence of use-ground sandstone but also ground haematite fragments, ground-edge volcanic hatchet heads, ground bone points, and ground ochre crayons (Chapter 3). The presences of these ground artefact technologies indicate the role of grinding stones even when the latter are not present in the sites or particular levels.

Table 1.2: Examples of ethnographically observed functions of Australian grinding stones.

Activity		References
Plant processing	Seed grinding	Allen 1974; Chaloupka & Giuliani 1984; Cleland & Tindale 1954; Edwards & O'Connell 1995; Gould <i>et al.</i> 1971: 164, 1977; Hawkes & O'Connell 1981; Latz 1982, 1995; Meggitt 1957; O'Connell & Hawkes 1981; O'Connell <i>et al.</i> 1983; Peterson 1968, 1977; Tindale 1977.
	Plant food processing	Chaloupka & Giuliani 1984; Gott 2002; Gould <i>et al.</i> 1971: 163-4; Jones & Meehan 1989; Latz 1995.
	Processing of native tobacco	Brokensha 1975: 29-30; Latz 1995: 62-64.
	Plant processing for poison and medicine	Chaloupka & Giuliani 1984; Latz 1995: 61; <i>personal observation</i> .
	Processing of resins	Brokensha 1975: 64-66; Latz 1995: 66-67; Peterson 1968: 568.
	Fibre processing for craft production	Latz 1995: 67; Chaloupka & Giuliani 1984; Wallis & Pitman 2012; Withnell 1901.
	Shaping of wooden objects	Hayden 1979: 114; Kamminga 1982: 63; McCarthy 1967: 62; Thomson 1964: 408.
Faunal processing	Animal food processing	Cane 1989: 113; Gould 1969: 19; 1980: 193-194; 1981: 164; Gould <i>et al.</i> 1971: 163; Hayden 1979: 141; Peterson 1968: 367.
	Bone working	Fullagar <i>et al.</i> 1999: 18; McCarthy 1967: 61.
	Shell working	Akerman 1975: 16; Bradley 1969: 133; Trench 1961: 284; White 1962.
Processing of inorganics	Pigment processing	Peterson & Lampert 1985: 6; Binford 1987: 474.
	Shaping of stone objects	Gould 1968: 120; Horne & Aiston 1924: 56; McCarthy 1967: 67; McCarthy & Setzler 1960: 218; Spencer 1982: 88.

The artefacts recovered from the 2012 excavations include the largest and most diverse assemblage of Pleistocene grinding stones in Australia. For this reason, the MJB assemblage has high potential for evaluating continuity and change in the form and function of grinding stones at

this single location, throughout the period of Aboriginal occupation, which spans periods of dramatic climate change (i.e., between Marine Isotope Stages 4 – 1 and before, during and after the Last Glacial Maximum).

Other early occurrences of grinding stones are reported at Lake Mungo, a dry lake bed within the Willandra Lakes region of New South Wales. These artefacts, first analysed in this PhD thesis, appear in late Pleistocene and early Holocene contexts, the earliest of which have now been securely dated to between 14 and 25 ka (Fitzsimmons *et al.* 2014; Fullagar *et al.* 2015; see Chapter 3). Even earlier evidence for grinding technologies at this time is indicated by the world’s oldest known ochre burial – Mungo III – dated at c. 42 ka (Bowler *et al.* 2003; see Chapter 3). The ochre on the bones was probably ground with stone to make a powder before mixing and application. Unlike MJB, located near the coast in the monsoonal tropics, Lake Mungo is located in the semi-arid region of inland Australia (Figure 3.1, Chapter 3). These two settings provide an opportunity to evaluate variation of tool function, tool morphology, tool manufacture and artefact life-histories through time in quite different environmental settings. In this thesis, I explore grinding stone variability in the context of environmental change, resource availability, social interactions, site context and/or other factors (Chapter 8).

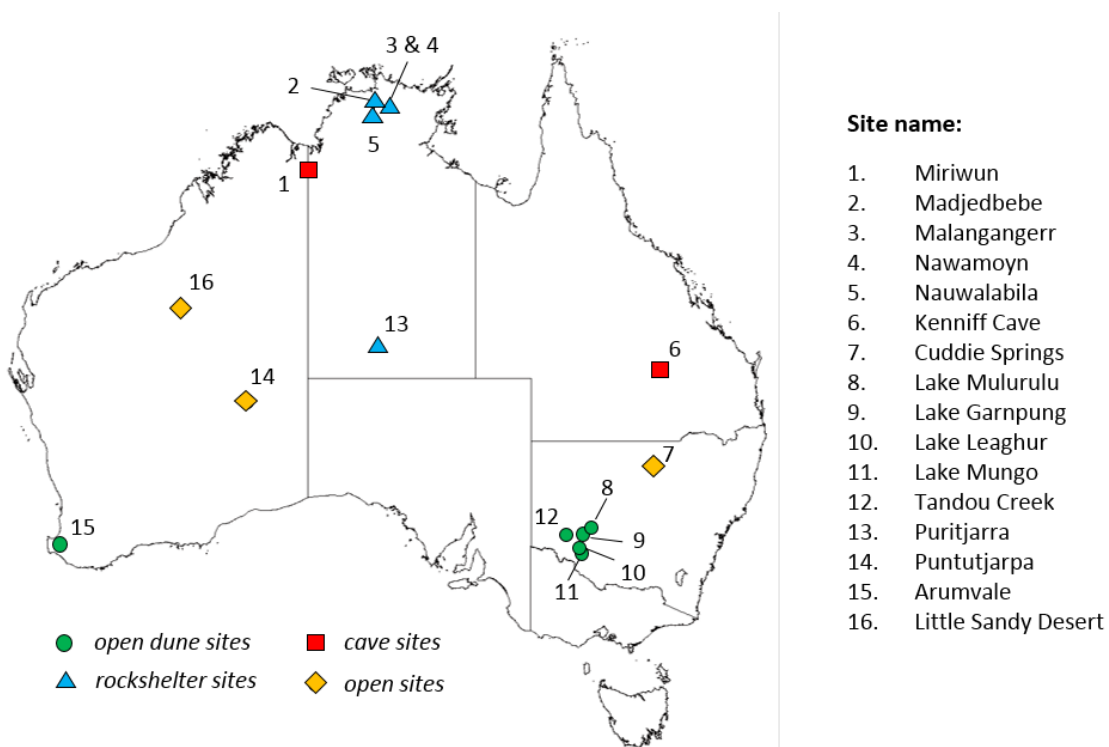


Figure 1.1: Map of Australia depicting Pleistocene sites with grinding stones. *After* Langley (2010).

A suite of optical, biological, chemical and elemental analyses were applied, in conjunction with experimental reference collections, in order to determine the material that had been processed by grinding (e.g., seeds, tubers, bone, shell, wood, pigment, etc.). Changes in tool function were then considered in relation to shifts in site function, variation of subsistence practices, food consumption, cultural and symbolic behaviour, and technological changes (including the use of different raw materials). Functional analysis has generally provided specific information about tasks, tools, subsistence and resource use, including the extraction and processing of plant foods that may otherwise be invisible in the archaeological record. Comparative study of the MJB and Lake Mungo grinding stone assemblages (from quite different environmental settings), has high potential for new insights into the life-ways and behaviours of the Aboriginal people who once occupied these sites.

1.4 Aims

The central argument of this thesis is that grinding technology was not a recent technological invention, contrary to some views, but has been a substantial component of Aboriginal lithic technology since initial colonisation. However, limited archaeological data have indicated that the role of grinding technology in resource processing and implement manufacture has not been constant through time, and marked spatial variability has been documented ethnographically. The broad objective of this thesis is to understand the context, history and variability of grinding stone technology in Australia during the late Pleistocene and Holocene. To achieve this, I have focussed on two sites with known grinding stone assemblages that span both time periods. The sites examined include MJB, a well-dated archaeological site that contains artefacts from 50 – 60 ka, from the time of the initial human colonisation of Australia, and Lake Mungo, in which grinding stones have been recovered from deposits as old as 25 ka.

The specific aims of this thesis are to:

- 1) undertake a detailed functional analysis of use-wear and residues on a selection of grinding stones recovered from MJB and Lake Mungo;
- 2) construct a sequence of grinding activities through time based on tool function, tool stone selection and artefact life histories;

- 3) evaluate the extent to which temporal and spatial variability of grinding stones is linked with site context, resource availability and environmental change.

The methodological approach includes:

- 1) functional studies of experimental and ethnographic grinding stones to develop a modern use-wear and residue reference library applicable to the archaeological assemblages;
- 2) minimisation of subjective interpretations by quantification via integration with a suite of optical, biological, elemental and chemical analyses, and evaluation by blind tests.

This research is significant because it provides the first comprehensive assessment of grinding stone technology and function in Australia. Previous studies of flaked stone artefact technology have provided models for understanding and evaluating Aboriginal adaptations and responses to resource stress, mobility, population growth, climate change, resource availability and foraging risk (e.g., Attenbrow *et al.* 2009; Hiscock 2002, 2006, 2008). A comparable, but independent, study of Australian grinding stones can provide a supplement to flaked stone artefact studies, with potential for further evaluating proposed models of social and behavioural adaptations in Australian prehistory. This research is also significant because it integrates what have been, until recently, distinct approaches to the study of stone tool function: use-wear, microscopically visible residues and non-visible residues (detectable only by chemical and elemental analysis). My aim is to integrate these approaches and other lines of evidence (e.g., technological stage at discard, macroscopic form, breakage, weathering and contextual site data) to reliably identify tool function.

1.5 Chapter outline

This first chapter has outlined the context, aims and scope of this thesis.

Chapter 2 provides a global overview of grinding tool technology in the archaeological record and a definition for use-ground and manufacture-ground stone tools. In particular, this chapter describes: (1) the various forms of grinding technologies with reference to archaeological implements made of stone, bone, wood, antler, ivory, shell and pigment; (2) past subsistence practices and grinding stone use in both Australia and the rest of the world, with a particular emphasis on seed grinding in Australia's arid zone; (3) evidence for the onset, geographic spread and intensification of a seed grinding economy and "dedicated" seed processing tools; and (4) the

geographic and temporal distribution of Australian grinding stones with a review of the Australian Aboriginal ethnographic literature about artefact manufacture and processing of diverse materials (e.g., fibres, pigment, plant and animal foods and medicines).

Chapter 3 provides details of the archaeological sites from which the grinding stones were recovered—MJB rockshelter in northern Australia and the Lake Mungo lunette in western New South Wales. Included are: (1) the site locations and surrounding landscape; (2) past site excavations; (3) the history of Aboriginal occupation; (4) contextual archaeological data, including the frequency of artefacts and the recognised stone tool classes, with particular emphasis on grinding stones; and (5) past vegetation/climate records.

Chapter 4 describes the analytical techniques of functional analysis available for both flaked stone and ground-stone artefacts. Specifically, this chapter outlines: (1) the main forms of use-wear and residue traces, including tool surface features and the microscopic morphology of common archaeological tool use-residues; (2) the quantification of functional traces, including methods of surface characterisation and biomolecular characterisation of removed residues; and (3) the factors affecting recognition of traces, including residue degradation, the transfer of non-use related residues through handling and environmental contamination, and the appearance of non-use related taphonomic wear.

Chapter 5 presents the technical methods of use-wear and residue analysis employed in this thesis, and includes: (1) artefact recording (i.e. photography, measurement and terminology used to describe the morphological characteristics of each grinding stone); (2) surface characterisation (i.e. microscopy and the documentation of wear traces), (3) residue removal (including the use of different sampling solvents, density separation and slide preparation); (4) optical, chemical and biological detection of residues; and (5) in-house contamination checks to assess the frequency of potential contaminants in preparation and examination laboratories and on laboratory consumables (e.g., sample tubes, gloves, pipette tips, glass slides and sample bags). The potential problems associated with the characterisation of use-wear and residues are discussed.

Chapter 6 presents the results of an experimental use-wear reference library generated through tool-use experiments, and examination of ethnographic sandstone tools. Experiments were designed to assess the formation of wear on sandstone tools used to process a range of materials, including those indicated ethnographically. The wear features associated with the processing of these materials are presented along with a review of previous experimental data sets derived from grinding different materials. The use-wear patterns identified on ethnographic grinding stones are

incorporated to supplement the experimental use-wear reference library. A selection of blind tests was undertaken to determine the limitations associated with functional analysis of grinding stones.

Chapter 7 presents the results of the functional analyses performed on archaeological grinding stones from MJB and Lake Mungo. This Chapter describes: (1) the key use-wear traces (quartz grain rounding, micro-scarring, use-polish, abrasive smoothing striations), along with the associated tool use-residues; (2) potential taxonomic identifications of processed plant material based on starch grain analysis (for specimens that were subjected to additional methods of starch recovery); (3) the frequencies of airborne contaminants in various laboratories and consumables; and (4) the confidence and reliability of my interpretations of the most likely function(s) for each tool (based on morphological, use-wear, residue and other evidence).

Chapter 8 discusses the grinding activities occurring at each site based on my functional analyses. In particular, this Chapter will discuss: (1) the temporal and spatial variability of grinding stone form and function from each site; (2) the extent to which such variability may be related to environmental change, resource availability, social interactions, site context and other factors, and (3) the implications of this functional data set for understanding other Australian and global grinding technologies.

Chapter 9 summarises the key findings of this research, the wider research implications and the significance of the results. The temporal and spatial variability of grinding stones from MJB and Lake Mungo is shown to be linked with several factors, including: local environmental conditions, the availability (and decline) of certain resources; site context; putative population densities and distance to water and other resources; and the availability of resources, including stone material type, seeds and other plant varieties that may have required processing. The results and conclusions are discussed in the context of the initial thesis aims. Finally, I discuss the implications of my study for future research.

Chapter 2:

Grinding stones and grinding technologies in the archaeological record

2.1 Introduction

Grinding technologies appear in the Old World archaeological record from about two million years (Ma) ago, well before the emergence of *Homo sapiens* (modern humans), and are associated with multiple hominid species. The earliest grinding technologies, which include all items that possess abrasive or grinding wear generated through either use or manufacture, include ground implements made of stone, bone and pigment (Table 2.1; Plate 2.1). Percussive stone implements, for crushing and pounding, can also have grinding traces (see below), and these artefacts are among the oldest tools known and are still used by modern non-human primates (e.g., chimpanzees, macaques and capuchin monkeys—see Haslam *et al.* 2009, 2013; Moura & Lee 2004; Ottoni & Izar 2008; Ottoni *et al.* 2005). Grinding stones that are used in a backwards and forwards or circular motion to process food, medicines, poison and other materials are only associated with *Homo sapiens*. Other ground artefacts that are exclusive to *Homo sapiens* include tools, ornaments and jewellery made from antler, ivory and shell, as well as ground stone tools such as ground-edge axes, knives and chisels. The technological capacity to process such diverse materials implies complex social behaviour (see Langley 2014; Lombard 2012; Lombard & Haidle 2012; McBrearty & Brooks 2000). Functional analysis, for determining how tools were made and used, appears to provide a powerful methodology for assessing technological capacities, with potential for distinguishing the tool-using species.

Within Sahul, the Pleistocene landmass comprising Australia and New Guinea, the evidence for grinding technologies is ubiquitous, commonly occurring in the form of ground-stone implements, bone points, ground shell and abraded haematite pieces. These items, which occur sporadically throughout the Pleistocene archaeological record, have been found in a few of the earliest human occupation sites of Sahul, including MJB and Nauwalabila (Table 2.2; Figure 2.1) (Jones & Johnson 1985; Roberts *et al.* 1990a). The temporal and geographic distributions of grinding technologies are highly significant, suggesting that ground-stone tools likely comprised part of the colonising tool kit and that grinding activities were a fundamental component of Aboriginal settlement. Problematically, grinding technologies in Sahul appear, on current evidence, to pre-date evidence for grinding technologies in southeast Asia, from where the first occupants of Sahul are thought to have emigrated. Such distributions raise interesting research questions. We know that grinding technology was part of the knowledge tool kit of *Homo sapiens* living in southeast Asia, so why is there an apparent absence of such technologies until so much later in the archaeological record? Was there migration from Sahul back to Sunda? What is the mix of climatic and cultural parameters that is important in determining the practice of specific kinds of grinding activities? Is

Table 2.1: Pre-modern human sites containing ground artefacts and ground-stone tools.

Site name	Country	Technology	Hominin sp.	Age (Ma)	Reference(s)
Drimolen	S. Africa	ground bone	<i>H. Erectus</i>	2.0 – 1.5	d’Errico & Backwell 2003
Sterkfontein	S. Africa	ground bone	<i>P. robustus</i>	2.0 – 1.7	d’Errico & Backwell 2003
Swartkrans	S. Africa	ground bone	<i>P. robustus</i>	1.8 – 1.0	d’Errico & Backwell 2003, 2009; Backwell & d’Errico 2008
Twin Rivers	Zambia	ground pigment	<i>not disclosed</i>	0.35	Barham & Smart 1996; Barham 1998, 2002
Gesher Benot Ya’aqov	Israel	mortars for nut processing	<i>not disclosed</i>	0.78	Goren-Inbar <i>et al.</i> 2002

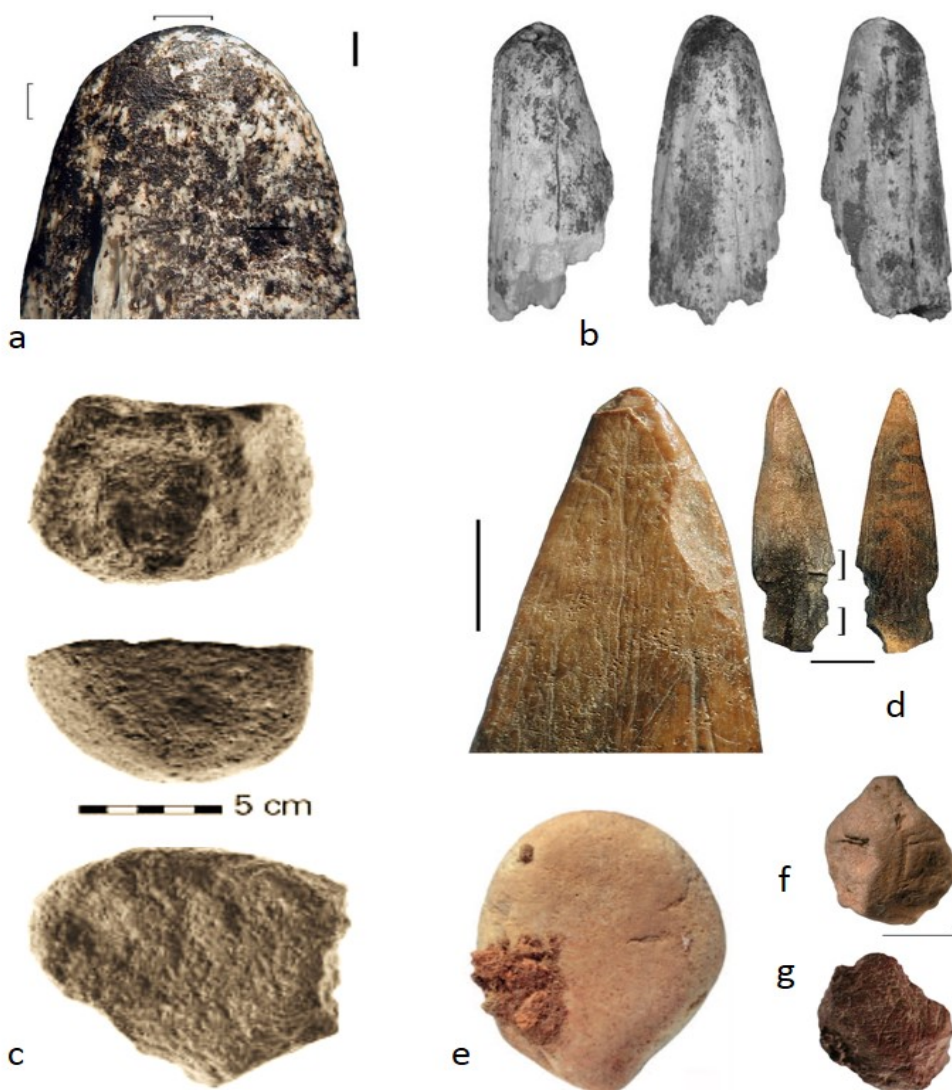


Plate 2.1a-g: Early examples of grinding technology: **a)** 2.0 – 1.5 Ma ground bone from Drimolen, South Africa (*from* Backwell & d’Errico (2008): Fig. 14.a); **b)** 1.8 – 1.0 Ma ground bone from Swartkrans, South Africa (*from* d’Errico & Backwell (2003): Fig 1.b); **c)** 0.78 Ma mortar stones (n = 3) used for processing nuts (*from* Goren-Inbar *et al.* (2002): Fig. 2.1-3); **d)** ground bone points from MSA deposits of Blombos Cave, South Africa (*from* d’Errico & Henshilwood (2007): Fig. 4.a-b); **e)** 100 ka ochre processing stone from Blombos Cave (*from* Henshilwood *et al.* (2011): Fig. 3); **f-g)** ground ochre/haematite from the MSA deposits of Blombos Cave (*from* Henshilwood *et al.* (2009): Figs. 15, 3.

the scarcity and absence of grinding technologies simply a consequence of archaeological sample size and the low number of archaeological sites excavated in a given region?

Within Australia, discussions of Pleistocene grinding technologies have also focussed on the apparent absence of specialised seed grinding tools (notably millstones) that are commonly only identified within Holocene deposits (e.g., Balme 1991; Smith 1989b). Grinding stones from within the earliest archaeological assemblages are limited and are only represented by small fragments of stone with no distinctive recurring form and no deliberate traces of manufacture or rejuvenation (see Plate 2.3a-b, 2.4f) (Hiscock & Wallis 2005: 42). These are often referred to as “amorphous” grinding stones (Smith 1985, 1986, 1989b). Consequently, Pleistocene-aged grinding stones are frequently assumed to be expedient tools likely to be used for a variety of functions; although the function of these tools remains relatively un-explored. Functional analysis of grinding stones is essential for archaeological investigations of tool use and reconstructing the activities of past human populations.

This Chapter defines the categories of grinding stones and provides an overview for the occurrences of these tools, along with other grinding technologies, throughout the world. The function of grinding stones is discussed with particular emphasis on the varieties identified in Australian contexts starting from the earliest sites of human occupation.

2.2 Defining ground-stone artefacts

Ground-stone artefacts (i.e., stones that possess grinding or abrasive wear) include all stone items that have been either intentionally modified to a specific form through grinding (i.e., *manufacture-ground*—implements such as ground-edge stone axes, chisels, knives); or used in the grinding, pounding or filing (abrading) of other materials (i.e., *use-ground*—implements such as mortars and pestles and grinding dishes) (Adams 1994: 17; Odell 2004: 74-85). In this thesis, I refer to all use-ground tools as *grinding stones*, where I distinguish two classes of implements: (1) *filing stones*, which are used to process a material through direct contact (*cf.* “abraders” or “polishers” as described by Adams 1993: 64, 2002: 143-5; and Hamon 2008: 1504); and (2) *coupled stones*, which are used in conjunction with another stone to process an intermediate material. Coupled stones often include one large, stationary “lower” grinding stone and a smaller, active “upper” stone that is held in the hand(s) (Odell 2004: 78; Wright 1994: 239). Coupled stones have different names depending on the geographical location in which they occur; for example, in the New World, the stationary basal stone is known as *metate*; the smaller hand-held counterpart is a *mano* or *hand-*

stone (Wright 1994). In other locales, basal stones may be referred to as *millstones* (McCarthy 1976), *mopan* (Liu *et al.* 2010a) or *saddle-querns* (Wright 1994), which are used in conjunction with smaller hand-held upper stones, sometimes referred to as *mullers* (McCarthy 1976), *mobang* (Liu *et al.* 2010a), and *upper millstones*, respectively. These artefacts may be previously unmodified stones, selected for size and shape, or they may have been manufactured, sometimes by grinding and flaking. Stone materials include sandstone, silcrete, quartzite, granite and basalt varieties, but other materials may be selected depending on the local geology and availability of particular stone material. The basal stone and the hand-held active stone are used together to process an intermediate material. The active stone is used in either a back-and-forth, rotary, or pounding motion to grind or otherwise process the material which is placed on the stationary basal stone.

Hammerstones and other percussion/pounding tools such as mortars, anvils and pestles, may also be classified as coupled stones, as processing involves the contact of two stones during pounding and crushing activities (De la Torre 2013: 313; Odell 2004: 79; Wright 1994: 239). These tools may show traces of crushing, pounding, grinding and battering (Kraybill 1977: 493). Mortars are bowls or flat-bottomed slabs with circular or oval depressions forming the concave receptacle that holds the material to be processed (Kraybill 1977: 491; McCarthy 1976: 63). Pestles are the accompanying pounding/grinding/crushing tools, which are usually fist-sized and rounded in section but can be elaborately carved. Pestles can simply be specially selected water-worn cobbles, and typically have crushing wear from impact with the mortar. Mortars and pestles are typically used to crack and pound hard materials such as seeds and nuts, which often contain a hard outer shell (e.g., Goren-Inbar *et al.* 2002; Peterson 1968). These implements may also be used to process other materials such as bone, shell and pigment (e.g., Liu *et al.* 2010b; Peterson 1968; Van Peer *et al.* 2003).

Filing stones are also widely found in the archaeological and ethnographic record, and are commonly used to process and shape a variety of materials such as stone, bone, wood, shell, ivory and ochre. Filing stones may exist as portable stone "*files*" (e.g., whetstones, fish-hook files), as fixed features on rockshelter walls, and as large boulders and as outcropping bedrock, where they often occur in the form of circular or ovate grinding grooves (e.g., axe-grinding grooves). One form of filing stone is the *whetstone*, a hand-held implement used for grinding and sharpening stone axe blades, chisels and knives (McCarthy 1976: 60-61). In Australia, a number of specific filing tools are documented with specialised functions for grinding shell, bone, wood and stone (McCarthy 1976: 61-62).

It is important to note that filing and coupled stones are not mutually exclusive; these tools may sometimes be used interchangeably to process multiple materials. For example, hammerstones and mullers can be used to polish wooden artefacts, and to process other materials on different lower stones (McCarthy 1976: 61). In this thesis, I will refer to a grinding stone as either a polishing, filing or coupled stone with reference to their design, dominant mode of use and most recent use.

2.2.1 Determining manufacture and use traces

Distinguishing between use-ground and manufacture-ground implements involves careful evaluation of the artefact design, manufacture traces and use-wear. Ground-edge hatchets, axes and knives will typically display a bevelled edge with a finely abraded surface. Grinding wear on use-ground implements will occur on the contact surface where grains have been altered or removed following contact with the processed material or upper stone. When only small fragments of a broken tool have survived, it may be very difficult to distinguish between use-ground and manufacture-ground traces.

Determining whether a use-ground stone should be classified as a coupled or filing stone depends on the artefact morphology and surface features recognised at various magnifications. For example, stones used for filing wood, shell or bone typically display a flat or concave cross section with no traces of stone-on-stone working—unless they were also used to sharpen or repair stone axes. In contrast, coupled stones such as mortars and pestles, and other lower and upper stones, will display stone-on-stone wear and will typically be concave and convex in section, respectively. Broken fragments of lower stones have problematic morphologies with concave-convex portions.

Although it is usually possible to distinguish between filing stones and coupled stones found archaeologically, the two tool classes are not necessarily mutually exclusive: it is possible to have a grinding stone which was used for multiple purposes, for example, an upper or lower stone used as an *impromptu* filing stone to sharpen a stone axe. Broken pieces are, again, much more difficult to identify.

2.3 Grinding technology in the archaeological record

Although evidence for grinding technology is not common prior to the emergence of *Homo sapiens* about 200 ka ago (see McBrearty & Brooks 2000: 511, 525), early ground-stone artefacts (and other grinding/pounding technologies) are present in a limited number of sites around Africa (n

= 4) and the Levant (n = 1), starting from around 2 Ma ago (Table 2.1). The earliest grinding technologies so far recognised in the archaeological record are represented by four deliberately ground bone tools that were reported in the early hominin (*Paranthropus robustus*) site of Swartkrans, South Africa, dated to 1.8 – 1.0 Ma (Plate 2.1b) (Backwell & d’Errico 2008; d’Errico & Backwell 2003, 2009). Scanning electron microscopy (SEM) images of the grinding wear on the bone tools from this site have indicated that these abraded bone tools were probably ground on termite mounds to produce a point that was suitable for digging (Backwell & d’Errico 2008: 2881). Assemblages from other early hominin sites of similar age, such as Sterkfontein and Drimolen in South Africa (associated with *P. robustus* and *Homo erectus*), also contain a number of bone artefacts with possible grinding wear (Plate 2.1a) (d’Errico & Backwell 2003: 1560).

The earliest ground-stone tools so far found in the archaeological record occur from ~0.78 Ma at the site of Gesher Benot Ya’aqov, Israel, and include pitted hammers and anvils (mortars) that were probably used to process at least seven species of edible nuts (Plate 2.1c) (Goren-Inbar *et al.* 2002). Cobbles showing traces of yellow pigment were reported from the site of Twin Rivers, Zambia, found in association with several pieces of abraded haematite and indirectly dated to 350 ka ago (Barham 1998, 2002). Ground pigment in the form of haematite crayons and heavily abraded ochre pieces are also prevalent in Middle Stone Age (MSA) contexts of Africa; associated with modern humans starting from 165 ka (Marean *et al.* 2007) but becoming more common after approximately 75 ka (Plate 2.1f, g) (e.g., d’Errico *et al.* 2010; Henshilwood & d’Errico 2005; Henshilwood *et al.* 2002, 2009; Henshilwood & Lombard 2013; Jacobs *et al.* 2006a; Rigaud *et al.* 2006; Watts 1999, 2002, 2010; Wurz 2000). Filing stones used to process ochre are reported from the 100 ka levels of Blombos Cave, South Africa (Plate 2.1e) (Henshilwood *et al.* 2011), with ochre stained grinding slabs identified in other MSA contexts in sub-Saharan Africa (e.g., Ambrose 1998; Avery *et al.* 1997: 274; Barham 1998; Walker 1987).

Other grinding stones that likely functioned in the processing of plant foods or the shaping and polishing of bone artefacts have been recognised in several African MSA sites (e.g., Brooks *et al.* 1995; De Beaune 2004; Klein 2009: 550; Van Peer *et al.* 2003; Yellen *et al.* 1995). Similarly, deliberately ground bone points have also been identified throughout southern and central Africa (Plate 2.1d) starting from 90 ka at Katanda, Upper Semliki Valley, Zaire (Brooks *et al.* 1995; Yellen *et al.* 1995). The higher frequencies of bone artefacts identified after this time are believed to be associated with the emergence of the Still Bay and Howieson’s Poort industries that are dated between 59 and 75 ka (d’Errico & Henshilwood 2007; Henshilwood *et al.* 2001, 2002, 2011; Jacobs *et*

al. 2006a, 2006b, 2008, 2013, 2015; Jacobs & Roberts 2009, 2015; Tribolo *et al.* 2006; (but see Tribolo *et al.*, 2009; 2013)).

Grinding tools and abraded objects also appear in the European Upper Palaeolithic (UP) record after about 50 ka, typically occurring in the form of shallow stone bowls, cupules, hand-stones and pestles (e.g., De Beaune 2004; Revedin *et al.* 2010), but also in the form of bone and ivory points (Plate 2.2e), ground-edge axes (including fragments thereof), pigments and ornaments of polished stone, bone and ivory (e.g., Conard 2009; De Beaune 2004; Derevianko *et al.* 2008; d’Errico *et al.* 1998; Mellars 1989, 2009, 2010; Svoboda 2008; Villa & d’Errico 2001). One particularly remarkable specimen is a finely polished bracelet shaped from semi-precious ground chloritite recovered from Denisova Cave, dated at ~30 ka (Plate 2.2a, b) (Derevianko *et al.* 2008). Polished ivory figurines dated at 30 – 25 ka and polished female “Venus” figurines carved from soft stone, bone, ivory or clay, have been identified within the early and middle phases of the UP (Plate 2.2c, d, f) (Conard 2009; d’Errico *et al.* 2011; Mellars 2009; Svoboda 2008; White 2006). The stone files used to produce the figurines have not been reported.

Deliberately shaped bone and ivory beads were identified in the earliest stages of the Aurignacian culture in both western and eastern Europe, dated in most places to around ~30 – 35 ka (Mellars 1989: 362; but see Jacobs *et al.* 2015). Bone and antler points that have been manufactured by grinding and polishing were recovered from UP Aurignacian and Châtelperronian sites that were occupied by both modern humans (*Homo sapiens*) and Neanderthals (*Homo neanderthalensis*) (d’Errico *et al.* 1998; Knecht 1993; Mellars 1989, 2010; Villa & d’Errico 2001). Abraded pigments were identified from sites of both *H. sapiens* and *H. neanderthalensis* around habitation sites dating from the Middle Palaeolithic (MP). The earliest occurrence of ground pigments in Europe were from the site of Pech de l’Azé I rockshelter, France, dated at ~50 – 60 ka, in association with a sandstone grinding slab (d’Errico *et al.* 2010: 3100; Soressi & d’Errico 2007; Soressi *et al.* 2009).

The earliest evidence for plant processing in Europe is represented by stone mortars at the sites of Kostienki 16 in Russia (dated to ~32 ka); Pavlov VI in the Czech Republic (~29 ka); Bilancino II in Italy (~28 ka BC); and Kostienki V (Aleksandrovskaya), Russia (~21 – 23 ka) (Revedin *et al.* 2010; Semenov 1964). The evidence for plant processing is recognised through the identification of multiple starch grains that have indicated the processing of at least 12 different plant taxa (Revedin *et al.* 2010: 18818). Grinding stones likely used for pigment preparation were also identified in European Neanderthal sites including Cueva del Conde and Cueva Morín, Spain, and Pech de l’Azé I and IV, France (Soressi & d’Errico 2007: 303). The grinding stones identified at these sites were

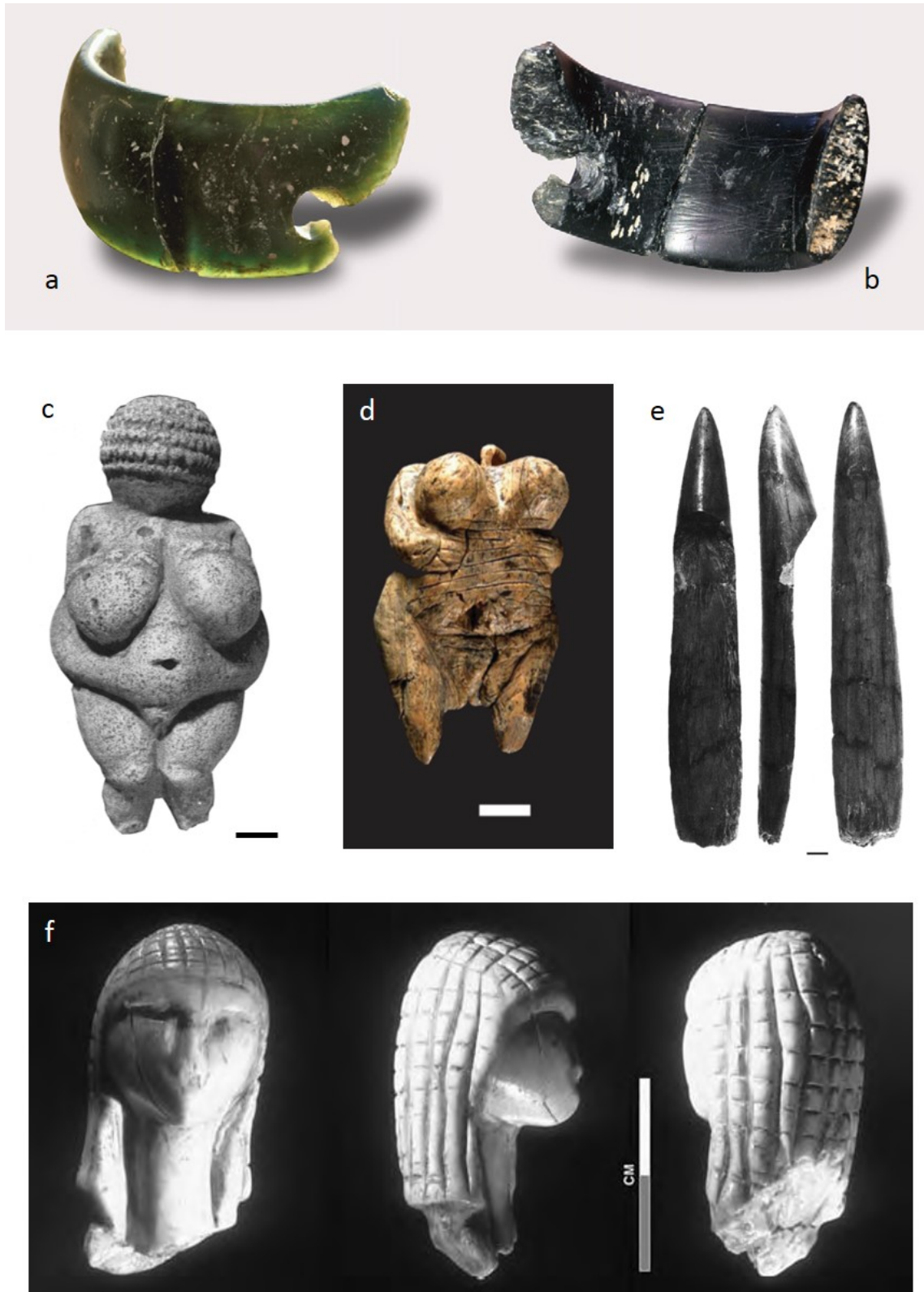


Plate 2.2a-g: Examples of ground figurines and ornaments from *Homo sp.* sites from Europe: **a-b)** Early Upper Paleolithic chloritolite bracelet from the eastern gallery of Denisova Cave (from Derevianko *et al.* (2008): Fig. 4.1-2); **c)** ivory “Venus of Willendorf: figurine (scale 1 cm) (from Soffer *et al.* (2000): Fig. 2); **d)** “Venus of Hohle Fels: figurine from Swabian Jura, Germany (scale 1 cm) (from Conard (2009): Fig 1); **e)** Ivory point from the site of Castel di Guido, Italy, (scale 1 cm) (from Villa & d’Errico (2001): Fig. 2); **f)** three views of the ivory figurine “La Dame à la capuche ou La Figurine à la capuche”—(“the hooded woman”) (from White (2006): Fig. 11).

found in association with fragments of pigment that show wear facets and evidence for scraping (McBrearty & Brooks 2000: 525).

Early grinding stones probably used to process ochre have been identified from Qafzeh Cave in the southern Levant, where evidence for ground pigments was present within the lowest UP layer (Ebeling & Rowan 2004; Hovers *et al.* 2003). Evidence for pigment processing was also present in surrounding sites where ground ochre pieces were recognised in association with grinding stones, dating from c. 45 – 20 ka (Ebeling & Rowan 2004; d’Errico *et al.* 2010). Bone and antler polishing stones were also identified in Natufian sites (De Beaune 2004: 148) and the processing of cereals using coupled stones has been identified at the site of Ohalo II during the early Epipaleolithic from 20 ka (23.5 – 22.5 ka cal BP) (Piperno *et al.* 2004). Other deep mortars have also been identified within the southern Levant, dated at between 14 and 20 ka BP, although their specific use has not yet been established.

Within southwest Asia, mortars and pestles appeared during the early Epipaleolithic, around 17 – 20 ka BP. In China, plant processing tools appeared during the early Holocene and functional analysis has revealed that they were likely used to process a variety of plant foods (Liu *et al.* 2010a, 2010b). At Niah Cave, evidence for the consumption of starchy plants and the possible grinding of toxic plant varieties has also been documented from ~40 ka BP (Barker *et al.* 2007; Barton 2005). Ground-edge axes were present in Japan from ~30 ka BP (~36 cal ka BP) (Takashi 2012: 73) with other polished forms of stone also present in east Asia from the terminal Pleistocene (e.g., Anderson & Summerhayes 2008; Oda & Keally 1992; Zhao *et al.* 2004). Ground-edge axes were identified from 20 ka BP within Eurasia and regions of southeast Asia, including the Valley of Yenisei in Siberia and Niah Cave in Malaysia, dated at 20 ka BP and 15 – 20 ka BP, respectively (Golson 2001; Oda & Keally 1992). At the site of Jerimalai, East Timor, pelagic fishing with baited hooks is suggested by large quantities of deep-sea fish bones from 42 ka (Plate 2.3c; Figure 2.1f) (O’Connor *et al.* 2011). At the same site, ground shell fish-hooks are dated to between 23 and 16 ka, and are the oldest ground fish-hooks in the world. Other evidence for shell fish hooks occur at Lene Hara Cave in East Timor, dated to ~9.7 ka (O’Connor & Veth 2005). Ground shell artefacts have been identified in sites of the Molluccas dating from 12 ka BP (Anderson & Summerhayes 2008: 51; Bellwood 1997: 187).

2.3.1 Sahul

Grinding stones dating to at least 50 ka have been identified in Australia, and occur within the lowest cultural units of MJB and Nauwalabila; two of the earliest dated human occupation sites

of Sahul. The lowest cultural units at MJB are represented by bracketing thermoluminescence (TL) ages of 61 ± 13 ka and 45 ± 9 ka (Roberts *et al.* 1990a) and single-grain OSL ages of 55.5 ± 8.2 ka and 44.2 ± 4.7 (Roberts *et al.* 1998a) (see Table 3.1, Chapter 3). The lowest cultural deposits at Nauwalabila have a single TL age of 53 ka (Jones & Johnson 1985; Roberts *et al.* 1994a, 1994b). In addition to grinding stones, the early cultural units of MJB and Nauwalabila also contained abraded haematite pieces that were probably ground on stone to produce pigment powder suitable for the production of paint (Plate 2.3e).

Other occurrences of Pleistocene-aged grinding stones and abraded haematite pieces have been identified within the Australian archaeological record from about 41 ka ago, occurring at sites in northern Australia, western New South Wales and the Cape York region (Table 2.2; Plate 2.3a-b, e; Figure 2.1a) (Allen 1972; Balme 1991; Bowler 1998; Cole *et al.* 1995; David 1991, 1993; Dortch 1977, 1986; Field & Dodson 1999; Fullagar & Field 1997; Gould 1977; Mulvaney 1975; Mulvaney & Joyce 1965; Rosenfeld 1991; Schrire 1982; Veth & O'Connor 1996). Seed-grinding implements probably first appear around 3.8 ka in Central Australia (Smith 2004: 172) and at the headwaters of the arid river systems from 3.2 ka (Morwood 1981; Smith 1986), but appear to be more common in desert assemblages from ~1.5 ka (Smith 2013: 200). Reports of earlier seed processing tools, however, are also suggested for a selection of Pleistocene sites (Section 2.4.1.1) (e.g., Allen 1974; Balme 1991; Balme *et al.* 2001; Fullagar & Field 1997; Fullagar *et al.* 2008, 2015).

Ground-edge implements of Pleistocene antiquity have been discovered in several regions of northern Australia, including Arnhem Land, the Kimberley and on the Cape York Peninsula (Figure 2.1b; Table 2.2) (Geneste *et al.* 2010, 2012; Golson 2001; Morwood & Trezise 1989; O'Connor 1999; Schrire 1982; White 1967). A ground-axe fragment recently discovered at Nawarla Gabarnmang, Northern Australia, is associated with a radiocarbon age of ~35 cal ka BP, and is among the earliest securely dated ground-edge stone fragments in Australia (Plate 2.3f) (Geneste *et al.* 2010, 2012). In Papua New Guinea, ground-edge axes and fragments occur in at least three sites from ~20 ka (Table 2.2). Even earlier occurrences of unground axe varieties, including the waisted axes from the Huon Peninsula, have been dated to between 40 ka and 61 ka (Golson 2001; Groube *et al.* 1986) although there is some discussion as to the accuracy of these ages (see Allen & O'Connell 2003; O'Connell & Allen 2004; Roberts 1997).

At the site of Mandu Mandu rockshelter, Western Australia, 22 deliberately modified shell beads (*Conus sp.*) and fragments were identified in deposits dating to at least 32 ka BP (Balme 1993; Balme & Morse 2006). Other shell beads have also been recovered from the sites of Riwi Cave and Devil's Lair, both in Western Australia, associated with radiocarbon ages of 30 ka (or older) and 19 –

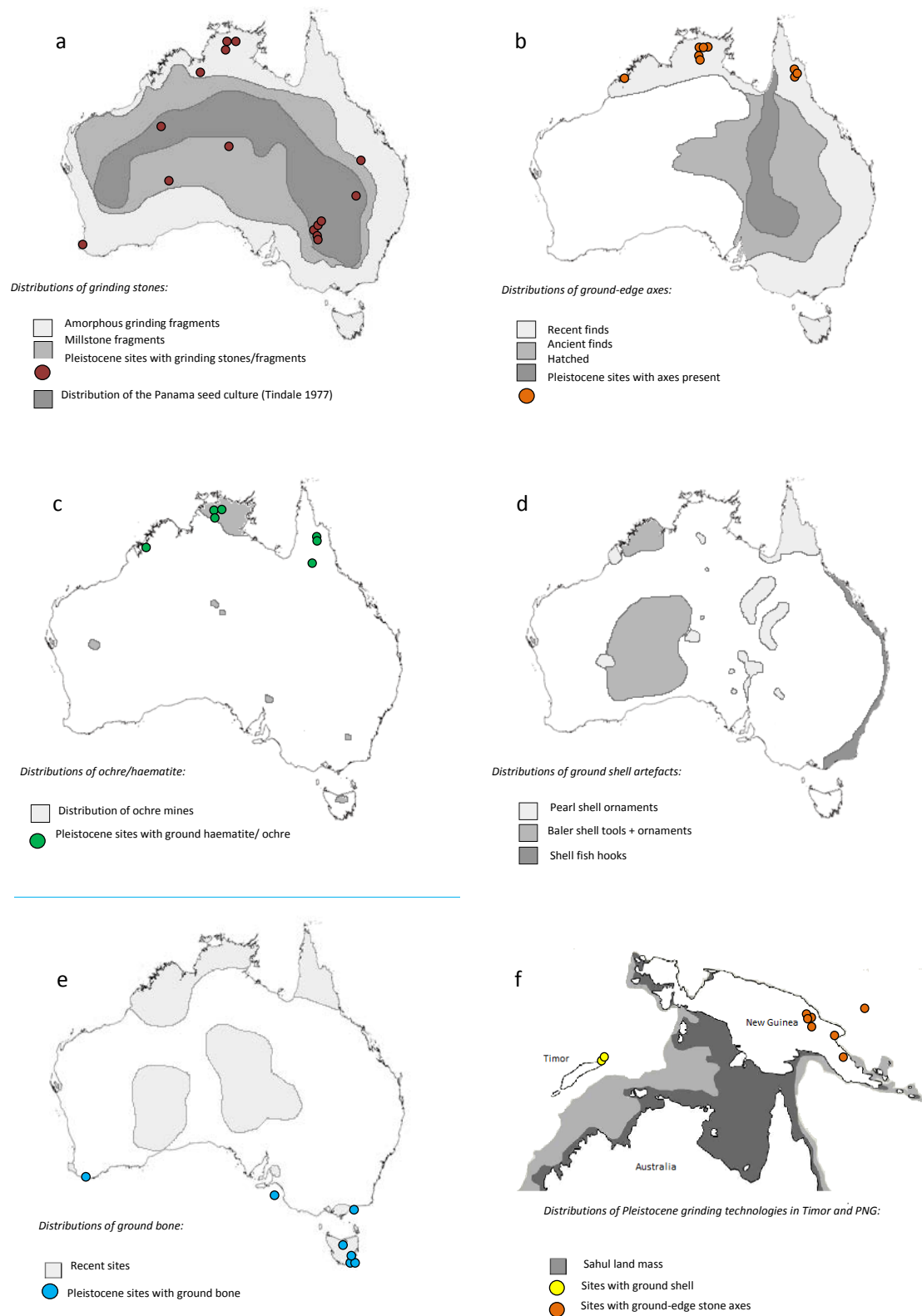


Figure 2.1a-f: Distributions of grinding technologies throughout Sahul: **a)** distributions of grinding stones (*after* Smith 2013: Fig. 6.9), red dots indicating location of Pleistocene occurrence; **b)** distributions of ground-edge axes (*after* Smith 2013: Fig. 8.9), orange dots indicating location of Pleistocene occurrences; **c)** distributions of ochre and haematite quarries; green dots indicating location of Pleistocene occurrence; **d)** distributions of ground shell artefacts; **e)** distributions of ground bone artefacts, blue dots indicating location of Pleistocene occurrence; **f)** distributions of ground shell and ground edge axes in PNG and Timor.

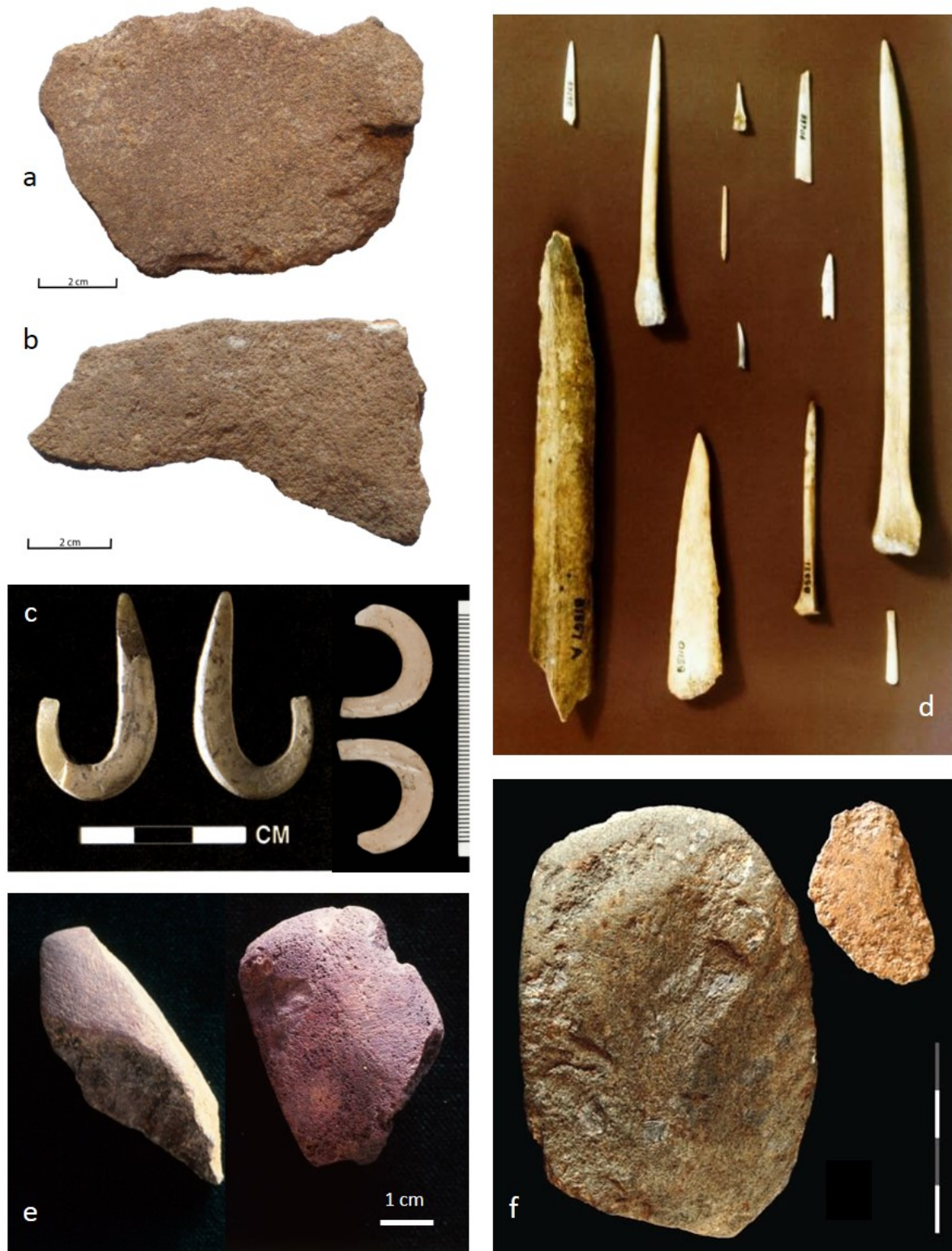


Plate 2.3a-f: Early manifestations of grinding technology in Sahul: **a-b)** “amorphous” grinding stones from early human occupation levels of MJB, dated at 45 ka; **c)** shell fish-hooks shaped by grinding, from Lene Hara Cave (left image—from O’Connor & Veth 2005: Fig. 5) and Jerimalai rock shelter, Timor (Right image—from O’Connor *et al.* 2011: Fig. S5); **d)** a selection of bone tools from Devil’s Lair, ages from 12 ka BP (from Langley 2009: Fig. 5.15); **e)** ground haematite pieces identified at the lowest excavated levels from MJB (1989 excavations) (Photo by R. Roberts, R. Jones & M. Smith); **f)** late Holocene ground-edge axe and Pleistocene axe fragment, dated at ~35.5 ka cal BP from Nawarla Garbarnmang (from Geneste *et al.* 2012: Fig. 4.E).

12.7 ka BP, respectively (Balme 2000; Balme & Morse 2006; Dortch 1979). Other potential shell beads are also noted at Carpenter's Gap rockshelter, also in Western Australia, dated between 25 and 17 ka (O'Connor 1995). The manufacture of shell beads at these sites usually involved the removal of the weakest part of the shell, the apex, probably by means of piercing or rubbing against an abrasive stone (Balme & Morse 2006: 803). Other, more recent examples of ground shell implements include ground-edge baler shell (*Melo* sp.) chisels from north-west Australia, used for the cutting of wood and the butchering of turtle and dugong (Akerman 1975: 16), baler shell knives from the Cape Range Peninsula (Przywolnik 2003: 18), ground shell adzes from the Kimberley region of Western Australia (Akerman & Bindon 1984: 357) and ground shell fish-hooks from coastal New South Wales (Section 2.4.2.1) (Attenbrow *et al.* 1998; Lampert 1971a, 1971b; Megaw 1974; Megaw & Wright 1966). Baler and pearl shell (*Pinctada* sp.) ornaments likely shaped by grinding are also recognised in some regions of Australia, apparently traded and distributed across the continent (Figure 2.1d).

Ground bone points occur in the Australian Pleistocene starting from ~26 ka, in sites around Western Australia, Tasmania, South Australia and Victoria (Table 2.2; Plate 2.3d; Figure 2.1e) (Allen 1989; Bowdler 1984; Dortch 1984; Dortch & Merrilees 1973; Dortch 2004; Flood 1980; Lampert 1981; Ossa *et al.* 1995; Ramson 1983; Webb & Allen 1990). The bone tools recognised at these sites are distinguished by grinding wear acquired from point manufacture. Both ground shell and bone artefacts are more frequently reported for late Holocene archaeological sites (e.g., Attenbrow *et al.* 1998; Fullagar *et al.* 1999).

2.4 Significance of ground stone artefacts

Like flaked-stone artefacts, functional analysis of grinding stones may provide information about resource use, mobility, subsistence practices and enhanced subsistence risk, as well as general insights into the cognitive abilities of past and present tool using hominids. De Beaune (2004) traced the use of grinding stones during the European MP and UP and noted a transition from pounding and hammering motions to backwards/forwards and rotary grinding motions. She suggested that the pounding and hammering motions of the MP represents a simple processing technique undertaken by multiple pre-modern hominin species; and that the backwards/forwards and rotary grinding motions occurring throughout the UP represented a more advanced method of processing undertaken solely by *Homo sapiens*. Pounding and hammering activities are also witnessed among modern non-human primates such as macaques, chimpanzees and capuchin monkeys (e.g., Haslam *et al.* 2009, 2013; Moura & Lee 2004; Ottoni & Izar 2008; Ottoni *et al.* 2005)

Table 2.2: Grinding technologies from Pleistocene sites in Sahul.

Artefact type	Site name	Location	Site type	Age (ka)	Reference(s)
Grinding stones	Nauwalabila	NT	Rockshelter	53; 22	Roberts & Jones 1994; Jones & Johnson 1985; Jones & Negerevich 1985
	Malakunanja II	NT	Rockshelter	52; 18	Kamminga & Allen 1972; Roberts <i>et al.</i> 1998a; Chaloupka 1993
	Cuddie Springs	NSW	Ephemeral lake	28-35	Fullagar & Field 1997; Field & Dodson 1999
	Puritjarra	NT	Rockshelter	32	Smith 2004; Smith <i>et al.</i> 1997, 1998
	Little Sandy Desert	WA	Open site	24(?)	Veth & O'Connor 1996
	Nawamoyyn	NT	Rockshelter	21	Schrire 1982
	Malangangerr	NT	Rockshelter	20	Schrire 1982
	Miriwun	WA	Rockshelter	18 BP	Mulvaney 1975; Dortch 1977, 1986
	Kenniff Cave	QLD	Cave	13-16	Mulvaney & Joyce 1965
	Lake Leaghur	NSW	Lunette	15-16	Allen 1972; Balme 1991
	Lake Mungo	NSW	Lunette	14 – 24	Fullagar <i>et al.</i> 2015
	Lake Garnupung	NSW	Lunette	15	Allen 1972; Balme 1991
	Lake Mulurulu	NSW	Lunette	15	Allen 1972; Balme 1991
	Tandou Creek	NSW	Open site	12.5	Allen 1972; Balme 1991
	Armuvale	WA	Coastal dune	13	Dortch 1986
	Puntutjarpa	WA	Rockshelter	12	Gould 1977
Ground haematite	Nauwalabila	NT	Rockshelter	53; 20–30	Jones & Johnson 1985; Roberts <i>et al.</i> 1994b
	Malakunanja II	NT	Rockshelter	52; 41–45	Roberts <i>et al.</i> 1998a
	Widgingarri I	WA	Rockshelter	42(?)	O'Connor 1999
	Nawamoyyn	NT	Rockshelter	20-30	Schrire 1982; White 1967
	Sandy Creek 1	QLD	Rockshelter	18-32	Morwood 1989; Morwood <i>et al.</i> 1995
	Fern Cave	QLD	Cave	18-32	David <i>et al.</i> 1993
	Early Man Cave	QLD	Cave	21.5	David 1991
Ground-edge axes	Bobongara (Huon Peninsula)	PNG	Open site	40-61	Groube <i>et al.</i> 1986; Roberts 1997; Golson 2001; Allen & O'Connell 2003; O'Connell & Allen 2004
	Malakunanja II	NT	Rockshelter	50-60	Clarkson <i>et al.</i> 2015; Fullagar <i>et al.</i> (in prep)

Artefact type	Site name	Location	Site type	Age (ka)	Reference(s)
Ground-edge axes (cont.)	Nawarla Gabarnmang	NT	Rockshelter	35	Geneste <i>et al.</i> 2010
	Widgingarri	WA	Rockshelter	32	Morwood & Trezise 1989
	Sandy Creek I	QLD	Rockshelter	32	Morwood & Trezise 1989
	Mushroom Rock	QLD	Rockshelter	32	Morwood & Trezise 1989
	Kosipe	PNG	Open site	25	White & O'Connell 1982; Golson 2001
	Nombe	PNG	Rockshelter	25	White & O'Connell 1982; Golson 2001; Mountain 1983
	Nauwalabila	NT	Rockshelter	25–30; 14	Jones & Johnson 1985
	Malangangerr	NT	Rockshelter	18–24	Schrire 1982; Golson 2001
	Nawamoyyn	NT	Rockshelter	18–24	Schrire 1982; Golson 2001
	Kuk	PNG	Wetlands/swamps	20	White & O'Connell 1982; Golson 2001
	Yuku	PNG	Rockshelter	14	Lampert 1975, 1983; White & O'Connell 1982; Golson 2001
	Pamwak	PNG	Rockshelter	13.5	Fredericksen <i>et al.</i> 1993
	Jimeri	PNG	Rockshelter	13	White 1967
	Kafiavana	PNG	Rockshelter	9.5–12.5	White 1972
	Sandy Creek II	QLD	Rockshelter	10	Morwood <i>et al.</i> 1995
Bone points	Devil's Lair	WA	Rockshelter	26	Dortch & Merrilees 1973; Dortch 1984; Dortch 2004
	Bone Cave	TAS	Rockshelter	12–24	Allen 1989, 1996; Ramson 1983; Webb & Allen 1990
	Warreen	TAS	Rockshelter	18–22	Cosgrove 1999; Ramson 1983; Webb & Allen 1990
	Kutikina Cave	TAS	Cave	15–20	Cosgrove 1999; Ramson 1983; Webb & Allen 1990
	Cave Bay Cave	TAS	Cave	18.5; 21–23	Bowler 1984
	New Guinea II	VIC	Rockshelter	4.6 – 21	Flood 1980; Ossa <i>et al.</i> 1995
	Seton Cave	SA	Cave	11	Lampert 1981
Ground shell	Mandu Mandu	WA	Rockshelter	>32	Balme & Morse 2006; Morse 1993
	Riwi	WA	Cave	>30	Balme 2000; Balme & Morse 2006
	Devil's Lair	WA	Cave	12.7–19	Dortch 1979
	Carpenters Gap	WA	Rockshelter		O'Connor 1995

and support De Beaune's argument that such processing techniques do not require enhanced cognitive abilities (i.e., amplified conceptual, technological and behavioural modularization, as defined by Lombard & Haidle 2012: 261). Identifying the use of grinding stones through functional analysis, therefore, provides a powerful methodology for assessing technological and cognitive abilities for tool using species, as well as providing information about past subsistence practices, resource use and mobility.

Grinding stones have often been linked to enhanced plant food processing and the onset of agriculture—assumed by the emergence of “standardised” grinding stone forms (e.g., Anderson-Gerfaud 1999; Dubreuil 2004; Piperno *et al.* 2004; Wright 1994). The proliferation of standardised grinding stones such as lower and upper millstones, mortars and pestles, has also been linked to enhanced resource stress and foraging risk, whereby the standardised forms represent an elaboration of an existing technology for the intensive processing of lower ranked resources. In Australia, it has been suggested that the high frequency of heavily used millstones in late Holocene sites was a technological adaptation in response to enhanced resource stress caused by climatic variability and leading to enhanced reliance on seed foods (e.g., Smith 1986: 126). The following sections describe the archaeological evidence for past subsistence practices based on the occurrence of grinding stones.

2.4.1 Grinding stones for subsistence

Ground-stone implements feature prominently in studies of past subsistence practices and the origins of agriculture, following the assumption that the transition from the reliance on wild plants to domesticated species was marked by changes in food processing technology, notably by modifications to the morphology and design of grinding stones (Hodder 2012: 195; Rowan & Ebeling 2008: 4). In the Levant, the emergence of agricultural societies is believed to be linked with the sudden increase in the variety of grinding implements after 12 ka ago (e.g., Anderson-Gerfaud 1999; Dubreuil 2004; Wright 1994). However, artefact morphology is not a reliable indicator of function, and specific agricultural regimes and subsistence practices cannot be recognised on this basis alone. For example, in the Near East, the long-held assumption that mortars were used in the processing of wild foods such as acorns and nuts, and that grinding stones were used for the processing of domesticated cereals, was effectively challenged by Wright (1994) using both experimental and ethnographic data. She concluded that tool morphology is not a reliable indicator of artefact function or diet. Conversely, the identification of starches indicative of processing both wild barley

(*Hordeum vulgare* L.) and wheat (*Triticum monococcum* L. and *Triticum turgidum* L.) on a single grinding slab, dated between 23.5 – 22.5 ka cal BP at Ohalo II, shows that the same implement was used to process more than one species well before domestication of cereals (Piperno *et al.* 2004). Starch grains identified in sediments at Niah Cave, Borneo, also suggest the consumption of plant foods (notably palm and yam) from ~40 ka BP (Barton 2005), although it is still unclear how these plants were processed (if at all) prior to consumption.

The identification of food processing tools is highly significant for the reconstruction of past human diet, allowing information to be gleaned about past human health, dietary preferences, environmental pressures and various social processes. Preparation of plant food by grinding enhances nutrient release, removes toxins and aids digestion (Hodder 2012: 197; Wollstonecroft *et al.* 2008: 19), while the processing of animal materials reduces wastage, aids mastication and enhances palatability (Gould 1980: 194; Peterson 1968: 367; Smith 1985: 24). Through functional analysis of grinding surfaces (Chapter 4), the processing of specific food materials may be gleaned. For example, it was shown that the processing of wild cereals, including barley, was occurring by 23.5 ka cal BP (Piperno *et al.* 2004). Likewise, the processing of acorns and other edible materials, including small animals, shell fish and nuts, is recognised on a number of mobang specimens from Donghulin, China, starting from ~9 ka (11 ka cal BP) (Liu *et al.* 2010a, 2010b). Liu *et al.* (2010b) suggested that such subsistence practices indicate a transformation from mobile hunter-gatherer society to an agricultural-based Neolithic economy. Similarly, in Australia, the analysis of grinding implements has enabled local subsistence strategies to be assessed. The following sections describe subsistence practices in Australia based on studies of grinding stone morphology, functional traces (residues and use-wear) and ethnographic reports.

2.4.1.1 Seed grinding in Australia

In Australia, the widespread occurrence of large basal millstones from Holocene sites located in the arid zone of Australia, are often thought to represent the onset of a seed-grinding economy, supported by extensive ethnographic reports of seed collection and consumption (Table 2.3) (e.g., Allen 1974; Cleland & Tindale 1954; Edwards & O'Connell 1995; Gould 1971, 1977; Hawkes & O'Connell 1981; Latz 1982, 1995; Meggitt 1957, 1962; O'Connell & Hawkes 1981; O'Connell *et al.* 1983; Peterson 1968, 1977; Tindale 1977). These artefacts, which are thought to be specialised seed grinding tools, are tabular slabs with well-worn surfaces and often with one or more grooves resulting from heavy and repetitive grinding (Plate 2.4b) (McCarthy 1976: 59-60; Smith 1985, 1986, 1989b). Sometimes accompanying these artefacts are mullers, a particular class of upper stone,

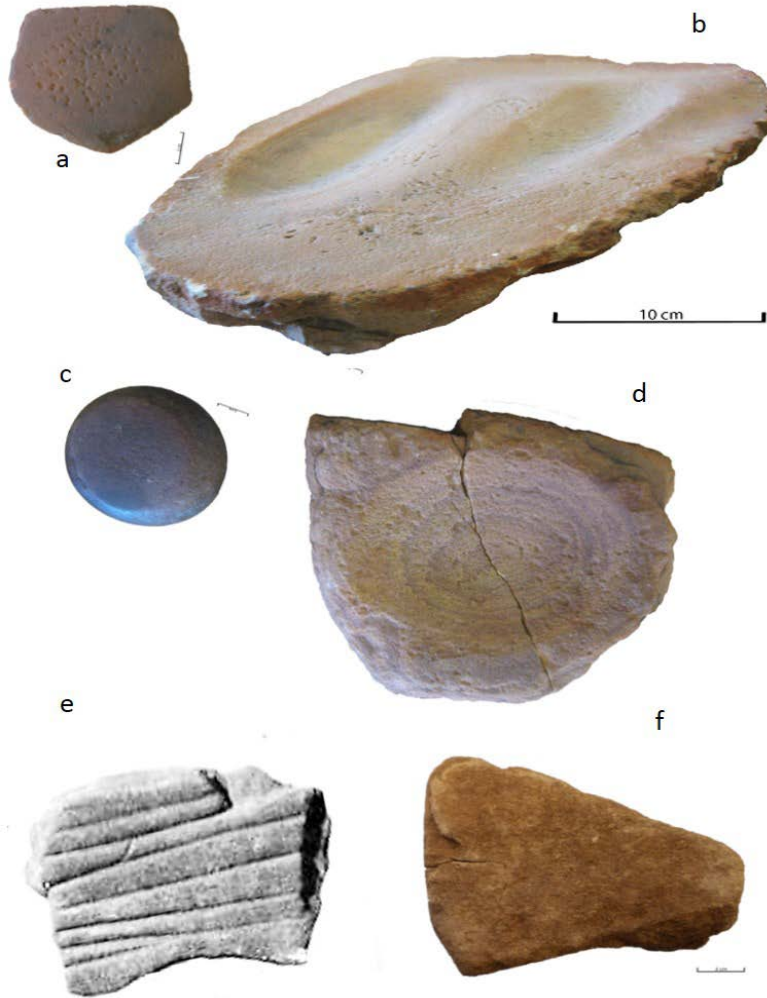


Plate 2.4a-f: Australian grinding stone classes: **a)** muller stone with peck (rejuvenation) marks; **b)** millstone with two large grooves on the upper surface of the stone, hammer dressing around the outer edges and pecking over the ground surface; **c)** pestle; **d)** mortar; **e)** fragment of a morah stone (photo by R. Fullagar); **f)** amorphous grinding stones with minimal grinding wear.

which are small, hand-held implements typically round to oval in shape; with grinding wear on one or both (upper and lower surfaces); and usually convex in section with a facet developed from the rocking motion during seed grinding (Plate 2.4a) (McCarthy 1976: 60; Smith 1985, 1986, 1989b). Based on a study of central Australian grinding implements and their uses, Smith (1986, 1988, 1989b) proposed that these coupled stones (millstones and mullers; mortars and pestles) (Plate 2.4a-d), were used in the wet milling of softer seeds and the cracking and pounding of harder seeds, respectively.

The economic importance of seeds was ethnographically documented in Australia by early explorers and surveyors (e.g., Mitchell 1848; Sturt 1849), who described the collection and consumption of seed foods by contemporary indigenous Australians. Tindale (1977) defined a “Panara” seed culture within the arid regions of Australia, characterised by the intensive use of grass known, including 67 varieties of seeds (47.9%); 26 of which are derived from grasses (family

Poaceae) (Latz 1995: 83-300). Within Arnhem Land, the Aboriginal use of 23 species of seeds has been reported, four of which were ground prior to consumption (Table 2.3, Table A1—Appendix A). These include *Brachychiton diversifolius* (Northern kurrajong) seeds, *Cycas media* (Cycas) seeds, *Nelumbo nucifera* (Pink water lily) seeds and *Oryza perennis* (Asian rice) seeds (Chaloupka & Giuliani 1984; Jones & Meehan 1989; McArthur 1960a, 1960b; McCarthy & McArthur 1960).

Despite their abundance, seeds are a high cost resource, requiring on average six hours per kilogram handling time (i.e., collection, cleaning, processing), whereby the most time is consumed grinding the seeds—this takes approximately two to six hours to produce one kilogram of flour (Smith 2013: 198). Taking into account the intensive labour involved, optimal foraging models (e.g. O’Connell & Hawkes 1981) have suggested that the decreasing availability of higher ranked resources in arid regions requires more effort to obtain than it does to collect and process the highly abundant seed foods (Smith 1989b). Seeds are a reliable food source, they can be stored and are relatively easy to access and harvest, unlike other seasonal food items such as yams and tubers, which may decay quickly once removed from the ground (Cane 1989: 111; Smith 2013: 197). Seeds are an abundant, carbohydrate-rich grain (typically 50 – 70% carbohydrate and 10 – 20% protein) (Smith 2013: 197). In Australia, as in some other parts of the world, seeds are traditionally collected and prepared by women, and, consequently, the initial archaeological occurrence of seed grinding stones may represent a period of social change, such as the sexual division of labour (Smith 2004: 183).

The apparently exclusive occurrence of specialised seed grinding artefacts (i.e., millstones, mullers, mortars and pestles) is believed to represent a formal technology facilitating intensive seed processing (Smith 1986: 126). The assumption that these “formal” grinding stone implements represent a seed-grinding economy, however, has been challenged by other researchers who have suggested that all grinding stone varieties, regardless of morphology, represent non-specialist implements used opportunistically for multiple purposes (e.g., Balme *et al.* 2001; Gorecki *et al.* 1997; Nash 1993). In such cases, the apparently diagnostic morphology represents the end product of a variable reduction process, rather than a specific functional type (Veth *et al.* 1997: 23). The dichotomous classification of formal seed grinding tools with expedient or “amorphous” varieties is therefore questionable, as tool form (morphology) is not always a reliable indicator of function.

The apparent over-simplification of Australian morphological grinding stone types and their relationship with artefact function is evidenced by ethnographic and archaeological accounts of grinding stone function. For example, Balme *et al.* (2001) identified blood and ochre residues on a



Plate 2.5a-f: Grinding stones used for subsistence: **a)** grinding Wangunu seed, Puritjara (*from* Gould 1977); **b)** wet-milling of seed using a millstone and muller, Kimberley, (photo by K. Akerman); **c)** processing *Nymphaea* water lily root using an upper and lower stones, Kimberley (*from* Field *et al.* (2009: Fig. 3, Photo by L. Head); **d)** pounding the vertebrae of a feral cat, Western Desert (*from* Gould (1980): pp.194) **e)** preparation of water lily seed, Kimberley (Photo by J. Atchison).

selection of millstone fragments from Puntutjarpa rock shelter within the Western Desert; and Furby (1995) identified both plant and animal residues on sets of grinding stones recovered from the semi-arid southeast at Cuddie Springs. Other investigations of millstone function from museum specimens

involving the removal and identification of residues has also indicated that multiple materials occurred on these artefacts (Stephenson 2011). In her investigations, Stephenson (2011) identified wood, resin, collagen, hair and starch on the surfaces of ten complete millstones. These were interpreted as use-residues and have indicated the processing of multiple substances in addition to seeds.

In addition to the archaeological evidence, ethnographic observations have shown that Australian upper stones, specifically pestles, are commonly used as impromptu hammers for stone flaking and the crushing of animal material (Cane 1989: 113). Similarly, Peterson (1968: 568) reports the use of mortars and pestles as pounding implements used for the preparation of vegetable and animal materials, as hammers and anvils in the preparation of spear blades and as palettes to mix and prepare resins and pigments for hafting and body decoration, respectively.

Currently, the largest most continuous sequence of seed grinding artefacts comes from Puritjarra rockshelter located in central Australia in the middle of the arid zone (Smith 1989a). The grinding stone assemblage from this site includes a number of surface finds with five distinct seed grinding implements (millstones) and 90 excavated grinding stones, most with signs of heavy use and a high rate of breakage (Smith 2004: 175). Of the 90 excavated specimens, 21 (or 23%) were believed to be fragments of millstones comprised of locally available sandstones. The earliest millstone fragment has been dated to between ~3.5 and 0.8 ka (3.8 and 0.7 ka cal BP). Interestingly, only amorphous grinding stones are identified before this time (earliest at 32 ka), so Smith (2004: 178) argued that seed grinding activities were probably absent prior to ~4ka ago. However, examination of the fragments from this site did not incorporate high magnification observations using vertical incident light and only limited examination of residues for the detection of starch. Previous studies on Australian ground stone tools have demonstrated the interpretive value of employing such techniques (e.g., Field & Fullagar 1998; Fullagar *et al.* 1996, 2008, 2015; Fullagar & Field 1997).

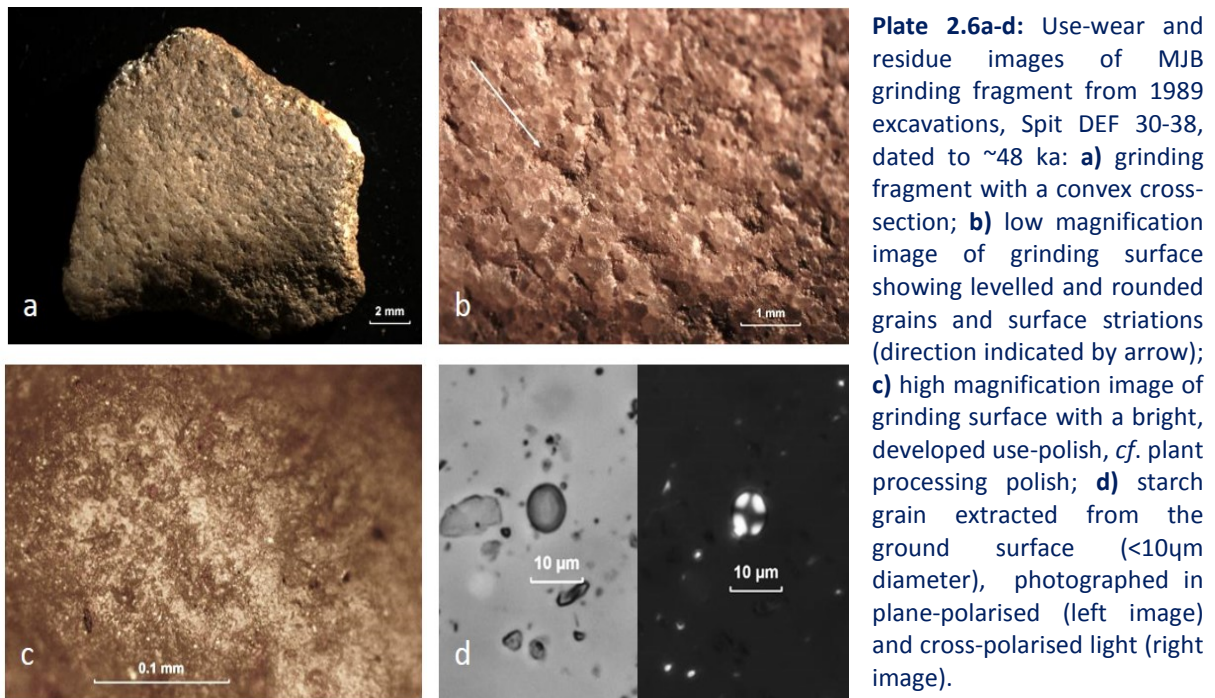
Reports of Pleistocene-aged grinding stones from semi-arid eastern Australia have indicated seed grinding at Cuddie Springs from at least 28 ka (~36 ka cal BP) based on residue, use-wear and technological studies (Fullagar & Field 1997; Fullagar *et al.* 2008). Artefacts from this site include fragments of the original implements, and at least two fragments have retained sufficient gross morphological features, residues and use-wear to indicate a seed-grinding function (Fullagar & Field 1997: 304-5). Wear traces include silica polish and diagnostic starch grains indicative of the processing of starchy and siliceous plants (including lily, nardoo and possible grass). These fragments represent two of six grinding stones recovered from Units 1 and 2 of the excavation, in which eight

radiocarbon dates have indicated an approximate calibrated radiocarbon age of around 39.2 – 36.5 ka cal BP (reported radiocarbon ages of 33.6 ± 5.3 – 29.2 ± 3.6 ka) (Fullagar & Field 1997: 302). The chronological resolution of the Cuddie Springs site remains unclear, with suggestions that the assemblage is an admixture of sediments, bones and cultural material from different levels (see Coltrain *et al.* 2004; David 2002; Gillespie & David 2001; Gillespie *et al.* 2006; Grün *et al.* 2010; Roberts 1997; Roberts *et al.* 2001a, 2001b). Consequently, the association of the dated material and the grinding stones of interest have been questioned. However, Field and colleagues (Field 2006; Field *et al.* 2001, 2006, 2008; Wroe & Field 2001a, 2001b; Wroe *et al.* 2004) have rigorously rejected these criticisms and strongly argue that the disturbance of bones and artefacts is minimal.

The occurrence of seed-grinding implements found eroding from open sites around rivers and lakes in the Darling Basin dated to ~8 ka cal BP (uncalibrated ages: 7.17 ± 0.1 ka BP) (Balme 1991), and from around the Willandra Lakes starting from ~25 ka (Chapter 7) (Fullagar *et al.* 2015) has indicated the use of such implements earlier than previously proposed. The age of these artefacts at some localities has been previously questioned by some who view the artefacts as lag deposits with no clear provenance (see references in Balme 1991: 3; Fullagar *et al.* 2015).

A preliminary investigation involving microscopic use-wear and residue analysis on a grinding stone fragment collected from MJB during the 1989 excavations and housed at the Museum and Art Gallery of the Northern Territory (MAGNT), provides evidence for the likely processing of plant materials, including possible seeds, from ~48 ka (Clarkson *et al.* 2015). This evidence includes a number of isolated starch grains (ranging from $<5 \mu\text{m}$ – $\sim 25 \mu\text{m}$) recovered from the ground surface, which is characterised by a distinctive use-wear polish indicative of seed grinding (Plate 2.6). Functional analysis performed on small flakes recovered from MJB has also indicated the processing of plant materials at this time (Hayes *et al.* 2014a).

There are relatively few functional studies of Pleistocene grinding assemblages, fewer still that involve residues and use-wear. With the exception of Cuddie Springs, Lake Mungo and MJB, functional analyses of Pleistocene grinding stone assemblages has not included high magnification observations with vertical incident light and examination of residues. For this reason, the antiquity of seed processing tools in the form of grinding stones is yet to be established with certainty, although there is evidence that seeds were collected and likely consumed in several early Australian human occupation sites (e.g., McConnell & O'Connor 1997). This evidence comes from the identification of macro-botanical materials recovered in Pleistocene deposits at sites such as Carpenter's Gap 1, dated at 15 – 22 ka BP (McConnell & O'Connor 1997) and MJB, dated at 52 ka (Florin 2013).



However, Smith (2013: 200) pointed out that the identification of seed material may only indicate seed collecting, rather than seed processing.

Gorecki *et al.* (1997: 145) noted that grinding stones, particularly millstones, are rarely discarded in archaeological sites and typically account for less than 0.3 per cent of the total artefact assemblage. Pleistocene-aged grinding stones are few in number and are usually represented by small fragments with few signs of manufacture or rejuvenation. Because fragments of specific grinding stone varieties are often difficult to recognise archaeologically (Smith 1989b: 306), it is unclear what functional types are represented within Pleistocene assemblages. Smith (2004: 170, 2013: 201) noted that often only 40 per cent of grinding stone fragments from archaeological sites may be assigned a typological form based on morphology, and therefore specific functional grinding stone types may be difficult to recognise.

2.4.1.2 Other plant food processing in Australia

Apart from seeds, many other plant parts have economic importance and are processed via grinding (Plate 2.5c, e) (e.g., Gott 2002; Jones & Meehan 1989; Latz 1995). Latz (1995) described 73 (non-seed) plant-food species used by ethnographic groups in Central Australia, with a similar number recognised in the semi-arid southeast of the continent (Gott 2002). Within the arid zone, including the Central and Western Deserts, grinding stones have been used to prepare paste from

dried solanum fruits, including *kampurarpa* (*Solanum* sp.), and ngaru (*Solanum eremophilum*) (Gould 1969: 20, 1971: 171; Gould *et al.* 1971: 163-4). In Arnhem Land, at least 238 plant species that have a documented Aboriginal use (see Table A1 for plant list and references), 33 of which are processed via grinding and pounding activities, and there are at least nineteen edible plant species that are ground prior to consumption (Table 2.3). Several fruits (e.g., *Buchanania obovata* and *Persoonia falcate*), cooked roots (e.g., *Eleocharis dulcis* and *Aponogeton elongates*) and underground storage organs (e.g., *Ipomea* and *Dioscorea* sp.) were processed by grinding, crushing and pulping using mortars and pestles (Table 2.3) (Chaloupka & Giuliani 1984; Jones & Meehan 1989; McArthur 1960a, 1960b).

In far northeast Queensland, incised slate grinding-stones, or “morahs” (Plate 2.4e), were used to crack and grind the kernels of both toxic and non-toxic nuts (e.g., Cosgrove 1996: 905; Woolston & Colliver 1971). Starch grain analysis performed on a selected morah implement has also confirmed the processing of at least two toxic nut varieties, including the Yellow walnut (*Beilschmiedia bancroftii*) and the Hairy walnut (*Endiandra insignis*). The occurrence of these specialised implements is significant for establishing the human settlement of rainforest regions, which was possibly facilitated by the ability to process toxic plants for consumption (Cosgrove *et al.* 2007; Field *et al.* 2009: 226). The earliest exploitation of toxic nut varieties (as determined by ages produced on the nut shell) in rainforest regions is suggested to have occurred by 2.5 ka cal BP and to have peaked after 1.5 ka cal BP (Cosgrove *et al.* 2007). Earlier occurrences for the consumption of toxic nuts (e.g., *Macrozamia riedlei*) are known elsewhere in Australia, from 13.5 ka BP in the southern region of Western Australia, although these foods may not have been ground to remove toxins. If not ground, the toxins could have been leached, fermented, roasted and aged (Smith 1982: 117).

At Kuk Swamp, PNG, the processing of starchy plants on several distinctive pounding tools is recognised from 10.2 ka ago, as indicated by the identification of starch grains from taro (*Colocasia esculenta*) and yam (*Dioscorea* sp.) (Fullagar *et al.* 2006). Starch grains identified on quartzite cobbles from Jinmium, a rockshelter in the Keep River region, northwest Northern Territory, indicated the processing of tubers from 2.3 ka ± 0.7 ka ago (Atchison & Fullagar 1998: 121; Field & Fullagar 1998: 105; Fullagar *et al.* 1996: 764, 770).

2.4.1.3 Faunal processing in Australia

The grinding and pounding of animal body parts has been observed ethnographically in many regions of Australia. The grinding of a complete animal carcass, including the bones, cartilage

and meat, was practiced to reduce wastage, aid mastication and digestion and in some cases, to improve taste (Binford 1987: 459; Peterson 1968: 367; Smith 1985: 24). In Arnhem Land, Peterson (1968: 567) observed the use of mortars and pestles in the breaking of animal long bones and skulls to extract marrow and brains; and in the pounding of cooked lizard, fish and kangaroo tail. The latter are pounded and ground into a palatable mass and consumed directly from the stone artefact surface. Similarly, in the Western Desert, local Aboriginal groups use grinding stones to pulverise small fauna, including introduced European species such as rabbits and feral cats (Plate 2.5d) (e.g., Cane 1989: 113; Gould 1969: 19, 1980: 193-194, 1981: 164; Gould *et al.* 1971: 163; Hayden 1979: 141).

The opportunistic use of grinding stones in the processing of animal body parts has also been documented for archaeological grinding stones from central Australia, Lake Mungo and north Queensland, where blood, animal collagen, hair fibres, feathers and bone fragments have all been identified on seed grinding stones (e.g., Balme *et al.* 2001; Fullagar *et al.* 2015; Smith *et al.* 2015; Stephenson 2011).

Table 2.3: Plant species from Arnhem Land that were ground (see Appendix A for references).

Pounding of plant flesh/roots	Pounding of seeds/shells/nuts	Pounding of plant for medicinal solutions	Pounding of stems to make fibre
<i>Amorphophallus paeoniifolius</i> <i>Aponogeton elongates</i> <i>Bridelia ovata</i> <i>Dioscorea bulbifera</i> <i>Dioscorea transversa</i> <i>Eleocharis dulcis</i> <i>Ipomea abrupt</i> <i>Ipomoea batatas</i> <i>Ipomoea diversifolia</i> <i>Ipomoea gracilis</i> <i>Ipomoea graminea</i> <i>Ipomoea velutina</i> <i>Pandanus spiralis</i> <i>Persoonia falcata</i> <i>Typhonium angustilobum</i>	<i>Brachychiton diversifolius</i> <i>Cycas media</i> <i>Nelumbo nucifera</i> <i>Oryza perennis</i>	<i>Buchanania obovata</i> <i>Calytrix brachychaeta</i> <i>Cassia mimosoides</i> <i>Cassia venusta</i> <i>Exocarpos latifolius</i> <i>Flagellaria indica</i> <i>Gymnanthera lucida</i> <i>Jacksonia dilatata</i> <i>Melaleuca viridifolia</i> <i>Morinda citrifolia</i> <i>Opilia amentacea</i> <i>Pityrodia jamessii</i> <i>Triodia microstachya</i>	<i>Tinospora smilacina</i>
n = 15	n = 4	n = 13	n = 1

2.4.2 Non-food uses for ground-stone tools

In addition to the processing of food for subsistence, grinding stones were also used in the processing of other materials for various purposes, including the provision of utilitarian tools such as

ground-edge implements, shell fish-hooks and bone points. These tools were used in the preparation of other materials such as hides and leather (Adams 1988, 1989a; Dubreuil & Grosman 2009; Cristiani *et al.* 2012), polished ornaments (e.g., Procopiou *et al.* 2011; Rosenberg & Golani 2012), and pigment (Adams 1998; Cristiani *et al.* 2012; Henshilwood *et al.* 2011; Nic Eoin 2012; Van Peer *et al.* 2003). In Australia, non-food grinding implements were used for processing a variety of organic and inorganic materials.

2.4.2.1 Organic materials

Grinding stones were used to shape wooden artefacts such as dishes, fighting sticks and digging sticks (Plate 2.7d) (e.g., Hayden 1979: 114; Kamminga 1982: 63; Thomson 1964: 408). Thomson (1964: 408) described the sharpening of wooden fighting sticks using a lower mortar stone, while McCarthy (1976: 62) described the use of smoothing and polishing stones (finely textured shale or sandstone pebbles) to finish the surface of wooden weapons and artefacts. Other plant materials, such as native tobacco, resins and gums, were also prepared using grinding and pounding stones. For example, the use of mortars and pestles in the preparation of *Erythrophleum chlorostachys* (ironwood tree) resin has been reported in Arnhem Land (Peterson 1968: 568), and spinifex gum (*Triodia sp.*) was prepared in the Western Desert (Plate 2.7a) (Brokensha 1975: 64-66; Latz 1995: 66-67). The preparation of native tobacco *Nicotiana gossei* and *Nicotiana excelsior* is also witnessed in this region, where the plant is crushed on mortar stones to release the nicotine prior to consumption (Plate 2.7c) (Brokensha 1975: 29-30; Latz 1995: 62-64). Other craft activities involving the production of string through the preparation of spinifex fibres are also documented for the Pilbara region (Withnell 1901). The fibres were softened by pounding between two stones, and then prepared into twine and used for making nets, baskets, cushions and other craft items (Latz 1995: 67; Pitman & Wallis 2012).

Grinding stones were used to process bone, shell and medicinal substances. Bone points, knives and other bone ornaments were shaped from macropod, bird and fish bones (Fullagar *et al.* 1999: 18; McCarthy 1976: 61). Bone-shaping stones are described by McCarthy (1976: 61) as flat-sided lumps or pebbles made of sandstone, shale or quartzite, used in the sharpening or shaping of bone or wood. These tools are identified from the east coast of Australia and from southeastern Australia, and may be recognised by the occurrence of long, narrow grooves on the surface. The crushing of human bones using mortars and pestles to create “magical” powder has also been reported for the Kimberly region (Plate 2.7b) (K. Akerman, pers. comm.).



Plate 2.7a-f: Grinding stones used in the processing of organic materials for non-subsistence purposes: **a)** preparing spinifex gum (*Triodia* sp.), Western Desert (from Brokensha 1975: 66); **b)** crushing human bone (radius) to create magical powder, Kimberley (photo by K. Akerman); **c)** preparing native tobacco, Western Desert (from Brokensha 1975: 30); **d)** sharpening of a wooden fighting stick, central Western Australia (from Thomson, 1964: 408); **e)** fish-hook files (from McCarthy (1976): Fig. 51).

Filing stones used for the production of shell fish-hooks have been ethnographically documented in southeastern Australia (e.g., Bradley 1969: 133; Tench 1961: 284; White 1962), with shell fish-hooks and fish-hook files documented archaeologically along the New South Wales coast

since the late Holocene (e.g., Lampert 1971a, 1971b; Megaw 1974; Megaw & Wright 1966). *Fish-hook files*, which have been described by McCarthy (1976: 62), occur as one of two morphological varieties: (1) triangular to leaf shape with a broad butt and flat upper and lower surfaces; or (2) cylindrical shape generally exhibiting a uniform diameter (Plate 2.7e). These tools are recognised in several regions of Australia, particularly along the coast of New South Wales, and are thought to be related to the production of shell hooks due to the identification of ground shell found in similar contexts (Attenbrow *et al.* 1998: 129). While many authors have accepted that the occurrence of these morphological stone varieties implies fish-hook manufacture (e.g., Dyall 1982: 55; Lampert 1971a: 68, 1971b: 128; Megaw & Wright 1966; Megaw 1974: 37; White & O'Connell 1982), many others expressed doubts as to the relationship between the files and the manufacture of shell fish-hooks (e.g., Bowdler 1983: 138; Flood 1989: 222; Walters 1988: 100). Functional analysis performed on a number of apparent fish-hook files from late Holocene contexts housed at the Australian Museum has indicated that, while some of these artefacts were used to grind shell, other worked materials, such as wood and possibly bone, were also documented, and thus some should be considered multi-functional tools (Attenbrow *et al.* 1998: 143-4). Other shell implements shaped from baler shell (*Melo sp.*), including ground-edge chisels and adzes (Plate 2.8a), are prepared using a small hand-held grinding (filing) stone made of silcrete and ferruginous grit, characterised by narrow, shallow grinding grooves (Akerman 1975: 16). The use of such tools has been observed in regions of in northwest Australia (Akerman 1975).



Plate 2.8a-b: Ground stone shell implements: **a)** hafted ground-edge baler shell (*Melo sp.*) adzes from Dampierland Peninsula, Western Australia; **b)** shell fish-hook file and shell fish-hooks (*Pinctada maxima* and *P. margaritifer*), northern New South Wales. Photos by K. Akerman.

At least 70 plant species from the central Australian desert are (or were) used for medicinal purposes, mostly represented by either *Acacia sp.* or *Eremophila sp.* (Latz 1995: 61). Within Arnhem

Land, at least 22 species of plants are used for medicinal purposes (Table A1, Appendix A), many of which are prepared by pounding and soaking to produce the required solutions ($n = 13$) (Table 2.3). The grinding of animal materials for medicinal purposes was observed recently in Arnhem Land during excavations at MJB. Mirarr ladies ground a green ant nest into a paste which was subsequently rubbed on the chest to reduce cold and flu symptoms. This was carried out using a portable upper stone and a bedrock grinding patch adjacent to the MJB rockshelter (Plate 8.7, Chapter 8).

2.4.2.2 Inorganic materials

Filing stones for processing inorganic materials such as haematite, ochre and stone are recognised both ethnographically and archaeologically in many regions of Australia (e.g., Gould 1968: 120; Horne & Aiston 1924: 56; McCarthy 1976: 67; McCarthy & Setzler 1960: 218; Vanderwal 1982: 88). The occurrence of ground-edge stone tools such as axes, hatchets, knives and blades, in both Pleistocene and Holocene contexts, has indicated that the grinding of stone was a common activity. This is evidenced by the occurrence of ground-edge stone axes (and fragments thereof) in northern Australia from 35 ka cal BP and in PNG from ~20 ka BP (28.8 ka cal BP) (Table 2.2) (e.g., Anderson & Summerhayes 2008; Clarkson *et al.* 2015; Geneste *et al.* 2010, 2012; Golson 2001; Schrire 1982). Two types of filing stone associated with the production of ground-edge stone implements are: (1) bedrock exposures with axe-grinding grooves (Plate 2.9b), and (2) portable, hand-held whetstones. Axe-grinding grooves are found throughout Australia, most commonly in sandstone surfaces along creek and river margins and less frequently in rockshelters (Dickson 1981: 43; Hiscock & Mitchell 1993: 6, 58, 69). Following robust experimental work, Dickson (1981: 43) suggested that axe-grinding grooves may be identified on the basis of their characteristic dimensions: between 20 and 25 cm in length, 5 and 8 cm in width, and 2 and 4 cm in depth at mid-length. Dickson (1972: 208) argued that grooves outside this size range were unsuitable for axe grinding and, therefore, were likely used for other purposes. Axe-grinding grooves are recognised on the basis of these dimensions, which are ubiquitous in many regions of Australia, particularly in northern Queensland (e.g., Morwood & Godwin 1982; Wallis *et al.* 2004), Arnhem Land (e.g., Taçon 1991) and throughout southern New South Wales (Dickson 1972: 208; McCarthy 1946: 266).

Whetstones are common along the interior of Australia but are scarce along the east coast (McCarthy 1976: 61). Australian whetstones typically range in size from 5 – 25 cm in length, are usually round and oval in shape, and may have a groove extending the full length of the stone surface. Although these whetstones are typically younger than ~5 ka in southeastern Australia,



Plate 2.9a-c: Grinding stones used to process inorganic materials: **a)** pressure flaking of glass using a stone anvil, Kimberley (Photo by K. Akerman); **b)** polishing an axe blade in a fixed groove, Tagi Valley, New Guinea (from De Beaune, (2004): Fig. 14); **c)** ochre stained grinding slab used to create pigment, Kimberley (Photo by K. Akerman).

older ground-edge axes are present in northern WA, NT and QLD and New Guinea from at least 35 ka cal BP. Bedrock grinding patches cannot be dated, and perhaps some could be of Pleistocene age.

In addition to the grinding of various stone varieties, the preparation of pigments, including the grinding of ochres and haematite, is observed ethnographically throughout Australia (Plate 2.9c) (e.g., Binford 1987: 474; Peterson & Lampert 1985: 6). In central Australia, within the Karrku ochre mine, ochre was ground into a fine powder through hammering and rubbing against grinding stones (Peterson & Lampert 1985: 6—Figure 2.1c shows locations of ochre mines). In northern Australia, pestles have also been reportedly used as palettes to hold pigment during ritual body decoration (Peterson 1968: 568). Binford (1987: 474) remarked on the frequent occurrence of grinding stones in the processing of red ochre that was used during male ritual ceremonies in the Central Desert. The occurrence of amorphous grinding stones in Pleistocene archaeological deposits, in association with abraded pigment pieces, may indicate that the stones functioned as filing stones used to process pigments. Abrasive wear on the pigment pieces sometimes include scratches of various orientations and depths, and may indicate contact with stone, either by means of direct rock painting (i.e., rock art on shelter walls) or via the use of filing stones (Taçon & Brockwell 1995).

Grinding and pounding stones are also directly linked with the production of rock art, for example, the production of petroglyphs and cupules, which are pecked circles or pecked pits that occur within a bedrock surface, and have been recorded in many regions of Australia, concentrated in the Kimberley, Keep River, Arnhem Land, Kakadu and Cape York areas in northern Australia (e.g., Chaloupka 1993; Cole & Watchman 2005; Donaldson 2007; Edwards 1979; Flood 1987, 1997;

Graham & Mulvaney 1995; Jones & Brockwell 1990; McNickle 1991, 1993; Sullivan & Haskovec 1986; Taçon *et al.* 1997; Walsh 1994; Watchman 1997, 2004; Watchman *et al.* 1997; Welch 1993). McCarthy (1976: 61) has noted the use of grinding stones as rock art engraving and pecking tools in the creation of these features, and use-wear analysis of cupules from northern Australia has indicated a likely manufacture process involving pounding stones (Wright *et al.* 2014: 96). Other use-wear studies performed on cobble stones found at Jinmium have indicated that these stones were probably used to produce circular engravings/cupules at the site, implied by low or no use-polish development and percussion damage evidenced on stone surfaces (Field & Fullagar 1998: 104).

A Pleistocene antiquity is suggested for some of the cupules found within Arnhem Land and the Kimberley region, the evidence for which is based loosely on oral histories (Chaloupka 1993: 235) and studies of art superimposition (e.g., Taçon & Chippindale 1994: 215). Direct radiocarbon ages for cupules have indicated a more recent minimum age for these features starting from approximately 5.2 ka (Kamminga & Allen 1973: 88). These ages have been provided following the dating of charcoal samples associated with buried slabs with cupule engravings; e.g., at Jinmium, dated at 2.3 ka cal BP (uncalibrated age: 1.79 ± 1.5 ka BP) (Roberts *et al.* 1998b: 359) and the Leichardt site, Arnhem Land, dated at 5.6 – 6.2 ka cal BP (uncalibrated age: 5.18 ± 1.3 ka BP) (Kamminga & Allen 1973: 87) and oxalate salts present in a mineral crust overlying a cupule in the Kimberley, dated at 3.9 – 4.5 ka cal BP (uncalibrated ages: 2.2 ± 0.1 – 3.88 ± 1.1 ka BP) (Aubert 2012: 575; Morwood *et al.* 2010; Watchman 1997, 2004; Watchman *et al.* 1997).

2.5 Distribution of Australian grinding stones

2.5.1 Geographical distribution of grinding stones

Grinding stones are found in most parts of Sahul, including the more temperate regions as well as the arid interior (Figure 2.1a). Most from the arid zone are fragments, many from broken millstones and other seed processing tools. These have been found in both open sites and rockshelters, and are usually made of sandstone, granite, basalt and quartzite. In the Pilbara region and stony desert of northwestern Australia, grinding implements are often formed on tough, hard rocks such as banded ironstone, granophyre and granite, in addition to sandstone. The hard stones from the Pilbara region are very resistant to weathering, and sometimes preserve rock art engravings as well as polished surfaces. Grinding stones from tropical regions of northern Australia and along the coastlines are similar to the stones identified in the desert regions. They are more commonly made of sandstone, but do not always display the same morphological forms as the

desert artefacts described by Smith (1985, 1986, 1989b)—commonly millstones, mullers, mortars and pestles (or fragments thereof). However, other morphological forms are noted, such as the incised slate grinding stones, or *morahs*, from far-north Queensland (Cosgrove 1996: 905; Cosgrove *et al.* 2007: 150) (Section 2.4.1.2), and specialised “fish-hook files” along the southeast coast of New South Wales (Attenbrow *et al.* 1998). Other filing stones, such as axe-grinding grooves, are recognised from many regions across Australia and generally present with consistent morphological features.

2.5.2 Temporal distribution of grinding stones

The temporal distribution of grinding stones in Australia can be summarised in relation to a number of general trends. Apart from the higher frequencies of grinding stones from more recent archaeological contexts, there appears to be marked variability in the morphological features of grinding stones recovered from Pleistocene and late Holocene contexts. Pleistocene grinding stones are typically represented by “amorphous” (Smith 1985, 1986, 1989b) grinding fragments and often display irregular surface features, no recurring form and less intensive grinding wear than in the Holocene. The grinding stone assemblages from the Pleistocene contexts of Cuddie Springs (Fullagar *et al.* 2008) and Lake Mungo (Fullagar *et al.* 2015) are currently the only exceptions to this general observation. In contrast, grinding stones appearing after 3 – 4 ka are often represented by tools resembling standardised grinding forms, such as millstones, mullers, mortars and pestles; and often display well-worn surfaces, distinct cross-sections and intensive grinding wear. Based primarily on the morphological features, grinding stones from Holocene contexts are believed to be specialised implements designed for processing specific materials. Millstones and mullers, for example, were used to process soft grass seeds and mortars and pestles were used to pound harder seeds, such as *Acacia* sp. In contrast, Pleistocene grinding stones are thought to have been used expediently for the processing of multiple materials, and, therefore, do not display any distinctive morphological features (Smith 2004). The lack of use-wear and residue studies performed on grinding stones from Pleistocene contexts, however, means that the function of these tools remains relatively unknown. Previous studies of grinding stone function here in Australia, and elsewhere in the world, have indicated that morphological features are not a reliable guide to artefact function (see Wright 1994). Not only are grinding stones from late Holocene contexts morphologically distinctive, but they also occur in much greater frequencies than the grinding stones recovered from Pleistocene or early Holocene contexts. Smith (2004: 175) reported a significant shift in the frequency of grinding stones from different chronological contexts of Puritjarra rockshelter, a site in the Central Desert spanning

>30 ka of occupation. He found that grinding stones were few in Pleistocene contexts but increased significantly at 7.5 ka and became even more abundant within the most recent occupation unit (Unit 1a, dated at 0 – 0.8 ka BP). In other Pleistocene sites across Australia, grinding stones are scarce. While this may be related to sampling strategy (i.e., there are relatively few excavated Pleistocene sites in Sahul), other researchers have argued that the proliferation of grinding stones (as well as other stone tool technologies) after 3 – 4 ka BP may represent risk mitigating strategies (e.g., Attenbrow 2004: 218; Attenbrow *et al.* 2009; Cosgrove *et al.* 2007; Hiscock 2002, 2006, 2008). The depletion of higher ranked resources resulting from the unpredictability and harshness of the environment is thought to have enhanced subsistence risk, causing an increase in residential mobility and standardisation of stone tool forms (Asmussen & McInnes 2013). This argument has also been presented for backed artefacts, whereby the frequency of these implements increased substantially during cooler, drier conditions of the mid-Holocene ~3.5 – 4 ka (Attenbrow *et al.* 2009: 2769; Hiscock 2002, 2006). Hiscock (2006: 85) argued that these standardised, multi-purpose artefacts would be most cost effective in “circumstances with low resource predictability, induced by either high mobility and/or unfamiliarity with the environment, in which systematic scheduling of activities was difficult”. It is possible that a similar scenario has influenced the frequency, form and distribution of grinding stones.

2.6 Chapter Summary

Grinding stones and other evidence of grinding technologies have frequently been observed ethnographically and found in many archaeological sites around the world. Particular forms of grinding and/or pounding technologies have been linked with early hominins, modern non-human primates, modern humans, and post-Pleistocene cultural sequences and phases (e.g., transitions from hunting and gathering to sedentism, and the origins of agriculture). How should we explain archaeological evidence for grinding stone technologies when they appear earlier in Sahul than in southeast Asia, from where the first Australians are thought to have emigrated? I argue that a key to understanding these technologies and associated behaviours in such diverse archaeological and environmental contexts is the nature of the grinding implements themselves; their form, their life histories and particularly their function. Ground implements are made of diverse material, including stone, bone, wood, antler, ivory, shell and pigment. Grinding stones, which I defined as use-ground stone implements, have the potential to provide information regarding past subsistence practices, craft activities and the social and economic structures of communities. In Australia, grinding stones are represented by stones shaped from a variety of materials, including sandstone, granite, basalt,

quartz, quartzite, silcrete, ironstone and slate. There is an increase in the number of grinding implements in sites from the arid region of Australia, during the late Holocene and after 1.5 ka. Grinding stones are still used by many contemporary Aboriginal groups. While seed grinding is often thought to be the most common function of Holocene grinding stones, other ethnographically documented functions include the grinding of stone implements (e.g., stone hatchets) and the processing of seeds, tubers, nuts, wood, bone, small animals, shell and pigments (e.g., ochre and haematite). Although grinding stones occur in Pleistocene contexts, they are rare, heavily worn and fragmented. Functional studies on artefacts of this antiquity are also rare. Previous studies suggest that two sites in Australia have particularly high potential for exploring the function and temporal distribution of grinding stones: MJB and Lake Mungo.

Chapter 3:

Archaeological sites: Madjedbebe and Lake Mungo

3.1 Introduction

The grinding stones analysed for this thesis were retrieved from two important archaeological sites in Australia: MJB and Lake Mungo, located within the Top End of the Northern Territory and western New South Wales, respectively (Figure 3.1). Both sites are significant for understanding the nature of the earliest material culture close to the time of initial human colonisation of Australia, with evidence in the form of abundant stone and other artefact assemblages present through major climatic cycles spanning the last 50 ka. Analysis of the artefacts from these sites has potential for investigating early settlement technology and technological/behavioural changes through time as well as human responses to climatic and environmental change. This chapter provides a description of each site, including details of the excavations, the archaeological materials recovered, site chronologies and the selection of artefacts for analysis.

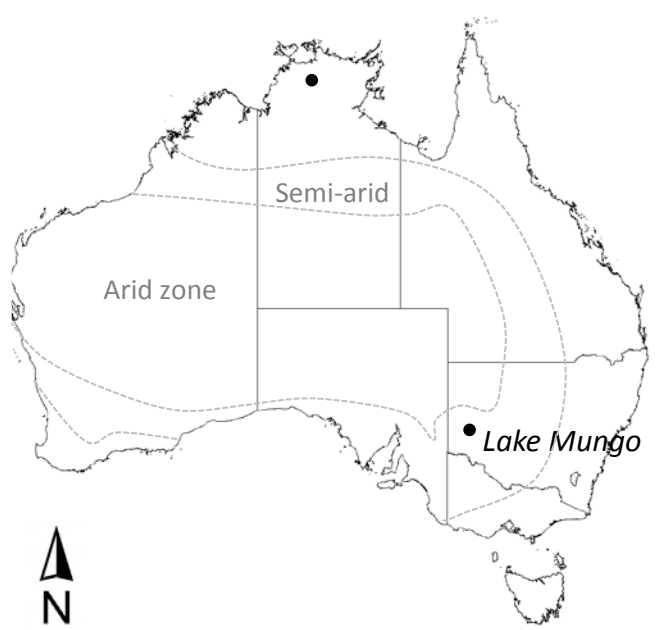


Figure 3.1: Map indicating location of study sites (MJB and Lake Mungo) and general climatic regions within Australia. After Smith (1986): Fig. 1.

3.2 Site 1: *Madjedbebe*

3.2.1 Site description

MJB is a narrow rockshelter located within Kakadu National Park, northern Australia, extending a few metres over a low-gradient sand-apron that has developed at the base of the western escarpment of the Arnhem Land plateau (Figure 3.2; Plate 3.1a-b) (Clarkson *et al.* 2015;

Roberts *et al.* 1990a). The overhang of the shelter on the northwestern face of the sandstone massif is relatively small compared to the length of the protected shelter floor (Plate 3.1b). An extensive gallery of rock art extends across much of the shelter wall, depicting images from both pre- and post-European contact (Plate 3.1c). The MJB sand-apron consists of ~460 cm of poorly sorted medium sand and silt overlying a rubble sandstone layer (Roberts *et al.* 1990a). The sediments are composed of weathered material from the adjoining quartzose sandstone escarpment of the Middle Proterozoic Kombolgie Formation (East 1996: 40). The site has been excavated three times, decades apart: in 1972, 1989 and 2012 (see Clarkson *et al.* 2015; Section 3.2.2). Within the excavated deposits, abundant cultural material included, for the most part, stone artefacts, pigments and faunal remains. Plant remains were also present. The 2012 excavations, carried out by Chris Clarkson and colleagues in partnership with the Gundjeimi Aboriginal Corporation (GAC), have provided all grinding stone specimens analysed as part of this thesis (Section 3.2.4).

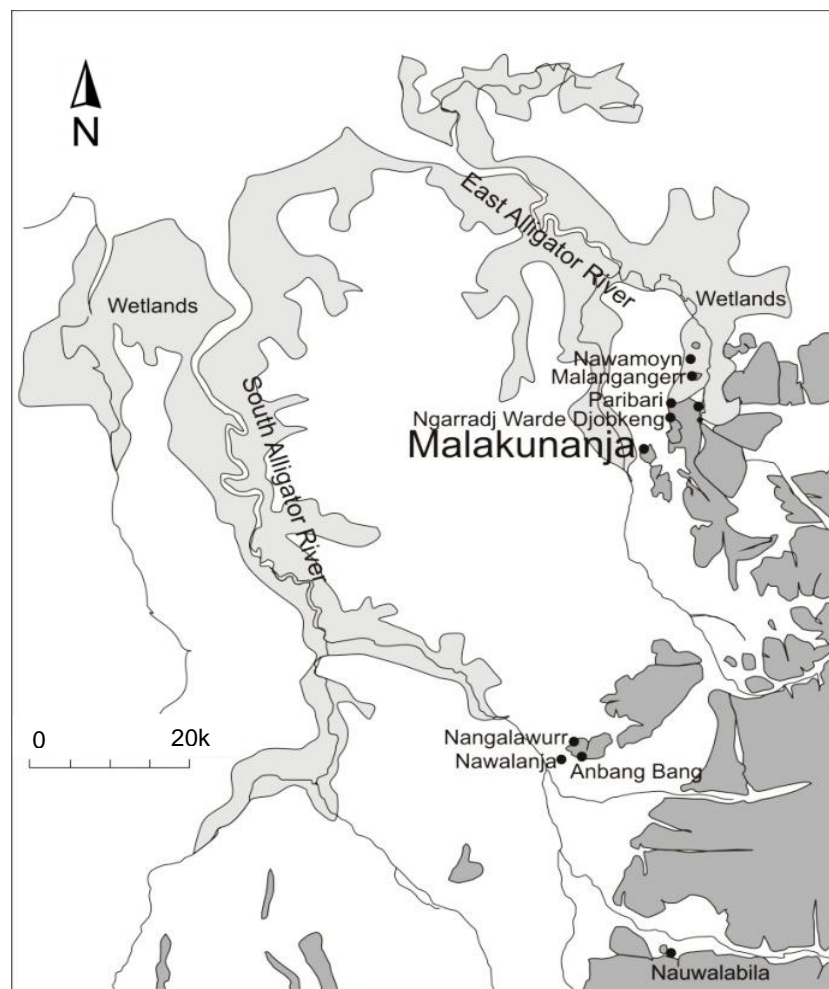


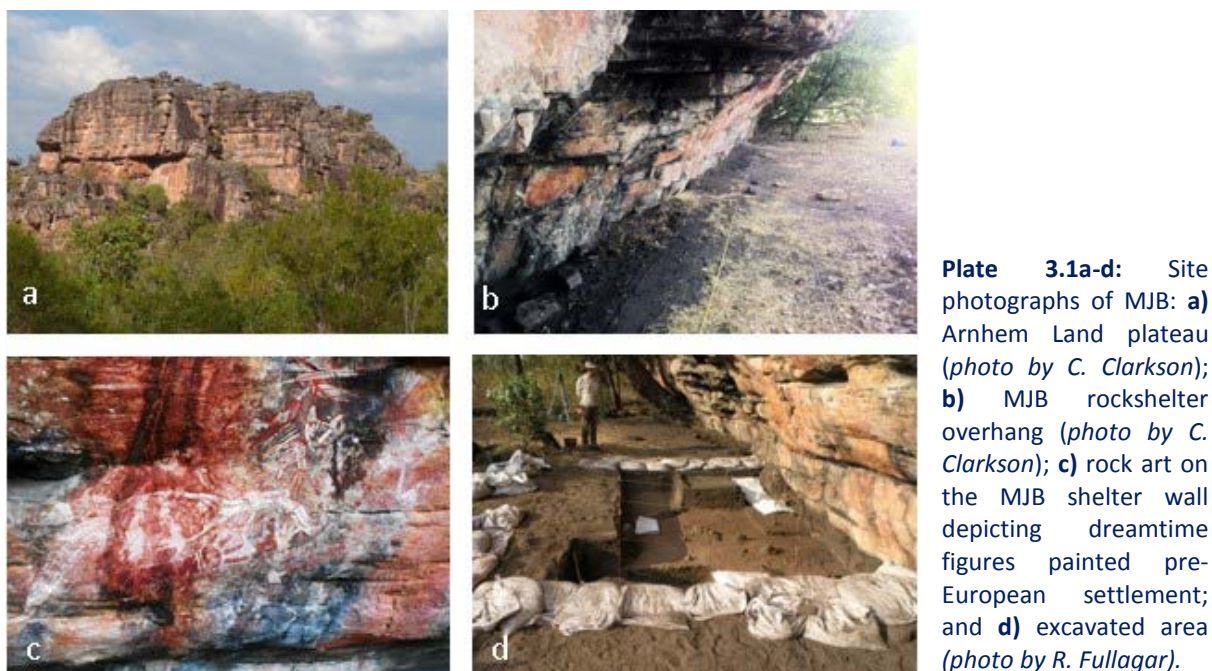
Figure 3.2: Location of MJB (referred to in map as “Malakunanja”) in relation to other excavated sites in Kakadu. After Clarkson *et al.* (2015): Fig. 1.

3.2.2 History of excavations

MJB was first excavated in 1972 by Johan Kamminga as part of a larger study to assess the antiquity and richness of archaeological resources in Kakadu National Park, Northern Territory (Clarkson *et al.* 2015; Kamminga & Allen 1973). A test pit was excavated against the back wall to a depth of 248 cm in which cultural material was identified near to the base of the excavation. An extensive shell midden was uncovered within the first 60 cm and contained human burials, the bones of bird, reptile and marsupial species, and the remains of crustaceans and molluscs. Numerous stone artefacts were identified, including several grinding stones and retouched points made from a variety of stone materials. Below the midden laid sandy deposits containing mostly quartz artefacts. At the base of the excavation, a number of haematite crayons and one very large and smooth grinding dish were identified. One radiocarbon age ($18,040 \pm 300$ BP—SUA265) came from Spit 19 (188 cm – 215 cm below surface), and about 60 cm – 33 cm up from the base of the excavation. However, this age estimate is considered problematic, owing to the limitations of the method on small old samples, and the depth over which the sample was collected.

The second excavation at MJB was carried out in 1989 by Mike Smith, Bert Roberts and Rhys Jones. In this excavation, a 1.5 x 1 m pit was excavated to a depth of approximately 460 cm. A dense occupation layer was identified ~202 – 252 cm below the surface and contained a large number of silcrete flakes, ground haematite, utilised pieces of red and yellow ochre, grindstone fragments and quartzite artefacts (Roberts *et al.* 1990a). A small number of artefacts were also found directly below this dense occupation layer, down to approximately 287 cm below surface. At the lowest artefact levels, a lens layer cut into the deposit and was excavated separately as Spits 41, 43 and 62. Sediments for thermoluminescence (TL) and charcoal and shell remains for radiocarbon dating were recovered from various depths; these have been used to create a chronology for the site (Section 3.2.3).

The most recent excavation of MJB was carried out in June/July 2012 by a small team led by Chris Clarkson, Richard Fullagar, Ben Marwick and Lynley Wallis, in partnership with the GAC. Mike Smith and Bert Roberts (members of the second excavation) also participated at various stages of fieldwork. Jo Kamminga (the first excavator) also visited the 2012 excavations. These excavations were focussed on increasing the artefact sample size and refining the site chronology, stratigraphy and assemblage composition. The excavated area on the surface included nine adjoining 1 x 1 m squares (C2, C3, C4, D2, D3, D4, E2, E3 and E4) and two smaller squares (~6 cm x 30 cm—B2; and 1 m x 50 cm—B3) (Figure 3.3). In the upper midden deposit, squares were excavated in 5 cm spits while in the lower sands, squares were excavated in 2 cm spits (Lowe *et al.* 2014: 150). Excavation was



discontinued at a depth of 120 cm in Squares E3, E4 and D4 to create a step into Squares C2, C3, C4, D2, D3 and E2. All of these squares were excavated to a depth of approximately 300 cm while Squares B2 and B3 were excavated to a depth of 350 cm (Plate 3.1d). Cultural material was identified throughout the deposit to a depth of ~280 cm, mostly consisting of stone artefacts, ground pigment and various forms of burnt flora and faunal remains (Section 3.2.4) (Clarkson *et al.* 2015). The location of each artefact was recorded in three-dimensional space using a Nikon Total Station with Trimble Survey Pro software so that an accurate recording of their distributions could be provided. The distributions of the lithic artefacts, including grinding stones, lithics and ground edge axes, as well as the distributions of ground haematite pieces, are presented in Figure 3.4. Figure 3.5 includes section drawings of the southeast (SE), northeast (NE) and northwest (NW) walls of MJB following the 2012 excavations.

3.2.3 Chronology

MJB is one of the oldest dated Aboriginal occupation sites in Australia, possibly predating sites such as Nauwalabila, Devil's Lair, Lake Mungo and Carpenter's Gap (Bowler & Price 1998; Bowler *et al.* 2003; O'Connor 1995; Roberts *et al.* 1998a; Turney *et al.* 2001). Original age estimates for the lowest cultural levels of MJB were obtained by Roberts *et al.* (1990a) using TL to produce bracketing ages of 45 ± 9 ka and 61 ± 13 ka. These ages were obtained from measurement of unheated quartz sediments using a combination of additive-dose and regenerative-dose multiple

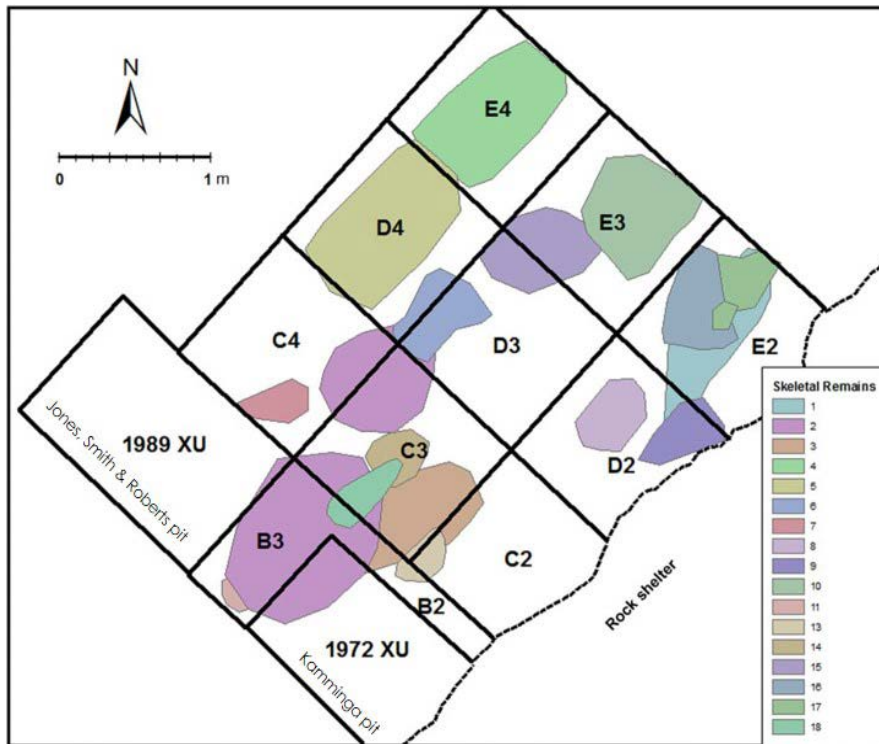


Figure 3.3: A plan view map diagram showing the nine 1 x 1 m test-pits (Squares C2, C3, C4, D2, D3, D4, E2, E3 and E4) and two smaller test-pits (B2 and B3) making up the MJB 2012 excavation. The coloured shapes indicate the locations of the 17 burials identified in the midden deposits. From Lowe *et al.* (2014): Fig. 5.

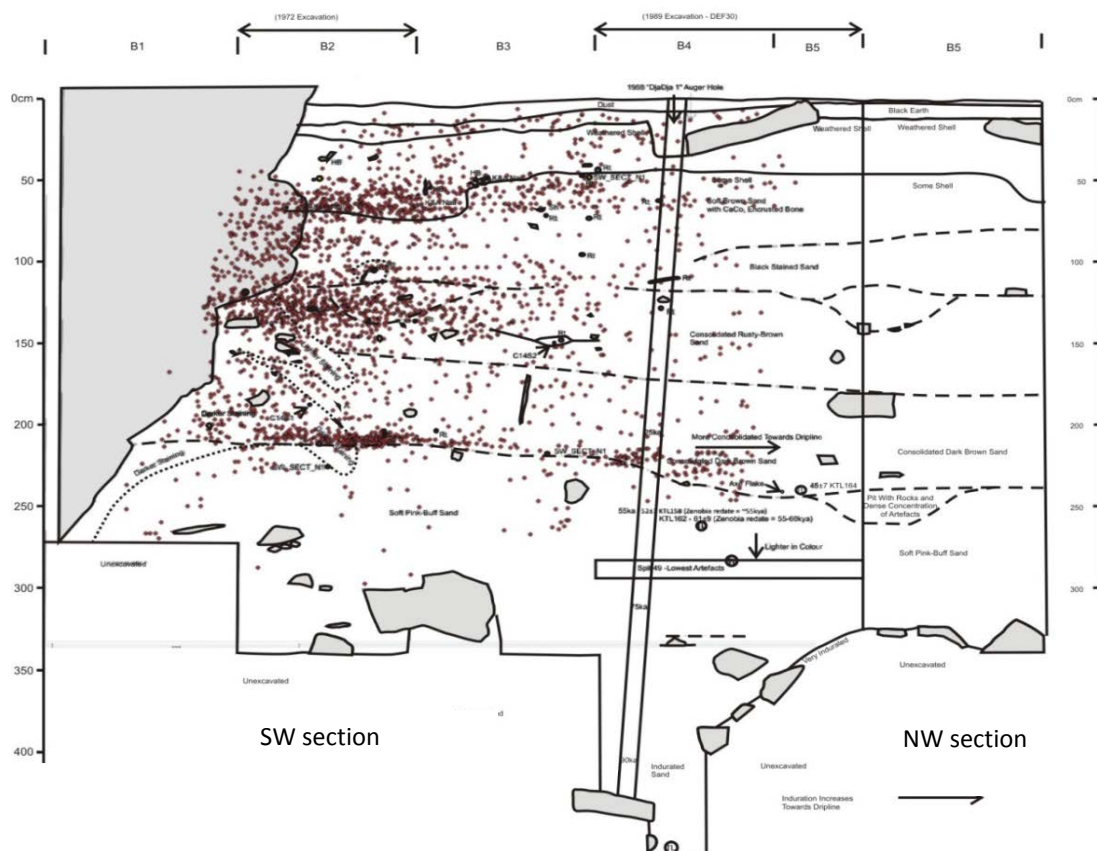


Figure 3.4: Distribution of artefacts (red circles) throughout the excavated sequence at MJB. Plotted finds included ground haematite, lithics, bone tools, grinding stones and ground edge axes. Note three distinctive artefact pulses.

aliquot techniques to obtain palaeodoses (Roberts *et al.* 1990a, 1998b; see Murray & Wintle 2000). Environmental dose rates were obtained by high-resolution gamma spectrometry (Roberts *et al.* 1990a). A confirmatory TL age of 52 ± 11 ka has been provided from an intervening sample obtained from a separate auger hole made adjacent to the original excavation (Figure 3.5) (Roberts *et al.* 1990a). Single aliquot and single grain methods of dating were not available when the first luminescence ages were generated.

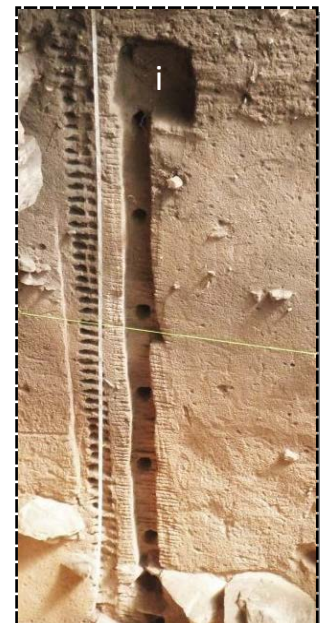
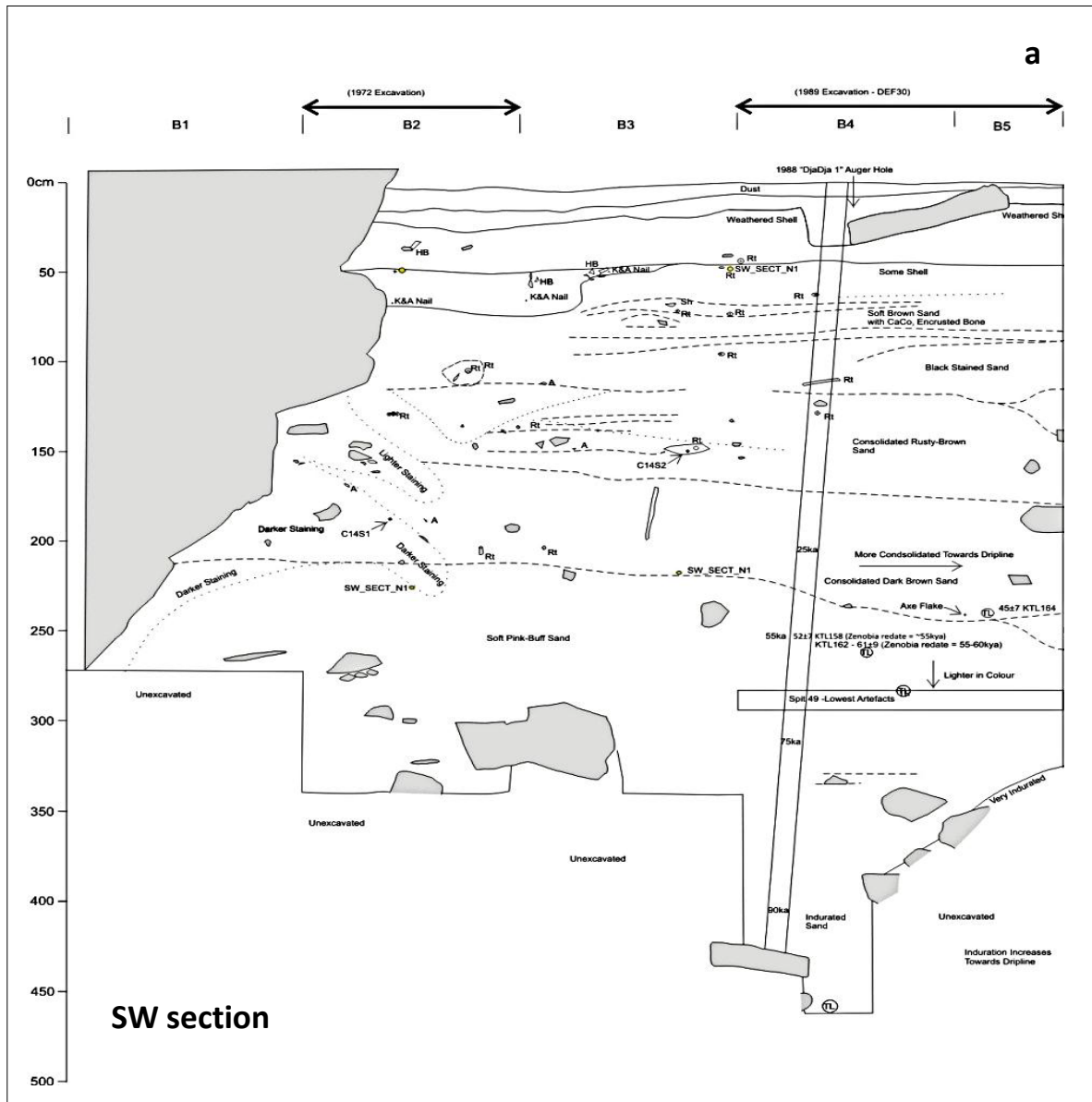
Key concerns associated with the initial ages provided by Roberts *et al.* (1990a) were related to issues of stratigraphic integrity of the site (e.g., Allen & O'Connell 2003; O'Connell & Allen 1998, 2004) and reliability of the TL ages themselves (Allen & O'Connell 2003). Post-depositional mixing of sediments by means of bioturbation may have caused the displacement of artefacts into younger or older unconsolidated deposits. Movement of sand grains from lower deposits upwards may have provided ages for artefacts that were not associated at the time of discard and deposition. While Roberts *et al.* (1990a, 1990b, 1990c) and Roberts (1997: 856) have argued that the stratigraphic integrity of this site had remained relatively undisturbed; the *in situ* status of the lowest artefacts has been questioned with some authors suggesting the downward displacements of artefacts (e.g., O'Connell & Allen 2004: 846). Roberts *et al.* (1990b, 1990c, 1994a, 1994b) insisted, however, that movement of artefacts over significant distances was unlikely, particularly as the vertical distribution of artefacts by raw material type appeared to be undisturbed and because the pit feature had been overlain by well-defined sedimentary units. Additionally, Roberts (1997: 856) maintained the *in situ* status of those artefacts recovered from a small pit feature at a depth of 232 cm. Roberts *et al.* (1990a) also noted that the TL ages were in correct stratigraphic order and were consistent with radiocarbon ages obtained from a similar depth interval (Table 3.1). More recent re-dating of the sediments using single-grain and multiple-grain OSL dating techniques, has also supported the TL ages of the earliest occupation levels (Roberts *et al.* 1998b). In these analyses, multi-grain OSL ages were provided for samples KTL 164 and KTL 162, yielding ages of 45.7 ± 4.1 ka and 60.7 ± 7.5 ka, respectively (Roberts *et al.* 1998b). Single-grain OSL measurements, that involve the measurement of OSL signals for individual grains, have also supported these ages, with ages of 44.2 ka \pm 4.7 ka for sample KTL 164 and 55.5 ka \pm 8.2 ka for sample KTL 162 (Table 3.1) (Roberts *et al.* 1998b). The application of this technique, which follows similar protocols of other numerical dating methods such as in fission-track and argon-argon whereby grains are analysed individually, enables an opportunity to identify and discard any aberrant grains within a sample before the final age determination (e.g., Jacobs *et al.* 2003, 2006a, 2006b; Roberts *et al.* 1999; Yoshida *et al.* 2000). The same degree of data validation is unattainable using aliquots composed of multiple grains as these

conceal the effects of the depositional and post-depositional history of a sample by providing an averaged measurement of the cumulative OSL signal.

Single-grain optical ages for samples KTL 162 and KTL 164 were obtained by measuring a total of 85 and 86 grains per sample, most of which were weakly luminescent and as such, only 18 of them produced significant OSL signals. Because the dates obtained from single-grain OSL have been produced by measuring only a small selection of grains, this method is not able to dismiss claims of post-depositional mixing—one of the known advantages of employing the single-grain methodology. Additionally, the sample tube diameters used to obtain the sediment samples were wide (approximately 10 cm), and included sand grains from other sedimentary units of different ages. In

Table 3.1: Published and unpublished luminescence and radiocarbon ages obtained from the 1972, 1989 and 2012 excavations at MJB. Ages produced by Clarkson *et al.* (2015) were made on samples from all excavations following new pre-treatment methods. Shaded squares indicate bracketing ages for the Pulses of grinding stones where ages have been attributed.

Sample no.	Depth (cm)	TL age (ka)	OSL [‡] age (ka)	OSL [†] age (ka)	C ¹⁴ age (ka BP)	C ¹⁴ age range (cal. ka BP)
KTL 156	1-2	0.2 ± 1.3 ^a	-	-	-	-
ANU-7002 [‡]	13	-	-	-	3.8 ± 0.08 ^d	4.3 – 4.1^d
ANU-7003 [‡]	59	-	-	-	6.3 ± 0.09 ^d	7.3 – 7.2^d
ANU-7004 [°]	93	-	-	-	7.3 ± 0.2 ^d	8.4 – 7.9 ^d
OZQ509 [°]	101	-	-	-	8.2 ± 0.1 ^d	9.4 – 9.1^d
ANU-7005 [°]	113	-	-	-	10.5 ± 0.1 ^d	12.6 – 12.4 ^d
ANU-7006 [°]	146	-	-	-	13.4 ± 0.4 ^c	16.7 – 15.5 ^c
KTL 165	149-155	15 ± 3 ^a	-	-	-	-
ANUA-9913 [°]		-	-	-	10.3 ± 0.2 ^c	11.9 – 12.4 ^c
ANUA-9914 [°]		-	-	-	13.1 ± 0.2 ^c	15.3 – 16.1 ^c
ANU-7007 [°]	158	-	-	-	15 ± 0.2 ^d	18.4 – 18.1^d
ANU-7115	178	-	-	-	18.8 ± 2.1 ^d	24.9 – 19.9 ^d
OZQ463	189	-	-	-	24.5 ± 0.1 ^d	28.8 – 28.3^d
KTL 97	190-209	24 ± 5 ^a	-	-	-	-
SUA-265 [°]		-	-	-	18.0 ± 0.3 ^c	21.9 – 21.1 ^c
OZQ698	210	-	-	-	31.9 ± 0.1 ^d	36.2 – 35.5^d
KTL 164	230-236	45 ± 9 ^a	45.7 ± 4.1 ^b	44.2 ± 4.7 ^b	-	-
KTL 158	241-254	52 ± 11 ^a	-	-	-	-
KTL 162	254-259	61 ± 13 ^a	60.7 ± 7.5 ^b	55.5 ± 8.2 ^b	-	-
ANUA-9915 [°]		-	-	-	10.8 ± 0.2 ^c	13.0 – 12.8 ^c
KTL 141	295-315	65 ± 14 ^a	-	-	-	-
KTL 116	390-411	86 ± 18 ^a	-	-	-	-
KTL 163	452-458	107 ± 21 ^a	-	-	-	-



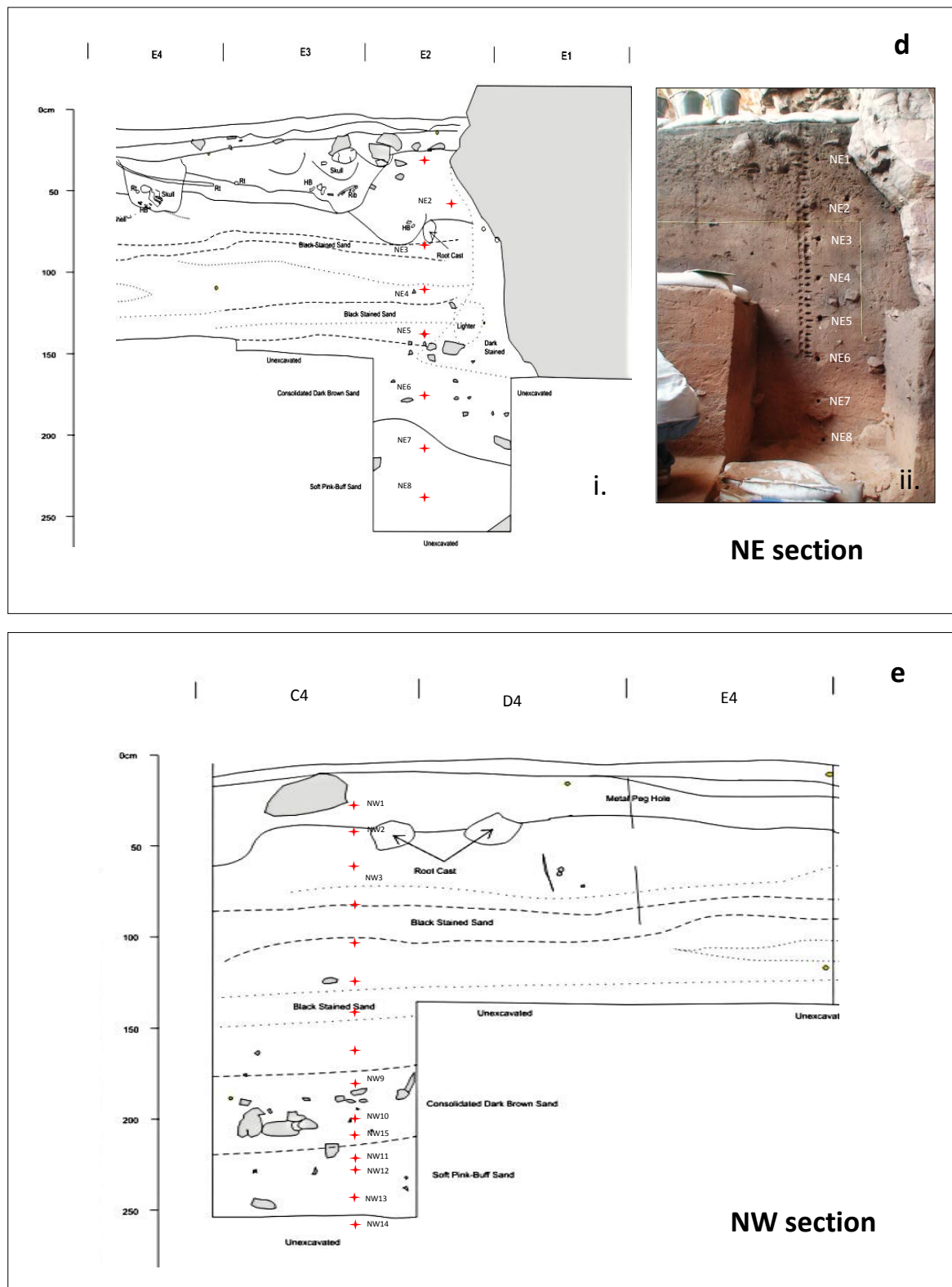


Figure 3.5: Section drawings of MJB showing site stratigraphy and OSL sample locations: **a)** *previous page*: southwest section of the site showing stratigraphy and key features; **b)** southwest wall showing the location of sediment removals for OSL dating (outlined), micromorphology (i) and phytoliths evaluation (ii); **c)** close-up image of OSL sediment sampling area (below micromorphology sample **d**) northeast section of the site showing site stratigraphy and OSL sample tube locations (red diamonds): **i)** stratigraphic illustration; **ii)** section photograph; **e)** northwest section of the site showing site stratigraphy and OSL sample tube locations (red diamonds).

order to assess claims of post-depositional disturbance of sediments and to attempt a more highly resolved chronology for the site, sediments suitable for OSL analyses were re-sampled during the 2012 excavations. Sediments were collected from three walls of the excavation; these included the southwest (SW) wall (n = 122, sampled at 2 cm intervals between depths of 77 cm and 334 cm), the northwest (NW) wall (n = 15, sampled at intervals of approximately 20 cm), and the northeast (NE) wall (n = 8, sampled at intervals of approximately 30 cm).

Single-grain OSL age measurements for the sediment samples collected in 2012 were analysed at the OSL laboratory at the University of Wollongong by Z. Jacobs. The preliminary analysis suggests that sediment mixing has occurred in several locations in the sequence and is most evident in samples collected closer to the shelter wall, i.e., samples collected from the SW and NW walls (unpublished data). The latest OSL chronology provided by Z. Jacobs confirms the antiquity of early occupation at MJB, but further refinement is required. In addition to the latest OSL chronology, radiocarbon dates have been provided for charred botanical remains collected from various depth intervals during the 2012 excavations.

3.2.4 Climate history, landscape change and palaeo-vegetation

The changing environmental conditions experienced throughout western Arnhem Land and the corresponding landscape and vegetation characteristics are summarised in Table 3.2. Oxygen isotope data derived from deep sea cores have provided global reconstructions of the Earth's paleoclimate whereby alternating warm and cool periods are characterised by marine oxygen-isotope stages (MIS). Based on the current chronology for the earliest human occupation at MJB, modern human populations likely entered the continent at the onset of MIS3 (60 ka – 27 ka), a period characterised by several abrupt climatic warming phases that saw the onset of mild, interstadial conditions (Van Meerbeeck *et al.* 2009: 33). At the time of colonisation, sea levels were at least 60 m below that of the present (Torgersen *et al.* 1988: 38). Late Pleistocene palaeo-environmental data for western Arnhem Land reconstructed from pollen evidence derived from an offshore marine core ("GC-2") has suggested wetter environments at c. 40 – 26 ka, characterised by intense wet season precipitation (Torgersen *et al.* 1988: 38). During this time, sea levels were much lower than present and the Arafura shelf was partially exposed resulting in the formation of a large lake in what is presently the Gulf of Carpentaria (Hiscock 2008: 21; Torgersen *et al.* 1988). Phytolith analysis performed on sediments from a nearby Kimberley site has also suggested a high diversity of grass species at c. 40 ka with palms becoming more prevalent at 30 – 40 ka (Wallis 2001). Following

this, conditions changed dramatically during the Last Glacial Maximum (LGM) between 18 and 30 ka BP, whereby increased aridity caused the development of a tropical savannah in western Arnhem Land (Tonrgersen *et al.* 1988). The Arafura shelf had become completely exposed and a land bridge had formed between Australia and New Guinea. During this time, western Arnhem Land was probably vegetated by temperate species of woodland and low open woodland and several semi-arid plant communities (Nix & Kalma 1972: 84–85). The decreasing temperature and precipitation at this time would have likely caused plant species biodiversity to be considerably lower than present, as evidenced in other regions around the world (e.g., Adler & Levine 2007; Forseth 2012; Gwitira *et al.* 2014; Joseph *et al.* 2012; Kreft & Jetz 2007). From 14 – 17 ka, precipitation in northern Australia was 30 – 50% below that of present and vegetation almost completely comprised low open woodland and savannah with only a few isolated rainforest patches that were protected by the surrounding deep-cut escarpment valleys (Allen & Barton 1989: 7; Nix & Kalma 1972: 85-86).

From the beginning of the terminal Pleistocene occurring from c. 8 – 14 ka, the summer monsoon system had re-established itself in northern Australia, causing increased precipitation (Fitzsimmons *et al.* 2013; Hiscock & Kershaw 1992: 49; Wyrwoll & Miller 2011). By 12 ka, sea levels had risen 120 m, greatly reducing the area of the exposed landmass between Australia and New Guinea, causing a decrease in evaporation levels and the onset of higher precipitation (Nix & Kalma 1972; Torgersen *et al.* 1988: 39; Williams *et al.* 2013: 3). As a consequence, northern Australia experienced wetter and warmer conditions; potentially enabling the expansion of monsoon forest vegetation throughout western Arnhem Land (Russell-Smith 1985: 241). During the mid-Holocene around 4 – 8 ka, variations of local vegetation were influenced by various events including the marine transgression at c. 8 ka that led to the inundation of the South Alligator River and surrounding floodplains by rising sea levels (Woodroffe *et al.* 1986: 122). This event caused a shallow marine embayment to be established in the river valley between 7 and 8 ka, characterised by mangrove fringes and bordering woodlands (Woodroffe *et al.* 1986: 122-126). At 7 ka BP, a “big swamp phase” began, causing mangrove communities to extend across the inundated embayment covering most of the existing floodplains (Wang & Chappell 2001; Woodroffe *et al.* 1985, 1986: 127). At 6 ka BP, sea levels began to retreat and the subsequent sedimentation resulted in the accretion of the flood plains that caused most of the mangrove swamp to be “choked out” by approximately 5.5 ka BP (Brockwell *et al.* 2009: 58; Woodroffe *et al.* 1985: 712). Precipitation continued to increase up until c. 4 ka BP when precipitation was at its highest (Shulmeister & Lees 1995: 12). Following this, conditions became more variable with enhanced seasonality and decreased precipitation that was most likely caused by the onset of the modern El Niño/Southern Oscillation (ENSO) conditions that

Table 3.2: Summary of past environmental conditions at MJB and Lake Mungo, including climate history, landscape change and palaeo-vegetation.

Time period	Climate	Landscape	Vegetation
Madjedbebe			
Lacustral phase <i>c. 30 – 60 ka</i>	Wet environment with intense wet-season precipitation	Arafura Shelf was partially exposed with a large lake forming in the Gulf of Carpentaria	
Last Glacial Maximum <i>c. 18 – 30 ka</i>	Decreased precipitation and decreased temperature leads to an increase in aridity	Arafura shelf is fully exposed joining Australia and New Guinea and expanding the current coastline by 300 km from present	Vegetation includes temperate and low open woodland species with fewer semi-arid plant communities. Biodiversity is significantly lower than present. Expanded grasslands.
Terminal Pleistocene <i>c. 14 – 18 ka</i>	Precipitation is 30 to 50% below present creating drier condition than that of the LGM	Arafura shelf remains exposed.	Vegetation is composed almost entirely of low open woodland and savannah with relict monsoon rainforest patches
Pleistocene-Holocene transition <i>c. 8 – 14 ka</i>	Summer monsoon system is re-established creating increased precipitation and warmer climate	Sea levels have risen 120 m from their 150 m low, decreasing the exposed landmass	Expansion of monsoon forest vegetation
Mid-Holocene <i>c. 4 – 8 ka</i>		Rising sea levels cause the inundation of the South Alligator River and surrounding floodplains	Mangrove fringes and bordering woodland around marine embayment's with extensive mangrove communities
Late Holocene <i>c. present – 4 ka</i>	Precipitation increases, reaching a peak at 4ka BP followed by decreased precipitation, greater climate variability and enhanced seasonality	Meandering river channels are established across western Arnhem Land creating a mosaic landscape of estuarine, freshwater and mudflat areas	Mangrove fringed coastal plains.
Lake Mungo			
Lacustral phase <i>c. 30 – 60 ka</i>	Warmer temperatures with increased precipitation	Major period of expanded lakes across inland Australia, Willandra lakes (including Mungo) are full.	Grasses and shrubs dominate
Last Glacial Maximum <i>c. 18 – 30 ka</i>	Precipitation is 50% less than that of today, causing enhanced aridity. Ocean evaporation is also greater with decreased temperatures	Willandra Lakes dry up and landscapes within the arid core of Australia become deserts.	Vegetation cover is reduced (decrease in trees/shrubs, expanding grasslands) resulting in a major phase of dune-building
Terminal Pleistocene <i>c. 14 – 18 ka</i>	Increased aridity	Oscillating lake levels: Lake Mungo may have dried out occasionally but mostly retained a substantial body of water	Decreased vegetation cover- grasses and shrubs
Pleistocene-Holocene transition <i>c. 8 – 14 ka</i>		Lake Mungo and the Willandra Lakes are dry; more arid conditions with short-lived episodes of landscape stability	Vegetation returns (increase in grass and shrub coverage) to dunes enhancing landscape stability
Mid-Holocene <i>c. 4 – 8 ka</i>	Locally more humid conditions	Lake Mungo and the Willandra Lakes are dry	Grasses and shrubs dominate
Late Holocene <i>c. present – 4 ka</i>	Precipitation increases	Lake Mungo and the Willandra Lakes are dry with reworking of sediments through wind and water action	Grasses and shrubs dominate

were documented in the Pacific from ~5.5 ka BP (Brockwell *et al.* 2009: 59; Lees 1992: 8; Shulmeister & Lees 1995: 111; Turney & Hobbs 2006: 1744). Following this period at ~2 – 4 ka BP, the ‘sinuous phase’ commenced, leading to the formation of meandering river channels creating a mosaic environment of estuarine, freshwater and mudflat areas (Bourke *et al.* 2007: 93; Brockwell *et al.* 2009: 58, 2013: 15; Hiscock 1999: 93; Hope *et al.* 1985). The rivers of western Arnhem land took their current form from c. 2.5 ka BP, developing the wide reaches and pointed bends characteristic of what is known as the ‘cusped phase’ (Brockwell *et al.* 2009: 58; Hiscock 1999: 93; Hope *et al.* 1985). Coastal sedimentation slowed and ceased at this time, causing the present mangrove fringed coastal plains (Bourke *et al.* 2007; Brockwell *et al.* 2009: 58; Hiscock 1999: 93). Without the influence of the tides, freshwater was able to accumulate within the palaeo-channels creating the current freshwater floodplains (Bourke *et al.* 2007; Brockwell *et al.* 2009: 58; Hiscock 1999: 93). Currently, western Arnhem Land is characterised by a tropical savannah climate with high humidity and two distinctive seasons that include a pronounced wet and dry season.

3.2.5 Cultural material

Over 2000 lithic artefacts were plotted and collected during the MJB 2012 excavations, including artefacts made from chert, quartzite, silcrete and quartz (Plate 3.2c) (Clarkson *et al.* 2015). The successive pulsing of these different raw material types at different depths was noted throughout the archaeological sequence, whereby quartz artefacts were more common in the more recent archaeological deposits while quartzite and silcrete artefacts occurred more frequently at the base of the sequence. Stone artefacts were also present in every spit of the 1989 excavation at MJB and showed distinct pulses of accumulation, most notably around 5, 7, 12.5, 18.4, 36.5, and 45 – 53 ka (Clarkson *et al.* 2015). Similar pulses were observed for all other artefact types recovered during the 2012 excavations, including grinding stones, ground haematite and other lithic material (Figure 3.4; Plate 3.2a-d). A dense shell midden was present between depths of approximately 10 cm and 70 cm, where 18 human burials were also identified, each displaying varying states of preservation and body orientations. The midden was composed of estuarine mollusc species dominated by *Cerithidae* sp. with smaller proportions of *Geloina* sp., *Telescopium* sp. and *Nerita* sp., and also contained abundant faunal remains from birds, reptiles, marsupials and crustaceans. Bifacial stone points were also identified in the midden, along with bone bi-points and pieces of ground haematite. The midden has unpublished radiocarbon ages that range between ~7 and 3 ka cal BP.

Charred plant remains were identified in the Pleistocene deposits down to a depth of 274 cm (Spit 54) and faunal remains occurred sporadically throughout the sequence (Florin 2013). Flora

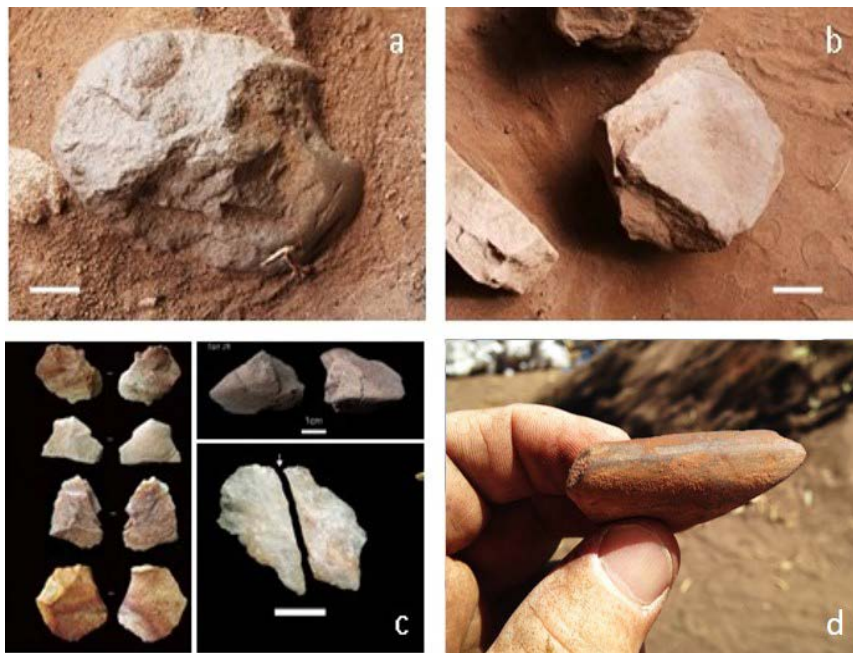


Plate 3.2: Examples of artefacts retrieved from MJB during the 2012 excavations: **a)** *In situ* ground-edge axe (Axe 1), Spit 27 (scale bar is 1 cm); **b)** *in situ* sandstone grinding stone (GS32), Spit 37 (scale bar is 10 cm); **c)** examples of lithic flakes of silcrete, chert and quartz (scale bars are 1 cm) (Photos by R. Roberts); **d)** example of ground haematite piece retrieved from sieve.

material was collected following flotation methods applied to bulk sediment samples from all excavated hearth features and the spits of a 1 x 1 m trench (C3/C2) and included the charred remains of wood, fruits, seeds, nutshells, tubers, roots and other plant parts (Florin 2013). Ten fragmented and complete ground-edge stone hatchets were also identified at MJB; one on the surface of the deposit (surface find) and nine between depths of 130 cm and 197 cm (Plate 3.2a) (Fullagar *et al.* in prep). These artefacts were made from a variety of volcanic materials and each possesses distinctive grinding wear. Ground haematite crayons ($n = 427$) were also identified and each displayed ground facets on at least one surface (Plate 3.2d). At least two varieties of haematite have been identified. Grinding stones were also evident throughout the Pleistocene deposits ($n = 91$) and accounted for 4% of the total stone artefact count (including all the flaked stone and grinding stones) (Plate 3.2b; 3.3). The grinding stones displayed varying degrees of macroscopic grinding wear and were represented mostly by fragmented sandstone pieces.

3.2.6 Grinding stone assemblage

Ninety-six grinding stone specimens were recovered from the MJB excavations in 2012, including 50 plotted grinding stones, 39 un-plotted grinding stones (including one whetstone), six plotted as 'lithics' and five plotted as 'rocks' (Plate 3.3). All of the un-plotted grinding stones were collected following sieving and identified during sorting. The majority of the grinding stones consisted of fine to medium grained sandstone ($n = 84$) of varying hardness, with fewer quartzite

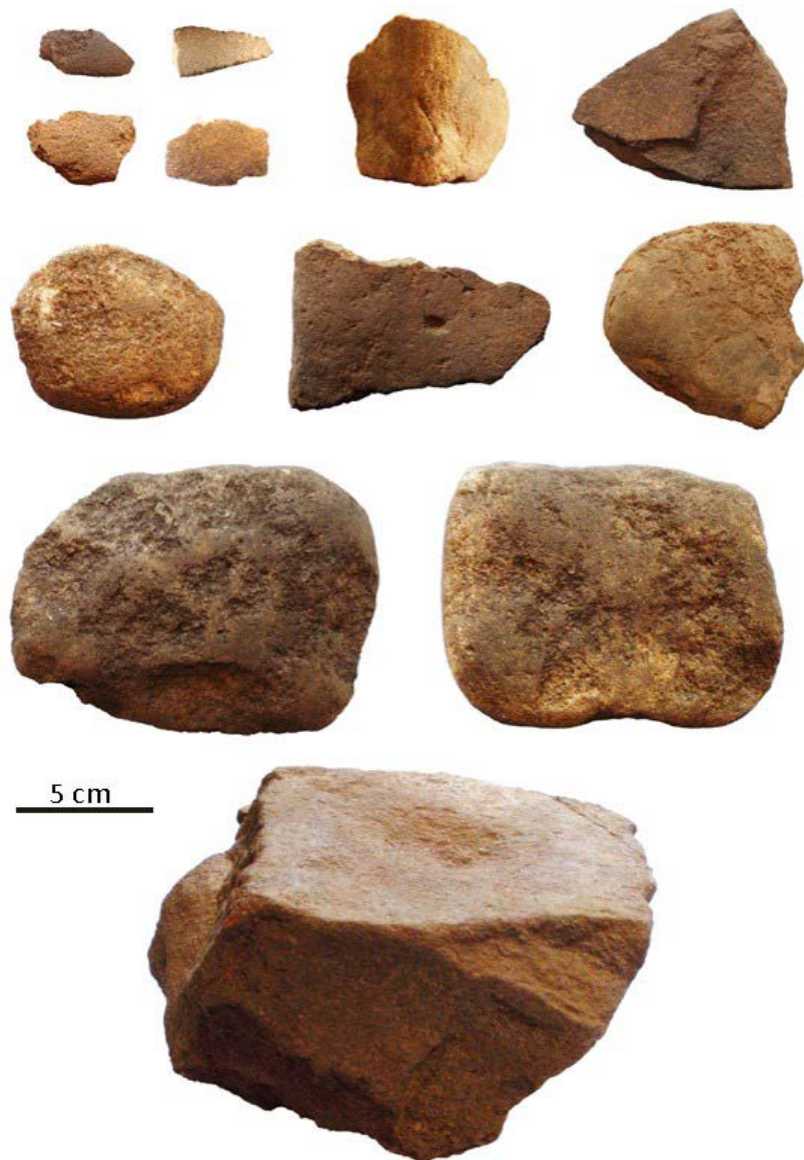


Plate 3.3: A selection of the grinding stones retrieved from the 2012 excavations at MJB mostly comprising sandstone fragments.

and metamorphic varieties ($n = 11$) and only one example of volcanic material (Table 7.1, Chapter 7). Similar to the distribution of other artefacts recovered from MJB, grinding stones occur in three distinctive pulses, correlating with average depths of between 182 and 209 cm (Pulse 1); 113 and 150 cm (Pulse 2) and 10 and 36 cm (Pulse 3) (Figure 3.4). Unpublished radiocarbon ages produced on charred botanical remains, in addition to the published luminescence ages, suggest bracketing ages of between 28.6 and 35.8, 9.2 and 18.2 ka, and 4.2 and 5.5 ka, respectively (Table 3.1, 8.1). Unlike other artefact distributions, ground stone artefacts, including grinding stones and ground-edge axes, are concentrated toward the rear of the shelter, possibly reflecting intentional discard of grinding fragments near the back of the rockshelter wall. Chapters 5 and 7 describe the methods of

functional analysis performed on these stones and the results of the residue and use-wear analyses, respectively.

3.3 Site 2: *Lake Mungo*

3.3.1 Site description

Lake Mungo is an ancient lake bed located within the Willandra Lakes region of western New South Wales (Figure 3.6). The site contains an extensive record of both Pleistocene human occupation and environmental change revealed through the various sedimentary units of the aeolian dune structures (lunettes) along the eastern margin of the lakes (now mostly dry). The Mungo (“Walls of China”) lunette is comprised of three distinct aeolian units; Golgol, Mungo and Zanci (earliest to most recent) (Figure 3.6). The upper two of these units contain an abundance of shell, burnt animal bones, charcoal and stone artefacts that have become exposed following extensive erosion and deflation processes. Within the Mungo Unit, which has been sub-divided into two groups, the Lower Mungo (LM) and the Upper Mungo (UM) deposits, the remains of two human (*Homo sapiens*) skeletons (known as M1 and M111) have been identified. These are currently the oldest human skeletons yet found on the Australian continent, the world’s oldest known human cremations and the oldest known ochred burial yet discovered (Bowler *et al.* 1970). Within the UM and LM deposits, other forms of cultural material include hearth features, ground ochre, flaked artefacts and ground stone implements (Allen 1972; Bowler *et al.* 1970; Stern 2013). Materials recovered from these cultural units have been dated by a variety of methods, including radiocarbon (e.g., Barbetti & Allen 1972; Bowler & Thorne 1976; Gillespie 1997, 1998), luminescence (e.g., Bowler *et al.* 2003; Fitzsimmons *et al.* 2014; Olley *et al.* 2006; Oyston 1996; Thorne *et al.* 1999), Uranium-series and electron spin resonance (ESR) (e.g., Thorne *et al.* 1999).

3.3.2 History of excavations

Cultural material was first documented at Lake Mungo between 1969 and 1972 during assessments of the stratigraphy and Quaternary geology of the dry lakes of western New South Wales (Allen 1972; Bowler *et al.* 1970, 1972). The identification of stone artefacts and ancient human remains prompted a detailed archaeological study in the following years. The site was extensively studied by Wilfred Shawcross between 1974 and 1980, where number of trenches were excavated, including at least one large trench extending to the Mungo Unit in sands below the

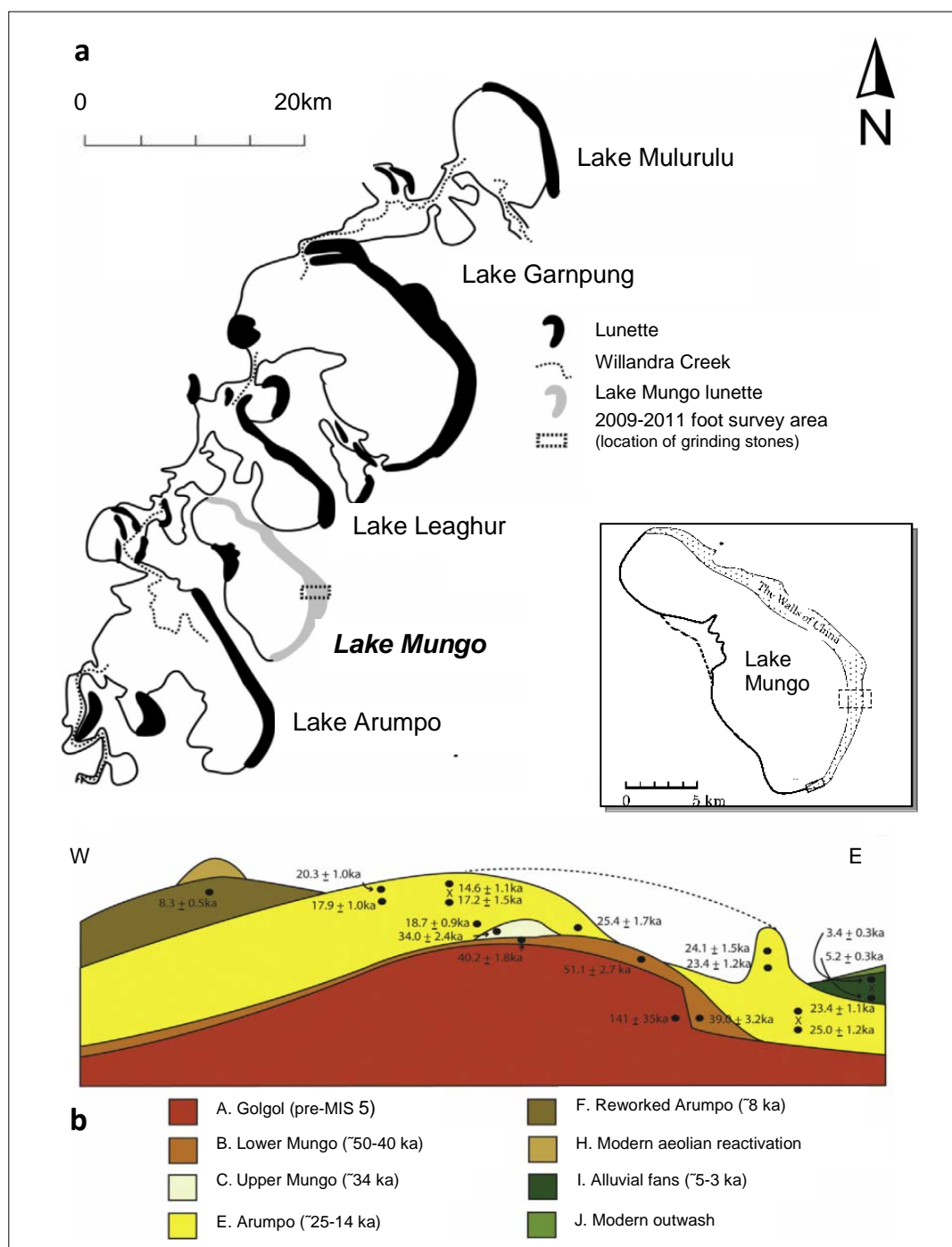


Figure 3.6: a) Map indicating the location of Lake Mungo in relation to the other Lakes within the Willandra Lakes region. *Inset:* Lake Mungo and location of foot surveys. b) Schematic diagram of the units composing Lake Mungo and associated OSL dates. Grinding stones analysed as part of this thesis were collected from Unit E and F. After Fitzsimmons *et al.* (2014): Figs. 1 & 2.

stratigraphic level in which the human remains were identified (Shawcross 1998). The purpose of these excavations was primarily to determine the stratigraphic integrity of the site and the association of the earliest artefacts with the Mungo Unit (Shawcross 1998: 187). A secondary

purpose for the excavations was to identify whether or not a stratified sequence of occupation levels could be found, and if so, to characterise the lithic industries identified (Shawcross 1998: 187). During these excavations, hundreds of stone artefacts ($n = 755$) were identified, scattered throughout the deposit to a depth of 200 cm from the top of the strata. Since these early investigations, Lake Mungo has been subjected to numerous additional investigations with attempts to refine site chronology (e.g., Barbetti & Allen 1978; Bell 1991; Bowler & Price 1998; Bowler *et al.* 2003; Fitzsimmons *et al.* 2014; Gillespie 1997, 1998; Grün *et al.* 2000; Olley *et al.* 2006; Oyston 1996; Simpson & Grün 1998; Thorne *et al.* 1999) and to report on the presence and variety of various cultural materials (e.g., Allen 1998; Fitzsimmons *et al.* 2014; Stern *et al.* 2013; Walshe 1998; Webb *et al.* 2006).

In 2009 – 2011, extensive foot surveys were carried out at Lake Mungo in order to record, for the first time, the distribution of archaeological traces in the Mungo lunette in relation to stratigraphic and/or sedimentary units that represent different lake conditions (Stern *et al.* 2013: 37). The surveys involved the mapping of both the stratigraphic boundaries and the locations of cultural features and included a 400 m wide area of the central portion of the lunette, beginning approximately 200 m north of the boardwalk at the “Walls of China” tourist site originally described by Bowler (1998) (Figure 3.6) (Fitzsimmons *et al.* 2014: 351). The locations of cultural features were plotted precisely in three-dimensional space using a total station or differential GPS, while litho-stratigraphic mapping was achieved following the recording of different stratigraphic boundaries and the presence of specific geological features (Fitzsimmons *et al.* 2014: 351-352). The cultural materials identified during these surveys are described in Section 3.3.5

3.3.3 Chronology

Initial radiocarbon ages for UM/LM boundary deposits (as defined by Bowler 1998), were obtained from lacustrine shell, fish otoliths and hearth charcoal acquired from various localities within the Walls of China lunette (Barbetti & Allen 1972; Bowler *et al.* 1970, 1972; Bowler & Thorne 1976). Integration of regional radiocarbon data provided age estimates of between 28 and 32 ka BP (Table 3.3) (Barbetti & Allen 1972; Bowler *et al.* 1970, 1972). The reliability of these initial radiocarbon ages, however, was questioned following repeated uncertainty regarding possible sample contamination and the efficiency of sample pre-treatment procedures (e.g., Gillespie 1997, 1998), as well as the failure of researchers to incorporate a calibrated radiocarbon timescale. The radiocarbon chronology has since been reviewed, and an updated data set of radiocarbon ages has been produced using samples that were subjected to sufficient pre-treatment methods. Using

Table 3.3: Original radiocarbon and OSL age estimates for the LM/UM transition with more recent OSL ages from surrounding units of the Mungo “Walls of China” lunette.

Unit		Sample number	Dating method	Material dated	Age (ka)	Reference
Zanci		EVA1002	SG OSL	quartz	25.0 ± 1.2	Fitzsimmons <i>et al.</i> 2014
		EVA1003	SG OSL	quartz	23.4 ± 1.1	Fitzsimmons <i>et al.</i> 2014
		EVA1004	SG OSL	quartz	17.2 ± 1.5	Fitzsimmons <i>et al.</i> 2014
		EVA1005	SG OSL	quartz	14.6 ± 1.1	Fitzsimmons <i>et al.</i> 2014
		EVA1008	SG OSL	quartz	24.1 ± 1.5	Fitzsimmons <i>et al.</i> 2014
		EVA1009	SG OSL	quartz	23.4 ± 1.2	Fitzsimmons <i>et al.</i> 2014
		EVA1011	SG OSL	quartz	25.3 ± 1.7	Fitzsimmons <i>et al.</i> 2014
		EVA1014	SG OSL	quartz	18.7 ± 0.9	Fitzsimmons <i>et al.</i> 2014
		EVA1015	SG OSL	quartz	17.9 ± 1.0	Fitzsimmons <i>et al.</i> 2014
		EVA1016	SG OSL	quartz	20.3 ± 1.0	Fitzsimmons <i>et al.</i> 2014
Mungo	Upper Mungo	EVA1013	SG OSL	quartz	33.9 ± 2.4	Fitzsimmons <i>et al.</i> 2014
	Lower Mungo /Upper Mungo boundary	ANU-372B	C ¹⁴	shell	27.1*	Barbetti & Allen 1972
		ANU-375A	C ¹⁴	soil carbonate	20.3*	Bowler <i>et al.</i> 1972
		ANU375B	C ¹⁴	charcoal	26.3*	Bowler <i>et al.</i> 1972
		ANU 618A	C ¹⁴	bone apatite	19.0*	Bowler <i>et al.</i> 1972
		ANU-618B	C ¹⁴	bone apatite	24.7*	Bowler <i>et al.</i> 1972
		ANU-667	C ¹⁴	charcoal	26.3*	Barbetti & Allen 1972
		ANU-680	C ¹⁴	charcoal	30.8*	Barbetti & Allen 1972
		ANU-681	C ¹⁴	charcoal	28.3*	Barbetti & Allen 1972
		ANU-682	C ¹⁴	charcoal	27.5*	Barbetti & Allen 1972
		ANU-683	C ¹⁴	charcoal	28.0*	Barbetti & Allen 1972
		ANU-303	C ¹⁴	charcoal	30.3 ± 0.1	Bowler <i>et al.</i> 1970
		ANU-331	C ¹⁴	charcoal	32.8 ± 1.3	Bowler <i>et al.</i> 1970
		ANU-4134	C ¹⁴	shell	40±2ka cal BP	Gillespie 1998
		MG1	SG OSL	quartz	41 ± 4	Olley <i>et al.</i> 2006
		n/a	OSL	quartz	41.9 ± 2.4	Bowler <i>et al.</i> 2003
		n/a	OSL	quartz	42.2 ± 2.5	Bowler <i>et al.</i> 2003
		J3	TL	unburnt quartz	41± 7	Oyston 1996
	Lower Mungo	EVA1007	SG OSL	quartz	39.0 ± 3.3	Fitzsimmons <i>et al.</i> 2014
		EVA1010	SG OSL	quartz	51.0 ± 2.7	Fitzsimmons <i>et al.</i> 2014
		EVA1012	SG OSL	quartz	40.0 ± 1.8	Fitzsimmons <i>et al.</i> 2014
		ANU _{OD} 174a+d	OSL	quartz	61± 2	Thorne <i>et al.</i> 1999
		BA,BB,BC,BD	U-Series	bone shavings	81 ± 21	Thorne <i>et al.</i> 1999
		n/a	ESR	tooth enamel	62 ± 6	Thorne <i>et al.</i> 1999
Golgol		EVA1006	OSL	quartz	141 ± 35	Fitzsimmons <i>et al.</i> 2014

the calibration curve defined by Gillespie (1998), radiocarbon ages for the UM deposits suggest an age of $c. 40 \pm 2$ ka cal. BP. The updated radiocarbon ages appear to be consistent with luminescence data: TL and OSL ages suggesting ages of 43 ± 3 ka (Bowler & Price 1998; Oyston 1996) and 40 ± 2 ka for the UM/LM boundary, respectively (Bowler *et al.* 2003; Olley *et al.* 2006). However, the reliability of these ages was again questioned, because of local differences in dose rates and the likelihood of incomplete bleaching (Allen & O'Connell 2003, 2004; Bowler & Price 1998; Gillespie & Roberts 2000). Thorne *et al.* (1999) presented an even earlier chronology for the site, providing ESR and U-Series age estimates for MIII human skeleton of 62 ± 6 and 81 ± 21 ka, respectively. These appeared to be consistent with OSL age estimates of 61 ± 2 ka, which had been derived from sediments associated with the MIII skeleton. However, the ages provided by Thorne *et al.* (1999) were considered to be over-estimates resulting from incorrect measurements of the beta and gamma dose rates. Because the environmental dose rates were determined by averaging dose rates from multiple locations within the upper portion of the LM soil, the authors did not account for the heterogeneous nature of LM soil and consequently the dose rates used were considered invalid (see Bowler & Magee 2000).

More recent ages provided through single-grain OSL suggest ages for the LM and UM units at approximately 50 – 40 ka and 34 ka, respectively, and place the timing of initial human occupation in this region at ~ 45 ka (Fitzsimmons *et al.* 2014). The method of single-grain OSL is assumed more reliable than that of multi-grain analysis as it allows each grain to be measured and analysed individually therefore providing the analyst with the ability to identify and discard any grains with aberrant OSL behaviours before the final age determination is calculated. Additional ages for the various units comprising the Mungo Lunette that are cited in this thesis have been provided by Fitzsimmons *et al.* (2014) using single-grain OSL techniques (Figure 3.6 and Table 3.3).

3.3.4 Climate history, landscape change and palaeo-vegetation

The Willandra Lakes represent a relict overflow system fed by the (now dry) Willandra Creek, a tributary of the Lachlan River with its headwaters originating from the south-eastern Australian highlands (Fitzsimmons *et al.* 2014: 349). The lakes of this region are a source of palaeo-environmental information, which have been assessed by the examination of the lake sediments and stratigraphic formation of the surrounding lunettes. Cycles of lake-full conditions are determined by layers in the lunettes on the eastern margin of each lake, sediments within the lake floors and the desert dunes that build-up downwind (Stern *et al.* 2013: 33). The alternating layers of sand and clay

represent changes in the amount and quality of water in the adjacent lakes: high energy environments (i.e., occurring in lake-full conditions) are characterised by the accumulation of quartz-rich sands and gravels, while lower lake levels are reflected in the presence of pelletal-clays that have accumulated as a result of increased evaporation (Stern *et al.* 2013: 34-35). The sediments from Lake Mungo have provided a particularly detailed account of past climatic conditions because it filled via an overflow channel from Lake Leaghur (Figure 3.6) and had no outflow apart from evaporation (Bowler 1998: 148; Stern *et al.* 2013: 34).

The stratigraphy of the Mungo “Walls of China” lunette documents a sequence of wetting and drying events beginning before the last interglacial (Bowler & Price 1998; Fitzsimmons *et al.* 2014: 350), whereby fluctuations in lake hydrology were caused primarily by changes in the extent and frequency of flood pulses, derived from the Australian Alps and associated with shifts in regional and global climates (Bowler 1971, 1998; Bowler *et al.* 2012; Stern *et al.* 2013: 33). At c. 70 ka, (start of MIS4) when sea levels were about 60 m below present, the Willandra Lakes were likely to be full, coinciding with the onset of a suggested “mega-lake phase”, a period of greater water availability across Australia reflected by the occurrence of larger and more frequent bodies of water in the arid regions today (Bowler 1982, 1998: 146; Jones & Bowler 1980: 9-11). This mega-lake phase likely continued until at least c. 45 ka, indicating lake-full conditions when humans first arrived at Lake Mungo at approximately the same time (Fitzsimmons *et al.* 2014: 350). Multiple oscillations in lake level were to follow with the final lake retreat occurring sometime shortly after the LGM when Willandra Creek, the major inflow channel, ceased to flow (Bowler 1998). Oscillating water levels and periods of lower lake fill during the LGM were the result of a continent-wide trend of increased aridity when conditions were much drier (Hiscock 2008: 58). Lowest sea-surface temperatures occurred at about 21 ka BP with high rates of evaporation and extremely cold land temperatures (Barrows *et al.* 2002: 171). As a consequence, landscapes surrounding the arid core of Australia dried up to become deserts, expanding the size of the arid interior (Hiscock 2008: 58).

Within the Willandra Lakes, the harsher conditions associated with the LGM caused a decrease in vegetation cover in the form of trees and shrubs, and an increased distribution of grasslands, possibly leading to enhanced dune-building cycles and intense dust storms (Hiscock 2008: 56, 58). Reduced temperatures and water levels within the lakes caused fish and freshwater mussels to become locally extinct between 25 and 19 ka (Bowler 1998; Hiscock 2008: 58). At c. 17.5 ka BP, after a period of major instability, conditions for human habitation began to improve with higher temperatures and increased vegetative cover returning to the dunes (Bowler 1998: 149). By 13 ka, dunes had stabilised and the landscape had acquired many features found today (Bowler

1976: 279). Lake levels oscillated during the terminal Pleistocene between about 14 and 18 ka BP with episodic flooding occurring into the Holocene (Fitzsimmons *et al.* 2013). Radiocarbon ages produced on shells recovered from the various lakes within the Willandra Lakes site has indicated the youngest shell was 14.5 ka BP (Gillespie 1998: 178), possibly indicating low fluctuating lake levels before the lakes dried out completely. Dune building along the south-east Australian coast during the late Holocene, in conjunction with pollen records, have indicated similar climatic conditions to that found in northern Australia, as determined via geomorphic data from cheniers, coastal dune fields and mineral sediments (Lees 1992: 7). Currently, the Willandra Lakes reside within the semi-arid region of Australia (Figure 3.1), characterised by precipitation levels that are below potential evapotranspiration, with vegetation cover dominated by grasses and shrubs. The changing environmental conditions experienced throughout the Willandra Lakes region of western New South Wales are summarised in Table 3.2.

3.3.5 Cultural material at Lake Mungo

Traces of past human activity at Lake Mungo are continuously being exposed on the modern surface, as a result of ongoing wind and water erosion. The most commonly recognised traces include scatters of hearthstones, clusters of burnt and unburnt food remains, flaked stone artefacts (including tools and the debris from their manufacture and repair), grinding stones, ground ochre and fragmented animal bones (Stern *et al.* 2013: 36). Perhaps the most remarkable are the burnt human remains of an adult female (M1) and the fully articulated skeleton of an adult male (M111) within the UM/LM units of the “Walls of China” lunette. The distinctive positioning as well as the partial cremation of M111 and the distinctive ochre-filled grave of M1 implies ritual burial practices and complex symbolic behaviours (Bowler *et al.* 1972, 2003).

During the most recent foot surveys of Lake Mungo (2009 – 2011), a number of cultural materials were identified, including thousands of flaked-stone artefacts, which were represented predominately by fine and coarse-grained silcrete and high-quality quartzite (Stern *et al.* 2013: 44-45). Flaked stones shaped from these materials varied in quantity at different locations of the site, although the higher flake to core ratio, smaller artefact size, and greater incidence of retouch identified on the quartzite artefacts has suggested that this material was worked more intensively than the silcrete, particularly the coarse-grained variety. Ground pigments, grinding stones and grinding stone fragments were also recognised in large abundances. Hearths containing either terrestrial or lacustrine resources were abundant; although hearths containing both resources were

rare. No shell middens and only two small scatters of non-culturally accumulated shell were identified.

3.3.6 Grinding stone assemblage

Seventeen grinding stone specimens were collected for analysis during systematic foot surveys between 2009 and 2011 and geological mapping in 2011 and 2013, and included 14 from dated contexts of the central Mungo lunette (Fitzsimmons *et al.* 2014; Fullagar *et al.* 2015; Stern *et al.* 2013). All analysed stones were formed on fine-grained, well-cemented sandstone material, most of which were derived from one of two stratigraphic units: Unit E (Arumpo – Zanci units), which was deposited between 25 and 14 ka representing the final lacustrine phase at Lake Mungo (n = 10); and Unit F, which accumulated after the lake had dried out between 14.5 and 6 ka (n = 4) (Fitzsimmons *et al.* 2014; Fullagar *et al.* 2015). Of the ten fragments identified from Unit E, eight are believed to be from the same original grinding stone. I was able to refit some but not all of the pieces (Plate 3.4b), one of which had precise stratigraphic provenience (LM GS 9), found *in situ* from eroding sands comprising Unit E of the Mungo lunette (Plate 3.4a). One of the grinding stones has a small fragment (LM GS 9) that was embedded in alternating sands and clays bracketed by OSL ages of 14.5 and 6 ka. This stone comprises one of nine refitting fragments, most of which were found within the shallow gully below. The remaining three specimens were loosely lying on an ancient

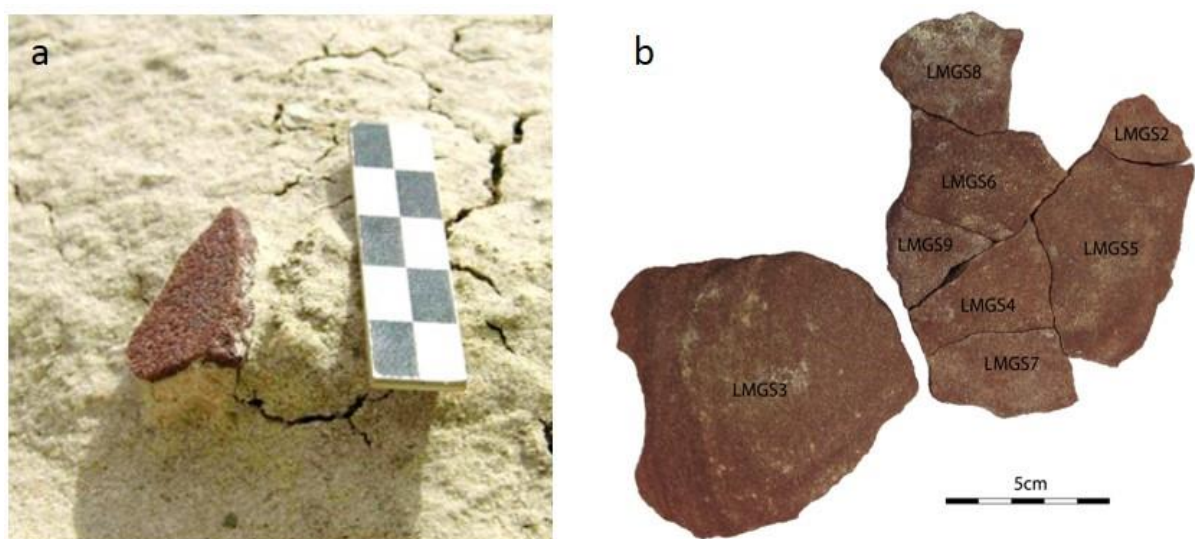


Plate 3.4: a) Artefact LM GS 9 found *in situ* in Unit E; b) Refitted fragments LM GS 2-9. LM GS 3 has worn margins and does not 'lock'; but it is most likely from the position shown. *From Fullagar et al. (accepted manuscript).*

erosional surface within the Mungo lunette but it is currently unclear as to when the artefacts were discarded. All seventeen specimens have been examined for traces of use-wear and residues, the methods and results are presented in Chapters 5 and 7, respectively.

3.4 Chapter summary

MJB and Lake Mungo are highly significant sites for Australian pre-history: not only do they provide evidence for earliest peopling of the continent at two distinctive geographical regions; they also provide some of the earliest evidence for both complex technologies and symbolic and ritual behaviour so far recognised in Sahul. Archaeological investigations at MJB, a sandstone rockshelter located in northern Australia, have provided the earliest evidence for human occupation in Sahul with TL and OSL ages of ~52 ka for the earliest cultural deposits (Roberts *et al.* 1990a, 1998a). Currently, MJB has yielded the earliest evidence for the systematic use of pigments in Sahul and the earliest global evidence for the manufacture and use of ground edge-axes (Clarkson *et al.* 2015; Fullagar *et al.* in prep). Palaeo-environmental data for the MJB region has indicated alternating environmental conditions over the past 60 ka. Changes in vegetation coverage in response to climatic variability would have altered the landscape, modifying distance to water sources, stone materials, food resources and trade networks. The availability of new resources such as plant foods and shellfish in response to climate change would have led to an alteration of foraging strategies, requiring the more intensive use of particular tool technologies. This is reflected archaeologically whereby “pulses” of technology are distinguished throughout the sequence with notable variations in artefact densities, stone materials and tool technologies (Clarkson *et al.* 2015).

Lake Mungo is an open site located in semi-arid southeastern Australia, and, with an OSL age of 45 ka, is currently the earliest dated site of the semi-arid region (Fitzsimmons *et al.* 2014). This site has yielded abundant cultural material in the form of ground stone and flaked stone technologies, hearth features, pigments and faunal remains. The occurrence of a 42 ka ochred burial (the oldest known globally) provides the earliest evidence for ritual and symbolic behaviour in Australia (Bowler *et al.* 2003). Similar to MJB, the paleo-climatic data for Lake Mungo has indicated climatic variation over the past 50 – 60 ka, facilitating changes in vegetation coverage and landscape, as well as the availability or the enhanced reliance on certain resources, such as seeds.

Because both MJB and Lake Mungo have been (more-or-less) continually occupied for 50 – 60 ka, the analysis of these sites and their cultural assemblages provides a remarkable opportunity to assess early settlement technology and technological/behavioural changes through time, which

may be linked with shifts in climate, population and other cultural paradigms. Additionally, the varying abundances, morphological tool types and tool functions of implements recovered from each site may provide insight into site contexts (e.g., rockshelter or open sites), resource availability (distance to stone material) and local environmental changes.

Chapter 4:

Functional analysis of stone artefacts

4.1 Introduction

As indicated in Chapter 1, stone artefact function is a vital component of prehistoric technology and is key for reconstructing prehistoric tasks, understanding aspects of past human behaviour and evaluating models of evolution and cultural transformation. A range of methodologies are available for determining tool function, including tool-use experiments, ethnographic analogy, tool design and the documentation of traces of use. Determining archaeological stone tool function is best achieved by an integrated methodology that includes examination of residues, use-wear, tool design, breakage and hafting (or prehension), in the archaeological context of discard. The study of wear and residues is particularly important because these traces potentially provide the most detailed indicators of the contact materials on the worked surfaces and edges of the tools. Wear and residues can accumulate as a consequence of diverse factors, including handling, use, storage, weathering and post-depositional processes. 'Use-wear' and 'use-residues' refer to traces on the edges and surfaces of the implement that accumulate as a result of contact with the worked material. Pioneering research by Semenov (1964), involving experiments and microscopic studies of wear, has formed the foundation of modern use-wear analysis. After extensive tool-use experimentation and establishing the mechanical principals of wear formation, Semenov argued that it was possible to determine tool function based largely on the character and appearance of microscopic traces remaining on the tool edges. This chapter will describe the various wear and residue traces commonly identified on stone implements, as well as methods of identification and quantification.

4.2 Wear traces

Wear traces on the surface of archaeological artefacts may provide evidence for past tool function(s), but may also indicate a range of other processes. Contact between the implement and the worked material (i.e., the material in direct contact with the working edge or surface of the tool) creates wear patterns that are potentially diagnostic of certain activities, and often accumulate in distinctive and predictable ways. The main forms of use-wear on flaked-stone tools include edge-scarring, striations, edge-rounding, abrasive smoothing and polish. On the utilised surface of ground-stone tools made of granular rock, use-wear features such as polish and striations are often visible, with harder individual grains (e.g., quartz crystals) displaying features such as edge-rounding, fracturing, levelling, polish and micro-striations (Adams *et al.* 2009: 49-53). The following sections will describe the four key use-wear forms commonly found on both flaked and ground stone tools.

4.2.1 Flake Scarring

Flake scars are a form of edge-damage commonly associated with tool-use on the edges of flaked stone tools. The processes involved in the formation of edge scars are similar in principle to the flaking of knapping (Tringham *et al.* 1974). The appearance and nature of the scars may be influenced by several factors, including: (1) the direction of use; (2) type of worked material(s); (3) the force applied when working; and (4) the morphology of the tool edge, platform edge angles, and distance of impact from edge (Fullagar 2014: 246; Kamminga 1982: 4-5; Kononenko 2011: 7). Consequently, the frequency, distribution, orientation, size, shape in plan-view and cross-section of the scars are considered to be potentially important variables for reliable determination of tool function (Fullagar 1986a: 76; Kamminga 1987: 82; Keeley 1980: 25; Vaughan 1985: 45). Scars on the edges of tools may be classified as one of five different morphological varieties following Cotterell & Kamminga (1979: 699-701). These include feather, step, hinge, plunging or bending scars, described in Table 4.1 (Plate 4.1a-d). These may be visible macroscopically but often require examination under magnification.

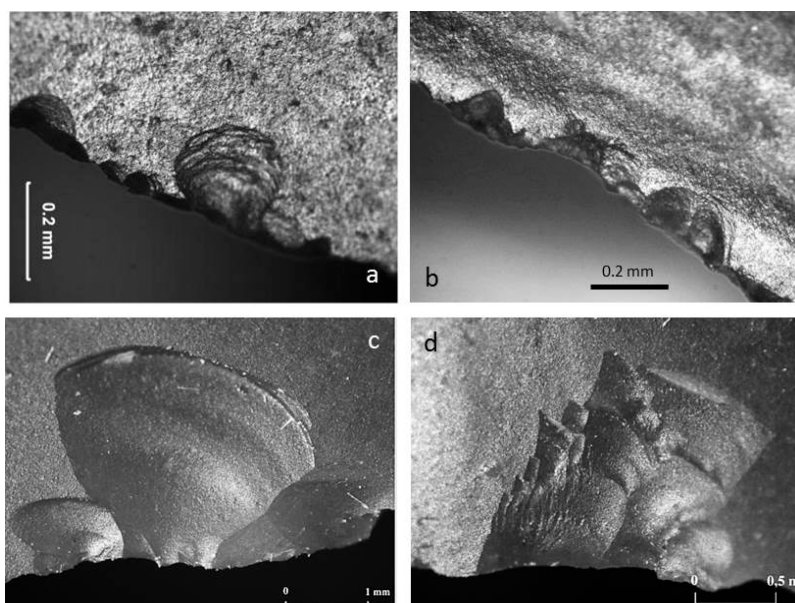

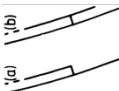





Plate 4.1a-d: Edge scarring on archaeological and experimental tools: **a)** scarring along tool edge reflected by feather (centre) and bending scars (left); **b)** bending or “half-moon” scars occurring along tool edge; **c)** scalar scars with feather terminations occurring on tool edge (From Rots 2010: Fig. Pl. 5); **d)** step scarring occurring along tool edge (From Rots 2010: Fig. Pl. 8).

4.2.2 Polish

Polish generally refers to the reflectivity of the artefact surface and may be described in terms of: (1) brightness, (2) degree of development, (3) distribution and (4) texture or surface morphology. Polish that occurs as a result of contact with the worked material (and is not the

Table 4.1: Description of scar types. *After Kamminga & Cotterell (1987).*

Scar type	Description	Illustration
Feather	Occur when the detached piece sheers off smoothly	
Step	Occur when the detached piece abruptly terminates in a right-angled break	
Hinge	Occur when the fracture surface turns sharply upwards, creating a hinge	
Plunging	Occur when the detached piece extends downwards	
Bending	Occur when the detached piece is removed away from the point of impact causing a half-moon shaped break	

natural reflectivity of the surface) may be referred to as “use-polish”. There are various explanations proposed for the formation of use-polish including mechanical smoothing, frictional heat, surface translocation and chemical alteration to the surface. The texture or surface morphology (e.g., grainy, undulating, reticular or net-like) is often a key indicator of the class of worked material. Numerous experiments to cut, scrape, drill, chop and otherwise process bone, meat, wood, soft plant, antler, shell and hide, have indicated that, despite some overlap, distinctive use-polish patterns (in conjunction with other use-wear features) correspond to these broad classes of worked material (Plate 4.2a-h) (Anderson 1980: 181; Bamforth 1988: 11; Bamforth *et al.* 1990: 414; Evans & Donahue 2008: 2229; Fullagar 1986a: 83; Fullagar & Matheson 2013: 7063; Keeley 1980: 179; Keeley & Newcomer 1977: 37; Mansur-Franchomme 1983: 223; Rots 2010; Van Gijn 2010).

Use-polish patterns are usually observed at relatively high magnification (>x200) under vertical incident light (Keeley & Newcomer 1977: 36); but may also be observed under magnification with stereomicroscopes and under a SEM at very high magnification (>x1000) (e.g., Mansur-Franchomme 1983; Ollé & Vergès 2008, 2014). The morphological variation observed on use-polished surfaces is probably related to the surface roughness and the physical properties of the worked material. The role of polishing agents, notably amorphous silica identified in plant materials, is believed to make a significant contribution to use-polish development (Anderson 1980: 183-4; Fullagar 1986a: 148, 1991: 1; Kamminga 1979: 144). The presence of natural lubricants may also cause variation in use-polish morphology with experimental studies showing variation of use-

polish when the same material is worked in a fresh or “wet” state (Mansur-Franchomme 1983: 224). Table 4.2 provides a description of use-polish patterns pertaining to various worked materials.

Use-polish extension, distribution and development are particularly related to the intensity of work as well as the worked material. Use-polish extension refers to the location of the use-polish on the artefact surface, for example, along the tool edge or intruding into the middle portion of the surface, while use-polish distribution refers to the continuity of the polish within a specific zone (Rots 2010: 33). Use-polish development may be indicated by the distribution of the polished surface. A spotty or discontinuous distribution implies a less developed use-polish, while an interconnected, continuous distribution with no distinguishable interruptions reflects a more advanced stage of use-polish development (Rots 2010: 32-33). The degree of use-polish linkage is important for determining the development stage: generally, more developed use-polish will extend to the lower zones of micro-topography while poorly developed use-polishes are restricted to the highest points (Rots 2010: 33). Vaughan (1985: 28-9) has argued that micro-wear use-polishes resulting from different worked materials are generally indistinguishable at the early stages of development, and, therefore, tools which were only used for short durations are unlikely to develop diagnostic polishes—he has referred to these as “generic weak polishes”. Those artefacts that have well-developed use-polish provide for a more confident interpretation of tool function may sometimes be diagnostic of worked material (e.g., Anderson 1980; Bamforth 1988; Fullagar 1986a, 1991; Kealhofer *et al.* 1999: 532; Keeley 1977, 1980: 174; Keeley & Newcomer 1977; Unger-Hamilton 1984).

4.2.2.1 Bright spots

‘Bright spots’ consist of smooth, highly lustrous patches of use-polish occurring in areas of very high friction, either as a result of human action or via natural agencies (Rots 2010: 34). Two general types of bright spots (flat and raised) are associated with natural formation processes and hafting respectively (Rots 2010: 34). Bright spots may be further described in terms of (1) morphology, (2) brightness, (3) linkage, (4) type and (5) extent (as for polish, see Section 4.2.2).

4.2.3 Edge-rounding

Edge-rounding is a form of use-wear often associated with abrasive smoothing, use-polish development and other forms of wear, occurring as tool edges are mechanically worn and reduced

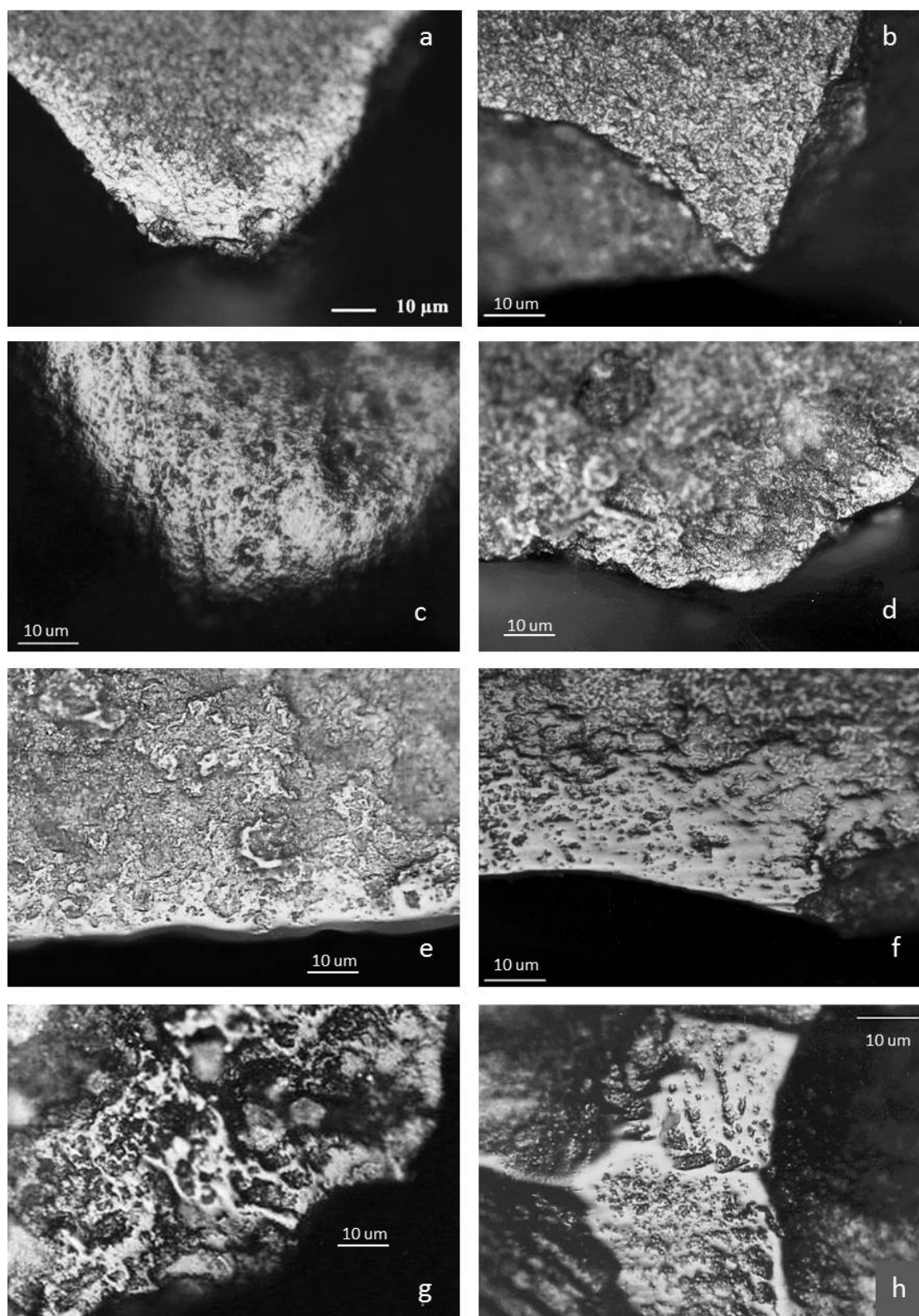


Figure 4.2a-h: Use-polish on experimental artefacts: **a)** use-polish from the processing of bone (*From Rots 2010 Fig. Pl. 105*); **b)** use-polish from the processing of fresh meat (*Photo from Waves database*); **c)** use-polish from the processing of fresh hide (*Photo from Waves database*); **d)** use-polish from the processing of shell (*Photo from Waves database*); **e)** use-polish from the processing of cereals (*From Rots 2010 Fig. Pl. 107*); **f)** use-polish from the processing of reeds (plant); (*Photo from Waves database*); **g-h)** use-polish from the processing of wood (*Photo by R. Fullagar*).

Table 4.2: Description of use-polish types (*after* Keeley & Newcomer 1977).

Polish type	Description
Wood polish	Very bright polish (highly reflective) with a smooth texture, commonly “domed” on high points. Well-developed polishes will become interlinked over time giving the polished region a reticular or net-like appearance with gentle undulations on the surface. Wood polish appears to be consistent regardless of wood type (i.e. soft, hard, fresh, seasoned).
Plant polish	This polish is highly smoothed, with a bright, highly reflective surface. Constituent plant materials (i.e. plant opal/silica and phytoliths) cause the polish to display a characteristic “fluid” appearance, with filled in striations and comet-shaped pits.
Bone polish	Polish develops on the high points of a stone surface giving it a rough, highly localised, uneven and pitted appearance. Polish appears bright, although not as bright as the polish produced via wood and plant working.
Hide polish	Hide polish varies depending on the state of the hide, i.e. the working of fresh or wet hide. This is due to the presences of lubricants.
Dry hide (leather)	Polish appears dull and pitted with a matte finish; often accompanied by small, circular pits (micro pot-lids) that occur from frictional heat developed on hide in the absence of lubricants. Dry hide polish is usually more pronounced than fresh hide polish.
Fresh hide	Polish develops slowly with a relatively bright, greasy appearance. Is similar in appearance to meat polish.
Meat polish	Meat polish may vary in brightness, but is generally dull showing little contrast with unaltered (un-polished) areas of stone. Polish has a greasy lustre.
Antler Polish	Two distinctive polishes may occur as a result of working antler under two different conditions. More commonly, polish will appear bright & smoothed- this type of antler polish is referred to as “smooth” antler polish. This occurs when antler is worked in scraping, planning or graving actions. This polish may be similar in appearance to wood polish (particularly in the early stages). Well-developed polish has small diffuse depressions that give the polish an even pock-marked appearance, anomalous to melting snow. Antler that has been worked via sawing produces a bright, rough and pitted polish. This latter polish type is referred to as rough antler polish and is very different to smooth antler polish, although quite similar to bone polish (although lacking the characteristic micro-pitting).

by abrasion, crushing or other mechanisms (Plate 4.3a-d) (Kamminga 1982: 17; Kononenko 2011: 8). This process causes the dulling (blunting) of an edge during use; a process that is further intensified by the presence of sand and other abrasive particles in the local environment (Fullagar 2014: 249; Kamminga 1982: 17; Mansur-Franchomme 1983: 224). Edge rounding may be described in terms of: (1) extent, (2) distribution, (3) associated use-polish development, and (4) by reference to edge and surface morphology within the zone where the rounding and smoothing occur (Rots 2010: 33-4). Discrimination between natural and use-derived processes may be difficult as some stones contain chemically unstable constituent minerals that may easily erode on edges exposed to natural elements (Kamminga 1982: 17). For this reason, the identification of other forms of wear is required before interpreting artefact function. When analysing ground stone artefacts, the degree of rounding on individual grains may be an indication of the extent and nature of the grinding activity (e.g., Dubreuil 2004: 1615).

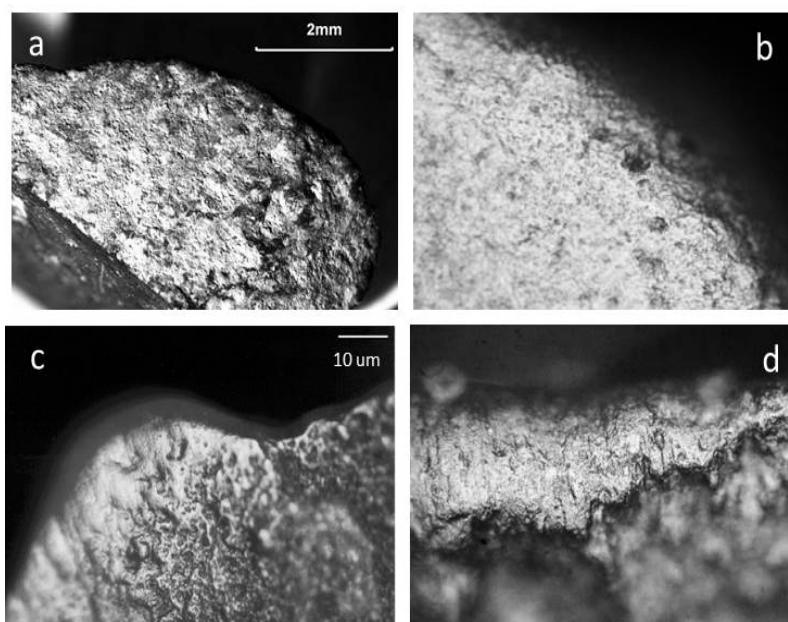


Plate 4.3a-d: Edge rounding on experimental and archaeological stone tools: **a)** rounded platform on archaeological “use-flake”; **b)** well-rounded edge of experimental hide scraping tool, x200 magnification (*From Rots 2010 Fig. Pl. 110*); **c)** well-rounded and highly polished edge of experimental ochre scraping tool (*Photo from Waves database*); **d)** well-rounded edge of experimental hide processing tool, x200 magnification (*Photo by R. Fullagar*).

4.2.4 Striations

Striations are linear deformations occurring on the surface of a tool (Plate 4.4), caused by the presence of abrasive particles (Kononenko 2011: 7) and are considered to have several forms. Following Mansur-Franchomme (1982, 1983: 229-230), these include: (1) *rough-bottomed striations*, i.e., striations that form a granular bottom following the removal of crystals from the surface; (2) *smooth-bottomed striations* or “*sleeks*” (probably the result of plastic deformation on the surface)

with either regular (ribbon-like) or irregular (fern-like) margins; (3) *filled-in striations*, i.e., narrow, deep striations filled with siliceous material; and (4) *additive striations*; i.e., aligned ridges of use-polish resulting from linear deposition of material on the surface. Striation morphology will vary depending on the size and hardness of the abrading particles as well as the presence of natural lubricants in contact material and in the environment such as water and grease (Kamminga 1982: 11). The size and morphology of the striations can, therefore, provide information about the nature of the worked material and the environment in which the tools were used (e.g., Meeks 1982: 332).

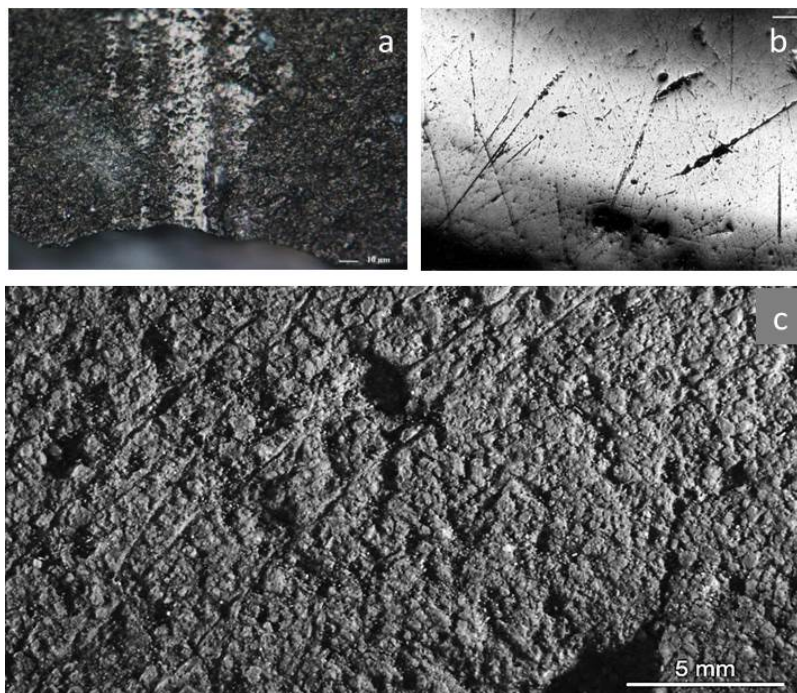


Plate 4.4a-c: Alignments and striations occurring on experimental artefacts: **a)** manufacturing striations occurring on experimental tool (From Rots 2010 Fig. Pl. 81) **b)** scratches (or furrows) occurring with multiple orientations on experimental flint flake (Photo by R. Fullagar); **c)** deep scratches on sandstone artefact.

In addition to their morphological characteristics, the orientation of striations is also important, indicating the direction of tool use (Keeley 1980: 23; Kononenko 2011: 7; Semenov 1964: 4, 17) and a likely indicator of tool action (e.g., drilling, cutting and scraping). Striation orientation is described in relation to the tool edge (i.e., parallel, oblique, perpendicular) and their distribution may indicate that the striations are use-related rather than the outcome of natural phenomena occurring in the burial environment (i.e., contact between the artefact surface and the sediment) (Keeley 1980: 30-31). The latter are usually distinguishable from use-related striations because of their “random” distribution and orientation in addition to other accompanying signs of abrasive smoothing on ridges (Mansur 1982: 217). Use-related striations are usually associated with other wear traces, such as use-polish and edge rounding.

4.2.5 Use-wear on grinding stones

Similar to flaked stone artefacts, grinding stones display distinct forms of use-wear that may be diagnostic of artefact function. Adams (1988, 1993, 2002a, 2002b, 2014) distinguishes four mechanisms responsible for the formation of wear present on ground surfaces: (1) adhesive wear; (2) abrasive wear; (3) fatigue wear and (4) tribochemical wear (Table 4.3). These various wear mechanisms involve surface modifications that are reflected in the macro- and micro-topography of the ground surface relative to an unworn surface, where 'micro-topography' refers to the microscopic elevational relief observed on the artefact surface (Adams *et al.* 2009: 28). Variation is also observed in the degree of grain rounding, the development and extent of use-polish, the frequency and nature of striations, and any residues or rock debris remaining within the interstices (interstitial spaces between grains) on the artefact surface (Figure 4.1) (e.g., Adams 1988: 311-312; Adams *et al.* 2009: 47-53; Dubreuil 2002, 2004; Hamon 2008: 1506). The appearance of these wear features is related to the intensity and duration of use, the properties of the material being worked (e.g., texture, hardness, moisture content, etc.) and the mineralogy of the grinding stone surface (i.e., the properties of the stone material, including hardness, durability, asperity, texture and cementation) (Adams 1993: 61-2; 2014: 130; Adams *et al.* 2009: 53; Delgado-Raack & Risch 2009: 9; Hamon 2008: 1504). Other modifications on ground-stone surfaces include (1) surface damage in the form of grain extraction; (2) micro-fracturing; (3) grain use-polish or sheen, and (4) the appearance of surface pits and cracks (Plates 4.5a-h) (Adams *et al.* 2009: 46). Use-polish may be characterised in terms of distribution, density and extent, as determined by experiments on flint, and other tool-stone (see Dubreuil 2002).

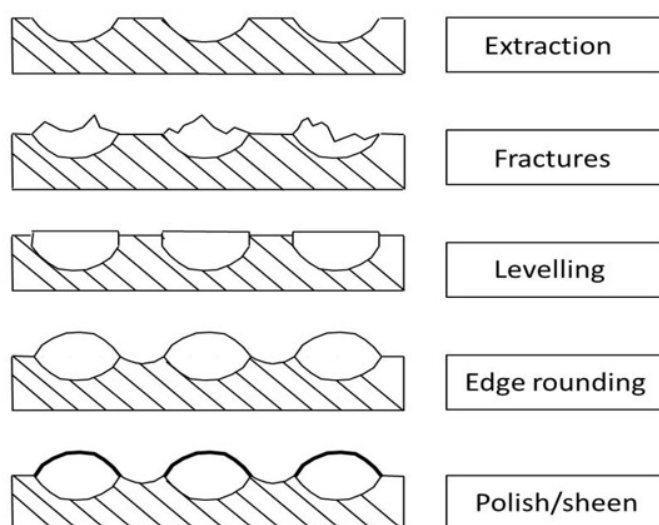


Figure 4.1: Potential grain features on utilised grinding surfaces. After Adams *et al.* (2009): Fig. 6.4.

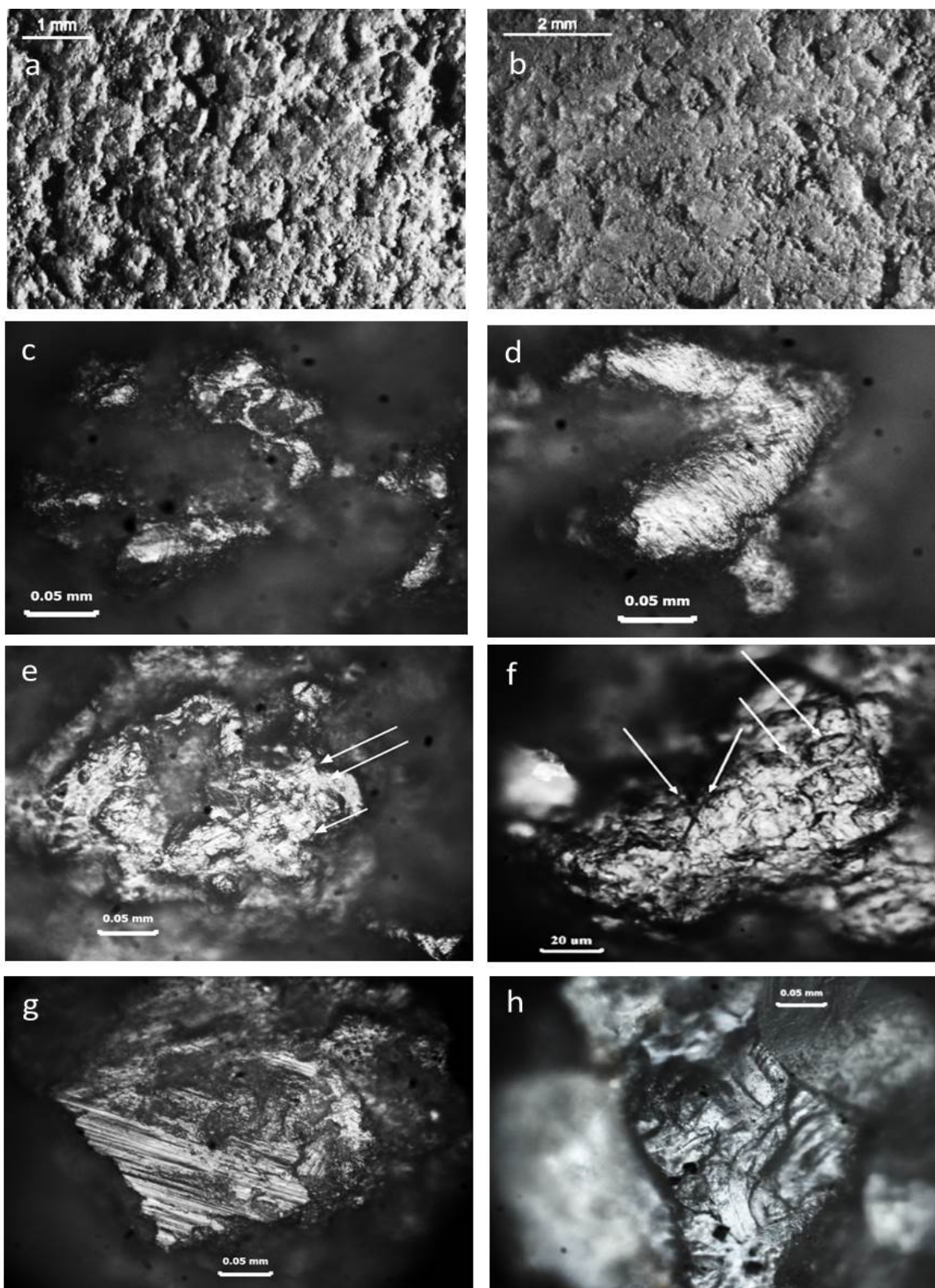


Plate 4.5a-h: Use-wear on grinding stones: **a)** low magnification image of grinding surface showing well rounded grains; **b)** low magnification image of grinding surface showing levelled grains and striations; **c-d)** high magnification images of the ground surface showing use-polish occurring on the highest grains, characterised by a bright, reflective surface; **e-f)** micro-striations occurring on use-polished quartz grains (arrows indicate direction of striations), **g-h)** micro-scarring of individual quartz grains on the surface of the sandstone.

Table 4.3: Description of wear mechanisms and wear traces on ground-stone artefacts. *After* Adams (1988, 1993, 2002a, 2002b, 2013a); Adams *et al.* (2009).

Wear mechanism	Description	Visible wear traces
<i>Adhesive wear</i>	<i>Adhesive wear</i> may be described as the wear resulting from contact between two surfaces in which molecular interactions are taking place, causing the formation of bonds. When the surfaces are moved away from each other, these bonds are broken, causing the release of energy in the form of frictional heat. The release of heat through the breaking of molecular bonds is only one factor that influences the wearing of contact surfaces, the other including any intermediate materials that are present between the contacting surfaces, including their hardness, durability and other physical properties (e.g. oils in hides, silica in vegetal remains). The effects of adhesive wear may not be visible in the early stages of use except under extremely high magnification, but may become more evident as the wear process continues.	Residues
<i>Abrasive wear</i>	<i>Abrasive wear</i> occurs when loosened particles become abrasive agents in the wear process, resulting from either environmental contaminants, the removal of surface particles or the nature of the material processed. Abrasive wear may also result from the movement of a harder, asperate surface across a softer, less durable surface. The constituent grains of the harder, more durable surface will dig into the softer contrasting surface, creating scratches in the direction of movement. The scratches, referred to as striations, may occur across both the artefact surface as a whole or across individual grains.	Striations and scratches, surface levelling, grain edge rounding
<i>Fatigue wear</i>	<i>Fatigue wear</i> occurs when the artefact pressure, impact, or the alternating stress of movement is applied to the contacting surfaces, causing a crushing mechanism on the artefact surfaces.	Fractures, cracks, pits, frosted appearance
<i>Tribochemical wear</i>	<i>Tribochemical wear</i> is a combination of mechanical and chemical interactions that cause the build-up of films and oxides resulting in a surface polish or sheen. This polish is typically only visible at higher magnifications as it is observed on individual grains.	polish or sheen

4.3 Residues

Residues may accumulate on artefacts as a consequence of many cultural and non-cultural processes (Fullagar & Matheson 2013). I define use-residues as the remnants of material (plant, animal or mineral) that have adhered to the tool surface during use. Residues acquired from hafting are distinguished from use-residues as they were not acquired from the worked material, but rather from the haft/handle and the hafting media. I refer to these as ‘haft-residues’. In certain stable environments, residues remain intact on the tool surface over a significant period of time, but more often they are better preserved within cracks of the stone material where they may be protected from external agencies (Hillman *et al.* 1993: 96; Shanks *et al.* 2001: 965). Grinding stones, which are often formed on coarse grained materials such as sandstone, are often porous in nature and therefore have the potential to preserve archaeological residues within the interstitial spaces. For this reason, residue analysis on porous grinding stone implements may be particularly valuable.

Microscopically visible residues are categorised under three main groups according to their origin: plant, animal, and inorganic. Visible tool-residues consist of distinct tissues, cells and films and other structures, whereas microscopically invisible residues such as lipids and other biomolecules (e.g., proteins, carbohydrates) require other means of identification (e.g., chemical characterisation and spectroscopy). Plant residues often have visible and distinctive thick-walled cell structures (Evert 2006). Animal residues (e.g., blood, bone, muscle, fat, collagen, hair and shell) sometimes have distinctive cell structures but often require staining for visibility or other chemical characterisation. Tool residues with an inorganic origin (e.g., haematite, ochre, pigment, calcite) can be identified microscopically but may also require further chemical characterisation. Microscopic observations and mapping of residues also provides information regarding tool-use action (mode of use) and non-use related residues (i.e., those accumulated from the depositional environment and from post-excavation contamination—see Sections 4.6.2 and 4.6.3). The following sections describe the residues commonly identified on archaeological artefacts.

4.3.1 Plant residues

Reconstructions of plant exploitation and cultivation practices of prehistoric human populations are becoming increasingly dependent on the identification of macro- and micro-botanical (plant) residues present on prehistoric implements. All plants are made up of a distinct composition of cells, tissues, organs and other structures identifiable microscopically (Evert 2006;

Raven *et al.* 2005). The general morphology of plant residues, their size, cell structure, birefringence (the double refraction of incident light) and the presence of additional plant cells, are potentially diagnostic of particular plant taxa. Taxonomic identification is complex and may require numerous specimens and extensive experimental reference libraries (e.g., starch grains, raphides, phytoliths, cellulosic matter, pollen, and exudates such as resin, gums and waxes,) (Plate 4.6). Identification of these residues may indicate plant utilisation but only after consideration and exclusion of potential non-use related residues including those related to past cultural activities (e.g., hafting or storage) and from 'contaminants' from within the depositional environment or post excavation handling.

4.3.1.1 Lignin and cellulose

Lignin and cellulose are plant tissues comprising the structural component of plant cell walls, and are the most abundant organic compounds on earth (Evert 2006: 66-70; Raven *et al.* 2005: 31-32). Lignins are polymers formed from three types of monomers, including coumaryl, coniferyl and siapyl alcohols, which occur in varying abundances depending on the type of plant (i.e., non-flowing seed plants, woody angiosperms, or grasses) (Raven *et al.* 2005: 31-32). In addition to providing structural support, lignin also waterproofs the cell wall, facilitating upward transport of water to the conducting cells of the xylem by restricting the movement of water between cells (Raven *et al.* 2005: 32). Under transmitted light, lignin presents as the rigid outer layer of the plant cell wall, causing the characteristically stiff, brick-like cell structure (Plate 4.6b). The lignin component of cell walls is birefringent and fluoresces under cross polarised light.

Cellulose forms the fibrous part of cell walls and is composed of monomers of glucose and other polysaccharides, such as hemicelluloses, pectins and chitin (Raven *et al.* 2005: 17-18). The long, rigid cellulose molecules combine to form microfibrils that wind together in fine threads, coiling around one another to form slender ribbon-like structures (Plate 4.6a) (Evert 2006: 66; Raven *et al.* 2005: 18). Under cross-polarised light, cellulose is birefringent and bright but may be translucent when viewed under high magnification.

4.3.1.2 Raphides

Raphides are needle-shaped calcium oxalate crystals found within plant tissue, functioning in plant defence, calcium storage and structural strength. Raphides are microscopically visible by virtue of their characteristic needle-like shape (Plate 4.6d) (Evert 2006: 56). Calcium oxalate can

survive in archaeological settings where organic materials, such as other plant remains, are unlikely to survive. Raphides on stone artefacts and ceramic pieces have been linked with processing and cooking of some aroids (family *Araceae*) (e.g., Horrocks & Bedford 2005: 70; Horrocks & Weisler 2006: 1193; Horrocks *et al.* 2008a: 297), including yam (e.g., *Dioscorea esculenta*) (Horrocks & Nunn, 2007: 742), taro (e.g., *Colocasia esculenta*) (Crowther 2005: 62; Horrocks & Nunn 2007: 742; Loy *et al.* 1992: 901), and non-*Colocasia* Araceae (e.g., Horrocks & Bedford 2005: 70). Raphides are highly abundant within the corms and rhizomes of aroids while in other plants they are typically restricted to the leaves, stems and roots, which are less likely to be processed or consumed by humans (Horrocks & Nunn 2007: 742; Loy *et al.* 1992: 901). Raphide size may vary considerably within certain plant species, and taxonomic differentiation is not always possible (Crowther 2009: 114). However, Loy *et al.* (1992: 906) argued that aroid raphides may be distinguished on the basis of size, shape, and cross section, and proposed several raphide “types” that included whisker-like and lath-like. The identification of raphides on stone tools has added supporting evidence to ancient starch research that has indicated the processing of yam in PNG (Horrocks *et al.* 2008b: 297), New Zealand (Horrocks & Barber 2005) as well as yam and taro within various islands of the Pacific (Crowther 2005: 64; Horrocks & Nunn 2007: 742; Horrocks & Weisler 2006: 1193; Horrocks *et al.* 2008a: 2455; Loy *et al.* 1992: 898). Consequently, raphides on stone artefacts are potentially significant indicators of horticultural crops and plant domestication processes.

4.3.1.3 Starch

Starch is a carbohydrate consisting of a large number of glucose units that act as an energy store that occur in the form of granules (grains) composed of distinct layers of amylase and amylopectin, which are visible under microscopic conditions (Evert 2006: 52-3; Gott *et al.* 2006: 35; Raven *et al.* 1999: 126, 2005: 17; Tester *et al.* 2004). Starch grains are individual spherical masses with a distinctive extinction cross, which is visible under cross-polarised light (Plate 4.6e-f) (Evert 2006: 52-3; Haslam 2004: 1716). The application of Iodine Potassium Iodine (IKI) may also be applied to prepared residue slides to distinguish undamaged starch, turning them a permanent blue/black colour (Banks & Greenwood 1975: 67; e.g., Balme *et al.* 2001: 4; Barton & White 1993: 174; Bruier 1976: 482; Loy 2006a; Loy *et al.* 1992: 904; Smith 2004: 178; Revedin *et al.* 2010: 11819)

The different botanical sources of starches may be determined through the evaluation of their morphological, thermal and rheological properties (Eastaugh *et al.* 2008: 894; Singh *et al.* 2003). Starch grain reference collections provide the basis for taxonomic distinctions based on

variations in grain size (approximately 1 – 100 µm in diameter), shape (round, lenticular, polygonal), hilum form, concentric growth rings, size distribution (uni- or bi-modal), association as individual or compound grain clusters, surface features and the nature of the extinction cross (Eastaugh *et al.* 2008: 894-7; Singh *et al.* 2003: 223; Tester *et al.* 2004: 152). Heating or degradation causes starch grain discolouration (from colourless to various shades of amber/brown), swelling and loss of birefringence in which case the extinction cross may no longer be visible (Banks & Greenwood 1975: 259-63; Morris 1990: 2; Singh *et al.* 2003: 223). Gelatinised starch grains are typical of starch that has been cooked or heated above 50°C (Banks & Greenwood 1975: 260; Gott *et al.* 2006: 44). The cooking of starchy plants is common ethnographically, often practiced to eliminate toxicity of the plant or to increase palatability. Biochemical stains such as Congo Red and Trypan Blue (Table 4.5) provide a means for identifying damaged or gelatinised starch grains (Barton 2007: 1754; Haslam 2004: 1716; Lamb & Loy 2005: 1434). A reference collection for cooked and damaged starch has been made available online and details of various cooking procedures (e.g., boiling, baking, parching, popping, fermenting) and the associated affects on starch grains (see Henry *et al.* 2009).

The interpretation of starch grains as use-residues requires, as for other traces of use, careful consideration of potential contaminants and associations with other traces of use (Barton *et al.* 1998: 1232; Crowther 2014). Similar organic residues typically found within soils have superficial similarities to starch grains. For example, particles such as ooliths, coccoliths, faecal spherulites, spherical avian uric acid, and fungal growths such as conidia, also exhibit a rotating extinction cross under cross-polarised light and may be strikingly similar to small starch grains (Canti 1998: 442; Folk 1969: 1515; Haslam 2006: 115; Lamb & Loy 2005: 1434; Loy 2006b).

Starch grain residues have been reported on stone tools from many sites in the Australian-Pacific region, spanning at least 30 ka (e.g., Balme *et al.* 2001; Fullagar & David 1997; Fullagar & Field 1997; Fullagar *et al.* 2008, 2015; Loy *et al.* 1992; Summerhayes *et al.* 2010). Starch on stone artefacts from other regions of the world, including Europe, the Levant and Niah Cave in southeast Asia; have also been reported from deposits starting from ~30 ka ago (e.g., Barker *et al.* 2007; Piperno & Holst 1998; Piperno *et al.* 2004; Revedin *et al.* 2010).

4.3.1.4 Phytoliths

Phytoliths are siliceous particles that form as a result of precipitation and mineral secretion from plant cells within organs such as leaves, stems and inflorescences (Evert 2006: 58; Piperno 2006: 5). Phytoliths are rigid, microscopic structures of varying size, shapes and ornamentations and

survive well archaeologically (Plate 4.6c). They have potential for reconstructing plant-use when compared with modern reference collections and when observed in association with other plant remains, such as starch grains and raphides (e.g., Hart 2011; Horrocks & Barber 2004; Horrocks & Bedford 2005; Horrocks *et al.* 2008b; Kealhofer *et al.* 1999; Parr & Carter 2003; Pearsall 2004; Wallis 2003a). Because phytoliths contain a high silica concentration, they can act as a polishing agent on stone tools, with use-polish development related to the internal silica content of the material worked (Section 4.2.3) (Fullagar 1991: 6-7).

Although phytoliths occur in many plants, they are particularly abundant in palms and grasses (Alam *et al.* 2009: 504) and have been identified as tool-residues adhering to archaeological artefacts (e.g., Hart 2011; Horrocks & Barber 2004; Horrocks & Bedford 2005; Horrocks *et al.* 2008b; Kealhofer *et al.* 1999; Pearsall 2004) and within archaeological sediments (Barboni *et al.* 1999; Bowdery 1989; Grave & Kealhofer 1999; Ishida *et al.* 2003; Mercader *et al.* 2000; Piperno *et al.* 2000; Runge 1999; Wallis 2001). Phytoliths have proven to be significant in determining the timing of plant domestication (e.g., Piperno *et al.* 2000; Rosen 1993), the extent of bioturbation (e.g., Grave & Kealhofer 1999) and for reconstructing palaeo-environments, sometimes driven by climate change (Alam *et al.* 2009; Clarkson & Wallis 2001; Wallis 2001, 2003b).

4.3.1.5 Resins, gums and waxes

Plant resins, gums and waxes are naturally occurring plant exudates forming as a response to trauma after wounding, infection, or insect attack (Evert 2006: 482; Langerheim 2003: 23-24; Pollard & Heron 2008: 236; Stern *et al.* 2008: 352). Archaeologically, the most common plant exudate occurs in the form of resin, a non-cellular, water insoluble substance that serves as an adhesive for hafting stone tools (e.g., Lombard 2006: 28, 2008: 30; Rots 2010: 21) and repairing broken pottery sherds and other artefacts (e.g., Charters *et al.* 1993a; Koob 1998). When found on stone artefacts, some resins appear as films that are characterised by a dark semi-translucence with smooth droplets or as desiccated, cracked deposits with plant tissue inclusions (Plate 4.6g) (Fullagar 2014: 243). Under high magnifications, these deposits may include starch grains, fibres, and other plant tissues with distributions that may indicate worked material and, sometimes, hafting or other adhesives. Methods available for the taxonomic identification of resinous material include gas-chromatography mass-spectrometry (GC-MS) (Section 4.5.2.3), which has proven to be useful in the characterisation of archaeological resins and the identification of the botanical source (e.g., Boëda 1996; Cârciumaru *et al.* 2012; Charrié-Duhaut *et al.* 2013; Eerkens 2002; Fox *et al.* 1995; Hayek *et al.*

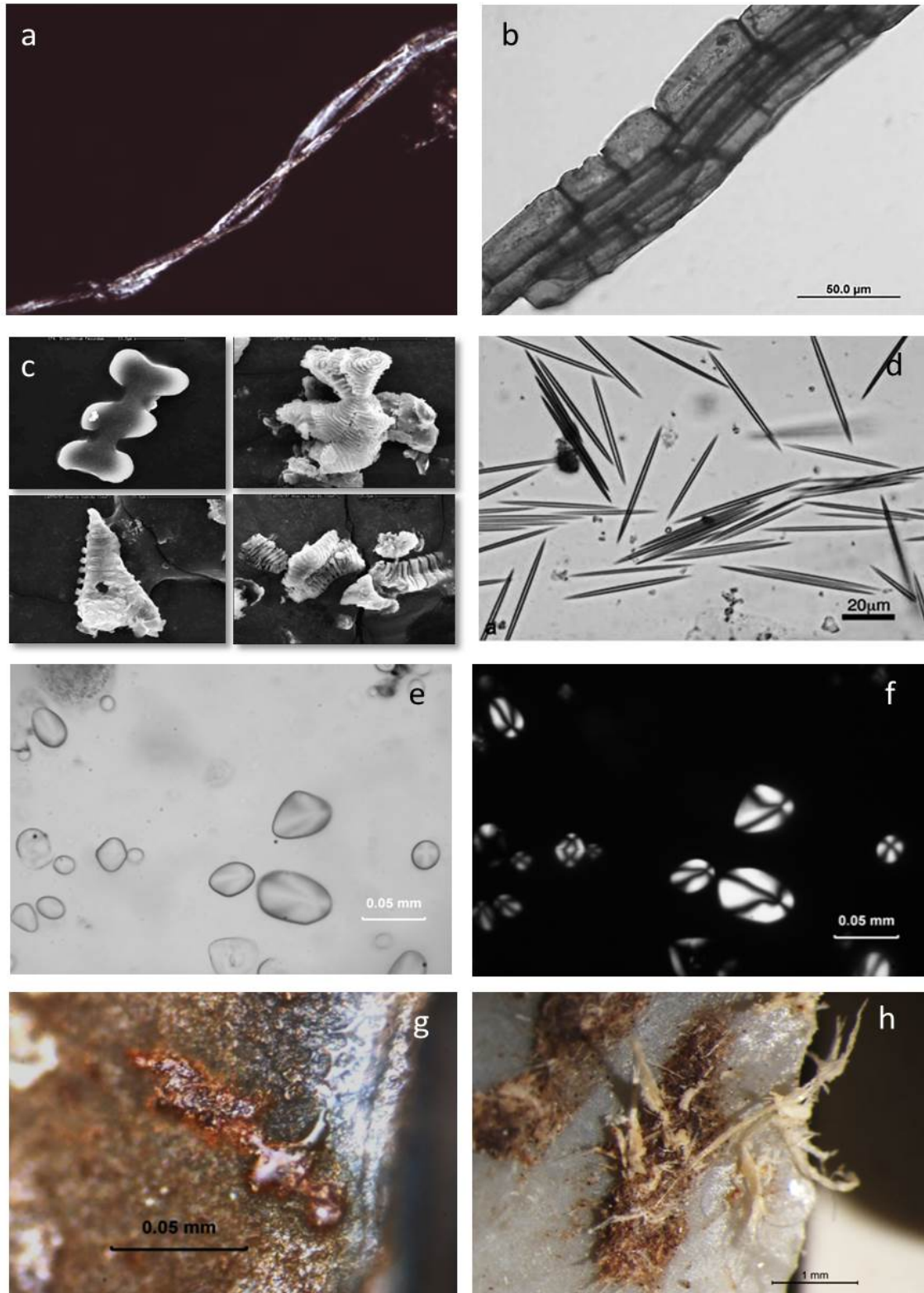


Plate 4.6a-h: Plant residues: **a)** twisted cellulose fibres exhibiting birefringence in cross polarised light; **b)** rigid plant material exhibiting lignified cell walls; **c)** diagnostic phytolith types from *Acacia* sp. (from Fullagar & Wallis (2012): Fig. 16); **d)** calcium oxalate crystals (raphides) from *Cordyline terminalis* (leaf), (from Crowther (2009): Fig. 2a); **e-f)** starch grains (potato) photographed in plane-polarised light (left) and cross-polarised light (right); **g)** plant exudate (resin) on artefact surface; **h)** woody fibres on experimental wood sawing artefact.

1990; Helwig *et al.* 2014; Matheson & McCollum 2014; Regert 2004). Other methods of analysis, such as Fourier Transform Infrared Spectroscopy (FTIR) (Section 4.5.2.3) have also proven successful (e.g., Blee *et al.* 2010; Cărciumaru *et al.* 2012; Charrié-Duhaut *et al.* 2013; Helwig *et al.* 2014). Determining the botanical origin of the resin on artefacts may provide clues as to the use of the tool, and may have significant implications regarding trade, long distance collection, and hafting preferences.

Plant gums are natural polysaccharides most commonly found in the woody elements of plants or seed coatings (Mauseth 1988). Like resins, they can be used as hafting adhesives in the manufacture of composite tools. Waxes are organic compounds that are insoluble in water, made up of a class of chemical compounds that are malleable at ambient temperatures. The use of waxes in tool manufacture is not common archaeologically, but may be present on wood working tools. Gums and waxes may vary greatly in colour but usually range from yellow to dark brown. Other plant structures, such as starch grains and other plant cells, may also be visible in residues of this variety.

4.3.2 Animal residues

Identification of animal residues may provide direct evidence for tool-use. Animal tissues such as blood, bone, muscle, collagen, fat, hair, feathers and shell may survive as residues on prehistoric implements (Plates 4.7, 4.8a). Certain animal residues have distinctive morphologies that enable them to be recognised microscopically. Often, these residues are found in association with one another, and the various components may be recognised on the basis of their distinctive microscopic cellular structures. The application of a number of immunological methods and the use of atlases to compare visual features such as size, morphology and shape, may enable some animal residues to be identified at a taxonomic level.

4.3.2.1 Blood

Blood is an organic tissue consisting of cells suspended in a fluid medium, or *plasma*, which functions in the transport of gases, nutrients, metabolic waste products, cells and hormones (Wheater *et al.* 1987: 36). The cells composing blood may be classified as one of three functional varieties; (1) red blood cells (RBCs), also known as *erythrocytes*; (2) white blood cells (WBCs), or *leucocytes*; and 3) platelets, or *thrombocytes* (Ross & Pawlina 2011: 268). RBCs are mostly involved

in the transport of oxygen and carbon dioxide, while WBCs contribute to the body's defence and immune system and are involved in defending the body against both infectious disease and foreign invaders (Wheater *et al.* 1987: 36). Platelets are small (approximately 2 – 3 μm in diameter), non-nucleated cells that appear round to oval in shape, and make up an important component of the blood clotting mechanism (Wheater *et al.* 1987: 45). Blood residues often occur on tools that have been used to process or prepare animal flesh, such as butchering or skin scraping tools. At low magnification, thick blood deposits occur as red-black blobs with distinct boundaries and a fluid like appearance often displaying a characteristic "mud-cracked" desiccated surface (Plate 4.8a). Thin blood deposits are more reflective and may occur in a range of red-yellow colours. At higher magnification, the presence of blood may be confirmed by the appearance of several visibly distinct structures, including WBCs and RBCs. These appear circular with a hollowed out centre, forming a distinctive biconcave disc shape (Plate 4.8b) (Ross & Pawlina 2011: 271; Wheeler *et al.* 1987: 36). Avian, reptile, fish and amphibian RBCs are distinguished by the presence of a nucleus creating a distinctive elongated shape (Campbell 1990: 229, 262, 282, 292; Clark *et al.* 2009: 33; Hawkey 1975: 3). Mature mammalian RBCs are distinguished by their lack of nucleus and appear as biconcave discs and are typically smaller in size than other animal classes (Andrew 1965: 161; Campbell 1990: 214; Hawkey 1975: 6; Ross & Pawlina 2011: 271). Occasionally, size and shape of animal RBCs may indicate order and species of mature animal species; however, both shape and size of blood are subject to change as the blood dries (Loy & Dixon 1998: 25; Steck 1989). Blood atlases are available for identifying the RBCs from some species (e.g., Andrew 1965; Clark *et al.* 2009; Hawkey 1975).

In addition to red and white blood cells, blood contains proteins that may be detected and analysed by immunological methods (see Table 4.4 for methods of protein and DNA detection) (e.g., Child & Pollard 1992; Loy 1983; Loy & Dixon 1998). Blood proteins include amino acids, haemoglobin, and a number of additional components that are present in all animal species. "Screening" tests for haemoglobin may be carried out using the Siemens Hemastix[®] (Chemstrip) test that allows chemical detection of minute and sometimes invisible blood residues (Johnson *et al.* 2008: 688; Loy 1983: 1269; Matheson & Veall 2014: 231; Tobe *et al.* 2007: 104; Williamson 2000). If a positive reaction occurs (i.e., the Hemastix strip changes colour as haemoglobin is detected) then it is presumed blood is present on the artefact surface (Loy 1983: 1269; Loy & Dixon 1998: 25). However, further analysis is required to validate the presence of blood following a positive reaction, as Hemastix[®] strips may also react with vegetable and bacterial peroxidises, chlorophyll, metals including manganese and copper ions and saliva (Custer *et al.* 1988: 343-345; Downs & Lowenstein 1995: 12; Gurfinkle & Franklin 1988: 89; Loy 1993: 49; Loy & Dixon 1998: 25; Manning 1994: 161;

Matheson & Veall 2014: 239; Tobe *et al.* 2007: 107). These are often present in soil matrices, and consequently all soils from which the artefacts were removed should also be evaluated as an extra precaution (Custer *et al.* 1988). Recent developments in the Hemastix® testing technique involve the addition of a chelating agent ethylenediaminetetraacetic acid (EDTA) to the residue sample before testing will act to reduce the reactivity of sample so that only certain substances (i.e., haem) will react with the Hemastix strip (Loy & Dixon 1998: 25; Matheson & Veall 2014: 235-236; Veall & Matheson 2013). Once the presence of blood is confirmed either through the presence of microscopically distinctive residues or positive Hemastix® reactions, donor blood species may be evaluated via protein, haemoglobin crystallisation or DNA (Deoxyribo Nucleic Acid) analysis. The methods of these analyses are described in Table 4.4 and have been applied to a number of archaeological and experimental materials with varying results (e.g., Dixon & Loy 1998; Fullagar *et al.* 1999; Garling 1998; Hardy & Raff 1997; Heaton 2009; Högberg *et al.* 2009; Hyland *et al.* 1990; Kooyman *et al.* 1992; Leach & Mauldin 1995; Loy 1983, 1993; Loy & Hardy 1992; Loy & Matthaai 1994; Loy *et al.* 1990; Matheson *et al.* 2009; Matheson & Loy 2001; Potter *et al.* 2010; Reuther *et al.* 2006; Shanks *et al.* 2005; Tuross *et al.* 1996, Wallis & O'Connor 1998; Williamson 1997). While the species of origin is sometimes able to be determined, the applicability of these methods on ancient archaeological samples is often hindered by issues surrounding the physical and chemical degradation of blood residues and sample contamination with modern DNA samples (i.e., through handling) (Hardy & Raff 1997: 602; Loy 1993: 53; Yang & Watt 2005: 335). Over time, blood residues may degrade or undergo diagenetic alteration as a result of taphonomic processes occurring within a burial environment and consequently species of origin via biochemical and immunological methods makes species of origin difficult to interpret (Cattaneo *et al.* 1993: 41; Eisele *et al.* 1995: 37; Gurfinkel & Franklin 1988: 93-94; Remington 1994: 298; Yang & Watt 2005: 331) and occasionally eludes to erroneous ascertains (see Fiedel 1996). Despite these concerns, blood residues have been observed on 2 Ma Oldowan stone tools from Sterkfontein, South Africa (Loy 1998). While these claims remain controversial, and have been challenged by other researchers (*cf.* Langejans 2009), evaluation of the micro-stratigraphy and burial matrix of the site has suggested that there were suitable conditions for residue preservation with an alkaline pH and a clay-rich high density of calcite and clay within the soil Breccia (Jones 1998: 102-103). The favourable preservation of blood in clay-rich sediments is further evidenced at the site of Cuddie Springs, where 36 ka old blood residues are identified on stone artefacts within the clay soils (Field *et al.* 2006; Garling 1998). Preservation of blood residues including protein and DNA molecules are believed to survive for even longer durations when they are sequestered in minute indentations and micro-cracks present on the artefact surface potentially preserving them for several millennia (Fullagar *et*

Table 4.4: Methods of DNA and protein analysis.

Method of protein analysis	
Haemoglobin crystallisation	Haemoglobin (Hb) crystallisation involves precipitation of Hb molecules to form distinctive micro-crystals typical of certain animal species (Loy 1983). The structure and appearance of the resulting crystals are determined by the different amino acid sequences unique to individual species and thus are distinguishable amongst animal species. Evaluation of donor Hb species requires a reference collection produced from a range of species (Loy 1993). This technique has been applied to a number of archaeological studies in order to determine species of origin of ancient blood residues (e.g., Loy 1983, 1993).
Radioimmunoassay (RIA)	RIA is a method of immunological analysis that involves the immune system and associated antibody responses. An “antibody” is a large Y-shaped protein that acts to protect the body against foreign particles (antigens) by fusing together (a process called “binding”). The binding process will only occur if species-specific anti-sera (blood serum containing anti-bodies) recognise the antigen. RIA analysis involves the production of antibody molecules (usually in the form of Immunoglobulin G - <i>IgG</i>) by the injection of target antigen into an animal host followed by removal and purification of the newly formed antibodies (Loy & Dixon 1998). These may then be added to an unknown protein sample. If the antibodies from the known species bind with the target antigen, it is likely that both animals are closely related. Stronger bonds will occur for more closely related species. Using scintillation counting, the degree of binding can be quantified when species-specific antibodies are introduced to sample antigens, thus allowing species of origin to be determined. Usually, however, identification is restricted to a family level (Loy 1993) with species-specific identifications often limited due to cross reactions with similar species. In degraded protein specimens, antigens of modern species may cross-react with unrelated species causing erroneous inferences (see Child & Pollard 1992; Fiedel 1996 for reviews). Despite potential misidentifications, the RIA method of analyses has been applied to a number of experimental (e.g. Ruether <i>et al.</i> 2006) and archaeological tools (e.g. Loy 1993; Potter <i>et al.</i> 2010) with excellent results.
Enzyme-linked immunosorbent assay (ELISA)	This method is similar to the RIA method in that the analysis is based on an antibody response. In ELISA, the antigen-antibody reaction is measured using colourimetric signals rather than radioactive signals. Unfortunately, this method is often prone to false positive results as a consequence of non-specific inhibition of antibodies with un-related antigens (Craig & Collins 2002; Fiedel 1996).
Iso-electric focussing (IEF)	IEF involves the separation of proteins based on their associated iso-electric point (<i>pI</i>) so that total protein content may be separated in discrete groups of highly purified protein concentrations (Loy & Dixon 1998). It is used to confirm the presence of Hb and serum albumin (Loy 1993). Taxonomic identification is achieved by determining the <i>pI</i> values of specific molecules as determined for a variety of species. Genetically-driven random mutations of amino acid sequences of individual organisms will display minor charge differences of protein molecules, however, species is usually still able to be identified (Loy 1993). This method has been used to confirm the presence of blood on archaeological tools (e.g., Loy 1993).
Western blot	The western blot or dot blot test is a technique for detecting, analysing and identifying proteins following a specific antibody response whereby IgG bonds with Staphylococcal protein A (SpA) (Loy & Hardy 1992; Loy & Wood 1989).
Method of DNA analysis	
Polymerase chain reaction (PCR)	PCR is a method of amplifying DNA in degraded sequences that are only represented by short sequences. The amplification of selected DNA sections is carried out through a number of cycles in which 2 – 3 discrete temperature changes are applied (the temperatures of which and the length of temperature hold are determined by a number of parameters, e.g., concentration of ions, enzyme varieties, melting temperature of constituent particles). The reproduction of the DNA (or RNA) sequence is subsequently amplified across several orders of magnitude, allowing species to be determined (Hardy & Raff 1997; Loy 1993; Sarkar & Sommer 1990). Extra precautions are required in PCR so that contaminate DNA (i.e. from handling) are not incorporated in the DNA amplification process. Following the PCR technique, DNA analysis has been carried out on a number of archaeological materials (e.g., Hardy & Raff 1997; Loy 1993; Matheson & Loy 2001; Shanks <i>et al.</i> 2005; Williamson 1997) and experimental materials (Hardy & Raff 1997).

al. 1996: 2; Shanks *et al.* 2001: 965). Section 4.6.1 further discusses residue preservation on archaeological artefacts and the conditions best suited for this.

4.3.2.2 Bone

Bone is dense connective tissue hardened by minerals, predominantly calcium, phosphate and carbonate, functioning as the rigid protective and supporting framework for most of the soft tissues in the body (Ross & Pawlina 2011: 219; Wheeler *et al.* 1987: 142-145). Like other connective tissues, bone is also composed of a variety of cells, proteins and collagen fibres. Bone residues appear amorphous and greasy and are often accompanied by collagen particles and bone cells, namely apatite (Fullagar 1986a: 105; Jahren *et al.* 1997: 247). The presence of bone residues on a tool is consistent with the working of bone, the butchering of animals and the removal or scraping of flesh. Bone cells are usually only visible as fine, white-translucent grains, or as shavings, usually smeared on the working edge (Plate 4.7e). A secondary mineral, vivianite ($\text{Fe}_3(\text{PO}_4)_2 \cdot 8\text{H}_2\text{O}$), is often found in association with fatty bone residues, appearing bright blue under cross-polarised light (Plate 4.7f) (Fullagar 2014: 245; Langejans 2009: 65; Robertson 2005: 96; Kraus *et al.* 1959: 354). Vivianite may appear as prismatic crystals or globular aggregates with a radial, fibrous structure (Kraus *et al.* 1959: 354). Like blood, bone contains protein and DNA that may be evaluated to determine species of origin if present in sufficient quantities (Hedges & Wallace 1978). Methods for DNA evaluation are described in Table 4.4.

4.3.2.3 Collagen, grease and fat

Collagen is the principal fibre found in the extracellular matrix of connective tissues and is composed of a variety of naturally occurring proteins (Ross & Pawlina 2011: 161; Wheeler *et al.* 1987: 53). Collagen is identifiable microscopically, occurring as a small bundle of fibres consisting of white-translucent ribbon-like twisted structures of variable width and indeterminate length (Plate 4.8d-e) (Ross & Pawlina 2011: 162). Under plane polarised light, collagen appears opaque but will display birefringence when viewed under cross-polarised light (Lombard 2008: 38). Muscle tissue is composed of densely compacted collagen tissue and often has a striated appearance (Plates 4.7c; 4.8c). Muscle, blood and collagen may be macroscopically visible on the artefact surface and (when all three are identified on the same artefact) usually indicate butchering or animal working (including hide and skin scarping) activities (Plate 4.7a-b).

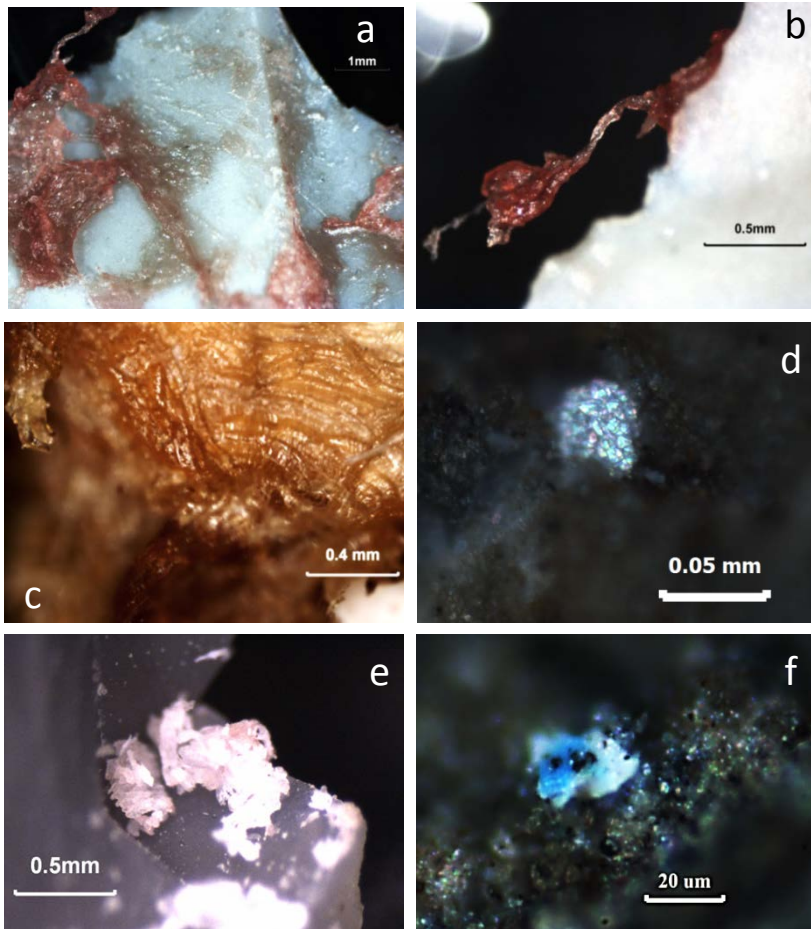


Plate 4.7a-f: Animal residues on tool surface photographed under reflected light: **a-b)** blood and collagen fibres on experimental butchering tools; **c)** striated muscle tissue on experimental butchering tool; **d)** multi-coloured nacre residue from shell grinding tool; **e)** bone residues from experimental bone scraping tools; **f)** bone residue with vivianite on an archaeological tool.

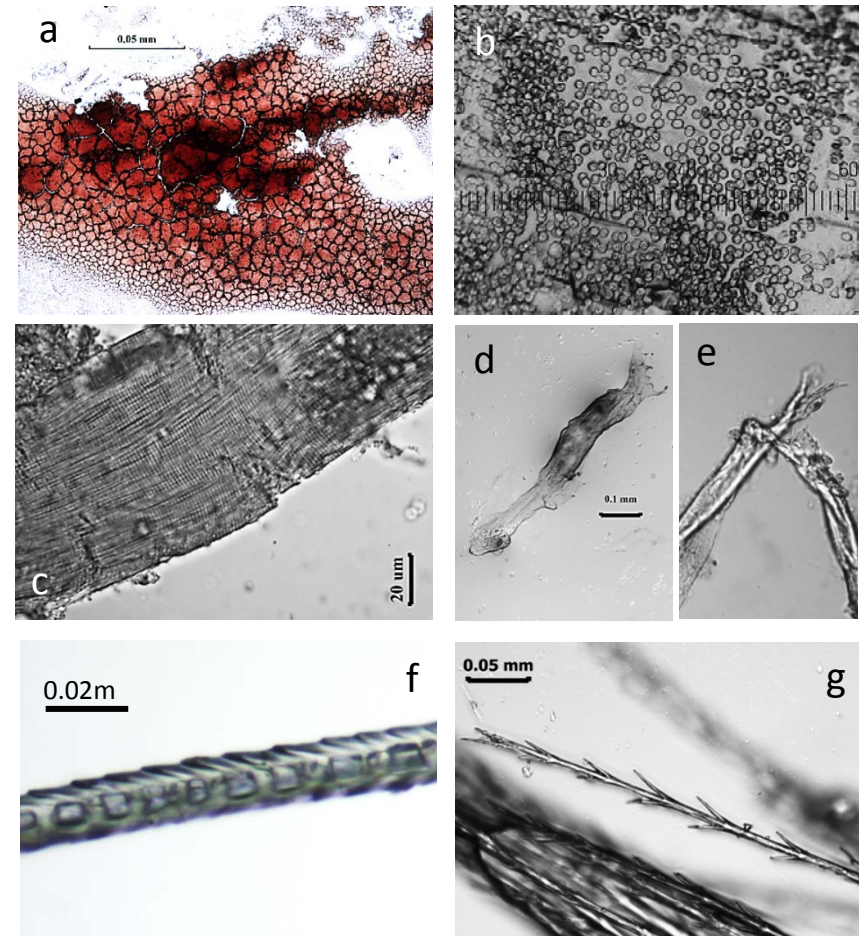


Plate 4.8a-g: Animal residues photographed under transmitted light: **a)** blood residue exhibiting a mud-cracked appearance; **b)** human red blood cells (platelets) (photo by R. Fullagar); **c)** striated muscle tissue and animal collagen; **d)** amorphous collagen fibre; **e)** collagen fibre exhibiting twisted fibrils at the ends; **f)** hair fibre (rodentae); **g)** feather barbule (faliconforme).

The identification of collagen on archaeological artefacts may not always imply animal processing, but often occurs as a result of modern handling contamination. Likewise, finger grease, or sweat or fat may also occur on artefact surfaces as a result from improper handling techniques (Plate 4.11f). These usually appear as globular-shaped viscous fluids, however when smeared crushed they may appear amorphous along the tool edge (Lombard 2008: 38). Use related fatty deposits may be recognised by associated animal tissues such as blood and collagen.

4.3.2.4 Hair and feathers

Keratin is the molecule responsible for forming hair, feather, horn, hoof, beak, claw and nails, and it is identifiable under cross-polarised light, emitting a pale blue birefringence. Hair is common on skin scraping tools and will occasionally occur on butchering tools and appears in long tubular (cylindrical) structures that exhibit central regions (medullae) and plate-like surface scales that make up the outer cuticle layer (Plate 4.8f) (Bonnichsen *et al.* 2001: 777; Ross & Pawlina 2011: 506; Wheeler *et al.* 1987: 136). Animal hair is a particularly informative piece of evidence, potentially indicating animal species depending on the various surface, cross-section and internal structures of the hair (Brunner & Coman 1974; Knecht 2012: 129; Teerink 1991). Using mammalian hair atlases, such as that of Brunner & Coman (1974), taxonomic identification is possible. Feathers may also be diagnostic of certain species, as they include microscopic features such as barbs, nodes and villi that possess distinctive morphologies allowing species recognition (Plate 4.8g) (Dove 1997: 47; Dove & Koch 2011; Robertson *et al.* 1984).

4.3.2.5 Shell

Shell is the hard, protective, outer covering of molluscs (i.e., invertebrate organisms comprising the phylum *Mollusca*, including chitons, snails and bivalves), which is predominately comprised of calcium carbonate (CaCO_3) (Claasen 1998: 16). The inner layer generally consists of a multi-coloured nacre; an organic-inorganic composite material composed of polygonal aragonitic tablets about 5 – 15 μm in diameter (Claasen 1998: 24-5; Nudelman *et al.* 2006: 176). The iridescent appearance of the nacre results from the thickness of the aragonite platelets that interfere constructively and destructively with different wavelengths of light at different viewing angles, creating structural colours. The working of shell may be reflected on a tool by the occurrence of crushed calcium carbonate and nacre residues appearing as smears on the tool surface (Plate 4.7d).

These residues exhibit birefringence (Fullagar 2014: 245) and may be accompanied by very minute apatite crystals ($\text{Ca}_5\text{F}(\text{PO}_4)_3$) that occur as small six-sided prismatic crystals with a weak birefringence (Rogers & Kerr 1942: 224). These are sometimes colourless and transparent but are usually opaque and variously coloured (Kraus *et al.* 1959: 351-2).

Worked-shell artefacts have been identified in many regions of Australia, and include ornaments such as beads and pendants, fish hooks, and other tools such as shell adzes and ground edge chisels (e.g., Akerman 1975; Akerman & Bindon 1984; Przywolnik 2003). These are created through grinding and/or flaking activities, and are used for a variety of purposes, including decoration, wood-cutting/working, and animal butchering/capture (Akerman 1975: 16).

4.3.3 Inorganic residues

Inorganic residues, i.e., those residues not acquired via contact with living organisms, may also be present on a tool surface. The most commonly observed inorganic use-residue on archaeological tools is ochre (Plate 4.9a-b). Ochre is a form of earth pigment that produces colour, derived from naturally tinted clay containing mineral oxides such as haematite and other forms of red iron oxide (Fe_2O_3) and yellow hydroxide (FeOOH) (Eastaugh *et al.* 2008: 903-907; Rogers & Kerr 1942: 196). Red ochre often contains a considerable amount of clay or sand particles and may also be partially composed of other iron oxide minerals such as goethite, haematite, lepidocrocite and magnetite, and is usually very soft and has a dull luster (Kraus *et al.* 1959: 302). On the surface of the artefact, red ochre may be visible macroscopically, characterised by brightly coloured grains. Other varieties of ochre may appear steel grey, reddish brown, iron black or yellow in colour (Plate 4.9a-b). Yellow ochres differ from red ochres in that they are derived from iron-rich soils and the decomposition of ore deposits, making them impure (Eastaugh *et al.* 2008: 905). They are composed primarily of iron oxide hydroxides goethite and, less frequently, lepidocrocite (Eastaugh *et al.* 2008: 905). Brown ochres differ again in structure, containing goethite, haematite and also black iron oxide, such as magnetite (Eastaugh *et al.* 2008: 907). Other colour varieties of ochre may be manufactured by roasting to various temperatures; a process that allows for the conversion of goethite to hematite and eventually magnetite, and thus leading to a subsequent colour change (Eastaugh *et al.* 2008: 905). Under higher magnifications, ochres appear to display an angular crystal form; in cross polarised light, they may appear dull, but their colour becomes enhanced under polarised light (Langejans 2009: 67). Ochre may be used for decorative purposes (for example, to

create paint), or in association with hafting resins (e.g., Lombard 2005: 293, 2007: 408; Wadley 2005, 2006: 318; Wadley *et al.* 2002, 2004: 670).

Haematite is the primary mineral that constitutes red ochre, and is the most common red iron oxide mineral; forming in a wide variety of geological environments (Eastaugh *et al.* 2008: 687). Massive haematite deposits are found in association with the oxidising zones of large iron ore deposits, but may also be present within sedimentary rocks such as sandstones with the iron oxide finely disseminated throughout the stones matrix (Eastaugh *et al.* 2008: 687). Ground haematite pieces are identified in Australian archaeological deposits starting from the Pleistocene (Table 2.2), and is also identified on other varieties of archaeological artefacts, including grinding stones and other flaked-stone tools. The red colour of haematite is often very intense owing to the magnetic coupling of the Fe cations (Dyar *et al.* 2008: 659). Under reflected light, this mineral displays a metallic lustre, appearing opaque or translucent red, and may be present in the form of anhedral and isotropic crystals with an extremely variable particle size and shape (Eastaugh *et al.* 2008: 686-7; Rogers & Kerr 1942: 196).

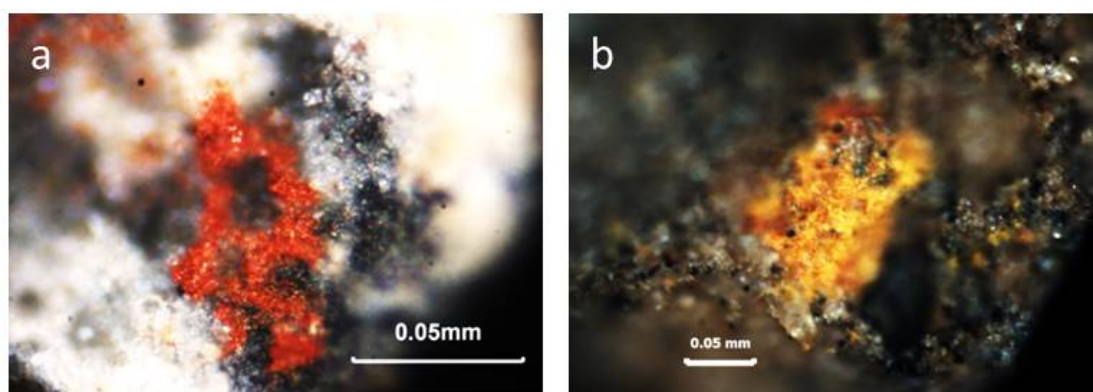


Plate 4.9a-b: Inorganic minerals on archaeological tools: **a)** red mineral pigment, *cf.* red ochre; **b)** yellow mineral pigment, *cf.* yellow ochre.

4.4 Observing residues and wear

4.4.1 Microscopy

Analysis of functional traces requires both macro and microscopic observations. Three varieties of light microscopes are commonly employed to assess and document traces of use, including: (1) the stereomicroscope with an external light source; (2) the compound incident-light

microscope for viewing opaque specimens; and (3) the compound transmitted-light microscope specimen for observing specimens mounted on a glass slide (Fullagar 2014: 239). The latter two microscopes enable higher magnification (up to x1000) than stereomicroscopes, which permit good resolution at lower magnifications (up to x100). One key difference between the so called “high-magnification” and “low-magnification” approach is that the latter is fitted with an external light source, thus allowing specimens to be viewed in three-dimensions. This allows for excellent observation of the relief on grinding stone surfaces and use-wear traces such as striations and edge damage. Another major advantage is that the observer is able to maintain a good overall view of the item despite its magnification (Rots 2010: 29). This allows the observer to map distributions of traces on the whole implement. Observations of other forms of use-wear (especially use-polish) and small residues, however, may require higher magnification for reliable identification. Compound incident-light (metallographic) microscopes that use reflected light are often required for viewing such wear-traces, and are particularly useful for identifying forms of micro use-polish and specific classes of residues. When analysing specimens that are too large to fit beneath standard microscopes, a Dino-lite™ microscope can be employed. These are small, portable, hand-held instruments capable of magnifications of up to x250. Dino-Lite™ microscopes may be useful when analysing specimens that cannot be moved to a laboratory or are too large to fit beneath standard microscopes. Transmitted light-microscopes are used for examining translucent residues extracted from artefact surfaces that have been prepared on glass slides at high magnifications (Fullagar 2014: 239) (see Section 5.5.1 for methods of residue extraction). Residues mounted on glass slides provide clear images of removed microscopic materials. The isolation and observation of residues associated with tool-use provides a direct means of identifying worked material.

Another useful instrument for the functional analysis of implements is the scanning electron microscope (SEM), an instrument that is able to generate high-quality images with excellent resolution and depth of field, producing surface images of use-wear and residue traces with outstanding topographical detail (Fullagar 2014: 239; Monnier *et al.* 2012: 3284). Such images show clear relief on highly polished surfaces (e.g., Anderson 1980; Borel *et al.* 2014: 50; Kamminga 1982; Mansur-Franchomme 1983; Ollé & Vergès 2014), striations (Borel *et al.* 2014; Fedje 1979) and residues such as phytoliths, raphides, red blood cells, woody fibres and starch grains (Fullagar 2014: 236; Hillman *et al.* 1993: 107). Other technical advantages include high resolution even at high magnifications, high control and precision in the manoeuvrability of samples, large depth of field and the ability to perform elemental analysis on the used surface (Borel *et al.* 2014: 55; Ollé & Vergès 2014: 62).

Until recently, samples examined under SEM required a carbon or gold coating before analysis. However, the recent development of Variable-Pressure (VP) SEM now permits analysis of uncoated specimens, thus making it suitable for most artefacts (see Monnier *et al.* 2012: 3285). Further developments in microscopy include the laser scanning confocal microscopy (LSCM) (e.g., Evans & Donahue 2008; Evans & Macdonald 2011; Ibáñez *et al.* 2014; Stemp & Chung 2011; Stemp *et al.* 2012; Stevens *et al.* 2010), the Atomic Force Microscope (AFM) (e.g., Faulks 2011, Faulks *et al.* 2011) and laser profilometry (e.g., Stemp 2014; Stemp & Stemp 2001, 2003; Stemp *et al.* 2008, 2009, 2010). These instruments record artefact surface roughness and texture, thus providing quantitative methods of wear characterisation.

While each of the instruments described have their own advantages and are all beneficial in use-wear and residue studies, one should never assume one instrument will be sufficient to observe and understand all the functional traces existing on any one implement. A series of magnifications and lighting arrangements must be employed to guarantee the maximum amount of information for any one specimen (Keeley 1980: 9). Integration of observations gathered from each instrument will provide the most robust approach of identifying traces of wear and residues on prehistoric implements.

4.5 Quantification of artefact function

Wear patterns are usually described on the basis of their visual appearance and assessment of variables that have been deemed significant on the basis of controlled and replicative experiments. Although wear variables can be assigned numerical values, interpretations are based on the analyst's ability to recognise wear patterns and cannot avoid a level of subjectivity. More sophisticated methods for objectively quantifying polish are currently being developed and are discussed below. Likewise, identifying specific residues that may have undergone biogenetic alteration is limited by the analyst's ability to confidently recognise a wide range of microfossils, inorganic structures and biological tissue, despite sometimes similar appearances and their potentially degraded state. For this reason, cross-checks and more sophisticated biochemical tests and methods for quantifying degradation and the chemical properties of residues have recently been developed. Functional analysis rarely incorporates multiple checks and methods of quantification. The following section describes the available suite of elemental, chemical, biological and optical methods of residue and use-wear quantification; and the particular methods adopted in this thesis are outlined.

4.5.1 Quantification of micro-wear

4.5.1.1 Optical methods of use-polish characterisation

The characterisation of use-polished artefact surfaces, which are described in terms of their visual appearance, are all prone to a certain degree of subjectivity by the analyst where inferences of tool usage are made based on personal interpretations. Incorrect characterisation of use-polish will lead to erroneous perceptions of artefact use. Quantitative methods of use-polish characterisation are essential for the validation of analyst interpretations. Attempts of use-polish quantification include non-destructive optical techniques designed to accurately measure surface texture, roughness and morphology, and elemental techniques used to evaluate use-polish composition.

Experimental flaked-stone tools used to work various materials have indicated that surface roughness provides a reliable account of use-materials based on their roughness characteristics (Stemp & Stemp 2001: 85, 2003: 287-292, 2008; Stevens *et al.* 2010: 2672). Likewise, quantitative methods of measuring use-polish texture (which vary depending on the contact material, see Section 4.2.2) may also infer worked material (Faulks *et al.* 2011; Kimball *et al.* 1995). Laser scanning confocal microscopy (Evans & Donahue 2008; Evans & Macdonald 2011; Ibáñez *et al.* 2014; Macdonald & Evans 2014; Stemp & Chung 2011; Stemp *et al.* 2012; Stevens *et al.* 2010), focus variation microscopy (FVM) (Macdonald 2014) and laser profilometry (Stemp 2014; Stemp & Stemp 2001, 2003; Stemp *et al.* 2008, 2009, 2010) are the most recent optical tools that allow a quantitative description of the surface topography to be generated by measuring the roughness parameters of the artefact surface. These methods have been used on experimental and archaeological flakes of various materials to infer artefact function following the assessment of corresponding roughness parameters of the polished surface (e.g., Evans & Donahue 2008; Evans & Macdonald 2011; Stemp & Chung 2011; Stemp & Stemp 2001, 2003; Stemp *et al.* 2009, 2010, 2012).

The LSCM constructs three-dimensional point data that may be expressed as either a high-resolution image (e.g., Stevens *et al.* 2010; Stemp *et al.* 2012: 5) or as quantitative data set (e.g., Evans & Donahue 2008; Stemp & Chung 2011) to visually or graphically display the roughness parameters of a given material. Alternatively, laser profilometry uses an optical focus technique to generate profiles (line scans) of an artefact surface to graphically display surface micro-topography. Additional methods of assessing surface roughness have been achieved via optical methods of interferometry (e.g., Anderson *et al.* 2006; Dumont 1982; d'Errico & Backwell 2009; Procopiou *et al.* 1998, 2011). These measurements are made using reflected light derived from a single light source

(the microscope lamp) that is reflected from the artefact surface and split by several reference mirrors to establish the interference fringes of the artefact surface. In this way, micro-topography may be established as height and depth profiles are created (Anderson *et al.* 2006; Dumont 1982). Methods of interferometry have been applied to both experimental (e.g., Dumont 1982; Procopiou *et al.* 1998, 2011) and archaeological stone and bone artefacts (e.g., Anderson *et al.* 2006; d'Errico & Backwell 2009) to evaluate artefact function following assessment of the associated roughness characteristics of the polished (or ground) artefact surface. Interferometry measurements of experimental ground-stone artefacts have also been conducted on experimental artefacts so that surface measurements could be obtained (Procopiou *et al.* 1998, 2011). The use of such methods have so far proven to be successful in the quantification of use-polish. A final assessment of surface roughness may be achieved through rugosimetry; a method that is used to provide a topographic surface profile of the artefact. This technique involves the use of a rugosimeter that measures the surface using a system of x, y (lateral movement) and z (vertical variation) to achieve an *n* profile of the surface topography that may be displayed as a three-dimensional image (Bofill 2012: 72).

Besides measurements of use-polish roughness, assessments of use-polish texture may be measured through use of the atomic force microscope (AFM) whereby three-dimensional plots of artefact surface features are constructed (e.g., Faulks *et al.* 2011; Kimball *et al.* 1995, 1998; Procopiou *et al.* 1998). The AFM uses a scanning tip to measure the atomic forces between the artefact surface and the scanning tip itself. The scanned data is stored in a digital format where three-dimensional surface plots, top-views and cross section profiles may be produced, allowing surface topography characteristics to be identified. This technique has been used to assess micro-wear traces on Mousterian tools from Weasal Cave, Russia, to interpret use-polish type and the worked material following measurements generated from a number of experimental tools with known use (Faulks *et al.* 2011; Kimball *et al.* 1995). The AFM has also been used to evaluate the surface features of experimental grinding stones (e.g., Procopiou *et al.* 1998), but the potential for this microscope on such tools is yet to be fully explored.

Finally, use-polish may be characterised through measurements of texture, pattern, and degree of development, through methods of image analysis (e.g., Barceló *et al.* 2001; Barceló Álvarez *et al.* 2008; Bietti 1996; González-Urquijo & Ibáñez-Estévez 2003). Digitised images are divided into pixels that show a concrete quantity of light whereby the texture of a surface is represented by the variability in the grey levels (i.e., a flat surface will possess similar coloured pixels, while a rough surface will display more variability). By quantifying the difference in the value of individual pixels, the degree of regularity on the artefact surface may be established. This

method of image analysis follows more crude evaluations of surface roughness that were determined on the basis of use-polish brightness and reflectivity of the artefact micro-topography using grey scale histograms. More recent attempts to quantify use-polish brightness are based on reflectivity measurements performed by laser projection (using a He-Ne beam) (Vardi *et al.* 2010). Subsequent analysis is based on reflected images thus providing evidence for specific worked material.

While these methods of use-wear quantification have mostly been applied to flaked stone artefacts, use of techniques such as LSCM have proven to be successful when measuring the roughness characteristics of basalt grinding surfaces as measured both directly from the artefact surface and from removed Polyvinyl Siloxane (PVS) peels (Bofill 2012). Like-wise, three-dimensional topographic measurements via methods of rugosimetry have also enabled the characterisation and classification of various degrees of surface wear represented on experimental grinding stones (e.g., Bofill 2012; Procopiou *et al.* 1998). Unfortunately, the quantification of wear on grinding surfaces has so far been restricted to only these two experimental studies.

Although some of these methods of use-wear quantification have proven successful in experimental and archaeological studies of stone tool function, they have also highlighted issues associated with basing functional interpretations on use-wear analysis alone. For example, using the LSCM, Evans & Donahue (2008: 2227) found that there was some overlap between the roughness characteristics derived from the use-polish generated from the working of wood and antler and dry and greasy hide. Macdonald & Evans (2014: 24) also found that roughness characteristics will vary depending on the solvent used to clean the tool prior to analysis, possibly rendering results inaccurate. The authors have suggested that cleaning with alcohol is not sufficient for either visual interpretation of use-wear or for use-wear quantification and have suggested cleaning with soapy water or acid and alkali solvents. However, cleaning with these products removes most small particulate matter, and hence any potential use-residues.

Other variables that need to be considered when applying these methods of use-wear quantification include the nature of the raw material of which the tool is made, in which differences in texture, grain size and formation will influence the formation of wear; duration of use, which will influence the development of wear causing difficulties in distinguishing worked material, and the influence of any post-depositional related wear, including wind and sediment abrasion. Because the ability for these methods to produce reliable results on sandstone artefacts is yet to be tested,

and because many of the quantification methods require cleaning prior to analysis, these methods were not undertaken as part of this thesis.

4.5.1.2 Elemental methods of use-polish characterisation

In addition to the quantification of morphological and textural features of use-polished artefact surfaces, insight into specific worked material may be gleaned through the application of methods of elemental analysis (e.g., Christensen *et al.* 1998; Šmit *et al.* 1998, 1999). Proton induced X-ray emissions (PIXE) are used to define the elemental composition of use-polish, allowing the elemental make-up of a material or sample to be established. The method requires exposing the material (i.e., the use-polished surface) to an ion beam, which causes atomic interactions to produce radiation of specific wavelengths that correspond to a specific element. As certain elements are more related to the use-polish of certain use-materials (as minute amounts of the original material adhere to the used edge), elemental composition may indicate the most likely material used. Experimental tools used to work a selection of wood and bone were analysed using PIXE to determine common elements obtained from use-polished surfaces that were subsequently applied to archaeological specimens (Šmit *et al.* 1998). The experimental study conducted by Šmit *et al.* (1998: 213) suggested that worked materials may be distinguished on the basis their elemental composition (which is usually dominated by calcium and phosphorus on use-polished surfaces) and have enabled the authors to infer archaeological specimens were most likely used on wood and bone. PIXE analysis may also provide quantification of archaeological residues by determining their elemental composition.

4.5.2 Quantification of residues

Identifying specific residues on archaeological artefacts typically involves microscopic analysis of adhering particles, observed either directly from the artefact surface or following residue removal. While microscopic examination may be suitable for artefacts collected from a number of contexts, discrimination of adhering particles is limited by the analysts' ability to confidently recognise specific use-residues present on the artefact surface. Residues that possess morphologically similar physical features may be difficult to discriminate without further methods of characterisation. Highly degraded residues, or those that have been physically altered due to

material processing or other taphonomic events, may also require additional methods of characterisation. Lombard & Wadley (2007: 156) have remarked on the visual similarity of some faunal and plant remains, while other authors have noted that highly degraded residues, or those that have been physically altered through heating or crushing and grinding activities, often possess un-diagnostic morphologies (e.g., Lamb & Loy 2005: 1433). For this reason, it is essential that methods of residue quantification are instigated in functional studies, so that erroneous interpretations are avoided. Furthermore, the application of additional analytical methods of residue characterisation may allow non-visible or absorbed biomolecules within a residue mixture to be detected. The following sections describe the various optical, biological, elemental and chemical methods of residue identification and characterisation.

4.5.2.1 Optical methods of residue identification

Optical methods of residue confirmation, whether it is to identify residues occurring as a result of tool use or via other agencies, may be achieved using a number of different microscopy and multi-wavelength lighting techniques. Microscopically visible residues may be observed directly from the surface of the artefact using low and high magnification incident light microscopy; while invisible residues may be identified using multiple wavelength light sources, specifically various forms of ultraviolet (UV) luminescence (e.g., Buonasera 2007; Conn *et al.* 1997; Koob 1998). Following residue removal, transmitted light microscopy and polarised light microscopy may be used to visually characterise the residues. Characteristics such as surface morphology, transparency, pleochrism, homogeneity, birefringence, extinction angles and refractive index may indicate the constituent materials of a residue.

Micro-UV-luminescence, which involves the exposure of a residue to a UV light source, may also allow removed residues to be characterised. The UV light source causes production of phosphorescence or fluorescence within the residue, allowing light to be emitted at different wavelengths producing different colours that enable specific substances to be recognised (Koob 1998: 53; Veall & Matheson 2014: 16). This method of residue characterisation has successfully identified different Australian plant exudates that may be useful to residue studies involving Australian wood working and hafting tools (Conn *et al.* 1997; Veall & Matheson 2014: 16), as well as animal glues used to repair broken pottery (Koob 1998).

4.5.2.2 Biological methods of residue identification

Biological methods of residue characterisation are useful in determining the nature of amorphous and damaged or highly degraded residues. These techniques typically involve the application of various solutions to the extracted residue material and observing any subsequent related changes in appearance, typically under microscopic conditions. A common method of biological residue identification is achieved through staining of the extracted material, often referred to as histological or biochemical staining. This approach involves microscopic examination of extracted residues following the application of a specific staining agent. The staining agent will react with a certain component of the residue, turning the designated material a distinctive colour, leaving the other constituent material unaffected (Plate 4.10, 5.1). The technique was first applied to archaeological residues by Bruier (1976) to isolate plant and animal tissues on a selection of stone artefacts. More recently, stains have been used to evaluate archaeological material to confirm the presence of both damaged and undamaged starch (e.g., Balme *et al.* 2001: 4; Barton & White 1993: 174; Fullagar *et al.* 2015; Lamb & Loy 2005: 1433; Loy *et al.* 1992: 904; Revedin *et al.* 2010: 11819; Smith 2004: 178); collagen and other animal material (Barton & White 1993: 174; Fullagar *et al.* 2015; Stephenson 2011: 36; Wright *et al.* 2014: 96); lipids (Stephenson 2011: 33) and plant fibres including cellulose, lignin and tannin (Barton & White 1993: 174; Fullagar 1986a; Fullagar *et al.* 2015; Stephenson 2011: 34). Table 4.5 lists the commonly utilised stains that may be applied to archaeological residues to highlight constituent fibres, particles or tissues. Also included in the Table are details regarding the materials stained and their subsequent colour change. Analysts must be aware that some stains will highlight multiple materials, so selection of an appropriate staining agent is required.

Other methods of biological analysis include enzymatic micro-digestion, micro-fusion and micro-solubility. Enzymatic micro-digestion is useful for determining the specific biomolecules present in a residue mixture by observing the relationship between specific enzymes and the substrates within the mixture. Because certain enzymes will digest and decompose specific substrates, the use of such a method may be applied to confirm the presence or absence of a biomolecule that corresponds to the enzyme used. Recent publications have described the use of amylase, protease, and lipase to digest starch, protein and lipids from archaeological samples (e.g., Hamed 2012; Hardy *et al.* 2009; Veall & Matheson 2014: 17-18).

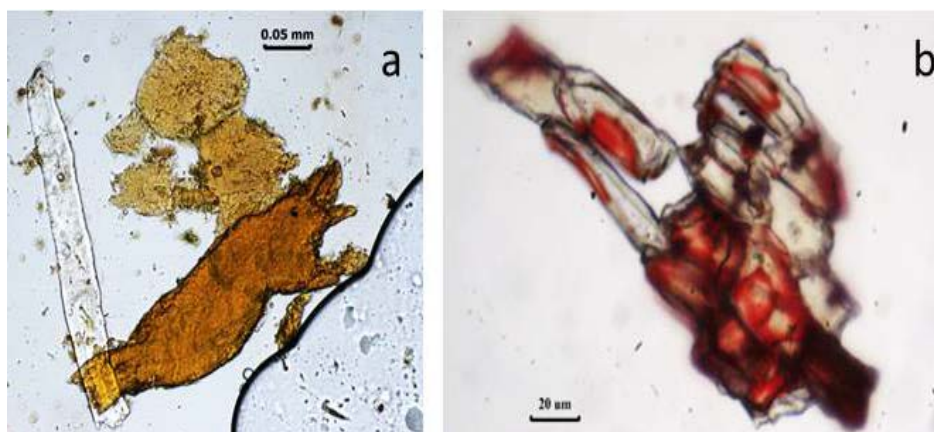


Plate 4.10a-b: Stained organic structures: **a)** experimental slide with plant and animal material, collagen is highlighted with Orange G, but the plant residue is unaffected; **b)** plant cells stained with Safranin to highlight the lignified tissue in the cell walls.

Micro-fusion is a technique that may be used to determine the melting point of a given substance (or components thereof) by heating the residue to determine the melting range (i.e., the temperatures between that of which the sample melts) (Veall & Matheson 2012). The variation observed in the melting ranges of different substances result from variation within the molecular structure or configuration of constituent particles. Residue components may be identified by comparing the melting range of experimental mixtures with archaeological materials (Veall & Matheson 2012). This technique is particularly useful when dealing with small residue samples, as it may be performed on as little as a single particle or crystal, and has proven to be extremely effective in the characterisation of inorganic crystals, waxes, resins and other amorphous residues (Veall & Matheson 2012).

Similar in principle to micro-fusion is micro-solubility (micro-dissolution), which involves determining the degree of solubility of a substance that may characterise the relationship between molecules of a substance. As solubility of a residue is directly related to the substance's polarity, dispersion, hydrogen and other intermolecular bonding of the substance, particular components may be established based on the substances ability to dissolve in various solvents (Koob 1998: 51; Ragazzi *et al.* 2003: 44). Australian resins have been characterised through processes of micro-solubility. Research in this field is useful not only for residue characterisation but also for establishing the optimal solvent for residue extraction, which is particularly useful when trying to remove residues that are likely to be insoluble in water (such as certain types of adhesive materials).

Table 4.5: Staining agents used in the identification of organic residue components and colour of the stained residue.

Staining Agent	Cellulose	Lignin	Starch	Gelatinised starch	Pollen	Collagen	Lipids	Keratin	Other
<i>Analine Blue</i>	-	-	-	-	-	green/blue	-	-	Muscle fibres, callose (blue)
<i>Brilliant Blue</i>	-	-	-	-	-	-	-	-	Protein (blue)
<i>Congo Red</i>	red	-	-	red	-	-	-	-	
<i>Crystal violet</i>	purple	purple	-	-	-	purple	-	-	Woody tissue, Nucleus, mitochondria (blue-purple)
<i>Fast Green</i>	green	-	-	-	green	green	-	-	
<i>Fuchsin</i>	-	-	-	-	-	-	-	-	Smooth muscle, Plasma, mitochondria (red)
<i>IKI</i>	-	-	red-purple	-	-	-	-	-	
<i>Methyl Green</i>	-	-	-	-	green	-	-	-	
<i>Methylene Blue</i>	blue	-	-	-	-	blue	blue	-	animal cells (blue)
<i>Orange G</i>	-	-	-	-	-	orange	-	orange	Plasma (red)
<i>Pico-sirius Red</i>	-	-	-	-	-	red	-	-	
<i>Phloroglucinol</i>	yellow/ brown	red-violet	-	-	-	-	-	-	
<i>Rhodamine B</i>	-	-	-	-	-	pink	-	pink	Cobwebs (pink)
<i>Safranin</i>	-	red	-	-	pink	yellow	-	-	Proteins, nucleus, chromosomes, chitin, cutin (red)
<i>Sudan IV</i>	-	-	-	-	-	-	red	-	
<i>Toluidine Blue</i>	-	blue-green	-	-	-	Pink-purple	-	-	Pectin (pink-purple), cartilage (clear blue)
<i>Wright's stain</i>	-	-	-	-	-	-	-	-	RBC, Leucocytes (blue)

4.5.2.3 Elemental and chemical methods of residue quantification

In addition to biological methods discussed above, analytical techniques of residue characterisation include characterisation of the various elemental and chemical constituents of a given substance. Some of the most commonly utilised methods for determining the nature of a residue include gas chromatography-mass spectrometry (GC-MS); Inductively Coupled Plasma Mass Spectrometry (ICP-MS); Raman spectroscopy; absorbance spectroscopy and Fourier Transform Infrared spectroscopy (FTIR); Proton Induced X-ray Emission (PIXE, described previously in Section 4.5.1.2); and various forms of biochemical testing and elemental analysis, such as X-ray fluorescence (XRF), X-ray diffraction (XRD) and SEM.

Other biological methods of residue identification specific to blood residues include PCR, IEF, ELISA, RIA, haemoglobin crystallisation and the western blot test (e.g., Hardy & Raff 1997; Heaton 2009; Kooyman *et al.* 1992; Loy 1983, 1993; Loy & Hardy 1992; Matheson & Loy 2001; Potter *et al.* 2010; Reuther *et al.* 2006; Williamson 1997). These methods may enable the species of origin to be recognised and are described in Table 4.4.

The first method, GC-MS, is particularly useful for archaeological residue investigations as it allows trace elements to be identified in residue mixtures that are otherwise undetectable. The method involves the separation of particles within a test sample so that the constituent materials and the various components of residue mixtures may be identified. The procedure involves separation of molecules that are ionised, detected and measured separately. This method has been successfully applied to archaeological materials to determine the origin of absorbed residues on pottery, ceramics and grinding stones (e.g., De Beaune 2004; Buonasera 2007; Charters *et al.* 1993b; 1995; Craig *et al.* 2005; Crowther *et al.* 2015; Eerkens 2002, 2005; Evershed *et al.* 2003; Mazzia & Flegenheimer 2015; Regert *et al.* 2003), binding media within paints and artworks (e.g., Andreotti *et al.* 2006; Bonaduce *et al.* 2007, 2009; Fiore *et al.* 2008; Marinach *et al.* 2004; Wei *et al.* 2012), tobacco constituents in Native American smoking pipes (e.g., Rafferty 2002, 2006; Rafferty *et al.* 2012) and resins on hafted artefacts (e.g., Bowden & Reynolds 1982; Cârciuamaru *et al.* 2012; Charrié-Duhaut *et al.* 2013; Helwig *et al.* 2014; Parr 1999: 23; Regert *et al.* 1998; Reynolds & Bowden 1980) as well as other adhesives (e.g., Charters *et al.* 1993b; Regert *et al.* 2003; Stacey *et al.* 1998; Wei *et al.* 2012). Other methods of mass spectrometry, such as ICP-MS, abide by the same principles to determine constituent residue components.

Absorbance spectroscopy is another method of residue analysis that measures and records the spectra of absorption for a given sample, allowing the chemical groups of the major constituents

within a mixture to be recognised. The method involves the collection of spectral data from a sample that is exposed to a wide spectral range, producing a “fingerprint” spectrum. The patterning of the spectra permits identification of the various residue components. Advantages of this technique are that only a small portion of the residue is required (approximately 2 μ L) and the majority of residue components can be quantified. Absorbance spectroscopy has been successfully applied to determine the presence of trace amounts of protein and haemoglobin within a tested sample (e.g., Sakata *et al.* 1982; Santos *et al.* 2003; Schweitzer *et al.* 1997). Another spectroscopic technique that works on similar principals is Raman spectroscopy, which is a technique based on inelastic scattering (and subsequent measurement) of monochromatic light, usually provided by a laser source. Preliminary investigations involving the sourcing of ochre using Raman spectroscopy on ochreous residues removed from Lestheto grinding stones have also proven successful (e.g., Nic Eoin 2012). Raman spectroscopy has also been used to characterise pigment samples from archaeological wall paintings and pottery sherds (e.g., Clark & Curri 1998; Edwards *et al.* 2000; Jezequel *et al.* 2011; Parras *et al.* 2009; Smith & Barbet 1999), pigment colourings in glass beads (Prinsloo *et al.* 2012), organic substances adhering to ancient vessels (e.g., Edwards *et al.* 1997), archaeological resins (Edwards *et al.* 2008), tobacco constituents within smoking pipes (Rafferty *et al.* 2012) and pigment components of ink present on ancient manuscripts (e.g., Chaplin *et al.* 2010; Clark 1995; Clark & Gibbs 1998). Another method that involves the collection of spectral data is FTIR, which generates a “fingerprint” for the sample that can then be compared to spectra collected from reference materials. The FTIR method has been used in archaeology to identify the provenance of ancient amber resins (e.g., Angelini & Bellintani 2005), ancient haematite use (e.g., Cristiani *et al.* 2012; Gialanella *et al.* 2011), specific organic binders present in ancient paint (Cristiani *et al.* 2012; Fiore *et al.* 2008), and to characterise plant and animal binders on Australian stone tools (e.g., Blee *et al.* 2010) and other hafted artefacts (e.g., Cârciumaru *et al.* 2012; Helwig *et al.* 2014).

Biochemical testing is another method that may be used to confirm the presence of specific biomolecules to determine their plant/animal origin. They include a range of colourimetric tests specifically designed to confirm the presence of proteins, carbohydrates, fatty acids, starches, haem and various other forms of organic materials. Testing involves the addition of a specific solvent to a particular amount of residue and watching for any observed changes in colour. The solvent, the amount of residue sample required and the colour indicating a positive reaction are specific for each test. Regrettably, biochemical testing is infrequently applied to archaeological residues, despite the high potential for residue characterisation.

Elemental analysis of inorganic residues may also be useful in determining specific materials utilised, as well as aiding in the sourcing of materials such as stone, haematite and ochre. Portable XRF devices have also enabled sources of pigments identified in Australian rock paintings to be distinguished based on their elemental composition (e.g., Huntley 2012). In addition to determining provenance of ochre sources, analysis of constituent materials, such as the quantity of haematite and iron enrichment has shown a preference of ancient populations to select pigments that contain the highest iron content, providing the reddest, most saturated and darkest streaks (e.g., d'Errico *et al.* 2010: 3100).

4.6 Factors affecting use-wear traces

Several factors influence the formation of wear during a tool's use life. In order to make accurate functional interpretations, the key variables must be recognised. The life history of a tool is made up of five stages: (1) manufacture, (2) curation, (3) use, (4) discard/post deposition, and (5) post-excavation handling and storage (Table 4.6) (McBrearty *et al.* 1998: 108-109). Each of these stages will contribute to the formation of wear on archaeological artefacts, which are controlled by a number of variables. Failure to identify the stages at which various forms of wear appear, leads to misinterpretation of wear and false identification of tool function (Hurcombe 1992: 71).

During utilisation, a number of factors influence the formation of wear. These include (1) mode of use (e.g., scraping, sawing, drilling, grinding, chopping, etc); (2) the physical properties of the worked material/contact surfaces (e.g., hardness, silica content of vegetal remains and the presence of lubricants such as oils and fats); (3) duration of use; (4) operator variance (i.e., different strengths, motions etc. of different operators); (5) use-angle; (6) abrasive environment; and (7) hafting/prehension mode (Table 4.6). In addition, post-depositional processes that occur after the tool has been discarded may also cause the accumulation of non-use related wear traces and the degradation of residues. Post-depositional processes include trampling, residue degradation and other physical disturbances to the cultural deposit from geological, animal and other agents. In addition, post-excavation processes introduced by archaeological investigation (e.g., sieving, transport, storage, handling) may further affect artefact wear and residues.

4.6.1 Residue degradation

In unstable environments, residues may degrade or undergo alteration caused by processes of natural weathering. Elements that may contribute to residue alteration/degradation include biological weathering caused by macro and micro-organisms (e.g., insects, bacteria, fungi), characteristic of the surrounding soil (e.g., pH, temperature, moisture content), mechanical (e.g., wind, rain and fire) and chemical weathering (e.g., surface etching), and exposure to UV light (Haslam 2004: 1720-1721; Langejans 2010: 973). A number of experimental studies have explored the influence of post-depositional processes on residue preservation in simulated burial environments (e.g., Barton 2009; Cattaneo *et al.* 1993; Eisle 1995; Gurfinkel & Franklin 1988; Hardy & Raff 1997; Langejans 2010, 2011; Lombard & Wadley 2007; Reber & Evershed 2004; Wadley *et al.* 2004) and in museum storage environments (Barton 2007). Unfortunately, experimental studies of residue preservation are difficult to stimulate and the time required to ensure adequate residue degradation can be up to several millennia and are dependent on certain conditions (e.g., burial environment, soil constituents, temperature, etc.). Experimental studies, therefore, can only assess the degree of residue preservation over relatively short durations. While some studies have suggested that a high percentage of the original residue will become partially or completely degraded in a short time, other studies show that, under appropriate conditions, the same residue may remain intact for very long periods of time, particularly when they remain in a stable environment (Langejans 2010: 218). Conditions suitable for residue preservation, as determined through the experimental work of Langejans (2010), include those occurring within more protected sites (e.g., some caves compared with open air sites) and those where the mechanisms of biological decomposition are minimal. Decomposition is generally lower in sediments that are anaerobic or near-anaerobic, extremely acidic or alkaline, waterlogged or desiccated, and in environments with extreme temperatures (see Langejans 2009: 96, 236, 2010: 973 and references therein). A stable soil matrix tends to reduce the effects of chemical, physical (including percolation of rain water) and biological processes (Cattaneo *et al.* 1993: 40). Despite variation in the degree of abundance, diagnostic residues have been preserved on a variety of archaeological tools from a range of depositional settings, including cave sites (e.g., Jones 1998; Langejans 2010, 2012; Lombard 2008; Loy *et al.* 1992), rockshelters (e.g., Langejans 2010, 2012) and open air sites (e.g., Fullagar & Field 1997; Kooyman *et al.* 1992: 266; Rots & Williamson 2004: 1297). Better preserved residues are typically removed from within the more protected locations on the artefact surface, such as micro-cracks, or fissures, and from step-termination micro-flake scars (Shanks *et al.* 2001: 965). Grinding stones with a porous structure are more likely to retain residues. Haslam (2004) provided a

Table 4.6: The five life stages of a tool and associated variables in forming wear.

		Life Stage			
Variables	<i>Manufacture</i>	<i>Curation</i>	<i>Use</i>	<i>Discard/ post deposition</i>	<i>Post excavation: Transport and storage</i>
	Raw material type	Retouch	Mode of use	Natural abrasion through wind and water	Trampling or mishandling by machinery
	Tool design: edge morphology, edge angle, and cross section of working edge	Accidental dropping	Physical properties of the worked material	Physical and chemical weathering	Removal from archaeological deposits
	Method of tool production	Rubbing against other artefacts during migrations	Duration of use	In situ soil movements and patination	Sieving
	Evidence of retouch		Operator variance	Trampling by humans or animals	Transportation from archaeological site
	Impact of hammer stone and ground following detachment from the core		Use-angle	Dropping at the time of discard	Contact with packing material
			Abrasive environment		Cleaning
Prehensile mode		Storage			

discussion of residue degradation for starch residues, and Langejans (2010) provided a discussion for the degradation of biological and vegetal residues.

4.6.2 Taphonomic traces of wear

Residues and wear accumulate from a mix of diverse sources, some culturally derived, some from use-related tasks and some from incidental contact and non-cultural agencies. The latter include post-depositional processes that need to be assessed to avoid misidentification of use-wear. Because an artefact will usually spend nearly all of its life in the depositional environment, it is likely that some form of wear will accumulate as a result of various post-depositional processes. Taphonomy is the study of biological, chemical, erosional and other processes within an archaeological deposit that may result in alterations to use-residues and the build-up of non-use related residues and wear on buried stone tools. *In situ* taphonomic residues include the build-up of stone surface patina caused by soil chemicals, organic growths including fungal hyphae, and other

soil constituents (e.g., starch grains) (Plates 4.11a-c, g-h). Wear may result from taphonomic processes such as solifluction, bioturbation and other movements of sediment that can cause striations and other forms of wear (Burroni *et al.* 2002: 1278; Keeley 1980: 28; Keeley & Newcomer 1977: 35). Not only can taphonomic processes introduce wear and residues, but mechanical and chemical weathering can potentially alter and remove traces of use including residues and use-polish (see Plisson & Mauger 1988: 4).

Use and non-use related wear may be distinguished on the basis of wear distribution, abundance and location on the tool (Kononenko 2011: 7; Tringham *et al.* 1974). Use-related wear traces usually occur along the tool edge where contact has been made with the worked material. Wear traces that are distributed with no consistent patterning along the tool surface with a range of orientations are probably the result of either post-depositional contamination or natural weathering prior to deposition. To assess these possibilities it is essential that all details of artefact recovery are recorded and that the depositional surroundings of the artefact and the site are considered. The surrounding soil matrix from which the artefact was recovered should be tested (e.g., pH, moisture content) to assess the preservation conditions and potential contaminants (e.g., starch and other constituent materials that occur as a result of *in situ* decomposition of plant materials). Contextual testing of sediment is standard practice for artefact residue studies (e.g., in the assessment of starch contamination, see Barton *et al.* 1998: 1233; Hart 2011: 3245; Kealhofer *et al.* 1999: 527; Loy *et al.* 1992: 909; Pearsall *et al.* 2004: 428; Piperno *et al.* 2000: 200).

In addition to soil analyses, replicative and controlled experiments are necessary to ensure the analyst is familiar with the potential forms of wear that may accumulate on an artefact. Controlled experiments keep other variables constant in order to assess the importance of one variable. Numerous agencies can cause fracture damage on stone implements (Kamminga 1982: 9), and many events contribute to the final pattern of wear. To address these concerns, experimental studies have investigated various post-depositional and post-excavational traces of wear, including the influence of mechanical and chemical weathering (Burroni *et al.* 2002; Cattaneo *et al.* 1993; Eisele *et al.* 1995; Gurfinkel & Franklin 1988; Hardy & Raff 1997; Keeley 1980: 28-35; Langejans 2010, 2011; Levi-Sala 1986a, 1986b; Lombard & Wadley 2007; Plisson & Mauger 1988; Wadley *et al.* 2004), movement of sediment and starch grains within the burial environment (Burroni *et al.* 2002; Keeley 1980: 34; Therin 1998, 2006); trampling (Domínguez-Rodrigo *et al.* 2009; Flenniken & Haggarty 1979; Gifford-Gonzalez 1985; Kamminga 1982; Keeley 1980: 34; McBrearty *et al.* 1998; Pryor 1988; Shea & Klenck 1993; Tringham *et al.* 1974); sieving (Gero 1978; Kamminga 1982); dropping (Moss 1983); transportation following excavation (Kamminga 1982); artefact cleaning

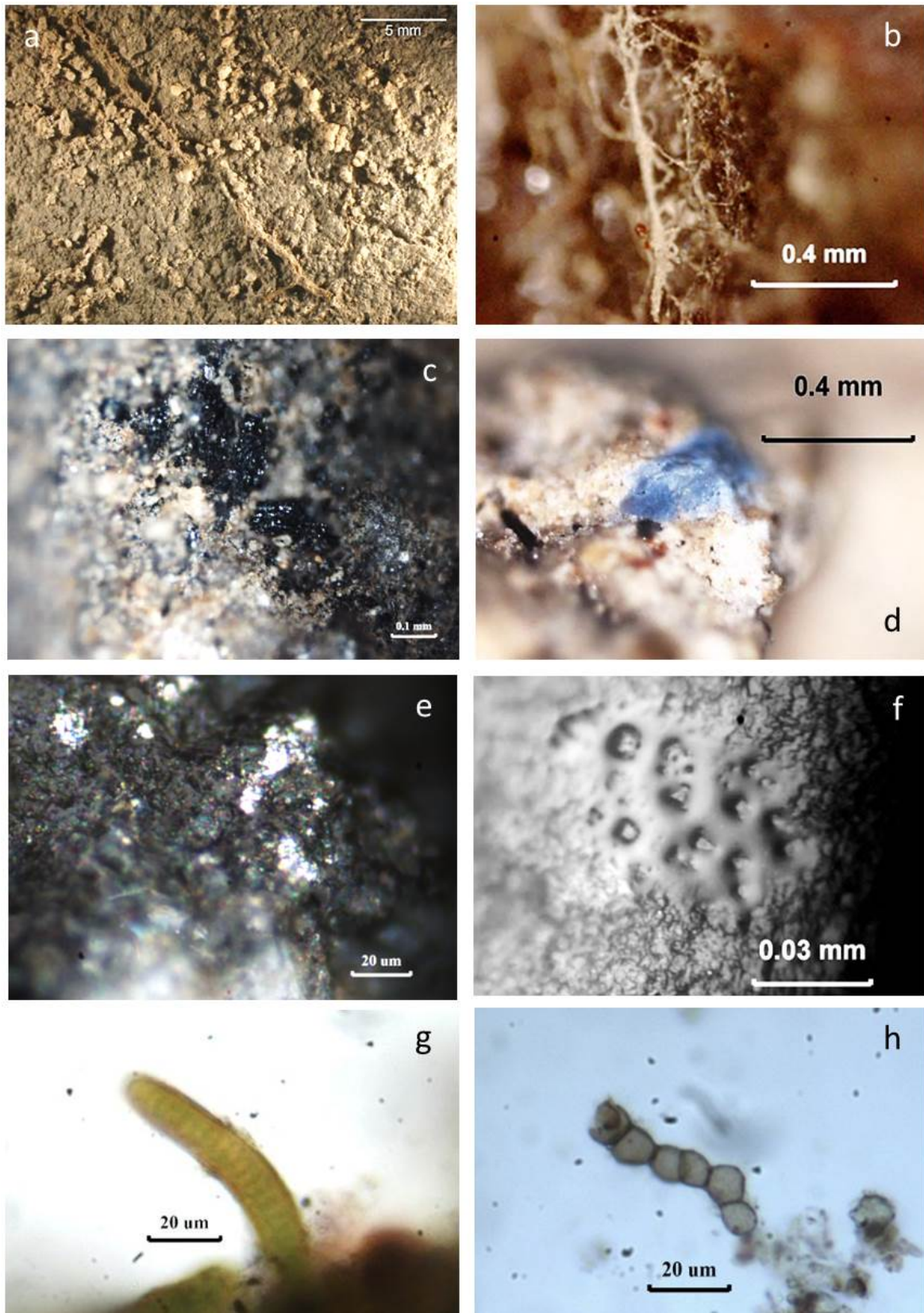


Plate 4.11a-h: Residues acquired post-deposition/following discard: **a)** root growth on artefact surface; **b)** fungal growth on artefact surface; **c)** charcoal accumulations on artefact surface; **d)** blue pen ink; **e)** metal residues acquired during excavations from contact with sieve or metal trowel; **f)** finger grease from artefact handling; **g)** lichen spores removed from artefact surface; **h)** fungal spores removed from artefact surface.

(Evans & Donahue 2005; Evans & MacDonald 2012; Gero 1978; Neumann & Sanford 1998); and artefact storage (Barton 2007; Gero 1978). Replicative and controlled experimental studies are indispensable for reliable interpretations of wear and residues.

4.6.3 Handling contamination residues

Handling of an implement immediately following excavation and analytical processes introduce new non-use related residues on the surface of the artefact. Such residues commonly include fibres from clothing, paper and storage boxes; traces of metal from trowels, sieves and measuring equipment (metal rulers and scales); pen ink from bag labelling and recording; and sweat and fatty excretions from handling (Plate 4.11d-f). The latter form of contamination presents a particular burden for analysts investigating animal processing tools in which techniques of DNA amplification (e.g., PCR) are employed (Shanks 2005: 28). Potter *et al.* (2010: 912) suggested a number of “safe-guards” when recovering and analysing archaeological artefacts, particularly if these are to be used for protein or DNA analysis. These recommendations include the wearing of latex gloves, immediate placement of artefacts in plastic zip-lock bags following collection, and no brushing or extensive cleaning of artefacts. Additional contamination controls for samples collected with specific intentions for DNA/protein recovery are discussed by Yang & Watt (2005: 333-5) and Cooper & Poinar (2000: 1139).

While recommended cleaning protocols vary, it is generally agreed that handling should be kept to a minimum and that sufficient safe-guards and controls should be operating during excavation and storage. If artefacts are to be cleaned prior to analysis, this should be done in such a way that the removed residues are still able to be analysed, following, for example, light brushing. Rinsing in harsh chemicals and acids should be avoided because they will likely affect both wear and residues. For a review of various cleaning procedures and their subsequent influence on micro-wear interpretation, see Evans & Donahue (2005) and Evans & Macdonald (2012).

4.7 Chapter Summary

Functional analysis provides a meaningful way to assess the nature and intensity of use on prehistoric tools. Use-wear may consist of scarring, striations, edge or grain rounding, abrasive smoothing and/or use-polish. Residues may include those related to hafting, use or other non-use

agencies. Use-residues may include plant (e.g., starch, cellulose, lignin, phytoliths, pollen), animal (e.g., bone, collagen, hair, feathers, blood), or mineral (e.g., pigments, mineral crystals) residues. Use-wear and residue traces may be examined under various microscopy conditions, including low magnification stereo-microscopy, high-magnification reflected light microscopy, and high-magnification transmitted light microscopy. Methods of use-wear and residue quantification have been trialled on collections of experimental and archaeological tools with varying results. Use-polish may be quantified using a LSCM, AFM, and a FVM; and by techniques of laser profilometry, interferometry, rugosimetry and image analysis. Because the application of these techniques on sandstone artefacts is yet to be fully explored, and require removal of any adhering residues prior to analysis, these methods unsuitable for the current study. Methods of residue quantification have also been applied to collections of experimental and archaeological artefacts, and include methods of optical, geological, elemental and chemical analysis. Owing to equipment availability and the costs associated with such analyses, only a selection of these methods were applied to residues for this study; these are described in Chapter 5.

Other adhering non-use related residues may occur on artefact surfaces; as may other non-use related surface scarring, striations and polish. It is important to distinguish non-use related wear from wear accumulated during the different stages of a tools life (i.e., during manufacture, curation, discard, burial and post-excavation collection, handling and storage). Finally, it is appropriate to be aware of mechanisms associated with the degradation of specific organic materials, which may render use-residues difficult or impossible to distinguish, if they have survived at all. Residue preservation is enhanced in certain contexts, and may survive if they are protected within a crack or fissure within a stone material. For this reason, identifying an appropriate sampling location is fundamental for maximising residue recovery.

Chapter 5:

Technical methods of use-wear and residue analysis

5.1 Introduction

I performed functional analysis on grinding stones from three artefact collections, including: (1) archaeological collections; (2) ethnographic collections; and (3) modern reference collections generated via modern tool-use experiments. My method of analysis has involved an integrated approach that included the analysis of tool morphology, documentation of use-wear features and the characterisation of residue mixtures. I followed the same protocols of examination, sampling and documentation for all stones comprising the three artefact collections I have analysed as part of this thesis. The wear traces identified on collections of experimental and ethnographic tools were documented so that a use-wear and residue reference library could be established. The identification of key use-wear features on these two artefact collections were then used to compare the wear on archaeological specimens so that interpretations of tool function could be made.

Artefact surfaces were examined for use-wear traces using a variety of microscopy and lighting techniques and documented by micrographs and surface impressions. The utilised surfaces of each stone were sampled for residues using a variety of solvents. The residue extractions were assessed using a transmitted light microscope and several elemental and chemical analyses to determine constituent materials. This chapter outlines the various procedures and analytical techniques employed in the documentation of use-wear and residue traces.

5.2 Analysed grinding stone collections

5.2.1 Experimental and Ethnographic grinding stone collections

I performed use-wear analysis on experimental and ethnographic grinding stones in order to supplement previous studies and specifically to create a use-wear reference library for sandstone tools applicable to archaeological collections made on Australian sandstones. Twenty-six experimental grinding stones and twelve ethnographic seed grinding tools were examined for use-wear traces using a variety of microscopy techniques (Section 5.4.1). Experimental artefact collections were manufactured and used during an experimental grinding workshop at Byragee Academic Retreat, Yadboro, during May, 2013. The experimental tools were prepared using a range of local Australian sandstones and were used to process a number of ethnographically documented materials. Processed material included native Australian seeds (kangaroo grass—*Themeda australis*, warrego grass—*Setaria jubiflora*, Acacia—*Acacia decora*, and kurrajong—*Brachychiton sp.*); fresh Australian hardwood (mulga—*Acacia sp.*), fresh bone (kangaroo femur bone—*Macropus fuliginosus*), and locally sourced Kakadu haematite. Other materials that had not been

ethnographically documented but were similar to grains used in the Old World, such as wheat, or possessed similar attributes (e.g., size and hardness) to ethnographically processed grains, were also ground. Volcanic stones (e.g., dolerite, basalt) and sandstone were also prepared on grinding implements to replicate the preparation of stone axes and to identify wear associated with stone-on-stone activity (see Table 6.3, Chapter 6).

An additional fifteen experimental grinding stones were also examined as part of a “Blind Test” that included sets of tools that had been used following an unknown experimental procedure. The experimental artefacts were prepared on water-worn sandstones, used to grind and pound a range of organic and inorganic materials under controlled settings. All experimentation was performed at University of Liège, Belgium. The aim of examining experimental artefacts through blind tests is to ensure accurate functional interpretations may be achieved by referring to previous experimental findings (i.e., the use-wear reference libraries), and to also highlight any methodological problems or analyst bias associated with the examination of wear.

Analysis and sampling of ethnographic seed-grinding specimens was carried out at the South Australian Museum (SAM), Adelaide, Australia. The analysed specimens included five seed grinding tools from part of the N.B. Tindale & C.J. Hackett (1933) collection, and seven seed grinding tools from part of the R. Edwards (1971) collection. Details of the residue composition and wear patterns derived from these experiments are described in Chapter 6.

5.3 Artefact examination and recording

All experimental, ethnographic and archaeological grinding stones were examined for functional traces using equipment available at five facilities, listed in Table 5.1. All specimens were lightly brushed with a soft nylon paintbrush to remove patches of loosely adhering residues and sediment prior to wear analysis. An artefact recording sheet was created by photographing each artefact surface (including the ground and unground surfaces) so that key features (including the locations of use-wear and residues) could be superimposed on the artefact image. Each grinding stone was individually weighed and measured recording the maximum length, width and depth (Table C1, Appendix C). Any macroscopic traces of wear were documented on the artefact recording sheet. Other surface features, including specimen shape in cross section and post-depositional alterations (e.g., fresh breaks, surface weathering and iron oxide staining) were also recorded (Table 7.4).

Table 5.1: Institutions, laboratories and equipment used for the functional analysis of experimental, ethnographic and archaeological grinding stones.

Institution	Laboratory name	Activity	Equipment used
University of Wollongong Wollongong Australia	Microscopy Laboratory	Use-wear examination of archaeological and experimental artefacts	Olympus SZ61 stereomicroscope Olympus BH-2 metallographic microscope Lumenera Infinity 2 camera Leica MZ16A stereo-microscope Leica DFC320 camera Leica LAS V4.4 software Dino-Lite™ AD7013MZT
	Wet Chemistry Laboratory	Sampling of residues from archaeological artefacts	Sampling solvents: 1) ethanol, water, acetonitrile; and 2) distilled water Fume hood; adjustable pipettes
South Australian Museum Adelaide, Australia	SAM museum store	Examination and sampling of ethnographic stones	Dino-Lite™ AD7013MZT PVS peels
Lakehead University Thunder Bay Canada	Archaeological Microscopy Laboratory	Examination of removed archaeological residues	Olympus BX-51 metallographic microscope Olympus DP72 Microscope Camera cellSens Camera Software
	Archaeological Chemistry Laboratory	Application of biochemical tests to archaeological residues	Epoch™ Multi-Volume Spectrophotometer System (Biotek) Gen 5 software
	Lakehead University Instrumentation Laboratory	Application of GC-MS to archaeological residues	Varian model 450 gas chromatograph Varian model 300-MS quadrupole mass spectrometer with FactorFour(TM) capillary column Version MS workstation version 6 software
University of New South Wales Sydney Australia	Biological Science Research Laboratory	Removal of starch from archaeological artefacts and starch grain analysis	Sonication bath Centrifuge Sodium polytungstate for density separation Zeiss Axioskop2 transmitted light microscope Zeiss HrC digital camera Axiovision software
University of Liège Liège, Belgium	“TraceoLab” Microscopy Laboratory	Examination of experimental “blind test” tools	Zeiss V16 stereomicroscope Zeiss Axioscope A1 metallographic microscope Zeiss Axioscope A1 transmitted microscope

5.4 Use-wear examination

Wear on the artefact surfaces (including both the ground and unground surfaces) was examined using a number of microscopy techniques, either through direct observation of the artefact surface or via surface impressions taken with Polyvinyl Siloxane (PVS) peels. The latter method was used to examine the surfaces of grinding stones that were too large to view directly under conventional microscopes, or when the artefacts were unable to be removed from the field or from the museum collections (such as in the case of the ethnographic stones examined from the SAM). Each artefact was visually scanned under low and high magnification on both the ground and unground surfaces. The unground surfaces were observed to evaluate residues and traces that may be linked with handling or anvil positioning during use, or to identify traces that may mimic use-wear, such as micro-fractures of quartz grains that may occur on non-used surfaces as a result of friction between sediment and artefacts within the depositional environment or other post-depositional/discard factors (see Table 4.6). Each stone was assigned a number ranging from 0 – 3 indicating the likelihood of use: 0 representing an un-used stone; 1 indicating possible use; 2 for probable use; and 3 for definite use. The likelihood of use was reassessed following high magnification examination. Traces of use observed on the artefact surface (e.g., residues, use-polish, degree of grain rounding, abrasion and striations) were recorded on an artefact photograph following a standard procedure.

5.4.1 Microscopy

Artefact examination involved the application of multiple microscopy and lighting techniques, including the use of both stereo and metallographic microscopes, transmitted and reflected light and external and vertical light sources. All archaeological and experimental grinding stones were examined in the Residue and Use-wear Microscopy (RUM) Laboratory at the University of Wollongong (UOW), New South Wales, Australia. Artefacts were observed under low magnification (x6.7 to x45) using an Olympus SZ61 stereomicroscope with an external fibre optic, 150 Watt halogen light source (Olympus LG-PS2) and a Leica MZ16A stereomicroscope with an automatic Z-stacking function. Multifocal images were obtained using a DFC320 Leica camera and stitched to create a focused image using Leica LAS V4.4 software. Both microscopes were effective at highlighting the occurrence of broad striations (mostly furrows) across the grinding surface. The use of an external point-source of light created shadow when the light source was placed at right

angles to the striation orientations. The degree of surface levelling and grain rounding was also best observed at lower magnifications, where multiple grains could be viewed in context.

Artefact surfaces were then examined under high magnification using an Olympus metallographic microscope (model BH-2) with vertical incident light (brightfield and darkfield) with objective lenses of x50, x100, x200, and x500 and polarising filters. The use of this microscope enabled a detailed view of use-polish, micro-fractures, micro-striations (including sleeks) and residues residing at lower grain elevations of the surface. Micrographs of these features were captured with an Olympus Infinity 2 camera permitting both colour and black and white digital images (recorded as TIF files).

Larger specimens or those that were documented outside the RUM Laboratory that were unable to be observed under conventional microscopes were examined using a portable Dino-Lite™ digital microscope (Model: Premier AD-7013MZT) equipped with a 5.0 megapixel sensor and up to 2592 x 1944 pixels of resolution. This model was suitable for identifying artefact surface features under both high and low magnifications with a magnification range of between x30 and x230. A limitation of this microscope is that it does not provide a point source of light and therefore furrows and use-polishes are less easily recognised. For this reason, sampling of the artefact surface via PVS surface impressions was the preferred method for examining larger grinding stones under high magnification.

5.4.2 PVS peels

Owing to the size of many of the grinding stones and availability of resources, it was not always possible to view wear traces using a metallographic microscope directly from the artefact surface. In these instances, PVS impression material was applied to ground surfaces to create negative impression of the artefact surface that may then be examined under magnifications of up to x500. The use of PVS peels to assess the wear on archaeological artefacts has been practiced on grinding stone implements from a variety of contexts (e.g., Dubreuil 2004; Fullagar 1991, 2006: 199; Field & Fullagar 1998; Liu *et al.* 2010a, 2010b, 2011) and has proved to be very useful for the examination of ground surfaces.

Prior to application, the grinding stone was evaluated for a suitable sample area in which the PVS material could be applied. Sampling areas usually included a small patch of the maximum development of grinding wear, smoothing and polish identified macroscopically. The area selected

for sampling was lightly brushed with a soft nylon paintbrush to remove any loosely adhering sediment and gently cleaned with ethanol wipes to remove any greasy films. The PVS compound was then applied to a clean plastic sample bag to act as a control for peel resolution before being applied on the desired artefact area (approximately 1 x 1 cm) using a dispenser that holds the PVS cartridge with an attached mixing tip. Once applied to the artefact, the PVS material was left to set on the surface for approximately 15 – 20 min to ensure adequate drying. At least one un-altered (i.e., unground) region on the artefact surface was also sampled using PVS material so that the unworn, naturally weathered surface could be documented and used as a control. The location of each peel was recorded on the artefact photograph.

5.4.3 Use-wear recording

Following the suggestions of previous investigators of grinding stone implements (e.g., Adams 1989; Adams *et al.* 2009; Dubreuil 2002, 2004; Hamon 2008) surface features were observed and described to ensure consistency amongst recorded features. These include, at low magnification: (1) degree of grain rounding; (2) degree of surface levelling; (3) presence of striations, use-polish and residues; and at high magnification: (4) use-polish brightness; (5) use-polish development; (6) use-polish coverage; (7) use-polish morphology; (8) presence of micro-striations; (9) presence of grain fractures including negative scarring, and (10) presence of residues (Table 5.2).

5.5 Residue examination

All archaeological grinding stones were sampled and examined for use-related and other residues. These procedures were carried out at three facilities: the RUM and Wet Chemistry Laboratories at the UOW, the Biological Science Research Laboratory at the University of New South Wales (UNSW), Sydney, and the various laboratories at Lakehead University (LU), Thunder Bay, Canada (Table 5.1).

5.5.1 Sampling methods

Two methods of residue extraction were employed in my investigations: (1) spot sampling via pipette extractions using a designated amount of solvent; and (2) ultra-sonication using distilled water in an ultra-sonic bath. The first method was preferred as this was the most practical for

sampling potentially very large, bulky grinding stones and has shown to be successful in the recovery of residue materials such as starch on similar sized artefacts (e.g., Field *et al.* 2009; Fullagar *et al.* 2015; Stephenson 2011). Additionally, this method is considered to be minimally destructive as only a small portion of the grinding stone is subjected to spot removal and the sampling locations may be carefully isolated. The latter is unachievable during sonication in which a much larger portion of the stone must be submerged. Multiple solvents could also be applied during spot sampling and therefore water-soluble and water-insoluble residues could be recovered.

Table 5.2: Wear features identified at low and high magnification and describing terminology. Adapted from Adams *et al.* (2009).

	Variable	Description
Low magnification (stereomicroscope)	1. Degree of grain rounding	<i>absent, minimal, moderate, high</i>
	2. Degree of surface levelling	<i>absent, minimal (disconnected), moderate, high (connected)</i>
	3. Presence of striations	<i>present/absent; common/rare</i>
High magnification (vertical incident light)	4. Use-polish brightness	<i>dull, moderate, bright</i>
	5. Use-polish development	<i>weak, moderate, developed, well-developed</i>
	6. Use-polish coverage	<i>localised, moderate, extensive</i>
	7. Use-polish morphology	<i>reticular; domed; rough-pitted; smooth-pitted; undulating; striated; un-diagnostic</i>
	8. Presence of micro-striations	<i>present/absent; common/rare; directionality; size: depth, width, length</i>
	9. Presence of grain fracturing/scarring	<i>present/absent; common/rare; scar type</i>
	10. Presence of residues	<i>present/absent; inorganic/organic; plant/animal</i>

5.5.1.1 Sampling solvents

Two solvents were selected for extracting residues: (1) a tri-mixture solution of ethanol, ultra-pure Millipore water and acetonitrile (EWA); and (2) distilled water. Because archaeological residues are typically composed of a number of unknown solutes, the EWA solvent mixture (prepared at a ratio of 1:1:1) was considered the most appropriate for sampling a range of unknown materials as it is capable of dissolving a large variety of organic compounds from an unknown solute

mixture (Crowther *et al.* 2015: 380). Water was included in the tri-mixture solution to enhance the polarity of the solvent mixture so that more polar compounds such as amino and nucleic acids, carbohydrates and oxidised organic molecules, could be solubilised. Other possible residue constituents, such as fatty acids, resins and alkaloids, are solubilised in less polar solvents, and therefore such solvents were also in the solvent mixture. Acetonitrile was chosen for its ability to dissolve materials such as resin acids, fatty acids, and some amino acids (Barnard *et al.* 2007; Shen *et al.* 2006; Sobolevsky *et al.* 2003). Ethanol was selected as it was effective at dissolving resin acids and alkaloids (Alqasoumi *et al.* 2012; Conforti *et al.* 2006; Popova *et al.* 2010; Zhang *et al.* 2005). Other solvents such as dichloromethane, chloroform, butanol and diethyl ether have been used in other archaeological residue studies and for resin and fatty acid characterisation (e.g., van Bergen *et al.* 1997; Charrie-Duhaut *et al.* 2007, 2013; Evershed *et al.* 1997; Malainey *et al.* 1999; Regert *et al.* 2008; Stern *et al.* 2003), but were not selected as part of this solvent mixture as they are immiscible with water and therefore will not form a solution. Other organic solvents that are miscible with water, such as methanol and acetone, were not selected for this solvent mixture as they have a low boiling point and will therefore evaporate too quickly making sampling difficult. Distilled water was selected as the other removal solution as it enables the removal of water-soluble materials (e.g., blood) and other water insoluble materials such as starch grains, plant fibres, and animal tissues that may be suspended in the liquid media.

5.5.1.1 Pipette extractions

All residue samples were removed from archaeological tools within the Wet Chemistry Laboratory at UOW using the EWA tri-mixture solvent and distilled water. Each solvent was placed on a small area of the artefact surface (<1 cm²) using an adjustable pipette fitted with a disposable nylon pipette tip. The sampling location was selected based on the likelihood of it containing residues; these included surface features that may “trap” residues, for example, in a crack or scar, or in areas where residues are macroscopically visible. In the absence of these features, areas with the highest degree of grinding wear and polish development were selected. At least one EWA and one water removal was obtained from each grinding surface, except where the specimen was too small to collect two samples or when the specimen appeared to be too fragile and the nylon pipette tip was damaging the surface. One water removal was obtained from each of the unground surfaces to act as a control.

Residues were removed by placing up to approximately 100 μL of solvent onto the artefact surface using an adjustable pipette and disposable nylon pipette tip over at least ten intervals. The solvent was placed onto the selected area and left to soak until partially absorbed into the sandstone matrix. For those particularly porous sandstone materials, more of the solvent was required as absorption was more rapid and not enough solution could be extracted. The solvent was left to soak so that during removal, residues contained within the deep pores of the stone could be removed. This allowed the most recent residue deposits from the top of the grinding stones to be removed as well as residues from other grinding events that reside deeper within the pores of the artefact. Once the solvent was on the stone surface, the disposable nylon pipette tip was used to agitate the selected surface area to dislodge the adhering residue. The residues were then removed by drawing the water sample back into the pipette until at least 20 μL of material was recovered. The removed samples, which typically appeared cloudy or dirty, were stored in nylon micro-tubes in labelled plastic bags until they were ready for microscopic examination and biochemical testing.

5.5.1.2 Ultra-sonication and separation

Removal of residues by ultra-sonication and the isolation of residue components such as starch, pollen and phytoliths through density separation is a common method for archaeological residue analyses, particularly for starch grain research. Previous residue studies performed on archaeological grinding stones have shown that this is a successful method of extraction, enabling particles to be dislodged from deep within the cracks and porous surface irregularities that are typical of sandstone (e.g., Fullagar *et al.* 2008; Piperno *et al.* 2004: 672). A pilot study was undertaken on a selection of the MJB and Lake Mungo grinding stones ($n = 22$) to determine the potential of improving residue recovery.

Twelve of the MJB specimens and ten on the Lake Mungo artefacts (the latter performed by another analyst) were selected to undergo further methods of residue extraction after use-wear and previous residue analysis had indicated that they were likely to contain plant materials. These included tools which displayed use-wear that was consistent with the processing of plants or tools in which previous pipette extractions had indicated the presence of starch (identified visually or via biochemical analysis, see below). The second extraction method involved sonication of an area of the ground surface to dislodge residues followed by density separation to isolate starch grains and other plant microfossils such as phytoliths, raphides and pollen. Ultra-sonication, separation and examination of the residues from the MJB grinding stones were carried out at UNSW in collaboration with Dr. Judith Field.

The MJB artefacts selected for additional examination included three groups of artefacts (Table 5.3). The first group (Group 1) consisted of three artefacts that were considered highly likely to contain starches. These include grinding fragments UP GS 2 and L49 that have most likely originated from the same complete tool, both recovered from Square C2 in Spit 5 at a depth of about 16 cm (and dated by radiocarbon to ~4.2 and 7.3 cal BP); and GS 3 from Spit 21, at a depth of around 100 cm, dated around 9.2 ka cal. BP (unpublished radiocarbon data). All three artefacts displayed a well-developed, extensive use-polish typical of plant processing and contained individual starch grains and/or raphides, which were identified within the pipette-extracted material.

Table 5.3: MJB artefacts sampled for starch analysis.

Group number	Artefact Number	Square/Spit
1	UP GS 2	C2/5
	L49	C2/5
	GS 3	E1/21
2	UP GS 26	C1/29
	UP GS 28	C1/36
	GS 39	D1/37
3	L52	C3/5
	UP GS 4	D2/10
	UP GS 14	E1/26
	UP GS 16	C2/26
	GS 49	C4/29
	GS 47	D2/39

The second group of artefacts (Group 2) included three artefacts from earlier deposits: UP GS 26 from Spit 29, UP GS 28 from Spit 36 and GS 39 from Spit 37, corresponding to depths of 149, 188 and 194 cm respectively, ranging in age from 19.3 – 29.4 ka cal BP (unpublished radiocarbon data). Similar to Group 1, all three artefacts possessed use-wear traces typical of plant processing, however, no starches were identified with pipette extractions. Group 2 was, therefore, selected to determine whether sonication and separation methods of residue extraction could enhance recovery of starches. The third group of artefacts (Group 3) included a selection of six stones that had been recovered from varying depths and which also possessed use-wear consistent with plant processing. These included L52 from Spit 5 (depth of 16 cm), UP GS 4 from Spit 10 (depth of 43 cm), UP GS 14 and GS 16, both from Spit 26 (depth of 128 cm), GS 49 from Spit 29 (depth of 149 cm), and

GS 47 from Spit 39 (depth of 202 cm). Similar to Group 2, starch grains were not visually observed on any of the residues recovered from the pipette extractions. The ten Mungo grinding stones selected for analysis were chosen because they were considered likely to contain starches.

The ultra-sonication process involved placing grinding stone fragments in distilled water in an ultra-sonic bath for 2 min to dislodge residues. The samples were obtained by either partially submerging (e.g., for GS 3, L49, UP GS 26, UP GS 28, GS 39) or completely submerging (e.g., for UP GS 2) the fragments in a weighing tray filled with distilled water and floated or held in the ultra-sonic bath. The recovered residue sample was then centrifuged for 3 min at 3,000 RPM to reduce the volume. Starch and any phytoliths were isolated with heavy liquid (Sodium polytungstate, Specific Gravity 2.3) and then centrifuged once more for 15 min at 1,000 RPM. After further rinsing in water, the samples were rinsed in acetone and allowed to dry. These were then transferred to micro-tubes and mounted on slides for microscopic examination.

5.5.2 Microscopy of residues

5.5.2.1 Slide preparation and examination

Extracted residues were prepared on glass slides and examined microscopically under transmitted light so that constituent materials could be identified. Slides were prepared at two facilities: the RUM Laboratory at the UOW, and the Archaeological Microscopy Laboratory at LU. Five micro-litres of extracted residue material was placed onto a clean slide (wiped with ethanol or acetone) ensuring that the mounted residue sample included a small amount of particulate material. A cover slip was applied above the sample and clear nail varnish was placed on each corner of the cover slip to set in place, the edges of which remained unvarnished so that additional solutions could be added if required. Examination of residues was carried out using an Olympus BH-2 microscope (described previously) at the RUM Laboratory at UOW and an Olympus BX-51 metallographic microscope with an Olympus DP72 Microscope Camera at the Archaeological Microscopy Laboratory at LU. Once placed under the microscope, slides were visually scanned for residues and were identified based on their morphology (i.e., size, shape, transparency, surface texture/pattern and colour) and their appearance in both plane-polarised and cross-polarised light (i.e., birefringence, pleochroism, retardation, anisotropy/isotropy, interference colours).

Residue samples that were recovered using ultra-sonication and separation techniques were viewed at the UNSW. Samples were mounted in 50% Glycerol/Water. Slides had total scans under a

Zeiss Axioskop2 brightfield transmitted light microscope fitted with Nomarski and polarising optics. All starch grains were photographed using a Zeiss HxC digital camera and then measured and archived with Axiovision software.

5.5.3 Characterisation of residues

A number of analytical techniques for the quantification of residues were applied to the MJB and Lake Mungo grinding stones. With the exception of staining (which was carried out at UOW), all methods were carried out at the Archaeological Chemistry Laboratory at LU.

5.5.3.1 Staining

Following microscopic analysis of extracted residues, several samples were selected for staining so that any highly degraded, fragmented or amorphous residues could be identified. These included a number of stains that highlight the presence of cellulose, lignin, damaged and undamaged starch, protein, fat, collagen and keratin (e.g., hair and feathers) (Plate 5.1). The staining agents selected to highlight these materials ($n = 8$) are listed below and summarised in Table 5.4. Stains were chosen on the basis of availability, cost and the procedure of application. Stains that required complicated procedures of application and long staining times were avoided. The suitability of each stain was assessed by applying each stain to an experimental sample and observing any associated colour change. The experimental material included at least one residue sample of animal origin (usually turkey meat) and one residue of plant origin (usually cellulose fibres obtained from tissue paper or from plant stems).

Congo Red

Congo Red ($C_{32}H_{22}N_6O_6S_2Na_2$) is a water-soluble dye that may be used as a general contrast stain for cellulose, amyloid fibrils, and damaged or gelatinised starches (Conn & Lillie 1969; Lamb & Loy 2005: 1439). The stain causes starch and cellulose to stain red while amyloid fibrils will stain green. The latter material is typically only stained in alkaline and acid buffer conditions (i.e., pH 2-4) where the stain is able to bind to carbohydrates, specifically amyloid (Chou *et al.* 2001: 218; Lamb & Loy 2005: 1439; Ramesh & Tharanathan 1999: 347). At a neutral pH, cellulose fibres and damaged or gelatinised starch may be stained in isolation. Both cellulose and starch are composed of the same monosaccharide molecule (glucose), however, differences between the bonds linking the glucose

units of both cellulose and starch account for their separate structures and properties (Lamb & Loy 2005: 1434). Undamaged or unaltered starch grains will not become stained with Congo Red as they are hydrophobic and, therefore, will not take up the stain. Alternatively, any alteration of the compact and regular arrangement of the starch layers following heating (e.g., cooking) or mechanical damage (e.g., grinding and pounding) will cause the stain to penetrate into the grain and stain the amylose content within the damaged/altered grains, turning them red (Plate 5.1a). The Congo Red solution was tested prior to application on archaeological specimens by applying a small amount of stain (up to 5µL) on heated corn starch in which a positive colour change (red) was identified.

Iodine Potassium Iodide (IKI)

Iodine Potassium Iodide (IKI) was used to stain intact undamaged starch granules because it is known to bind to the amylose polymers (made up of glucose units) within the starch (Banks & Greenwood 1975: 67; Yeung 1998: 132). The stain provides an immediate colour change causing undamaged starch grains to turn yellow (Plate 5.1b). In time, the starch will turn a permanent dark-blue/black colour (Banks & Greenwood 1975: 67; Evert 2006: 53). The IKI solution was tested prior to application on archaeological specimens by placing ~5 µL of stain onto a prepared slide containing potato starch in which a positive colour change was identified. The IKI stain also displayed a positive colour change with cellulose material mounted on other experimental slides (instantly staining purple).

Methylene Blue

Methylene Blue ($C_{16}H_{18}N_3SCl$) is a water-soluble dye that may be used to highlight non-lignified cell walls such as cellulose fibres within plant material (Cutler *et al.* 2008: 180; Wilson 1907: 647). The stain binds to the acidic pectins on the cellulose cell wall that are stained various shades of blue (Plate 5.1c) (Lillie 1976: 425; Stadelmann & Kinzel 1972). The colour and intensity of the highlighted cellulose fibres is related to the purity of the material: the darker the blue, the more pure the cellulose. Methylene Blue solution was tested prior to application on archaeological specimens by placing ~5 µL of stain onto a prepared slide containing tissue paper in which a positive colour change was identified. A colour change was not identified on prepared collagen slides.

Orange G

Orange G ($C_{16}H_{10}N_2Na_2O_7S_2$) is an acidophilic dye used to stain protein and highlight various animal fibres including collagen and keratin, which typically stain orange (Plate 5.1d). The associated change in colour occurs as the stain binds with proteins within the target materials. When used in conjunction with other stains, such as acid fuchsin and malachite green, pollen granules may be stained red (Alexander 1969; Lillie 1976: 121). The Orange G solution was tested prior to application on archaeological specimens by placing up to 5 μ L of stain onto a prepared slide containing a thin section of turkey meat in which a positive colour change was identified. No colour change was observed on slides containing plant materials.

Phloroglucinol

Phloroglucinol ($C_6H_6O_3$) is a water-soluble dye used as a general contrast stain for lignin. The stain reacts with structures within the xylem and sclerenchyma of plant cells to turn the substance red (Plate 5.1e) (Cutler *et al.* 2008: 180; Jensen 1962). However, experimental staining of plant cells using Phloroglucinol of an altered pH, caused lignified tissues to turn a yellow-brown colour. Subsequent analyses of archaeological residues were confirmed for lignin if the latter colour change was observed.

Rhodamine B

Rhodamine B ($C_{28}H_{31}ClN_2O_3$) is a basic dye used to highlight the presence of animal fibres such as hair, feathers and collagen, binding with proteins to allow the target material to turn a pink/purple (Plate 5.1f) (Lisberg 1968; Wessley *et al.* 1981). In general, Rhodamine dyes are water-soluble and are most commonly used in applications of fluorescence microscopy, flow cytometry, fluorescence correlation spectroscopy and ELISA. The Rhodamine B solution was tested prior to application on archaeological specimens by placing \sim 5 μ L of stain onto a prepared slide containing highly degraded hair removed from an ancient, Native American leather artefact in which a positive colour change was identified.

Safranin

Safranin ($C_{20}H_{19}ClN_4$) is a staining solution used as a contrast stain to highlight chromosomes, nuclei, lignin, and cell walls. A positive colour change will occur in the presence of the latter two

features as the stain reacts with the xylem and sclerenchyma, causing lignified cell walls to turn pink while lignified fibres turn red (Plate 5.1g) (Srebotnik & Messner 1994). The Safranin staining solution was tested prior to application on archaeological residues by placing up to 5 µL of stain onto a prepared slide containing plant cells from a plant stem in which a positive colour change was identified. A colour change was not identified on prepared collagen slides.

Because the Safranin stain will highlight other materials such as pollen grains, mitochondria and various animal cells, Phlorogluconol was the preferred stain used for the identification of lignin. However, Phlorogluconol was only readily available at the laboratory at the LU and therefore was not used to process any of the specimens analysed at UOW, where Safranin was used on the remaining specimens to highlight suspected lignin.

Sudan IV

Sudan IV ($C_{24}H_{20}N_4O$) is a fat-soluble dye used to stain sudanophilic substances including lipids, triglycerides and lipoproteins, causing them to turn red (Plate 5.1h) (Cutler *et al.* 2008: 180; Liliie 1976: 169; Yeung 1998: 133). This stain is one of six dyes used for Sudan staining (i.e., the staining of sudanophilic substances), with similar dyes including Sudan I-III, Oil Red O and Sudan Black B. These dyes vary from one another in terms of their physical characteristics, including melting point, maximum absorption and chemical compositions.

Sudan IV was the preferred stain to highlight sudanophilic substances owing to availability of the solution, ease of preparation and cost of solution. The Sudan IV solution was tested prior to application on archaeological residues by placing up to 5 µL of stain onto two separate slides containing milk and butter. The lipids within the product were identified by a positive colour change that was not identified on materials of plant origin.

Only a limited number of samples ($n = 4$) were selected for application of Sudan IV. This stain is classified as a Category 3 carcinogen by the International Agency for Research on Cancer (Refat *et al.* 2008) and, therefore, it was applied selectively to residues that had a high potential for containing lipid residues. These include samples that had previously tested positive for fatty acids with biochemical tests, or those that may have been associated with animal processing. Sudan IV was not applied to samples that may display lipids relating to the processing of plant or seed foods.

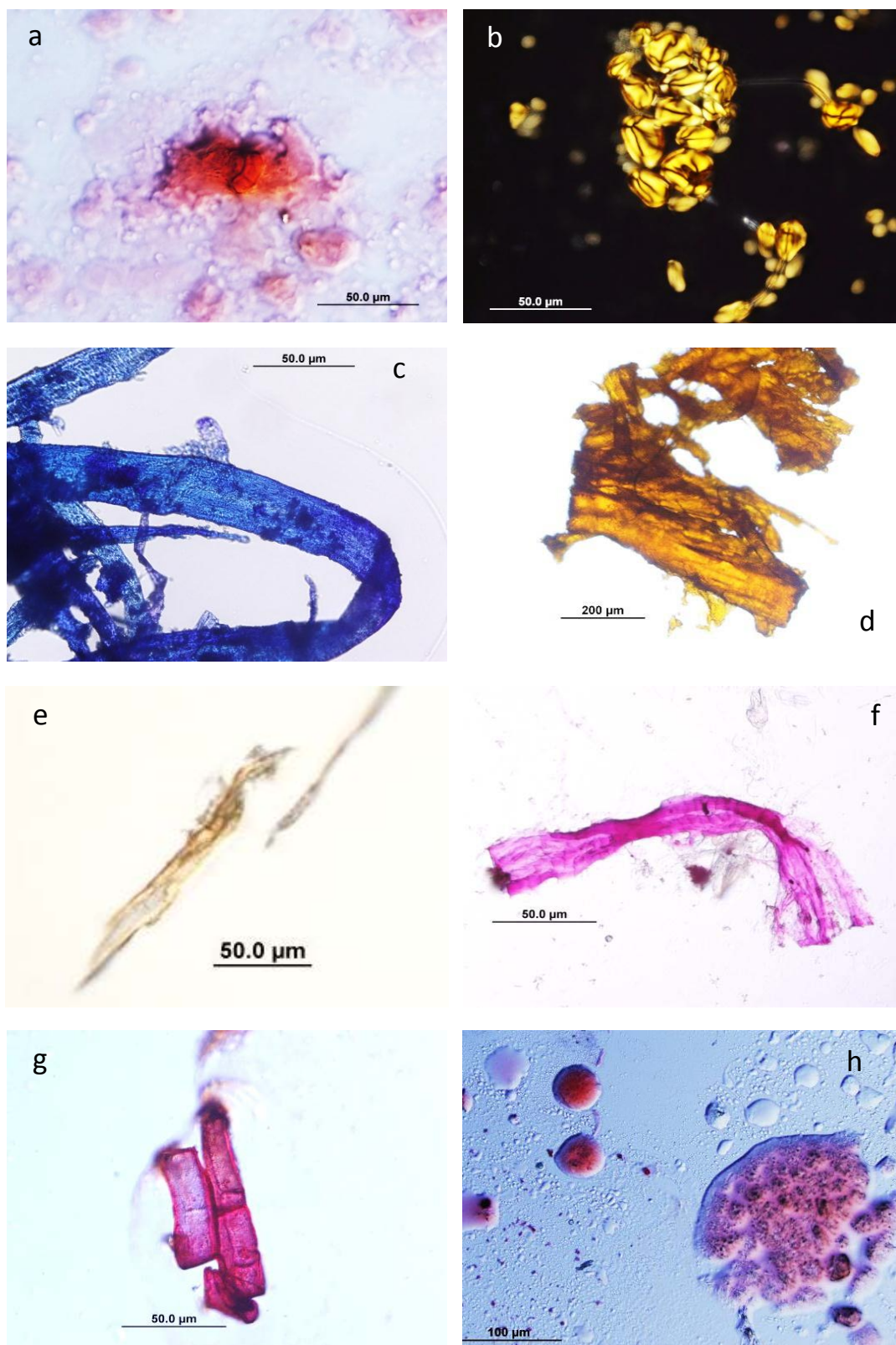


Plate 5.1a-h: Stained materials from residue reference library: **a)** gelatinised corn starch stained with Congo Red; **b)** un-damaged potato starch stained with IKI (cross-polarised light); **c)** cellulose fibres stained with Methylene Blue; **d)** turkey meat stained with Orange G; **e)** lignin stained with Phloroglucinol; **f)** degraded hair fibre stained with Rhodamine B; **g)** plant cells containing lignin stained with Safranin; **h)** vegetable oil stained with Sudan IV.

Staining procedure

Stains were selected for application based on the presence of amorphous material identified in residue mixtures sampled from the grinding surfaces. Approximately 10 – 40 µL of staining solution was applied to each of the selected slides until the residue sample was sufficiently covered. Each stain was left for at least 10 min to enable the stain to develop. After the stain had been left on for an optimal duration (depending on uptake), the excess solution was rinsed out using distilled water. For those samples stained with temporary stains, including Congo Red, Phloroglucinol and Methylene Blue, only a minimal amount of rinsing (if any) was carried out as to remove only the excess stain and not to wash out the colour from the target particle. Lamb & Loy (2005) recommend the use of NaCl when staining with Congo Red, however, this step was avoided as this solution was found to cause significant precipitation of the stain making examination of the slide difficult. Once stained with the respective solutions, residue slides were examined using a transmitted light microscope to assess any positive colour changes in the constituent residue material. The specific stain applied to each removal is presented in Table C6, Appendix C.

Table 5.4: Name and chemical formula of staining agents applied to residue mixtures sampled from MJB and Lake Mungo residue examination.

<i>Staining agent</i>	<i>Chemical formula</i>	<i>Stained material</i>	<i>Colour change</i>
Congo Red	$C_{32}H_{22}N_6O_6S_2Na_2$	gelatinised starch damaged starch cellulose	red
Iodine Potassium Iodide (IKI)	IKI	intact starch cellulose	blue/black
Methylene Blue	$C_{16}H_{18}N_3SCl$	cellulose	blue
Orange G	$C_{16}H_{10}N_2Na_2O_7S_2$	collagen keratin	orange
Phloroglucinol	$C_6H_6O_3$	lignin	yellow/brown
Rhodamine B	$C_{28}H_{31}ClN_2O_3$	collagen keratin	pink/purple
Safranin	$C_{20}H_{19}ClN_4$	lignin cell walls cell nuclei	red
Sudan IV	$C_{24}H_{20}N_4O$	lipids triglycerides lipoproteins	red

5.5.3.2 Absorbance spectroscopy

Absorbance spectroscopy is a method of residue characterisation used to determine the compounds present within a residue mixture (Section 4.5.2.3). While it is less specific and less sensitive than other methods of residue characterisation such as GC-MS, it was included as an initial screening test for the presence of organic materials. The absorbance spectra of extracted residue material sampled from both the ground and unground surfaces using both the distilled water and the EWA solvent were measured at the Archaeological Chemistry Laboratory at LU. Accompanying sediment samples (where available) were also analysed to provide a further check for potential environmental contamination. Dried residue samples were dissolved with distilled water and diluted as needed. Two micro-litres of solution was placed in a Take 3TM plate ensuring that no particulate material was present within the sample as this may cause scatter within the scan. Absorbance spectra were then measured between 200 nanometres (nm) and 900 nm using an EpochTM Multi-Volume Spectrophotometer System (Biotek) at 2 nm increments. The data was collected and analysed using Gen 5 software.

Nine readings within the measured range of 200 and 900 nm were of particular interest; these include: (1) the initial reading between 200 and 205 nm in which a peak height in the graph will indicate the amount of organic material (plant and animal) present within the measured sample); (2) 230 ± 5 nm, indicating the presence of pheolates and carboxyl groups to support fatty acid identification; (3) 240 ± 5 nm, indicating the presence of alcohols, including plant sterols; (4) 250 nm, indicating alkaloids and carbon/nitrogen bonding; (5) 260 nm, indicating the presence of nucleic acids; (6) 270 nm, indicating the presence of phenols; (7) 280 nm, indicating the presence of protein derived from plant material; (8) 410 ± 5 nm, indicating the presence of haemoglobin, myoglobin and animal proteins; and (9) 560 nm, indicating the presence of plant components such as chloroforms and keratins (Matheson pers. comm; summarised in Table 7.13). The identification of distinctive “shoulders” or peaks indicates a positive reading.

5.5.3.3 Biochemical testing

Biochemical tests are rarely included in archaeological residue studies (but see Fullagar *et al.* 2015; Matheson & Veall 2014) and were included here as a pilot investigation to assess their applicability to potentially very old residue mixtures. Although biochemical tests are specific for a group of compounds (e.g., protein), they are unable to identify individual compounds (e.g., collagen, myoglobin) and are, therefore, less sensitive than other methods of residue characterisation such as

GC-MS. Biochemical tests are, therefore, only suitable for providing an initial screening test for the presence of specific groups of organic compounds, for example, carbohydrates, proteins and fatty acids.

Six biochemical tests were selected for the detection of protein, carbohydrates, fatty acids, starch and ferrous iron (including haem) as detected via the Bradford Assay; Diphenylamine and Phenol-Sulphuric Acid (PSA); Copper triethanolamine diphenyl-carbazide (hereafter referred to as the “Falholt” test); Iodide-Potassium-Iodine (IKI); and Hemastix® tests, respectively (Table 5.5). These tests were selected for application as they allow for the detection of a wide range of organic materials (in addition to inorganic iron-rich mineral crystals), including various plant and animal tissues. Importantly, the selected tests were also able to be modified so that they may be performed as micro-biochemical tests (requiring less residue material) and analysed using a spectrophotometer.

Biochemical tests were performed on residue mixtures extracted from the ground and unground artefact surfaces using either water or EWA solvent. Each test was performed on a small portion of sample (<5 µL) and observed for a subsequent reaction, indicated by a specific colour change. Positive reactions were identified using the Epoch™ Multi-Volume Spectrophotometer System (described previously) following a set of standard measurements using blood protein, corn starch, cooking oil and a combination of sucrose and glucose. The readings from these measured standards were considered the minimum value for the detection of proteins, starch, fatty acids and carbohydrates, respectively. To assess the possibility of environmental contamination, all accompanying sediment samples were also tested using the above set of biochemical tests. For those samples that were not accompanied by sediment samples, tests were performed on removals from the unground surfaces. The specific methods of each test are described below.

Testing for proteins

Bradford Assay

Protein was identified through application of the Bradford Assay following the procedures described by Jones *et al.* (1989) and Kruger (1994). Five micro-litres of water-extracted material was added to 25 µL of Bradford Assay reagent (100 mg of Coomassie Blue G250, 50 mL of 95% ethanol and 100 mL of 85% phosphoric acid; made to 1 L with distilled water) and mixed for 20 min at 1,000 RPM at 25°C. Absorbance was then read for 2 µL of this solution at 595 nm.

Testing for carbohydrates

Diphenylamine

Carbohydrates were detected using the Diphenylamine test (Kanzaki & Berger 1959). Five micro-litres of water-extracted sample was mixed with 10 μ L of Diphenylamine solution (0.05 g Diphenylamine (MW 169.22), 5 mL Glacial Acetic Acid and 0.125 mL sulphuric acid) and heated for 10 min at 80°C. Following heating, 2 μ L of solution was measured for absorbance at 595 nm.

Phenol-Sulphuric Acid

The Phenol-Sulphuric Acid (PSA) test is credited as the easiest and most reliable method of carbohydrate detection (Masuko *et al.* 2005: 69). The test is often used to measure the neutral sugars present within oligosaccharides, proteoglycans, glycoproteins and glycolipids, and was selected as an additional method of carbohydrate detection in the analysis of the MJB and Lake Mungo grinding stones. Five micro-litres of the water-extracted residue solution was mixed with a PSA solution (5 μ L 4% Phenol and 25 μ L Sulphuric acid). The mixture was left for 10 min at room temperature to ensure adequate binding of the PSA solution to any potential carbohydrates. Following resting, 2 μ L of solution were read for absorbance at 490 nm.

Testing for starch

Iodine Potassium Iodine (IKI)

The presence of starch (intact and gelatinised) was assessed using the IKI biochemical test (McCready & Hassid 1943). This test was selected owing to the high probability that some of these artefacts were used in the processing of plant materials, and such a test will indicate the presence of starch even if they are unable to be visually identified. Five micro-litres of the water-extracted material removed from each of the used surfaces were mixed to a solution of 5 μ L potassium iodide (KI) (0.12M) and 5 μ L of iodine (I) (0.01 M). Samples with <5 μ L of extraction available were added to smaller portions of KI and I, ensuring that the ratio remained at 1:1:1. Two micro-litres of solution were read for absorbance at 595 nm.

Testing for fatty acids

Falholt test

Fatty acid compounds were detected following the application of the Falholt test (Falholt 1973). This test was considered highly useful for the analyses of grinding stones that may have been

used to process materials with a high fatty acid content, such as seeds. Because fatty acids are also present in animal tissues and oily excretions of the hands, further characterisation of specific fatty acid compounds is required to determine the residue source. Residue extractions were freeze-dried for 48 hours so that any additional liquid was removed, and then resuspended in 10 μL of acetonitrile and left for at least 24 hours. Five micro-litres of sample were added to 20 μL of copper triethanolamine (Cu-TEA) [0.05 mol-1 Cu (NO_3)₂ and 0.1 mol-1 triethanolamine pH 8.1] and 5 μL of diphenyl-carbazide (DPC) (500 μL of 4% 1.5 diphenyl-carbazide and 50 μL of triethanolamine). After 15 min, 2 μL of the mixture were read for absorbance at 550 nm.

Table 5.5: Biochemical tests applied to residue mixtures, molecule detected and optimal wavelength for detection.

<i>Biochemical test</i>	<i>Biomolecule detected</i>	<i>Removal solution</i>	<i>optimal wavelength</i>
Bradford assay	protein	water	595 nm
Diphenylamine	carbohydrates	water	595 nm
PSA	carbohydrates	water	490 nm
Falholt	fatty acids	EWA	550 nm
IKI	starch	water	595 nm
Hemastix® test strips	ferrous iron (haem)	water	n/a

Testing for ferrous iron (including haem)

Hemastix®

The presence of haemoglobin (and other iron containing materials) was assessed using the presumptive haemoglobin specific chemical reagent test strip (Hb-CRTS): Seimens Hemastix® test strips. Five micro-litres of solution from the water-extracted residue sample was placed on the Hemastix® test pad and left for 1 min to see if a colour change occurred. If no colour change had occurred after 1 min, the sample was deemed negative for haemoglobin. Evaluations of colour change would not be made after 1 min as the pad can auto-oxidise and change colour, creating a false-positive result. Colour change was ranked on a scale of 0 – 5 as recommended on the Hemastix package: 0 representing no change in colour; 1 for a speckled colour change and 2 – 5 for a broad colour change ranked on increasing darkness. These correspond to negative, slight trace, trace, small, moderate, and large traces of haemoglobin, respectively. Any sample that displayed a

positive reaction (i.e., colour change ranking from 1 – 5) was then assessed for contamination by testing the corresponding sediment sample - sediments were submerged in distilled water and the suspended solution was assessed for potential residues causing a positive Hemastix® reaction. Because several other materials found within the burial environment are known to react with Hemastix, for example plant material and metal ions present within the soil (see Section 4.3.2.1), testing the soil sample will indicate whether the positive reaction was instigated by other factors. Those samples from the used surface that provided an initial positive reaction were retested following the addition of 1.0 M ethylenediaminetetraacetic acid (EDTA) solution, which increases the specificity of the test and eliminates the reaction of metal ions within the tested sample (Matheson & Veall 2014). This mixture aims to eliminate any environmental or metal (including haematite) residues that cause a positive reaction in the Hemastix®. A sample that tests positive following the addition of the EDTA solution is likely to contain haemoglobin. In this way, we can determine which specimens are likely to contain blood and haematite residues.

5.5.3.3 Gas Chromatography-Mass Spectrometry (GC-MS)

GC-MS is a highly-specific method of residue characterisation enabling organic compounds within a residue mixture to be recognised (Section 4.5.2.3). The mass spectrum for each compound is distinctive and results from the way in which the compound fragments, creating a unique “fingerprint” spectra. All residue samples (including those removed with both water and EWA solvent) and accompanying sediment samples (where available) were prepared for GC-MS so that trace amounts of adhering material could be identified. This included 92 residue samples collected from the surface of the MJB sandstone fragments, including samples from all 91 grinding stones and one unused sandstone fragment (GS 42). One residue sample, Lift 1 from GS 1, was analysed twice using the same standard procedure (described below) to assess the reproducibility of the GC-MS data. Seventy-nine sediment samples from the corresponding MJB deposits were also measured with GC-MS to assess the extent of environmental contamination. Twelve residue samples collected from the grinding surfaces of the Lake Mungo specimens were also analysed, but no sediment samples were measured from this set of artefacts.

The preparation process involved desiccating all residue samples to ensure complete removal of solvents. This usually involved freeze-drying sample tubes for a period of at least 48 hours. This step was not necessary for sediment samples that had not been removed with solvent. Once all the residue samples were desiccated with only the particulate material remaining, 500 µL of acetonitrile was added to each sample tube and left for at least 24 hours. The acetonitrile was then

removed and placed into a separate glass vile ensuring that no particulate material was present. Before sealing, all oxygen was removed from the glass vile by purging the vial with nitrogen gas and sealing it with aluminium caps.

GC-MS analysis was performed using a Varian model 450 gas chromatograph coupled with a Varian model 300-MS quadrupole mass spectrometer fitted with FactorFour™ capillary column (VF-5ms, 30 m x 0.25 mm ID, DF = 0.25 µm), following the methods described by Crowther *et al.* (2015: 380). The chemical compounds recovered from each residue mixture were identified following the characterisation of their ion spectra and the ionisation peaks (e.g., the molecular ion, M⁺ peak, M+1 peak and the various ionisation peaks M-15 peaks), using Varian MS Workstation Version 6 and the NIST98 Mass Spectral Database (National Institute of Standards and Technology). Compounds were then cross-referenced with published data to enhance taxonomic identification.

5.5.4 Comparative starch reference collections for MJB plant residues

A modern comparative reference collection for locally available plant materials was prepared for a small number (n = 7) of economically important plant varieties. This involved a review of the literature of utilised northern Australian plants (Table A1, Appendix A) as well as vegetation surveys of the local Kakadu area. The published and unpublished literature for the region has indicated the use of at least 238 plant species, including the consumption of 136 plants. Other uses include the crafting of wood and bark into implements (e.g., spear heads, spear throwers, digging sticks, musical instruments, string bags, fishing nets—number of species = 157); the use of seeds as decorative ornaments (n = 3), the use of gum and exudates as organic binders (n = 4), and the preparation of plant material for medicinal purposes (n = 22). While the preparation of such plants has not been extensively documented, some ethnographic work for the region has indicated that at least 33 species (i.e., approximately 14%) were prepared by grounding or pounding (Table A1).

Vegetation surveys were carried out by a small research team lead by C. Clarkson in collaboration with Willie Burgess, an employee at the George Brown Darwin Botanic Gardens who is highly regarded in the Territory for his knowledge of the flora and Indigenous plant use. Seventy-seven species of plants were documented during this research trip, only a selection of which were collected (n = 27). Some of these plants identified during this field trip had already been analysed for starch for use in other reference collections (e.g., *Tacca leontopetaloides* and *Dioscorea bulbifera*). A number of additional species were sampled for starches, including *Amorphophallus paeonifolius* (elephant foot yam), *Dioscorea transversa*, *Cyperus bulbosus*, and *Nelumbo nucifera* (water lily),

which were selected because they contain abundant starches and are economically important in the region. Plants that were deliberately avoided were those that are not known to contain starch (e.g., woody plants) or those that may have been consumed but were not typically ground (e.g., *Pandanus* sp.).

Slides for starch grain analysis were prepared for each of the seven plant species listed above by grinding starch samples in a glass mortar and pestle, smearing on a dry slide, and mounting with 50% Glycerol/Water and sealed with a clear coverslip and nail varnish. Slides were then examined using the procedures outlined previously (Section 5.5.2.1). A minimum of 100 grains were measured for each specimen, ensuring maximum dimension through the helium was recorded, as well as any features such as faceting, fissures, location of the helium (i.e., eccentric/centric) and presence or absence of lamellae, following the procedures outlined in other published studies of starch grain analysis (*cf.* Fullagar *et al.* 2008: 163; Piperno *et al.* 2004: 672-3). These data were then stored and compared to the archaeological residues so that specific plant taxa could be gleaned.

5.5.5 Assessing laboratory contamination

In order to establish the authenticity of the residues identified, a number of intra-laboratory checks were carried out to ensure that the identified residues are not the outcome of residues that may have accumulated post excavation, specifically, during storage and analysis. Crowther *et al.* (2014) have suggested a set of systematic procedures to assess intra-laboratory contamination, which includes examination of laboratory consumables, airborne contaminants, and decontamination techniques (oxidation, boiling, autoclaving, torching). Three rooms at the UOW (RUM Laboratory, Wet Chemistry Laboratory and storage room) were assessed for the presence of airborne contaminants through the strategic placement of residue traps in the form of exposed microscope slides designed to capture airborne particles. This involved the placement of a clean glass slides (rubbed with ethanol prior to use) fitted with approximately 3 x 1 cm of double-sided tape in at least one location within each of the rooms. The slides were typically placed in higher locations, such as above book shelves or laboratory stands and sometimes beneath air vents. Each slide was left for a minimum period of 60 days to ensure an adequate exposure time was achieved.

Laboratory consumables were also examined for contaminants via direct methods of observation (i.e., examining the product directly under high magnification). The consumables examined included one pair of starch-free gloves (used during examination and handling of artefact specimens); three 5 mL sample tubes, a 4 x 4 cm square of bubble wrap, one plastic sample bag,

three pipette tips, two glass slides (examined both before and after wiping with ethanol) and two cover slips. All items were scanned at magnifications ranging from x100 – x500 under reflected or transmitted light. The visual identification of contaminating particles on each item was recorded.

5.6 Chapter summary

This Chapter has described the methods of use-wear and residue analysis employed in this thesis to document the use traces on collections of grinding stones. Use-wear of the grinding surfaces was examined microscopically using a low magnification stereomicroscope and a high magnification reflected light microscope. Grinding surfaces were examined both directly from the artefact surface, and indirectly, through the inspection of impressions made with PVS material. The unground artefact surfaces were also examined microscopically to document any non-related wear traces that may be present on the artefact surface. Wear traces were documented digitally with high-resolution micrographs. Tool use-residues were documented using multiple methods of analysis. Residues were first removed using a selection of solvents and extraction techniques and prepared for visual and chemical characterisation. Residue samples were placed on glass slides and examined using a high magnification transmitted light microscope using polarised and cross polarised light. Use-residues were visually identified following the application of one of seven staining agents designed to highlight specific materials. Non-visible use-residues were characterised using a collection of six biochemical test, absorbance spectroscopy and GC-MS. Storage, handling and laboratory contamination was evaluated using strategically placed residue “traps” to document airborne contaminants and through the examination of laboratory consumables in which all artefacts are in contact. These included storage bags, pipette tips, disposable gloves, bubble wrap, removal solvents, glass slides and cover slips. The functional interpretations generated from the analytical methods described in this Chapter are presented in Chapters 6 and 7.

Chapter 6:

Use traces on grinding stones:
Developing a task-specific
reference library of wear patterns
and residues

6.1 Introduction

Functional interpretations of archaeological specimens may be achieved through the identification and interpretation of specific use-wear signatures present on the artefact surface. Artefacts with known functions provide the basis for recognising the use-wear traces relating to a specific task or worked material. Detailed descriptions of artefact function typically accompany tool-use experiments and some ethnographic collections. The surface features and wear patterns identified on artefacts in these collections form the basis of use-wear reference libraries from which one can interpret and evaluate the function of archaeological specimens. In order to become familiar with the range of patterns and specific use traces preserved on Australian implements, a number of replicative and controlled experiments were performed using ethnographically documented raw materials applicable to Australian grinding stones. Ethnographic grinding stones collected from central Australia were also examined so that key use-wear traces could be recognised. This chapter outlines the experimental procedure and results obtained for collections of both experimental and ethnographic artefacts that were analysed in order to establish a reference library of wear and residue patterns.

6.2 Experimental data sets

Replicative and controlled experiments are important for interpreting artefact function, allowing reference libraries of distinctive and diagnostic use-wear signatures to be generated so that they may be compared with wear on archaeological artefacts. Experiments may also help determine the limits of interpretation and highlight any problematic issues associated with analysis, such as overlap of use-wear patterns for different worked materials. Pioneering research by Semenov (1964), Odell (1977, 1980, 1981a, 1981b), Keeley (1980), Kamminga (1982) and later work by many others (e.g., Fullagar 1986a; Hurcombe 1992; Lawrence 1979; Lombard *et al.* 2004; Lombard & Pargeter 2008; Moss 1983; Vaughan 1985) have provided decades of systematic experimental data sets for interpreting wear (and residue) traces on the surfaces and edges of flaked stone tools. Analyses performed on sets of experimental grinding stones have provided similar data sets and use-wear reference libraries, though they are much less numerous than for the flaked stone artefacts, and with less focus on edges and more on the surface topography and surface features such as striations, pits, rounding of grains, grain fractures, residues and use-polish (see Table 6.1 for references). In most investigations of grinding stone tool use, experiments were designed to incorporate the grinding and processing of ethnographically relevant materials so that reference

Table 6.1: Published use-wear studies performed on experimental grinding stones, including stone material type and worked-material.

Reference	Raw material of g-stone	Worked-material
Adams 1988	Sandstone, quartzite	hide, corn
Adams 1989a	sandstone	corn, sunflower seed, pottery, clay, wood, bone, hide, shell
Adams 1989b	sandstone, quartzite	stone, bone, wood, shell
Adams 1993	basalt	stone, wood, bone, hide
Adams 1999	basalt, granite, sandstone, quartzite	maize, sunflower seed, amaranth seed
Adams 2014	basalt, sandstone	hide, maize
Adams <i>et al.</i> 2009	basalt, limestone, schist, sandstone	wheat, barley, rice, fava beans
Cristiani <i>et al.</i> 2012	limestone, siltstone	stone, hide, haematite/ochre
Delgado Raack 2008	schist	barley
Delgado Raack & Risch 2009	quartzite	cereals: bran, flour
Dubreuil & Grosman 2009	basalt	hide
Dubreuil 2002	basalt	wheat, barley, nuts, acorns, mustard seeds, fenugreek, fava beans, lentils, dried meat, dried fish, ochre, shell
Dubreuil 2004	basalt	ochre, domesticated wheat, wild barely, acorns, nuts, mustard seeds, fenugreek, fava beans, dried meat, dried fish
Fullagar <i>et al.</i> 2012	sandstone, tuff	seeds, acorns
Gilabert <i>et al.</i> 2012	sandstone, limestone, quartzite, gneiss, granite	hazelnuts, stone
Goren-Inbar <i>et al.</i> 2002	basalt	stone (flaking activities)
Hamon 2006	sandstone	wheat, hulled barely, spelt, legumes, hazelnuts, plants, flint, bone, temper, clay, bone, antler, shell, limestone, schist, skin
Hamon 2008	sandstone	wheat, barley, spelt, legumes, hazelnuts, plants, clay, pigment, burnt flint, burnt bone, grog, dry and wet bone, antler, shell, limestone, schist ornaments, dry and wet hide
Hamon & Plisson 2008	sandstone	wheat, bone, cartilage, dry meat, hide, acorn, calcite
Logan & Fratt 1993	sandstone	pigment
Liu <i>et al.</i> 2011	sandstone	stone, shell, bone, haematite, bamboo, acorn, mung beans, millets, oats
Menasanch <i>et al.</i> 2002	gabbro; schist	wheat, barley
Mills 1993	sandstone	volcanic stone (axe)
Procopiou <i>et al.</i> 1998	quartzite	wheat, barley
Procopiou <i>et al.</i> 2011	corundum, sandstone	diasporite (precious stone)
Risch 2002	gabbro, schist	Wheat, barley
de la Torre <i>et al.</i> 2013	quartzite	stone, nuts, meat, plants.
Verbaas & Van Gijn 2008	sandstone	cereals
Wright 1993	sandstone	maize
Zurro <i>et al.</i> 2005	sandstone	millet

libraries could be established relevant for interpreting archaeological assemblages from particular regions of Europe, America, Australia, Asia and Africa.

In order to develop a reference library valid for Australian grinding stones, a set of experimental artefacts were assembled to document the key use-wear traces associated with processing ethnographically known Aboriginal resources. In my experiments, I processed a selection of these materials using sandstone grinding stones and then examined the tools for use-wear and related residue traces.

6.2.1 Experimental design

Twenty-six experimental grinding stones (EGS) were assembled from a range of local Australian sandstones (Table B1, Appendix B). The sandstones included material either collected *in situ* from relevant locations or commercially purchased from suppliers. My experiments included three sandstone sources from New South Wales (Jemalong Ridge in central NSW and two from the Illawarra region in southern NSW), one source from Western Australia (Kimberley region) and one source from the Northern Territory (Kakadu region) (Figure 6.1). Sandstone was collected on-site at MJB, Kakadu National Park, as it was thought to be the most applicable to use-wear comparisons of archaeological grinding stone specimens from the same area. Other sandstone varieties were also selected depending on their availability, suitability for experimental work (i.e., shape, weight) and their varying degrees of hardness (as a relative ranking based on the relative proportion of quartz minerals comprising the sedimentary matrix of the sandstone and the nature of the cementing material—this was determined via XRD analysis and visual identification of constituent minerals—see Appendix B), texture and compositional differences (Table 6.2). The latter selection criteria are essential for determining both the efficacy of varying sandstone materials for particular tasks and for understanding the accumulation, recognition and diagnostic specificity of use-wear (Delgado-Raack *et al.* 2009). The experimental artefacts included a number of hand stones (upper stones) ($n = 8$), lower stones; ($n = 8$), and stone “files” (abraders or filing stones) used singly to sharpen or shape a given material ($n = 11$) (Table 6.3).

The grinding stones were used to process ethnographically documented materials as well as a number of locally and commercially available materials listed previously (Section 5.2.1; Table 6.3, 6.4). The grinding or pounding of these materials was performed by five researchers (C. Clarkson, R. Fullagar, E. Hayes, C. Pardoe & B. Stephenson) over one week at an experimental grinding workshop at Byangee Academic Retreat, Yadboro, New South Wales (Figure 6.1).

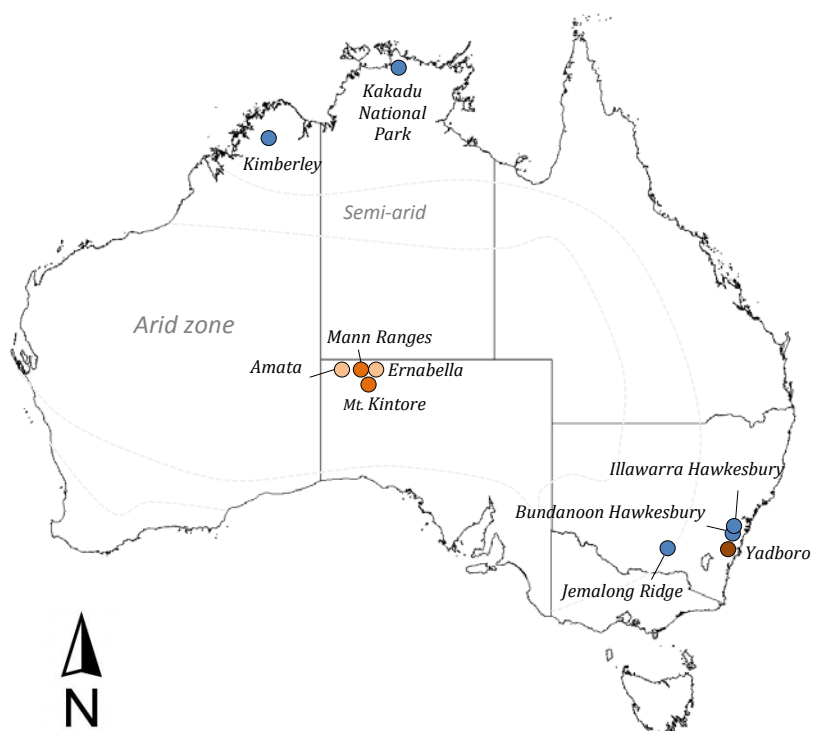


Figure 6.1: Map of Australia showing the location of the ethnographic stones (orange and peach dots), location of experimental grinding workshop (brown dot) and the locations of the sandstone sources that were used to make experimental grinding stones (blue dots).

Table 6.2: Summary of stone materials used in experimental grinding workshop, relative hardness and average grain size. Relative hardness was determined by the percentage of quartz and clay minerals present and the degree of cementation following XRD and SEM analysis (Appendix B).

Stone ID no.	Sandstone name/ collection location	% Quartz	Relative hardness	Size range of quartz grains	Other minerals present
1	Kakadu National Park, Northern Territory	96.9	2	150 – 200 μm	Kaolin 0.2 % Illite 2.9%
2	Jemalong Ridge, central New South Wales	95.7	1	80 – 150 μm	Kaolin 0.9 % Illite 3.4%
3	Hawkesbury sandstone; Wollongong/Austinmer, New South Wales	95.4	3	200 – 400 μm	Kaolin 2.6 % Illite 1.8 % mixed illite 0.2%.
4	Kimberley, Western Australia	90.4	4	80 – 400 μm	Calcite 0.1 % Kaolin 5.3 % Illite 3.9% mixed illite 0.3%
5	Hawkesbury sandstone; Bundanoon, New South Wales	77.7	5	150 – 400 μm	Kaolin 19.7 % Illite 2.4% mixed illite 0.2%

Table 6.3: Experimental grinding stone numbers and their corresponding grinding stone type, material, and the location in which they were sourced (numbers correspond to those presented in Table 6.5).

Exp. grinding stone no	GS Material	Sandstone Source	Grinding stone type	Worked-material
EGS 1	quartzite	1	filing stone	wheat
EGS 2	quartzite	1	filing stone	wood
EGS 3	sandstone	5	filing stone	bone
EGS 4	sandstone	5	filing stone	wood
EGS 5	quartzite	1	upper stone	bone
EGS 12	sandstone	2	lower stone	warrego grass seeds
EGS 13 (side 1)	sandstone	5	filing stone	stone (basalt)
EGS 13 (side 2)	sandstone	5	filing stone	stone (dolerite)
EGS 15	sandstone	5	lower stone	wheat
EGS 16	sandstone	5	lower stone	kangaroo grass seeds
EGS 17	sandstone	3	lower stone	acacia seed
EGS 18	sandstone	4	filing stone	stone (basalt)
EGS 19	sandstone	5	mortar (lower stone)	kurrajong seeds
EGS 20	sandstone	3	anvil (lower stone)	bone
EGS 23	sandstone	2	upper stone	<i>Acacia</i> seed
EGS 24	sandstone	2	upper stone	kurrajong seed
EGS 25	sandstone	2	upper stone	<i>Acacia</i> seed
EGS 28	sandstone	2	upper stone	warrego grass seeds
EGS 29	sandstone	2	upper stone	kangaroo grass seeds
EGS 31	sandstone	2	lower stone	warrego grass seeds
EGS 32	sandstone	2	lower stone	<i>Acacia</i> seed
EGS 33	sandstone	5	pestle (upper stone)	warrego grass seeds
EGS 34	quartzite	river cobble	pestle (upper stone)	bone
EGS 35	quartzite	1	filing stone	haematite
EGS 36	quartzite	1	filing stone	haematite
EGS 38	sandstone	1	filing stone	stone (sandstone)
EGS 39	sandstone	1	filing stone	stone (sandstone)

Processed material	No. of experiments performed	No. of tools
Seeds	6	12
Wood	2	2
Bone	3	4
Wheat	1	2
Coffee	1	2
Volcanic stone	3	2
Sandstone	1	1
Haematite	2	2
Total	19	27

Table 6.4: Number of experiments performed and list of materials processed.

Table 6.5: Experiment number and corresponding experimental tool(s), material processed, processing method and duration of use. In situations where two experimental tools were used, the lower stone (i.e. millstone, mortar, anvil) is listed first, followed by the upper stone (hand stone, pestle, hammer).

Exp. no	Exp. tool number(s)	Operator	Worked-material	Processing method	Duration of use (mins)
1	3	RF	bone	sharpening	120
2	5	RF	bone	sharpening	120
3	20; 34	BS	bone	pounding	30
4	2	EH	wood (mulga)	sharpening	120
5	4	EH	wood (mulga)	sharpening	120
6	16, 29	RF	kangaroo grass seed	grinding	90
7	12, 28	EH	warrego grass seed	grinding	240
8	31, 33	CP	warrego grass seed	grinding	150; 110
9	32, 23	BS	<i>Acacia</i> seed (dry)	pounding	120
10	17, 25	EH	<i>Acacia</i> seed (soaked)	pounding/grinding	120
11	19, 24	EH	kurrajong seed	pounding	150
12	15, 1	RF	wheat	grinding	75
13	11, 37	CP	coffee beans	grinding	30
14	13 (side 1)	CC	basalt stone	sharpening	60
15	13 (side 2)	CC	dolerite stone	sharpening	80
16	18	CC	basalt stone	sharpening	60
17	38, 39	EH	sandstone	grinding	20
18	35	CC	haematite	grinding	10
19	36	EH	haematite	grinding	97

A total of 19 experiments were conducted using 26 grinding stones that were used individually (*cf.* filing stones) or partnered as a dedicated pair (*cf.* coupled stones) (Table 6.3). Experimental details, including the specific material used, the duration of use, and the method of processing (i.e., grinding, pounding) are presented in Table 6.5. Images for each experiment are presented in Plates 6.1, 6.5, 6.8 & 6.16.

6.2.2 Analytical procedures

Prior to use, each of the sandstone grinding slabs was photographed and examined microscopically using magnifications of x30 – x230 through a portable Dino-Lite™ (Section 5.3). This microscope was suitable for viewing large grinding stones in the field where the use of conventional microscopes was not possible. Several high-magnification images were captured before, during and after episodes of use, so that wear development could be documented and compared to images of

the original, un-altered surface. PVS peels were also collected from the artefact surface prior to use and at regular intervals throughout use so that the progressive development of wear could be documented (Section 5.4.2). Several experimental tools were sampled at regular intervals with PVS peels taken from the same location, so that the progress of use-polish development could be established on these artefacts. The location of each PVS peel is recorded on the artefact photograph. The number of PVS peels sampled, as well as the time intervals after which they were collected, are presented in Table B2.

Following use, all artefacts (and PVS peels) were analysed for functional traces using the sampling and microscopy procedures described in Chapter 5 (Section 5.4). As outlined in the previous chapter, functional analyses of experimental artefacts followed a set of specific observations whereby key surface features were defined. These features included (at low magnification): (1) degree of grain rounding; (2) degree of surface levelling; (3) presence of striations, polish and residues; and (at high magnification): (4) use-polish brightness; (5) use-polish development; (6) use-polish coverage; (7) use-polish morphology; (8) presence of micro-striations, (9) presence of grain fractures, including negative flake scars, referred to here as “micro-fractures” or “micro-scarring”, and (10) presence of residues (Section 5.4.3; Table 5.2). Use-polish morphology described as “un-diagnostic” refers to a stage of use-polish formation that, on its own, is not diagnostic of material worked. Such use-polish may also be described as “weakly developed” with a “localised” distribution.

The following sections describe the experimental design, materials processed and key use-wear features observed. Results of this experimental regime are compared with previous experimental data sets. The primary research objective of this study was to determine the key distinctive use-wear features but also included description of related residues for each task.

6.2.3 Results: tool-use experiments

The use-wear exhibited on each of the experimental artefacts is summarised in Table B3 (Appendix B); the range of use-wear traces by worked material and mode of use is presented in Table 6.7. The specific use-wear traces are described and illustrated in the following sections, and have been grouped below according to the materials that were ground or otherwise processed.

6.2.3.1 Bone grinding

Three bone grinding experiments were carried out using four experimental artefacts. The first two experiments (Experiments 1 and 2) involved the use of stone “files” (filing tools) made from different sandstones that were used to shape fresh Kangaroo (*Macropus fuliginosus*) femur bones. The bones were ground in a backwards and forwards motion for a total of two hours each (Plate 1a-b). Macroscopic observations were recorded after every 20 min of use, with high magnification observations recorded after 2 hours. EGS 3 (made from the softer Bundanoon sandstone) displayed a macroscopically visible groove after 20 min, which continued to become deeper and more clearly defined as grinding continued. After two hours, the artefact displayed a deep, highly smoothed groove with uni-directional, macroscopic striations following the length of the groove (Plate 6.2a).



Plate 6.1a-d: Experimental bone processing tools: **a)** Experiment 1: EGS 3 sharpening kangaroo femur bone; **b)** Experiment 2: EGS 5 sharpening kangaroo femur bone; **c-d)** Experiment 3: pounding kangaroo bone with EGS 34 (upper stone) and EGS 20 (lower stone).

At low magnification, bone fragments in the form of white crystal structures (i.e., apatite and collagen) were documented within the groove and were commonly restricted to the interstitial spaces of the sandstone (Plate 6.2b). The sandstone grains were not levelled except at several locations within the groove, where grains also appeared highly rounded (Plate 6.2d). At high magnification, the use-polish appeared dull, weakly developed and was un-diagnostic of the worked material (Plate 6.2c; e-f). The lack of distinctive bone processing use-wear is probably related to the nature of the sandstone file, which was made of the relatively soft Bundanoon sandstone. During

grinding, the constituent grains and sandstone matrix were continually eroded before the bone was able to make sufficient contact to generate diagnostic use-wear traces visible at high magnifications.

The use-wear displayed on EGS 5 (made from the harder quartzite stone—Plate 6.3a), which was used to process kangaroo femur bone for the same duration, did not display macroscopically visible striations or a visible groove, although other distinctive surface features were present. At low magnification, quartz grains appeared smooth, slightly levelled with moderate to high edge rounding (Plate 3b). Powdery white bone tissue was abundant over the used artefact surface but the diagnostic characteristics of bone tissue were not visible at low magnification. At high magnification, the artefact displayed a moderately bright use-polish with a well-defined, smooth and pitted morphology, coupled with numerous linear micro-striations that had created a “smeared” or striated appearance (Plate 6.3c-f). Distinctive bone residues were present in the form of greasy white bundles and angular crystals (Plate 6.3e). The apparent differences in the development of use-wear on each of these tools are likely the outcome of variable hardness of each sandstone implement. The constituent grains within the harder sandstone were less likely to be removed during the grinding activity and therefore would have been in contact with the bone for a longer duration, allowing increased development and distinctiveness of the wear.

The third bone working experiment (Experiment 3) involved the use of two experimental grinding stones (one used as an anvil and the other used as a hammerstone) used to pound fresh kangaroo femur bone for 30 min (Plate 6.1c-d). This procedure was carried out to replicate marrow extraction from the fresh kangaroo bone—an activity that is ethnographically documented among Australian Aboriginals (e.g., Peterson 1968: 367). Following use, both the anvil (EGS 20) and the pounding stone (EGS 34) were observed under high and low magnifications (Plate 6.44a-h). Macroscopically, bone, blood and marrow residues were visible on the artefact surfaces. These occurred as thick, layered deposits, primarily consisting of bone and marrow. Following the removal of these residues through gentle agitation and rinsing, low magnification observations of the artefact surface (using a Dino-Lite™ and stereo-microscope) indicated bone tissue in the form of white crystals and greasy white bundles firmly attached to the stone surface (Plate 6.4b). On EGS 20 (anvil stone), quartz grains appeared to be moderately levelled with slight to moderate rounding, but striations were not visible (Plate 6.4c). High magnification observations made on the PVS peels from the used surface of EGS 20 indicated use-polish was present but only on the highest peaks of each quartz grain, with a rough-pitted micro-topography accompanied by a low number of micro-striations (Plate 6.4f). Micro-fractures occurring on individual grains were common (Plate 6.4d) but these were also observed on the eroded cortex of the unused surface and therefore may not always

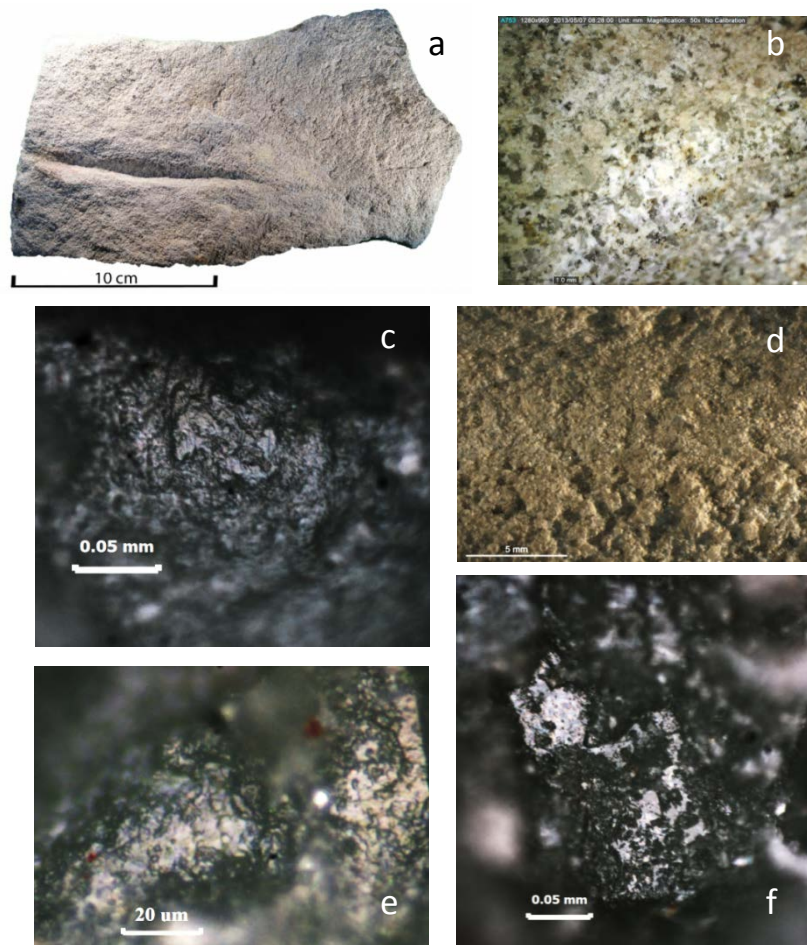


Plate 6.2a-f: Experiment 1 artefact image and use-wear: grinding bone: **a)** EGS 3 with macroscopically visible groove; **b)** Dino-Lite™ surface image of groove showing residue accumulation within the quartz grains; **d)** low magnification surface image showing minimal grain rounding and levelling; **c, e-f)** weakly developed use-polish with slightly domed but mostly un-diagnostic morphology.

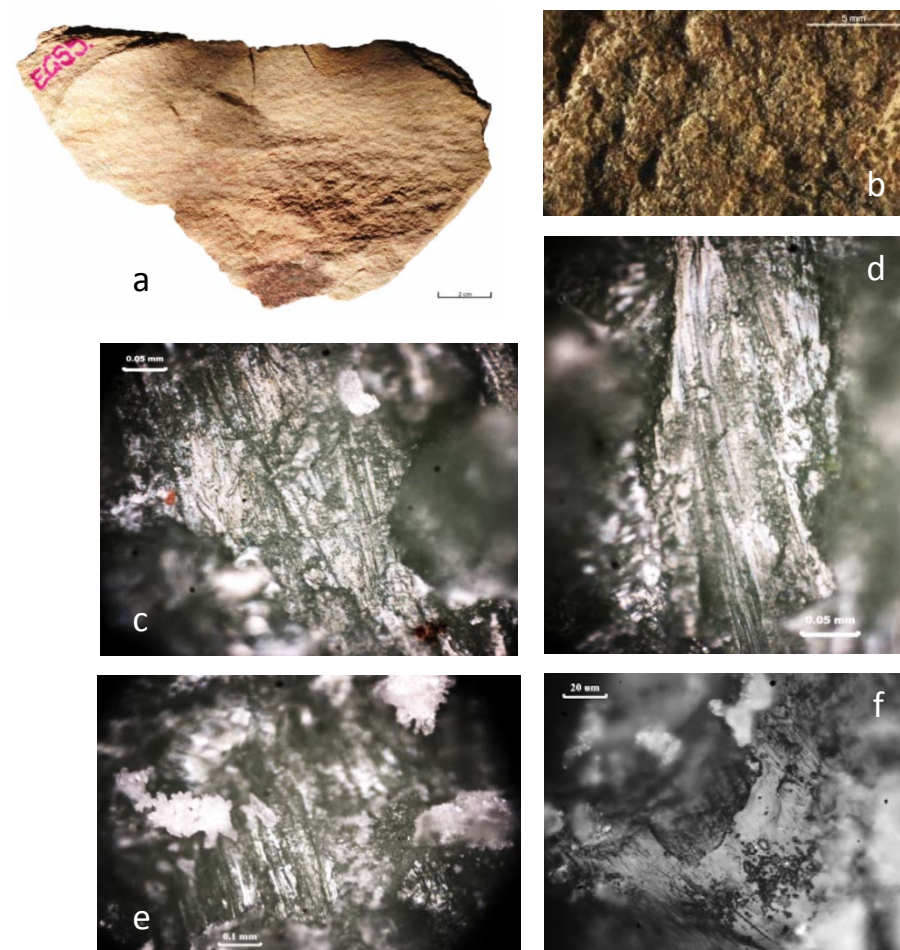


Plate 6.3a-f: Experiment 2 artefact image and use-wear: grinding bone: **a)** EGS 5; **b)** low magnification surface image showing slightly levelled and moderately to highly rounded quartz grains; **c-d)** moderately bright use-polish with a well-defined, smooth-pitted morphology and numerous linear micro-striae **e)** use-polish with greasy white bundles *cf.* bone; **f)** flake scar interrupting smooth-pitted polish.

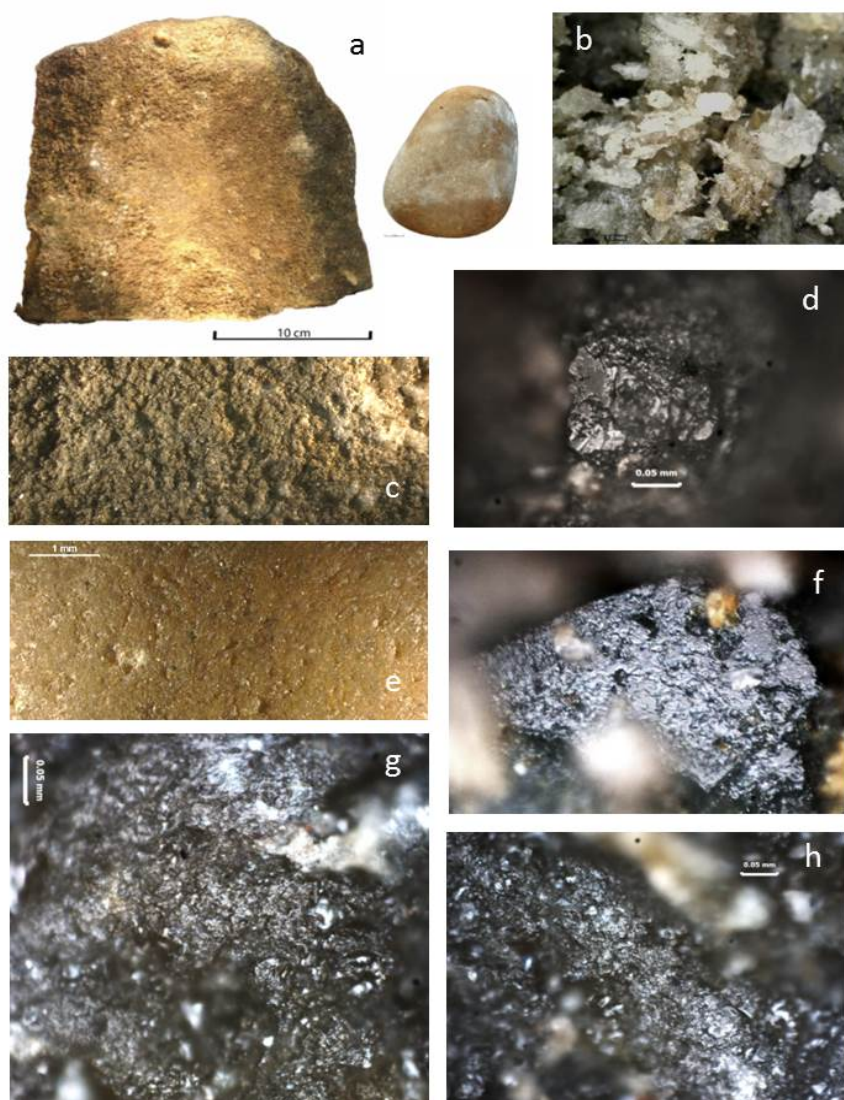


Plate 6.4a-h: Experiment 3 artefact images and use-wear: pounding bone: **a)** EGS 20 (lower stone) and EGS 34 (upper stone); **b)** Dino-Lite™ image of surface EGS 20 showing the build-up of bone residues (white bundles); **c)** low-magnification image of EGS 20 showing slight to moderately rounded quartz grains with moderate surface levelling; **d)** micro-scar on quartz grain, EGS 20; **e)** low magnification image of EGS 20 showing a high degree of grain rounding and surface levelling; **f)** rough-pitted use-polish, EGS 20; **g-h)** rough surface use-polish, EGS 34.

represent use-related wear. The higher frequency of micro-fractures on the ground surface, however, suggests that many are related to use, but these were difficult to distinguish. Low magnification observations made on EGS 34 revealed a high level of grain rounding and surface levelling (Plate 6.4e) with macroscopic striations visible under appropriate lighting conditions. At high magnification, the use-polish displayed a moderate coverage with a rough morphology of the micro-topography (Plate 6.4g-h).

6.2.3.2 Wood grinding

Two wood grinding experiments were carried out using two grinding stones of different hardness (EGS 2 and EGS 4—Experiments 4 and 5). The artefacts were used to abrade freshly cut

mulga (*Acacia* sp.—an Australian hardwood), for two hours, acting as files to shape and grind the wood (Plate 6.5a-b). Both of the artefacts proved to be very effective at abrading the wood, although each displayed very different macroscopic surface features, both during and after use. EGS 4, made of the loosely-cemented Bundanoon Hawkesbury sandstone, sustained a macroscopically visible groove after 40 min (Plate 6.6a). This groove became increasingly deeper as grinding continued, and smoothing became macroscopically visible on the highest exposed quartz grains within the groove. After 2 hours, macroscopic and low magnification striations were visible along the length of the groove (Plate 6.6b), oriented along its axis. Individual grains were only slightly levelled with moderately rounded edges. Residues within the groove appeared as flaky, light brown smeared deposits (Plate 6.6c). At high magnification, weakly developed use-polish, only visible on the highest grain micro-topographies, generally displayed morphology that was un-diagnostic of wood working. However, in several locations, where use-polish appeared more developed, a slightly undulating/reticular use-polish texture was visible, sometimes accompanied with micro-striations (Plate 6.6d-g). Only several, isolated occurrences of micro-fracturing occurred on some of the grains.



Plate 6.5a-b: Experimental wood (*Acacia* sp.) processing tools: **a)** Experiment 4: EGS 2 sharpening hardwood; **b)** Experiment 5: EGS 4 sharpening hardwood.

Wood was ground along a natural groove present on the surface of EGS 2 (Plate 6.7a). Along the contact surface, macroscopic and low magnification striations formed parallel to the direction of use, and a waxy coating appeared along the natural groove. At low magnification, grains displayed more intensive wear, with highly rounded and moderately levelled surfaces (Plate 6.7b). At high magnification, micro-fractures were extremely common on individual grains (Plate 6.7c), and abundant woody residues were visible in the form of fine powder and, less commonly, individual twisted fibres. The use-polish in the groove of this artefact was, for the most part, only weakly developed. However, in some isolated patches along the groove, use-polish appeared bright, better developed and displayed a domed surface and reticular morphology (Plate 6.7e-f). Micro-striations were also visible on the use-polished surface (Plate 6.7d).

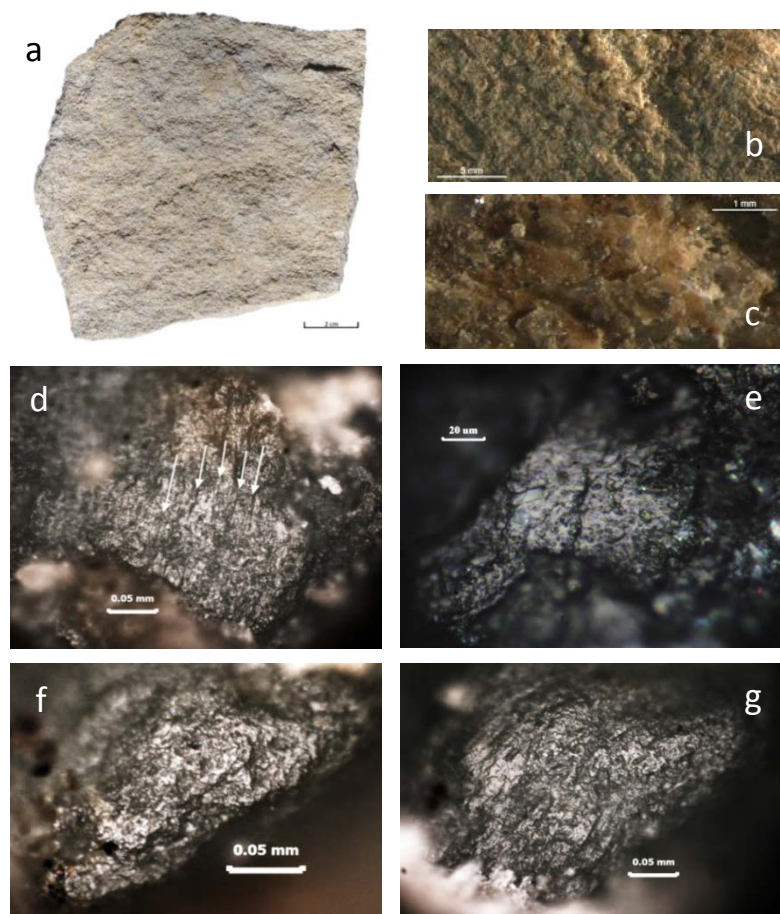


Plate 6.6a-g: Experiment 4 artefact image and use-wear: grinding hardwood. **a)** EGS 4 (pre-use) **b)** low-magnification image of groove with visible striations of a singular orientation; **c)** low-magnification image inside the groove: individual quartz grains are slightly levelled with moderately rounded edges; residues occur as flaky, light brown smeared deposits; **d-g)** high magnification images of surface use-polish, displaying a domed and a slightly reticular morphology. The use-polish appears localised and moderately bright.

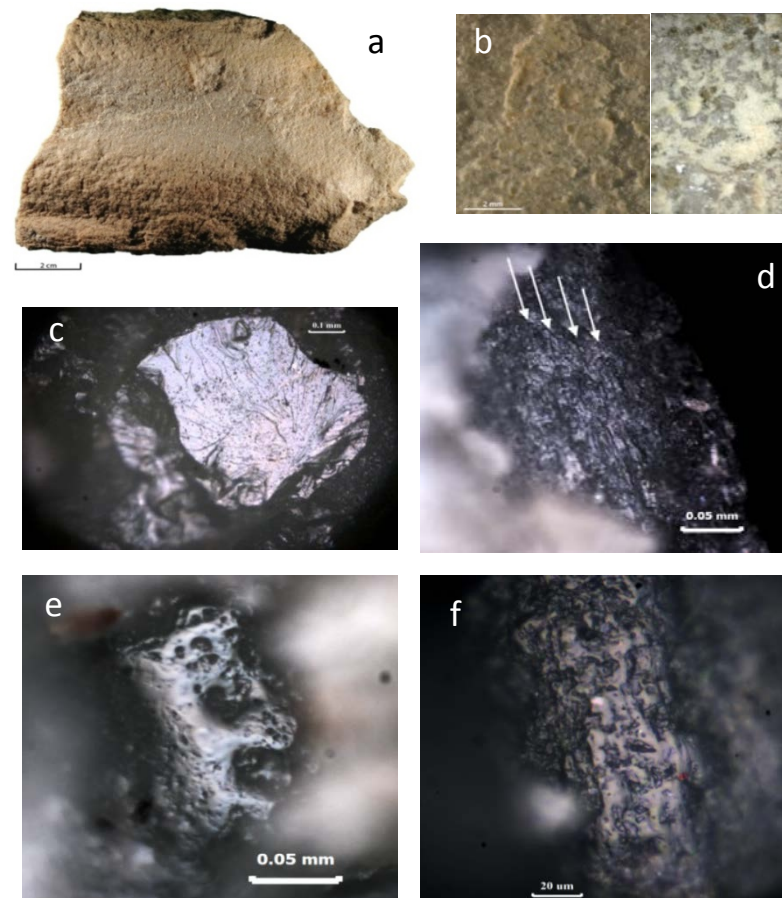


Plate 6.7a-f: Experiment 5 artefact and use-wear: grinding hardwood. **a)** EGS 2 (post-use); **b)** low-magnification image of utilised surface – quartz grains are highly rounded with moderate levelling and parallel striations are visible in the direction of use. A waxy coating is also present on the surface; **c)** micro-scar on quartz grain; **d)** parallel striations in the direction of use; **e-f)** domed, reticular use-polish with micro-pitting.

6.2.3.3 Native Australian seed processing

Six seed grinding experiments were undertaken using 12 coupled stones that were partnered and used as a dedicated pair (Table 6.5). Each couple consisted of a large millstone or mortar (lower stones) and one smaller hand-stone or pestle (upper stones) of the same or similar stone material. The seed grinding experiments included the dry milling of kangaroo grass (*Themeda australis*) seeds (Experiment 6); the dry and wet milling of warrego grass (*Setaria jubiflora*) seeds (Experiments 7 and 8); the dry and wet pounding of *Acacia* (*Acacia decora* – western golden wattle) seeds (Experiments 9 and 10); and the dry pounding of kurrajong (*Brachychiton sp.*) seeds (Experiment 11) (Plate 6.8). The seeds selected for these experiments were chosen because they represent different varieties of hard and soft seeds, and were easily obtainable—either through field collection or purchase). The processing of many tree, shrub, grass, and other seed producing species has been ethnographically documented in Australia (e.g., Cleland & Tindale 1954: 63; Gould *et al.* 1971; Latz 1995: 49-55; Meggitt 1957: 143; O’Connell & Hawkes 1981). Each pair of artefacts was used to process the seeds in either a pounding or backwards and forwards grinding motion in order to produce fine meal or to remove the husk (hard outer seed coating). The processing times varied for each artefact and seed variety (Table 6.5) but each tool was used for a minimum of 90 min. One pair of grinding tools (EGS 12 and EGS 28) was used for a maximum of four hours. Wear traces were examined at both low and high magnification by direct viewing on the artefact surfaces and on the PVS peels taken at regular intervals (Table B2).

Experiment 6 involved the dry-milling of Kangaroo Grass seeds for 90 min using Hawkesbury sandstone (EGS 16) and sandstone collected from Jemalong Ridge (EGS 29) (Plate 6.9a). Following use, macroscopically visible striations occurred across the surface of EGS 16, where low magnification observations indicated moderately to highly rounded quartz grains, with only slight levelling (Plate 6.9c). Plant fibres were abundant within the interstitial spaces between grains. At high magnification, use-polished zones were restricted to the highest exposed quartz grains, and appeared bright, moderately developed, moderately extensive, and reticular in morphology (Plate 6.9b, e). Micro-striations, however, were not common. Low magnification use-wear on the accompanying experimental upper stone (EGS 29) appeared far more developed than the use-wear on EGS 16, with highly levelled and highly rounded quartz grains composing large patches of wear (Plate 6.9d). Fine striations and small, string-like plant fibres were visible both macroscopically and at low magnification. At high magnification, however, use-polish was visible across most of the artefact surface but was often only weakly developed with an irregular (i.e., non-uniform, highly localised) surface coverage. On the highest grains, however, where grains appear highly levelled, a

bright use-polish had developed with a reticular morphology (Plate 6.9f-g). Micro-striations were present within the use-polished surface (Plate 6.9g).



Plate 6.8a-h: Experimental seed processing tools: **a-b)** Exp. 7: EGS 12 (lower stone – LS) and EGS 28 (upper stone – US) milling Warrego grass seed; **c)** Exp. 8: EGS 33 (LS) and EGS 31 (US) wet milling Warrego grass seed; **d)** Exp. 9: EGS 32 (LS) and EGS 23 (US) pounding (dry) Acacia seed; **e-f)** Exp. 11: EGS 19 (LS) and EGS 24 (US) pounding Kurrajong seed; **g)** Exp. 10: EGS 17 (LS) and EGS 25 (US) milling soaked Acacia seed; **h)** Exp. 12: EGS 15 (LS) and EGS 1 (US) grinding wheat.

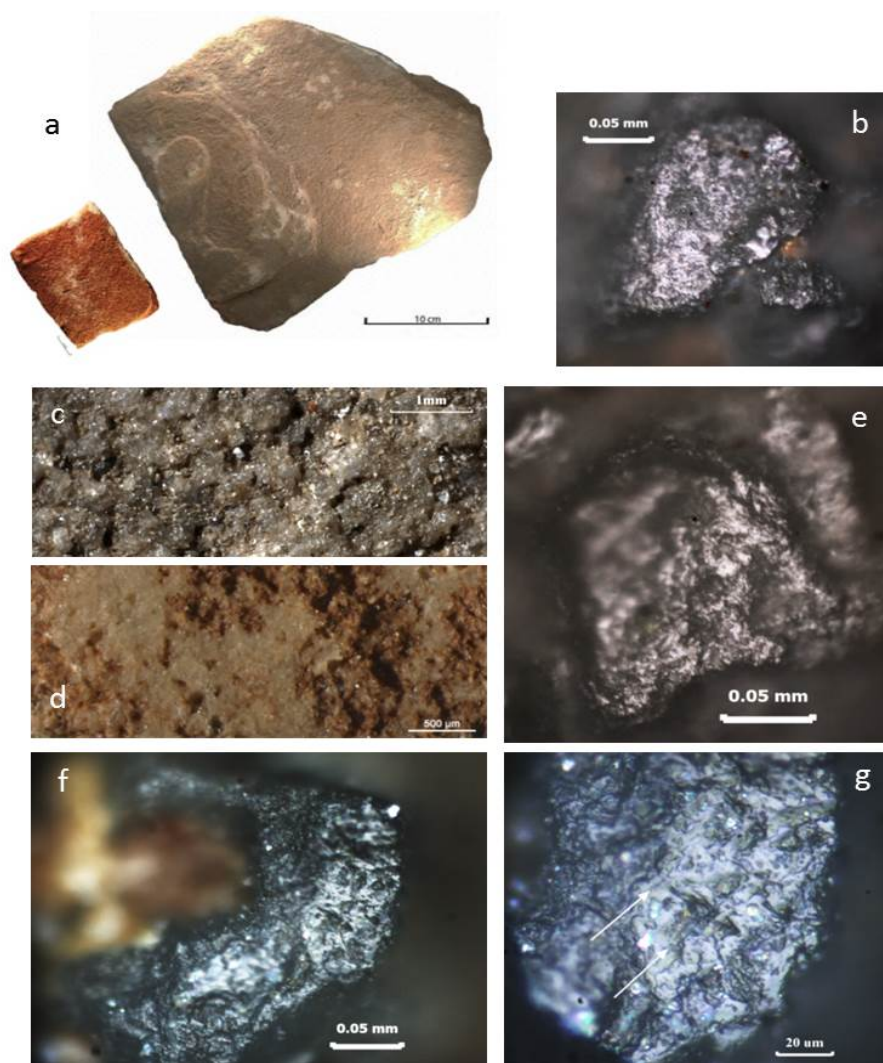


Plate 6.9a-g: Experiment 6 artefact images and use-wear: seed grinding (kangaroo grass): **a)** EGS 16 (lower stone) and EGS 29 (upper stone); **b, e)** use-polish on the highest grains displaying a bright, moderately extensive, reticular morphology, EGS 16; **c)** low magnification image showing moderately to highly rounded quartz grains but minimal grain levelling, EGS 16; **d)** low magnification surface image showing highly levelled, highly rounded grains, EGS 29; **f-g)** use-polish with a bright, reticular morphology, EGS 29.

Experiment 7 involved both the dry and wet milling of warrego grass seed for a total of four hours using EGS 12 (lower stone) and EGS 28 (upper stone) (Plate 6.10a). The seeds were firstly processed dry using a backwards and forwards grinding motion for a total of three hours. Water was then added so that the use-wear from processing wet versus dry seed could be evaluated. PVS peels were sampled from both EGS 12 and EGS 28 at regular intervals so that the development of wear could be documented over time. Low magnification use-wear developed faster on the smaller upper stone, where highly levelled, highly rounded grains were evident after the first hour of grinding. The grains of EGS 12, however, were only levelled in the regions of the highest topography. The degree of levelling and grain rounding became more intensive and more uniform on both stones as grinding continued. After 240 min (four hours), both stones displayed highly levelled, highly rounded surface grains, visible at low magnifications (Plate 6.10c-d). On the surface of EGS 12, plant fibres were visible within the interstitial spaces (Plate 6.10c), and on EGS 28, directionality was evident in the form of fine striations across quartz grains. At high magnification, the use-polish on both artefacts



Plate 6.10a-g: Experiment 7 artefact images and use-wear: seed grinding (warrego grass): **a)** EGS 12 (lower stone) and EGS 28 (upper stone); **b)** high magnification image showing bright, well-developed reticular use-polish and micro-striations, EGS 12; **c)** low magnification image showing highly levelled, highly rounded quartz grains and plant fibres, EGS 12; **d)** low magnification surface image showing highly levelled, highly rounded quartz grains, EGS 28; **e-g)** high magnification images showing a bright, well-developed, reticular use-polish, EGS 28.

was bright, with a well-developed, reticular morphology (Plate 6.10b, d-g). Very fine, micro-striations were only visible occasionally on some use-polished regions (Plate 6.10b). While wear at each stage of development was similar, the degree of grain levelling, grain rounding and use-polish became more developed, with high connectivity of use-polished patches as the milling process continued. The observed use-wear is consistent with other experimental grinding studies involving stone-on-stone action and an intermediate material (e.g., Adams 1989a; Fullagar *et al.* 2012).

Experiment 8 also involved the wet and dry milling of warrego seed but a different sandstone material (Jemalong Ridge sandstone) was used and seeds were only processed for a total of 150 min. Two top stones were used in the course of this experiment, the first, EGS 30 (made of Bundanoon Hawkesbury sandstone), wore down rapidly and was discontinued, subsequently replaced with EGS 33 (Jemalong Ridge sandstone). Both upper stones were used in conjunction with a lower stone—EGS 31—made from Jemalong Ridge sandstone. After use, EGS 31 and EGS 33 (Plate

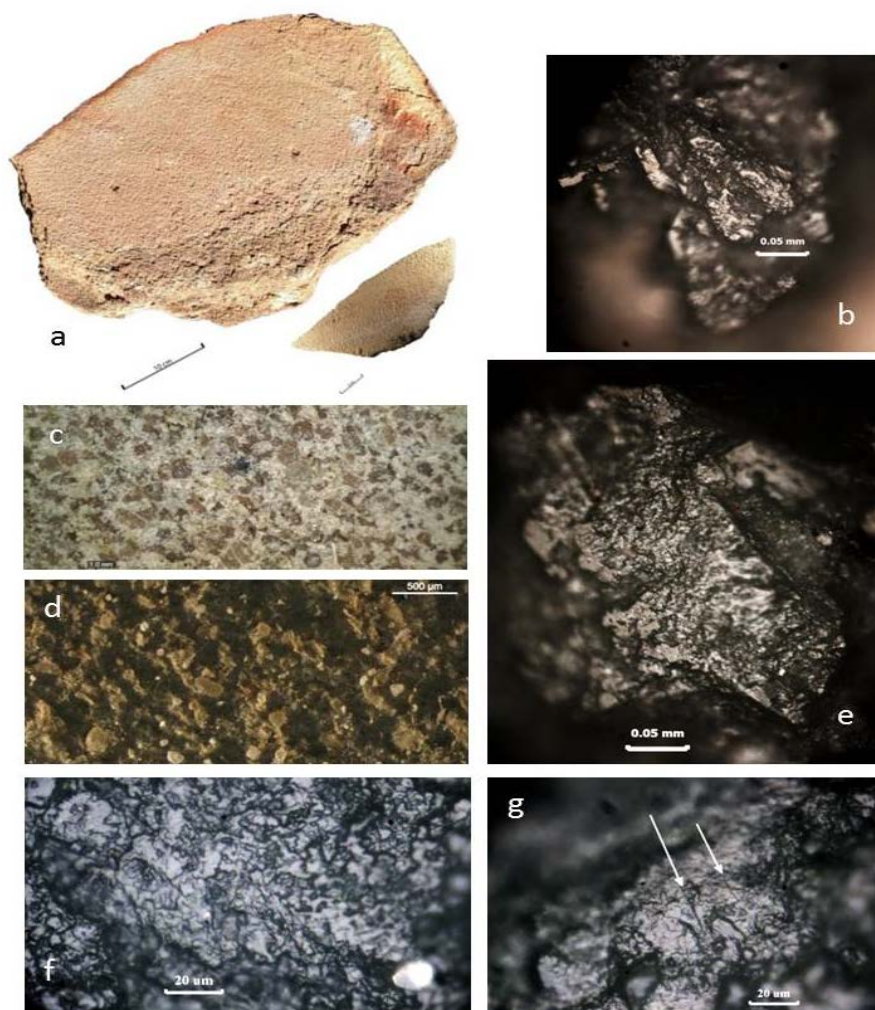


Plate 6.11a-g: Experiment 8 artefact images and use-wear: seed grinding (warrego grass): **a)** EGS 31 (lower stone) and EGS 33 (upper stone); **b)** high magnification image showing localised use-polish on the highest quartz grain micro-topographies, EGS 33 **c)** low magnification image showing highly levelled, moderately rounded quartz grains, EGS 31; **d)** low magnification image displaying minimal grain levelling and only moderately rounded quartz grains, EGS 33; **e)** use-polish and micro-scarring on quartz grain, EGS 33; **f)** high magnification image of domed use-polish, EGS 31; **g)** high magnification images showing use-polish and fine micro-striations, EGS 31.

6.11a) were examined for use-wear features. At low magnification, artefact EGS 31 displayed highly levelled and moderately rounded quartz grains, while EGS 33 displayed only slightly levelled and rounded grains (Plate 6.11c-d). Woody plant fibres are abundant on both grinding surfaces where seed husks had been crushed and ground. At high magnification, fractures were visible on some of the grains (Plate 6.11e), but use-polish was only weakly developed, localised on the highest elevations of the surface grains and un-diagnostic of worked material (Plate 6.11b). In several localised patches, use-polish had an undulating surface texture, appearing reticular with brighter use-polish on the highest points of the grain (Plate 6.11f). Micro-striations were rare, and characterised by shallow, short alignments (Plate 6.11g).

Unlike the Experiments 6, 7 and 8, where seeds were processed in a backwards and forwards grinding motion, Experiments 9, 10 and 11 involved the processing of seeds via pounding and crushing/rolling actions. Each experiment consisted of a lower stone (mortar or anvil) and an

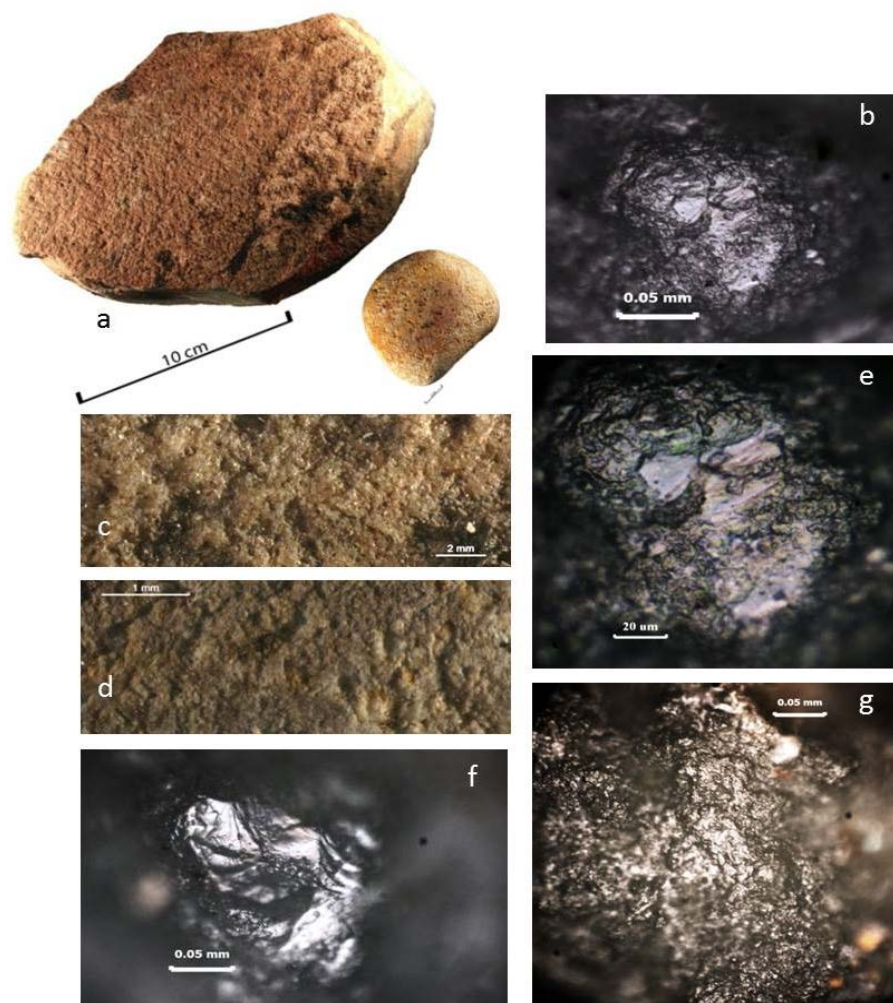


Plate 6.12a-g: Experiment 9 artefact images and use-wear: dry seed grinding/pounding (*Acacia*): **a)** EGS 32 (lower stone) and EGS 23 (upper stone); **b, e)** high magnification images showing a bright but disconnected, undulating (domed) use-polish, EGS 32; **c)** low magnification surface image showing slight to moderate rounding with minimal surface levelling, EGS 32 **d)** low magnification surface image of EGS 23; **f)** micro-scar on quartz grain, EGS 32; **g)** high magnification image showing bright use-polish, EGS 23.

upper stone (pounding stone or pestle) used to pound both dry and wet *Acacia* seed and dry kurrajong seed, respectively. After the experiments, each artefact was examined for traces of use. Large residue accumulations were visible on experimental artefacts EGS 32 and EGS 23 (Plate 6.12a), which were used to crush dry *Acacia* seed for 120 min. These included thick deposits of crushed seed husk and clear, string-like plant fibres comprising a mixture of cellulose and lignin. Quartz grains present on EGS 32 (lower stone) displayed only slight to moderate rounding with only slight levelling (Plate 6.12c). Hammer damage (crushing and pitting) was present across the entire used surface where the upper stone (EGS 23) had come into contact with the lower stone. At high magnification, these contact areas typically had frequent negative scars across individual grains (Plate 6.12f) and a bright, disconnected and undulating (domed) use-polish, visible on the highest grains (Plate 6.12b, e). Wear on EGS 23 displayed moderately levelled, moderately rounded grains and striations, visible under low magnification. These striations were typically short and oriented in multiple directions. Use-polish was of similar morphology to that of EGS 32, although less developed

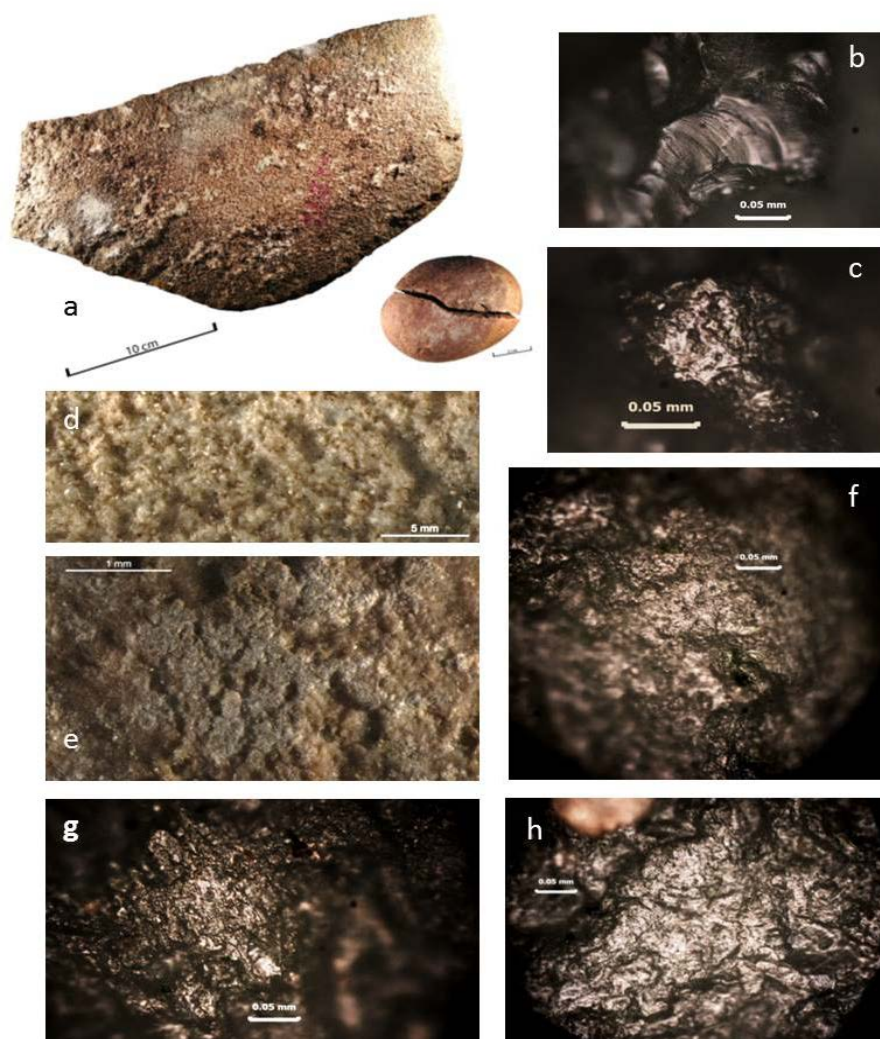


Plate 6.13a-h: Experiment 10 artefact image and use-wear: soaked seed (*Acacia*) grinding and pounding. **a)** EGS 17 (lower stone) and EGS 25 (upper stone); **b)** micro-scar on quartz grain; EGS 17 **c)** use-polish on EGS 25; **d)** low magnification image showing minimal surface levelling and moderately rounded quartz grains; GS 17; **e)** low magnification image showing highly rounded quartz grains and moderate surface levelling and striations, EGS 25; **f-h)** high magnification image of reticular use-polish, EGS 25.

and restricted to only a few small areas (Plate 6.12g). Negative flake scarring, however, was much less frequent across individual grains than on other experimental artefacts. Experiment 10 also involved the pounding and grinding of *Acacia* seed for a total of 120 min using artefacts EGS 17 and EGS 25 (Plate 6.13a). Prior to processing, *Acacia* seeds were soaked overnight to soften the hard outer seed husk. Following use, EGS 17 (lower stone) displayed only slightly levelled and moderately rounded grains at low magnification, with several large spaces where surface grains had been removed or “plucked” (Plate 6.13d). At high magnification, negative fractures were common on individual grains but there was no diagnostic use-polish (Plate 6.13b).

EGS 25, which split during use as a result of contact with the lower stone, displayed more intensive use-wear than that of EGS 17. Crushed seed particles were abundant across the artefact surface. These residues appeared on both the used and unused surfaces. Macroscopic pitting was visible on the stone where pounding took place. At low magnification, grains appeared highly

rounded with moderate levelling, and striations were abundant (Plate 6.13e). At high magnification, a bright, moderately developed, reticulated use-polish occurred across the surface (Plate 6.13c, f-h). Fine, uni-directional micro-striations were also identified across this surface.

The final seed grinding experiment involved the pounding of soaked kurrajong seed for a total of 60 min, using EGS 19 (lower stone) and EGS 24 (upper stone) (Plate 6.14a). Following use, macroscopically visible seed residues were common, wedged between interstitial spaces and in thick, flaky accumulations across both contact surfaces (Plates 6.14c-d). Quartz grains on both utilised surfaces appeared angular, with only occasional grain levelling. Large impact fractures were visible at low magnification on both utilised surfaces. Micro-scarring of individual grains was commonly observed at high magnification, but striations were absent (Plates 6.14b, e). Use-polish in most regions was not distinctive except for several localised zones, where grain reflectivity was higher, caused by smoothing of the highest peaks of the individual grains (Plates 6.14f-g). This use-polish, however, is only weakly developed and not diagnostic of seed grinding.

The first three seed grinding experiments (Experiments 6, 7 and 8) provided the most distinctive and diagnostic examples of seed grinding use-polish. Constant contact with the seed and the artefact ensured the development of use-wear. While the other artefacts involved with Experiments 9 and 10 also displayed a reticulated use-polish, this was not as well developed and fracturing of quartz grains was more common—probably the result of the specific use-action (pounding) of the tool.

6.2.3.4 Wheat grinding

Two experimental grinding tools (EGS 15 and EGS 1—Experiment 12) were used to process commercially purchased wheat (*Triticum* sp.) (Plate 6.15a). Wheat kernels were pounded and then ground for ~45 min following 30 min of stone preparation (stone-on-stone working to get the surface topography even) (Plate 6.8h). PVS peels were gathered before and after this initial stage of surface preparation, and again after 45 min of wheat grinding.

The wear present on the PVS peel sampled from EGS 15 after 30 min of stone-on-stone working was in the form of a moderately bright, moderately extensive use-polish restricted to the highest grains. Striations and micro-fractures were common on grain surfaces. The wear on PVS peels from both the upper and lower stones (EGS 15 and EGS 1) after 45 min of wheat grinding was comparable to the wear on the seed grinding implements (Experiments 6 – 12—Plates 6.9 – 6.14).

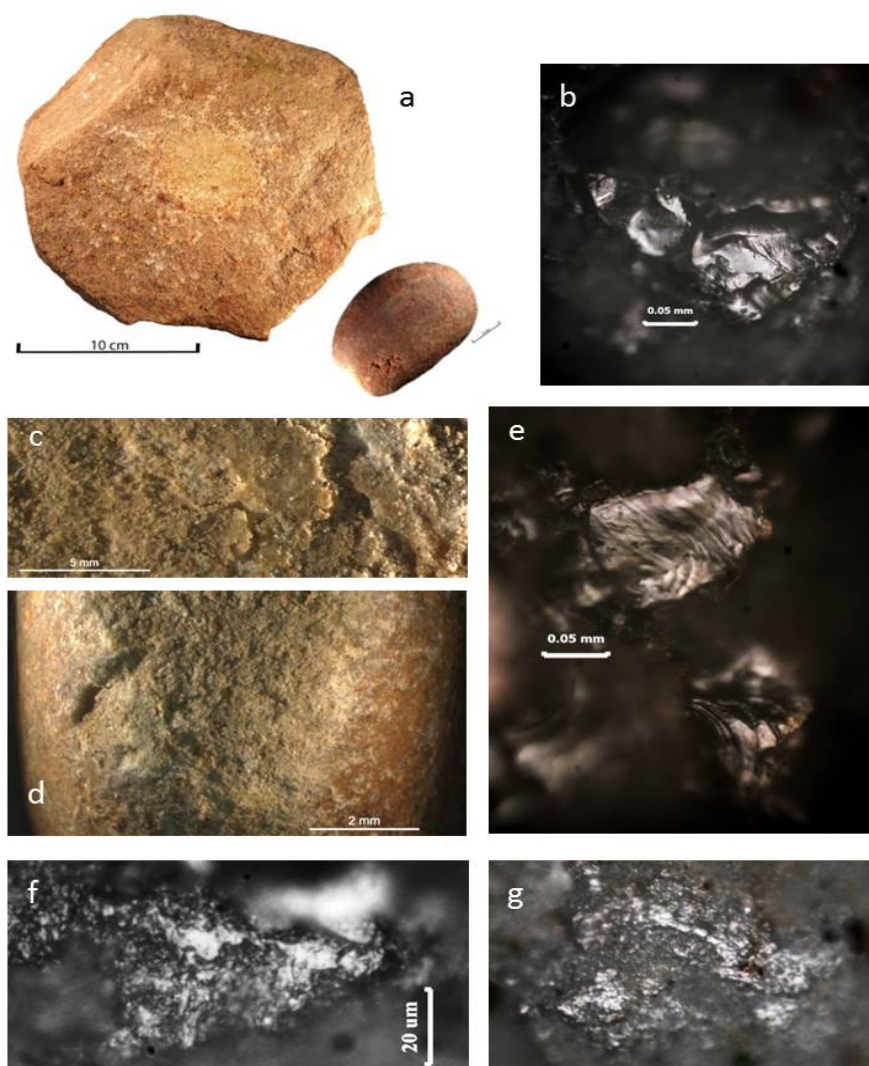


Plate 6.14a-g: Experiment 11 artefact images and use-wear: seed pounding (kurrajong seed): **a)** EGS 19 (lower stone) and EGS 24 (upper stone); **b)** micro-scarring on quartz grain, EGS 19; **c)** low magnification image of residue accumulation, EGS 19; **d)** low magnification image showing hammer damage and residue accumulation, EGS 24; **e)** micro-scarring on quartz grain, EGS 24; **f-g)** high magnification images of localised use-polish, EGS 24.

At low magnification, grains on the surface of EGS 15 appeared highly levelled and rounded, often with striations (Plate 6.15c). At high magnification, use-polish on EGS 15 appeared moderately bright with a reticular morphology, but less developed than on the seed grinding implements (Plate 6.15d). Micro-striations in the use-polished surface appeared as fine, parallel alignments (Plate 6.15b). EGS 1 displayed less distinctive micro-wear at both stages of use. The PVS peel, sampled after 30 min stone-on-stone grinding, displayed un-diagnostic use-polish morphology that was sometimes accompanied by fine micro-striations of similar orientation. After an additional 45 min of wheat grinding, woody residues were visible at both high and low magnifications, in the form of fibres, some layered with a characteristic rigid structure, and others clear and string-like. At low magnification, grains appeared highly levelled and moderately rounded, with striations, also visible macroscopically (Plate 6.15e). At high magnification, use-polish typically appeared weakly developed with an un-diagnostic, disconnected morphology. In several isolated regions, use-polish was

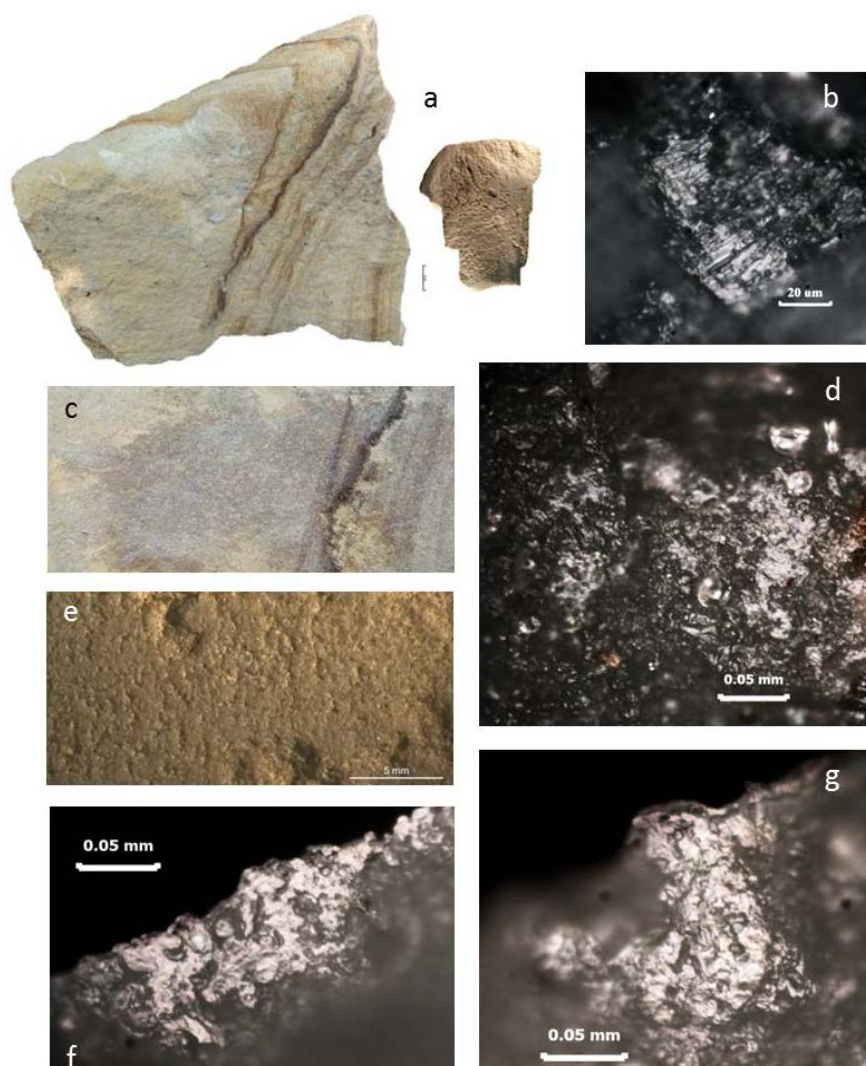


Plate 6.15a-g: Experiment 12 artefact images and use-wear: wheat grinding: **a)** EGS 15 (lower stone) and EGS 1 (upper stone); **b)** high magnification image showing a striated use-polish with conspicuous unidirectional striations, EGS 15; **c)** low magnification image showing a highly levelled surface topography and highly rounded quartz grains, EGS 15 **d)** high magnification image showing moderately bright, reticular use-polish, EGS 15 **e)** low magnification image showing highly levelled and rounded quartz grains, EGS 1; **f-g)** high magnification image showing a bright, reticular use-polish, EGS 1.

developed, bright, and reticular in morphology, with common micro-striations (Plate 6.15f-g). These regions of more developed use-polish formed on the highest, most intensively levelled grains.

6.2.3.5 Axe grinding

Three axe grinding experiments were conducted on two grinding slabs of different sandstone varieties: the weakly cemented, highly abrasive Bundanoon Hawkesbury sandstone (EGS 13) and the much harder, finer-grained Kimberley sandstone (EGS 18) (Plate 6.16a-c). The latter sandstone (Plate 6.17a) was used to shape and sharpen the edge of a flaked basalt biface to make a ground-edge axe. After adding water and sand, the axe was ground at the edges for ~60 min in a circular motion. Following use, the grinding stone was examined for key use-wear features. At low magnification, grains appeared highly levelled with moderate edge rounding and common,

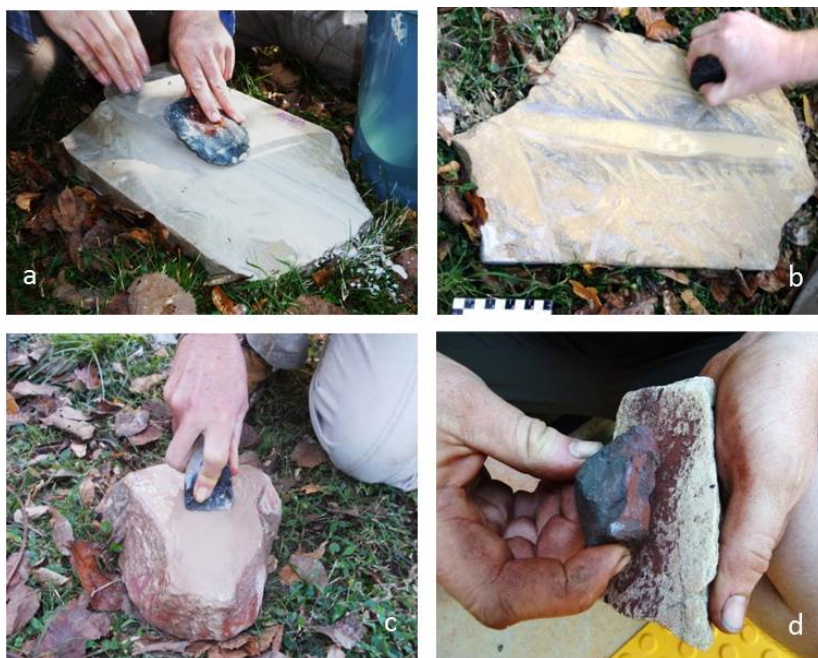


Plate 6.16a-d: Experimental stone and haematite processing tools: **a)** Experiment 15: EGS 13 Surface 2: shaping a dolerite axe; **b)** Experiment 14: EGS 13 Surface 1: shaping a basalt axe; **c)** Experiment 16: EGS 18 shaping a basalt axe; **d)** Experiment 18: EGS 35 grinding haematite.

multi-directional striations visible under the stereomicroscope (Plate 6.17b). At high magnification, use-polish appeared bright, developed and extensive with a reticulated morphology (Plate 6.17c, e). Micro-striations were common, typically occurring in parallel alignments of varying depth (Plate 6.17d, f, h). Micro-scarring of quartz grains occurred frequently across the ground surface (Plate 6.17g). Residues were not visible apart from fine chalk-like powder resulting from stone-on-stone abrasion.

Because this particular sandstone is inherently hard and well cemented, the effectiveness of this grinding implement for axe grinding was poor. However, following the introduction of additional abrasive particles (sand) the grinding proceeded more rapidly. Conversely, artefact EGS 13, which is comprised of the weakly cemented Hawkesbury sandstone, was very effective at sharpening the axe edges, and, for this reason, both surfaces were used to sharpen two different volcanic varieties of stone axe: Surface 1 (Plate 6.18b) was used to grind a basalt axe, and Surface 2 (Plate 6.18a) was used to grind a dolerite axe (Plate 6.18c). Both axes were sharpened in a backwards and forwards motion while continually adding water to the grinding surface following the methods of Dickson (1972). The basalt axe (sharpened on Surface 1) was ground for a total of 80 min while the dolerite axe (used on Surface 2) was ground for 60 min. Almost immediately the sandstone grinding slab began to show traces of wear as the surfaces were quickly worn down, forming deep grooves. The size of these grooves differed across both surfaces only because of the varying angles used to sharpen each axe. At low magnification, both grooves displayed highly

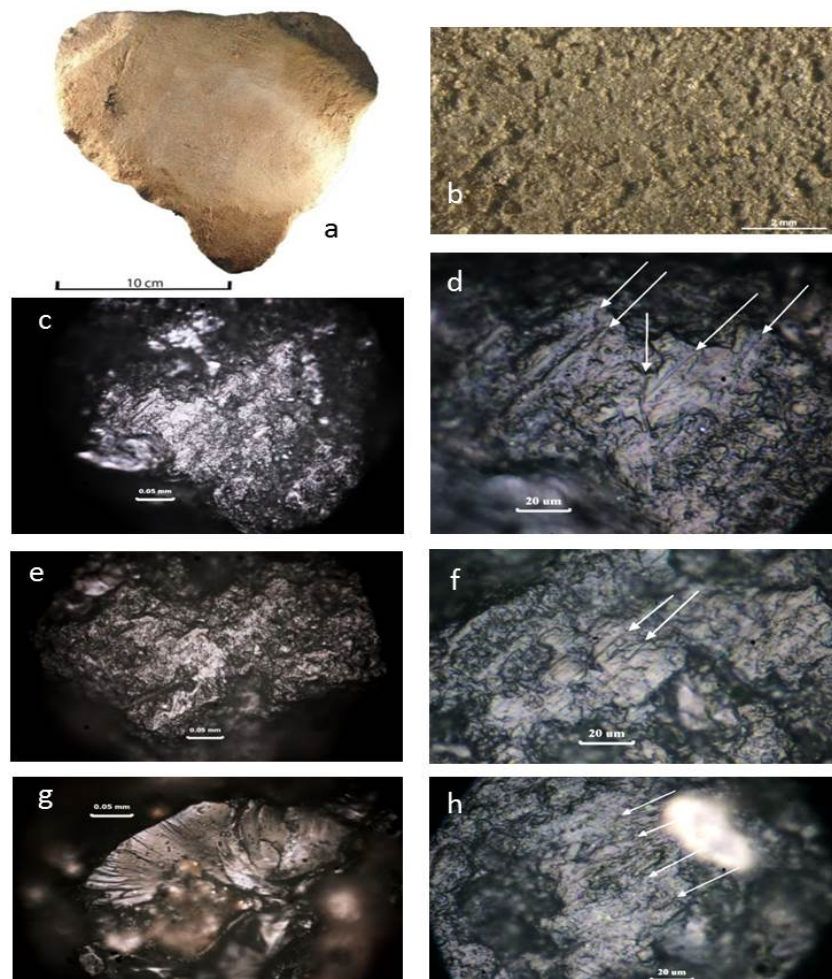


Plate 6.17a-h: Experiment 16 artefact image and use-wear: basalt axe grinding with added abrasives (sand): **a)** EGS 18 (post-use); **b)** low magnification image of ground surface showing highly levelled quartz grains with moderate edge rounding and common, multi-directional striations; **c-f; h)** high magnification images of quartz grains showing a bright, reticular use-polish with common micro-striations; **g)** micro-scarring on quartz grains.

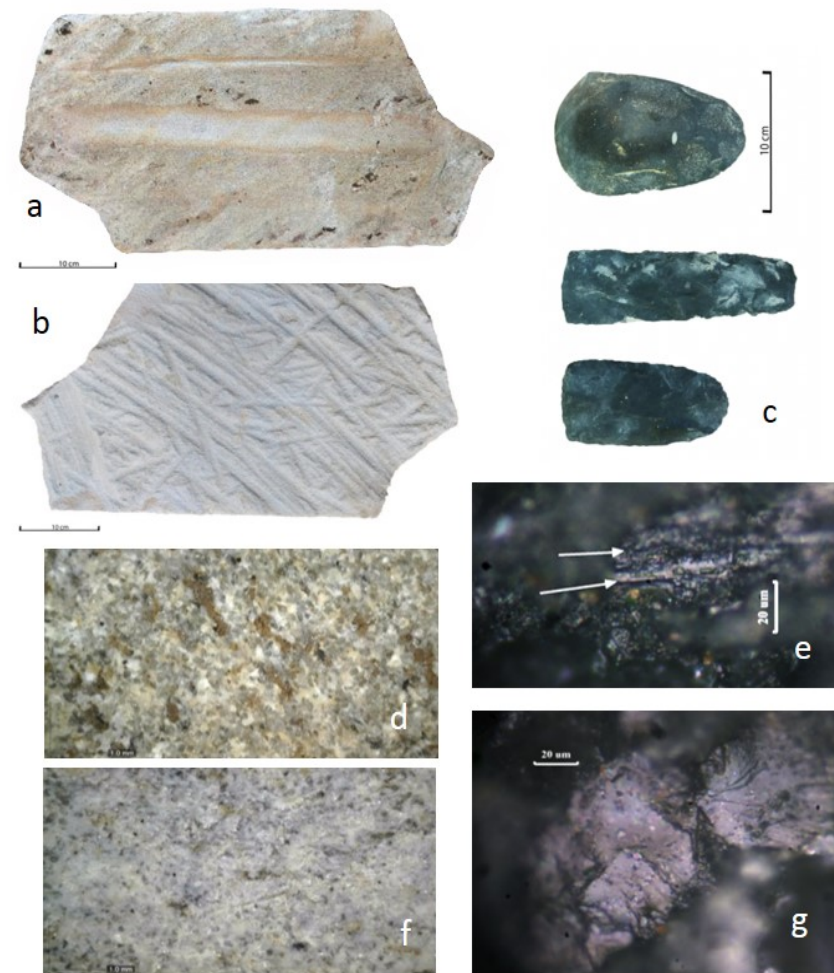


Plate 6.18a-g: Experiment 14 and 15 artefact image and use-wear: basalt axe grinding (Surface 1) and dolerite axe grinding (Surface 2): **a)** EGS 13 Surface 2; **b)** EGS 13 Surface 1; **c)** ground-edge axes produced during experiments 14 and 15; **d)** low magnification image showing a levelled surface, Surface 1; **e)** high magnification image of micro-striations, Surface 2; **f)** low magnification image showing a levelled surface; Surface 1; **g)** micro-scarring of quartz grain, Surface 2.

levelled grains (Plate 6.18e-f), but at high magnification, no diagnostic use-wear features were visible. Micro-scarring of individual grains (Plate 6.18g) and occasional micro-striations (Plate 6.18d) appeared sporadically across the ground surfaces. Similar to other materials ground on Bundanoon Hawkesbury sandstone, (e.g., Bone on EGS 3; wood on EGS 4), the grinding motion continually caused the weakly adhering grains to continually be plucked from the surface, therefore constraining development of use-polish on any one grain.

6.2.3.6 Stone-on-stone (sandstone) grinding

Two tools (EGS 38 and EGS 39) were used in Experiment 17, designed to assess the nature of use-wear associated with stone-on-stone contact using two sandstone tools. The wear associated with this activity is important to document, as contact is often made between an upper hand-stone and a lower millstone during seed and any other grinding activities. This wear also forms in the manufacture or surface preparation of some grinding implements. Experimental tools were ground together in a backwards and forwards motion for 30 min in an attempt to create two regular flat surfaces. Tools were then examined for use-wear features. At low magnification, the highest ridges of each stone displayed moderately rounded, highly levelled grains with deep, interstitial spaces where the lower grains had remained unaffected (Plate 6.19d-e). Some fine, chalky powder resided within the deeper spaces and was loosely adhering to the highly levelled surface. At high magnification, a bright, flat, striated use-polish was visible in isolated regions (Plate 6.19b-c, f-g), often accompanied by frequent striations of uniform size and appearance, orientated in the same direction (Plate 6.19c, f). Micro-scarring was occasionally documented on individual quartz grains across the grinding surface and mineral residues were wrapped around grains.

6.2.3.7 Pigment processing (haematite)

Two experimental artefacts were used to file haematite in order to create a fine powder suitable for the production of paint. Each artefact was used to grind small haematite fragments using a backwards and forwards rubbing motion. The haematite fragments used in both experiments were sourced from the same location (a parking facility available close to the MJB site in Kakadu National Park), so that comparable results could be obtained. Two varieties of haematite were collected, a dense, hard, metallic red haematite and a fine, powdery, red haematite. Experiment 18 involved the grinding of the hard, metallic variety for 10 min (Plate 6.16d). This artefact was only



Plate 6.19a-g: Experiment 17 artefact images and use-wear: stone-on-stone (hard sandstone/quartzite): **a)** EGS 38 (above) and EGS 39 (below); **b-c)** high magnification images of EGS 38 (b) and EGS 39 (c) showing bright, localised polish and parallel striations; **d)** low magnification image showing highly levelled quartz grains with moderate edge rounding and the deep interstitial spaces, EGS 38; **e)** low magnification image of ground surface showing highly levelled quartz grains and moderate grain rounding, EGS 39; **f)** parallel micro-striations, EGS 39; **g)** bright, extensive use-polish, EGS 39.

used for a short time so that the wear would represent expedient usage of the tool. Owing to the inherent hardness of the grinding stone (EGS 35) used in this experiment, wear developed quickly with immediate levelling of grains and surface staining (Plate 6.20a). At low magnification, grains appeared highly levelled and rounded, with large accumulations of red granular mineral pigment within the interstitial spaces of the grains (Plate 6.20b). At high magnification, haematite residues were abundant, occurring both as powdered granules and as larger, streaked deposits with obvious directionality (Plate 6.20e-f). Use-polish was weak to moderate but was obscured by residue accumulations that remained even after artefact cleaning, and therefore use-polish morphology was difficult to distinguish (Plate 6.20c-d). This could be the outcome of a short use-life (~10 min) and the fact that frequent smears of haematite obscured the artefact surface. Micro-striations were visible throughout the residue deposits and on individual quartz grains, although it is unlikely that all

of these are use-related. In order to remove residues, the artefact was cleaned by scrubbing with a soft nylon brush, possibly introducing additional (non-use related) striations that could not be distinguished from use-related striations. Micro-scarring was occasionally recognised on individual quartz grains, although grains with this pattern were uncommon.

Experiment 19 involved the filing of different varieties of haematite (including the hard, metallic and the softer, weakly cemented varieties) with surface observations made at varying time intervals up to a total of 97 min of grinding. Different haematite pieces were ground for varying times so that a use-wear reference library for ground haematite could also be created. After 25 min of grinding, macroscopic traces of wear began to appear on the artefact—a sandstone piece collected from Kakadu National Park (EGS 36)—with the highest surface grains becoming levelled (Plate 6.21a). Wear did not develop as quickly as that identified on EGS 35, the previously used experimental tool, probably as a result of varying hardness of the stone and individual operator variance. After 40 min of use, grain levelling became enhanced with isolated zones of levelling becoming more interconnected, displaying macroscopically evident directionality. After 97 min, grains displayed moderate levelling (Plate 6.21b). At the completion of the experiment, residues were washed and scrubbed under tap water so that a better view of the surface could be obtained. While haematite residues were still abundant across the surface, a moderately bright, undulating use-polish was visible, sometimes with individual striations on the use-polished quartz grains (Plate 6.21c-g). Micro-scars were occasionally identified on the surface of quartz grains. Haematite residues occurred both as loosely adhering red, powdery mineral pigment and also as thick, dark accumulations with high reflectivity. It was important to distinguish use-polish from the highly reflective residues.

6.2.4 Previous experimental data sets

Like previous experimental studies, those conducted for the purpose of this thesis have indicated that there are distinct and recognisable patterns of use-wear that result from contact with specific materials. Coupled grinding stones that are used to process an intermediate material between two stones show distinctive use-wear from grinding stones used as files, which may involve stone-on-bone, stone-on-wood, or stone-on-pigment (Figure 6.2). The processed materials are usually more pliable than stone and therefore filing stones create different conditions and consequent use-wear patterns from those observed from stone-on-stone working (Adams 1993:

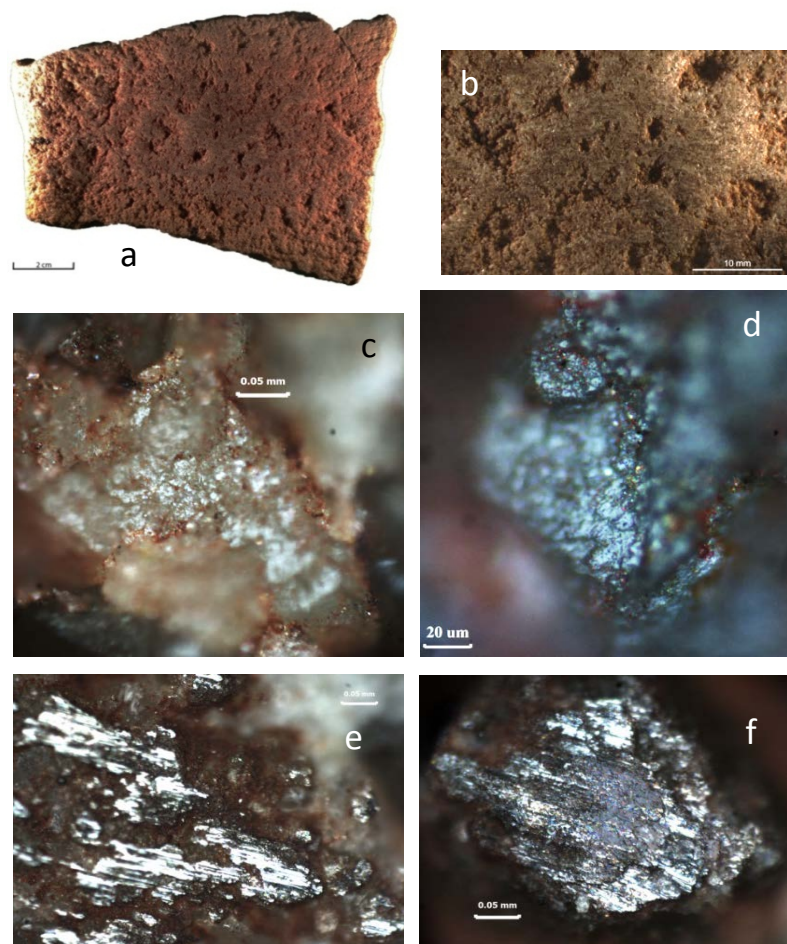


Plate 6.20a-f: Experiment 18 artefact image and use-wear: grinding haematite: **a)** EGS 35 (post-use) showing macroscopic red haematite residues; **b)** low magnification image showing highly levelled, highly rounded quartz grains; **c-d)** weakly developed, un-diagnostic, localised use-polish; **e-f)** streaked metallic haematite residues with evident directionality.

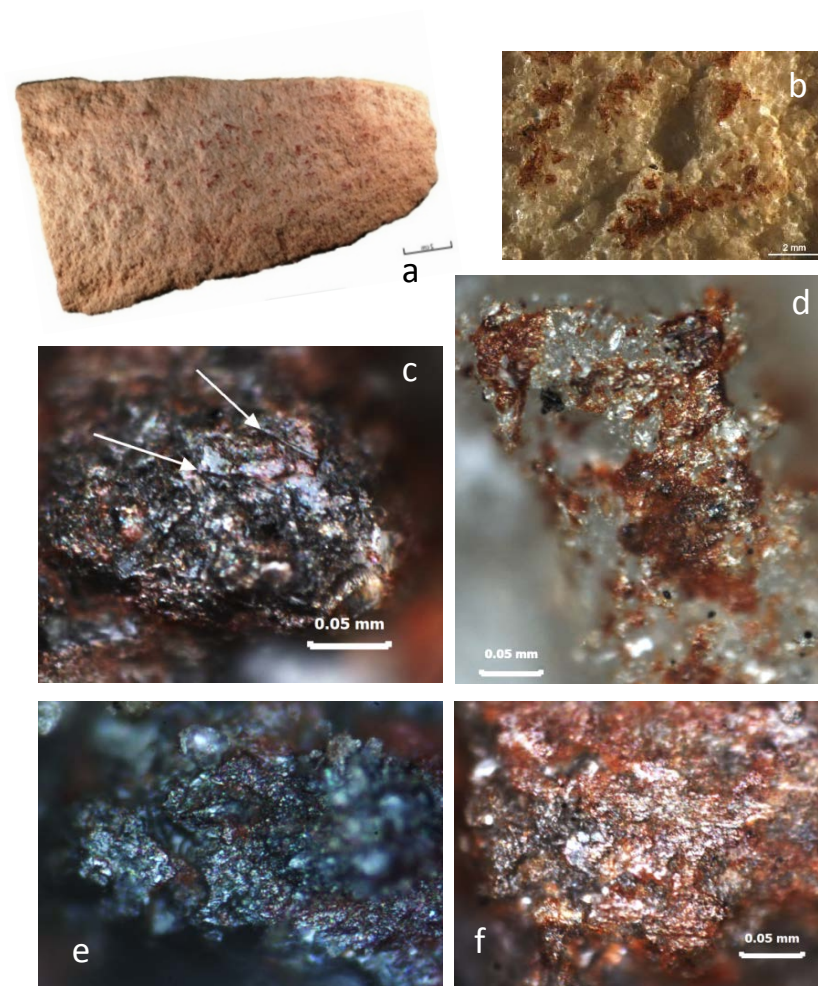


Plate 6.21a-f: Experiment 19 artefact image and use-wear: grinding haematite: **a)** EGS 36 (post-use) showing red haematite residues on the highest quartz grains; **b)** low magnification image showing moderate grain rounding and levelling of the highest quartz grains; **c-f)** high magnification images of quartz grains showing abundant haematite residues and a moderately bright, localised, undulating use-polish. Individual striations are sometimes present within the polished surface (image c).

2010: 140). Filing stones used for processing more pliant materials usually create a more irregular surface topography, where grains become rounded but show lower degrees of levelling (Dubreuil & Grosman 2009: 940) (Figure 6.2c). Alternatively, coupled stones that are used to grind an intermediate material are often characterised by areas of highly levelled grains and more frequent micro-scarring. Dubreuil (2002, 2004: 1619) and Dubreuil & Grosman (2009) have suggested that use-polish will develop faster and appear better developed on abrading (filing) and polishing tools when compared with coupled stones, as observed on sets of experimental basalt grinding stones. These authors also found that variation in wear features occur as a result of different contact surfaces (worked material) and that the intermediate material processed between two stones will also affect use-wear formation depending on their hardness, asperity, and internal chemical properties that may act as polishing agents (e.g., silica content, presence of natural lubricants such as oils or fats, and the degree of hydration).

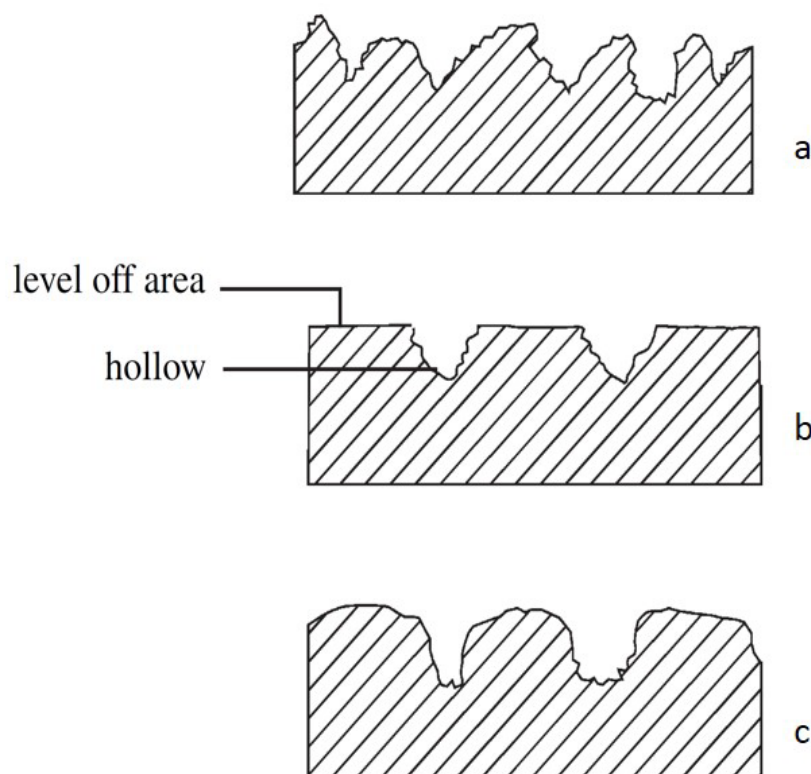


Figure 6.2a-c: Idealised schematic cross-section representation of ground surfaces. **a)** Unused surface manufactured by pecking; **b)** the working surface of a grinding tool with a complimentary implement (i.e. stone-on-stone), allowing for the formation of flat plateaus; **c)** the working surface of an implement used as an abrader/polisher (e.g. stone-on-wood, stone-on-bone), displaying a more irregular surface topography and increased rounding of grains. *After* Dubreuil (2004): Fig. 1 and Dubreuil & Grosman (2009): Fig. 7.

6.2.4.1 Filing stones

6.2.4.1.1 Bone filing stones

The two experimental bone grinding tools (EGS 3 and EGS 4) displayed different use-wear features that were influenced by the different physical properties (e.g., hardness, degree of cementation) in the sandstone from which they were made. EGS 3, a soft, loosely cemented sandstone, was worn away quickly, leaving a distinctive groove, but no other recognisable use-wear traces such as use-polish. Fullagar & Field (1997: 302) have remarked on the use-wear associated with weakly cemented sandstone pieces, stating that “...*weakly cemented sandstone is limited in extent by the constant abrasion of quartz grains*”, with wear more easily recognised on the harder sandstone varieties. This was exemplified on EGS 5, a much harder sandstone variety, which displayed an elongated zone of well-rounded grains and homogenous zones of smoothing in the path of bone contact. Similar observations on other experimental bone abraders were made by Dubreuil (2004: 1616-1617) and Adams (1989a: 368, 1989b: 268), who noted similar damage for both sets of experiments with an indistinguishable degree of grain rounding for each experiment type. According to Adams (1988, 1989a: 367, 1989b: 268, 1993: 70), grain rounding may be the result of adhesive bonding, pulling of small particles from the grains following the working of a softer, more pliable material, and differing from stone-on-stone action, in which the more aspirated surface causes the grains to be chipped and crushed by abrasive wear and surface fatigue (Figure 6.2b-c). Only at high magnification are filing tools used to grind bone or wood distinguished, with notable differences in use-wear arising from tribochemical processes (Table 4.3) that cause variation in use-polish morphology and development. Adams (2010: 140-141) suggested such differences in wear may arise from the varying abundances of natural lubricants such as fats and oils in both material types. Fresh bone, for example, is very greasy and will tribochemically react with the surface of the stone to create sheen.

Residues present on wood grinding stones occurred mostly on the ground region of experimental tools, often coating individual grains but also extending into the interstitial spaces. Previous experiments have also shown that a build-up of residues wedged between individual grains is particularly pronounced when preparing fresh (green) wood (e.g., Adams 1989a, 1993: 70, 2010: 140). At high magnification, use-polish has been described as domed with high linkage and micro-pitting, described similarly in accounts of experimental flint and quartzite wood working flaked stone tools (e.g., Vaughan 1985: 33; Fullagar 1991).

6.2.4.1.3 *Haematite/pigment filing tools*

The processing of haematite by two operators for varying amounts of time produced two different macroscopic wear patterns. EGS 35 was used as a filing stone to grind ochre for 10 min. The artefact surface was rapidly levelled and red mineral residues were visible after one contact stroke, becoming thicker and more distinctive as grinding continued (Plate 6.20a-b). Similar macro-wear has been described by Dubreuil & Savage (2014) and Dubreuil (2004: 1618) who noted that the grinding surface became entirely levelled after 300 min of ochre grinding that resulted in the intense regulation of the entire ground surface. Interestingly, EGS 36 displayed a more irregular surface topography, despite haematite processing for a longer time period—a total of 97 min. Instead, this surface only had small, isolated patches of levelling with increased grain rounding. It is possible that the discrepancies in surface appearance may be the result of the hardness of the haematite selected for preparation: a harder, metallic piece was selected to be worked by EGS 35, while a softer, more powdery piece was worked on EGS 36. The harder haematite piece created a worn surface topography closely resembling wear from stone-on-stone working (Figure 6.2b). Similar to observations made by Dubreuil (2004: 1617) and Hamon (2008: 1511), the grinding of haematite also produced micro-scarring of grains and striations in the use-polished surface.

6.2.4.1.4 *Axe grinding/filing tools*

The axe-grinding implements displayed variable surface wear depending on the hardness of the sandstone material. Similar to the bone and wood working experiments performed on the softer, weakly cemented Bundanoon sandstone, EGS 13, of the same material, failed to show any distinctive use-wear features at high magnification, although well-defined grooves were visible macroscopically after only a short duration of working (5 – 10 min) (Table 6.7, 6.8; Plate 6.18a-b). This material was found to be extremely effective as an axe sharpening tool with the constant removal of quartz grains acting as an additional abrasive agent. Such findings are consistent with that of Dickson (1972: 208), who, following sets of axe grinding experiments designed to evaluate the most efficient means of preparing stone axes, noted “*To grind a stone axe, the best abrasive is soft sandstone...*”. Less effective was EGS 16, a harder sandstone from the Kimberley region of Western Australia. While no macroscopically visible grooves were noted on this artefact, some recognisable stone-on-stone use-wear was recognised, including with highly levelled grains and frequent striations of multiple orientations (Plate 6.17d). A bright, striated use-polish developed, similar to that described by Fullagar & Field (1997) who observed wear on sandstone tools that had come into contact with another stone during grinding. Interestingly, the use-polish on EGS 18 was

similar to that identified on some of the seed grinding stones, with their most developed use-polish on the highest grains with low use-polish development on the lower elevations of the surface (Plate 6.17c). Polishing experiments conducted by Hamon (2008), using a flint adze that was ground on both hard and soft sandstones, also showed an increase in more developed wear traces on the harder sandstone implement. In her experiments, the harder, well cemented sandstone displayed a highly uniform surface and was accompanied by a dense pattern of fractures on the constituent grains (Hamon 2008: 1515).

6.2.4.1.5 *Stone-on-stone grinding wear*

Stone-on-stone contact with no intermediate processing material probably results in levelling of the highest grains leaving the interstitial spaces un-altered. Such wear was described by Dubreuil (2004: 1616) and Adams (1989b: 267, 1993: 68), noting that the first points of contact and abrasion were the highest elevations of the stone. Micro-scarring was also observed on individual grains on all sets of my experimental tools. This feature was suggested by Adams (1988, 1989b: 267) as be the outcome of abrasive wear, whereby common fracturing creates a “frosted-like” appearance. Micro-striations were also visible on all my experimental stone-on-stone grinding tools, consistent with previous experimental studies (e.g., Cunnar 2007; Fullagar *et al.* 2012; Owen 2007).

6.2.4.2 Coupled grinding stones

The coupled stones used in the processing of wheat and seeds had use-wear consistent with that reported on other experimental couple stones used to process an intermediate material. Experiments conducted by Adams (1988: 308-309, 1989a: 360) using replicated North American metate (lower stone) and mano tools (upper stones) to grind an intermediary material including corn and sunflower seeds, often displayed macroscopically visible striations and large distinctive patches of levelled grains, occurring as a result of stone-on-stone grinding (Figure 6.2b). Similar tools used by Dubreuil (2004: 1616); Hamon (2006, 2008); Hamon & Plisson (2008) and Delgado Raack & Risch (2009) that were to process intermediate materials such as nuts, cereals and legumes, produced highly levelled grains with frequent, deep striations occurring on the plateau-like areas of the surface. Most of the coupled stones used in my experiments showed distinct regions of highly levelled quartz grains. An exception is millstone EGS 16 and upper stone EGS 33, where individual grains displayed only slight levelling (Plate 6.11d). Angular, unlevelled grains were also observed on EGS 19 and EGS 24, used to pound soaked kurrajong seed. The lack of grain levelling on the latter

two specimens may be related to the pounding action, causing the build-up of residues surrounding individual quartz grains, protecting them from damage, or as a result of the hardness of the seeds being processed. As Adams (1989a, 1989b) noted, the rapid accumulation of residues that coat the grains and fill up the interstitial surface spaces, can interfere with the stone-on-stone contact. Previous experimental work by Adams (1989a: 365) has also demonstrated that the stone-on-stone grinding of sunflower seeds allowed grains to maintain higher angularity than those identified on stones used to prepare a softer material such as corn. Consistent with the findings of Adams (1988, 1999: 487), residue accumulations are also typically seen within the interstitial spaces of the grinding surfaces of coupled tools used to grind wheat and other seeds.

The use-polish from plant processing on quartz grains in sandstone grinding tools is comparable to that on flint or quartz artefacts (e.g., Fullagar 1986b; Knutsson 1986); the use-polish on individual quartz grains appears bright, domed, reticular and interconnected, and in some cases, highly smoothed (e.g., EGS 28—Plate 6.10g, 6.22d). The specific use-polish may be related to the internal make-up of different seeds including silica content and presence of oils. Several authors (e.g., Kamminga 1979; Fullagar 1991; Fullagar & Field 1997: 302) suggest that materials with high silica content tend to more rapidly sustain a bright, interconnected use-polish, almost featureless in its most developed state except for micro-pitting (such as on the use-polish evidenced on EGS 28—Plate 6.10g), while Adams (1988: 309) suggested that a bright to moderately-bright use-polish is often evidenced on tools used to process well lubricated soft material. Seed grinding experiments performed by several authors (Table 6.1) (Cunnar 2007; Hamon 2008; Liu *et al.* 2010b: 824, 2011: 3526; Fullagar *et al.* 2012) on a range of stone materials show that use-polish of this variety (i.e., bright and reticular) is observable on seed grinding implements. Like-wise, Verbaas and Van Gijn (2008: 194-196) have demonstrated that stones used to grind cereals sustain use-wear comparable to that of the experimental wheat grinding implements. In these latter instances, use-polish is domed and interconnected, often with short striations of a single orientation. Linear features are also observed on these seed grinding implements and those performed by other authors (e.g., Liu *et al.* 2010a, 2010b, 2011), usually in the form of micro-striations with multiple orientations, most likely occurring as a result of abrasion between the stones as constituent particles break off.

6.2.4.3.1 *Coupled pounding stones*

Damage of individual quartz grains on artefact surfaces appeared more frequently on tools involved in pounding or hammering activities (e.g., Experiments 9 – 11), whereby micro-scarring is

common on individual grains. In her investigations involving the use of coupled stones, and particularly occurring with pounding and hammering activities, Adams (1988: 308-309, 1989a: 363-364) also noted micro-scarring on quartz grains. Use-polish was present on the highest grains of these tools but appeared less extensive than that identified on other seed grinding implements. This is similar to the observations made by Fullagar *et al.* (2012) who noted differences in use-polish formation on pounding versus grinding tools in the processing of acorns. In these experiments, use-polish was better developed on grinding tools compared with pounding tools, the latter also displaying far more surface pitting.

6.2.4.3.2 *Seed pounding tools*

Only a weakly developed use-polish was recognised on artefacts EGS 19 and EGS 24, used to process soaked kurrajong seed. The lack of use-polish development on these artefacts is probably the result of a shorter processing time and variation in the mode of use. Impact marks, scars and breakage have also commonly been observed on experimental percussion tools, the intensity of which are especially sensitive to the raw material of both upper and lower implements (De la Torre *et al.* 2013; Dubreuil & Savage 2014). Lack of, or fewer, striations on these tools may be related to the cushioning effect of large kernels and minimal contact between the upper (i.e., hand-stone) and lower grinding stone (anvil). A similar observation was made by Hamon (2008: 1511) and Liu *et al.* (2010b: 829) who attributed the absence of striations on acorn pounding tools to the cushioning effect of the processed material. In this latter example, along with the experiments performed in my study, residues were also found to be common within the interstitial spaces of the artefact surface, probably impacted between grains by pounding actions. Fullagar *et al.* (2012) also suggested that the processed material acts as a buffer during the grinding process, thus restricting the development of use-polish and micro-striations on the stone tool surfaces.

6.2.4.3.3 *Bone pounding tools*

The bone pounding implement was found to have sustained only slight wear development, with rounded quartz grains but little other surface damage. Use-polish was restricted to the highest grains and had a rough-pitted morphology (Plate 6.4f). These observations are consistent with those obtained by De la Torre *et al.* (2013: 321-323), who noted that macroscopic wear, in the form of peck marks, are created only when the hammer accidentally strikes the anvil, with the elasticity of the bone surface preventing the force from the blow being directly transmitted to the anvil. De la Torre

et al. (2013: 223-225) also noted the presence of micro-scars on both the hammer and anvil stones—these scar features were also observed in my experiments (Plate 6.4d). Levelling of individual grains appeared to be minimal, a trend also noted by Hamon (2008) and Hamon & Plisson (2008: 32), in which constituent grains were described as uniform, but without visible macroscopic levelling.

6.3 Ethnographic collections

Similar to analyses of experimental collections, ethnographic artefact assemblages are a significant supplement for investigations into the development and characterisation of use-wear, enabling key use-wear signatures to be established for artefacts of known use. Relevant ethnographic artefact collections are those that have been acquired from indigenous populations following observation of their specific contextual use. Use-wear associated with ethnographic tools have been examined in various studies of ground and flaked stone artefacts (e.g., Clemente *et al.* 2002; Cunnar 2007; Dubreuil & Savage 2013; Hayden 1987; Liu *et al.* 2010b), but are restricted to ethnographic materials from within Europe, China and the Levant.

Unlike experimental tools, which have been used for relatively short time periods (usually several hours), ethnographic artefacts may have been curated, stored, transported and used over a longer time, in some cases for generations, and often in environments directly relevant to archaeological questions of interest. Significantly, the artefacts were also used by people with experience in undertaking specific processing tasks in relevant geographic and cultural settings. For this reason, ethnographic tools may be more comparable to archaeological specimens.

Two collections of ethnographic grinding stones totalling 12 artefacts were examined for use-wear traces to add to my use-wear reference library. These include five specimens collected from arid South Australia that comprised part of the Tindale/Hackett (1933) collection, and seven specimens collected from nearby locations that comprised part of the Edwards (1971) collection (Figure 6.1). Both artefact collections were made available by the South Australian Museum (SAM) in Adelaide, Australia. Unfortunately, only a small sub-sample of ethnographic stones was examined from each collection, and detailed accounts of the context in which they were collected and used were not always available. All twelve specimens were made from hard sandstone/quartzite and were all used to process a variety of seeds.

Functional analysis of the ethnographic artefacts involved examination of the artefact surface using a portable Dino-Lite™ microscope and examination of PVS peels collected from at least two locations on the artefact surface: an area of maximum abrasion or use-polish, as indicated by high surface reflectivity, and an area containing no visible signs of alteration, acting as a ‘control’. The control surface may have accumulated wear from handling and transport and should be distinct from the wear on grinding surfaces. The PVS peels were examined under high magnification using a reflected light microscope at the RUM Laboratory at UOW. The results of these various analyses are presented within the classification and artefact number sequence provided by SAM (Appendix B).

6.3.1 N.B. Tindale & C.J. Hackett (1933) collection

Five ethnographic grinding stones comprising part of the N.B. Tindale & C.J. Hackett (1933) collection were examined for distinctive use-wear traces. The analysed specimens included four grinding stones made of very strongly cemented metamorphosed sandstone and one grinding stone made of very fine-grained quartzite (Plate 6.22). The artefacts were collected from three locations within central Australia along the South Australian border: the Mann Ranges, Musgrave Ranges and Mt Kintore (Table 6.6; Figure 6.1). The artefacts were used by the Pitjandjara people and are described as “upper millstones” that were used on a granite surface to grind and mill a number of Australian seeds, including wattle, grass and kurrajong seed (Table 6.6). It is unknown whether the seeds were dry or wet milled, and no details were given in regards to the individuals who were using the artefacts. Use-wear on the artefact surfaces should reflect the processing of multiple Australian seed varieties.

All five ethnographic grinding stones displayed similar morphological use-wear characteristics, varying only in relation to the extent of the use-polish development and the frequency and orientation of striations. Macroscopically, each artefact displayed high levels of smoothing on the ground surface with at least one of the artefacts displaying macroscopically visible patches of use-polish (Specimen 21733). Constituent quartz grains exposed on all utilised artefact surfaces appeared highly levelled and well-rounded. At high magnification, four of the five specimens (21733, 21736, 21738 and 21739) displayed a well-developed, bright, reticular use-polish accompanied by frequent micro-striations (Plate 6.23a-d, g-h). These striations varied on each artefact, but typically occurred as either furrows of varying thickness and depth but with the same orientation (Plate 6.23d), or as fine, parallel alignments (Plate 6.23b). Noticeably, use-polish was also

present within the lower surface elevations of artefact 21738 (Plate 6.23a-b) indicating multi-functional use i.e., the grinding of both hard and soft seeds.



Plate 6.22a-e: Ethnographic seed grinding artefacts comprising the Tindale/Hackett (1933) collection. **a)** Specimen 21738; **b)** Specimen 21733; **c)** Specimen 21737; **d)** Specimen 21736; **e)** Specimen 21739.

Specimen 21737 displayed a domed, reticular use-polish, but this appeared to be less extensive than the use-polish distributed on the other four artefacts. The use-polish on this grinding stone was also restricted to the highest elevations of the artefact surface (Plate 6.23e-f). Micro-striations were not visible on the PVS peel from the sampled area. Also present on this artefact was macroscopically visible crushing and hammer damage on the distal end of the stone, indicating a secondary use as a hammer/pounding tool. Based on the use-wear, this artefact was used as a multi-purpose tool, which is supported by the ethnographic report, mentioning that “*the extremities [of the stones] show hammering, due to the preliminary pounding of the same seeds*” (Table 6.6).

6.3.2 R. Edwards (1971) collection

Seven ethnographic specimens were analysed from the R. Edwards (1971) collection to document key use-wear features (Plate 6.24). These specimens were collected during the Uprange Ministerial Expedition between May 19 and June 12, 1971. All seven specimens are upper stones made from hard, well cemented sandstone. Similar to the artefacts comprising the Tindale/Hackett collection, these artefacts were used by the Pitjandjara people and collected from two regions in central Australia: from Amata and a region near Ernabella, both in arid South Australia (Figure 6.1). While the official report for the use of these artefacts was unable to be located, basic artefact recording sheets provided by the SAM has indicated that these artefacts were used to process seeds.

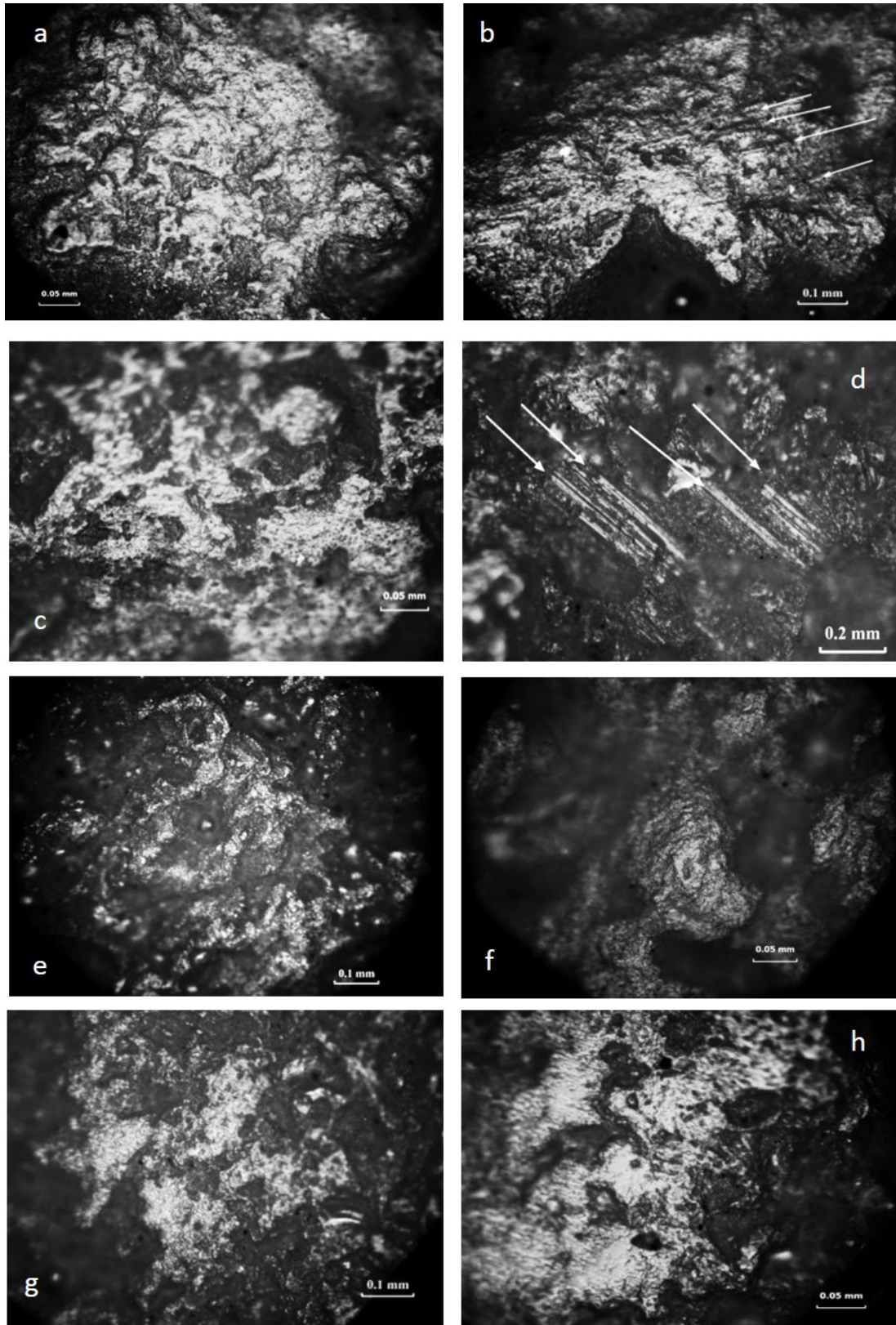


Plate 6.23a-h: High magnification images of ethnographic seed grinding artefacts (Tindale/Hackett collection) showing a bright, reticular use-polish that is best developed on the highest grains but also present at lower surface elevations, suggesting the processing of both hard and softer materials: **a-b)** use-polish and micro-striations on Specimen 21738; **c-d)** use-polish and micro-striations on Specimen 21733; **e-f)** use-polish on Specimen 21737; **g-h)** use-polish on Specimen 21736.

Table 6.6: Summary of the ethnographic documentation for the N.B Tindale and C.J Hackett. (1933) collection and the R. Edwards Uprange Ministerial Expedition. Information made available by the South Australian Museum.

	Stone no.	Category	People	Locality	State	Date of collection	Description of use:
Tindale, N.B. Hackett, C.J.	21733	grindstone	Pitjandjara	Pudalja, western extremity of Musgrave Range; Camp 8	South Aust.	28 Jun 1933	“...these upper millstones present special characteristics; they are used in conjunction with granite rock surface as nether mill in grinding of kurrajong seed and wattle seed and other grasses; the extremities show hammering, due to the preliminary pounding of the same seeds.”
	21736	grindstone	Pitjandjara	Wankarei, north of Mt Charles, Mann Range; Camp 12	South Aust.	5 July 1933	
	21737	grindstone	Pitjandjara	Angaltakutjara, west of Mt Charles, Mann Ranges; Camp 13	South Aust.	5 July 1933	
	21738	grindstone	Pitjandjara	Pakiwandi, 5 miles east of Trew Gap, south side of Mann Range; Camp 15	South Aust.	13 Sept 1933	
	21739	grindstone	Pitjandjara	Wiluwiluru, 4 miles east of Mt Kintore; Camp 19	South Aust.	17 July 1933	
R. Edwards: Uprange Ministerial Expeditions	62365	grindstone	Pitjandjara	Amata	South Aust.	19 May- 12 June 1971	upper stones for grinding seeds
	62378	grindstone	Pitjandjara	Near Ernabella	South Aust.	19 May- 12 June 1971	upper stones for grinding seeds
	62382	grindstone	Pitjandjara	Near Ernabella	South Aust.	19 May- 12 June 1971	upper stones for grinding seeds
	62384	grindstone	Pitjandjara	Near Ernabella	South Aust.	19 May- 12 June 1971	upper stones for grinding seeds
	62420	grindstone	Pitjandjara	Amata	South Aust.	19 May- 12 June 1971	upper stones for grinding seeds
	62421	grindstone	Pitjandjara	Amata	South Aust.	19 May- 12 June 1971	upper stones for grinding seeds
	62422	grindstone	Pitjandjara	Amata	South Aust.	19 May- 12 June 1971	upper stones for grinding seeds

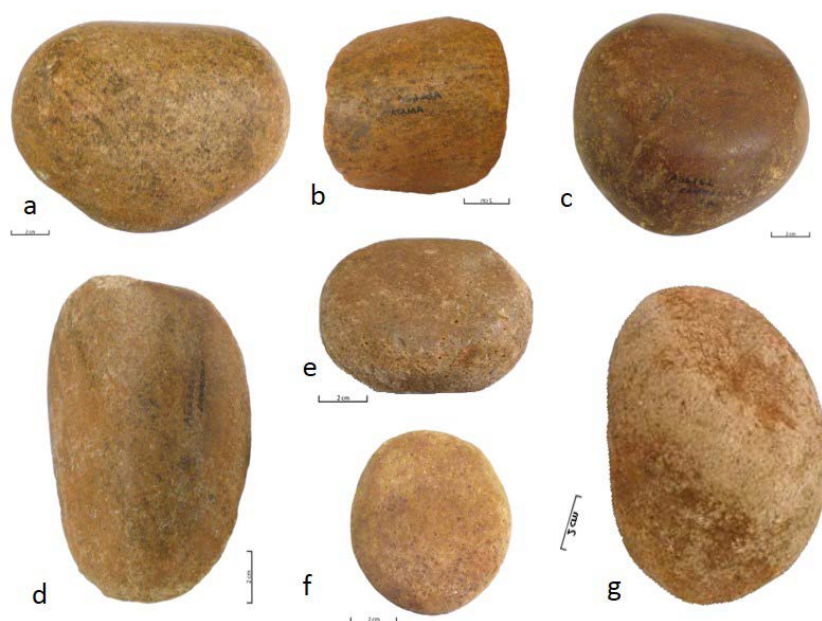


Plate 6.24a-g: Ethnographic seed grinding artefacts comprising the Edwards (1971) collection: **a)** Specimen 62365; **b)** Specimen 62420; **c)** Specimen 62382; **d)** Specimen 62384; **e)** Specimen 62421; **f)** Specimen 62378; **g)** Specimen 62422.

The use-wear on all seven ethnographic stones was comparable with grains appearing highly levelled and rounded at low magnification, with a bright, reticular use-polish that was visible at high magnification. Micro-striations were common on the use-polished grains and micro-scarring of quartz grains was distinguished on all artefact surfaces. Wear appeared the best developed on artefact 62382 (Plate 6.25c), which was also the hardest sandstone of the specimens analysed in this collection. Use-polish on this specimen was visible macroscopically, and appeared uniform and consistent across the entire working surface when viewed under high magnification. Micro-striations were present on the polished quartz grains, characterised by wide, deep furrows of multiple orientations. Because the full ethnographic report for the seven stones comprising this collection was not obtained, it is unclear whether this artefact was used for a variety of additional tasks, or whether these more distinctive features accumulated at other stages of the artefacts life history.

Residues were sampled from one specimen (62421) using distilled water pipette extractions and examined under transmitted light. Plant cells, lignin fibres and other plant tissues were distinguished within the removed residue samples, the latter of which were confirmed following the application of Congo Red stain (Plate 6.26b). As the artefacts from this collection were stored at the SAM and wrapped in newspaper for protection, it is likely that some of the cellulose fibres identified were the result of storage contamination, rather than use. Despite this, the abundance of cellular plant structures is an indication of plant use.

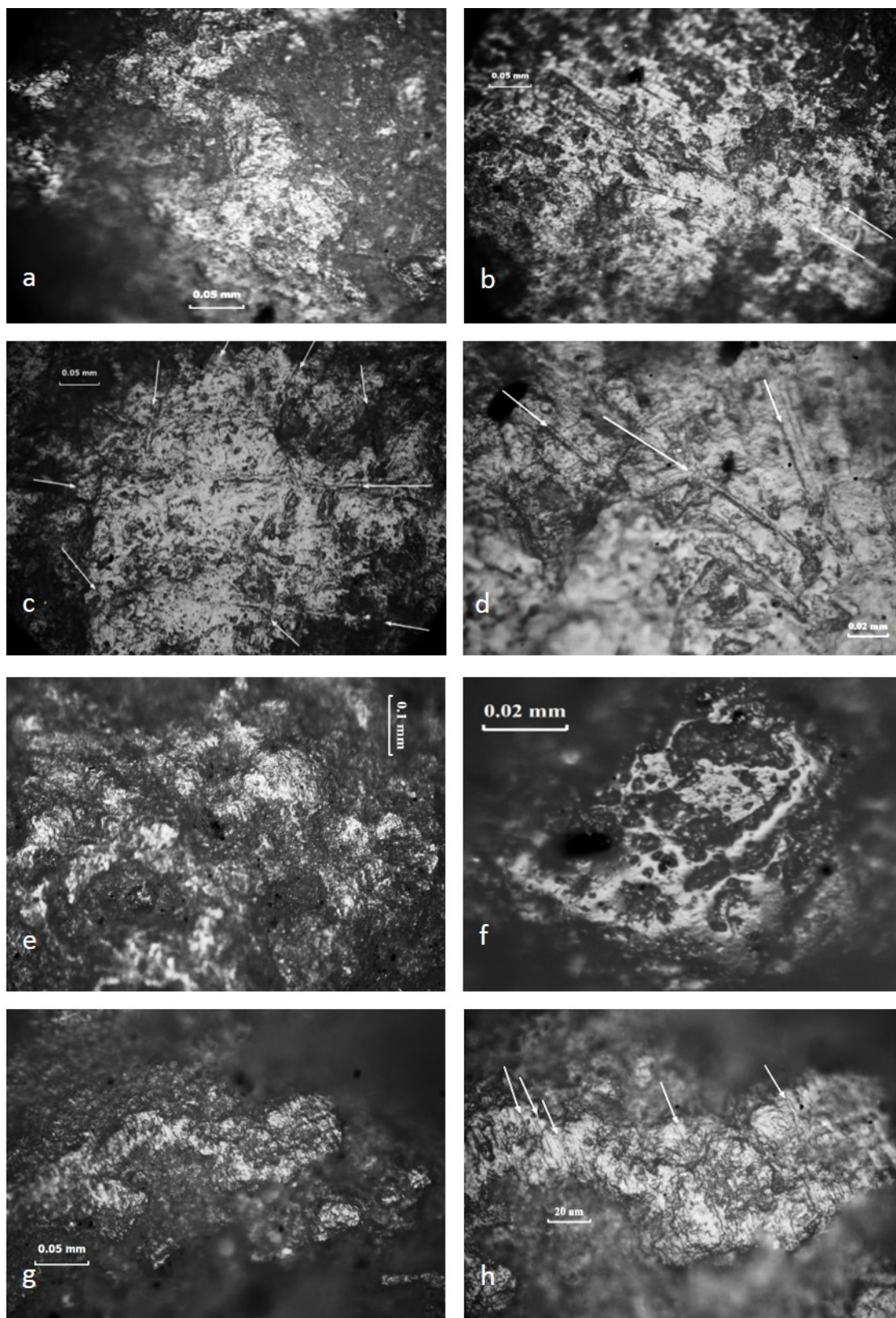


Plate 6.25a-h: High magnification images of ethnographic seed grinding artefacts (Edwards collection) showing a well-developed, reticular use-polish and frequent micro-striations often of multiple orientations: **a)** use-polish on Specimen 62365; **b)** use-polish on Specimen 62384; **c-d)** use-polish and deep furrows on Specimen 62381; **e)** use-polish on Specimen 62420; **f)** use-polish on Specimen 62378; **g-h)** use-polish and striations on Specimen 62422.

Interestingly, macroscopically visible ochre residues were visible on one specimen (62378) (Plate 6.26a). The ochre was identified on the ground surface of the artefact and within the interstitial spaces of the grains, potentially indicating that they are use-related. However, the ochre residues appear to be restricted to only one small area of the artefact surface, and therefore it could have accumulated from incidental contact during Aboriginal transport and storage, or via modern storage where incidental contact with ochre pieces may have also occurred.

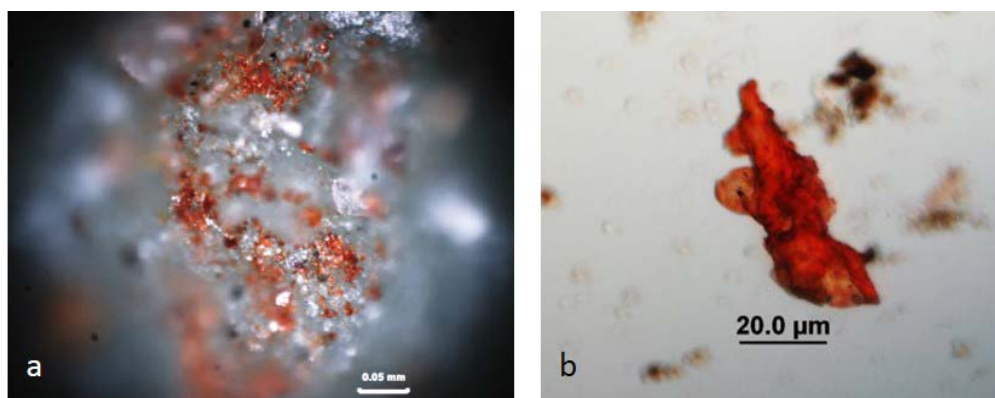


Plate 6.26a-b: Residues on ethnographic seed grinding specimens from the Edwards collection: **a)** ochre residues from the surface of Specimen 62378; **b)** amorphous plant tissue from Specimen 62365, stained with Congo Red.

6.3.3 Discussion: ethnographic grinding stones

All of the ethnographic seed grinding stones ($n = 12$) displayed clearly defined use-wear that was diagnostic of seed grinding. At low magnification, individual grains appeared highly levelled, and, on one of the artefacts (62382), a macroscopic use-polish was visible. At high magnification, a bright, well-developed reticular use-polish was present, accompanied by frequent micro-striations represented by deep furrows of multiple orientations. However, I could recognise differences between the wear produced on my experimental seed grinding stones and those comprising the ethnographic collections, particularly in the degree of use-polish development and the frequency and size of striations. These differences may be the result of several factors. The ethnographic specimens were almost certainly used for longer durations than my experimental artefacts, and therefore I would assume wear traces would appear much better developed than those generated on experimental artefacts, which were used for relatively short durations. For the artefacts comprising the Tindale/Hackett collection (Table B4), the enhanced frequency in striations may be the result of incidental contact with a harder surface: the ethnographic report states that the artefacts were used to process seeds on a lower granite millstone. As my experiments only included

sandstone and quartzite artefacts, I am unable to assess the variability of wear traces resulting from the use of having coupled stones made of two different materials, specifically, hard sandstone and granite. The occurrence of use-polish on the ethnographic stones within the lower micro-topographic features of the grains suggests contact of additional materials with the artefact surface.

The higher frequency of striations documented on the ethnographic specimens may also be related to the environment in which they were used. Both ethnographic collections were collected from desert environments in the arid regions of South Australia (Figure 6.1). Consequently, the decreased rainfall and increased dust in the surrounding environment would have resulted in more airborne particulate material (dust and sand) causing enhanced striations (*cf.* Meeks 1982: 332) that were absent on my experimental tools.

The wear on the ethnographic specimens may also include non-use related wear acquired during curation and discard. One potential complication when analysing ethnographic tools is that their full life history is largely unknown. Artefacts that were used over multiple generations were likely to have been used for a large number of unreported tasks prior to collection. Because only the most recent use of the artefacts are reported, it is not clear whether the artefacts were used for additional purposes prior to the final reported use, whether they had been discarded at any stage in their life history (and exposed to harsh environmental conditions) or whether they had been curated or transported in a bag of some sort (e.g., soft woven or skin bag) that may create additional, non-use related wear traces. If the stones were also discarded for some period of time, we might expect to see non-use related use-polish formation and striations resulting from sandblasting or additive organic coatings, such as “desert varnish” (see Dragovich 1998: 445, 2000: 871 for description), on the artefact surface. The latter has been identified previously on non-artefact sandstone pieces in desert environments (Gould & Saggers 1985: 127).

The accumulation of non-use related wear traces that may occur during curation, discard and deposition have been investigated and suggest that these traces are likely to occur on stone artefacts (e.g., Kamminga 1982; Levi-Sala 1986a). If an artefact was to be carried in a soft woven or skin bag, we may expect wear traces to accumulate that may superficially reflect the processing of hide or soft plant, despite having been used for a potentially completely different purpose.

While non-use related features on ethnographic stones potentially complicate functional interpretations, they more closely resemble the artefacts identified archaeologically (when compared to experimental sets). Although the use of controlled experiments helps to eliminate the complication of having to identify non-use related wear patterns, archaeological specimens are also

likely to possess non-use related wear resulting from manufacture, curation, discard, deposition, excavation and storage (Table 4.6). For this reason, ethnographic material provides a good analogue to functional interpretations of archaeological specimens, and may be more representative of some wear traces identified on archaeological tools.

6.4 Use-wear reference library

Table 6.7 summarises the range of use-wear traces documented on collections of experimental and ethnographic sandstone tools. All artefacts displayed distinctive grinding wear and often displayed use-wear that was diagnostic of worked material. Specific use-wear traces such as the degree of grain rounding, grain levelling and the presence of use-polish, striations and micro-fractures, may be distinguished and can be used to determine artefact function. These use-wear traces varied depending on several factors, including: (1) the stone material from which the artefact was made, specifically hardness and degree of cementation; (2) the artefact class, including whether the artefact was used as an upper, lower or filing stone; (3) the worked material, including physical properties such as hardness and elasticity and internal composition; (4) the mode of artefact use, i.e., grinding and/or pounding; (5) the intensity and duration of use; and (6) operator variance. An additional factor that may influence the appearance of use-wear, which was not noted in my experiments, is the degree of surface weathering that may be present on an artefact. For the ethnographic specimens, additional factors that may affect wear include artefact curation and discard, which may generate non-use related wear traces.

All tools comprising my experiments ($n = 26$) displayed distinctive grinding wear, usually visible macroscopically but certainly visible at low magnification, and after relatively short durations of use (<30 min for most specimens) (Table 6.8). The softer, weakly cemented Bundanoon sandstone produced the most distinctive macroscopic grinding wear with distinctive grooves visible after just 5 – 10 minutes of use. For one artefact (EGS 13), grinding wear could be attributed to stone axe manufacture (based on the dimensions of the groove) after just 10 min of grinding. At high magnification, the Bundanoon sandstone displayed low or no use-polish development, and individual quartz grains often did not display high degrees of levelling or rounding. Consequently, no use-wear traces (as observed at high magnification) that were diagnostic of worked material could be recognised on artefacts made from the Bundanoon sandstone. I attribute the low level of modified quartz grains to the continual removal of surface grains preventing the development of diagnostic use-polish.

Table 6.7: Synthesis of the range of use-wear characteristics identified on experimental grinding stones by activity type, excluding data from stones of raw material number 2 (softer Bundanoon sandstone)

Activity		Low magnification			High magnification					
		Degree of surface levelling	Degree of grain edge rounding	macro striae	polish morphology	polish brightness	polish coverage	polish development	fine striae	grain fractures
Bone-on-stone		minimal-high	moderate-high	present	smooth-pitted; striated	bright	extensive	developed	common	present
Wood-on-stone		moderate	moderate	present	domed-pitted; reticular	bright	extensive	developed	present	present
Stone-on-stone (with intermediate material)	Bone pounding	moderate-high	slight-high	present	rough-pitted	dull-bright	localised	weak	present	common
	Seed pounding	minimal-moderate	moderate-high	uncommon/absent	un-diagnostic/reticular	dull-moderate	localised-moderate	weak-moderate	uncommon/absent	present
	Seed grinding	minimal-high	moderate-high	present-common	reticular	moderate-bright	localised-extensive	weak- well-developed	common	present
	Wheat grinding	high	high	present	reticular; striated	dull-moderate	localised-moderate	moderate	present	present
	Stone grinding	high	moderate	present	striated	dull-moderate	extensive	developed	present	common
	Axe grinding	high	moderate	present	striated; reticular	bright	extensive	developed	common	present
Pigment-on-stone		High	moderate-high	absent	undulating	dull-moderate	localised-moderate	weak-moderate	present	present

The harder sandstones, which include the Jemalong Ridge, Illawarra Hawkesbury, Kimberley and Kakadu sandstones, also displayed distinctive grinding wear after short durations, usually between 10 – 30 min of grinding. Rather than forming distinctive grooves, macroscopic grinding wear on the harder sandstones was distinguished by highly levelled grains and a uniform surface topography. Artefacts EGS 2 and EGS 5 (quartzite filing tools used to process wood and bone) took the longest time to develop macroscopic grinding wear, visible after 40 min of use (although residues were distinguishable after less than 10 min of contact). The slow development of macroscopic grinding wear on these artefacts is probably related to the relative hardness of the quartzite grinding stone, compared with the softer worked material: both wood and bone are pliable materials and will not readily alter the harder quartzite surface, and as such macroscopic surface modifications take longer to be produced.

Grinding wear also varied depending on the artefact class; i.e., if the artefact was used as a filing or coupled stone. The filing stones, which came into direct contact with the worked material, generally displayed a lower degree of grain levelling and infrequent micro-striations. The coupled stones, on the other hand, generally displayed connected zones of highly levelled grains with more frequent micro-scarring and micro-striations resulting from the stone-on-stone contact. An exception to was seen on one of the filing stones that was used to process haematite (EGS 35 and EGS 36), which displayed frequent micro-striations, and for one artefact (EGS 35), highly levelled grains resembling stone-on-stone wear. The latter wear feature may be attributed to the hardness of the ground haematite piece, which is comparable to hard stone material. Residues occurring on filing stones often display directionality indicating the direction of tool-use. On coupled stones, residues often appeared deep within the interstitial spaces of the sandstone where they have been wedged in by pressure from the other stone.

Use-wear traces also varied depending on the worked material, i.e., the material that was in direct contact with the sandstone surface. This variation is likely related to the pliability of the material being processed (e.g., elastic/inelastic properties) and its internal composition (i.e., silica content, degree of hydration, and presence of natural lubricants such as oils or fats). The properties of the worked material will affect use-polish formation and the rate at which quartz grains are modified or worn away. At high magnification, wear traces associated with the broad categories of worked material were distinguished on the harder sandstone artefacts, recognised between 10 – 120 min of grinding. EGS 35, a filing stone used to process haematite (Experiment 18), was the fastest (along with EGS 13 discussed previously) to develop diagnostic use-wear indicative of worked material. Haematite residues were visible after one contact stroke, and continued to build up on the

artefact surface as grinding continued. After 10 min, the surface of EGS 35 appeared highly levelled and striations were visible macroscopically, occurring both as alignments in the residue and as scratches or furrows on the stone surface. At high magnification, the artefact displayed an undulating use-polish and micro-striations were present on individual quartz grains. The other artefact used to process haematite, EGS 36 (Experiment 19), also displayed similar wear at high magnification, although this artefact took longer to develop macroscopic use-wear than EGS 35, which was only visible after 25 min of grinding. As with EGS 35, red pigment residues were abundant, distinctive and could not be removed with rinsing or scrubbing. The longer processing time required on EGS 36 to develop macroscopic grinding wear is probably the hardness of the haematite piece that was being worked, which will vary depending on the habit of the haematite (i.e., specular or massive) and the relative proportions of iron hydroxide minerals comprising the haematite (e.g., goethite, limonite); as well as operator variance (CC conducted Experiment 18; EH conducted experiment 19). Because residues quickly accumulated on both artefacts within the first 5 min of grinding and could not be removed easily, I suggest that grinding stones used to process pigments may be recognised after <10 min of grinding. In the absence of residues, pigment processing tools can be recognised by diagnostic use-wear traces within 10 – 25 min of grinding.

Filing stones used to process other materials such as bone (EGS 3) and wood (EGS 4) also displayed several distinctive use-wear features visible at high magnification, recognised after 60 min of processing. For the harder sandstones, the use-wear features included, for bone: a striated, smooth pitted use-polish, micro-fractures, and abundant, uni-directional micro-striations; and for wood: a domed/pitted reticular use-polish, micro-fractures and (less abundant) micro-striations (Table 6.7). These features became better developed as processing time continued. The use-wear observed on the softer sandstones used to process wood and bone did not display diagnostic use-wear at high magnification, but macroscopic grinding wear was visible within 5 min of grinding (Table 6.8).

Coupled stones made from the harder sandstones that were used to process seeds and wheat displayed diagnostic use-wear traces indicative of worked material. All but one set of artefacts (EGS 17 and EGS 25) displayed a moderate to high level of grain rounding and levelling with a bright, reticular use-polish that was visible at high magnification after 60 – 120 min of grinding (Table 6.8). Other coupled stone artefacts, including those used to pound seeds and bone, took slightly longer to generate wear traces diagnostic of worked material. Although all of these artefacts displayed distinctive grinding wear after 10 – 20 min of grinding/pounding, they usually took between 75 and 120 min to develop wear features indicative of worked material (Table 6.8).

Coupled stones used to grind seeds produced the most distinctive use-polish that was consistent across the used stone surfaces. Although variation existed in the extent of use-polish development, coverage and brightness, use-polish morphology was described on all seed grinding artefacts as reticular (Table 6.7). The most developed wear was observed on EGS 28 and EGS 12, used to process warrego grass seeds for 240 min (Experiment 7). Both artefacts displayed macroscopic traces of grinding after 10 – 15 min of use and use-wear traces that were diagnostic of worked material after 65 min of grinding. The grinding wear on both artefacts (identified macroscopically and at high magnification) became progressively more distinctive as grinding continued, existing firstly as weakly developed surface abrasion in localised zones, and later becoming increasingly developed and interconnected (Plate 6.27). Use-duration is therefore an important factor influencing the form of use-wear and specifically, the formation of use-polish.

While evidence for the grinding of seeds and cereals may be identified on artefacts that have been used for up to 120 min, it is not possible to distinguish the specific taxa of plant processed by use-wear analysis alone. It is possible, however, to distinguish between the processing of hard and soft plant material, including small hard-cased seeds and softer plant material, through the characterisation of the use-polish documented at high magnification. Harder seeds are less pliable than other forms of softer plant materials, including leaves, underground storage organs, roots and some larger seeds. Use-polish resulting from the processing of harder seeds will be restricted to the highest grains with low or no use-polish development within the lower interstitial spaces of the sandstone. Use-polish resulting from the processing of softer, more pliable plant materials will extend into the lower recesses/interstitial spaces of the sandstone as these areas will be in direct contact with the worked materials. However, distinguishing between use-polish produced from soft or hard plant processing is only possible after working for longer working durations (>60 min). For example, the hard sandstone wood filing tool (EGS 4) displayed a similar use-polish to seed processing tools after 60 min of grinding. After 120 min, the wood and seed/cereal processing tools could be distinguished by the abundance of micro-striations, which were far more common on the latter artefacts as a result of the incidental stone-on-stone contact when grinding. Rather surprisingly, the hard sandstone artefact used to sharpen the stone axe (EGS 18), also displayed reticular use-polish (Plate 6.17) similar to that identified on the plant processing tools. Micro-striations were also abundant within the use-polished area resulting from direct stone-on-stone contact. As use-polish formation is heavily influenced by the silica content of the worked material (see Fullagar 1991), then the processing of volcanic stones may also produce a silica use-polish similar to that documented on plant processing tools. High magnification examination of individual

Table 6.8: Time taken for diagnostic grinding wear and use-wear diagnostic of worked material to develop on the experimental artefacts used to process a range of materials.

Artefact number	sandstone number	stone type	worked material	Time taken for use-wear diagnostic of grinding to develop	Time taken for use-wear diagnostic of worked material to develop
EGS 1	4	US	wheat	10 mins	45 mins
EGS 2	4	FS	wood	40 mins	120 mins
EGS 3	2	FS	bone	10 mins	DND
EGS 4	2	FS	wood	10 mins	DND
EGS 5	4	US	bone	40 mins	120 mins
EGS 12	1	LS	Warrego grass seeds	10 mins	65 mins
EGS 13 (side 1)	2	FS	stone (basalt)	5 – 10 mins	10 mins
EGS 13 (side 2)	2	FS	stone (dolerite)	5 – 10 mins	10 mins
EGS 15	2	LS	wheat	10 mins	45 mins
EGS 16	2	LS	Kangaroo grass seeds	10 mins	90 mins
EGS 17	3	LS	acacia seed	15 mins	DND
EGS 18	5	FS	stone (basalt)	15 mins	60 mins
EGS 19	2	LS	Kurrajong seeds	15 mins	60 mins
EGS 20	3	LS	bone	15 mins	30 mins
EGS 23	1	US	acacia seed	15 mins	120 mins
EGS 24	1	US	Kurrajong seed	15 mins	60 mins
EGS 25	1	US	Acacia seed	15 mins	120 mins
EGS 28	1	US	Warrego grass seeds	10 mins	65 mins
EGS 29	1	US	Kangaroo grass seeds	10 mins	90 mins
EGS 31	1	LS	Warrego grass seeds	20 mins	150 mins
EGS 32	1	LS	Acacia seed	10 mins	120 mins
EGS 33	1	US	Warrego grass seeds	10 mins	85 mins
EGS 34	river cobble	US	bone	15 mins	30 mins
EGS 35	4	FS	haematite	<10 mins	10 mins
EGS 36	4	FS	haematite	25 mins	25 mins
EGS 38	4	FS	stone (sandstone)	10 mins	60 mins
EGS 39	4	FS	stone (sandstone)	10 mins	60 mins

quartz grains comprising the sandstone has indicated that micro-scarring is abundant and far more common on the axe sharpening stone (Plate 6.17g). Further distinction between the axe and plant processing tools can be achieved through residue analysis: plant residues are visually distinctive from inorganic minerals and biochemical tests, specific for certain biomolecules found in plants, (e.g., carbohydrates, proteins) may identify these products.

The mode of use (i.e., grinding, pounding), was also distinguishable on all artefacts even when the worked material remained constant. Stones that were used to grind or file a material often displayed frequent striations and directionality of the smeared residues; while sandstones that were used to pound materials displayed macroscopically visible pounding damage and frequent micro-scarring, distinguished at high magnification. Harder sandstones that were used to file softer, more pliable materials, took the longest to develop distinctive grinding wear. Distinctive pounding wear was visible macroscopically after 10 min on tools that were used to crack and crush kurrajong seeds (Experiment 11—EGS 19 and EGS 24), *Acacia* seeds (Experiment 10—EGS 17 and EGS 25) and bone (Experiment 3—EGS 20 and EGS 34).

My experiments did not include the evaluation of use-wear on multi-functional implements used to process more than one material. However, some of the ethnographic specimens that I observed were used to process more than one seed variety, and this was reflected in the use-wear on these stone artefacts. Striations were more apparent on the ethnographic seed grinding tools compared to the experimental seed grinding tools, which were often only characterised by fine striations that were oriented in the same direction. As discussed previously (Section 6.3.3), this may be the outcome of different processing techniques, stone material, duration of use, processing environment and the accumulation of wear traces associated with curation and discard. From this experimental data set, I propose distinctive grinding wear can be recognised after relatively short time periods: for most sandstone artefacts, grinding wear was recognised macroscopically after less than 30 min of grinding. For quartzite artefacts used to process more pliable materials, such as bone and wood, grinding wear may only be distinguished (using a microscope) after 15 – 25 min of grinding and macroscopically after processing times exceeding 40 min. Archaeological grinding stones that have been used for durations exceeding 25 min will be able to be recognised, if not macroscopically, then under microscopic conditions. In my experiments, the use-wear associated with the processing of seeds and cereals may be distinguished at high magnification after 30 min of grinding for some varieties, while other seeds take longer to produce distinctive use-wear traces (up to 120 min). I suggest that archaeological artefacts used for durations exceeding 120 min will be able to be recognised. While residue analysis of the experimental grinding stones was not included

in the development of my use-wear reference library (but see Hayes *et al.* 2014b), I suggest that the integration of residue analysis will further enhance functional interpretations.

6.5 Blind tests

In addition to the experiments described above, a number of “blind tests” were performed on sets of experimental grinding stones ($n = 15$) prepared at the University of Liège (ULg), Belgium, to determine whether traces of use on grinding implements are interpretable in practice. The blind tests have enabled me to evaluate the applicability of the use-wear reference library on grinding stones of an unknown function. Blind tests involve the examination of a set of experimental stone tools (in this case, grinding stones) that have been used in a controlled setting by an external participant. The aim for the analyst is to determine tool function by referring to previous experimental findings using a use-wear reference library. The tests not only provide an evaluation of the analyst’s ability, but also highlight any problems associated with identification, gaps in the experimental reference library, and the limits of functional inferences (e.g., Hamon & Plisson 2008; Keeley & Newcomer 1977; Lombard & Wadley 2007; Newcomer *et al.* 1986; Odell & Odell-Vereecken 1980; Rots 2010; Rots *et al.* 2006; Wadley *et al.* 2004; Wadley & Lombard 2007). Although most published accounts of blind testing provide functional interpretations of experimental flaked stone tools, blind tests performed on experimental sandstone grinding stones have indicated that accurate functional interpretations may be achieved (Hamon & Plisson 2008).

6.5.1 Experimental design and analytical procedures

Fifteen experimental grinding stones were used to process a variety of inorganic and organic materials at the ULg, by experienced tool maker Christian Lepers (Table 6.9). The grinding tools were made on sandstone river cobbles that displayed a high degree of natural surface wear as a result of water and sediment friction, creating surface grains with a high degree of grain rounding. The range of potential processed materials were not disclosed prior to analysis, but included bone, shell, antler, oily seeds, cereals, stone, clay and ochre (Table 6.9; Plate 6.27). All materials were ground for 10 - 25 min. Following use, each stone was rinsed with tap water to remove surface residues and given a ULg reference number. Coupled stones that were used in conjunction to process the same intermediate material were given the same reference number, specifying which was used as the

Table 6.9: ULg laboratory code, stone material, grinding stone type, material processed, activity and duration of use for experimental tools comprising the blind tests

ULg GS number	Stone material	GS type	Worked-material	Activity	Use duration
1	sandstone	filing stone	stone	axe grinding	25 mins
2	sandstone	filing stone	antler	antler working	20 mins
3	sandstone	filing stone	shell	shell working	20 mins
4	sandstone	filing stone	bone	sharpening bone	20 mins
5	sandstone	filing stone	wood	sharpening wood	10 mins
6	sandstone	lower stone	clay	grinding dry clay	20 mins
6'	sandstone	upper stone	clay	grinding dry clay	20 mins
7	sandstone	lower stone	linseed	extraction of linseed oil	18 mins
7'	sandstone	upper stone	linseed	extraction of linseed oil	18 mins
8	sandstone	lower stone	cereal	cereal processing	15 mins
8'	sandstone	upper stone	cereal	cereal processing	15 mins
9	sandstone	lower stone	ochre	pounding ochre for powder	15 mins
9'	sandstone	upper stone	ochre	pounding ochre for powder	15 mins
10	sandstone	lower stone	wheat	wheat processing	18 mins
10'	sandstone	upper stone	wheat	wheat processing	18 mins

upper and lower stones. All artefacts were examined in the “TraceoLab” Microscopy Laboratory at the ULg using three microscopes: (1) Zeiss V16 stereomicroscope with external light sources; (2) Zeiss Axioscope A1 metallographic microscope with vertical incident light (brightfield and darkfield) equipped with a long working distance stage; and (3) Zeiss Axioscope A1 transmitted light microscope fitted with DIC and polarising filters. Use-wear features were documented following the same procedure as the experimental and ethnographic artefacts (Section 5.4.3; Table 5.2). Residues were removed from the artefact surfaces using distilled water pipette extractions, or, where macroscopic residues were visible, removed with clean metal tweezers. Removed material was mounted on slides (Section 5.5.2.1) and examined under transmitted light. The staining agent Orange G was applied to selected residues to confirm the presence of collagen. Descriptions of the use-wear and residue traces identified on these experimental artefacts are presented in Tables B5 and B6 (Appendix B).



Plate 6.27a-c: Christian Lepers conducting grinding experiments on sandstone artefacts for blind testing: a) using grinding stones ULg 9 and 9' to prepare ochre; b) using grinding stones ULg 10 and 10' to grind wheat; c) using grinding stones ULg 6 and 6' to crush clay.

6.5.2 Summary of results: blind tests

Tables 6.10, 6.11 and 6.12 provide a summary of the functional interpretations given to this set of experimental artefacts based on the evidence obtained through use-wear and residue analyses. I had a 93% success rate (14 of 15 tools) for identifying the worked surface of the artefact after 10 – 25 mins of contact. I had a 60% success rate (9 of 15) for determining the broad categories of worked material (i.e., inorganic, plant and animal) based on use-wear alone and an 85% success rate (12 from 15) for determining the material processed based on use-wear and residues combined (Table 6.10). The inability to identify use-wear diagnostic of worked material on six of the experimental grinding stones (ULg GS 2, 5, 6, 6', 10 and 10') is probably related to the limited processing time (10 – 20 mins) resulting in the weak development of distinctive use-wear traces. With the inclusion of residue analysis, interpretations of tool use were greatly enhanced, enabling the worked material for three of the six unknowns (ULg GS 5, 10 and 10') to be determined. Residues removed from the nine other grinding specimens supported my use-wear observations, creating an additional line of evidence to justify my interpretations (Table 6.10). The integration of use-wear and residue analysis has, therefore, led to a greater confidence in my functional interpretations, specifically, the nature of the worked material.

The three broad categories of worked materials (i.e., inorganic, plant and animal) were correctly identified for 12 of the 15 analysed stones (85%) after use-wear and residue analyses were performed. All plant processing tools ($n = 7$) were correctly identified, with 60% (3 from 5 tools) correctly identified as inorganic processing tools, and 66% (2 from 3) correctly identified as animal

Table 6.10: Interpretation of worked-material of blind test tools after use-wear and residue examination.

ULg GS no.	Interpretation of worked material:					
	use-wear analysis	correct Y/N	use-wear and residue analysis	correct Y/N	use-wear and residue analysis: broad categories of worked material	correct Y/N
1	stone	Y	stone	Y	inorganic	Y
2	unknown	-	unused	N	unused	N
3	bone or shell	Y	bone	N	animal	Y
4	bone	Y	bone	Y	animal	Y
5	unknown	-	starchy plant	Y	plant	Y
6	unknown	-	animal?	N	animal	N
6'	unknown	-	unknown	-	unknown	-
7	oily seed	Y	oily seed	Y	plant	Y
7'	plant	Y	plant	Y	plant	Y
8	hard-cased seed/ cereal	Y	hard-cased seed/ cereal	Y	plant	Y
8'	hard-cased seed/cereal	Y	hard-cased seed/ cereal	Y	plant	Y
9	pigment	Y	ochre	Y	inorganic	Y
9'	pigment	Y	ochre	Y	inorganic	Y
10	unknown	-	starchy plant	Y	plant	Y
10'	unknown	-	starchy plant	Y	plant	Y
	<i>total correct</i>	9/15	<i>total correct</i>	11/15	<i>total correct</i>	12/15
	<i>% correct</i>	60%	<i>% correct</i>	73%	<i>% correct</i>	85%

processing tools. The two tools that were used to process inorganic materials that were incorrectly identified (ULg GS 6 and 6') were used to process clay. This activity was not included in my experimental program and therefore the use-wear associated with clay processing had not been documented. However, on these artefacts, an "undulating" use-polish was recognised, similar to that described for other inorganic mineral processing tools, such as haematite and ochre (Section 6.2.3.7). Interestingly, multiple varieties of residues were also identified on the clay processing tools, including both plant and animal tissues (Table B6). Further examination of the clay material is required to determine the presence of plant and collagen fibres within the clay itself, which may cause misleading residue interpretations.

The remaining artefact that was misidentified was the sandstone filing tool used to work antler (ULg GS 2). My grinding experiments did not include the processing of antler as this is a material not processed in Australia. Macroscopically and at low magnification, the surface of the artefact did not appear to display visible traces of grinding wear, and I suggested that this tool was

Table 6.11: Interpretation and actual use of experimental artefacts comprising the blind tests.

<i>ULg GS no.</i>	Interpretation: use material/activity	Actual: use material/activity
1	axe grinding	axe grinding
2	unknown	antler working
3	bone filing	shell working
4	bone filing	sharpening bone
5	starchy plant processing	sharpening wood
6	unknown—animal processing?	grinding dry clay
6'	unknown	grinding dry clay
7	oily seed/starchy plant	extraction of linseed oil
7'	Plant processing	extraction of linseed oil
8	hard-cased seed/cereal	cereal processing
8'	hard-cased seed/cereal	cereal processing
9	ochre processing	pounding ochre for powder
9'	ochre processing	pounding ochre for powder
10	starchy plant processing	wheat processing
10'	starchy plant processing	wheat processing

unused. The lack of distinctive grinding wear on the antler processing tool was probably the result of the limited working time. As demonstrated through my experiments, pliable materials such as wood and bone do not readily produce distinctive use-wear on harder sandstone artefacts until at least 40 min of grinding. As antler has similar characteristics to bone, I would expect that the bone filing stone used in my experiments may be analogous to the wear on the antler processing stone that was part of this blind test. Consequently, I would not expect distinctive use-wear traces to be identified in less than 40 min of grinding.

Experimental tools comprising part of this blind test that were used to process wood and bone were correctly identified after residue analysis. The experimental wood processing tool (ULg GS 5) did not display any distinctive traces of use to imply the processing of wood (although grinding wear was evident but only under high magnification). This tool was suggested as a wood processing tool after residue analysis had revealed abundant lignin, large wood fibres, cellulose and starch, indicating the worked material was of plant origin. Although a striated use-polish was identified on experimental filing stone used to work bone, the use of this artefact to process this material was only confirmed after residue analysis. Bone residues were visible on the artefact surface and observation of extracted residues and subsequent staining with Orange G indicated that collagen was present in relatively large abundances. The lack of diagnostic use-wear traces on the grinding

Table 6.12: Interpretations of the broad categories of worked materials based on use-wear and residue analyses. *Blue dots indicate analyst interpretation of worked material; red dots represent the worked material.*

ULg GS number	Processed material				correct Y/N
	Inorganic	Organic		Unknown/ unused	
		Plant	Animal		
1	<div><div></div><div></div></div>				Y
2			<div><div></div></div>	<div><div></div></div>	N
3			<div><div></div><div></div></div>		Y
4			<div><div></div><div></div></div>		Y
5		<div><div></div><div></div></div>			Y
6	<div><div></div></div>		<div><div></div></div>		N
6'	<div><div></div></div>		<div><div></div></div>		N
7		<div><div></div><div></div></div>			Y
7'		<div><div></div><div></div></div>			Y
8		<div><div></div><div></div></div>			Y
8'		<div><div></div><div></div></div>			Y
9	<div><div></div><div></div></div>				Y
9'	<div><div></div><div></div></div>				Y
10		<div><div></div><div></div></div>			Y
10'		<div><div></div><div></div></div>			Y
SCORE	3/5	7/7	2/3	n/a	12/15
% correct	60%	100%	66%	n/a	80%
Total percentage correct					80%

stones used to process these more pliable materials suggests that a processing time of 10–20 mins is too short to adequately produce use-wear traces diagnostic of wood or bone processing. However, the rapid accumulation of residues after as little as 10 min of working ensures that functional interpretations may still be achieved through documentation of residues, assuming they can survive archaeologically.

In addition to the misidentification of the antler processing tool, one other animal processing tool was erroneously attributed to the processing of bone. This artefact (ULg GS 3), which was used to process shell, was described as a “bone or shell processing tool” following microscopic examination. This interpretation was based on the identification of white organic material smeared within the lower micro-topographies of the sandstone matrix. Following residue analysis, the material was misidentified as bone, despite failure of Orange G to confirm the presence of collagen.

The tool functions of all the remaining experimental grinding stones were correctly identified. Four of the seven plant processing tools displayed reticular use-polish morphology similar to that described previously (Section 6.2.4.2; Table 6.7), one displayed a “domed morphology” (ULg GS 10') and the remaining two were described as un-diagnostic (Table B5). The lack of developed use-polish on these two artefacts (ULg GS 5 and ULg GS 10) may be the result of limited processing time. ULg 10 and 10', which were used to process wheat for 18 min, did not display use-wear traces with enough development to confidently assign tool function. Indicated by my experiments, tools used to process wheat require at least 30 min of contact with the worked material to produce diagnostic use-wear traces. Similarly, the filing stone used to sharpen wood did not display any distinctive use-wear features. However, following residue analysis, all three artefacts were correctly assigned a plant processing function. These artefacts, along with the other four plant processing tools, contained residues that were consistent with the processing of plant materials. The residues identified included starch grains, phytoliths, plant cells and other plant tissues.

The two stones used to process ochre (ULg GS 9 and 9') displayed a large amount of macroscopic red pigment residues that remained on the artefact even after washing. At high magnification, surface use-polish was described as “undulating”, which was noted on other experimental pigment processing tools and the tools used to process other inorganic minerals such as clay. Examination of removed residues also indicated a large amount of red pigment crystals that were subsequently identified as ochre.

The remaining artefact (ULg GS 1) was correctly identified as an axe grinding tool. This identification was made after assessing the artefact morphology, which displayed a macroscopically dished surface resulting from contact with a much harder material. Grain fractures on this stone were frequently observed on the grinding surface at high magnification, indicating contact with a hard material *cf.* volcanic stone. No organic material was identified in the residue samples, as a consequence this tool was attributed to the grinding of a stone axe.

The results of the blind test have indicated that the use-wear reference library is suitable for comparisons of wear features on artefacts that have an unknown function. However, the use-wear library is not always applicable for specimens used for very short durations, in which use-wear traces appear only weakly developed and are, therefore, un-diagnostic of worked material. The inclusion of an additional line of evidence in the form of residue analysis has greatly enhanced my interpretations for the function of tools comprising these blind tests. Consequently, I suggest residue analysis is an important method for determining artefact function, and should be included in all functional studies.

6.6 Chapter Summary

Analysis of experimental and ethnographic grinding stones has provided the basis for creating a use-wear reference library for sandstone tools. I have supplemented the wear descriptions with residue observations. Other published experimental data sets have shown that diagnostic use-wear traces may be identified on grinding implements made on sandstone, granite, basalt and other stone materials (Table 6.1). These have shown that distinctive grinding wear can form on a range of stone materials that is often recognised macroscopically or at low magnification, and that after certain durations, use-wear may be diagnostic of broad categories of worked materials, including bone, stone, wood, hide, clay, shell, ochre, soft plants, cereals and hard and soft seeds. I have supplemented previously documented experimental assemblages with a set of new experiments that were tailored for two archaeological sandstone assemblages from central and northern Australia. I focussed on generating wear on hard and soft sandstones that had been used to process a range of materials documented ethnographically, and also include a range of resources that cover the broad classes of resources likely to have been ground in the past: soft plant, wood, bone, pigment and mineral. My experiments, although not comprehensive themselves, in conjunction with previous studies, provided the basis for constructing a use-wear reference library that has indicated distinctive, diagnostic and overlapping patterns of wear linked with particular aspects of function at various stages of development.

My experiments have demonstrated that use-wear traces will vary in part as a consequence of sandstone hardness. Soft sandstones will display macroscopically visible traces of grinding wear but often do not possess traces at high magnification that are distinctive of worked material. Alternatively, hard sandstones require longer processing times to develop macroscopically visible traces of grinding wear, but are more likely to possess use-wear traces diagnostic of worked material (visible under high magnification)—assuming processing time exceeds that required to produce such wear. For this reason, stone material must be taken into account when performing functional analysis.

Chapter 7:

Results of use-wear and residue analyses performed on MJB and Lake Mungo grinding stones

7.1 Introduction

Functional interpretations of archaeological tools require an integrated approach involving the identification and recording of three key features. These include: (1) tool morphology; (2) use-wear features; and (3) the presence of residues either visually identified or detected at a molecular level (i.e., the detection of non-visible biomolecules). Functional analyses undertaken by others, and my own investigations of experimental and ethnographic artefacts, have demonstrated that grinding wear on sandstone and quartzite tools can be distinguished from other forms of wear (e.g., weathering), and can sometimes be diagnostic of tool motion (e.g., grinding, pounding and filing) and the broad classes of processed materials (Chapter 6). The blind test that I completed (see Section 6.5) provided a high level of confidence in my interpretations of wear and residues on sandstone: 60% success rate for determining the broad categories of worked material (based on use-wear alone after 15 mins of working); and an 85% success rate for determining the worked material (based on use-wear and residues combined). Important forms of use-wear on sandstone tools include variations in the macro and micro topography of the ground surface, constituent quartz grains and the crystalline matrix. The main forms of use-wear on ground stone implements include abrasive smoothing, striations, pits, grooves, use-polish, quartz grain rounding and micro-scarring (Table 5.2). In addition to use-wear, the implement shape, size, and dimensions of the entire ground surface were significant for determining the artefact's life-history, including how it functioned as a tool at different stages (i.e., as an upper, a lower, or a filing stone). Microscopically visible residues and biochemically detected non-visible biomolecules may be indicative of certain processed materials. For example, residues associated with the grinding of seeds may include starch, phytoliths and cellulose, while non-visible adsorbed residues could include lipids, proteins, fatty acids and carbohydrates. The processing of faunal material may result in visually identifiable residues such as collagen, bone, blood and hair, while non-visible biomolecules could include various proteins, amino acids and lipids. In this Chapter, I report on the morphology, use-wear and residue traces recognised on grinding stone implements recovered from MJB and Lake Mungo. Tabulated data sets outlining the key features for each tool are presented in Appendix C.

7.2 Madjedbebe grinding stones

7.2.1 Grinding stone morphology

Ninety-six potential grinding stones and grinding stone fragments were analysed from MJB, comprising all identified grinding stones from the 2012 excavation. Further sorting of sieved

material may add to the grinding stone assemblage, but the stones analysed for this thesis included only the specimens that were plotted during excavation or collected on-site shortly after sieving. All specimens derive from the three main cultural layers and include artefacts from both Holocene (n = 13) and Pleistocene (n = 76) contexts. Two specimens could not be attributed to either context as they were recovered from backfill deposits within the Kamminga trench and their antiquity is not known. Five sandstone fragments were excluded from the analysis as they were considered unused following microscopic examination. Of the remaining 91 specimens, 12 were complete tools and 79 were fragments. Although none of the grinding fragments could be refitted, based on the stone material, artefact size and shape, it is likely several pieces are from the same implement: i.e., L49 and UP GS 2 (both from Square/Spit C5/5—both examined for starch, see Section 7.2.3.2.1) GS 29 and GS 30 (from D1/34); GS 45 and GS 46 (from D2/39A and D2/39); GS 44 and GS 47 (from D2/39A and D2/39); UP GS 10 and UP GS 14 (from D2/25A and E1/26). Most of the stones consisted of fine – medium grained, well-cemented sandstones of varying hardness (n = 80), with fewer quartzite and metamorphic varieties (n = 10) and only one example of volcanic stone (Table 7.1). Following macroscopic examination using a low angled external light source, the number of possible grinding surfaces on each stone was determined (total grinding surfaces = 126). Most of the artefacts displayed only one grinding surface (n = 66), but specimens containing two (n = 18), three (n = 5), four (n = 1) and five (n = 1) ground surfaces were also recognised. Five of the analysed stones did not display any traces of grinding wear, and once examined microscopically (at high magnification) were all classified as unused (Table 7.2). Residue extractions (n = 2) were sampled from one of these unused artefacts (GS 42) to document the range of non-use related residues that were present on the stone surface. In the absence of recognisable use-wear, residues still may have accumulated on the stones, but it would not be possible to relate them reliably to tool-use. In general, the fragments (n = 78) were much smaller than the complete artefacts, ranging in size from 3 g to 2792 g, and with a median mass of 137 g. The complete tools (n = 12) ranged in size from 98 g to 8400 g, with a much larger median mass of 900 g (Table C1, Appendix C).

Of the 126 grinding surfaces present on the 91 tools, most were flat in cross section (n = 81), with 38 surfaces displaying a convex grinding surface and six surfaces displaying a concave surface morphology (Table 7.3, C2). For one of these artefacts with a concave surface (GS 32), the size and shape of the artefact and the presence of hammer damage is consistent with a typological classification as a mortar stone, as defined by McCarthy (1976: 63) and Smith (1985, 1986, 1989b). The remaining concave specimens, which displayed macroscopically worn surface depressions, did not appear dished and do not contain any grooves.

Table 7.1: Stone material of MJB and Lake Mungo grinding stones.

Raw material variety	Number of artefacts / %	
	MJB	Mungo
sandstone	85 / 89%	17 / 100%
quartzite	8 / 8%	0
mudstone	2 / 2%	0
volcanic	1 / <1%	0
<i>stones examined</i>	<i>96</i>	<i>17</i>

Table 7.3: Shape of grinding surfaces on MJB and Lake Mungo grinding stones.

Cross-section morphology	Number of artefacts / %	
	MJB	Mungo
flat	81 / 64%	18 / 69%
convex	38 / 30%	3 / 11.5%
concave	6 / 5%	3 / 11.5%
faceted	0	2 / 8%
<i>total</i>	<i>126</i>	<i>26</i>

Table 7.2: Number of grinding surfaces on grinding stones from MJB and Lake Mungo.

Number of grinding surfaces	Number of artefacts / %	
	MJB	Mungo
0	5 / 5%	0
1	66 / 69%	9 / 53%
2	18 / 19%	7 / 41 %
3	5 / 5%	1 / 6%
4	1 / <1%	0
5	1 / <1%	0
<i>number of stones</i>	<i>96</i>	<i>17</i>
<i>number of grinding surfaces</i>	<i>126</i>	<i>26</i>

7.2.1.1 Post-depositional/discard alteration

Post-depositional/discard alteration was observed in some form on a number of the artefacts (n = 57, ~59%) (Table 7.4), and included:

1. surface weathering, indicated by abrasive wear lacking directionality and grain rounding over much of the artefact, as seen on the unground surfaces (n = 10) (Plate 7.1e),
2. iron oxide staining, indicated by red stained quartz grains, which were probably a natural feature of the sandstone (n = 47) (Plate 7.1b),
3. iron oxide accretion, indicated by a hard thick film that has most likely accumulated after discard and covering the ground surface, obscuring wear traces (n = 2) (Plate 7.1d); and
4. breakage as a result of excavation and transport (n = 7) (Plate 7.1b-c).

Post-depositional residue contamination of the artefact surface in the form of decaying termite nests, rootlets and other organic material, were also observed on a selection of artefacts (n = 24) (Plate 7.1a).

Table 7.4: Post-depositional alteration and contamination identified macroscopically on analysed grinding stones from MJB and Lake Mungo.

	<i>Feature</i>	<i>MJB</i>	<i>Mungo</i>
<i>Type of post-depositional alteration</i>	iron oxide stain within the stone	47	14
	iron oxide accretion (post-depositional)	2	0
	weathered surface	15	9
	broken tool/ fractures post-excavation	8	0
	<i>Total with alteration</i>	<i>57</i>	<i>14</i>
	<i>% assemblage</i>	<i>59%</i>	<i>82%</i>
<i>Type of post-depositional contamination</i>	rootlets	20	1
	termite/insect contamination	6	0
	bacterial spores	4	0
	hyphae	17	1
	lichen	1	2
	patina	2	1
	pen ink	1	0
	metal (non-use related)	2	0
	<i>Total with contamination</i>	<i>52</i>	<i>5</i>
	<i>Total with environmental contamination</i>	<i>49</i>	<i>5</i>
	<i>% with contamination</i>	<i>57%</i>	<i>29%</i>

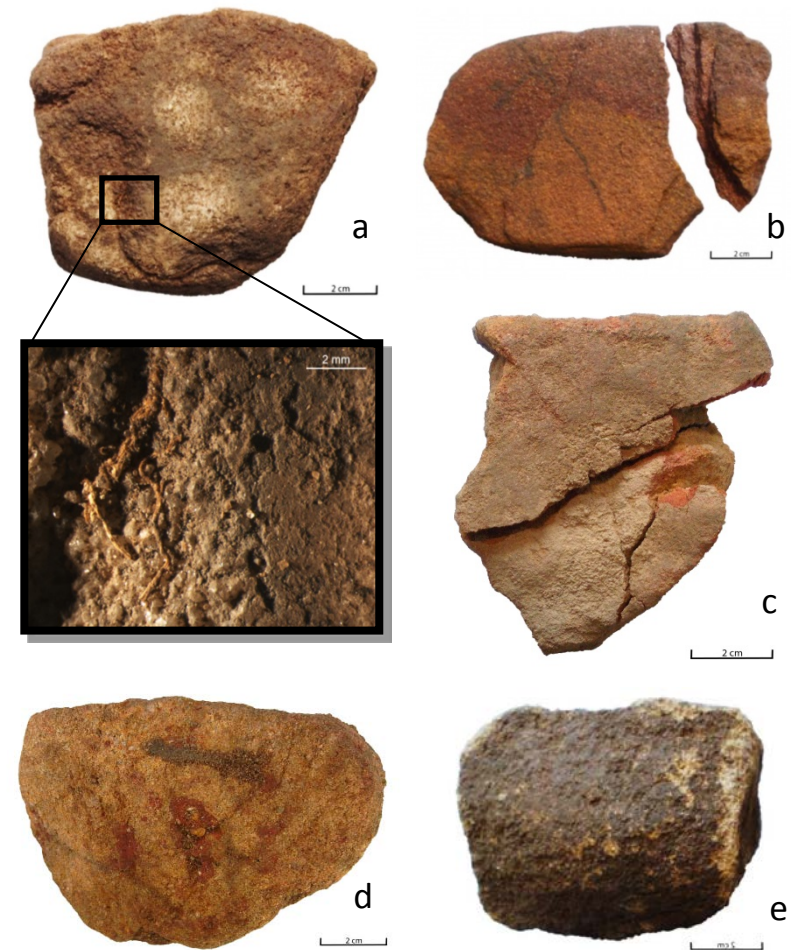


Plate 7.1a-e: Grinding stones from MJB showing post-depositional/discard alteration. **a)** (and inset) rootlet occurring on GS 4; **b)** iron-oxide staining and breakage of specimen GS 5; **c)** breakage and refitting of artefact GS 41; **d)** iron oxide accretion (red) partially covering surface, GS 6; **e)** surface weathering on UP GS 19 (scale is 2 cm).

7.2.2 Use-wear

Macroscopically and at low magnification, the MJB artefacts varied in the degree of grain rounding, frequency of striations and the extent of surface levelling. Some surfaces possessed slight patches of abrasion while others had more distinctive grinding wear with a uniformly worn topography (Table C3; Plate 7.2a-f). About 48% of the MJB grinding stone surfaces ($n = 126$) displayed highly rounded grains ($n = 61$); 41% displayed highly levelled grains ($n = 52$) and 81% displayed macroscopic surface striations ($n = 102$) (Table 7.5-6, C3). At high magnification, wear also differed for each grinding surface, ranging in appearance from weakly developed smoothing to a well-developed, bright, extensive use-polish that was morphologically diagnostic of a particular worked material (Plate 7.3a-h). For many of the MJB specimens, use-polish was comparable to that documented on experimental and ethnographic tools, indicating a range of worked materials including plants and seeds (Plate 7.4), bone and pigment (Plate 7.5). Eight morphological varieties of use-polish were noted: (1) reticular (*cf.* seed grinding and plant processing, $n = 38$ of 126 grinding surfaces examined) (Plate 7.3b-d); (2) undulating (*cf.* pigment processing, expedient plant processing, $n = 26$) (Plate 7.3e-f); (3) striated or “smeared” (*cf.* axe sharpening, bone working, direct stone-on-stone contact— $n = 3$); (4) smooth-domed (*cf.* plant processing) ($n = 1$); (5) rough-domed (*cf.* bone working, $n = 1$); (6) undulating – reticular ($n = 8$); (7) reticular and striated ($n = 6$); or (8) undiagnostic, displaying a disconnected or highly localised, weakly developed formation with no distinctive morphology ($n = 36$) (Table 7.7, C3; Plate 7.3g). Occasionally, multiple use-polishes were observed across the same grinding surface, for example, when a reticular use-polish was recorded with a flat, striated use-polish ($n = 6$), or when most of the surface had an undulating/reticular use-polish morphology ($n = 8$). These morphological use-polish categories sometimes showed intra-group variation in terms of their brightness, extent and development. Micro-striations were sometimes visible on the individual use-polished grains (Table C3).

The variation in the extent and development of key wear features, such as the degree of grain rounding, surface levelling and the development of use-polish, is the outcome of at least five variables. These include: (1) tool stone properties, including raw material and stone hardness; (2) worked material (e.g., plant, animal, mineral); (3) processing technique (e.g., grinding, pounding, filing); (4) duration of use (i.e., expedient versus prolonged use); and (5) taphonomic or weathering agencies. As most of the artefacts were produced on fine-grained, strongly cemented sandstone ($n = 85$), stone tool properties would have been similar for most of the artefacts. In my experiments, I found that use-wear varied on artefact surfaces as a result of the processing technique and the contact with different worked materials. I attribute the variation of wear traces to differences of

	Surface feature	Number of grinding surfaces	
		MJB	Lake Mungo
<i>low mag.</i>	grain levelling	119	25
	grain rounding	120	26
	macro-striations	102	13
<i>high mag.</i>	distinctive polish morphology	83	20
	micro-striations	92	24
	micro-fractures	21	1

Table 7.5: Use-wear features documented on the ground surfaces on MJB and Lake Mungo grinding stones identified under low and high magnification.

<i>Degree of grain levelling</i>	no. of surfaces		<i>Degree of grain rounding</i>	no. of surfaces	
	MJB	Mungo		MJB	Mungo
absent	7	1	absent	6	0
minimal	25	13	slight	8	9
minimal-mod	0	0	slight-mod	8	0
moderate	27	7	moderate	33	7
moderate-high	12	0	moderate-high	9	2
high	52	5	high	61	8
<i>Total</i>	<i>126</i>	<i>26</i>	<i>Total</i>	<i>125</i>	<i>26</i>

Table 7.6: Degree of surface grain levelling/rounding on the grinding surfaces from the MJB and Lake Mungo grinding stones as documented on the most modified area of the surface.

processing technique, the nature of the worked material and the influence of taphonomic and weathering agencies. I suggest that the variation observed on the artefact surfaces reflects a range of processing techniques and worked materials at the site.

Taphonomic and weathering agencies have affected the appearance of use-wear traces on the earliest grinding stones. Wear on artefacts recovered from deposits below 202 cm (i.e., below Spit 39 for all squares but C4) were typically less developed than those identified in more recent deposits. While distinctive grinding wear was still evident on grinding stones from earlier contexts, use-polish was typically undiagnostic of worked material with no distinctive morphological features. I suggest that bioturbation and subsurface movement of sediment grains within the depositional environment has altered the appearance of use-polished surfaces. Experimental replication designed to investigate the effect of bioturbation on use-polished surface has indicated that sediment contact will cause the obliteration of weakly developed use-polished surfaces, although well-developed use-polished surfaces, such as sickle-gloss, will remain intact (Levi-Sala 1986b: 241-242). Wet, gravelly sand was shown to be the most effective at removing use-polish. Levi-Sala (1986b: 234) also noted that mobile sediment contact contributed to the formation of other wear,

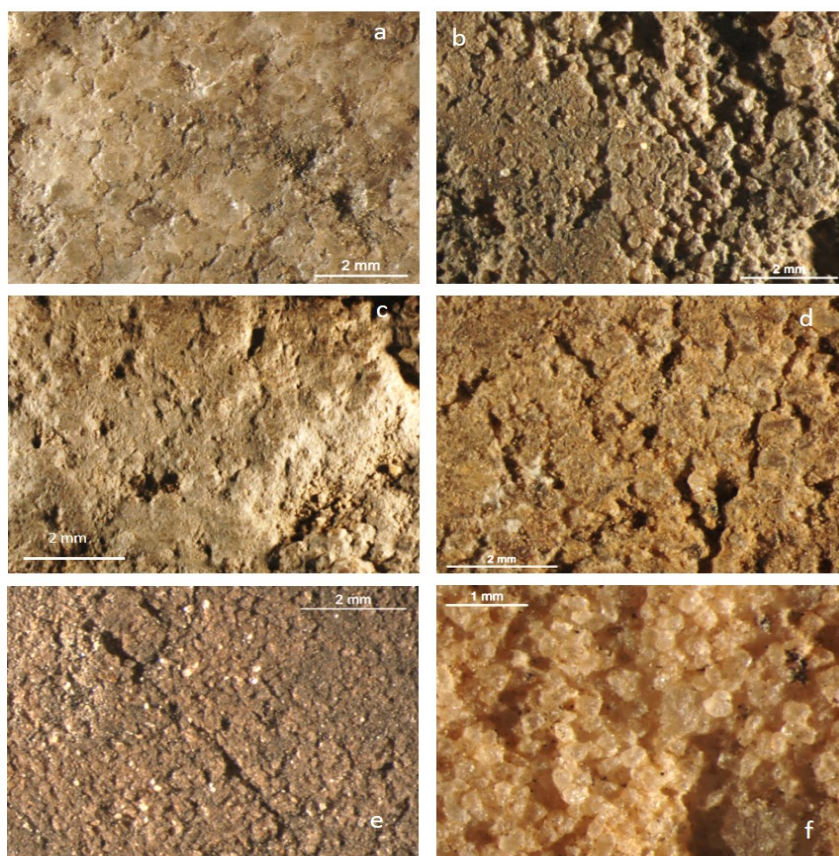


Plate 7.2a-f: Images of the low magnification variation of MJB grinding surfaces: **a)** uniform levelling of the stone surface, UP GS 14; **b)** isolated patches of highly levelled and rounded grains, UP GS 16; **c)** highly rounded but unlevelled grains, UPGS 22; **d)** rounded and levelled grains and deep interstitial spaces resulting from grain plucking, UP GS 27; **e)** deep striation/ furrow, GS 10; **f)** grains showing minimal modification, GS 48.

such as bright spots and striations, although she claimed that these were distinguishable from use-wear. Artefacts buried for long durations may be more susceptible to sand-grain erosion, and use-polish is likely to be altered or removed, particularly on discarded tools with only weakly developed wear.

7.2.3 Residues

7.2.3.1 Visual residue identification (pipette extractions)

Residues were visually identified on all 126 grinding surfaces, examined under transmitted light from samples removed with distilled water and the EWA solvent mixtures using adjustable pipettes. The identified residues occurred most frequently as inorganic mineral crystals (number of surfaces with residue present = 126) and various forms of plant material ($n = 116$) (Table 7.8, C5). The latter included cellulose fibres ($n = 112$), lignified and woody tissue ($n = 48$), intact and gelatinised starch grains ($n = 21$), microfossils such as raphides ($n = 3$), phytoliths ($n = 17$) and pollen ($n = 1$), and various structures of vascular plant tissue such as perforation plates, sieve cells and bordered pits ($n = 6$) (Plate 7.6a-h). Plant fibres such as cellulose were further distinguished through

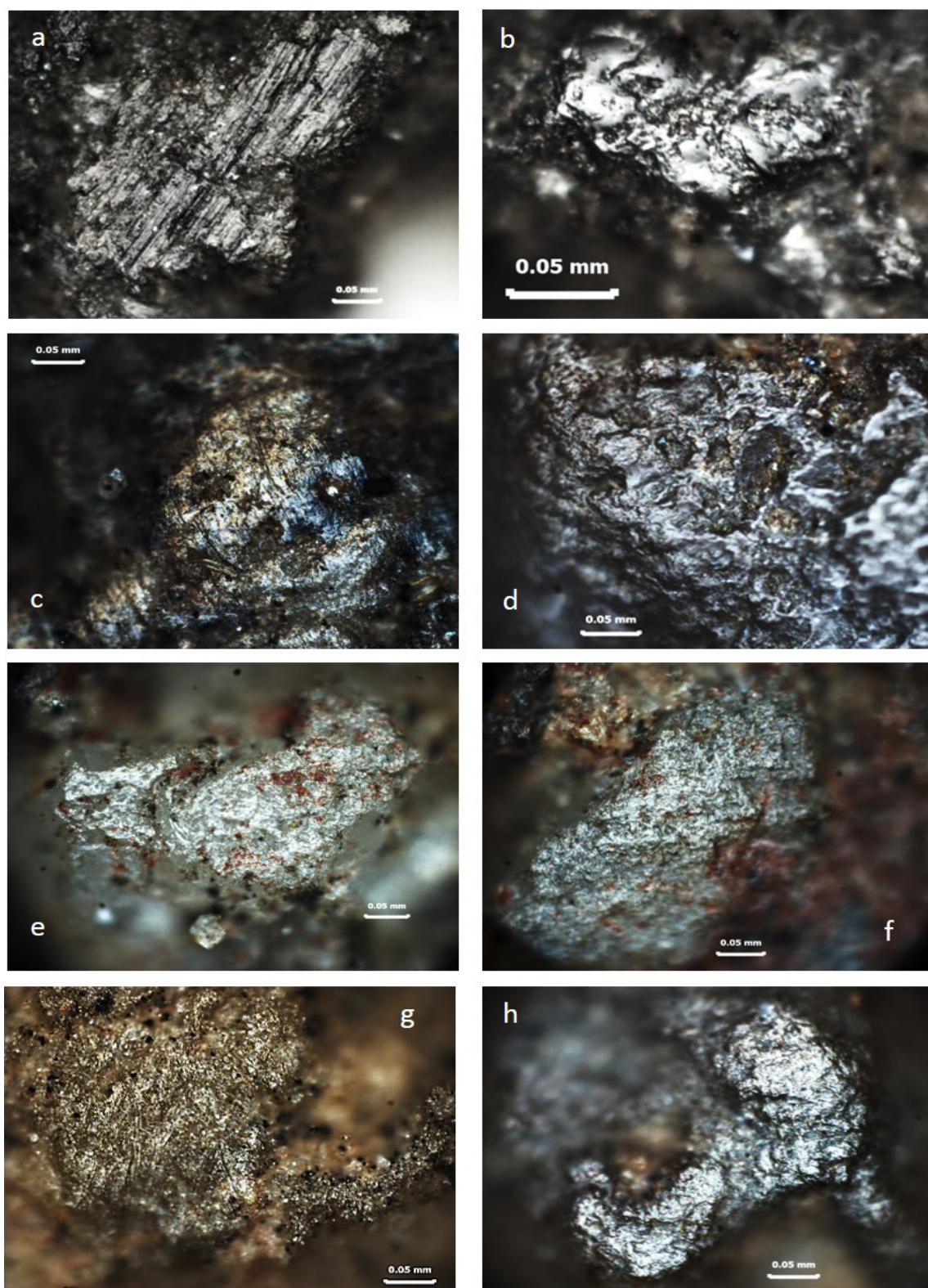


Plate 7.3a-h: Use-polish on MJB grinding stones: **a)** striated use-polish from stone-on-stone contact, GS 2; **b)** reticular use-polish with highly smoothed surface morphology *cf.* silica gloss from plant processing, L49; **c)** reticular use-polish on the highest grain micro-topographies and micro-striations *cf.* small/hard seed processing, GS 30; **d)** reticular use-polish extending into the lower grain micro-topographies, *cf.* soft plant/seed processing or multi-functional use, GS 23; **e-f)** undulating use-polish with scattered pigment residues, *cf.* pigment processing, L813; **g)** non-descript use-polish undiagnostic of worked material, GS 45; **h)** bright, rough-domed use-polish, GS 44.

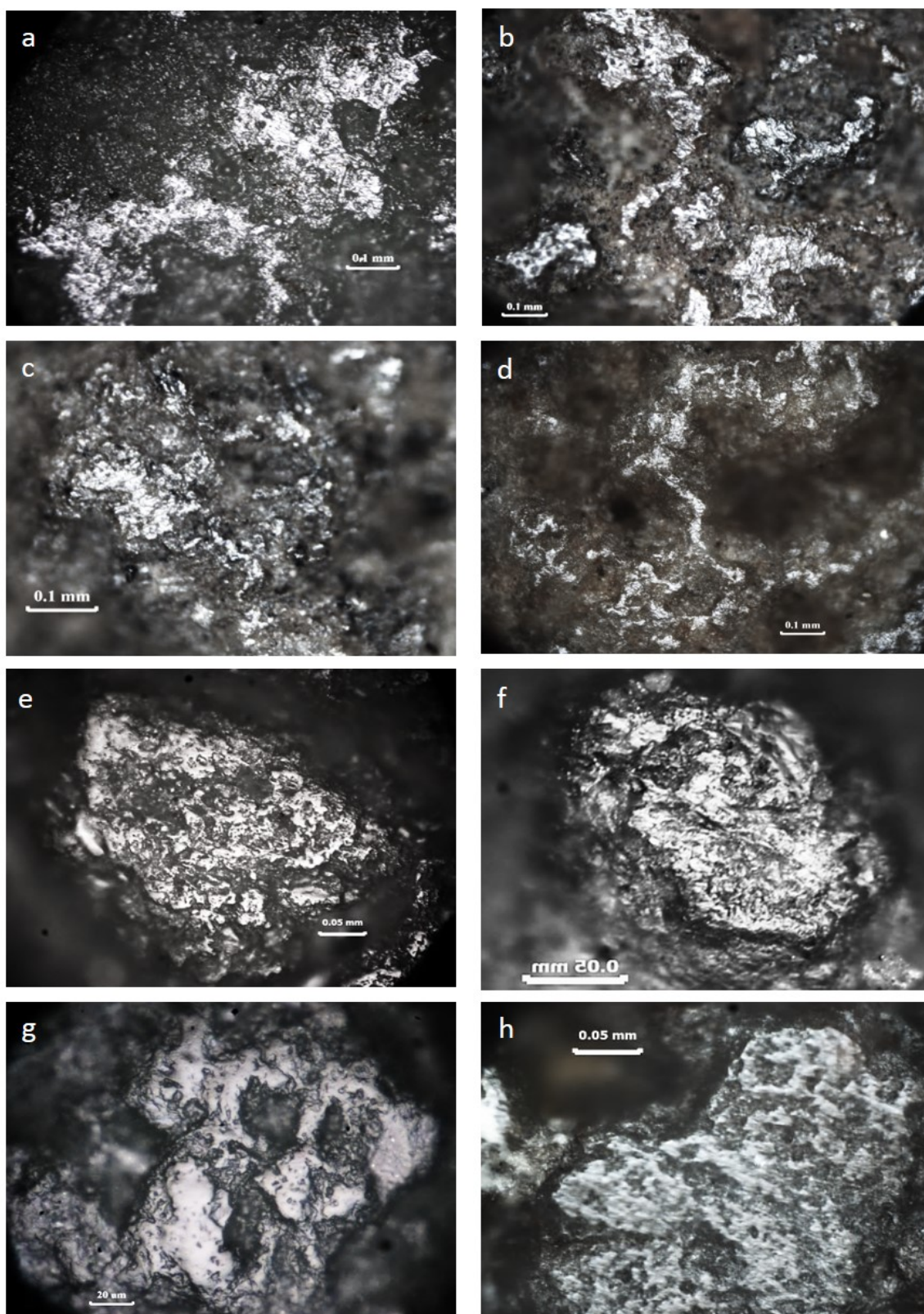


Plate 7.4: Reticular use-polish on experimental and archaeological plant processing tools at high magnification: **a)** experimental artefact EGS 12; **b)** MJB artefact GS 16, Surface 1; **c)** MJB artefact GS 16; **d)** Lake Mungo artefact LM GS 11; **e)** experimental artefact EGS 12; **f)** Lake Mungo artefact LM GS 14; **g)** experimental artefact EGS 28; **h)** Lake Mungo artefact GS 16.

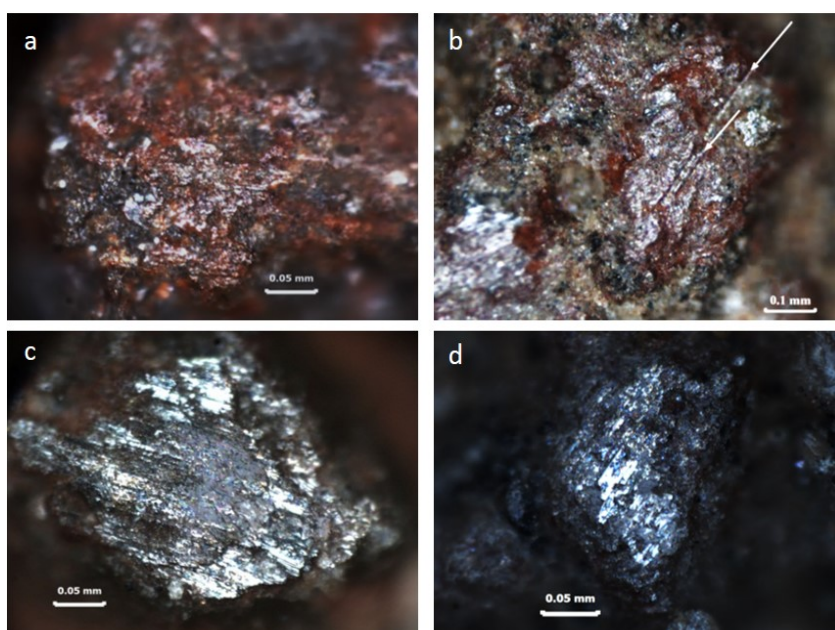


Plate 7.5: Comparison of wear features on experimental and archaeological tools used for the processing of pigment (high magnification): **a)** undulating surface polish with red mineral residues, experimental artefact EGS 36; **b)** undulating surface polish with micro-striations and abundant red pigment, MJB artefact GS 15; **c)** highly levelled grains with metallic, striated residue, experimental tool EGS 35; **d)** metallic, striated residue with parallel alignments, MJB artefact GS 21.

<i>Polish morphology</i>	MJB	Mungo
reticular	38	20
undulating	26	0
striated	3	0
smooth-domed	1	0
rough-domed	1	0
undulating to reticular	8	0
reticular and striated	6	0
un-diagnostic	36	5
absent	7	1
<i>Total grinding surfaces examined</i>	<i>126</i>	<i>26</i>

Table 7.7: Summary of use-polish morphologies identified on grinding surfaces from MJB and Lake Mungo grinding stones.

the application of staining agents Congo Red and Methylene Blue, and intact and gelatinised starch were highlighted using IKI and Congo Red, respectively. Safranin and Phloroglucinol were used to confirm the presence of lignin and tannin structures. The specific stains applied to each residue mixture are outlined in Appendix C, Table C6. While most of the starch identified from the pipette extractions appeared to be damaged (probably as a consequence of grinding), several intact starch grains were also recognised. Phytoliths appeared as rod-like, rigid, rectangular structures while raphides (identified on only two artefacts) displayed symmetrical point terminations. Given the low abundance of other plant related microfossils such as phytoliths, raphides and pollen, taxonomic identification was not possible and contamination cannot be ruled out.

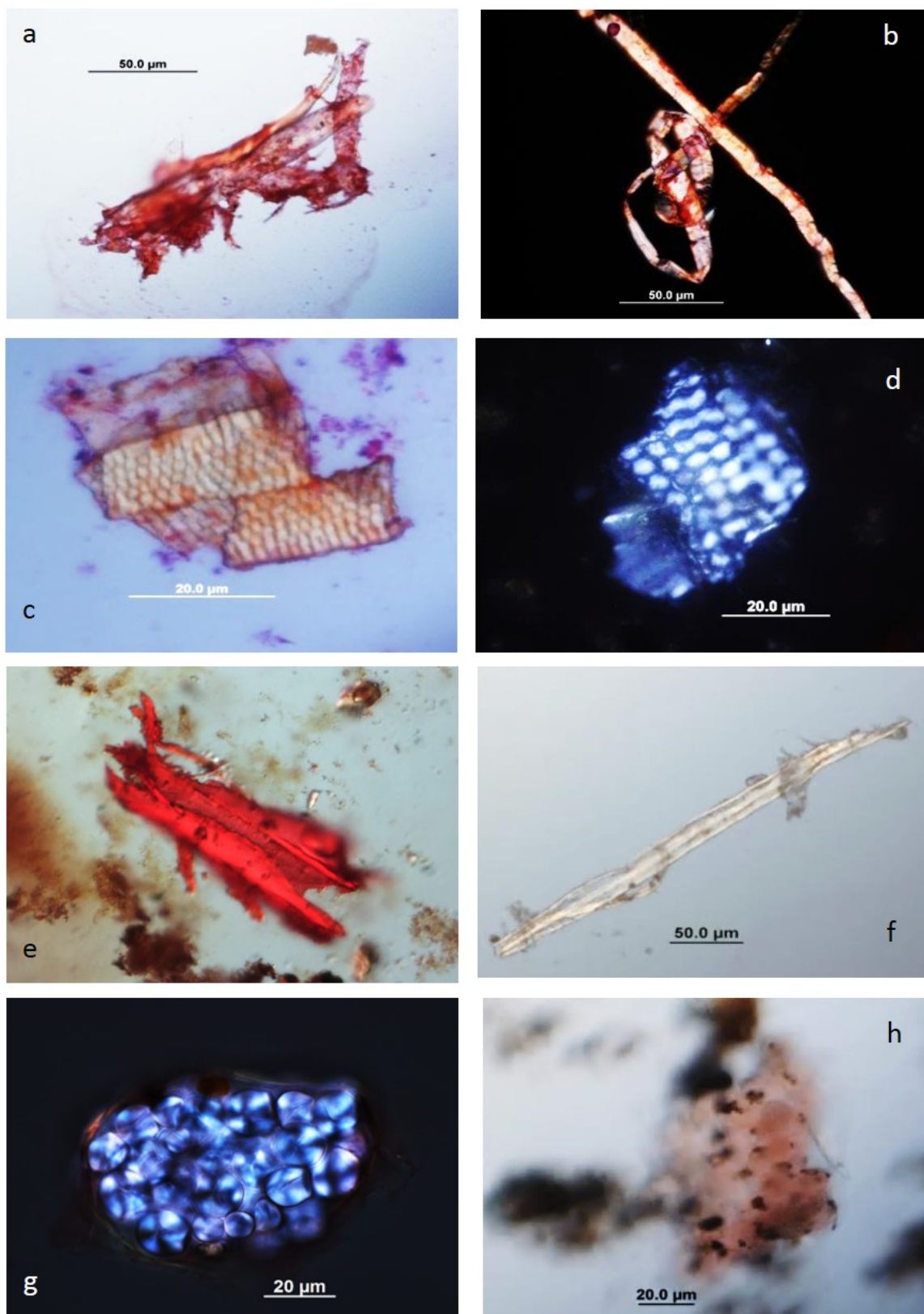


Plate 7.6a-h: Plant residues identified on MJB grinding surfaces: **a)** cellulose fibres stained with Congo Red, L52; **b)** cellulose fibres stained with Congo Red, photographed in cross-polarised light, UP GS 14; **c)** plant cells stained with IKI, R5; **d)** plant cells stained with IKI, photographed in cross-polarised light, GS 3; **e)** lignin stained red with Safranin, UP GS 16 (Surface 1); **f)** lignin stained yellow/brown with Phloroglucinol, GS 24; **g)** intact starch granules, L49; **h)** gelatinised starch stained with Congo Red, GS 1.

Animal residues were less frequently identified within residue mixtures (n = 28 of 126 surfaces) but appeared in the form of collagen (n = 25), bone (n = 4), hair (n = 2) and feather barbules (n = 2) (Table 7.8, C5; Plate 7.7a-f). Collagen was recognised on 25 grinding surfaces, and often occurred as singular fibres only (20 of 25 incidences). In fewer circumstances, collagen was also identified in association with other animal material such as bone (n = 2), hair (n = 1) and feathers (n = 2). Hair and feather barbules were identified as single fibres and often in isolation without other animal materials, and therefore were assumed to be non-use related. The hair fibres (n = 2) were highly degraded and were distinguished following the application of Rhodamine B (for the staining of collagen and keratin) (Plate 7.7c). While the taxonomic origin of the hairs could not be determined owing to the high degree of degradation, the size and width of the hairs has indicated that they are probably down or guard hair from a small mammal. Other keratin structures such as feathers, were also confirmed with Rhodamine B on two additional specimens (UPGS 17 and GS 44) (Plate 7.7d). In both instances, the barbules displayed distinctive spine-shaped nodes of uniform distribution along the length of the barbules, and therefore likely originated from either falconiformes (i.e., birds of prey, e.g., hawks) or galliformes (i.e., fowl-like birds, e.g., chicken) (*cf.* Dove & Koch 2011). Blood tissue could not be visually confirmed on any of the residue samples analysed, although presumptive tests on water extractions with Hemastix® test strips indicated ferrous iron (a principal component of red blood cells) was present on at least 32 of the utilised surfaces, however, many of the positive Hemastix® results were assumed to be the result of environmental contamination (see Section 7.2.3.3). Red and yellow pigments were identified on most artefacts (n = 61), documented *in situ* on the artefact surfaces prior to residue removal (Plate 7.8a-d). Red pigment was identified on 79 grinding surfaces, seven of which also displayed small accumulations of yellow pigment potentially resulting from chemical reduction/oxidation of oxides. I attribute most of the pigment residues to post-depositional and post-excavational handling (and sieving) contamination, as most pigment clusters occur with no apparent pattern that can be attributed to deliberate grinding. Moreover, the use-wear that is present is not consistent with pigment processing (as indicated by the experimental use-wear library, see Section 6.2.3.7). Pigments that were considered to be use-related include those that were present in lower interstices of the grinding surface, those that occurred in abundance (i.e., >20% of the artefact surface) and those that appeared “smeared” or had alignments running through them (Plate 7.5b, d, 8.2c-d, 8.4).

Environmental contamination (i.e., post depositional/discard residue accumulation acquired from surrounding sediments) was identified on 52 artefacts. Residues of this nature included bacterial spores (n = 4), hyphae (n = 17), rootlets and loosely adhering modern cellulose fibres (i.e.

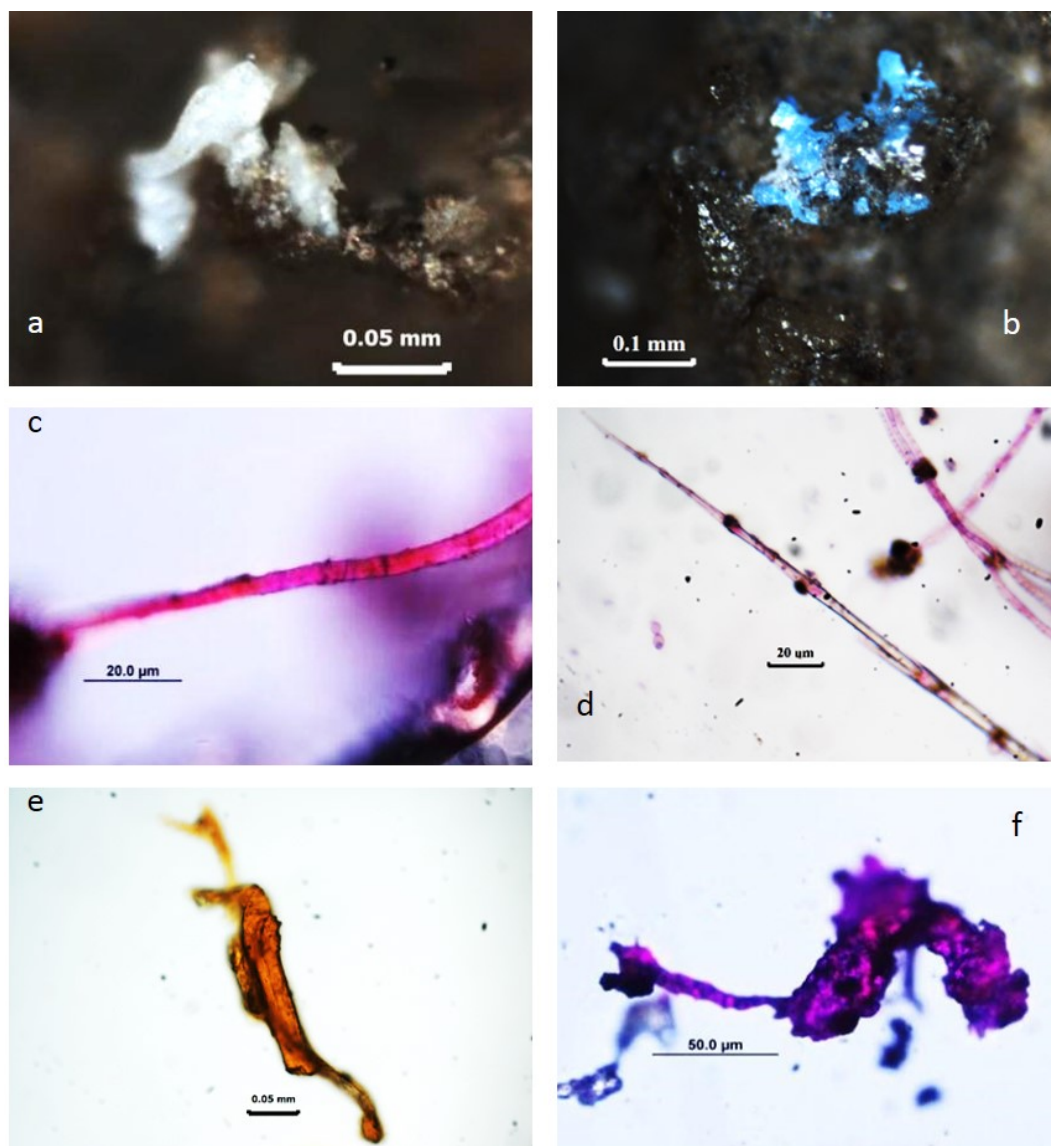


Plate 7.7a-f: Animal residues identified on MJB grinding stones: **a)** bone residue, UP GS 21; **b)** bone residue with blue crystallised mineral Vivianite, UP GS 21; **c)** degraded hair fibre stained with Rhodamine B, UPGS 17; **d)** feather barbule stained with Rhodamine B, UP GS 17; **e)** collagen fibres stained with Orange G, UP GS 26; **f)** amorphous collagen stained with Rhodamine B, UP GS 17.

those that did not display any traces of degradation or mechanical damage), identified on the artefact surface (Table 7.4, C5). Macroscopically visible traces of insect contamination, i.e., the remnants of decayed termite nest fragments (number of artefacts = 6) and large rootlets (i.e., >2 mm thickness; n = 20), were also identified (Plate 7.1a). Post-excavational contamination included metal residues (n = 2), which were likely acquired from contact with metal trowels or sieves, pen ink (n = 1) and other synthetic and organic fibres that may have transferred onto the tool surface during storage and examination. Airborne contamination was documented on all four residue traps that had been placed in three rooms at the UOW: the Wet Chemistry Laboratory, the RUM Laboratory

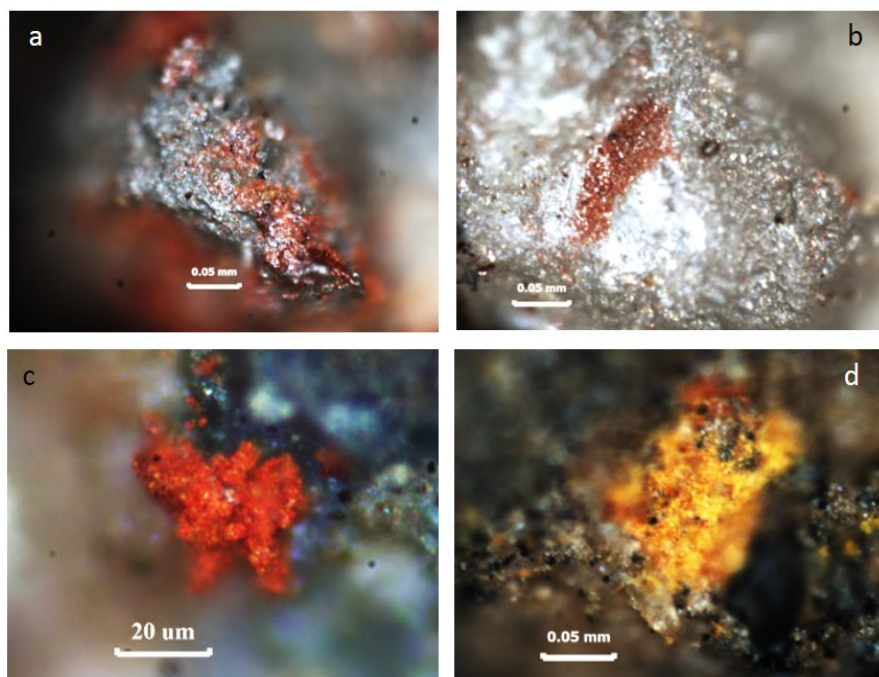


Plate 7.8a-d: Red and yellow pigment residues photographed *in situ* on MJB artefact surfaces: **a)** red pigment coating individual grain, UP GS 34; **b)** streak of red pigment on individual grain, UP GS 36; **c)** red, granular pigment cluster, UP GS 34; **d)** yellow granular pigment cluster wedged between grains, R68.

and the storage facility where the grinding stones had been stored in clean plastic tubs. Airborne contaminants included synthetic fibres, cellulose, hair, feather barbules, insect remains and amorphous organic material (Table 7.8). No airborne starch grains, phytoliths, raphides or pollen were identified in any of the residue traps, however, the occurrence of amorphous organic tissue and organic fibres were common. Modern contamination could be distinguished from archaeological residues as they did not display any visible evidence for degradation or physical damage.

Laboratory consumables, including glass slides, cover slips, gloves, pipette tips, sample tubes, plastic sample bags and bubble wrap, were also examined for contaminating particles (Table 7.9). The most common materials identified on these consumables included amorphous organic material, cellulose, synthetic fibres, and unidentified particles, probably dust. The highest incidence of contamination occurred on the glass slides prior to cleaning. At least 80% of these particles were identified within 2 mm from the edge of the slide. Three intact starch grains (representing at least two separate taxa) were identified on one of the slides. Two of the grains were relatively small, ranging in length from 19.7 to 10.8 μm , and displayed a rounded morphology. The remaining grain was larger with a length of 47.3 μm and an elongated surface morphology. Much fewer (75% less) organic particles were present after the slide was wiped clean with ethanol. Similar to previous observations, residues on cleaned slides were typically restricted to within a few millimetres of the slide edges and included small fragments of unidentified particles, but starch grains and long cellulose fibres were not identified. Very few particles were observed on the bubble wrap, pipette

Table 7.8: Summary of airborne contaminants identified in residue traps placed in various rooms/laboratories at the University of Wollongong.

Contamination type	Examined area			
	Wet Chemistry Laboratory (shelf)	Wet Chemistry Laboratory (fume-hood)	Microscope Laboratory (shelf)	Storage facility (shelf)
<i>synthetic fibre</i>	27	145	3	22
<i>cellulose fibre</i>	20	9	12	3
<i>woody fibre</i>	1	1	3	0
<i>starch</i>	0	0	0	0
<i>hair fibre</i>	1	1	0	0
<i>feather barbule</i>	1	0	0	0
<i>amorphous organic material</i>	12	6	20	3
<i>insect</i>	0	3	0	0
<i>spores (fungal, lichen)</i>	1	0	0	0
<i>unidentified</i>	1	1	5	0
Total number of contaminating particles	64	166	45	28

Table 7.9: Summary of contaminant particles recognised in laboratory consumables used during residue analysis.

Contamination type	Consumable product							
	disposable gloves**	pipette tips**	Sample tubes**	sample bag	bubble wrap	glass slides (pre wipe)*	glass slides (post wipe)*	cover slips*
<i>Synthetic fibre</i>	0	0	4	0	1	5	0	0
<i>Cellulose fibre</i>	0	4	4	0	6	94	4	0
<i>Woody fibre</i>	0	0	0	0	0	2	0	0
<i>Starch</i>	0	0	0	0	0	3	0	0
<i>Hair fibre</i>	0	0	0	0	0	0	0	0
<i>Feather barbule</i>	0	0	0	0	0	0	0	0
<i>Amorph.organic material</i>	0	20	4	0	1	503	82	0
<i>Insect</i>	0	0	0	0	0	0	0	0
<i>Spores (fungal, lichen)</i>	0	1	0	0	0	1	0	0
<i>Unidentified</i>	0	0	1	0	2	8	0	0
Total number of contaminating particles	0	25	15	0	10	616	86	0

* indicates the examination of three samples; ** indicates the examination of ten samples.

tips or sample tubes. Cellulose fibres and other residues were restricted to the edges and corners of the 4 x 4 cm bubble wrap square, which were probably acquired during handling. Residue particles, such as starch grains and other plant tissues; were not recognised on the gloves and no particles were identified in or on the plastic sample bags or within the extraction solvents. Non-use related

residues acquired within the depositional environment resulting from environmental contamination were the dominant contributing contamination type on the MJB grinding stones.

Visual examination of extracted residues sampled from the artefact surfaces with the EWA solvent mixture and the distilled water did not make a noticeable difference to the extent of material observed. Although other researchers have suggested that solvents containing acetonitrile may break up organic residues (such as collagen), I found that this had no effect and that stains were still effective at highlighting constituent materials.

7.2.3.2 Visual residue identification (ultra-sonicated extractions)

Although the ultra-sonication method of residue extraction was technically more difficult than pipette sampling, often requiring two analysts to complete the removal (one to hold the artefact in the weighing tray and the other to hold this in the ultrasonic bath), residue recovery was greatly enhanced with this procedure. When coupled with density separation techniques, starch was readily isolated and easily identified on slide preparations. Recovered starch grains were photographed, measured and compared to other measured starch grains comprising local reference collections. Seven of the twelve grinding stones that were sampled for residues using methods of ultra-sonication and separation contained starch or some other form of diagnostic plant material. The following sections discuss the starch grains recovered from specimens from each of the three groups.

7.2.3.2.1 *Starch on Group 1 grinding stones*

All grinding stones in Group 1 (i.e., GS 3, UP GS 2, L49) contained significant quantities of starch with over 200 grains documented for each specimen (Plate 7.9). Previous sampling of these same artefacts via pipette extractions had indicated only singular occurrences of starch and other microfossils, with the exception of UP GS 2, in which at least 20 raphides were identified. Documentation of starch on these three artefacts was restricted to 200 grains. Table 7.10 provides a summary of starch grain frequency and size. Figure 7.1 is a box plot illustrating starch grain measurements for all starch grains documented on the MJB Group 1 specimens. Artefact L49 contained a distinctive assemblage of starch, in which two separate plant species are represented (distinguished on the basis of grain size and shape). These included grains similar to those characteristic of tubers ($n = 75$) as well as another, currently unidentified variety that is distinguished from the tuber-like starches on the basis of starch grain morphology ($n = 131$) (Plate 7.9c-d).

Several of the starch grains documented on this artefact exhibited physical damage that had resulted in the loss of the extinction cross. Phytoliths and pollen grains were also observed on L49 but in lower frequencies. Significantly, the phytoliths documented from this tool were not characteristic of grasses.

Only one starch grain variety was documented on UP GS 2—a small flake that likely originated from the same complete tool as L49, both of which were recovered from Square/Spit C2/5 (Plate 8.6). The starch on UP GS 2 (that included over 200 grains) was morphologically similar to one of the starches recovered from L49, but the absence of the tuber-like starch grains had indicated that at least one more starchy plant species was processed using L49 after UP GS 2 had been removed. GS 3 also displayed a distinctive starch assemblage that may have been derived from a single plant species. Starch grains on this artefact were similar to those identified on UP GS 2 and the non-tuber starch grains on L49, whereby most occurred in the form of compound grains (Plate 7.9a). Some of these grains also appeared damaged, probably as a result of processing (i.e., grinding and pounding).

The starch grains on UP GS 2, GS 3 and one of the collection of starch grains from L49 were morphologically and dimensionally consistent with at least one species of local plant—*Tacca leontopetaloides* (Polynesian Arrowroot), which has previously been documented in reference collections from NE Queensland (Plate 7.10a). The box plot presented in Figure 7.1 also shows starch grain measurements from *Tacca leontopetaloides* and *Dioscorea transversa* (another locally available species) (Plate 7.10b) with dimensions that have been graphically compared with the tuber-like starches from L49. Because only a small amount of reference material has been prepared, it is not clear at this stage whether the starch grain assemblages are diagnostic of *Tacca leontopetaloides* and *Dioscorea transversa*, or whether the starch grain morphology and dimensions overlap with other species not yet sampled. Other comparisons with starch grain reference material has indicated that several economically important plant species may already be ruled out, including *Nelumbo nucifera*, which is represented by smaller and compound grains; *Cycas media*, *Cyperus bulbosus* and *Amorphophallus paeonifolius*, which are typically composed of smaller starch grains than those documented on the archaeological specimens (Plate 7.10b-c, e-f). The tuber-like starches that occurred on L49 are yet to be further classified. The development of a more robust starch grain reference library for the economically important plants of northern Australia is required to make secure taxonomic identifications. Starch reference libraries need to be expanded to include a larger range of plant species.

Table 7.10: Starches identified on the MJB and Lake Mungo grinding stones following sonication and separation techniques.

Site name	Group	Grinding stone no.	no. grains	Size range (μm)
MJB	1	GS 3	211	4.83-49.7
MJB	1	UP GS 2	216	5.39-24.98
MJB	1	L49 (total)	206	6.18-46.19
MJB		L49 (tuber starches)	75	10.13-46.19
MJB		L49 (other)	131	6.18-31.37
MJB	2	UP GS 26	0	-
MJB	2	UP GS 28	0	-
MJB	2	GS 39	6	14.74-29.15
MJB	3	L52	0	-
MJB	3	UP GS 4	3	15.52-38.69
MJB	3	UP GS 14	3	16.12-20.66
MJB	3	GS 16	0	-
MJB	3	GS 49	0	-
MJB	3	GS 47	1	3.1406
Lake Mungo	n/a	LMGS 1	0	-
Lake Mungo	n/a	LMGS 3	4	6.48-21.98
Lake Mungo	n/a	LMGS 10	6	11.07-22.96
Lake Mungo	n/a	LMGS 11	2	18.88-19.61
Lake Mungo	n/a	LMGS 12	7	4.73-20.64
Lake Mungo	n/a	LMGS 13	4	13.63-24.26
Lake Mungo	n/a	LMGS 14	4	15.23-28.24
Lake Mungo	n/a	LMGS 15	2	20.92-26.96
Lake Mungo	n/a	LMGS 16	1	25.52
Lake Mungo	n/a	LMGS 17	1	15.24

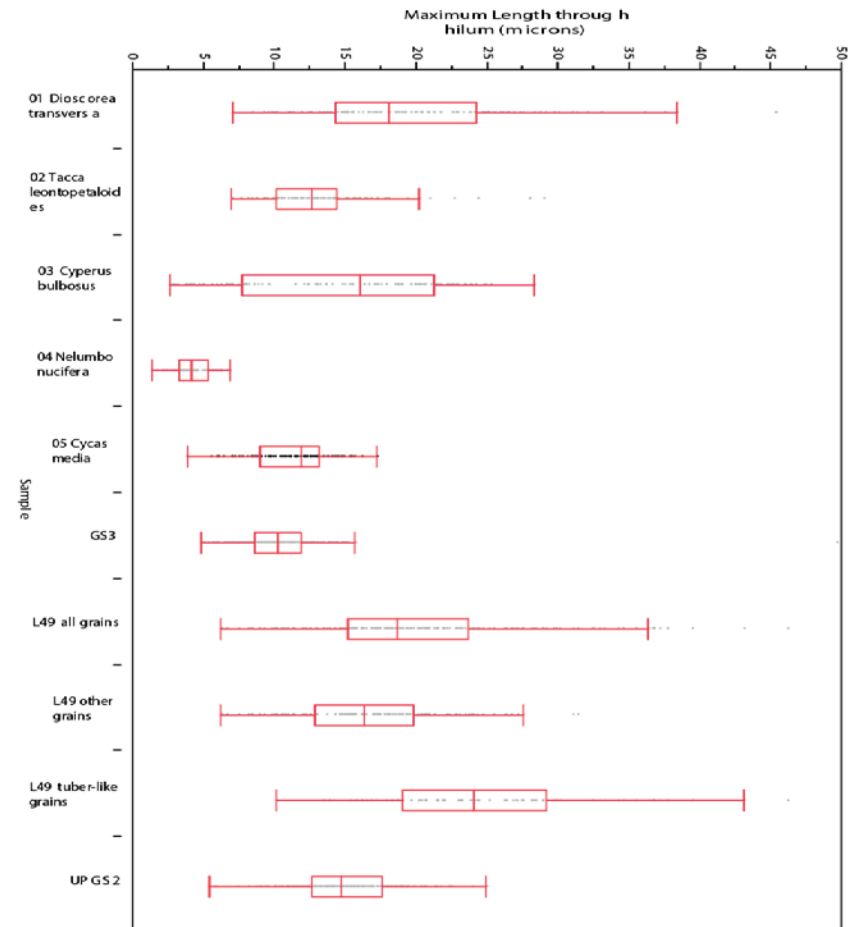


Figure 7.1: Box Plot of starches documented on the Group 1 MJB grinding stones. All L49 grains were plotted together and they were also separated into 'tuber-like' grains and 'other'. Starch from economically important plant species (*Dioscorea transversa*, *Tacca leontopetaloides*, *Cyperus bulbosus*, *Nelumbo nucifera* and *Cycas media*) have been added to illustrate the possible overlap. (After Field 2014).

The frequency of starch grains noted on these artefacts (i.e., >50 grains documented), together with evidence for mechanical damage, have indicated that the starch was use-related and not the outcome of contamination. Additionally, the starch grains identified on each of the grinding stones from Group 1 were morphologically distinct but consistent on each tool, and were sometimes accompanied by both phytoliths and pollen (Table 7.12). Such features would be extremely unlikely if this was related to contamination. Because of the high frequency of starch grains on these three tools, of which most possess distinctive and consistent morphologies, the potential for identifying genera or species through reference material is high. The size and morphology of the starch from L49 is typical of tubers and yams, while the smaller starch grains on GS 3, L49 and UP GS 2 are likely to originate from a different plant species.

7.2.3.2.3 Starch on Group 2 and Group 3 grinding stones

Sonication and separation methods of residue extraction performed on the Group 2 artefacts (i.e., UP GS 26, UP GS 28, GS 39) from earlier cultural deposits revealed that these tools contained significantly less starch. Starch grains were absent on UP GS 26 and UP GS 28, and only six starch grains were identified on GS 39. The starch on this latter artefact, although limited in number, had facets that may potentially be attributed to grinding and ranged in size from ~15 – 30 μm (Table 7.10; Plates 7.9e, 8.4f).

Ultra-sonication of artefacts comprising Group 3, which included grinding stones from earlier as well as more recent deposits, saw only a limited recovery of starches. Starch was recognised on three artefacts from this group: UP GS 14 (number of grains counted = 3); UP GS 4 (n = 3); and GS 47 (n = 1) (Table 7.10). The remaining three specimens did not display any visible traces of starch.

The lack of starch grains on specimens from Group 2 and Group 3 may indicate two possibilities: (1) that the processing of starchy plants was not common; or (2) that the starch grains (and other organic residues) have not survived. I suggest that an absence of starch on the more recent specimens is a reflection of tool function, while the lack of starch on older specimens from deeper deposits may be the result of either degradation or absence of starchy plant processing. Although none of the Pleistocene-aged specimens contained starches of significant quantity, GS 3 from Spit 21, dated at 9.2 ka cal. BP, contained at least 211 starch grains as well as a number of other plant materials including phytoliths, pollen and cellulose fibres. At least three other grinding stones from Group 2 (collected from more recent contexts) had a limited recovery (if any) of starch and other plant microfossils. The occurrence of starch on GS 3, an artefact that was recovered from

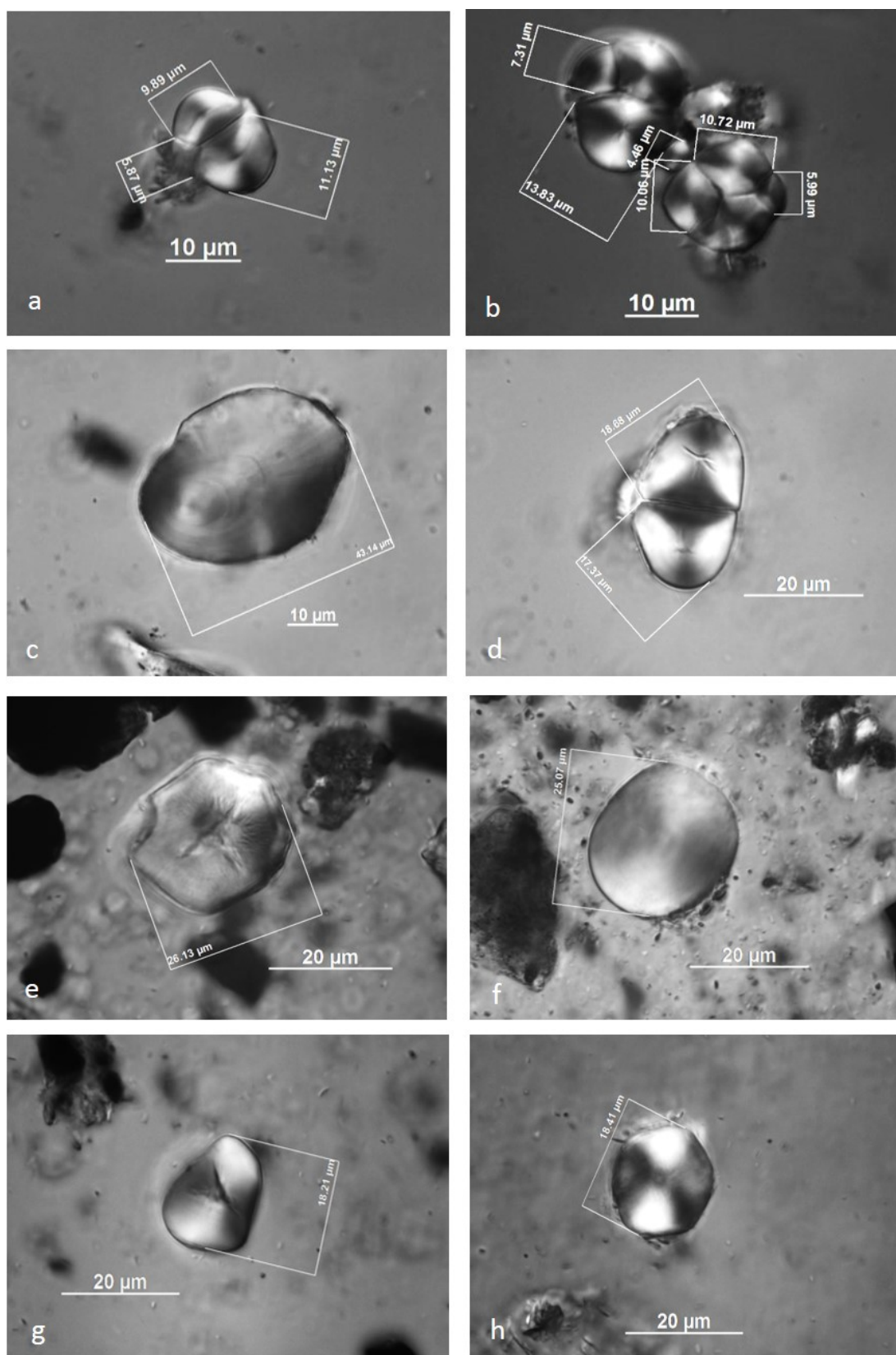


Plate 7.9a-h : Starch grains on MJB grinding stones from Group 1 (a-d), Group 2 (e) and Group 3 (f-h) following sonication and separation: **a)** compound starch grains on GS 3; **b)** compound starch grains on UP GS 2; **c)** starch grain *cf.* tubers and other under-ground storage organs, L49; **d)** non-tuber-like compound starch grains, L49; **e)** starch grain, GS 39; **f)** starch grain, UP GS 4; **g)** starch grain, UP GS 14; **h)** starch grain, GS 47. *Photos by J. Field.*

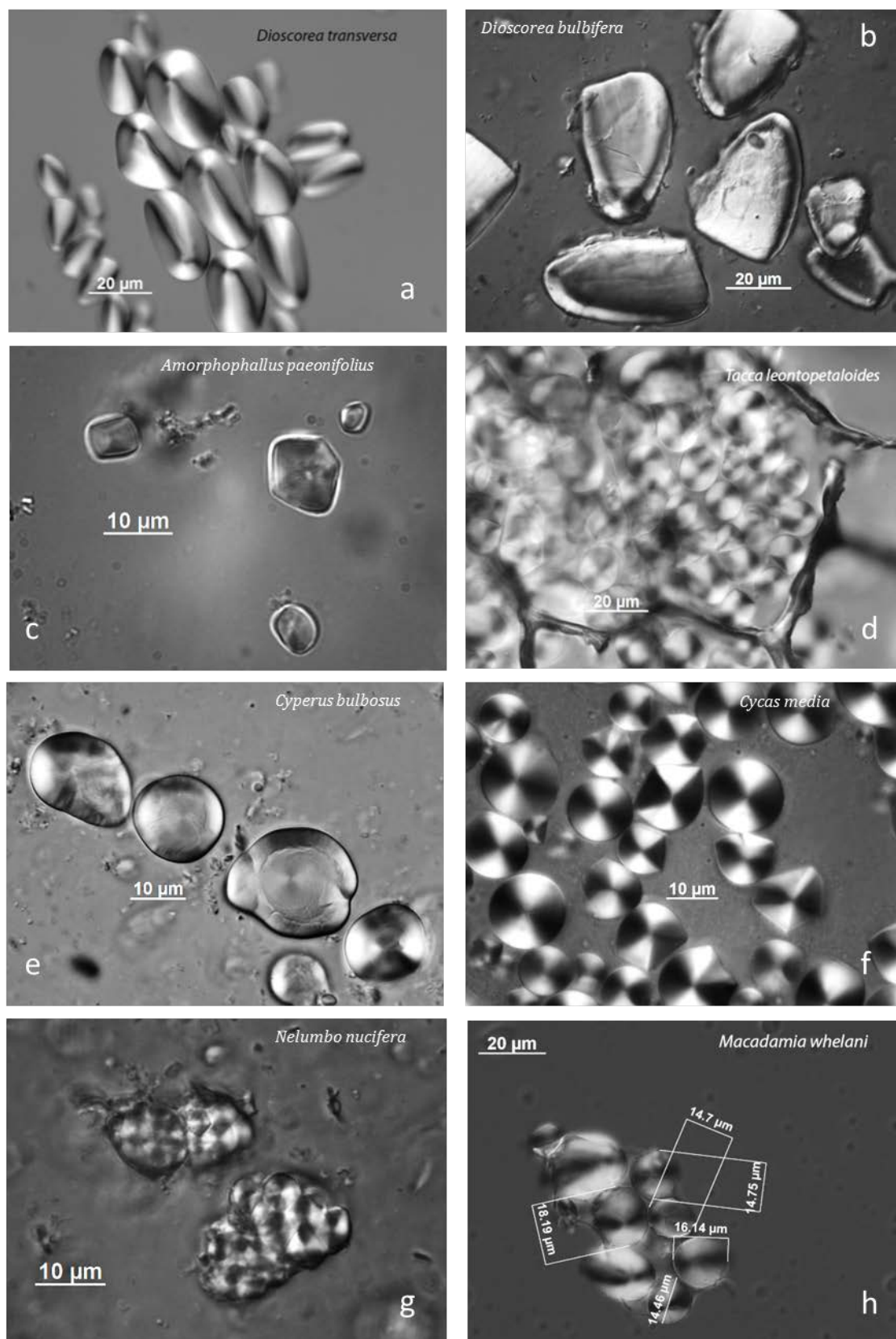


Plate 7.10a-h: Starch grain reference images and measurements: **a)** *Dioscorea transversa*; **b)** *Dioscorea bulbifera*; **c)** *Amorphophallus paeonifolius*; **d)** *Tacca leontopetaloides*; **e)** *Cyperus bulbosus*; **f)** *Cycas media*; **g)** *Nelumbo nucifera*; **h)** *Macadamia whelani* (documented in other regions of Australia and used in this study as a comparative). Photos by J. Field.

an earlier context to many of the Group 2 specimens, suggests the preservation of starch on early Holocene-aged grinding stones. While it is possible that the micro-environments surrounding specific Squares/Spits, including variation in pH and enzymatic/micro-biological activity, may cause more rapid depletion of particular residues, sediment evaluations revealed a generally consistent soil pH range (range: 5 – 7) and a limited presence of organic compounds, the latter of which has been assessed through GC-MS analysis performed on sediment samples (Section 7.2.3.5).

7.2.3.3 Biochemical residue identification

Biochemical testing of residue mixtures sampled from the MJB grinding surfaces (n = 126) indicated the presence of a number of biomolecules, including proteins, carbohydrates, fatty acids and haem (Table 7.11). Complex carbohydrates were the most commonly detected compound group. Starch was detected with the IKI test on 67 of the 126 grinding surfaces (mostly in trace amounts) and was also visually identified on 17 of the 67 residue mixtures with positive readings (Table 7.11). No starch was visually identified in any of the residue samples that had tested negative with the IKI biochemical test. Interestingly, only trace amounts of starch were detected on artefacts L49 and UP GS 2, despite each artefact having over 200 starch grains identified microscopically after ultra-sonication. Because the biochemical tests were performed on residue samples that were collected via pipette sampling, the detection of starch may be limited by the amount of starch recovered using only pipette extractions. This was previously demonstrated following the microscopic examination of both pipette and ultra-sonicated samples whereby residue recovery was greatly enhanced following ultra-sonication. I suggest that future applications of the IKI test should include the measurement of ultra-sonicated samples, rather than those obtained via pipetting alone. Because starch was also detected with the IKI test on the unground artefact surfaces and/or sediment samples for over half of the artefacts (n = 56 of 91), environmental contamination resulting from the transferral of material from the depositional environment is possible. In certain instances (n = 26), the detection of starch was greater for the sediment sample compared to the used artefact surface, suggesting that small amounts of starch from the sediment may have been transferred to artefact surfaces.

The PSA and Diphenylamine tests for the detection of carbohydrates, including sugars such as sucrose and glucose, appeared relatively consistent with each other, providing positive readings for 51 and 38 grinding surfaces, respectively. The discrepancy between the two methods of carbohydrate detection may be related to several factors, including the sensitivity of the different tests and the specific carbohydrate chains detected. The same tests performed on each of the

corresponding sediment samples suggested that transfer of carbohydrate residues from sediments to the artefact surface was uncommon (number of control samples with positive carbohydrate readings = 9) (Table 7.11, C8).

The Bradford Assay test for the detection of protein provided a positive reading for residue samples from 34 of the 126 grinding surfaces and 16 of the 91 tested sediment samples. The source of the protein is likely to be of plant origin as all tested residue samples also contained abundant plant tissue, with the exception of two artefacts (UP GS 29 and UP GS 36). Only five specimens that contained visually confirmed collagen fibres (as indicated by staining agent Orange G and Rhodamine B) tested positive for proteins. About 18% of sediment samples (16 of 91) also tested positive for proteins, although the origin of the protein (i.e., from plant or animal) is unknown. Because starch was also detected in these samples, it is likely that the sediment contains plant material potentially transferring to the artefact surface.

The Falholt test for the detection of fatty acids provided positive readings for 58 residue samples from 126 grinding surfaces, with only one of the sediment samples and two of the un-ground surfaces providing a positive reading. Fifty-two of the 58 surfaces that tested positive for fatty acids also had various forms of visible plant tissue (identified microscopically), and further residue characterisation have indicated that the specific fatty acid compounds were related to plants (see Section 7.2.3.5). The detection of fatty acids on the remaining 12 surfaces may also (in part) originate from animal tissues: 11 also contained traces of collagen (as identified microscopically from residue removals) and one contained traces of bone (as identified directly from the artefact surface). In general, the results suggest that the fatty acids were dominantly of plant origin, although the transferal of finger grease and other fatty deposits (such as those present in hand creams and soaps) during modern handling is also probable. The identification of specific fatty acid compounds from GC-MS analysis, including octadecanoic and hexadecanoic acid, confirm handling residues (in addition to other use-related residues) on 24 specimens (further elaborated in Section 7.2.3.5).

Hemastix® testing yielded positive results for 32 of the 126 utilised surfaces (Table 7.12, C7), as indicated by an immediate colour change of the test strip that was scored on a scale of 0 – 5 (Section 5.5.3.2.4). Thirteen of the 32 residue samples displayed trace amounts of haem with a Hemastix® score of 1 or 2. The remaining eighteen samples displayed low amounts of haem, with Hemastix® scores of 3. Because previous investigations have shown that Hemastix® will also react with other substances, for example, manganese within sediments, saliva, some food products and (sometimes) haematite crystals (e.g., Custer *et al.* 1988; Downs & Lowenstein 1995; Loy 1993; Loy &

Dixon 1998; Manning 1994; Matheson & Veall 2014; Tobe *et al.* 2007), testing of the unground surface was required to evaluate the extent of potential contamination and other reactive agents. Positive tests for the unground surface were returned for 22 of the 32 samples that had previously tested positive, indicating potential environmental and/or handling contamination. In order to determine whether the detected haem component originated from blood, all positive extractions were re-tested following the addition of a chelating agent, EDTA (Section 5.5.3.2.5). This solution is added to residue mixture to prevent the Hemastix® reacting with substances within the residue sample that are not blood (Matheson & Veall 2014). Only four specimens returned a positive Hemastix® reaction following the addition of EDTA, and only in trace amounts (Table 7.12). Matheson & Veall (2014) suggested that highly degraded blood residues, such as those that may be present on tools that have an ancient origin, may not be detected with Hemastix® once EDTA has been added to the residue mixture. Despite this, the MJB grinding stones do not display compelling evidence for the presence of blood through Hemastix® testing. The trace amounts of haem detected on the four specimens were not present in large enough quantities to be diagnostic of animal processing. I propose that the positive Hemastix® reactions (prior to the addition of EDTA) were the result of environmental contamination or from the detection of haematite particles.

Although the biochemical tests have enabled an initial “screening test” for the detection of certain residues, their lack of sensitivity prevents highly degraded residues or specific residue compounds from being detected. Furthermore, they do not allow the extent of environmental or handling contamination to be adequately assessed, as the origin of many residues cannot be further refined. I suggest that more robust methods of residue characterisation are required if more reliable and detailed residue interpretations are desired, such as GC-MS or other more sensitive methods of detection.

7.2.3.4 Absorbance spectroscopy

Absorbance spectroscopy readings for the MJB artefacts indicated a range of organic material on the ground (and sometimes unground) surfaces (Table 7.13). While absorbance was not read for most of the MJB artefacts ($n = 82$), nine specimens displayed distinctive “peaks” or shoulders that were specific for groups of biological compounds. Although no artefacts displayed shoulders at 410 nm (to indicate the presence of animal proteins), several artefacts displayed shoulders at 230 ± 5 nm ($n = 2$); 240 ± 5 nm ($n = 4$); 250 nm ($n = 6$); 260 nm ($n = 7$); 270 nm ($n = 6$) and 280 nm ($n = 1$), indicating the presence of (mostly) plant related compounds. Only one artefact

Table 7.11: Summary of detected biomolecules from residue mixtures and sediment samples from the MJB and Lake Mungo grinding stones.

		Biochemical test					
		Bradford Assay	Diphenyl-amine	Falholt	PSA	Hemastix	IKI
MJB							
Ground surfaces (n= 126)	Present	23	28	50	42	22	29
	Trace amounts	11	10	8	9	15	35
	<i>Total number of surfaces with positive readings</i>	34	38	58	51	37	67
Sediment / un-ground surfaces (n= 91)	Present	11	4	3	2	13*	21
	Trace amounts	5	3	0	0	11*	35
	<i>Total number of surfaces with positive readings</i>	16	7	3	2	24*	56
Lake Mungo							
Ground surfaces (n= 14)	Present	2	3	0	2	0	3
	Trace amounts	1	0	0	1	0	3
	<i>Total number of surfaces with positive readings</i>	3	3	0	3	0	6

*indicates removals from unground surface (n=31) from specimens with at least one surface testing positive with Hemastix.

Table 7.12: Hemastix® test scores for residue mixtures sampled from the ground and unground surfaces of MJB and Lake Mungo artefacts. Score of 0 indicates no traces, scores of 1-2 indicate slight traces, and scores of 3-5 indicate low, moderate and large abundances of haem, respectively.

	Ground surfaces				Un-ground surfaces/soil samples			
	MJB		LM		MJB		LM	
Hemastix reaction	residue sample	residue + EDTA	residue sample	residue + EDTA	residue sample	residue + EDTA	residue sample	residue + EDTA
0	57	28	8	0	10	22	0	0
1	8	1	0	0	7	0	0	0
2	5	3	0	0	2	0	0	0
3	18	0	0	0	9	0	0	0
4	1	0	0	0	4	0	0	0
5	0	0	0	0	0	0	0	0
not measured	2	59	5	13	59	69	13	13
Total	91	91	13	13	91	91	13	13

(GS 38) also had an absorbance reading at 340 nm, indicating interference with particulate material present within the residue mixture. The lack of detectable absorbance on many of the MJB artefacts (n = 82) is associated with the sensitivity levels of the test whereby only compounds present in large abundances will be detected. Owing to the age of many of the MJB specimens, it is likely that many of the residues were highly degraded, and therefore detection of absorbance is limited for this assemblage. More sensitive methods of residue characterisation are therefore required for residue characterisation on the MJB assemblage.

Table 7.13: Absorbance readings for MJB grinding stones.

Absorbance	Detected compound(s)	Artefacts	n=
200nm	generic organic material (plant and animal)	All artefacts	91
230 ± 5nm	pheolates and carboxyl groups	GS 2; GS 3	2
240 ± 5nm	alcohols, including plant sterols	GS 2; GS 3; GS 16; GS 38	4
250nm	alkaloids and carbon/nitrogen bonding	GS 3; GS 10; GS 14; GS 15*; GS 16*; GS 35*; GS 38	7
260nm	nucleic acids	GS 2*; GS 3; GS 13; GS 14; GS 15; GS 16*; GS 35*; GS 38	8
270nm	phenols	GS 2; GS 3; GS 10; GS 15*; GS 16*; GS 38;	6
280nm	protein from plants/animals; amino acids	GS 2	1
340nm	particulate material (interference)	GS 38	1
410 ± 5nm	haemoglobin, myoglobin, animal proteins	-	0
560nm	chloroforms and keratins	-	0

** indicates absorbance read from the unground surface.*

7.2.3.5 GC-MS

GC-MS analysis of residue mixtures sampled from the MJB specimens indicated a range of chemical compounds (n = 220), including fatty acids, aromatic carbons, amino acids, proteins (including porphyrin structures and blood components), carbohydrates and bioactive compounds (Table D1, Appendix D). For the sample that was measured twice (Lift 1 from GS 1), GC-MS spectra appeared to be mostly comparable for both analyses with only a few minor exceptions (see summary table—Table C10).

The most common compounds detected in the residue mixtures sampled from the grinding surfaces include: [2,4-bis(dimethylbenzyl)-6-*t*-butylphenol] (number of grinding surfaces with compound present = 43), [2,6-bis(1,1-dimethylethyl)-4-(1-methyl-1-phenylethyl)-phenol] (n = 41), [Bis(4-hydroxyphenyl)propane] (n = 21), and [1-ethyl-4-methylbenzene] (n = 19), all of which are consistent with plant materials (see Table D1 for references). Other common residues, including hexadecanoic acid (n = 40) and octadecanoic acid (n = 31), which are fatty acid compounds that may originate from plant or animal. When these two compounds are identified in combination, they usually indicate the presence of handling residues from oily excretions of the hands (Croxtton *et al.* 2010; Gutiérrez *et al.* 1999; Malainey *et al.* 1999; Michalski *et al.* 2013; Regert *et al.* 2001). Other, non-specific residues such as azelaic acid (a fatty acid breakdown product) were also detected within many residue mixtures sampled from both the ground surface (n = 38) and collected from sediment samples (n = 8). Owing to their high level of degradation, it is unclear whether the fatty acids originated from plant or animal products. A complete list of the 220 compounds identified within the residue mixtures extracted from the MJB grinding stones, along with details of its potential origin and references, is compiled in Table D1.

Most of the compounds identified are associated with plant residues (number of artefacts = 47), with relatively few detected compounds associated with animal residues (n = 3) (Table 7.14, C10). In many cases (n = 26), plant residues were further distinguished as those originating from seeds, nuts, tubers, roots, leaves, wood or fruit, based on the combination of compounds present, including the relative ratios of bioactive compounds, fatty acids and aromatic hydrocarbons (Table D1). In very few cases (n = 6), bioactive alkaloids such as [11-norcanabinol-9-carboxylic acid, narcissidine-7-one], [1,3-diacetyl-4,12-dihydro-, (1.alpha.,2.beta.,3.alpha.)-] and [Tyramine], have indicated the possible processing of toxic or narcotic plants that may have hallucinogenic effects (Adams & Camp 1966; de Andrade *et al.* 2012; Aneela *et al.* 2014; Bastida *et al.* 2011; Camp & Norvell 1966; Clement *et al.* 1998; Culvenor *et al.* 2005, Santana *et al.* 2008). This could imply the processing of certain plants to remove toxins or for medicinal/ceremonial purposes.

Compounds originating from faunal materials were identified on fewer specimens (n = 3) and included amino acids (e.g., [N-(2-methyl-1-oxo-2-propenyl)-N-glycine]), animal fats [cis-10-heptadecenoic acid] and protein compounds found only in blood [(2,8,12,18-tetraethyl-3,7,13,17-tetramethyl-21H, 23H-porphinato(2-)-N21,N22,N23,N24)-, (SP-4-1)-]. It is possible that other compounds such as azelaic acids, which may originate from animal or plant materials, may also

Table 7.14: Summary of residues identified from GC-MS analysis.

		Residues identified					
As identified from:		Plant	Animal	Handling (contamination)	Unknown	Bacteria	No residue detected
MJB	artefact surface (n= 91)	47	3	14	24	0	20
	sediment sample (n=79)	7	0	2	9	1	61
Lake Mungo	artefact surface (n= 12)	3	0	2	3	0	6

result from the processing of animal materials, although evidence is too limited to adequately associate such compounds with animal processing activities. Interestingly, the residue sample that tested positive for blood with GC-MS (GS 3) did not test positive with Hemastix®. However, GC-MS analysis had indicated that the blood identified on GS 3 was highly degraded, and therefore may not be detected with Hemastix® testing (see Matheson & Veall 2014 for discussion). Handling residues (i.e., hexadecanoic and octadecanoic acids) and residues that were possibly acquired during storage (i.e., phallic acids, which are present in plastics but also in plants) were detected on some of the tool surfaces (n = 12 and 21, respectively). Other forms of contamination, such as those that may have accumulated during deposition, discard, and/or excavation, were not detected. GC-MS failed to detect the occurrence of residue materials in large abundance on the unground surfaces or in the sediment samples, with only a few exceptions (see Tables C10, D3).

Interestingly, GC-MS analysis performed on the residues sampled with distilled water did not detect organic compounds to the extent that they were detected in the EWA samples. I suggest that this is related to the absence of water soluble residues present on the MJB artefacts. The intense wet season precipitation at MJB would have allowed the artefacts to be exposed to ground water and therefore all water soluble particles may have already been removed through natural agencies. For this reason, I suggest that all residue samples collected with the intention of GC-MS analysis should be sampled with solvents such as the EWA that enable the removal of water insoluble particles.

There are some discrepancies among the compounds detected with GC-MS and the biochemical tests. As the biochemical tests are designed to test groups of compounds only (e.g., proteins, fatty acids and carbohydrates) they are less sensitive, and, unlike GC-MS, they are unable to detect specific compounds. For this reason, highly degraded compounds, such as azelaic acid,

cannot be detected with biochemical testing. Residue mixtures that contained degraded fatty acid compounds detected with GC-MS therefore did not always test positive for fatty acids with the Falholt test. I suggest that for the characterisation of (potentially very ancient) archaeological use-residues, highly sensitive methods of GC-MS are required to investigate degradation products, and the biochemical tests performed are inconclusive, although they provide a valuable screening test for the detection of broad compound groups.

7.2.4 Functional Interpretation

Following artefact examination, I classified the grinding stones (for their dominant phase of use) as upper stones ($n = 23$), lower stones ($n = 6$) or filing stones ($n = 30$), in which five specimens displayed evidence for use as both coupled and filing tools (Table 7.15, C10). Another eight specimens were classified as coupled stones but I was unable to determine whether they had originated from upper or lower stones. Flat lower stones were distinguished from filing stones based on surface wear that appeared to be diagnostic of stone-on-stone contact. Such wear is typically absent from filing tools (with the exception of whetstones and those used to prepare other stone materials).

With the exception of one grinding stone (GS 32), none of the MJB specimens could be described as “formal” grinding stone varieties as defined by Smith (1985, 1986, 1989b) and described by McCarthy (1976: 63). This tool displayed heavy pounding damage in the centre and was consistent with morphological descriptions of mortar stones (i.e., all stone dimensions are within the suggested range of mortar stones and an anvil pit is present within the middle of a working depression). Although the remaining five artefacts displayed concave cross sections, they did not display any distinguishable grooves or rejuvenation marks (pecking) and, therefore, were not consistent with morphological descriptions of millstones or mortars. Rather, these artefacts displayed lightly worn, shallow depressions with uneven surface levelling, possibly reflecting the natural downward sloping surface of the stone materials. Only one of the five artefacts (GS 20—a small fragment with a concave surface) displayed compelling evidence for use as a lower stone.

In addition to GS 20 and GS 32, another four specimens were classified as lower stones, all of which had flat grinding surfaces. These were identified as lower grinding stones as most (all but one fragmented piece) were much larger than the other tools (mass range: 137 g – 8400 g; median mass: 701.5 g) and all contained evidence for stone-on-stone contact. The large size of most of the artefacts did not support their use as hand-held upper stones. In total, six of the 91 MJB grinding

Grinding stone type	Number of artefacts	
	MJB	Mungo
filing stone	30	1
coupled stone	37	13
upper stone*	23	5
lower stone*	6	10
uncertain*	8	0
multi-functional (filing + coupled stones)*	5	1
uncertain (<i>inc.</i> unused)	34	4
recycled*	0	2
Total artefacts examined	96	17

Table 7.15: Grinding stone classes from MJB and Lake Mungo, as determined by morphology, size, and use-wear.

* tools that have been previously accounted for.

stones (6.6%) were classified as coupled lower stones, and all possessed use-wear and residue traces consistent with the processing of plant material, including two artefacts (GS 1 and GS 30) that were probably used to process seeds. Another one of these six artefacts (R66) may have also been used to prepare/sharpen stone axes. Whilst this artefact did not display visible grinding grooves, micro-scars were abundant on individual quartz grains comprising the sandstone matrix, and were not present on the unground surfaces. Such features were also identified on the experimental axe-grinding stones made from harder sandstone (EGS 18, see Chapter 6).

Twenty specimens displayed at least one convex grinding surface and have been classified as upper stones. Three other specimens that displayed flat grinding surfaces were also classified as upper stones as they displayed stone-on-stone wear but were also the appropriate size to be used as a hand-held upper grinding stone. Similar to the grinding stones that displayed concave grinding surfaces, none of the upper stones could be described as “formal” seed grinding tools. Although two hammer/pounding stones were identified (GS 7 and GS 18)—distinguished by the presence of hammer and pounding damage—no specimens displayed facets, and therefore could not be classified as “mullers” according to Smith’s (1985, 1986, 1989b) definition.

Use-wear and residue analysis of the upper stones suggests plant processing on nearly all tools examined (n = 22 of 23 artefacts), including evidence for the processing of seeds and nuts (n = 12), starchy plants (including underground storage organs) (n = 3), roots (n = 1) and wood (n = 1) (Table C10). Of the 22 plant processing upper stones, three are considered multi-functional as they also contain evidence for the processing of haematite (UP GS 25) and animal materials (UP GS 21), with one artefact that was also used as a hammerstone for flake manufacture (GS 18). The function of the remaining upper stone that did not possess evidence for plant processing (GS 49) is unknown,

but is classified as an upper stone as it is convex in section and possesses distinctive stone-on-stone wear.

Of the 37 coupled stones identified from MJB (~41% of the grinding stone assemblage), 16% were described as lower stones (n = 6), 63% were described as upper stones (n = 23) and 21% were unknown (n = 8). The coupled stones classified as “unknown” were typified by small sandstone fragments that displayed flat grinding surfaces and stone-on-stone use-wear but were unable to be distinguished as upper or lower stones. The relatively higher occurrence of upper grinding stones compared with lower grinding stones may imply that upper stones were more heavily utilised artefacts that required more frequent replacement; or perhaps some lower stones were recycled as upper stones when they broke. The small size of most of these artefacts ensured transport was easy and may have been carried away from the site and used elsewhere. Ethnographic observations have indicated that Aboriginal women often carried upper stones with them around the landscape as a portable implement and used them opportunistically to grind many substances (Fullagar pers. comm.). I have also seen in my own experiments that upper stones typically wear down much more rapidly than lower stones, with use-wear traces (such as grain levelling and use-polish) developing much faster. Consequently, I would expect more frequent replacement of upper stones that would be reflected by a higher number of discarded specimens, which is also noted archaeologically.

In addition to coupled stones (n = 37), filing stones were also identified in the MJB assemblage (n = 30) and account for approximately 33% of the grinding stone assemblage. Filing stones were distinguished as stones that typically possessed flat grinding surfaces (n = 24) and an absence of stone-on-stone wear, often evidenced by a lack of micro-striations and a lower degree of grain levelling. Use-wear and residue analyses have indicated that half of the filing stones were used to process pigment (n = 15), but filing stones used to process plant (n = 9, including wood (n = 2) and fruit (n = 1)), animal (n = 2) and stone (n = 3) were also recognised (Table C10). Stones used to work the latter included one formal whetstone abrader (GS 39) and one manufacture-ground edge that may or may not be related to use (GS 3). The remaining artefact with evidence for stone working (GS 38) may have been used in stone axe manufacture.

Of the 30 filing stones recognised, six were also used as coupled stones, indicated by isolated patches of intensively levelled grains and use-residues consistent with the processing of plant materials that are typically processed with two stones (e.g., leaves, seeds). All six artefacts displayed evidence for the processing of two or more materials (including bone, animal flesh, plant and haematite) and are therefore all considered to have been multi-functional implements.

<i>Grinding stone function</i>	<i>Number of artefacts</i>	
	<i>MJB</i>	<i>Mungo</i>
pigment processing	16	0
seed/plant processing	52	15
animal processing (<i>inc.</i> bone)	4	0
axe sharpening	3	0
stone shaping/knapping	3	0
unknown	24	2
none (unused)	5	0
multi-functional*	11	0
<i>Total stones examined</i>	96	17

Table 7.16: Summary of grinding activities at MJB and Lake Mungo, based on functional analysis of grinding stones. Analyses included morphological characterisation and the documentation of use-wear and residue features.

Thirty-four grinding stones from the MJB assemblage (~35%) could not be classified as a coupled or filing stone as morphological and macroscopic and low magnification use-wear features were too limited to accurately assign an artefact class. However, high magnification examination and characterisation of residue mixtures indicated that some of these artefacts were used to process plants ($n = 13$) with two artefacts also possessing possible animal residues (e.g., GS 9 and UP GS 17). The most commonly processed material recognised on the MJB grinding stones was plant ($n = 52$), accounting for 57% of the total analysed assemblage and 97% of analysed couple d stones (36 of 37 stones) (Table 7.16). Red haematite was the next most common worked material, processed on 16 specimens and accounting for 18% of the total assemblage. Of these 16 artefacts, 15 were classified as filing stones, contributing to 50% of the total filing stone population. Less commonly identified were animal processing tools (including bone) ($n = 4$, ~4% of the analysed assemblage), all of which were likely used opportunistically rather than as dedicated animal processing tools. As all four specimens also displayed evidence for plant processing, which is most likely the dominant use, these also represent multi-functional tools. Other multi-functional tools include those used to process both stone and plant materials ($n = 2$) and plant and pigment ($n = 5$) (Table C10).

Twenty-four specimens (~26%) displayed clear grinding wear but could not be assigned an artefact function as they did not possess developed use-wear that was diagnostic of worked material and because residue recovery was limited. An additional five specimens were classified as unused and were not considered to be grinding tools. These specimens lacked traces of wear from use or manufacture, and also lacked use-related residues. The 24 specimens that could not be assigned a function were usually recovered from deeper deposits (depth range: 46 cm – 211 cm, median depth: 170 cm) and therefore represent some of the oldest grinding stones at the site. I attribute the lack of wear and residue traces diagnostic of worked material to taphonomic and weathering agencies (e.g.,

sediment turbation) that may result in the obliteration of wear and the degradation of use-residues in the depositional environment. Observations made on the unground surface support this interpretation, whereby quartz grains often displayed micro-abrasion probably resulting from friction between sandstone and sediments in the depositional environment, or perhaps before the sandstone was formed. Previous experimental work by other authors on flaked stone tools has also shown that the movement of sediments may also cause use-polish to diminish over time (e.g., Levi-Sala 1986a).

The lack of formal seed grinding tools at the site, specifically millstones and mullers, does not imply a lack of plant processing or seed grinding activities. Use-wear and residue analysis has shown that most of the grinding stones ($n = 52$, ~57%) were used to process seeds or plants, and has indicated that the processing of these materials was a dominant on-site activity (Table 7.16). Furthermore, 15 of the 34 (~44%) artefacts that were unable to be classified as either filing or coupled stones, were able to be assigned a function based on use-wear and residue evidence. The identification of use-wear and residue traces that may be diagnostic of worked material on artefacts that lack distinctive morphologies validates the potential of functional studies for interpreting the function of grinding stones generally. In particular, it has highlighted the value of performing use-wear and residue analyses on “amorphous” grinding stones and fragments, rather than simply dismissing them as expedient tools as they are often described in the literature (see Smith 1985, 1986, 1989b). In addition, the presence of large, stationary bedrock grinding patches in surrounding contexts has also suggested the use of these facilities for similar or other grinding practices, perhaps in preference to portable grinding implements. These bedrock grinding patches were used less expediently than the discarded tools recovered from MJB, and often feature well-worn grooves and traces of rejuvenation (Plate 8.7).

The stone material of the grinding stones did not influence the artefact function. Most artefacts ($n = 80$ of 91, ~88%) were shaped from the same or similar sandstones that displayed only minimal variability in hardness, grain size and degree of cementation. The sandstone artefacts functioned as both coupled and filing stones and were used for a variety of tasks. Of the eight quartzite stones identified, of which only seven displayed recognisable grinding wear, three were identified as upper stones (two of which were also probably used as hammerstones), two were identified as filing stones, and one had evidence for use as both an upper stone and a filing stone. The remaining three specimens could not be classified as coupled or filing stones owing to the small size of the fragments (mass range: 11 g – 79 g; median mass: 15 g) although it is possible that two of these artefacts came from the same original grinding stone (UP GS 10 and UP GS 14).

In addition to sandstone and quartzite pieces, two mudstone and one volcanic (*cf.* dolerite) grinding stones were identified. The volcanic artefact (UP GS 37) displayed distinctive grinding wear most likely originating from use, and may be distinguished from other manufacture-ground volcanic stones (such as the ground-edge axes) as manufacture grinding wear was not recognised (i.e., grain levelling was minimal or absent). Establishing artefact function through use-wear characterisation was difficult on the volcanic stone as my experiments had not included examination of use-ground volcanic stones of this type. Residue recovery for this artefact was minimal, possibly as a result of the age of the specimen or the nature of the material—the volcanic stone being much less porous than the sandstone, and therefore had a lower potential for residue protection and preservation. The function of this artefact is unknown.

The two mudstone artefacts were recovered from two distinctive depositional levels of the site. UP GS 39 was recovered from very recent deposits and represented a post-contact manufactured whetstone, used for sharpening metal and stone axes. GS 28, a fragment recovered from Pleistocene-aged levels of the deposit (Spit 29—a depth of ~150 cm) was used as an upper stone used to process plant material. As the mudstone material is characterised by hard, fine-grain minerals, wear traces on this material are comparable to wear traces identified on very hard sandstone/quartzite pieces that were included in my experiments.

7.3 Lake Mungo grinding stones

7.3.1 Grinding stone morphology

Seventeen potential grinding stones and grinding stone fragments from Lake Mungo were recovered for functional analyses. The grinding stones mostly derive from well-dated strata within the Mungo lunette and can be attributed to particular units of time. All artefacts were shaped from fine-grained, well-cemented sandstone (Table 7.1). The stones ranged in size from 4 – 183 g, with a median mass of 22 g (Table C1). The stones examined included only one complete grinding stone and 16 fragments, eight of which (LM GS 2 – 9) probably originated from the same artefact. I was able to refit some but not all of the grinding fragments (e.g., LM GS 2 and LM GS 6) (Plate 3.4). One of the eight fragments (LM GS 9) had clear provenience, found *in situ* from eroding sands comprising Unit E of the Mungo lunette, dated to approximately 25 – 14 ka (Fitzsimmons *et al.* 2014; Fullagar *et al.* 2015).

All but one artefact had at least one definite grinding surface ($n = 16$). The remaining sandstone fragment (LM GS 13) had one surface with indistinct but possible grinding wear. Most artefacts displayed only one grinding surface ($n = 9$, including LM GS 13), and seven had probable or definite grinding wear on two surfaces. One artefact (LM GS 11) displayed definite grinding wear on at least three surfaces (Table 7.2, C1). Of the 26 grinding surface morphologies (including the one possible grinding surface exhibited on LM GS 13), most were flat in cross section ($n = 18$), three were “dished” (i.e., concave) on one surface, three were convex and two of these were faceted, *cf.* mullers (Section 2.4.1.1; Table 7.3, C2). The morphological features of the analysed grinding fragments (i.e., those that display a dished or faceted grinding surfaces) were consistent with those typical of seed grinding tools that have been identified in other archaeological and ethnographic artefact collections (see Smith 1985, 1986, 1989b). However, no peck marks or other diagnostic traces of surface rejuvenation were identified on any of the grinding stone fragments examined.

7.3.1.1 Post-depositional/discard alteration

Post-depositional/discard alteration resulting from surface weathering was observed on most of the artefacts surfaces ($n = 14$ —approximately 84%), indicated by abrasive wear lacking directionality and grain rounding over much of the artefact, as seen on the unground surfaces. Although iron oxide accretions were not present, most artefacts ($n = 9$) displayed iron oxide staining of quartz grains, although this is likely to be a natural feature and not related to post-depositional/discard alteration. Post-depositional residue contamination of the artefact surface in the form of decaying rootlets ($n = 1$), lichen spores ($n = 2$) and hyphae ($n = 1$) were also observed on a selection of artefacts ($n = 4$) (Table 7.4).

7.3.2 Use-wear

Similar to the MJB specimens, variation in the degree of surface wear on the Lake Mungo artefacts was distinguishable at low magnification, particularly in the degree of grain rounding and surface levelling (Table 7.6, C4). Variation in wear may be the result of differential weathering on the artefact surfaces related to the context in which the artefacts were deposited. Because all of the grinding stones were collected from the surface of an eroding landform, they were all exposed to wind and water erosion. ‘Sandblasting’ could result in the obliteration of face-up use-polished surfaces, which had been previously documented on experimental flint artefacts that were left in very windy, sandy environments for several months (Barton & Bergman 1982). The weathering of

the use-polished surfaces, however, is thought to be minimal because use-polish has been preserved in sufficient detail to make direct comparisons with experimental and ethnographic tool surfaces (Plates 7.4d, f, h). Fourteen of the 17 specimens displayed use-polish patterns that were broadly similar across most surfaces whereby the higher elevated zones on the use-polished quartz grains displayed a bright reticular use-polish, compared with the lower zones, between quartz grains, in the interstices, which displayed low or no use-polish development (Plate 7.11). The distribution and degree of wear development varied across each artefact, but generally the wear was extensive and the degree of use-polish development was very high (Table 7.7; C4). Micro-striations were present on the use-polished surfaces, and typically occurred oriented in multiple directions and had varying widths and depths. Broad, bright alignments of use-polish are likely the result of abrasion, occurring from the friction of stone-on-stone activities. Narrow, short, shallow striations are likely the result of stone and grit that was incorporated into the crushed seed mixture during grinding.

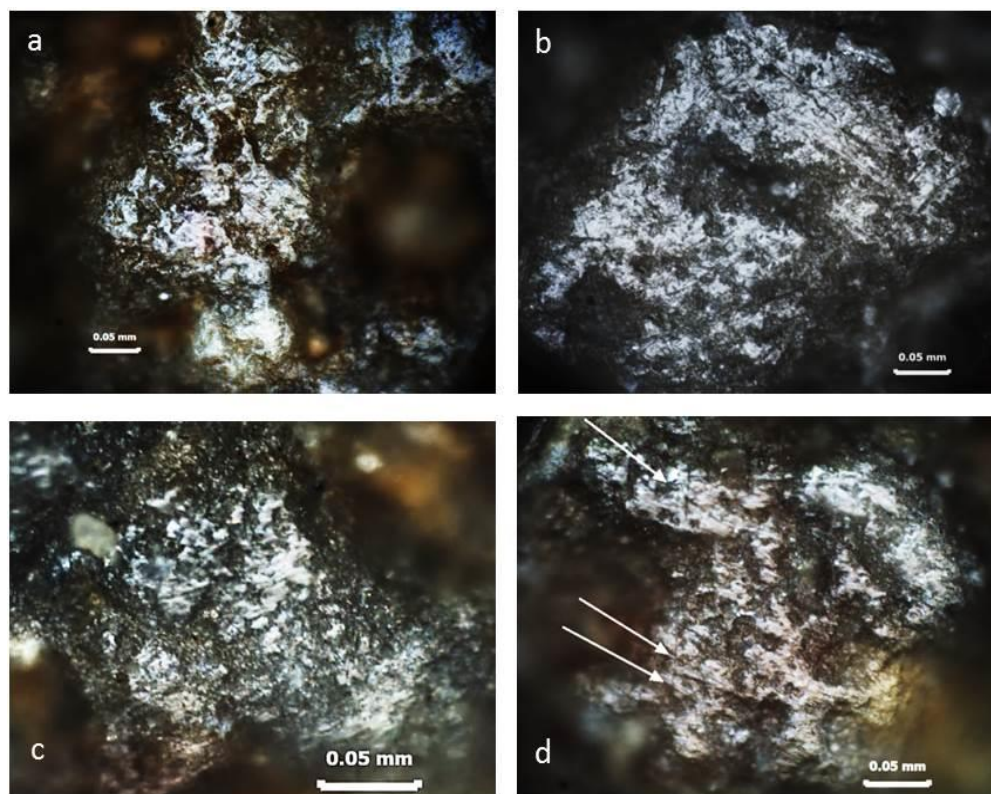


Plate 7.11a-d: Reticular use-polish on Lake Mungo grinding stones: **a)** LM GS 11; **b)** LM GS 10; **c)** LM GS 16; **d)** use-polish and striations LM GS 14.

A higher degree of rounding and surface undulation on some quartz grains indicated that other tissues were likely to have been processed, and may have included larger, softer substances—possibly wood or and other soft plant material. On artefact LM GS 11, use-polish occurred on the

highest grain elevations and extended onto the lower interstices, indicating soft plant processing or contact with more pliable materials. Two specimens (LM GS 12 and 13) have sustained scattered patches of weakly developed use-polish that were undiagnostic of worked material. The absence of other residues on these artefacts, however, suggests that only plants were processed.

7.3.3 Residues

7.3.3.1 Visual residue identification (pipette extractions)

Plant and animal tissues were the most common materials identified in the residue mixtures removed via pipette extractions (Table 7.8). Plant material in the form of cellulose fibres and amorphous organic tissue (confirmed as plant following the application of various staining agents) were the most common organic materials, recovered from most of the artefacts ($n = 12$) (Plate 7.12). Gelatinised and intact starch grains were also observed from extracted material but were present on only a select number of stones and were low in abundance ($n = 4$). The intact starch grains, which were all found individually (rather than in clusters or as compound grains), were spherical and generally quite small (roughly $<5\ \mu\text{m}$ in diameter—but see Fullagar *et al.* 2015 for starch analysis on the same stones using other methods of extraction). One damaged starch granule ($20\ \mu\text{m}$ diameter) was recorded, following the application of Congo Red. The taxonomic origin(s) of the starch grains could not be determined.

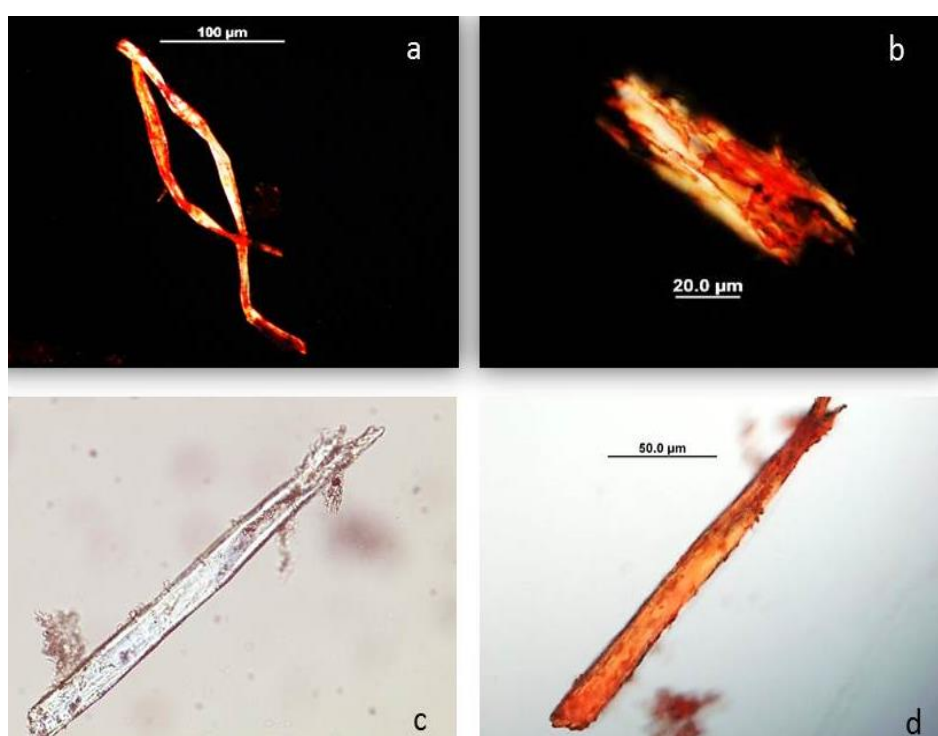


Plate 7.12a-d: Plant residues on Lake Mungo grinding stones. **a-b)** cellulose fibres stained with Congo Red, photographed in cross-polarised light, LM GS 16; **c)** unstained lignified plant tissue, LM GS 11; **d)** lignified plant tissue (same as previous image) stained with Safranin, LM GS 11.

Animal residues were observed on four of the thirteen artefact extractions, occurring in the form of collagen fibres that were highlighted with staining agent Orange G (n = 3) (Plate 7.13a) and one feather barbule (Plate 7.13b). While the identification of collagen fibres has indicated the opportunistic use of grinding stones for processing animal tissue, the isolated feather barbule in absence of accompanying collagenous residues, suggested that the feather barbule was not related to use.

Environmental contamination in the form of hyphae and lichen spores was also observed in residues sampled from three artefacts. Fullagar *et al.* (2015) noted that the sediments composing Unit E were held in place by a thin crust of lichen and therefore any grinding stones that were embedded in or lying on these surfaces, such as LM GS 1 and LM GS 3, are likely to have lichen attached. As discussed in Section 7.2.3.1, the likelihood of residues from laboratory contamination is low.

In addition to my residue analysis, ultra-sonication and additional pipette extractions were also retrieved for a selection of the Mungo grinding stones by two other analysts: Judith Field (JF) and Birgitta Stephenson (BS) (Table C11) (see Fullagar *et al.* 2015). BS reported the presence of starch (number of artefacts with residues present = 3 of 11 analysed), cellulose (n = 9) and collagen (n = 3), the latter of which were identified following the application of an additional staining agent,

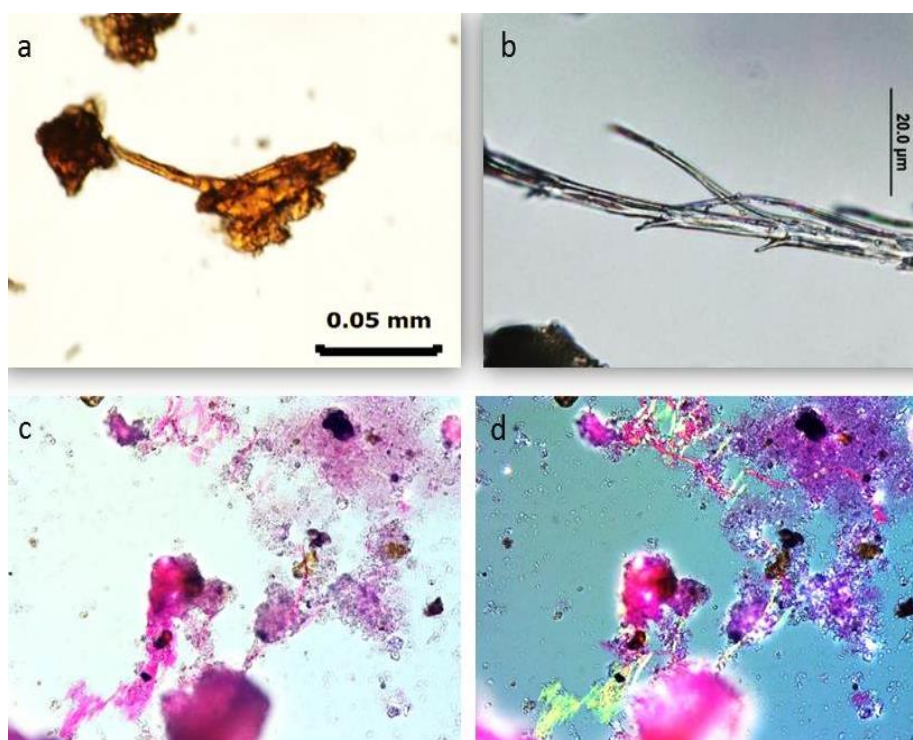


Plate 7.13a-d: Animal residues on Lake Mungo grinding stones. **a)** amorphous collagen stained with Orange G, LM GS 17; **b)** feather barbule, LM GS 5; **c-d)** amorphous collagen stained with Picro-Sirius Red, photographed at x400 in (c) part-polarised (collagen appears pink) and (d) cross polarised light (collagen appears yellow), LM GS 1. Photographs of c-d by B. Stephenson.

Picro-sirius Red (Plate 7.13c-d; Table C11). JF was also able to confirm the presence of starch on at least nine grinding stones, the details of which are presented below.

7.3.3.2 Visual residue identification (ultra-sonicated extractions)

Ten of the Lake Mungo grinding stones were subjected to additional residue analyses by means of ultra-sonication and separation, performed by JF. As evidenced with the MJB specimens, residue recovery was enhanced with methods of ultra-sonication and separation. Starches were identified on nine of the ten specimens but were represented by only a few grains (number of grains per artefact: 1 – 7) (Table 7.10) (Fullagar *et al.* 2015). Damage due to grinding was noted on most of the recovered grains (Plate 7.14), providing direct evidence of starchy plant processing. Because of the low number of starch grains recovered, species of origin could not be determined, but the dimensions and morphology are not typical of known grass seeds.

7.3.3.3 Biochemical and elemental residue identification

Biochemical testing selected to detect protein, carbohydrates, fatty acids and starch, has indicated the presence of various compound groups, summarised in Table 7.11 (for details, see Table C8, Appendix C). Protein was detected on three artefacts, while carbohydrates and starch were detected on three and six artefacts, respectively. No fatty acids were detected on any of the artefacts. The three specimens that tested positive for carbohydrates included LM GS 3, LM GS 16 and LM GS 17, confirmed by the Diphenylamine and PSA tests. An additional three specimens tested positive for starch: LM GS 1, LM GS 11 and LM GS 12. Starch was visually identified by JF on all six specimens after ultra-sonication and separation techniques. Although a similar number of visible residues were documented in extractions sampled from the MJB and Lake Mungo assemblages, bimolecular residues occurred less frequently on the Lake Mungo artefacts.

7.3.3.4 Absorbance spectroscopy

No absorbance that could be diagnostic of worked material was read for any of the Lake Mungo specimens. The low sensitivity of the tests, along with the age and degree of preservation of the residues on the Lake Mungo grinding stones, ensured that more specific compounds could not be characterised using this method.

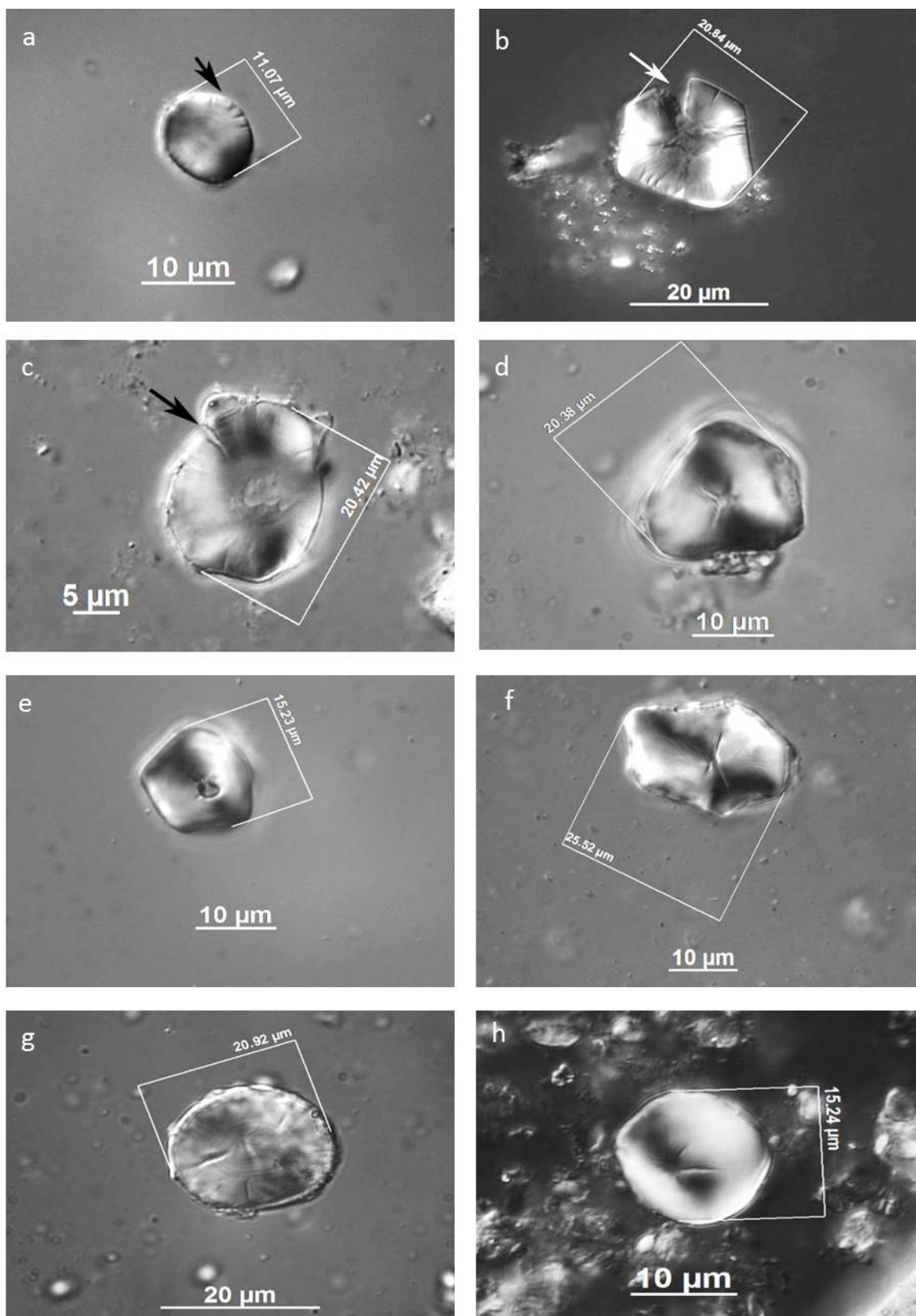


Plate 7.14a-d: Starches identified on Lake Mungo grinding stones by JF following sonication and separation. Arrows indicate damage from grinding. **a)** Damaged starch, LM GS 10; **b)** damaged starch, LM GS 11; **c)** damaged starch, LM GS 12; **d)** starch grain, LM GS 13; **e)** starch grain, LM GS 14; **f)** starch grain, LM GS 15; **g)** starch grain, LM GS 16; **h)** starch grain, LM GS 17. Photos by J. Field.

7.3.3.5 GC-MS

GC-MS analysis has indicated the presence of a limited range of chemical compounds ($n = 7$) occurring on the ground surfaces of 12 artefacts, all of which have originated from plant material (Table D2). The most common compound recognised was [1-ethyl-4-methylbenzene] (present in five of the 24 residue samples collected from 12 artefacts), which is a compound commonly found in plants (among other materials), and may be an indication of processing seeds or nuts. Other commonly detected compounds included azelaic acid ($n = 4$) and hexadecanoic acid ($n = 4$), which are fatty acid compounds and may also be present within plant residues. A summary of the GC-MS data has indicated the presence of plant residues on three of the 12 artefacts examined (LM GS 1, LM GS 3 and LM GS 5), one of which also contained evidence for handling, reflected by the occurrence of octadecanoic and hexadecanoic acids found in combination (LM GS 5) (Table 7.14). All three artefacts with evidence for plant processing as indicated through GC-MS are from Pleistocene contexts removed from the Unit E sands. Residue mixtures sampled from the remaining nine specimens were unable to be characterised with GC-MS. Residues from these samples were not present in large enough quantities to enable detection and have indicated that residue preservation is limited. The three specimens that contained the highest quantities of residues are larger specimens, two of which had two grinding surfaces.

Similar to the visual identification of residues from pipette and ultra-sonicated extractions, residue detection with GC-MS was low. I attribute the lower abundance of residues to be the result of poor preservation of residues on tools from an open site context. Previous experimental work by Langejans (2010) has revealed that open sites, particularly those with enhanced sun exposure and an associated increase in enzyme activity, leads to more rapid decay of residues. Similarly, Langley (2014) has found that organic materials are less frequently identified in open sites compared to cave and rockshelter sites, and as such we would expect to see limited preservation of organic residues.

7.3.4 Functional Interpretation

Two main classes of grinding stone implement were identified among the Lake Mungo specimens, based on their morphology and use-wear. These included both upper and lower coupled stones, some of which may be classified as “formal” seed grinding tools, specifically, millstones and mullers (*cf.* Smith 1985, 1986, 1989b). Only one filing stone was identified (LM GS 11). All artefacts were manufactured on the same (or very similar) kind of sandstone.

Twelve specimens were identified as lower stones, and displayed concave surface morphologies or were a thin portion of a well-worn lower stone. Six specimens (LM GS 1, 3, 2, 10, and 11) were identified as upper stones, including two with distinct facets (*cf.* mullers). Two specimens (LM GS 1 and LM GS 3) with concavities on one surface appeared to have been recycled lower (millstone) fragments, subsequently used as upper stones. One small specimen appeared to be a complete upper stone (LM GS 11), with wear on three surfaces and used as an upper seed grinding stone and a stone file for polishing other plant materials, possibly wood. It is uncertain whether three specimens (LM GS 13, 14 and 15) functioned primarily as upper or lower grinding stones as all possessed relatively flat or irregular grinding surfaces. No peck marks or traces of surface rejuvenation could be identified, and the fragments were typically too small to confidently identify any part of a worn groove.

At least 15 of the 17 examined grinding stones from Lake Mungo were plant-processing tools, 14 of which displayed use-wear and morphological characteristics consistent with seed grinding. Use-wear on 14 of the grinding stones was characterised by highly levelled grains and a bright, reticular use-polish visible at high magnification. LM GS 11 also displayed a reticular use-polish but this extended into the lower recesses of the grains, indicating the processing of a softer plant material. The remaining two artefact specimens (LM GS 12 and LM GS 13) did not show any diagnostic traces of use. Starch grains were documented on nine specimens and often displayed mechanical damage, most likely acquired through grinding. The lack of starch is probably related to taphonomic processes occurring on exposed artefacts. In a detailed review, Haslam (2004) suggested that the local and depositional environment affects starch survival, with some destructive factors including the presence of enzymes, clays and metals within the soil.

7.4 Comparison of MJB and Lake Mungo artefact collections

Functional analyses performed on grinding stone specimens from MJB and Lake Mungo has indicated a range of grinding activities at both sites starting from at least 50 ka at MJB and 14 – 25 ka at Lake Mungo. At MJB, grinding activities included the processing of organic material such as seeds, starchy plants and bone; as well as the preparation of inorganic materials, including stone and pigment. At Lake Mungo, evidence for the processing of seeds and other organic plant materials were also documented, but grinding stones used for craft purposes (including the preparation of pigment), were not identified. Grinding stones identified from each site were classified as coupled stones (for MJB, $n = 38$ of 91, ~42%; for Lake Mungo, $n = 13$ of 17, ~76%) or filing stones (MJB: $n =$

29, ~32%; Lake Mungo: n = 1, ~6%). The relative proportions of coupled and filing stones identified at each site may have been the outcome of several factors that could have included availability and accessibility of obtaining certain resources, as well as environmental pressures at each site. At MJB, filing tools were used to process red haematite and sometimes for the preparation/sharpening of volcanic stone for axe manufacture, while coupled stones were generally used to process plant materials that included seeds, roots, leaves, tubers, nuts and fruits. At Lake Mungo, the only filing tool (LM GS 11) was most likely used as a polishing stone for the preparation of wooden artefacts, while the coupled stones were used for the processing of seeds. The coupled stones from Lake Mungo generally showed a very different morphology to the coupled stones from MJB, sometimes displaying dished or faceted surfaces, indicative of millstones and mullers as defined by Smith (1985, 1986, 1989b). In contrast, the MJB grinding fragments lack a recurring form and are considered “amorphous” (Smith 1985). I suggest that the difference in morphology is related to the extent of seed processing, which was a dominant activity at Lake Mungo. The lack of lower stones identified throughout the excavated sequence of the MJB, and the absence of formal seed grinding millstones, has indicated that different grinding stone morphological types at this site are different from seed grinding stones from the arid and semi-arid regions of Australia. Three of the Lake Mungo tools have also been recycled, suggesting that these sandstone artefacts were more heavily utilised at this site prior to discard. This is probably a reflection of the availability of sandstone blanks, which were less prevalent at Lake Mungo and, therefore, artefacts would have been used more extensively prior to discard.

The preparation of different plant resources at MJB and the dominance of seed grinding at Lake Mungo is the outcome of the local environmental circumstances or the availability of processed materials, including surrounding vegetation, distance to water sources and reliability of resources. The preparation of inorganic material at MJB, such as pigments and volcanic stone, may reflect the different symbolic and cultural practices that occurred in the past (see Chapter 8 for discussion). The use of grinding stones for processing of animal tissue was also identified on the surfaces of a few artefacts from each assemblage, but likely only reflect the opportunistic use of grinding stones for faunal processing tasks.

The larger sample of grinding stones examined from MJB compared with Lake Mungo may explain why a greater range of activities is noted for MJB. Evidence for the grinding of ochre is indicated at Lake Mungo by the presence of two ochre stained human burials at c. 30 – 40 ka (Bowler *et al.* 1970, 2003); however, grinding stones with evidence for ochre grinding of similar age are yet to be identified. I suggest that with a larger sample size, pigment processing tools at Lake

Mungo will be identified, but are less common at the site than seed grinding or other plant processing tools.

Apart from the specimens in the lowest excavated levels, the MJB artefacts show better preservation with a wider variety of residues and use-wear than the Lake Mungo artefacts. I attribute the poorer preservation at Lake Mungo to surface exposure in an open site setting compared with MJB, a protected rockshelter site, where artefacts were deposited in a relatively stable deposit with little evidence of substantial subsurface disturbance or artefact weathering—apart from chemical weathering of dolerite (see also Clarkson *et al.* 2015). The MJB artefacts were all collected from within stratified deposits underlying a rockshelter, and were protected by sediments within the depositional environment, despite a degree of subsurface mixing closer to the rock wall. In contrast, the Lake Mungo specimens were exposed (probably for months) on the surface, eroding from a previously buried landform and were thus subjected to both wind and water erosion for an unknown time (although not so much as to obliterate wear at high magnification). Variation in preservation of some traces, including residues and use-wear, may therefore be explained by differential weathering of the artefacts (Fullagar *et al.* 2015).

7.5 Chapter Summary

Three main classes of grinding stone implements were identified among the MJB and Lake Mungo specimens, based on their morphology and use-wear. Implement classes include *filing* tools, used singularly to process another material; *lower stones*, used beneath another stone to process an intermediate material; and hand-held *upper stones*, used on a lower stone to process an intermediate material. Use-wear on the quartz grains was important for determining stone-on-stone contact, which was indicated by highly levelled grains on the grinding surface accompanied by frequent, conspicuous micro-striations (Figure 6.2a-c). The macroscopic shape of the stone, particularly the cross-section of the grinding surface (flat, concave or convex) was important (in conjunction with use-wear) for identifying lower and upper stones. The identification of key use-wear features such as use-polish, striations, and features of the quartz grains (e.g., presence of fractures, degree of rounding/levelling), as well as the characterisation of residues, were important for determining worked material. Through the integration of morphological, use-wear and residue data, artefact function was able to be determined for many of the artefacts.

In this chapter, I have summarised the key morphological and technological features of each stone examined from MJB and Lake Mungo, and discussed the use-wear and residues documented

on these artefacts. In the following chapter, I discuss the implications of these analyses for on-site activities, occupation and behavioural adaptations to changing environmental conditions and cultural practices.

Chapter 8:

Functional variability and distributions of grinding stones in Australia and implications for past human behaviours

8.1 Introduction

Functional analysis of grinding stones from MJB and Lake Mungo has provided a means for evaluating the specific grinding activities occurring at each site during the late Pleistocene and Holocene. At MJB, activities included the grinding of organic material such as seeds, starchy plants and bone, as well as the preparation of inorganic materials, such as stone and pigment. At Lake Mungo, evidence was documented for the processing of seeds and other organic plant and animal materials, but grinding stones used for craft purposes, including pigment preparation, were not identified. Site chronologies have provided a means for evaluating the extent to which temporal and spatial variability of grinding stone function can be linked with site context, resource availability and environmental change. This chapter discusses the temporal, spatial and functional distributions of grinding stones at both sites, and the implications for grinding stone variability across Australia.

8.2 Madjedbebe

8.2.1 Grinding stone functions

Ninety-one grinding stones and grinding stone fragments were identified within the various levels of the MJB 2012 excavated sequence. The function of many of these grinding stones was determined through examination of grinding stone morphology, use-wear and residue analysis. Artefact functions included the processing of plant ($n = 52$), animal ($n = 4$), stone ($n = 6$) and pigment ($n = 16$) (Table 7.16). Eleven artefacts displayed evidence for the processing of more than one material and were classified as multi-functional implements.

Grinding stones that functioned as plant processing tools consisted of stones that were used to process both soft and hard seeds, starchy plants, and other softer plant materials such as roots, leaves and underground storage organs. Use-wear indicative of hard plant processing (e.g., seeds and nuts) was usually recognised by the occurrence of a bright, well-developed reticular use-polish that was restricted to the highest points of the quartz grain micro-topography, while the processing of softer plant material was recognised by a reticular use-polish that extended into the lower micro-topographic regions of the grains (Plate 8.1, 8.5, 8.6). Starch grain analysis and the detection of specific residue compounds through GC-MS enabled the identification of specific plant residues to be further attributed to certain plant varieties, for example, seeds, tubers, roots, leaves and fruit.

Evidence for the processing of animal material was mostly reflected by the presence of residues detected via biochemical analyses or visually identified from within residue extractions.

Visually identified animal residues included bone, collagen and highly degraded hair fibres. GC-MS analysis also detected animal fats, amino acids and degraded blood molecules on two of the grinding stones (GS 3, UP GS 21) (Chapter 7). All artefacts that displayed animal residues also contained traces consistent with the processing of another material, usually plant, and were therefore all classified as multifunctional implements. I suspect that these implements were used opportunistically to process a range of locally available resources.

Several grinding stones displayed evidence for direct stone-on-stone contact, including one whetstone, two hammerstones, two larger filing stones and two stones with manufacture-ground edges. Wear features associated with direct stone-on-stone contact included macroscopic surface levelling (and sometimes edge bevelling) and a high frequency of striations and micro-scarring of quartz grains. Other evidence for the processing of inorganic materials was reflected on grinding stones that were used to process red haematite. Wear features indicative of this activity were recognised by the occurrence of red granular pigment, often wedged deep within the interstitial spaces of the quartz grains with evident directionality, as well as the presence of an undulating use-polish (Plate 8.2, 8.5). Ground haematite pieces also occurred frequently throughout the MJB cultural sequence, most of which displayed facets and use-wear consistent with grinding or processing on sandstone surfaces (Figure 3.2d).

Twenty-three grinding stones did not have use-wear or residue traces diagnostic of worked material. All 23 specimens, however, displayed evidence of grinding wear, but the specific function of these artefacts is unknown.

8.2.2 Chronological distribution

Similar to the other artefact distributions at MJB (Section 3.2.5), grinding stones were concentrated in three distinctive pulses, correlating with average depths of between approximately 182 and 209 cm (Pulse 1); 113 and 150 cm (Pulse 2); and 10 and 36 cm (Pulse 3), the latter coinciding with the most recent accumulations of the shell midden (Figure 8.1). Unpublished radiocarbon ages produced on charred botanical remains and gastropod shell from the 1989 and 2012 excavations gave bracketing ages of between 28.6 and 35.8 ka cal BP (Pulse 1), 9.2 and 18.2 ka cal BP (Pulse 2), and 4.2 and 5.5 ka cal BP (Pulse 3), respectively (Table 8.1). There was some overlap between the pulses of grinding stones and other cultural materials, such as ground haematite and other flaked stone artefacts, as reported by Clarkson *et al.* 2015 (Section 3.2.5; Figure 3.4). The deposits in which

all artefact frequencies per unit volume were the highest probably indicate more intensive site occupation.

Grinding stones recovered from deposits above 84 cm (i.e., those that accumulated after Pulse 2, $n = 13$) were considered to be from Holocene contexts (i.e., younger than 10 ka). Grinding stones recovered from deposits below 113 cm, including all grinding stones from Pulse 1 and 2 and in between ($n = 76$), were considered to be from Pleistocene contexts and from the Pleistocene/Holocene boundary. Another two grinding stones were analysed but derive from the backfill removed from the Kamminga trench and their antiquity is not known.

Table 8.1: Grinding stones occurring in Holocene and Pleistocene contexts and associated pulses.

	Location of grinding stones	No of grinding stones	Depth range of GS(s) (cm)	Spit range	Bracketing ages
Pleistocene contexts ($n = 76$)	Below P1	3	210 – 222	41 – 44	36 and 45* ka
	Pulse 1	25	182 – 209	34 – 40	28.6 and 35.8 ka
	B/W P2 and P1	1	172	32	19 and 25** ka
	Pulse 2	47	113 – 150	21 – 29	9.2 and 18.2 ka
Holocene contexts ($n = 13$)	B/W P3 and P2	4	74 – 84	16 – 18	7.2** and 8.4** ka
	Pulse 3	8	10 – 36	4 – 10	4.2 and 5.5** ka
	Above Pulse 3	1	7	3	150* and 300* cal BP
	Surface finds	0	n/a	n/a	n/a

8.2.2.1 Grinding stones from Pleistocene contexts

Seventy-six grinding stones were recovered from Pleistocene contexts, accounting for nearly 84% of the grinding stones I have analysed from MJB. These included all grinding stones recovered from Pulse 1 ($n = 25$; 185 – 209 cm), Pulse 2 (including those deposited during the Pleistocene/Holocene transition) ($n = 47$; 101 – 150 cm), and other deposits either in between ($n = 1$) or directly following ($n = 3$) these two pulses. Coinciding with the higher frequencies of grinding stones were high densities of quartz and silcrete artefacts among other artefact classes. Most of the grinding stones recovered from Pleistocene contexts functioned as plant processing tools ($n = 44$), with less frequent occurrences of pigment ($n = 15$), stone ($n = 3$) and animal processing tools ($n = 3$) (Table 8.2). Other grinding technologies also occurred in Pleistocene contexts, most frequently in

the form of ground or abraded haematite pieces and ground-edge axes (and fragments thereof). Preliminary use-wear and residue analysis performed on the ground-edge axes has indicated that they were likely used for the chopping of wood (Fullagar *et al.* in prep), while use-wear analysis of a small collection of flaked-stone tools (n = 104) from similar contexts has also indicated that wood working was a dominant on-site activity (Hayes *et al.* 2014a: 89).

Similar to the grinding stone frequency, other lithic artefacts also occurred more frequently in the Pleistocene deposits. Previous analyses of flaked stone pieces recovered from the 1989 excavations have shown technological change through time, whereby the lowest band of occupation is dominated by silcrete and quartzite artefacts, which are overlain by artefacts representing an industry of bipolar working of white and crystal quartz (Clarkson *et al.* 2015). Preceding this is an assemblage of chert and non-local quartzite, including broken distal tips, which probably indicate manufacture of bifacial points (Figure 8.2). Changes in the relative proportions of artefact varieties may be the result of several behavioural adaptations related to changing environmental conditions, discussed in the following sections.

Table 8.2: Distribution of MJB grinding stones by function. Note: multi-functional tools are subtracted.

Material processed	Number of grinding stones identified										
	Pleistocene						Holocene				Un-known
	After Pulse 1	Pulse 1	b/w P1 & P2	Pulse 2	Total	%	b/w P3 & P3	Pulse 3	Total	%	
Plant	0	12	1	31	44	58	1	7	8	62	1
Animal	0	0	0	3	3	4	0	0	0	0	0
Pigment	2	4	0	9	15	20	1	0	1	8	0
Stone	0	1	0	2	3	4	2	1	3	23	0
Unknown	1	9	0	11	21	28	2	0	2	15	1
Multi-functional	0	1	0	9	10	13	1	0	1	8	0
Total	3	25	1	47	76	-	5	8	13	-	2

8.2.2.1.1 Grinding stones from below Pulse 1

Three grinding stone specimens were identified in deposits pre-dating Pulse 1, in depths below 211 cm. The lowest grinding stone, UP GS 36, was recovered from a depth of 222 cm and has an associated single-grain OSL age of younger than 44.2 ± 4.7 ka, as determined from ages produced

from sediments gathered from slightly deeper contexts (230 – 236 cm) (Table 3.1) (Roberts *et al.* 1998a). Even earlier grinding stones were recovered from MJB during previous excavations by MS, BR and RJ in 1989; dated at c. 50 ka (Clarkson *et al.* 2015; Roberts *et al.* 1998a). Of the three specimens recovered below 211 cm during the 2012 excavations, two displayed evidence for the processing of red pigment while the function of the third tool could not be determined. The occurrence of ground haematite pieces in similar aged deposits (and even earlier—see Clarkson *et al.* 2015) have provided additional support for the grinding of pigment at this time. Although use-wear analysis was performed on a limited number of ground haematite pieces that were restricted to the earliest cultural deposits (n = 34) (Cox 2014), the macroscopic surface features on most of the ground haematite pieces were generally consistent for most specimens extending down the sequence. Experimental use-wear reference libraries produced for haematite pieces from MJB have indicated that most pieces displayed wear traces indicative of contact against hard sandstone (e.g., Cox 2014; Hodgkiss 2010). Evidence for plant processing is not recognised on any of the artefacts pre-dating Pulse 1, although it is possible that organic use-residues resulting from such activities have degraded and are no longer detectable. Similarly, use-polish may have been obliterated in the depositional environment. Examination of flotation material recovered from the site has indicated the presence of burnt plant material from similar depths, mostly in the form of vegetative parenchyma, indicating that plants may have been deliberately brought into the site. The recovery of charred botanical remains at MJB from depths up to 274 cm (Spit 57) has indicated the collection and possible consumption of plant foods by approximately 52 ka (Florin 2013). However, there is little evidence to suggest that these items were ground, and the lack of grinding stones used as plant processing tools may indicate that plant foods were not being processed onsite by grinding. Indirect evidence for the use of grinding stones since the initial occupation of the site c. 52 ka BP was also reflected by the occurrence of a small ground-edge axe fragment that was recovered from a depth of 255 cm (Spit 52) during the 2012 excavations. This fragment had distinctive grinding wear that could only have been acquired through stone-on-stone contact; such wear could only be produced by grinding on another stone. Functional analysis of the earliest grinding stones recovered from the 1989 excavations may shed light on the grinding activities of the earliest colonists.

8.2.2.1.2 Grinding stones from Pulse 1

Twenty-five grinding stones were recognised in Pulse 1 (182 – 209 cm below surface) with bracketing ages of 28.6 and 35.8 cal BP (Table 3.1). The grinding stones from this Pulse accumulated during the Lacustral Phase (30 – 60 ka) but decreased in frequency towards the onset of the LGM

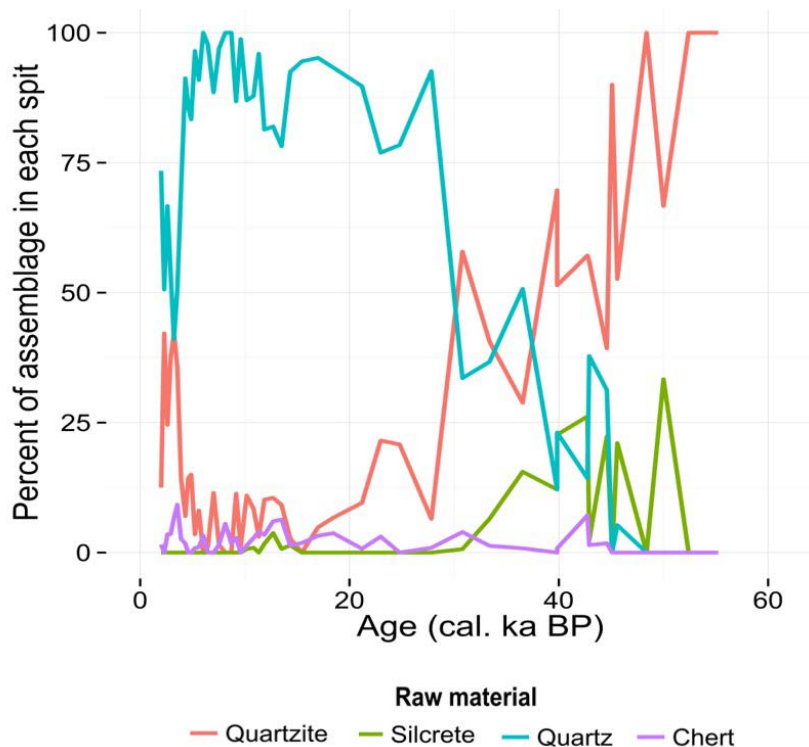


Figure 8.2: Raw materials changes at MJB by interpolated age (from 6 mm sieve totals, 1989 trench). After Clarkson *et al.* (2015): Figure 9.

before disappearing entirely for several thousand years (Figure 8.1). The higher frequencies of other lithic artefacts (including silcrete and quartz) in these deposits have indicated more intensive site occupation prior to the LGM, when conditions were more favourable, characterised by intense wet season precipitation and a high diversity of grass species (Torgersen *et al.* 1988: 38; Wallis 2001).

The grinding stones recovered from Pulse 1 included tools that were used for the processing of plant ($n = 12$) and red pigment ($n = 4$). Nine of the 25 specimens (or 36%) could not be assigned a function as they did not possess clear use-wear traces or use-residues in large enough quantities to be diagnostic of worked material. I attribute the absence of diagnostic use-wear and use-residues to taphonomic processes that have caused the obliteration of use-polish and the degradation of use-residues through sediment friction in the depositional environment, rendering such features undetectable. Single-grain OSL data generated from sediments collected from the rear of the shelter in the NW section has indicated sediment mixing throughout the deposit and especially within the lower levels of the deposit, particularly along the back wall where most grinding stones were discarded (Figure 8.1). Such mixing implies sediment movement throughout the deposit, and hence turbation of sediments may account for the low visibility of use-polish on many of the grinding stones from these deposits. Furthermore, the examination of the unground surfaces of grinding stones from Pulse 1 has also indicated the accumulation on non-use-related wear, including striations that were probably caused from sediment friction (i.e. abrasive contact between artefacts

and sediments in the depositional environment), and several “bright spots” of polish—but these may also be natural features of the sandstone.

Twelve grinding stones from Pulse 1 displayed evidence for the processing of plants. Although plant taxa could not be distinguished, organic compounds indicative of seeds and charred plant remains from wood, seed, nut and tuber, were detected through GC-MS on three specimens. These included two upper stones (GS 39 and UP GS 26) and one lower stone (GS 30), recovered from Spits 37, 35 and 34, respectively. Additionally, one large pitted anvil stone (*cf.* mortar—GS 32; Spit 37) displayed use-wear consistent with the pounding of hard seeds and/or nuts, but use-residues relating to these specific plant materials were too limited and were not detected via GC-MS. Assuming that these four artefacts represent seed processing tools, as suggested by the use-wear and residue evidence, then these four artefacts represent the oldest seed processing tools at MJB. The remaining eight specimens with evidence of plant processing may well have been used for the processing of seeds, however, the evidence is too limited to confidently associate the identified plant material and use-wear traces specifically to seed processing.

The oldest seed grinding tool, GS 39, was recovered from a depth of 201 cm and had convincing evidence for the processing of seeds (Plate 8.1). Although this tool did not represent a “formal” seed grinding tool (*cf.* Smith 1985, 1986, 1989b), distinctive use-polish indicative of the grinding of seeds was documented on the ground surface and GC-MS detected plant compounds consistent with the processing of burnt seeds and nuts. All detected plant compounds were restricted to the grinding surface and were absent from all controls (*i.e.*, sediment sample and unground surface). Six starch grains were recognised in residues sampled from this artefact following methods of ultra-sonication and density separation, but taxonomic identification was not achieved. I attribute the plant residues on this artefact to use and suggest that the low abundance of starch grains is related to poor residue preservation. Poor residue preservation is also consistent with an overall decrease in the abundance of residues detected/identified (both visually and biochemically) on grinding stones recovered from lower depositional contexts.

Despite the low preservation of use-residues, charred botanical remains were recovered from deposits coinciding with the Lacustral Phase, identified as *Pandanus* sp. drupe ($n = 14$), vegetative parenchyma ($n = 197$) and endocarp ($n = 1$) and are likely to be culturally derived (Florin 2013: 48). Other early evidence for plant processing occurs on the ground-stone axes identified at similar depths, as well as use-wear present on ‘use-flakes’ and ‘retouch flakes’ from 45 ka levels of MJB excavated in 1989 that have been used for wood working activities (Hayes *et al.* 2014a: 89).

Four grinding stones from Pulse 1 contained traces of use consistent with the processing of red pigment (e.g., GS 33, GS 40, GS 41 and GS 43), indicated by the presence of haematite/ochre granules and an undulating use-polish (Plate 8.2). Although most of the residues on these tools occurred across the used surface as isolated scatterings of red granular minerals (and did not cover more than 20% of the ground surface), pigment was also present within the lower interstices of the sandstone matrix and therefore considered to be use-related (Plate 8.2d). The occurrence of ground facets on pieces of haematite from Pulse 1 and at similar depths has provided further evidence for the processing of pigments at this time. Use-wear analysis should be performed on a greater collection of modified haematite pieces from various deposits extending down the sequence to identify contact material following the methods set out by Cox (2014).

8.2.2.1.3 Grinding stones from the LGM

Only one grinding stone (L1349) was identified between Pulse 1 and 2 (150 – 176 cm), a period coinciding with the LGM (18 – 30 ka BP). Owing to a lack of diagnostic use-wear and residue traces, the function of this stone was not determined. The scarcity of grinding stones and the lower frequency of other cultural material during this period may indicate only minimal site usage during the LGM. The cessation of flaked stone artefacts made from silcrete in deposits coinciding with the LGM could also reflect a reduction in mobility, the interruption of exchange networks, or the change in configuration of group territories (Clarkson *et al.* 2015), possibly related to the environmental stress that had resulted from harsher environmental conditions whereby temperature and precipitation had decreased, causing enhanced aridity. Population curves provided by Williams *et al.* (2013) have indicated that the population fell by about 60% between 21 and 18 ka. The resulting lower population and the relocation of existing populations into refuge areas may imply decreased site occupation that could explain an overall decrease in cultural materials at the site during this period.

8.2.2.1.4 Grinding stones from Pulse 2

Forty-seven grinding stones were recognised in Pulse 2, representing just over 50% of the 2012 excavated grinding stone assemblage for MJB (n = 91). Other artefact classes also peaked during this time and included large accumulations of quartz and silcrete artefacts, but faunal bones and shell were not abundant (Clarkson *et al.* 2015). Functional analyses of grinding stones from Pulse 2 has indicated a more diverse range of processed materials compared with specimens

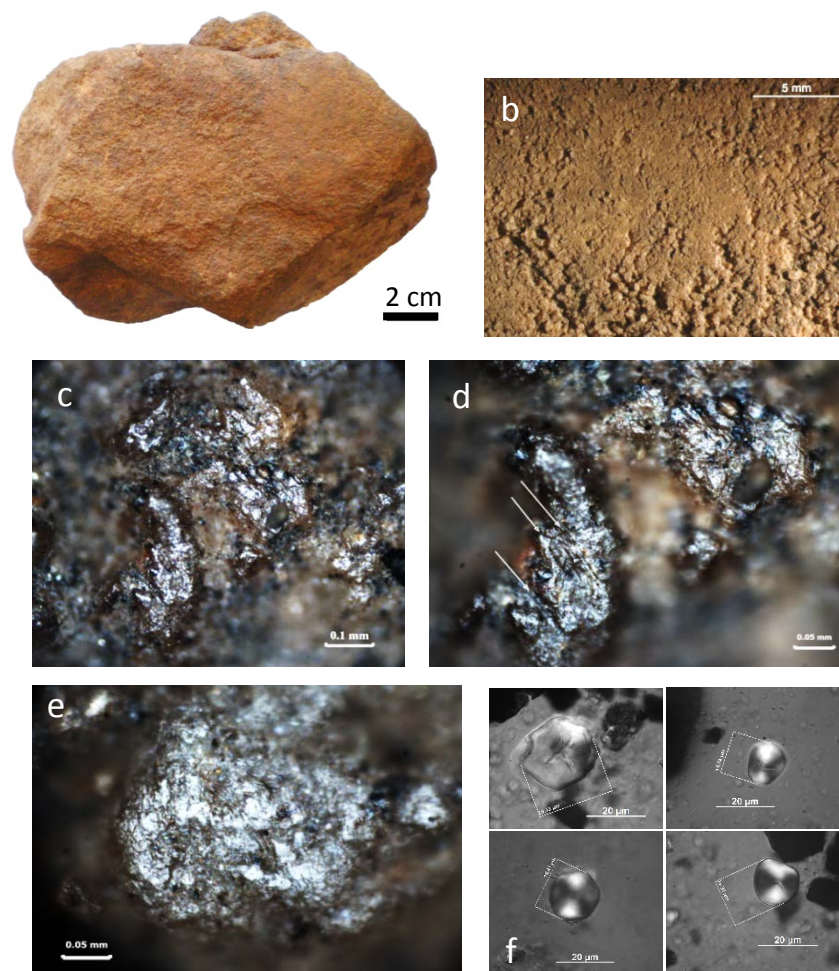


Plate 8.1: Use-wear and residue images from MJB artefact GS 39 from Pulse 1, used for the processing of starchy plants. **a)** Artefact image showing ground surface; **b)** low magnification image of ground surface showing highly levelled and highly rounded grains; **c-e)** high magnification images of reticular use-polish with fine, parallel striations; **f)** (four images) starch grains recovered from ground surface following ultrasonication and density separation.

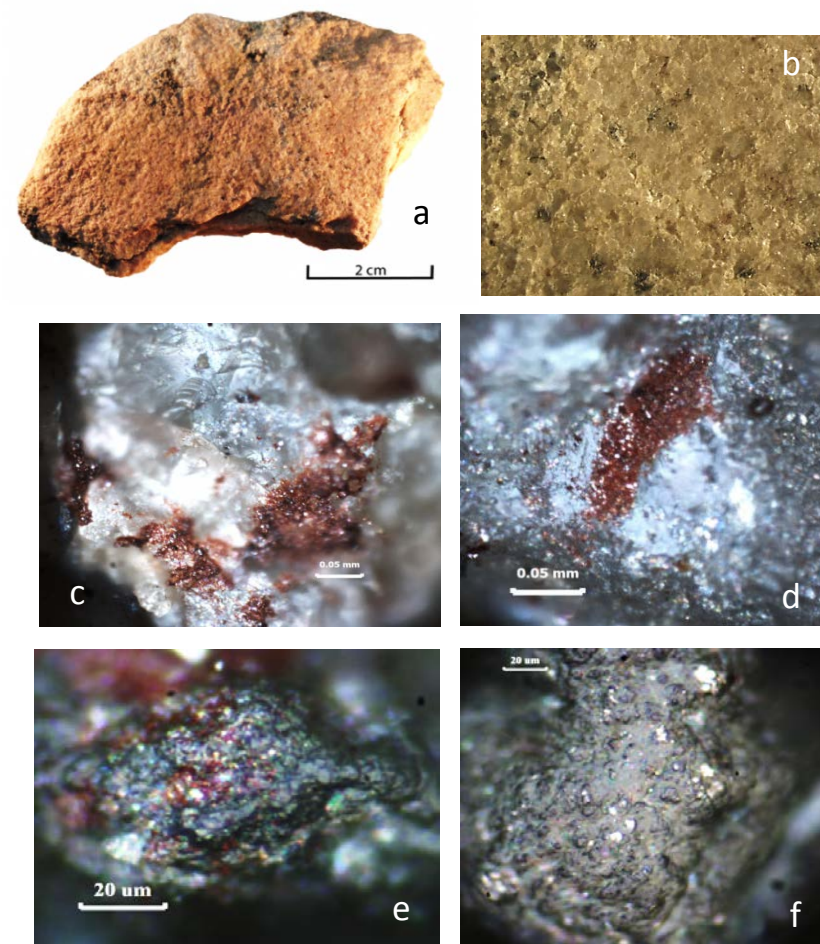


Plate 8.2: Use-wear and residue images of MJB artefact UP GS 36, used for the processing of red pigment. **a)** Artefact image depicting ground surface; **b)** low magnification image of ground surface showing highly levelled and moderately rounded grains; **c-d)** micro-scarring on quartz grain and haematite use-residues, note the evident streaking in image d; **e)** haematite use-residues and undulating surface use-polish; **f)** high magnification image of undulating surface polish with metallic residues and residue film.

recovered from Holocene contexts (Section 8.2.2.2) and has evidence for the processing of plant (n = 31), animal (n = 4), pigment (n = 9) and stone (n = 2). The functions of the remaining 11 specimens were not determined. Nine of the grinding stones (approximately 19%) were considered to be multi-functional with evidence for plant processing identified on tools that also displayed evidence for the processing of stone (n = 1), animal (n = 4) and haematite (n = 4). All of the animal processing tools (GS 3, GS 9, UP GS 17, UP GS 21) and four of the haematite processing tools (GS 4, GS 21, UP GS 14, UP GS 25) were considered multi-functional implements as they displayed use-wear (and some residues) consistent with the processing of plant materials in addition to use-residues consistent with the processing of animal materials and haematite, respectively. Collagen, hair, feathers and blood were documented on the four animal processing stones, and were either visually identified with the aid of stains or detected biochemically with GC-MS. The limited number of animal processing tools compared with grinding stones used for other tasks has indicated that animal processing was not a dominant activity at the site. In addition, the occurrence of well-developed use-polish indicative of plant processing has indicated that these tools were primarily used as plant processing implements. I suggest that the animal residues identified on these four tools represent the remnants of infrequent processing events where the stones were used opportunistically to process a selection of animal and other materials. The use of grinding stones as opportunistic tools has been suggested in the past by other researchers (e.g., Balme *et al.* 2001; Gorecki *et al.* 1997; Nash 1993), and there is ethnographic evidence to support the use of millstones for impromptu tasks, such as in the grinding of birds and other small fauna (Smith *et al.* 2015).

One example of a multi-functional implement recovered from MJB is grinding tool GS 3, which displayed multiple lines of evidence for the processing of starchy plants, animal materials and the grinding of stone. This sandstone tool exhibited a manufacture-ground edge which was most likely shaped through filing with another stone (Plate 8.3a-b). Use-residues removed from the manufacture-ground edge included starch grains (present in excess of 200 grains) (Plate 8.3e-f) and degraded blood components, animal fats and plant compounds detected via GC-MS (Plate 8.3g-h). Use-polish on the working edge of this tool is consistent with the processing of plant materials, occurring bright with a reticular morphology (Plate 8.3c-d). Based on this evidence, I suggest that this tool was likely deliberately shaped to act as a cutting and grinding tool for both plant and animal processing.

Nine grinding stones displayed evidence for the processing of pigments, most likely haematite. These tools displayed abundant use-related pigment residues that present across the entire grinding surface (Plate 8.4). Residues were identified deep within the interstitial spaces of the

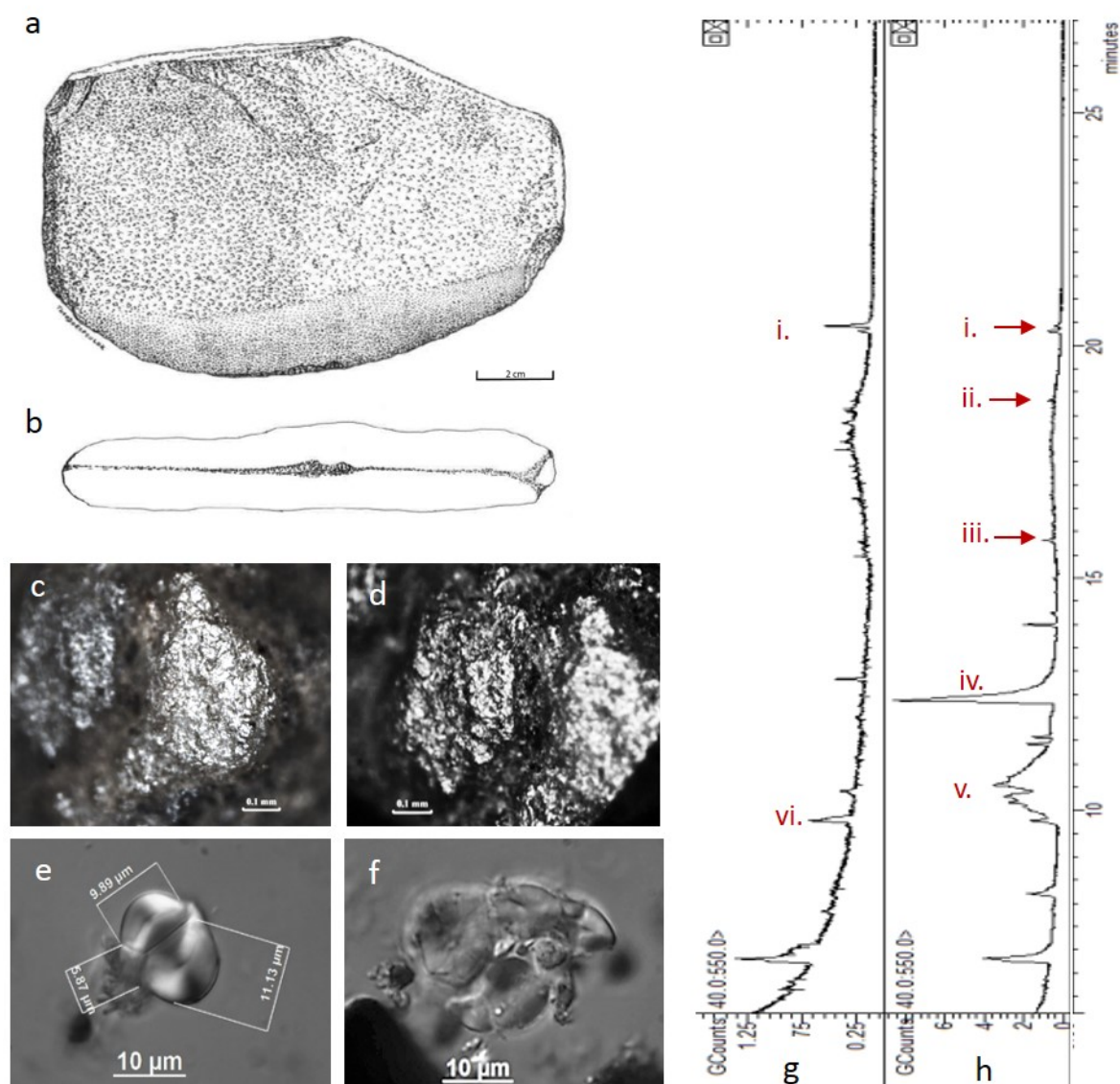


Plate 8.3: Use-wear and residue images of MJB artefact GS 3 from Pulse 2, used for the processing of starchy plants and animal materials. **a)** Artefact sketch depicting manufacture and use-ground edge (Surface 2); **b)** ground edge cross section; **c-d)** high magnification images of reticular use-polish on ground edge; **e-f)** starch grains recovered from ground edge following sonication and separation techniques—note the damaged grains in Plate f; **g-h)** GC-MS chromatograph of residue mixtures sampled from Surface 2 GS 3. Labelled peaks represent detected compounds (**i**) [2,4-bis(dimethylbenzyl)-6-t-butylphenol]—plant origin; (**ii**) cis-10-heptadecenoic acid—animal origin; (**iii**) [(2,8,12,18-tetraethyl-3,7,13,17-tetramethyl-21H,23H-porphinato(2-)-N21,N22,N23,N24)-(SP-4-1)-], i.e. degraded porphyrin ring *cf.* haem or myoglobin—animal origin; (**iv**) dodecandioic acid—plant origin; (**v**) [2-phenyl-2-oxophenyl-propane] —origin unknown; (**vi**) [2-ethylhexanoic acid]—plant origin, possibly honey. Compounds for unlabelled peaks are presented in Appendix E.

quartz grains and may therefore be attributed to purposeful contact. Ground haematite pieces were common in similar contexts of the MJB deposit and have indicated practices of craft and artistic production. The occurrence of ground ochre and haematite fragments as well as the grinding stones used to process them, could indicate “pulses” of artistic activity that may potentially reflect changes in artistic style and reflecting broader changes in economy, social life and ideology (Taçon &

Brockwell 1995). The occurrence of grinding stones used to grind haematite in Pulse 2 may therefore indicate a pulse of artistic activity, as well as the onset of more frequent ritual or symbolic practices such as for the colouring of clothing, hair or skin.

Thirty one of the grinding stones from Pulse 2 (approximately 66%) were used to process plant material, including seeds, roots, leaves and starchy plants (Table 8.2). The presence of burnt botanical remains and culturally derived vegetative parenchyma in similar aged deposits (n = 56) provides further support for the processing and preparation of plant foods at this time (Table 8.3) (Florin 2013: 56). Of the 31 specimens that were used to process plant material, four were likely used to process toxic plant varieties (GS 14, GS 16—Plate 8.5, GS 23 and GS 27) with bioactive alkaloids detected with GC-MS. This has indicated that plants selected for consumption may have required grinding to remove toxins or that specific plants were selected and ground for their medicinal or hallucinogenic effects, as documented ethnographically (e.g., Latz 1995: 61). The consumption of toxic nuts is known elsewhere in Australia from around this time, at 13.5 ka BP in southern Western Australia, in which *Macrozamia riedlei* were consumed following methods of leaching, fermenting, roasting and aging (Smith 1982: 117). More recent evidence has also suggested that *Macrozamia* sp. were consumed from at least 5 ka (Asmussen & McInnes 2013).

Table 8.3: Charred macro-botanical remains recovered from MJB during the 2012 excavations. The remains are grouped by the identified categories and quantified by the number of identified specimens. *After Florin (2013): Table 4.*

Bracketing ages (cal BP)	flotation Spit/Square	<i>Pandanus</i> sp. drupe	Vegetative parenchyma	Endocarp	Other
0 – 4 ka	C3/2	45	22	0	11
	C3/4A	15	60	1	9
	C3/5	49	123	0	10
	E4/6A	1	24	0	14
4 – 8 ka	C4/9A	0	8	0	4
	C3/13	0	19	0	1
	D3/16B	1	5	0	0
8 – 14 ka	C4/19	0	16	0	0
	C2/21A	0	24	0	1
	C3/24	1	16	0	0
14 – 30 ka	D2/30	7	0	0	0
	C2/33A	11	188	1	1
30 – 60 ka	C2/35A	10	150	6	1
	C2/37A	0	17	0	0
	C1/43A	0	9	0	0
	C2/57	4	11	0	0

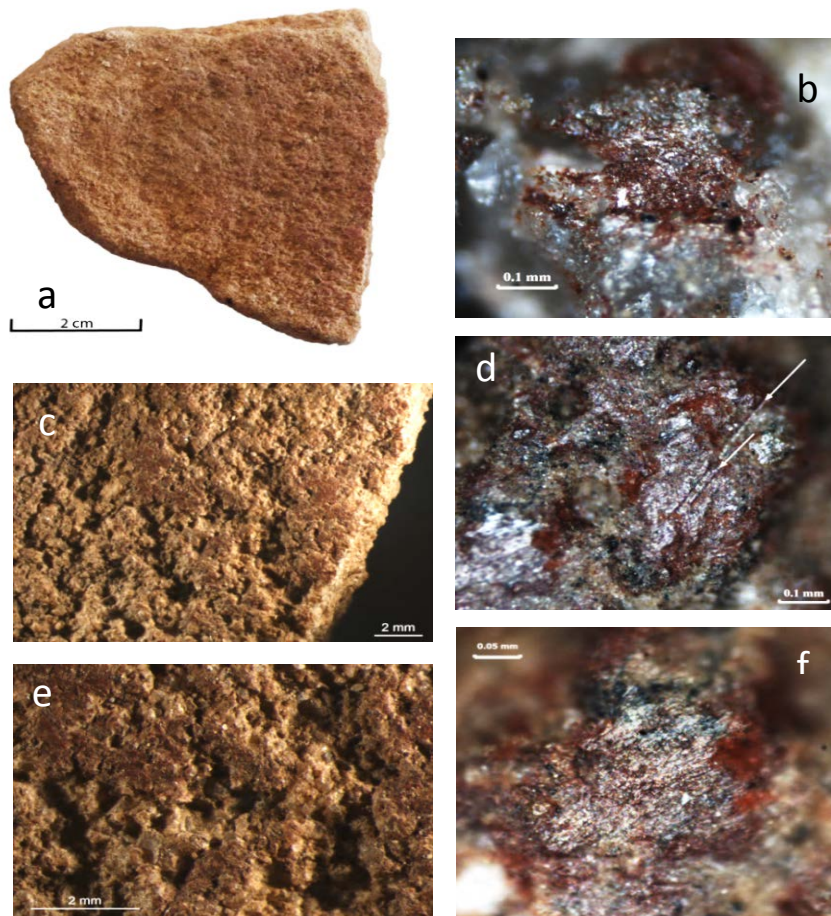


Plate 8.4: Use-wear and residue images of MJB artefact GS 15 from Pulse 2, used for the processing of red pigment. **a)** GS 15 image of ground surface; **b)** high magnification image of haematite accumulations; **c)** low magnification image of ground surface showing highly rounded and levelled grains; **d)** high magnification image showing bright, undulating use-polish with micro-striations; **e)** low magnification image of ground surface showing thick accumulations haematite within the interstitial spaces of the grains; **f)** high magnification image of undulating use-polish with haematite residues.

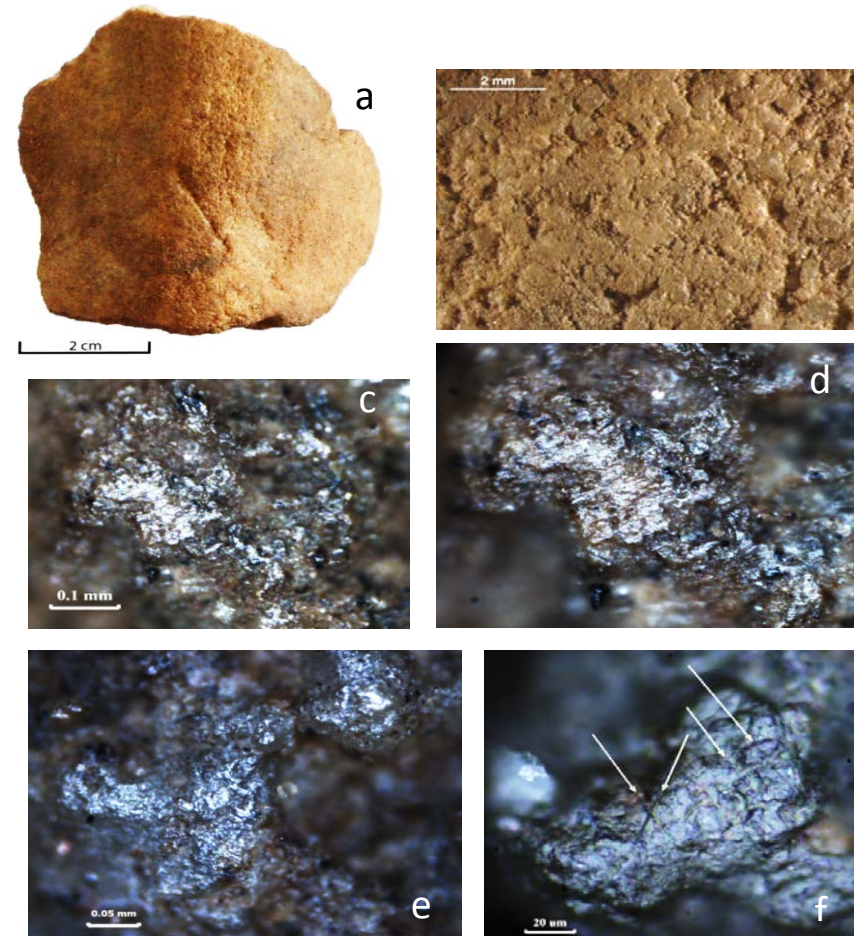


Plate 8.5: Use-wear images of MJB artefact GS 16 from Pulse 2, used for the processing of seeds. **a)** GS 16 image of ground surfaces (left side: Surface 1; right side: Surface 2); **b)** low magnification image of ground surface showing moderately to highly rounded and highly levelled grains; **c-e)** high magnification image of surface polish presenting with a bright, reticulated morphology; **f)** high magnification image of surface polish accompanied with fine, multi-directional micro-striations.

The relatively high percentage of grinding stones used for plant processing activities during Pulse 2 and the large abundance of charred botanical remains from similar contexts may indicate a change in foraging strategies whereby plants became more heavily exploited, possibly as a result of changing environmental conditions. The grinding stones began to accumulate at the conclusion of the LGM (~18 ka cal BP); at the onset of this Pulse at around 18.2 ka, and until approximately 14 ka, precipitation in northern Australia would have been 30 – 50% below that of present (Allen & Barton 1989: 7; Nix & Kalma 1972: 85-86), with vegetation almost completely comprised of low open woodland and savannah; and several isolated rainforest patches (Table 3.2) (Allen & Barton 1989: 7; Nix & Kalma 1972: 85-86). As such, a change in vegetation cover would have facilitated the need to exploit new resources and thus a change in foraging strategies was required. Also occurring at this time is a decreased frequency of silcrete artefacts that disappeared completely from the archaeological record (Figure 8.2) (Clarkson *et al.* 2015). The loss of silcrete artefacts from the MJB archaeological record just after the LGM may reflect reductions in mobility, modifications to exchange networks, sea level changes causing materials from the north to no longer be available, reductions in territory size, or change in configuration of group territories. These factors may have in turn required the adaption of new technologies, including grinding stones. From 14 ka, the summer monsoon system had been re-established and precipitation began to increase, peaking at around 12 ka BP. After 9.2 ka, there is not only a reduction in the frequency of grinding stones but also total artefacts (see Clarkson *et al.* 2015: Table 2), potentially indicating decreased intensity of site occupation for this period.

8.2.2.2 Grinding stones from Holocene contexts

The cultural material recovered from Holocene contexts at MJB included lithic artefacts (both flaked and ground stone pieces), faunal bones, haematite pieces, human skeletal elements (including the articulated and disarticulated remains of at least 18 individuals) and an extensive shell midden that extended 60 cm down the profile of the excavated sequence (spanning a depth of between 10 and 70 cm) (Section 3.2.5) (Clarkson *et al.* 2015). Thirteen grinding stones were recovered from Holocene contexts; one artefact from very recent deposits proceeding the shell midden (recovered from a depth of ~7 cm); eight from within the Pulse 3 coinciding with the shell midden deposits (11 – 46 cm) and four from between Pulse 3 and 2 (74 cm – Pulse 83 cm), predating the midden deposits. The following sections describe the functional varieties of grinding stones that have been identified from Holocene contexts and discusses their appearance (and disappearance) from the archaeological record as a result of environmental and cultural factors.

8.2.2.2.1 Grinding stones from early Holocene contexts

Four grinding stones were identified in Holocene contexts but were not restricted to Pulse 3. These were found in earlier Holocene deposits prior to the accumulation of the shell midden (c. 7.2 – 8.4 ka cal BP) and were recovered from depths ranging from 74 – 84 cm (Table 8.1). These artefacts were likely used for the processing of plants (n = 1); pigments (n = 1) and stone (n = 2) (Table 8.2). Similar to grinding stones, other artefacts are less frequently observed in these deposits of this depth range, with small quantities of shell, ground haematite and quartz artefacts. The lack of abundant cultural material in the deposits preceding the midden may reflect a period of decreased occupation at the site or a decrease in on-site grinding activities.

8.2.2.2.2 Grinding stones from Pulse 3

All grinding stones from Pulse 3 (n = 8) were found within the earliest accumulations of the shell midden, dated at ~4.2 – 5.5 ka. These included seven sandstone fragments from six plant processing tools, five of which displayed evidence for the processing of seeds and two of which displayed evidence for the processing of starchy plants (Table 8.2). The latter two grinding fragments (L49 and UP GS 2) originated from the same complete tool, UP GS 2 being a small flake that has been removed from L49 (Plate 8.6a-b). Starch grains on these two artefacts are morphologically comparable with the starch grains of at least one economically important plant species: *Tacca leontopetaloides* (Polynesian Arrowroot). This plant has an ethnographically documented use in Arnhem Land whereby both the flesh and root of the plant were consumed by Aboriginal groups (see Appendix A for references). However, a more robust reference collection with a larger diversity of plant taxa is required before secure identification can be made. On one of these artefacts, L49, a second group of starch grains were recognised, indicating that this tool was used to process at least one additional plant species following the removal of UP GS 2. While taxonomic identification of the second set of starch grains is yet to be made, the size and elongated morphology has indicated that they may have originated from a tuber or other underground storage organ. In addition, GC-MS characterisation of residue mixtures analysed from this artefact were consistent with the processing of tubers and softer plant materials, including roots and leaves, as well as seeds. This has indicated that L49 was used to process multiple plant varieties, including seeds and at least one other species of starchy plant, most likely a tuber or underground storage organ. Seed grinding use-wear was evidenced on four other artefacts: GS 1, GS 2, GS 8 and L52, although the specific plant taxa could not be identified. Two of these artefacts (GS 1 and GS 8) also contained bioactive compounds (detected via GC-MS) indicative of toxic plant/seed processing. One other artefact (R2) displayed

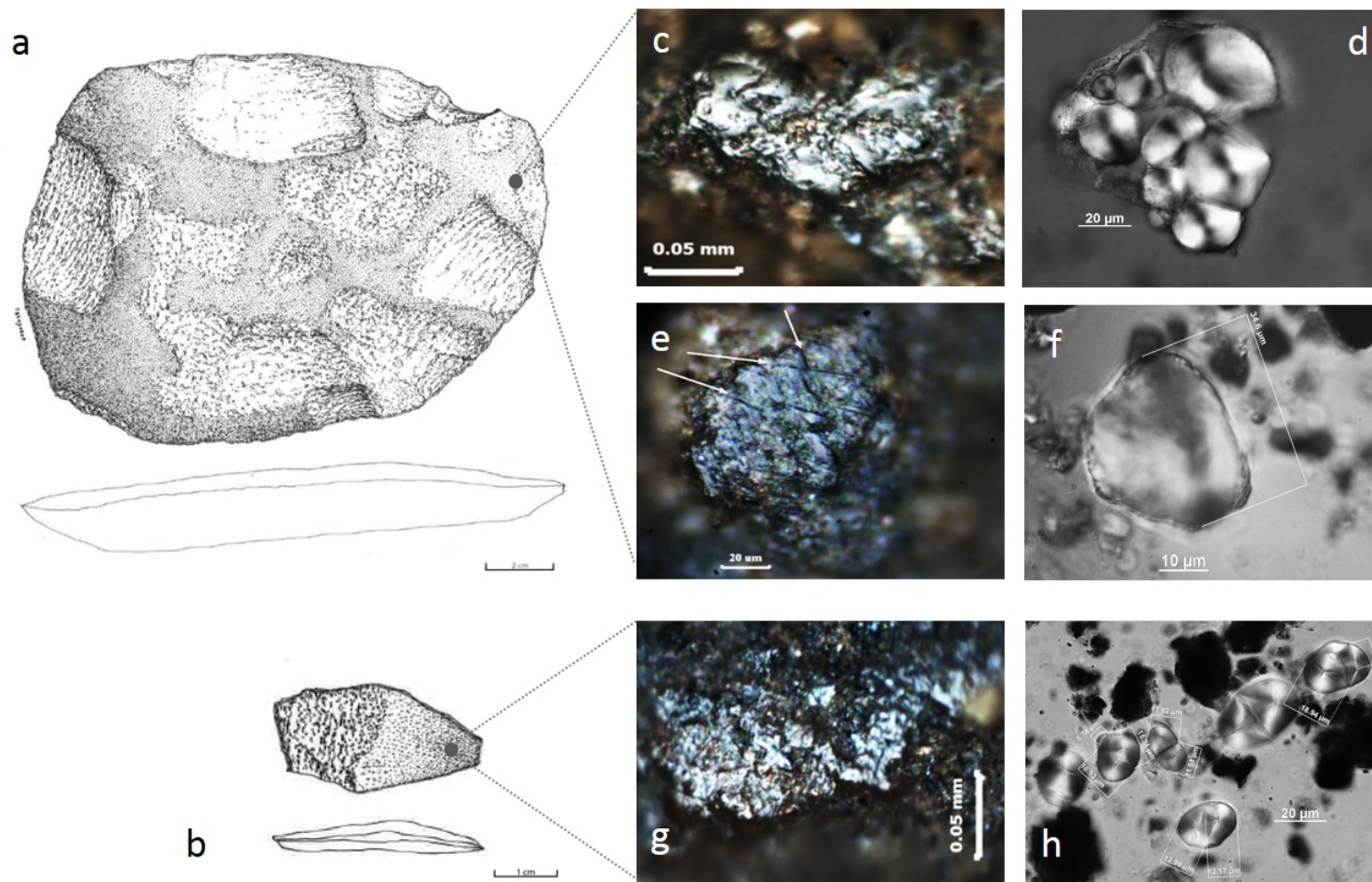


Plate 8.6: Use-wear and residue images from grinding stones recovered from Pulse 3 of the MJB assemblage. **a)** Sketch of grinding surface and cross section of artefact L49, used for the processing of seeds and starchy plants; **b)** sketch of grinding surface and cross section of artefact UP GS 2, a small flake originating from L49; **c)** high magnification image of highly smoothed silica use-polish on L49; **d)** compound starch grains removed from L49; **e)** high magnification image of reticular use-polish and micro-striations on L49; **f)** tuber-like starch grain identified on L49; **g)** high magnification image of reticular use-polish on UP GS 2; **h)** compound starch grains removed from UP GS 2.

traces of use that were consistent with the processing of plants, but I was unable to determine whether this included seed processing. The remaining grinding stone recovered from this Pulse (UP GS 3) could not be assigned a function but did contain isolated clusters of ochre and a small amount of collagen fibres, potentially reflecting the processing of haematite in addition to animal materials. Owing to the lack of distinguishing use-wear features, however, the function of this implement is yet to be determined. This tool may have been used expediently or opportunistically, and has not sustained wear traces indicative of intensive use.

Further evidence for the consumption and/or use of plants during Pulse 3 was reflected by the presence of macro-botanical remains recovered from the adjacent deposits. Flotation of bulk sediment samples at MJB has indicated that a large amount of botanical material was brought into the site from 4 – 8 ka BP, most likely for human consumption. At this time, and spanning all of Pulse 3, the remains of vegetative parenchyma, i.e., the fragmented sections of geophytes including roots, rhizomes, tubers, bulbs and corms, were identified (number of fragments = 32) (Table 8.3). Although the recovered plant remains did not display any physical evidence to suggest that they were ground, they were likely to be culturally derived. Florin (2013: 56) has suggested that these plants, which are root-stock regenerators (i.e., they rely on underground organs to regenerate) are not readily burnt in bush fires and therefore require purposeful digging to acquire (Jones & Meehan 1989: 123; McArthur 1960a, 1960b: 98, 101). Additionally, ethnographic observations have indicated that such plant foods were a prominent part of the diet of Indigenous populations from western Arnhem Land, and often required grinding and cooking to remove toxins and render them edible (Atchison & Head 2012; Jones & Meehan 1989; McArthur 1960a, 1960b; Meehan 1989). Toxic alkaloids were detected on two of the plant processing grinding stones from Pulse 3, and may indicate that grinding was a method employed to reduce toxins.

The higher frequencies of grinding stones identified in Pulse 3 are consistent with other artefact accumulations identified within the midden deposit. Large quantities of lithic artefacts were recognised in the midden deposits from 5 ka (Clarkson *et al.* 2015) and included flakes and bipolar flakes shaped from quartz, quartzite and chert. The shell midden itself was composed of a variety of locally sourced fresh water shell fish, including *Cerithidae* sp., *Gelonina* sp., *Telescopium* sp. and *Nerita* sp. The relative abundances and apparent shifts in molluscan taxa have reflected the well-documented environmental changes that occurred throughout the last marine transgression, as well as the associated shifts in mangrove forest structure (Clarkson *et al.* 2015). The higher frequencies of grinding stones (and other artefacts) identified within the midden deposits may therefore reflect changes in foraging strategies to facilitate the exploitation of newly available resources following

dramatic environmental transformations. The occurrence of dense artefact accumulations from 7 – 4 ka is probably related to a climatic trigger resulting from the altered ENSO pattern that caused conditions to become more variable with enhanced seasonality and decreased precipitation (Attenbrow *et al.* 2009: 2769; Brockwell *et al.* 2009: 59; Lees 1992: 8; Shulmeister & Lees 1995: 111; Turney & Hobbs 2006: 1744). The change in climate likely resulted in other environmental transformations and saw the onset of the “big swamp phase” in which there was extensive mangrove development that facilitated the growth of new plant food resources (Section 3.2.4) (Hiscock 1999: 91; Woodroffe *et al.* 1986, 1988). Pollen data has revealed shifts in vegetation of mangrove forest communities—at 6.8 ka BP, the mangrove forests were dominated by *Rhizophora* sp. which was succeeded by an *Avicennia* sp. community by 6 ka BP (Hiscock 1999: 92; Woodroffe *et al.* 1986). By 5.3 ka BP, there was dominance of Poaceae and Cyperaceae, and over the next one thousand years, the mangrove forest was replaced almost completely by grasses and sedges. It is during this time grinding stones for seed processing became abundant in the MJB archaeological record, potentially indicating a change in foraging strategies and the exploitation of locally available grass seeds. Further starch grain analyses are required to determine whether starch and other plant microfossils are consistent with grass seed processing.

In addition to grinding stones, other grinding technologies, including ground haematite pieces (n = 63, recovered from Spits 4 – 8 during the 1989 and 2012 excavations) and bone bi-points, were also recognised within the more recent midden deposits, but no grinding stones from Pulse 3 displayed secure evidence for the processing of pigments or animal material (with the exception of possible evidence from UP GS 3). Because use-wear analysis is yet to be performed on the ground bone pieces, it is currently unclear whether these points were manufactured using a sandstone file or another abrasive material. Use-wear analysis of ground pigment pieces was restricted to a small collection of haematite pieces (n = 34 with a total of 42 facets) recovered from the lowest artefact levels of the 1989 excavation (i.e., Spits 54 – 57 inclusive) (Cox 2014). Using a comparative reference library generated through robust experimental work, Cox (2014: 33) found that most haematite specimens displayed grinding wear indicative of contact against sandstone grinding stones (n = 28 of 42 facets). Cox (2014: 35) also recognised wear resulting from secondary grinding/rubbing actions whereby the possible working of animal skins or wood was indicated by the presence of fatty or woody residues, respectively. Currently, no high magnification analyses have been performed on ground haematite recovered from late Pleistocene/Holocene contexts. Macroscopically, the abrasion on the ground haematite pieces from Pulse 3 is consistent with the abrasion I have seen on experimental haematite pieces that were ground on hard sandstone, in which the protruding quartz grains had created relatively deep furrows on the surface of the

haematite. Such observations are consistent with the experimental findings of Cox (2014: 24) and Hodgkiss (2010: 3347). The apparent lack of grinding stones used to process haematite identified in Pulse 3, despite the occurrence of ground haematite with wear indicative of stone contact, may imply that they were processed on stone that was never deposited at the site. For example, haematite may have been directly applied to the rock shelter walls or prepared on the near-by bedrock grinding patches that are ubiquitous at the site in surrounding areas (Plate 8.7). Haematite residues were recognised macroscopically on one of these grinding patches located a few metres from the site, and could indicate the preference for the use of this grinding tool rather than portable stone files. Unfortunately, it is unclear when this artefact was used for such activities, and whether the haematite residues are from recent grinding events or have a much greater antiquity.

Eight other grinding stones were recovered from Pulse 3 during the 1989 excavations but as they have not been examined for use-wear and residue traces, the function of these artefacts is unknown.

8.2.2.1.3 Grinding stones from late Holocene contexts

Only one grinding stone was recovered from deposits overlying the shell midden above Pulse 3: UP GS 39, a near-complete whetstone used for the sharpening of metal and stone axes (Plate 8.8). Unlike many of the other grinding stones from MJB made from sandstone, this artefact is a mudstone brick that was introduced post contact. Unpublished radiocarbon ages have indicated that this artefact was deposited around 150 – 300 years cal BP, making this the most recent grinding stone deposited at the site.

More recent grinding events have been documented at the site—to the west of the rockshelter there is a large sandstone monolith that has been used as a bedrock grinding patch to process a variety of materials (Plate 8.7a). Macroscopic and ethnographic evidence have indicated the use of this artefact for the processing of red pigments and green ant nests, the latter being ground for medicinal purposes (Plate 8.7b). No axe grinding grooves were recognised on this artefact and evidence for the processing of other organic material was not identified macroscopically. Ethnographic evidence suggests that this artefact was used right up until contemporary times, but it is unclear for how long it was used and if its use extends into early Holocene or Pleistocene times. Other bedrock grinding patches were also identified in the area surrounding MJB; these often displayed well-worn surface depressions indicating extensive use as grinding tools (Plate 8.7c-d). Although many of these depressions displayed macroscopically visible



Plate 8.7: Bedrock grinding patches surrounding MJB: **a)** large sandstone bedrock grinding patch with two deep grinding depressions and macroscopic grooving, located ~1km north of MJB; **b)** bedrock grinding patch located adjacent to MJB; **c)** depression on the bedrock grinding stone adjacent to MJB, photographed with upper stone after it was used to grind a green ants nest (photo by L. Wallis); **d)** large immovable lower stone with evident grooving and deep depressions, and upper stone, reportedly used for processing fruits (plums), located ~1km north of MJB.

use-polish and gloss, *cf.* plant processing, high magnification use-wear and residue analysis of the sandstone surfaces is required to determine whether plant materials had been processed and to what extent.

Portable grinding stones used to process plant material were not identified in deposits above Pulse 3, despite the occurrence of large quantities of charred botanical remains that were recovered from other late Holocene deposits (0 – 4 ka). These included *Pandanus* sp. (n = 110), vegetative parenchyma (n = 229), endocarps (n = 1), as well as a number of unidentified plant remains (n = 44) (Table 8.3). The remains were considered to be of anthropogenic origin and deliberately brought into the site. Although there is no physical evidence to suggest that these plant remains were ground, ethnographic research from the area has indicated that plant materials (e.g.,

Pandanus sp.) were often charred and pounded/ground prior to consumption (e.g., Hamby 2010: 112; Jones & Meehan 1989: 122; cf. McArthur 1960a, 1960b; Meehan *et al.* 1978). The absence of grinding stones used for the processing of plants during the late Holocene at MJB (with the possible exception of the bedrock grinding patch) may be the outcome of several factors: (1) grinding activities generally ceased/decreased, or (2) grinding activities continued elsewhere, but decreased on-site. I attribute the lower frequency of grinding stones at this time to the reduction of grinding activities occurring on site. This may be related to social factors, in which the reduction of grinding stones coincides with occurrence of human skeletal remains that have been intentionally dug into the occurrence of human burials at the site would have ensured a reduction in site occupation or possibly even site abandonment for several generations and thus a reduced frequency of grinding stones (as well as other lithic artefacts). Another explanation could be that grinding activities occurred on the near-by sandstone outcrops that were used as bedrock grinding patches, but an age for these artefacts must be determined before this assumption can be made.

Also of relevance is the spatial distribution of grinding stones at MJB, whereby grinding stones tend to be concentrated to the rear of the shelter, potentially indicating they had been intentionally placed against the back wall (Figure 8.1). Grinding stones were more frequently recognised in the Holocene deposits of the Kamminga trench adjacent to the rockshelter wall, compared to the 1989 trench, which is located a further 200 – 400 cm from the rear of the shelter (Figure 3.3). A similar observation was noted at Puritjarra rockshelter, where Smith (2004: 178) observed that grinding stone distribution was concentrated towards the back wall of the rockshelter. Unlike those identified from MJB, grinding stones from Puritjarra were mostly characterised by (larger) fragments and thus this site was suggested to reflect a potential discard area.

Gorecki *et al.* (1997: 144) have suggested that the high incidence of grinding stone fragments within stratified rock shelter deposits (such as MJB) may reflect components of exhausted grinding stones that have been intentionally placed under shelters for uses such as heat retainers in hearths or anvils for lithic reduction. This may explain why charred remains, including charcoal, have been visually identified on many of the artefact surfaces. Evidence of artefacts being used as anvils, however, is limited with only a small number of potential examples (e.g., GS 32). Gorecki *et al.* (1997: 144) have suggested that a higher frequency of complete, undamaged specimens was more likely in open campsites, and that rock shelters were likely discard locations. The latter argument may explain why MJB houses mostly fragments (n = 84 of 96) rather than complete tools.

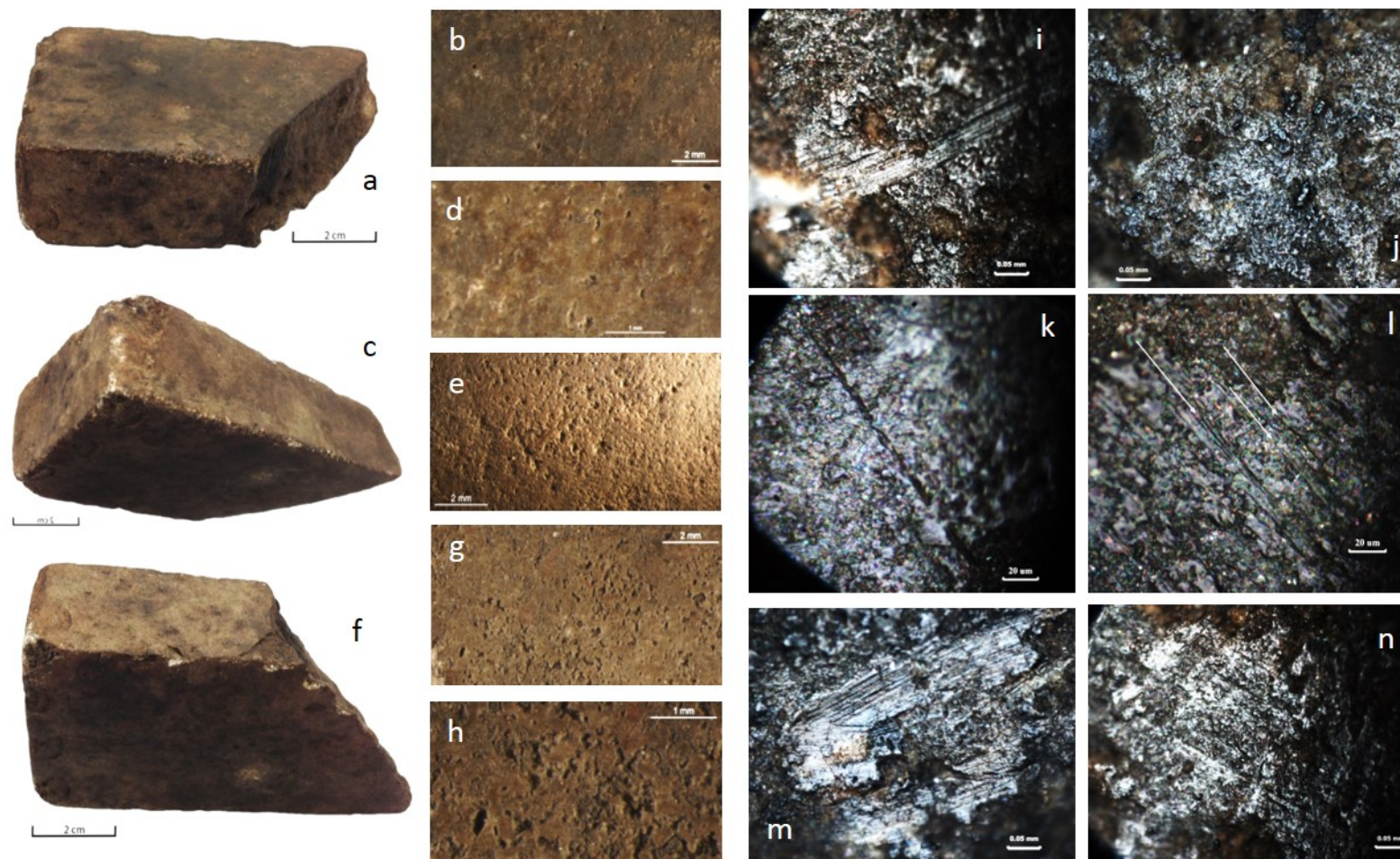


Plate 8.8: Use-wear and residue images MJB artefact UP GS 39 from used to file stone and metal axes: **a)** UP GS 39 artefact image depicting grinding on Surfaces 1 (above) and 4 (below); **b)** low magnification image of Surface 1 showing highly levelled grains; **c)** artefact image depicting grinding on Surfaces 5 (to the left) and 3 (to the right); **d)** low magnification image of Surface 2 showing highly levelled grains; **e)** low magnification image of Surface 3 showing highly levelled grains; **f)** artefact image depicting grinding on Surfaces 4 (above) and 2 (below); **g)** low magnification image of Surface 4 showing highly levelled grains; **h)** low magnification image of Surface 5 showing highly levelled grains; **i-n):** high magnification use-wear images of UP GS 39: **i)** bright, striated use-polish on Surface 1; **j)** bright, undulating use-polish on Surface 3; **k)** use-polish with deep furrow on Surface 1; **l)** striated use-polish with common uni-directional micro-striations on Surface 2; **m)** metal residues on Surface. 3, occurring as alignments; **n)** striated use-polish with fine micro-striations on Surface 1.

8.2.2.3 Grinding stones from other deposits

Of the remaining two un-provenanced stones that were derived from back-fill deposits, evidence for the processing of starchy plants is identified on one artefact (UP GS 1). The other specimen (UP GS 38) could not be assigned a function. As it is unclear from which depositional contexts these artefacts may be attributed, no ages could be provided for these specimens and therefore they have not been included in discussions of temporal grinding stone functions.

8.3 Lake Mungo

8.3.1 Grinding stone function

Seventeen grinding stone fragments were collected from three cultural units of the Lake Mungo lunette and examined for functional traces. All 17 specimens were most likely derived from larger, broken grinding stones that had been carried into the landscape and were therefore all considered to be artefacts. As with the MJB specimens, artefact function was determined following the evaluation of artefact morphology, use-wear and use-residues. Fifteen of the 17 grinding stones were used to process plant materials; 14 of these 15 grinding stones displayed use-wear and morphological characteristics consistent with the processing of seeds. The function of the remaining two sandstone fragments was unable to be determined, and distinctive grinding wear could only be recognised on one of the two artefacts. No pigment or dedicated animal processing tools were recognised among the 17 analysed specimens.

8.3.2 Chronological distribution

The 17 grinding stones analysed from Lake Mungo were gathered from an area of ~1 x 1 km along the Mungo foothills (Figure 3.6). Not all of the stones had an obvious provenance, although 15 of the 17 stones could be directly linked with particular strata in the central Mungo lunette. These included Unit E (the lateral equivalent of Bowler's Arumpo and Zanci units, see Bowler 1998: 125) dated at 14 – 25 ka (n = 10), and Unit F, dated between 6 and 14.5 ka (n = 4) (Section 3.3.6) (Fitzsimmons *et al.* 2014; Fullagar *et al.* 2015). Only one specimen, LM GS 9, was found *in situ* from Unit E (but note the eight refits). The remaining three specimens, LM GS 12, LM GS 13 and LM GS 14 were found within an ancient erosional surface of the Golgol Unit and were of an unknown age. As such, these three specimens may or may not be Pleistocene artefacts.

8.3.2.1 Grinding stones from Pleistocene contexts

8.3.2.1.1 Unit E

Ten of the analysed grinding stones have been directly linked to the Unit E strata, dated to between 14 and 25 ka, and corresponding to a period of enhanced aridity associated with the LGM (Fitzsimmons *et al.* 2014). One of these specimens, LM GS 9, had clear provenance, recovered *in situ* from within the Unit E Mungo deposits (Plate 3.4a). This fragment was one of eight pieces (LM GS 2 – 9) that refitted to form a single artefact, all derived from Unit E. Another two specimens—LM GS 1 and LM GS 11—were also derived from the Unit E strata. All ten specimens had plant processing traces and nine were probably used for processing seeds. The morphological features that have indicated seed grinding included the presence of “dished” surfaces, typical of millstone fragments (n = 3) and evidence for artefact recycling and the secondary use as hand held upper stones (n = 2: LM GS 1—Plate 8.9, and LM GS 3). The use-wear features on all ten specimens were also consistent with this functional interpretation. Documented use-residues included plant remains such as cellulose fibres, phytoliths and starch grains. While some of the phytoliths identified were consistent with those found within some grass seed varieties, the limited occurrence of starch prevented the taxonomic identification of utilised plant species.

8.3.2.2 Grinding stones from early Holocene/ late Pleistocene contexts

8.3.2.2.1 Unit F

Four of the analysed grinding stones could be directly linked to the Unit F strata, dated between 8 and 14 ka (Fitzsimmons *et al.* 2014). All four grinding stones functioned as plant processing tools, most likely for the processing of seeds. Morphological features consistent with seed grinding included the presence of a distinctive facet on one the grinding stones (LM GS 10—Plate 8.10), *cf.* muller stones (Smith 1985: 26-27, 1986: 32). The remaining three tools had flat grinding surfaces and could not be assigned a function based on tool stone morphology. Despite this, all tools displayed use-wear typical of seed processing and all four artefacts yielded one or more starch grains (from unknown taxa) in addition to other plant tissues. Although starch recovery was low, grains usually displayed facets to indicate mechanical damage that can be attributed to grinding or another means of processing. In the absence of higher counts and species identification, the starch grain evidence was best interpreted as an indicator of possible starchy plant processing (including seeds).

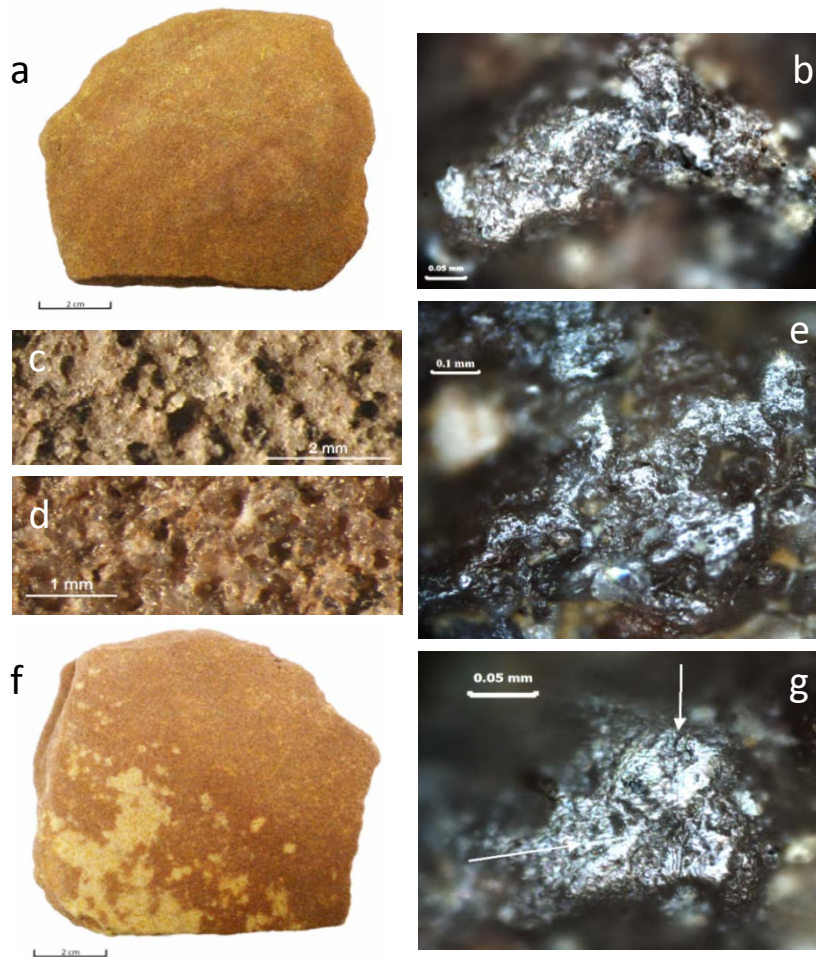


Plate 8.9: Use-wear images for Lake Mungo artefact LM GS 1 from Unit E, used in the processing of seeds. **a)** LM GS 1 artefact image depicting grinding wear presenting on Surface 1; **b)** high magnification image of reticulated surface polish, Surface 1; **c)** low magnification image of Surface 1 displaying well rounded grains and plateaus of levelling; **d)** low magnification image of Surface 2 displaying a levelled but highly weathered surface; **e)** high magnification image of reticular use-polish, Surface 2; **f)** artefact image showing Surface 2; **g)** high magnification image of reticular use-polish and fine micro-striations, Surface 2.

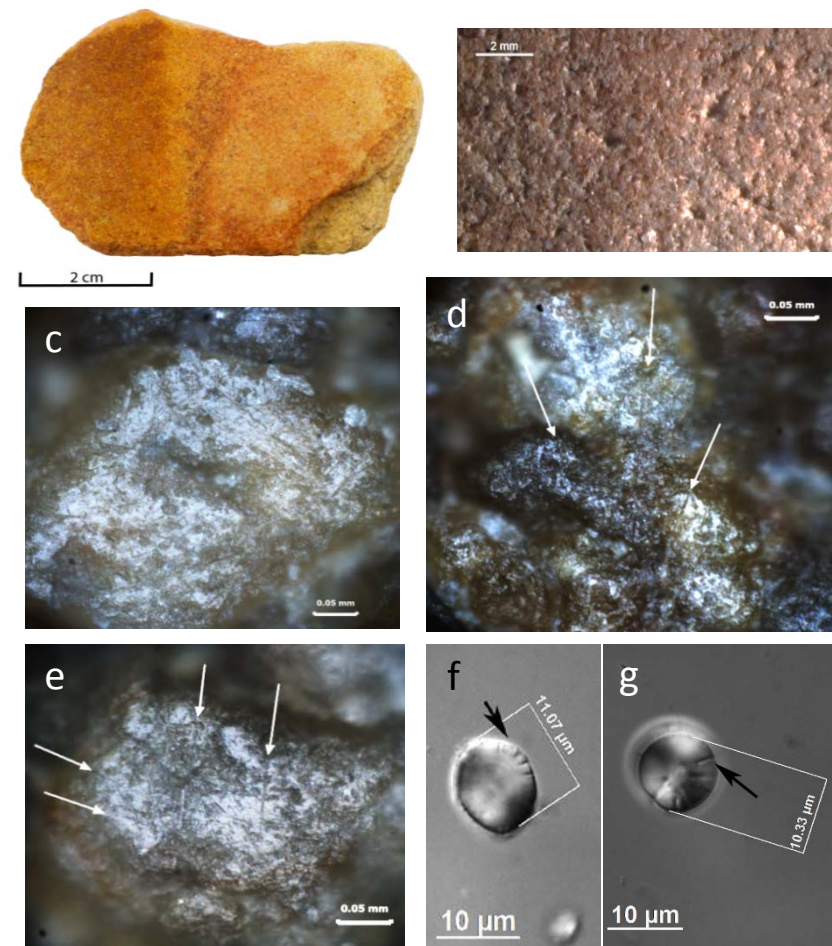


Plate 8.10: Use-wear and residue images for Lake Mungo artefact LM GS 10 from Unit F, used as a muller stone to process seeds. **a)** LM GS 10 artefact image depicting ground surface; Surface 1; **b)** low magnification image of grinding surface showing highly rounded and levelled grains with visible striations; **c-e)** high magnification images of reticulated surface polish *cf.* seed grinding. Arrows indicate direction of striations; **f-g)** starch granules exhibiting mechanical damage (black arrow), removed from grinding surface and observed under transmitted light (photos by J. Field).

8.3.2.3 Grinding stones from other deposits

8.3.2.3.1 Erosional gully within Golgol Unit

Three specimens were found within an ancient erosional surface of the Golgol Unit and were unable to be dated. Only one of these (LM GS 14) could be assigned a seed grinding function. The remaining two specimens displayed heavily weathered surfaces and consequently the functions of these tools could not be determined. LM GS 12 displayed weakly developed use-wear while LM GS 13 had no distinctive traces of use. Residues, including starch, were recovered in low abundance on these two artefacts and may be derived from use. However, the lack of compelling use-wear evidence has ensured that the function of these artefacts remains unknown.

8.4 Temporal distributions of grinding stones in Australia

The temporal distributions of grinding stones by function at MJB and Lake Mungo can be summarised as follows:

1. Grinding stones occurred at both MJB and Lake Mungo in late Pleistocene and Holocene contexts, but are most abundant in Pleistocene contexts.
2. Grinding stones were not common during the LGM at MJB, but were present at Lake Mungo and used predominately for seed processing.
3. Grinding stones recovered from Pleistocene contexts at MJB (pre-dating and post-dating the LGM) were used to process a variety of materials, including plant, red pigments, stone and animal materials. The earliest grinding stones were used to process red pigment (*cf.* haematite). Most grinding stones from Pleistocene contexts occurred as amorphous sandstone fragments with usually only one grinding surface, no visible traces of rejuvenation and no evidence for recycling.
4. Grinding stones recovered from Pleistocene contexts at Lake Mungo were used exclusively for plant processing, most notably seeds. Many of these tools displayed heavily worn grinding surfaces, sometimes with dished surface morphologies and evidence for stone recycling.
5. Grinding stones recovered from Holocene contexts at MJB were most abundant when all artefact frequencies were the highest. These grinding stones were used predominately to process plant materials. Only one pigment processing stone was recognised, but ground pigments and ground bone points were recognised throughout the midden deposit. Grinding stones were not recovered from deposits

coinciding with the human burials and lower artefact frequencies could also suggest site abandonment at this time. Bedrock grinding patches are ubiquitous in the surrounding area, and ethnographic evidence has suggested that some of these were used in recent times.

6. Grinding stones from Holocene contexts at Lake Mungo were identified but only four were analysed for functional traces. These all had traces of use consistent with plant processing and were all heavily utilised. The lack of functional data from Holocene grinding stones at Lake Mungo is likely an issue of sample size.

Based on these key observations of the MJB and Lake Mungo grinding stone sequences, one may conclude that tool stone morphology, function and distribution vary both temporally and spatially in sites of different environmental settings. This section discusses the temporal distributions of functional classes of grinding stones from MJB and Lake Mungo in relation to other grinding stone tools recognised in other sites throughout Australia.

8.4.1 Temporal distribution and comparison of grinding stone morphology

In Australia, grinding stones are most commonly recognised in late Holocene deposits and are present in many regions and archaeological sites across the continent. Grinding stones from late Holocene contexts are often distinguished on the basis of their ground surface morphology, size and configuration; sometimes displaying distinctive grooves, facets, peck marks and traces of recycling and rejuvenation. Alternatively, grinding stones from Pleistocene contexts are typically represented by fewer specimens that generally occur as irregularly-shaped pieces of stone with no distinctive recurring form, and thus are often described as “amorphous” (*cf.* Smith 1985, 1986, 1989b). Contrasting to this general trend, I found that grinding stones at MJB of Pleistocene age were more numerous than those recovered from Holocene contexts, and that only minimal morphological variation exists between grinding stones recovered from the Pleistocene and Holocene contexts. Nearly all of the grinding stones examined from MJB (62 of 91 specimens) were classified as amorphous fragments (*i.e.*, specimens that displayed flat or irregularly shaped grinding surfaces), regardless of whether they were retrieved from Holocene or Pleistocene contexts. In general, however, grinding stones recovered from Holocene contexts were larger than those retrieved from Pleistocene contexts, with an average and median mass of 1184 g and 530 g, respectively, compared with an average and median mass of 364 g and 149 g for the Pleistocene specimens (Table 8.4). Based on the median masses alone, this has suggested that the grinding specimens retrieved from the Holocene contexts are generally around three to four times larger than those retrieved from the

Pleistocene contexts. The relatively higher frequencies of fragmented grinding stones in Pleistocene deposits may reflect changes in discard behaviour whereby higher occurrences of recycled or discarded tools could indicate an enhanced foraging economy (Smith *et al.* 2015). This may be related to environmental pressures associated with the Pleistocene that were followed by the onset of more sedentary lifestyles during the Holocene. Support for the latter is enhanced by the local occurrence of many large bedrock grinding patches indicating a preference for stationary grinding slabs. Many of the bedrock grinding patches had distinctive morphological grinding stone features such as well-worn depressions, grooves and traces of rejuvenation that are consistent with many features commonly attributed to grinding stones recovered from late Holocene contexts. Unfortunately, it is not yet possible to date the earliest use of these artefacts, and therefore it is unclear whether such tools were used during the Pleistocene or whether their use was restricted until more recent times.

Table 8.4: Comparisons of the average and median mass and size dimensions for grinding stones/fragments recovered from MJB Holocene and Pleistocene deposits.

		mass (g)	length (mm)	width (mm)	depth (mm)
Pleistocene	average:	364	77	56	41
	median:	149	62	52	33
Holocene	average:	1184	120	76	38
	median:	530	117	73	26

At Lake Mungo, tool stone morphology also appeared remarkably consistent during the late Pleistocene and Holocene, with a number of Pleistocene specimens also displaying distinctive features typically attributed to more contemporary grinding stone specimens. While many of the Lake Mungo grinding stones occurred as smaller fragments with flat grinding surfaces, three specimens displayed well-worn, dished grinding surfaces and one artefact displayed a distinctive heel, or facet, indicating probable use as a muller stone. Pleistocene fragments with similar morphologies are also known from Cuddie Springs, also located within the semi-arid regions of Australia. I have suggested that the appearance of well-worn grinding stones from these regions may be related to the local availability of suitable stone resources whereby limited availability has ensured that artefacts are more heavily utilised and thus more distinctive grinding features are recognised.

In another investigation involving the examination of the grinding stone sequence from Puritjarra rockshelter in the central Australian desert, Smith (2004) noted a transition in tool stone morphology at various stages of pre-history. Smith described a collection of 90 grinding stones in which the most recent surface finds included distinct seed grinding implements (millstones) most with signs of heavy use and a high rate of breakage. Other millstone fragments were identified in buried deposits dated between 0.7 ka and 3.8 ka cal BP, however; only amorphous tools were recognised before this time. Based on this evidence, Smith (2004: 178) had argued that seed grinding activities were absent. However, as I have shown in this thesis, tool stone morphology does not necessarily imply tool stone function, and seed grinding activities were occurring at both MJB and Lake Mungo before this time. In order to eliminate seed grinding activities before 3.8 ka, functional analysis must be performed on earlier artefacts incorporating high magnification observations and more robust residue analyses. The morphologically distinctive grinding stones represented in the more recent deposits at Puritjarra may reflect the more intensive utilisation of grinding stones in response to foraging risks that became more pronounced during the mid to late Holocene (see below for more in depth discussion).

Despite the evidence suggested by MJB data in this thesis, grinding stones are still more frequently reported for Holocene sites and, with the exception of specimens from Lake Mungo and Cuddie Springs, grinding stones from Pleistocene contexts usually occur as amorphous fragments. The apparent higher frequency of grinding stones from late Holocene contexts and the enhanced diversity of tool stone morphologies may be linked to several factors, including (but not restricted to):

1. the number of excavated sites;
2. demographic change and population increase;
3. artefact life-histories (including tool function and the extent of use);
4. climate and landscape changes facilitating the exploitation of new resources;
5. the availability of resources, including suitable stone material; and
6. increased foraging risk associated with environmental change, resource depletion and enhanced mobility requiring the exploitation of lower-ranked resources.

The most obvious explanation for the more limited occurrences of Pleistocene-aged grinding stones is related to the number of excavated sites. Langley (2010, 2014) identified 223 Pleistocene sites within Sahul (Figure 8.3), most of which are enclosed rockshelters and caves (61.8%) that are characterised by small excavation areas consisting of (on average) four squares that are typically 1 x 1 m or 0.5 x 0.5 m in area and 1 m in depth (Langley *et al.* 2011: 203). Within Australia, ground-

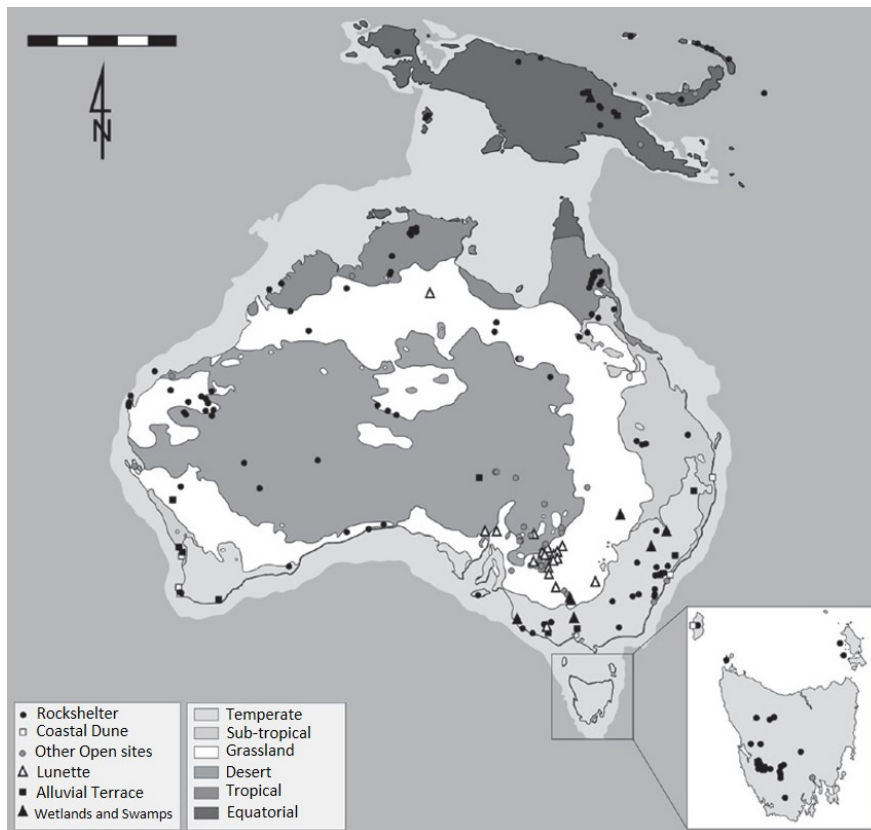


Figure 8.3: Distribution of Pleistocene sites in Sahul. From Langley 2014.

stone artefacts typically account for less than 0.3 per cent of the stone artefacts comprising archaeological assemblages (Edwards & O’Connell 1995; Gorecki *et al.* 1997: 145). As such, grinding implements can be expected to be absent or rare in small cultural assemblages (Gorecki *et al.* 1997; Hiscock & Wallis 2005: 42). For this reason, only the sites with very high artefact abundance (e.g., Cuddie Springs) or with largest areas (e.g., Lake Mungo, MJB) have yielded large assemblages of grinding stones.

The limited occurrence of Pleistocene sites and low recovery of Pleistocene-aged artefacts can be attributed to lower population densities during the Pleistocene. Reconstructions of past Aboriginal Australian populations have indicated lower populations during the Pleistocene followed by a slow stepwise increase starting from the Holocene transition and continuing in pulses between approximately 8.3 and 6.6, 4.4 and 3.7, and 1.6 and 0.4 ka BP (Williams 2013: 5). Higher population densities occurring during the Holocene would have resulted in enhanced site occupation and higher artefact frequencies. From this perspective, the rarity of grinding stones in Pleistocene sites is related to low population densities and high mobility that have created circumstances where recovery of grinding stones is unlikely in excavated site inventories (Smith 2004: 171).

The morphological variation of grinding stones from Pleistocene and Holocene contexts may be attributed to artefact life-history, including the stone material selected for use, the extent in which the artefact is used (influenced by the availability and distance to suitable stone material), and the processed material. In my experiments, I showed that variation of tool stone morphology and wear traces following use may be related to the physical properties of the stone material and the time in which the tool was used. In locations where suitable stones are readily available, such as around northern Australia and particularly Arnhem Land sites where the local geology is characterised by the various sandstone formations, sandstone grinding tools are more likely to be used expediently and as such will be morphologically distinctive from grinding stones at sites where suitable stone is not readily available. In these latter sites, grinding stones have longer use-lives and consequently display more intensive grinding wear. Gorecki *et al.* (1997) have also suggested that the availability of stone material will influence the extent of grinding stone reduction and therefore the presence of formal seed grinding implements at a site. The occurrence of large sandstone outcrops at MJB has suggested the use of bedrock grinding patches rather than portable stone materials. Alternatively, the lack of suitable stone material in the region surrounding Lake Mungo and the Willandra Lakes has ensured that grinding tools were used more extensively and thus such artefacts differ in morphology.

Smith (1986, 1988, 1989b, 2004) has suggested that morphologically distinctive grinding stones, such as those often identified in late Holocene contexts, represented an elaboration of an existing technology whereby tool-stone morphology is the outcome of the extensive processing of seeds. Although seeds were processed during the Pleistocene as indicated by the functional studies presented here as well as by other authors (e.g., Balme 1991; Fullagar & Field 1997; Fullagar *et al.* 2008, 2015), the higher prevalence of seed processing tools during the late Holocene may be related to environmental changes, resource stress and resource availability that facilitated the more intensive processing of seeds. Hiscock (2008: 209) has suggested that the appearance of dedicated seed grinding tools during the Holocene between 1 and 2 ka is related to the onset of wetter climatic conditions facilitating the growth of more stable grasslands and thereby increasing the economic benefits of intensive seed-grinding and thus promoting millstone use.

The local availability of seed sources has been suggested to influence the morphology of grinding stones from arid and non-arid regions of Australia. Previous studies of inter-assemblage variability in the Great Sandy Desert (Cane 1989) and in Central Australia (O'Connell 1977: 280) have shown that proximity to seed resources is key factor in the frequency of seed-grinding implements in site inventories. Investigations of botanical resources have indicated that grasses (family Poaceae)

and Acacias are more abundant in the arid regions of Australia, with Tindale (1977) defining a “Panara” seed culture in which grass seeds were intensively utilised in many regions across the arid zone of Australia. Pardoe (2003) noted the relative occurrences of grinding and pounding tools used for the processing of soft seeds (such as seeds from grasses, portulaca, gum tree and saltbush) and harder seeds (such as Acacia and nardoo seed) around the Menindee Lakes region on the Central Darling River. Through the integration of environmental data using Geographic Information Systems (GIS), Pardoe (2003: 49) found that the distribution of grinding and pounding stones was correlated with vegetation communities, where grasses and hard seed producing plants might be distinguished. Consequently, the local vegetation communities likely have a big influence over grinding stone morphology and use. As Lake Mungo and Cuddie Springs are located within the arid semi-arid region of Australia, one may expect that dedicated seed grinding tools are more likely to be abundant in these sites. However, functional analysis of MJB specimens have shown that many of these grinding stones were used to process seeds, and the identification of burnt macro-botanical remains has provided direct evidence for the harvesting of seeds (Florin 2013). Such evidence has potentially reflected an early seed grinding economy, even though morphologically distinctive seed grinding stones were absent.

Finally, an increase in “foraging risk” (*cf.* Attenbrow 2004; Attenbrow *et al.* 2009; Hiscock 2002, 2006, 2008) created by increased harshness and unpredictability of the environment associated with the El Niño – Southern Oscillation (ENSO) during the mid-Holocene (~4 – 5 ka), was suggested to have resulted in the proliferation of a number of artefact varieties, including both grinding and flaked stone tools. For example, the production of backed artefacts in south-eastern Australia increased substantially between 3.5 – 4 ka but declined rapidly after 1.5 ka and were completely absent by the time of British colonisation (Attenbrow *et al.* 2009). Attenbrow *et al.* (2009) and Hiscock (1994, 2002, 2006, 2008) have argued that the timing of the backed artefact proliferation is related to a strong climatic trigger whereby these implements were considered the most cost effective in circumstances where resource predictability was low and thus foraging risk was much greater. Response to enhanced foraging risk is also reflected at this time by an increase in retouch (*i.e.*, reduction) of other types of flaked stone tools as reported by others around northern Australia (*e.g.*, Clarkson 2002, 2007) and south-east New South Wales (Hiscock & Attenbrow 2002, 2003). Substantial increases in the exploitation of lower-ranked resources are consistent with the predictions that increased foraging risks were a key outcome of the emergence of the ENSO system. At this time, there is an enhanced consumption of toxic plants (*e.g.*, Asmussen & McInnes 2013; Cosgrove *et al.* 2007) and seeds (*e.g.*, Smith 2004: 169; Veth 1989: 83)—often represented by the presence of grinding stones but also discarded and carbonised plant remains. The apparent

proliferation of grinding stones, often with distinctive morphological varieties, may therefore reflect an elaboration of an already existing technology in response to enhanced foraging risk.

8.4.1 Distributions by grinding stone function

Most of the grinding stones recovered from MJB were amorphous grinding fragments with no distinctive morphological features. Despite their seemingly consistent morphologies, variation of grinding stone function was distinguished for tools recovered from Pleistocene and Holocene contexts. Grinding stones retrieved from Holocene contexts were most often used as plant processing tools, while those recovered from Pleistocene deposits were used for a wider variety of processing tasks, including plant and pigment grinding, stone working and the opportunistic processing of animal materials. There was no marked variability in the function of grinding stones retrieved from Pleistocene and early Holocene contexts at Lake Mungo. All artefacts examined from this site ($n = 17$, with the exception of two grinding fragments) were used for the processing of plant materials, most of which also displayed traces for the processing of seeds. The apparent lack of more than one functional variety is probably related to the availability of local resources and number of analysed grinding stones.

8.4.1.1 Function of Pleistocene grinding stones

Both assemblages have yielded evidence for the processing of plant materials during the Pleistocene. Radiocarbon ages produced on charred botanical remains associated with the earliest seed grinding tools at MJB have provided bracketing ages of 28.6 ka and 35.2 ka cal BP. The ages produced for these artefacts have ensured that they are among the oldest seed grinding tools so far identified in Australia, the earliest of which (GS 39) only marginally post-dates the millstone fragments recovered from 36 cal BP deposits at Cuddie Springs (see Fullagar & Field 1997: 302; Fullagar *et al.* 2008). The lack of seed processing tools in earlier deposits at MJB may be attributed to a number of possible scenarios: (1) seed grinding tools do not exist before 35 ka cal BP; (2) functional traces relating to seed and plant processing are unable to be recognised in older deposits due to the degradation of plant residues or other taphonomic issues associated with the removal of use-wear traces (e.g., weathering of surface; removal of polish through sediment contact); or (3) the sample size of older excavated artefacts was too small. Only a limited amount of organic material was documented on the grinding stones from Pulse 1 and distinct use-wear traces (most notably use-polish) were less common, possibly due to taphonomic alteration of the use-polished surfaces.

Consequently, it would be possible that seed grinding tools were used earlier than 35 ka, but the current evidence is too limited to support this interpretation. The sudden onset of seed grinding activities occurring on site may be attributed to the availability of a greater variety of grass and palm species at 30 – 40 ka BP, as determined through the analysis of ancient phytolith assemblages from the Napier Range in inland southwest Kimberley (Wallis 2001). Greater biodiversity enabled additional resources available for human consumption, requiring new processing methods and facilitating the need for grinding stones.

Pleistocene seed grinding tools were also identified at Lake Mungo, the earliest of which were recognised from slightly earlier contexts, recovered from Unit E deposits dated at between 14 and 25 ka (Fitzsimmons *et al.* 2014). Bowler (1998) has suggested that the occurrence of seed grinding implements in Pleistocene deposits from Lake Mungo has reflected a technological response to local ecological stress occurring from 19 – 25 ka, when changes in landscape and plant availability required new adaptive responses from human occupants. The onset of arid conditions almost certainly modified vegetation and restricted Aboriginal access to many areas (e.g., altered distances from water sources and other resources), resulting in a possible contraction of territory and decreased resource base (Edwards & O’Connell 1995: 773). Past human population models such as those discussed by Williams *et al.* (2013) have suggested that during the LGM from 25 – 12 ka Aboriginal Australian populations contracted to refugia, characterised by well-watered ranges and major riverine systems (Figure 8.4). The Willandra Lakes region within the Murray Darling Depression became a refugium from 25 – 12 ka and thus higher populations, in conjunction with enhanced ecological stress, facilitated the need for grinding stones specifically for plant processing.

Alternatively, the lack of grinding stones recognised at MJB during the LGM ($n = 1$) may reflect lower site occupation in response to decreased populations. Other cultural material is also limited in LGM deposits compared to the amount of material identified in earlier or more recent deposits. Grinding stones from LGM deposits are also less common in other sites around northern Australia, with only a few occurrences (see Table 2.2 for site list), but are noted more frequently in the semi-arid and arid regions of the continent, including the Little Sandy Desert in Western Australia, Cuddie Springs in New South Wales and other sites within the Willandra Lakes region. The more frequent occurrence of grinding stones from these sites may be related to more intensive grinding practices in these regions, probably as conditions became harsher and populations retreated to refugia.

Following the LGM, grinding stones that were used for plant and seed processing were recognised at both sites, coinciding with Pulse 2 at MJB and Unit F at Lake Mungo. The use of

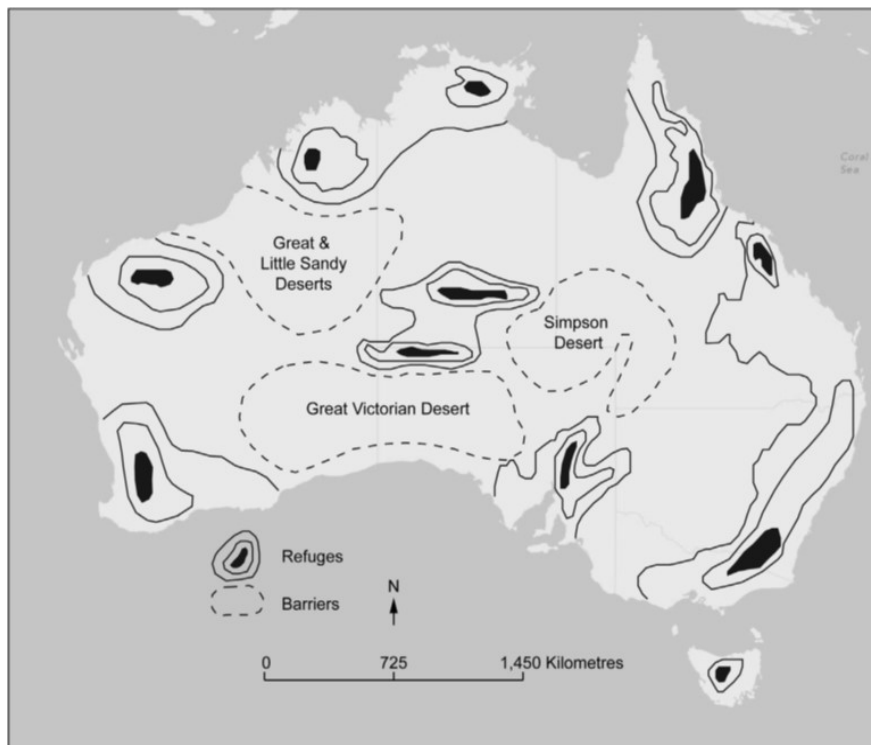


Figure 8.4: Location of Australian refugia during the LGM. From Veth 1989.

grinding stones for plant processing activities has been reported for other Pleistocene sites around Australia following the LGM. Balme *et al.* (2001) found evidence for seed and plant processing on grinding stone fragments at Puntutjarpa Rockshelter in Australia's Western Desert dating to at least 10 ka BP. Similar to the grinding stones identified at MJB, the grinding stones examined at ($n = 49$) did not have any distinctive morphological features indicative of seed or plant processing, and most were fragments that lacked design or deliberate shaping, often with minimal macroscopic grinding wear. The examination of these tools under high magnification, and the identification of starch grains on these artefacts, however, has indicated that they were predominately used for the processing of seeds and plants, with relatively few incidences of pigment and animal processing. The identification of plant and seed grinding tools on amorphous grinding stones that are typically not attributed with such activities, highlights issues associated with inferring diet on indirect conclusions based primarily on artefact morphology (*cf.* Smith 1985). Grinding stones with morphological features and use-wear traces consistent with seed grinding are also recognised from the semi-arid regions of Australia, and include millstone fragments from Cuddie Springs and Lake Mungo (discussed below), but morphologically distinct varieties are not known from northern Australia.

Unlike the tools examined at MJB (which included over five times as many specimens), pigment processing tools were not identified on any of the Lake Mungo specimens, despite evidence

for use of ochre associated with the MIII ritual burial dated at c. 40 ka (Bowler *et al.* 2003). The ochre used to cover the MIII skeleton was likely sourced some distance from the site, approximately 200 km away, and therefore had to be collected and transported some distance. The fine powdery appearance of the ochre has indicated that it was likely processed via grinding or pounding, probably using grinding stones. Interestingly, grinding stones used for ochre (or other pigment) preparation have not been recognised at Lake Mungo. I suggest that the lack of pigment processing tools is related to the lack of available ochre/haematite sources in close proximity to the site as well as the limited number of analysed grinding stones. As abraded pigment pieces are occasionally identified at the site (Stern *et al.* 2013: 36), some ochre grinding is likely. Finding evidence for such practice through the examination of grinding stones will require an increased sample size and the analysis of additional grinding specimens. Although the grinding of pigment is not overly common at Lake Mungo, it is a common practice around northern Australia, with many sites yielding large quantities of ground or abraded haematite and ochre pieces that have originated from Pleistocene contexts (Figure 2.1c) (e.g., Jones & Johnson 1985; Roberts *et al.* 1994; Schrire 1982). The rich assemblage of rock art in Western Arnhem Land dating to the Pleistocene (as determined through superposition of painted pieces) supports the intensive use of pigments at this time. The occurrence of pigments and extensive rock art paintings throughout this region of Australia is suggested to be associated with proposed cultural cycles of enhanced artistic behaviour during the Pleistocene (see Taçon & Brockwell 1995).

Animal residues were recognised only on a limited number of grinding stones from MJB, and probably represent the opportunistic use of these tools for animal processing. Although collagen fibres and feather barbules were also recognised on some of the Lake Mungo artefacts ($n = 3$), I do not consider the feathers to be related to use as they were recognised as single fibres and were not found in association with other animal residues (e.g., blood, bone). Stone working tools were not recognised at Lake Mungo, but at MJB, a number of ground-edge stone axes were found in Pleistocene deposits ($n = 9$), as well as a number of other smaller flakes believed to be fragments of ground-edge axes. The axes were most likely shaped on bedrock slabs and honed with stone files; and some grinding stones with direct stone-on-stone use-wear were identified in Pleistocene deposits ($n = 3$), suggesting the maintenance of ground-edge axes on site.

8.4.1.2 Function of Holocene grinding stones

Most of the grinding stones from MJB and all of the grinding stone from the Lake Mungo Holocene deposits were used to process plant material. From MJB, tools were used for the

processing of seeds and starchy plants, and there was also evidence to indicate the processing of toxic plant species. The processing of toxic plants is also known for other regions of Australia starting from around 3.5 ka, reflected in part by the occurrence of incised “morah” stones that are present in both open and rockshelter archaeological sites within the Queensland rainforest (Cosgrove 1996: 905; Cosgrove *et al.* 2007; Horsfall 1985: 347, 387). These tools were believed to process various species of toxic and non-toxic nuts, as indicated through starch grain analysis (Cosgrove 1996: 905). Additionally, Asmussen and McInnis (2013) have reported on the human consumption of *Macrozamia* sp. seed around eastern Australia from 5 ka. This seed was roasted and leached to remove toxic properties before being pounded to remove the woody outer shells. The consumption of these lower-ranked resources was suggested to be related to greater foraging risk resulting from the emergence of the ENSO system approximately 5 ka ago. Other lower ranked resources including seeds and other plant varieties were also processed in Australia during the mid – late Holocene. Past seed grinding activities are often assumed based on the presence of “dedicated” grinding tools—recognised on the basis of their ground surface morphology, size and configuration (rather than the nature of wear traces). Tools of this variety are typically found in sites around Central Australia and are not commonly identified before 3 – 4 ka BP (e.g., O’Connor *et al.* 1998; Smith 2004; Thorley 1998; but see Fullagar & Field 1997; Fullagar *et al.* 2008, 2015). Such tools are now considered to constitute part of the “Desert Culture” along with adzes and other composite tools (Smith 1986, 2004; Hiscock & Veth 1991; Veth *et al.* 2011).

Only one grinding stone used for the processing of red pigment was recovered from *in situ* Holocene contexts at MJB. The abundance of ground haematite pieces within the Holocene levels of the site, and the plethora of rock art described and dated around Arnhem Land, has indicated the systematic use of pigment and symbolism during the Holocene. The lack of portable stone files from similar depositional contexts at MJB could imply a different processing method for processing pigment in lieu of grinding stones, such as direct application of pigment to rock walls by use of small haematite crayons. The presence of ochre and haematite residues on a near-by bedrock grinding patch has indicated the possible use of such grinding patches for the processing of pigments.

The most recent grinding stone identified in the MJB deposit was a mudstone brick that was used for the sharpening of metal and stone axes (Plate 8.8). One ground-edge axe was identified on the surface of the MJB deposit, but no metal axes were identified. This could suggest that these implements were not used extensively on-site.

8.5 Australian grinding technologies and the global perspective

As discussed in Chapter 2, pounding and grinding technologies have a very ancient origin and are not restricted to *Homo* species. Additionally, other modern non-human primates, such as chimpanzees, macaques and capuchin monkeys, are also known to pound and crack nuts using mortar and hammerstones (e.g., Frugaszy *et al.* 2004; Haslam *et al.* 2009, 2013; Moura & Lee 2004; Ottoni & Izar 2008; Ottoni *et al.* 2005). While pounding technologies are not unique to modern humans or any particular region of the world, the function of grinding technologies vary on a temporal and global scale. De Beaune (2004) has traced the transformation of pounding to grinding and polishing motions, reflected in the Lower and Middle Palaeolithic, respectively. Others have traced the processing of starchy plant foods, determined following the characterisation of tool residues. In these studies, the consumption of grass seeds was recognised during the late Pleistocene prior to MIS 2, and is believed to be associated with resource stress that may have enhanced the consumption of certain plant foods. Evidence for such processing is reflected at c. 23 ka at Ohalo II in Israel (Piperno *et al.* 2004; Weiss *et al.* 2008); c. 23 – 19.5 ka at Shizitan Locality 14 in China (Liu *et al.* 2013); c. 30 ka at Bilancino II in Italy, Kostenki 16-Uglyanka in Russia, and Pavlov VI, in the Czech Republic (Revedin *et al.* 2010); c. 40 ka BP at Niah Cave in Malaysia (Barker *et al.* 2007; Barton 2005); and c. 36 ka cal BP at Cuddie Springs, Australia (Fullagar *et al.* 2008). The data presented in this thesis has also suggested the processing of starchy plants at MJB and Lake Mungo from c. 35 ka and 14 – 25 ka, respectively. The adaptation of grinding stones for use as plant processing tools following climatic variability and resource stress is therefore documented globally. The appearance of grinding stones throughout Neolithic sites of the Middle East (in conjunction with an “entanglement” of other traits; *cf.* Hodder 2012: 195-196) is also suggested to represent the onset of an agricultural economy (Zeder 2009). Grinding stones such as mortars and large basal grinding slabs were present in Middle Eastern sites from 24 ka, becoming ubiquitous at c. 12 ka in the Natufian and Pre-Pottery Neolithic.

The occurrences of grinding stone tools were thought to represent increased sedentism and intensive cultivation, whereby the grinding stones represent channelled adaptations in the direction of the increased intensification of plant use, thus making early agriculture possible (Hodder 2012: 197; Wright 1994). The occurrence of grinding stones in other regions of the world, such as China and South and North America, have also been linked to enhanced sedentism and agricultural practices starting from 9.2 ka cal BP (Section 2.3) (Liu *et al.* 2010a, 2010b). The independent emergence of agriculture in Sahul has also been documented for the New Guinea Highlands whereby use-wear and residue analysis of grinding stones from Kuk Swamp has indicated the

processing of at least two economically important plant foods: taro (*Colocasia esculenta*) and yam (*Dioscorea* sp.) (Fullagar *et al.* 2006). Fullagar *et al.* (2006) have argued that the processing of introduced taro and yam began by at least 10.2 ka cal BP, although the authors have acknowledged that these may not represent cultivated plant forms. Other published evidence from Kuk Swamp confirms New Guinea as a primary centre for agricultural development by c. 6.9 – 6.4 ka BP, where the processing of taro, yam and other plants were likely integrated into cultivation practices on the wetland edge (Denham *et al.* 2003, 2004). Such cultivation practices pre-date the introduction of southeast Asian domesticates associated with Austronesian expansion soon after 3.5 ka cal BP (Bellwood 1997). While there is no evidence for agricultural practices occurring within the Australian landmass prior to European settlement, evidence for the use of grinding stones for plant food processing activities, coupled with ethnographic evidence for the intensive processing of seeds, has indicated the importance of such tools for modern hunter-gather societies; and that grinding technology is not generally tied to a trajectory of agriculture, urbanism and complex political structures, as once thought

Forms of grinding technology may be attributed to at least two hominin species. Abraded pigments associated with *Homo neanderthalensis* are most notably found at habitation sites dating from the end of the Middle Palaeolithic, including of sites in the southwest of France in which a number of ground pigments, including iron oxides, haematite, goethite and manganese dioxide are associated with the Mousterian (e.g., d’Errico *et al.* 2009; Soressi & d’Errico 2007). Similar ground pigments have also been identified in modern human sites from the MSA in South Africa, becoming more abundant during proposed cultural cycles where the emergence of new tool industries (i.e., Still Bay and Hoowieson’s Poort industries) are thought to imply enhanced symbolic storage and behavioural modernity (see McBrearty & Brooks 2000). Other forms of grinding technologies that reflect artistic practices included those associated with polished figurines, ornaments and other sophisticated artworks, and are only known for *Homo sapiens*, with the exception of the chloritite bracelet identified from Denisova Cave, possibly attributed to the recently discovered Denisovans (Derevianko *et al.* 2008). Polished figurines made of bone, wood, stone, clay and ivory are known from 35 ka cal BP, identified within the early and middle phases of the Upper Palaeolithic (see Section 2.3) (e.g., Conard 2009; d’Errico *et al.* 2011; Mellars 2009; Svoboda 2008; White 2006). The recent discovery of sophisticated artwork in sites within southeast Asia, dated from 39.9 ka, have indicated that parietal art was present in sites en route to Australia outside of Europe, and therefore that artwork was already part of the cultural repertoire of the first human populations to reach Australia (Aubert *et al.* 2014). While polished stone and bone figurines are not recognised in the early human occupation sites of Australia, the occurrence of ground haematite pieces at the base of

the MJB excavation (as well as other Australian sites—see Table 2.2), and the identification of an ochred burial at Lake Mungo, have indicated symbolic practices were undertaken by the earliest Australians (see Langley 2014). Greater abundances of ground haematite pieces in Arnhem Land at certain times throughout pre-history can be linked with proposed cultural cycles of artistic pulses (*cf.* Taçon & Brockwell 1995).

Other evidence for grinding technologies occurs in the form of utilitarian tools such as ground points shaped from wood, bone and ivory, as well as other ground objects shaped from shell and stone, the latter of which are only known for *Homo sapiens*. Interestingly, the earliest occurrences of ground shell and stone are found within Sahul, most notably from sites around East Timor (e.g., 42 ka cal BP shell fish hooks from Jerimalai) and northern Australia (ground-edge axe flakes from the earliest cultural levels of MJB, dated at ~50 – 60 ka) (Table 2.2). Ground-edge axes and other ground-edge stone implements do not appear in other regions of the world until at least c. 38 ka cal BP, most notably from sites in Japan and more recently in China (Section 2.3) (Takashi 2012) and from 20 ka within Eurasia. Within the Australian archaeological record, ground-stone axes are restricted to northern Australia in regions above 20°S, and particularly for sites around Arnhem Land and northern Queensland (see Table 2.2 for references), and are absent further south until about 4.5 ka BP (Akerman 2014: 143; Mulvaney & Kamminga 1999: 221). The exclusive occurrence of ground-edge axes at this time, and their restriction to a relatively small area of the colonised land-mass, may reflect an elaboration of an already existing technology created to facilitate different environmental or cultural parameters.

Takashi (2012: 73) has noted that the late Upper Pleistocene edge-ground hatchets found in Japan were restricted to the islands of Kyushu and Honshu and appeared only for a short duration between 36 and 32 ka cal BP, and do not reappear in Japanese pre-history until the Incipient Jomon Period from between 13 and 10 ka BP. Such trends imply changing paradigms that facilitated a need for manufacturing ground edge hatchets. In Australia, ethnographic research has implied the use of ground-edge axes for woodworking activities, such as the removal of trees and the manufacture of wooden implements and canoes (Dickson 1972, 1981). Chopping trees to extract honey (perhaps one of the most highly valued foods) from bee-hives is also another common practice for Aboriginal people living within the Kimberley region of Western Australia (Akerman 2014: 143).

Functional analysis of ground-edge axes and axe flakes from MJB is currently underway (Fullagar *et al.* in prep). Determining the function of these implements may be the key to reliably identifying the cause of their exclusive occurrence in this region of world, for example, whether it is related to cultural or environmental parameters. One way of testing this would be to examine

assemblages from other archaeological sites of similar antiquity and past environmental conditions, to determine whether ground-edge stone implements are also found in these sites. Because the southeast Asian archaeological record is composed of only a small selection of sites compared to other regions of the world, it is possible that the lack of similar aged implements is the result of a limited sample size. Other investigations have shown that ground-edge axes and grinding stones usually contribute to only a very small portion of the total artefact assemblage, and therefore to identify them within the archaeological record a larger sample size is required. It is interesting that in Australia, the sites that have undergone the largest excavations, such as Cuddie Springs, Lake Mungo and MJB, have uncovered the largest collections of Pleistocene-aged grinding stones and axe fragments. The recent discovery of the world's oldest rock art in Sulawesi in Southeast Asia (Aubert *et al.* 2014), which pre-dates the rich corpus of sophisticated parietal artworks in many European sites, has highlighted the potential for southeast Asian sites to add to our global understanding of human behaviour, where other well-dated evidence has been scarce or supposedly absent.

8.6 Chapter Summary

Based on the Australian evidence, it is clear that grinding technologies were part of the cultural repertoire of the First Australians. How these technologies differ from other global occurrences is related to artefact function and may be linked with climatic parameters, resource use and proposed cultural cycles that are reflected by pulses of artistic or symbolic activity. Functional analysis performed on two assemblages of Pleistocene-aged grinding stones has indicated the specific functions of many of the analysed specimens, allowing for the specific on-site activities to be established. The chronological and functional distribution of grinding stones at both MJB and Lake Mungo has provided insight as to the timing of specific activities and whether this may be related to environmental change associated resource stress, site occupation and other factors. At Lake Mungo, grinding activities are predominately reflected in the processing of plant foods, such as seeds, while grinding activities at MJB also include the grinding of materials in the preparation of other technologies (such as stone axes) and for craft purposes (such as for the processing of pigments). The different activities reflected at each site are probably the result of several factors, including different ecological zones, environmental pressures that differentially favoured seed processing for food, availability of local sandstone sources, and sample size.

Chapter 9:

Thesis summary and conclusions

9.1 Introduction

Global archaeological evidence has indicated that pounding stone technology has a very ancient origin, appearing in the Old World archaeological record from at least 0.78 Ma, and that it can be attributed to multiple hominin species (Chapter 2). Grinding technology, as indicated by ground bone points, is at least 2 Ma old. The occurrence of grinding technologies in the earliest levels of MJB has indicated that these technologies were elements of the cultural repertoire of the earliest Australians, and were likely a significant part of their colonising toolkit. The study of pounding and grinding stone function(s) from two early human occupation sites, MJB and Lake Mungo, and their spatial and temporal distributions, has formed the basis of this thesis. This chapter provides a summary of the initial aims and key findings; discusses prospects for future research; and presents the main conclusions.

9.2 Aims revisited

The broad objective of this thesis has been to compare and understand the context, history, and variability of grinding stone technology in Australia by undertaking a detailed functional analysis of grinding stones from MJB and Lake Mungo. My approach included further modern tool use experiments, novel biochemical analyses and blind tests. I constructed a sequence of grinding activities through time, based on tool function, tool stone selection and artefact life-history, so that I could evaluate the extent to which temporal and spatial variability of grinding stones can be linked with site context, resource availability and environmental change. This section revisits the original aims outlined in Chapter 1 with reference to my methodological approach and my proposed chronology for grinding stone technology in Australia.

9.2.1 Specific/substantive aims

1) To undertake a detailed functional analysis of use-wear and residues on a selection of grinding stones recovered from MJB and Lake Mungo.

One-hundred and thirteen grinding stones and grinding fragments were recovered from two early Australian archaeological sites and analysed for diagnostic traces of use indicative of tool function. Functional analyses included the recording of artefact size (maximum width, depth, length, and mass); cross sectional shape of the grinding surface; use-wear at low and high magnification;

and adhering residues visible under optical microscopy and/or detected by biochemical analyses (Chapter 5). The study of use-wear and use-residue traces, in conjunction with artefact morphology, provided a reliable basis for determining tool use and, with varying degrees of specificity, the nature of contact materials and tasks performed.

Ninety-six potential grinding stones and fragments were recovered from MJB, and 91 specimens displayed wear consistent with grinding activities. Functional analysis of the 96 specimens revealed 126 utilised surfaces on 91 tools (including 11 multi-functional implements). There were four main classes of contact material: plant (number of grinding stones with evidence for plant processing = 52), animal (n = 4), stone (n = 6) and pigment (n = 16). Seventeen grinding stones from Lake Mungo were analysed, at least 14 of which were recovered from Pleistocene/early Holocene contexts. Fifteen artefacts displayed traces of use consistent with the processing of plant material, 14 of which could be further distinguished as seed processing tools.

2) To construct a sequence of grinding activities through time based on tool function, tool stone selection and artefact life histories.

Grinding activities were indicated by ground implements (e.g., bone points and stone axes) as well as by the grinding stones themselves. Three distinctive pulses of grinding stone accumulation were recognised at MJB, occurring between 28.6 and 35.8 ka cal BP (Pulse 1), 9.2 and 18.2 ka cal BP (Pulse 2), and 4.2 and 5.5 ka cal BP (Pulse 3) (Table 8.1). Most of the grinding stones were found within Pleistocene contexts that pre- or post-date the LGM (n = 76), with relatively fewer specimens identified from late – mid-Holocene (n = 9) and early Holocene (n = 4) contexts.

A high percentage (58%) of the 76 analysed grinding stones from the Pleistocene deposits functioned as plant processing tools, most of which were identified in Pulse 2 (n = 31), following the LGM. The associated environmental changes forced a shift in vegetation that increased potential plant food resources that required the enhanced use of grinding stones. Other social processes are also reflected shortly after the LGM, with a loss of silcrete artefacts from the MJB assemblage possibly indicating reductions in mobility, cessation of exchange networks, reductions in territory size, or change in configuration of group territories (Clarkson *et al.* 2015). The earliest plant/seed processing tools have been dated to between 28 and 35 ka cal BP and originate from Pulse 1. Older grinding stones were used to process red haematite, or were unable to be assigned a function. It is possible that grinding stones used for plant processing pre-date those recovered from Pulse 1, and that diagnostic traces for such function are no longer visible, due to residue degradation and/or taphonomic processes obscuring wear traces. Recent use-wear analyses on flaked-stone artefacts

from Pleistocene levels of MJB have indicated that wood-working was a common activity (Hayes *et al.* 2014a: 89).

Functional analysis of grinding stones recovered from Holocene contexts of MJB have indicated that plant processing was a dominant activity at that time, with seven of the eight grinding stones from Pulse 3 displaying diagnostic traces of plant processing. Use-residues recovered from these specimens have also indicated the processing of multiple plant taxa, suggesting that plant processing was a highly important activity. The presence of plant processing tools during the Holocene, particularly during Pulse 3, may be linked with environmental changes that facilitated the exploitation of newly available plant-food resources. Interestingly, no unequivocal evidence for the processing of animal materials was obtained from Holocene contexts at MJB, although ground bone (*cf.* bird) points were recovered from within the most recent levels of the midden deposits, coinciding with Pulse 3. The apparent absence of sandstone grinding stones used to manufacture bone points in Holocene contexts, has suggested that either another, as yet unrecognised, tool (e.g., a flaked stone surface) was used for point manufacture, or that the ground bone points were manufactured elsewhere before being discarded at the site.

Although abraded haematite pieces were recognised in the Holocene deposits of MJB, only one grinding stone displayed evidence for the processing of pigment. The frequency of abraded haematite pieces found in Holocene contexts has indicated that pigment use was common, but the pigments were probably not processed using portable filing stones. The haematite pieces may be the stubs of ‘crayons’, used to directly apply pigment, or they maybe the remnants of haematite that were processed by surfaces on other implements (e.g., stone flakes or cores). In contrast, grinding stones from Pleistocene contexts with traces of use consistent with the filing pigment were recognised much more frequently—on 20% of grinding stones ($n = 15$). Consistent with the higher frequency of Pleistocene grinding stones used for pigment processing, abraded haematite pieces were also more prevalent in Pleistocene contexts, and also appeared in the lowest excavated levels of the site (Clarkson *et al.* 2015; Cox 2014). Consequently, it was to be expected that the earliest grinding stones from MJB were used for filing pigment. Interestingly, the earliest occurrences of filing stones elsewhere in the global archaeological record were also apparently used by *Homo sapiens* to grind pigment (e.g., Henshilwood *et al.* 2011). Studies of the filing stones, pigment and rock art is potentially important for tracking shifts in rock art style. For example, the frequency of pigment filing tools and ground pigment pieces during various phases of occupation can potentially be linked with the type of pigment, application technique, processing technology and the proposed styles of rock art in Arnhem Land during the Holocene and Pleistocene (*cf.* Taçon & Brockwell 1995).

The function of the Lake Mungo artefacts remains relatively unchanged through time. All but one tool displayed use-traces that could be attributed to the processing of plant materials, suggesting that processing of seeds had been a consistently important activity since at least 25 ka.

There does not appear to be any significant changes in the raw material type selected for grinding stone manufacture at MJB, with most specimens ($n = 85$) made from locally available sandstone. A notable exception is the post-contact mudstone brick that was recovered from recent site deposits. The occurrence of this artefact indicates opportunistic use of newly available material that was specifically modified to sharpen metal axes that had also been introduced after European contact (Meehan *et al.* 1978). Within the immediate area of MJB, bedrock grinding patches are common (Plate 8.7), and may offer an alternative facility for a lower grinding stone, with a larger, stationary base, rather than portable lower stones. In contrast with the intensively used bedrock grinding patches, the excavated portable grinding stones from MJB appear to have been used expediently (certainly not at the end of their use-lives) with no distinctive groove development or traces of rejuvenation. None of the MJB grinding stones appeared to have been recycled and therefore the life history of each implement is relatively straightforward. In contrast, the grinding stones analysed from Lake Mungo were made of less tough sandstone, with more wear and longer, more complex life-histories: three displayed “dished” surfaces, and two had been recycled from a lower to an upper grinding stone. In contrast with the availability of tool stone at MJB, sandstone is not locally available at Lake Mungo and had to be imported over long distances. Consequently, the Lake Mungo artefacts were less likely to have been used expediently and more likely to have been used until they were exhausted, with evidence of recycling.

3) To evaluate the extent to which temporal and spatial variability of grinding stones is linked with site context, resource availability and environmental change.

The frequency, form and function of grinding stones and their spatial and temporal distribution are related to at least three variables: site context, resource availability and environmental change. The distribution of grinding stones identified throughout MJB was consistent with the distribution of other cultural materials whereby “pulses” of accumulation are reflected by greater frequencies of lithic materials, charred botanical remains and ground haematite pieces. I suggest that the layers in which all artefact frequencies per unit volume were highest reflect times of enhanced site occupation and larger populations. Pulses of accumulation centred on 12.5 and 7 ka are consistent with an Australia-wide population growth as proposed by Williams (2013: 5), with decreased site occupation during the LGM reflected by fewer artefacts, and coinciding with lower

population densities, which reportedly fell by about 60%. Only one grinding stone was recognised in deposits overlying the shell midden, despite human population curves indicating higher populations at the time. I suggest that the limited occurrence of grinding stones (as well as other artefacts) in these deposits may reflect site abandonment for several generations following the human burials that were dug into the midden deposits. Abandonment of burial sites is known ethnographically in many parts of Australia.

Palaeo-environmental data generated for western Arnhem Land has suggested distinctive environmental phases in which changing precipitation and evaporation levels influenced the local vegetation and landscape morphology (Section 3.2.4). Distance to water, availability of plant foods and contractions of territory would have played a role in the frequency and distribution of certain artefact classes, including grinding stones. For example, in Holocene deposits, grinding stones were most prevalent during the earliest phases of the shell midden, dated from 4.2 – 5.5 ka cal BP. At this time, precipitation was increasing and meandering river channels had formed along the South Alligator River, facilitating the extension of mangrove communities. Grinding stones from these deposits were used almost exclusively for plant processing. Similarly, an expansion of the monsoon rainforest at ~12 ka BP following wetter and warmer conditions saw the onset of new plant resources in the local area (Russell-Smith 1985: 241), coinciding with an increase in grinding stones. Thus, local environmental change and the shifting availability of resources is reflected in the frequency, form and function of particular artefact classes.

At Lake Mungo, grinding stone frequencies are highest in deposits associated with the Unit E strata, dated at 14 – 25 ka and coinciding with the LGM. Williams *et al.* (2013: 4620-1) have suggested that between 25 and 12 ka, the Willandra Lakes region in the heart of the Murray Darling Depression became a refugium at a time when Aboriginal populations retreated to the well-watered ranges of the major riverine systems. As a consequence, local population levels at Lake Mungo would have been higher than that evidenced around the rest of Australia where population levels were in decline (Williams 2013). Bowler (1998) has suggested the higher frequency of grinding stones from 19 – 25 ka may reflect a technological response to local ecological stress that affected local landscapes, plants and larger animals that required a new adaptive response from human occupants to exploit newly available plant resources. Evidence for the processing of plants, specifically seeds, on grinding stones recovered from deposits associated with the LGM, support the interpretation provided by Bowler (1998).

Grinding stone morphology differs substantially at MJB and Lake Mungo, despite evidence suggesting that many of the artefacts were used primarily to process plant materials. The distinctive

well-worn, dished and recycled artefacts at Lake Mungo suggest a lack of available sandstone material. Sandstone is not locally available at Lake Mungo, and therefore grinding stones made from this stone are more likely to be used until exhausted, and well-worn, recycled grinding tools are more common. As sandstone is ubiquitous at MJB, grinding stones made from this material were more likely to be used expediently, rather than have an extended use-life. Thus, site context and resource availability are seen to play a significant role in determining grinding stone morphology.

9.2.2 Methodological approach

1) Functional analyses performed on experimental and ethnographic grinding stones to develop a diagnostic use-wear and residue reference library applicable to the archaeological assemblages.

A selection of experimental sandstone ($n = 28$) and ethnographic grinding stones from the South Australian arid zone ($n = 12$) were examined for use-wear traces to supplement previous studies and target the particular archaeological materials to be analysed (Chapter 6). Previous published data had shown that diagnostic use-wear traces may be identified on grinding implements made on sandstone, granite, basalt and other stone materials (Table 6.1). In my experiments, I focussed on generating wear on a variety of hard and soft sandstones used to process a range of materials documented ethnographically, as well as other materials that shared similar properties to the broad classes (e.g., seeds) under investigation. Classes of processed materials included soft plant, seeds, wood, bone, pigment and stone. My experiments, although not comprehensive themselves, in conjunction with previous studies, provided the basis for constructing a use-wear reference library that has defined distinctive, diagnostic and overlapping patterns of wear linked with particular aspects of function at various stages of development. Significant use-wear features for distinguishing these classes of processed materials included the degree of grain rounding and grain levelling; the presence of macroscopic surface striations; and the occurrence of micro-fractures, use-polish and striations observed at high magnification (Table 5.2). Analysis of the experimental artefacts demonstrated that use-wear traces on sandstone artefacts will be influenced by the artefact class (i.e., coupled or filing stone), mode of use (pounding, filing, rotary/backwards and forwards grinding), material worked, duration of use and the nature of the sandstone material (i.e., hardness, grain size and the composition of the cementing matrix).

In addition to generating a use-wear reference library, my experiments have highlighted a number of issues associated with the identification of diagnostic use-wear traces and the limitations

of functional inferences. For example, wear on tools that were used for very short durations may not possess wear that is developed enough for an analyst to make clear interpretations of function, or even whether or not a tool has been ground at all, as is the case for tool used for very short contact times (<10 min for most activities, but see Table 6.8). While most of my experiments have shown that diagnostic use-wear occurs rapidly (<60 min), overlapping patterns of wear were recognised at various stages of development for different processed materials, particularly in the early stages of use. Despite this, I found that in general, use-wear patterns were distinctive of the broad categories of processed material (e.g., seed, bone, stone, haematite and wood).

In addition to the experimental tools, twelve ethnographic seed grinding tools from the South Australian arid zone were examined for functional traces. The ethnographic tools provided a case study of functional traces on Aboriginal grinding stones from the recent past. Only the last episode of use was documented, and we do not know the full life-history of these ethnographic stones. The ethnographic artefacts provide significant contributions to the use-wear reference library particularly because they pose similar interpretative issues raised by study of archaeological tools whose full life-history is also unknown.

2) Minimisation of subjective interpretations by quantification, integration of use-wear with a suite of optical, biological, elemental and chemical analyses, and evaluation by blind tests.

In this thesis, I have employed a number of optical, biological, elemental and chemical analyses to characterise tool residues (Chapter 5). These methods of quantification included: (1) the application of biochemical stains to highlight cellular structures and distinguish organic materials; (2) the removal, isolation and recording of starches from selected grinding stones to identify plant taxa; (3) absorbance spectroscopy and (4) biochemical testing, to characterise non-visible biomolecule compound groups; and (5) GC-MS, to characterise residue mixtures and identify specific non-visible compounds.

Following microscopic analysis of extracted residues, several samples were selected for staining so that the origin of any highly degraded, fragmented or amorphous residues could be inferred. Staining solutions included those that highlight cellulose, lignin, damaged and undamaged starch, protein, fat, collagen and keratin (Table 5.4). This method of optical and biological characterisation was particularly beneficial when residues displayed mechanical damage (a likely by-product of grinding) and when they appeared to lack distinguishing features, resulting from residue

degradation. While staining permitted the identification of specific organic structures, it was not always possible to determine whether the material identified was use-related or the outcome of contamination from deposition or handling. Inferences for use-related residues could only be made once observations had also been made on an unground surface(s).

Starch grain analysis was performed on a selection of grinding stones from MJB (n = 12) and Lake Mungo (n = 10) in collaboration with Dr. Judith Field at the UNSW. The specimens selected for analysis included those that were considered likely to contain starches after the initial use-wear and residue screening had indicated that they were probably used as plant processing tools (Table 5.3). These included tools that displayed use-wear consistent with the processing of plants, and tools that displayed starch (identified visually from pipette extractions or via biochemical analysis). Ultrasonication of the ground artefact surface followed by heavy liquid density separation enabled enhanced recovery of starch (as well as other plant microfossils). Recovered starch was photographed, measured (maximum length across the helium) and archived so that the grains could be compared with modern starch grain reference libraries, available for local plant species. Taxonomic identifications of the MJB and Lake Mungo specimens are yet to be confirmed, owing to the limited amount of reference material available for the Kakadu region and the low recovery of starch on the Mungo specimens. However, the starches that occur in large abundance (for the MJB Group 1 specimens) and/or as fractured grains, are highly likely to be use-related,

The presence of non-visible compound groups (e.g., carbohydrates, proteins, fatty acids) on grinding surfaces was evaluated using six biochemical tests, selected to detect the presence of carbohydrates, starch, protein, haem (ferrous iron) and fatty acids (Table 5.5). Biochemical tests are non-specific and were only used as an initial screening test to identify the selected compound groups. Similarly, absorbance spectroscopy was only employed as an initial screening test to determine the presence of other non-visible compound groups. A limitation with this latter method, however, was low detection sensitivity, and absorbance spectroscopy was not useful for determining constituent residues within a mixture of potentially highly degraded residues or those in limited abundance. GC-MS was found to be a highly sensitive method of residue characterisation that could detect individual compounds (rather than compound groups). Using this method, specific plant and animal compounds were detected in the analysed residue mixtures, many of which occurred in low abundance or were highly degraded—and had not been distinguished through previous methods of residue analysis.

Through the application of these additional methods of residue characterisation, I have minimised subjective interpretations of tool-use residues, enabling a more accurate account of tool

functions to be gleaned. Methods of use-wear quantification were investigated but I decided not to employ them in this thesis, first owing to a lack of experimental use-wear quantification studies performed on sandstone tools, and second because I wanted to avoid the need to clean tool surfaces, which would require large scale removal of residues.

Blind tests, in conjunction with colleagues at the University of Liège, were undertaken to evaluate the reliability of my identifications of use-wear and residue patterns on grinding stones that were used for a variety of tasks. The results indicate high success at identifying most tasks by direct microscope observations (60% success for use-wear analyses alone and 85% success with use-wear and residue combined). Subsequent staining and biochemical testing of the residues increased the reliability of my identifications.

9.3 Research implications

9.3.1 Technological change of grinding stones from the Pleistocene and Holocene

Examination of tool stone morphology for many Australian grinding stones has indicated vastly different morphological features. Grinding stones from Australian Pleistocene contexts are often amorphous fragments, and Holocene specimens possess distinctive grinding wear often resulting from a more heavily utilised surface. But one size does not fit all! With the exception of size differences, such variability was not noted among the Pleistocene/Holocene specimens from MJB and Lake Mungo. Results of my analysis suggest that technological variability of grinding stones here, and in many other regions of Australia, can be linked to sampling, social and environmental factors. These include: (1) number and size of excavated Holocene and Pleistocene sites; (2) demographic change and population increase; (3) artefact life-histories (including tool function and the extent of use); (4) climate and landscape changes that encourage the exploitation of new resources; (5) the availability of resources, including suitable stone material; and (6) increased foraging risk associated with environmental change, resource depletion and enhanced mobility requiring the exploitation of lower-ranked resources (Section 8.4.1). The apparent shift in artefact size favouring larger specimens during the Holocene at MJB, as well as the occurrence of heavily utilised bedrock grinding patches, may imply changes in mobility in which a more sedentary lifestyle is reflected. The Holocene grinding stones from depositional contexts at MJB were most frequently used to process plant materials, thus reflecting a foraging lifestyle whereby plant foods were ground on-site.

9.3.2 Grinding stone and flaked stone technology

This thesis focused on providing a detailed functional analysis of grinding stones from MJB and Lake Mungo. Although I have looked at a small collection of flaked stones from MJB ($n = 104$, see Hayes *et al.* 2014a), functional analysis is yet to be performed on much of the excavated flaked stone material. Similarly, there has been limited functional work performed on flaked stones from Lake Mungo. But what can the functional studies of grinding stones and flaked stones tell us? I propose that they are complementary and overlapping in the sense that they may provide independent information about past resource use, mobility, and responses to enhanced subsistence risk. For example, the proliferation of backed artefacts from 4.5 – 5 ka, and the occurrence of heavily retouched tools and intensively worn millstone fragments shortly after this, have indicated an adaptation of existing technologies to minimise risk and to invest more energy on lower ranked but more predictable foods like grass seeds (Attenbrow *et al.* 2009; Hiscock 1994, 2002, 2006, 2008). Functional analysis performed on collections of backed artefacts from southeastern Australia has indicated that these were general purpose tools, used for working wood, bone, and a variety of other materials (Attenbrow *et al.* 2009; Robertson *et al.* 2009). Hiscock (2006: 85) has suggested that the proliferation of such tools represented the onset of lower resource predictability resulting from either enhanced mobility and/or unfamiliarity with the environment whereby the systematic scheduling of activities was not possible. Heavily worn millstones and a higher incidence of retouch on other flaked stone tools could also reflect enhanced foraging risks and higher mobility in which stone sources become less frequently replaced.

9.4 Research implications and significance of findings

I have provided a comprehensive assessment of grinding stone technology in Australia as evaluated from two early human occupation sites, located in two distinctive geographical and environmental regions of Australia. Significantly, both sites yielded cultural material derived from Pleistocene and Holocene contexts. Through functional analysis, I have shown that the temporal and spatial variability of grinding stones can be linked with site context, resource availability and environmental change, and that morphological characteristics alone do not provide a reliable indication of artefact function. I suggest that artefact morphology is dominantly a reflection of the availability and type of stone material suitable for grinding, rather than tool function.

Both sites have yielded evidence for seed grinding activities occurring during the Pleistocene, starting from c. 35 ka cal BP at MJB and from 14 – 25 ka at Lake Mungo. Previous

studies on Pleistocene grinding stones have indicated even earlier occurrences of seed grinding tools, from 36 ka cal BP at Cuddie Springs (Fullagar *et al.* 2008). The identification of grinding stones used for seed and other plant processing in Pleistocene contexts has refuted the proposition that seed grinding technology was a late Holocene invention, although the sheer abundance, size and morphology of Holocene seed grinding stones does suggest innovation—a response to a different scale of risk. The late Pleistocene context and timing for seed grinding and other plant processing tools from Cuddie Springs, first reported by Fullagar and Field (1997), now seems less anomalous than it did at the time. With the exception of the plant processing tools identified at the site of 8-B-11, in Sai Island, Sudan, dated at 220 – 150 ka (Van Peer *et al.* 2003), and more recently from 40 ka cal Bp from Niah Cave, 30 ka ago from Bilancino II in Italy, Kostenki 16–Ugryanka in Russia, and Pavlov VI, in Czech Republic (Barker *et al.* 2007; Barton 2005; Revedin *et al.* 2010), the Australian evidence for plant food processing using grinding stones appears to be among the earliest in the world. Similarly, other grinding technologies, such as ground-edge axes and ground shell, are first recognised in distinctive geographical regions of Sahul and do not manifest in other regions of the world until later (Fullagar *et al.* in prep; Geneste *et al.* 2010, 2012; O’Connor *et al.* 2011).

Although grinding stones used for pigment processing were not identified at Lake Mungo, 16 grinding stones from the Pleistocene levels of MJB displayed traces of use diagnostic of this practice (Table 7.16). Grinding stones used to prepare ochre are known elsewhere in the world, most notably in the Near East and southern Africa, starting from 100 ka (e.g., Henshilwood *et al.* 2011; Hovers *et al.* 2003). Artefacts from these sites may be distinguished from earlier pigment processing tools such as the cobble stones identified at the site of Twin Rivers, Zambia, which have been indirectly dated to 350 ka ago (Barham 1998, 2002), on the basis of processing method (i.e., pounding rather than grinding motions, see De Beaune 2004 for discussion). The earliest occurrence of grinding stones used for the processing of pigment at MJB was noted from Spit 44 (depth of 222 cm below surface), dated between ~35 ka and 45 ka, while ground haematite and ochre pieces are also found down to a depth of 249 cm and associated with a TL age of 52 ± 7 ka (Clarkson *et al.* 2015; Roberts *et al.* 1990a). Although grinding stones were not recovered from these depths during the 2012 excavations, the identification of ground haematite has provided some of the earliest evidence in Australia for the processing of red pigments. Although the specific use of these ground pigment objects is unknown, further study of their origins, use actions and contact surfaces may shed light on early artistic activities. Currently, no in-depth use-wear studies have been performed on these tools.

The use of grinding stones for the production of pigment powder is suggested to reflect a symbolically mediated behaviour and early artistic activities that are considered hallmarks of

modern human behaviour (Langley 2014; Marean & Henshilwood 2003; McBrearty & Brooks 2005; Wadley 2001). The continuous presence of ground ochre and haematite throughout MJB (and other Pleistocene sites), has indicated that various forms of symbolic expression were a common occurrence in Pleistocene culture, as has been suggested by others (e.g., Chippindale & Taçon 1998). The temporal distribution and varying abundances of ochre and haematite pieces with traces of abrasion may indicate “pulses” of artistic activity, potentially showing changes in artistic style reflecting an evolving economy, social life and ideology (Taçon & Brockwell 1995). The relative abundances of pigment pieces at different sites and at different times may shed light on regionally different symbolic expressions.

9.5 Future work

In this thesis, I have further developed methods of functional analysis to examine grinding stones from two Australian sites, so that I could propose a sequence of grinding activities through time. Although my interpretations present a robust account of grinding stone functions for each of the analysed sites, more work is required to identify the functions of other on-site grinding activities and to identify the specific plant and animal taxa on processing tools. Future methodological research is also required to determine the applicability of the methods of residue analysis employed in this thesis to other tool classes (e.g., flaked stone, bone and shell), as well as the applicability of use-wear quantification methods on sandstone tools. Future work is needed to quantify the effect of weathering (such as sand blasting) on use-wear and residue traces on sandstone tools, through controlled taphonomic experiments. The following section outlines limitations of current approaches and potential research directions.

1) Limitations of sample size.

I have examined 96 grinding stones from MJB, representing all of the recovered specimens from the 2012 MJB excavated sequence. Further sorting of the sieved material at the University of Queensland has since added to the grinding stone assemblage, but these have not been examined for functional traces. Once all sieved material has been sorted, a complete functional sequence of grinding stones may be completed, which may modify and refine the interpretations I have presented in this thesis. In addition, more detailed study of bedrock grinding patches in Kakadu and particularly those close to MJB, will determine the extent and nature of grinding activities (including worked material) that were performed on these immovable items of site furniture, and provide a means to assess my hypotheses about why on-site grinding stone activities seemed to decline.

Samples for use-wear and residue analysis can be collected *in situ* (see Fullagar & Wallis 2012), using PVS peels and various solvent extractions, following methods developed in this thesis.

Further study of more recently recovered MJB and Lake Mungo artefacts has been planned. The current assemblage from Lake Mungo includes only 17 artefacts, the vast majority of which were used as plant processing tools. Additionally, grinding stones have since been recovered from the Unit E deposits at the site but are yet to be analysed for functional traces. The occurrence of other grinding technologies at Lake Mungo, including ground ochre found on a human skeleton dated at c. 40 ka, has suggested that with an expansion of sample size, grinding stones used for the processing of pigments (as well as other possible materials) may be recognised.

2) Documentation of manufacture and use-wear traces on other grinding technologies from MJB.

Besides grinding stones, other grinding technologies were also identified at MJB, sometimes present in the earliest occupation levels (see Clarkson *et al.* 2015 for artefact frequencies). These included ground haematite pieces, ochre crayons, ground-edge axes and bone points (although the latter artefact class was restricted to the midden deposits only). Investigations are currently underway to determine the manufacture, use and maintenance of the ground-edge axes (Fullagar *et al.* in prep), and similar investigations should also be performed on the other ground materials identified at the site. Recognising manufacture traces on the bone points may indicate whether these artefacts were shaped using sandstone files or other tools (e.g., stone files). The apparent lack of bone filing tools within the midden deposits has suggested that grinding stones at MJB were not used for the manufacture of bone points, and could indicate that these implements (if manufacture traces are indicative of stone contact) were produced elsewhere and brought to the site. This would have significant implications for past social processes, potentially indicating the development of exchange networks and communication among different Aboriginal groups. Analysis of bone points from MJB is being carried out by another student, Adriana Basiaco (University of Queensland) as part of her PhD project.

Interestingly, there was a low frequency of pigment processing tools ($n = 16$) compared with the relatively large number of abraded haematite pieces recovered from almost every level of the MJB 2012 excavation ($n = 427$). This has suggested a number of possible scenarios: (1) that grinding stones were not routinely used to process pigments and that traces of abrasion occur as a result of contact between another artefact class/contact surface (e.g., skin, hair); or (2) that pigments were processed away from the site. Determining how the pigments were processed and used will have

significant implications for past artistic and social practices: if they were not ground on sandstone filing tools, were they directly applied to rock shelter walls? Or perhaps they were used for decoration of wooden implements, or applied directly to the hair or skin during ceremonies, or to indicate social status as seen ethnographically elsewhere in Australia (e.g., Binford 1987: 474; Peterson 1968: 568; Peterson & Lampert 1985: 6)? Addressing these questions is critical for interpretations of past grinding activities and behaviour since the earliest human occupation. My own macroscopic investigations, and those performed by others (e.g., Cox 2014; Hodgkiss 2010), have suggested that use-wear markings on haematite and ochre pieces are indicative of contact material. Pigments that have come in contact with sandstone and dolerite grinding slabs displayed relatively flat micro-topographies and uni-directional parallel striations (or groups of parallel striations at angles to each other) visible macroscopically, caused by the protrusion of quartz grains on the grinding slabs (Hodgkiss 2010: 3347). Preliminary, macroscopic examination of ground haematite pieces removed from MJB during the 2012 field season has indicated that some of these artefacts probably sustained grinding wear from stone contact. However, such observations were made on a very small sample without the use of a microscope or comparisons with other experimentally ground haematite pieces. A use-wear reference library for abraded pigments is required, and I have completed a set of controlled experiments for haematite pieces that have been ground for varying durations on hard sandstone grinding tools. My use-wear reference library is being expanded to include ground pigments that have been used on skin, wood, hair and bone, using rubbing, grinding and scoring techniques, following the methodology presented by Hodgkiss (2010).

3) Expansion of the experimental grinding stone collection.

To supplement my archaeological analysis, I examined a collection of experimental and ethnographic tools so that I could generate a use-wear reference library for sandstone tools. My experiments included five sandstone sources that varied in hardness, grain size, and nature of the cementing matrix (Table 6.2). I found that the development of use-wear varied on different sandstones and that worked material and grinding motion played a significant role in producing certain use-wear traces. However, my experiments did not include grinding stones that were used to process multiple materials, and measures of grinding stone tool efficiency (i.e., time motion studies to measure surface erosion rates) were not evaluated. The latter is important for estimating tool use-life and the time involved in generating certain wear traces, particularly those that are visible at a macroscopic level (e.g., grooves). Future experiments to further build the use-wear

reference library should aim to target multiple uses of the same tool (including different grinding actions and multiple worked materials), artefact recycling, grinding stone efficiency, additional sandstone types and additional worked materials.

4) Expansion of the starch reference library for local flora.

Starch was identified on 21 grinding stones from MJB and 11 grinding stones from Lake Mungo (Table 7.10). While taxonomic identification of the starch recovered from the Lake Mungo specimens was not possible owing to the limited recovery of starches (<7 grains for all specimens), at least three specimens from MJB contained starches in excess of 200 grains. One of these three artefacts, L49, displayed at least two starch grain varieties, indicating that this tool was used to process at least two species of starchy plant. Owing to the high recovery of starch from these three artefacts, taxonomic identification is highly probable once an adequate reference collection is established. The published and unpublished literature for the local Kakadu region has indicated 238 economically important plant species, and some of these were known to be ground. The current starch reference collection for this area includes starch grains that originate from seven species of local edible plant, but does not provide a comprehensive library for economically important plant species. The development of a more robust starch reference collection for the local Kakadu area is currently being negotiated and will be carried out in collaboration with the starch research team at the UNSW with Judith Field and team in the coming years.

5) Increase sample of grinding stones sampled for starch.

In my analysis, I found that starch grain recovery was greatly enhanced with methods of ultra-sonication and heavy liquid density separation, despite the enhanced technical difficulty associated with these methods (Section 7.2.3.2). Twelve specimens from MJB and ten specimens from Lake Mungo have already been sampled using ultra-sonication and density separation, but additional specimens from MJB should also be analysed in this way. Owing to the time, difficulty and associated cost of such analysis, the application of this method should be restricted to only those specimens that displayed a high likelihood for containing starch (as indicated by use-wear analysis and the presence of specific plant compounds detected via GC-MS). In my analysis of the MJB grinding stones, I recognised 52 plant processing tools (in which 12 have already undergone methods of starch grain recovery) and I would suggest that those recovered from the more recent deposits (i.e., Pulse 3 and the first part of Pulse 2) should be subjected to these additional methods

of starch recovery. I plan on performing these additional analyses once an adequate reference collection for starches in the local Kakadu area has been established.

6) Introduction of an experimental program to assess the applicability of residue analyses on artificially weathered specimens.

My study has indicated that the survival of residues is linked with tool use on most of the grinding stones analysed in this thesis. Use-residues were most abundant on artefacts recovered from MJB, a protected rockshelter site in which artefacts were recovered from sediments composing a 350 cm depositional sequence. In contrast, use-residues were limited on grinding stones recovered from Lake Mungo, an open site where artefacts were exposed on the eroding dunes comprising the Mungo lunette. Based on this evidence, and experiments performed by others (e.g., Langejans 2010), it is clear that residue survival is greatly influenced by environmental settings in which the artefact was recovered. In order to understand the nature of residue degradation under different circumstances, controlled taphonomic experiments are required. These experiments should focus on the effects that certain environmental factors such as wind, water, heat and UV radiation have on residue preservation, and, in particular, which residues (e.g., animal, plant, mineral, fibres, tissues, non-visible molecules) are most likely to survive under such circumstances. Experimental grinding stones containing a variety of residues will be artificially exposed to a number of weathering agencies under controlled settings with the aim to replicate certain environmental conditions that may occur over a number of millennia. This will include placing artefacts under strong UV light and heating lamps for various time periods, and in artificial wind and wave generators where varying amounts of abrasive agents (clay, sand, gravel) can be introduced. Following the experiments, all methods of residue analysis that were employed in this thesis will be applied, to determine whether such methods are appropriate for analysing potentially very old and damaged residues. To supplement these analyses, blind tests will be performed on experimental artefacts used by Richard Fullagar over 30 years ago, to determine what molecules and distinctive residues are still detectable. The applicability of biochemical stains on residues removed from these experimental tools will also be examined. Such analyses have never been performed before, but have the potential to enhance our understanding of the taphonomic processes in play at particular archaeological settings and the applicability of these methods on samples with complicated life histories. All facilities required to conduct such experiments are available at the UOW.

7) *Experiments to determine the extent of weathering and the effect this has on use-polish characterisation.*

All the grinding stones analysed from Lake Mungo have been recovered from the surface of an eroding sand dune and were thus subject to wind and water erosion. Consequently, variation in wear traces may be the result of differential weathering on the artefact surfaces. Fullagar *et al.* (2015) have suggested that 'sandblasting' could result in the obliteration of face-up polished surfaces of these artefacts. In order to explore the effects of natural processes such as water damage, wind, and post-depositional trampling on use-wear markings on artefact surface, controlled experiments are required to document any changes in the appearance of wear traces before and after each process. Similar to the experiments described above to determine the effects of weathering agencies on tool residues, experimental tools (in which wear traces had been previously documented) should be placed in wind and wave generators to artificially replicate the effects of sandblasting and water erosion on artefacts found in exposed settings. Subsequent use-wear analysis should aim to document surface alterations on the artefact surface, such as the removal of use-polish and the addition of striations. Determining the effect certain weathering agencies have on sandstone tools will strengthen use-wear interpretations by allowing non-use related wear to be recognised. Such experimental research will have implications for all tool-use studies around the world.

8) *Assessment of the applicability of use-polish quantification on sandstone tools.*

Although methods of use-wear quantification have proven successful in experimental and archaeological studies of stone tool function, they are usually performed on flaked stone tools (e.g., Barceló *et al.* 2001; Barceló Álvarez *et al.* 2008; Bietti 1996; Evans & Donahue 2008; Evans & Macdonald 2011; González-Urquijo & Ibáñez-Estévez 2003; Stemp & Chung 2011; Stemp & Stemp 2001, 2003; Stemp *et al.* 2009, 2010, 2012) and less commonly on bone (e.g., Anderson *et al.* 2006; d'Errico & Backwell 2009) and grinding stone implements (e.g., Bofill 2012; Procopiou *et al.* 1998) (Section 4.5.1.1). In her investigations, Bofill (2012: 72) found that the LSCM was successful at measuring the roughness characteristics of basalt grinding surfaces as measured both directly from the artefact surface and from removed PVS peels. Similarly, Procopiou *et al.* (1998) found the AFM to be a useful device in evaluating the surface features of experimental grinding stones. The applicability of these methods, however, is yet to be tested on tools made from sandstone material. I will be exploring the applicability of the LSCM and the AFM on experimental sandstone grinding

stones (both directly on the artefact surface as well as on PVS peels), to determine whether such methods are suitable for characterisation of use-wear traces on tools of this material.

9.6 Concluding remarks

In this thesis, I have shown how functional studies on grinding stones shed light on resource use, subsistence and the settlement history of Aboriginal Australia. However, multiple lines of evidence are needed to reliably determine the function of archaeological specimens (whether complete implements or broken fragments). I have argued that several variables are of particular importance: (1) artefact shape and surface morphology; (2) wear (from manufacture, use, weathering and discard); (3) residues (from incidental contact, sediments, use etc.); (4) toughness and composition of the tool stone. Through my investigations, I have found that artefact morphology is not, on its own, a reliable indicator of grinding stone function. In Australia, fragments are often so small that we cannot reconstruct the surface morphology of the original (unbroken) implement. In this thesis, I have shown that even small grinding stone fragments may retain use-wear and residue traces from which function can be reconstructed. I have integrated diverse approaches of functional analysis that included the characterisation of use-wear and residue traces through microscopic examination, and the application of innovative residue characterisation techniques, including biochemical staining, absorbance spectroscopy, biochemical testing and GC-MS analysis. Using a combination of use-wear and residue analyses, functional interpretations for two grinding stone assemblages, MJB and Lake Mungo, were attained, and have indicated a range of on-site activities. At Lake Mungo, seed grinding activities are common and grinding stones appeared to have been heavily utilised; alternatively, grinding stones from MJB appeared to have been used expediently to process a wider range of materials, including plants, pigment, animals and stone. The apparent variability of both tool morphology and tool function can be explained in terms of site context, resource availability and the local environmental conditions (and environmental change) that characterise each site. Whether the site is a rockshelter, cave or open site; distance to water sources and other social factors (such as whether the site is used for ceremonies, burials, etc.) will influence site occupation and thus the frequency of artefacts. The availability of resources for manufacturing artefacts and the distance to suitable stone materials will influence the use-life of an artefact: at sites where suitable stone material is abundant, tools may be used more expediently, whereas sites where stone is less readily available may contain tools that display traces of retouch, recycling and rejuvenation. Local environmental factors will influence the availability of plant food resources as well as the local landscape, affecting distance to water and defining territories. Studies

of grinding stone function complement and provide an independent test of interpretations based on other evidence, including flaked stone, to enhance our understanding of subsistence practices, mobility, resource availability and reactions to foraging risks at different times throughout prehistory. Characterisation of use-wear and residues are key for reconstructing prehistoric tasks, understanding past human behaviour and evaluating models of evolution and cultural transformation.

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Appendix A

Aboriginal uses for Arnhem Land flora

Table A1: List of Arnhem Land plant species with documented Aboriginal uses, including a description of use and whether the plant was ground or pounded.

	Plant name	Common name	Plant use	Ground Y/N	Reference(s)
1	<i>Abrus precatorius</i>	Rosary Pea	seeds used for ornaments	N	Chaloupka & Giuliani 1984
2	<i>Acacia aulacocarpa</i>	Hickory Wattle	wood used for making wooden implements	N	Chaloupka & Giuliani 1984
3	<i>Acacia auriculiformis</i>	Earleaf Acacia	wood used for making wooden implements; bark used for making sting; green pods used as bush soap	N	Chaloupka & Giuliani 1984
4	<i>Acacia difficilis</i>	River Wattle	wood used for making wooden implements; bark used for making string, heated leaves used alleviate pain of the chest, back, ears; consumption of seeds/nuts, edible gum; leaves and green pods used as bush soap; gum used as an adhesive and pigment binder	N	Chaloupka & Giuliani 1984
5	<i>Acacia holosericea</i>	Silver Leaf Wattle	wood used for making wooden implements; bark used to make string; green pods used as bush soap; consumption of edible gum, seeds and nuts	N	Chaloupka & Giuliani 1984
6	<i>Acacia latescens</i>	Ball Wattle	wood used for making wooden implements; consumption of edible gum	N	Chaloupka & Giuliani 1984
7	<i>Acacia latifolia</i>	Golden Wattle	wood used for making implements	N	Chaloupka & Giuliani 1984
8	<i>Acacia leptocarpa</i>	Leptocarpa Wattle	wood used for making implements; bark used for making string; consumption of edible gum	N	Chaloupka & Giuliani 1984
9	<i>Acacia megalantha</i>	-	wood used implements	N	Chaloupka & Giuliani 1984
10	<i>Acacia mimula</i>	-	wood used for making implements; leaved branches used by menstruating women	N	Chaloupka & Giuliani 1984
11	<i>Acacia oncinocarpa</i>	-	wood used for firewood	N	Chaloupka & Giuliani 1984
12	<i>Acacia plectocarpa</i>	Black wattle	wood used for making spear shafts; firesticks	N	Chaloupka & Giuliani 1984
13	<i>Acacia sericata</i>	-	wood used for making spear heads, spear thrower; music sticks	N	Chaloupka & Giuliani 1984
14	<i>Acacia sp. (unnamed)</i>	-	consumption of edible gum; use of bark for making string; inner bark used to soak up honey	N	Chaloupka & Giuliani 1984
15	<i>Acacia torulosa</i>	Tourulosa wattle	consumption of edible gum; wood used for making spear hears, throwing pegs; bark used for making string	N	Chaloupka & Giuliani 1984
16	<i>Aidia cochinchinensis</i>	-	consumption of fruit	N	Chaloupka & Giuliani 1984
17	<i>Allosyncarpia ternata</i>	Anbinik tree	solution treatment of sores and open wounds; wood used for making fighting sticks	N	Chaloupka & Giuliani 1984
18	<i>Alstonia actinophylla</i>	Milkwood	wood used to make paddles	N	Chaloupka & Giuliani 1984

	Plant name	Common name	Plant use	Ground Y/N	Reference(s)
19	<i>Amaranthus viridis</i>	Green Amaranth	consumption of leaves	N	Chaloupka & Giuliani 1984
20	<i>Amorphophallus galbra</i>	Cheeky Yam	consumption of roots	N	Chaloupka & Giuliani 1984
21	<i>Amorphophallus paeoniifolius</i>	Cheeky Yam	consumption of flesh; leaves may be used as a tobacco substitute	Y	Wightman & Andrews 1989; recent unpublished surveys
22	<i>Ampelocissus</i> sp.	Native grape	wood used for smoking pipes; consumption of fruit, roots	N	Chaloupka & Giuliani 1984
23	<i>Aneilema siliculosum</i>	-	consumption of roots	N	Chaloupka & Giuliani 1984
24	<i>Antidesma ghaesembilla</i>	Black current tree	consumption of fruit	N	Chaloupka & Giuliani 1984
25	<i>Antidesma parvifolium</i>	-	consumption of fruit	N	Chaloupka & Giuliani 1984
26	<i>Aponogeton elongatus</i>	-	consumption of cooked roots	Y	Jones & Meehan 1989
27	<i>Aristolochia holtzei</i>	Dutchman's pipe	consumption of roots	N	Chaloupka & Giuliani 1984
28	<i>Atalaya variifolia</i>	-	wood used for making spear thrower	N	Chaloupka & Giuliani 1984
29	<i>Atylosia cinerea</i>	-	leafy branches used	N	Chaloupka & Giuliani 1984
30	<i>Atylosia grandifolia</i>	-	leafy branches used for fire; wood used as firesticks	N	Chaloupka & Giuliani 1984
31	<i>Austodolichos errubundus</i>	-	consumption of roots	N	Chaloupka & Giuliani 1984
32	<i>Bambusa arnhemica</i>	Arnhem land bamboo	wood used for making spear shafts, didgeridoo	N	Chaloupka & Giuliani 1984
33	<i>Banksia dentata</i>	Tropical Banksia	wood used as burning sticks or fire torches; consumption of nectar	N	Chaloupka & Giuliani 1984
34	<i>Barringtonia acutangula</i>	Indian Oak	bark used for string, protective coverings	N	Chaloupka & Giuliani 1984
35	<i>Bombax ceiba</i>	Northern Cottonwood	wood used to make paddles, firewood; consumption of roots	N	Chaloupka & Giuliani 1984
36	<i>Brachychiton diversifolius</i>	Northern Kurrajong	wood used to make paint brushes; bark used to make string, fish nets, bags; consumption of seeds/nuts	Y	Chaloupka & Giuliani 1984
37	<i>Brachychiton paradoxus</i>	Red flowering Kurrajong	wood used to make paint brushes, firesticks; bark used to make string, fishnets, bags; consumption of seeds/nuts	N	Chaloupka & Giuliani 1984
38	<i>Breynia cereua</i>	Gagilamo	consumption of fruit	N	Chaloupka & Giuliani 1984
39	<i>Bridelia ovata</i>	-	consumption of fruit	Y	Chaloupka & Giuliani 1984
40	<i>Buchanania arborescens</i>	Little gooseberry tree	consumption of fruit	N	Chaloupka & Giuliani 1984
41	<i>Buchanania obovata</i>	Wild Mango	heated leaves alleviate pain of the chest, back, ear; consumption of fruit	Y	Chaloupka & Giuliani 1984
42	<i>Callitris intratropica</i>	Cypress pine	wood used for making implements	N	Chaloupka & Giuliani 1984
43	<i>Calophyllum sil</i>	Ladderwood	wood used for making spear heads; spear thrower, fighting sticks and axe	N	Chaloupka & Giuliani 1984

	Plant name	Common name	Plant use	Ground Y/N	Reference(s)
			handles		
44	<i>Calytrix arborescens</i>	-	wood used for making spear heads, spear thrower pegs, firewood	N	Chaloupka & Giuliani 1984
45	<i>Calytrix brachychaeta</i>	-	crushed bark is mixed with water and used as an eye medicine and a solution applied to sprains; wood used as fire wood	Y	Chaloupka & Giuliani 1984
46	<i>Calytrix brownii</i>	-	wood used for spear thrower peg, firewood	N	Chaloupka & Giuliani 1984
47	<i>Calytrix exstipulata</i>	-	wood used for making spear heads, spear thrower pegs, firewood, music sticks, boomerangs	N	Chaloupka & Giuliani 1984;
48	<i>Canarium australianum</i>	Mango Bark	wood used for fighting sticks, paddles; consumption of fruit	N	Chaloupka & Giuliani 1984; Jones & Meehan 1989
49	<i>Canthium lucidum</i>	-	consumption of fruit	N	Chaloupka & Giuliani 1984
50	<i>Carallia brachiata</i>	Freshwater Mangrove	wood used for making spear heads; spear thrower, fighting sticks, axe handles, music sticks; consumption of fruit	N	Chaloupka & Giuliani 1984; unpublished
51	<i>Cartonema parviflorum</i>	-	consumption of roots	N	Chaloupka & Giuliani 1984
52	<i>Cassia leptoclada</i>	-	leafy branches used as fish poison	N	Chaloupka & Giuliani 1984
53	<i>Cassia mimosoides</i>	Five-leaf Cassia	leaves crushed and used as an antiseptic	Y	Chaloupka & Giuliani 1984
54	<i>Cassia venusta</i>	Spectacular Cassis	leaves crushed and used as an antiseptic	Y	Chaloupka & Giuliani 1984
55	<i>Cassytha filiformis</i>	False Dodder	consumption of fruit	N	Chaloupka & Giuliani 1984
56	<i>Cayratia trifolia</i>	Native Grape	consumption of fruit, roots	N	Chaloupka & Giuliani 1984
57	<i>Chrysogon sp.</i>	-	stems used to soak up honey	N	Chaloupka & Giuliani 1984
58	<i>Cissus sp.</i>	-	consumption of fruit	N	Chaloupka & Giuliani 1984
59	<i>Clerodendrum floribundum</i>	Lolly bush	wood used for smoking pipes, firesticks	N	Chaloupka & Giuliani 1984
60	<i>Cochlospermum fraseri</i>	Kapok Tree	bark used for string; wood used for firesticks, paint brushes; woolly fruit interior used as body decoration; consumption of roots, fruit	N	Chaloupka & Giuliani 1984; unpublished
61	<i>Cochlospermum gillivraei</i>	Native Kapok Tree	consumption of roots	N	Chaloupka & Giuliani 1984
62	<i>Cochlospermum gregorii</i>	Cotton Tree	wood used to make paint brushes, , firesticks, bark used for string, consumption of roots, woolly fruit interior used as body decoration	N	Chaloupka & Giuliani 1984
63	<i>Coelospermum reticulatum</i>	Medicine Bush	plants used to make dyes; consumption of fruit	N	Chaloupka & Giuliani 1984
64	<i>Colocasia esculenta</i>	Elephant-ear Taro	consumption of trunk pith or palm	N	Jones & Meehan 1989
65	<i>Cordia subcordata</i>	Sea trumpet	consumption of fruit	N	unpublished
66	<i>Corypha elata</i>	Buri Palm	consumption of trunk pith or palm	N	Jones & Meehan 1989

	Plant name	Common name	Plant use	Ground Y/N	Reference(s)
67	<i>Crotalaria crassipes</i>	Rattlepod	dry stems with seed pods used as rattles	N	Chaloupka & Giuliani 1984
68	<i>Crotalaria linifolia</i>	Rattlepod	dry stems with seed pods used as rattles	N	Chaloupka & Giuliani 1984
69	<i>Croton arnhemicus</i>	-	wood used as firesticks	N	Chaloupka & Giuliani 1984
70	<i>Cucumis melo</i>	Muskmelon	consumption of fruit	N	Chaloupka & Giuliani 1984
71	<i>Curculigo ensifolia</i>	-	consumption of root/bulb	N	McCarthy & McArthur 1960
72	<i>Cycas angulata</i>	Marlborough Blue Sago	consumption	N	Meehan 1989
73	<i>Cycas media</i>	Cycas	consumption of seeds/nuts	Y	Chaloupka & Giuliani 1984; Jones & Meehan 1989
74	<i>Cymbidium canaliculatum</i>	Black Orchid	repellent against leaches; juice of roasted bulbs used as pigment binder	N	Chaloupka & Giuliani 1984
75	<i>Cymbopogon procerus</i>	Scented oil Grass	used to alleviate symptoms of colds, fever, respiratory illness	N	Chaloupka & Giuliani 1984
76	<i>Cynanchum pedunculatum</i>	-	consumption of fruit	N	Chaloupka & Giuliani 1984
77	<i>Cyperus bulbosus</i>	Bush Onion	consumption of seeds/nuts, rhizomes	N	Chaloupka & Giuliani 1984; Jones & Meehan 1989; unpublished
78	<i>Cyperus javanicus</i>	Javanese Flat Sedge	wood used to make paint brushes; bark used to make an open mesh dilly bag	N	Chaloupka & Giuliani 1984
79	<i>Decaisnina brittenii</i>	-	solution for treatment of sores, open wound etc.; wood used as firesticks	N	Chaloupka & Giuliani 1984
80	<i>Dioscorea bulbifera</i>	Round Yam	consumption of tuber	Y	Atchison & Head 2012; Jones & Meehan 1989; Wightman & Andrews 1989; unpublished
81	<i>Dioscorea sativa</i>	Purple Yam	consumption of roots, bulb	N	Chaloupka & Giuliani 1984; McCarthy & McArthur 1960
82	<i>Dioscorea transversa</i>	Long Yam	consumption of tuber, roots	Y	Atchison & Head 2012; Chaloupka & Giuliani 1984; Jones & Meehan 1989; Meehan 1989; Wightman & Andrews 1989; unpublished
83	<i>Diospyros calycantha</i>	-	wood used for making spear thrower	N	Chaloupka & Giuliani 1984
84	<i>Diospyros sp.</i>	-	wood used for making spear thrower, axe handles	N	Chaloupka & Giuliani 1984
85	<i>Dolichandrone filiformis</i>	Soap Tree	wood used for making spear shafts, spear thrower, axe handles,	N	Chaloupka & Giuliani 1984

	Plant name	Common name	Plant use	Ground Y/N	Reference(s)
			firesticks		
86	<i>Drynaria quercifolia</i>	Oak Leaf	consumption of roots	N	Chaloupka & Giuliani 1984
87	<i>Drypetes lasiogyna</i>	-	consumption of fruit	N	Chaloupka & Giuliani 1984
88	<i>Dysoxylum oppositifolium</i>	Pink Mahogany	wood used for making spear thrower, axe handles	N	Chaloupka & Giuliani 1984
89	<i>Ectrosia leporina</i>	-	used as a herb in ground ovens when cooking macropods	N	Chaloupka & Giuliani 1984
90	<i>Eleocharis dulcis</i>	Water Chestnut	stems used to make string; consumption of roots	Y	Chaloupka & Giuliani 1984; Jones & Meehan 1989; Meehan 1989
91	<i>Eriosema chinese</i>	Bush Carrot	consumption of roots	N	Chaloupka & Giuliani 1984
92	<i>Erythrophleum chlorostachys</i>	Cooktown Ironwood	gum used as adhesive; wood used for making wooden implements; consumption of edible gum; solution used externally during severe illness, person also exposed to smoke of its leaves	N	Chaloupka & Giuliani 1984; McCarthy & McArthur 1960
93	<i>Eucalyptus dichormophloia</i>	?	wood used to make game objects, firewood	N	Chaloupka & Giuliani 1984
94	<i>Eucalyptus ferruginea</i>	-	wood used for didgeridoo, firewood	N	Chaloupka & Giuliani 1984
95	<i>Eucalyptus latifolia</i>	-	wood used for didgeridoo, smoking pipes, firewood; consumption of sugary deposits from leaves	N	Chaloupka & Giuliani 1984
96	<i>Eucalyptus miniata</i>	Woollybutt	wood used for goose whacking sticks, smoking pipes, torches; consumption of seeds/nuts	N	Chaloupka & Giuliani 1984
97	<i>Eucalyptus papuana</i>	Ghost Gum	wood used to make game objects, firewood; bark used by young boys when practicing spear throwing	N	Chaloupka & Giuliani 1984
98	<i>Eucalyptus polycarpa</i>	Long Fruit Bloodwood	wood used for making wooden implements	N	Chaloupka & Giuliani 1984
99	<i>Eucalyptus porrecta</i>	Grey Bloodwood	wood used for smoking pipes, firewood; fruits used for fishing bait	N	Chaloupka & Giuliani 1984
100	<i>Eucalyptus ptychocarpa</i>	Swamp Bloodwood	wood used as firewood; leaves played as a musical instrument	N	Chaloupka & Giuliani 1984
101	<i>Eucalyptus sp. (bloodwood)</i>	Common Bloodwood	wood used for didgeridoo, smoking pipes	N	Chaloupka & Giuliani 1984
102	<i>Eucalyptus tectifica</i>	-	outer bark for fire when straightening spears; wood used as firesticks	N	Chaloupka & Giuliani 1984
103	<i>Eucalyptus tetradonta</i>	Darwin stringybark	wood used for making wooden implements; bark and wood used for ground cover, waterproof sheeting, containers, shelters, bark paintings; leaves used as a herb when cooking macropods	N	Chaloupka & Giuliani 1984
104	<i>Exocarpos latifolius</i>	Scrub Sandal-wood	leaves crushed and used as a solution treatment of open wounds	Y	Chaloupka & Giuliani 1984
105	<i>f. Asclepiadaceae</i> <i>Apocynaceae</i>	-	wood used for making spear thrower, firesticks	N	Chaloupka & Giuliani 1984

	Plant name	Common name	Plant use	Ground Y/N	Reference(s)
106	<i>Ficus leucotricha</i>	Fig Tree	consumption of fruit	N	Chaloupka & Giuliani 1984; Jones & Meehan 1989
107	<i>Ficus platypoda</i>	Desert Fig	consumption of fruit	N	Chaloupka & Giuliani 1984; Jones & Meehan 1989
108	<i>Ficus racemosa</i>	Cluster Fig	consumption of fruit	N	Chaloupka & Giuliani 1984; Jones & Meehan 1989
109	<i>Ficus scobina</i>	Sandpaper Fig	wood used as firesticks; leaves used as sandpaper; consumption of fruit	N	Chaloupka & Giuliani 1984; Jones & Meehan 1989
110	<i>Ficus virens</i>	White Fig	plant used to make string bags, fish nets, headbands, chest strings worn by women during their first menstruation; bark strip and string; consumption of fruit	N	Chaloupka & Giuliani 1984; Jones & Meehan 1989
112	<i>Fiscus virens</i>	Banyan tree	bark used to make string	N	Chaloupka & Giuliani 1984; Jones & Meehan 1989
113	<i>Flacourtia territorialis</i>	-	consumption of fruit	N	Chaloupka & Giuliani 1984
114	<i>Flagellaria indica</i>	Supplejack	consumption of fruit; use of stems to make rope, thread, bracelets and armbands, leaves crushed and used for the treatment of influenza, fever, muscular disorders, eye problems, toothache, sore throat and chest pain; bark used for string.	Y	Chaloupka & Giuliani 1984; Wightman & Andrews 1989
115	<i>Ganophyllum falcatum</i>	Scaly Ash	wood used for making spear thrower; fighting sticks, axe handles, wooden paddles	N	Chaloupka & Giuliani 1984
116	<i>Gardenia fucata</i>	-	wood used as firewood; leaves used to flavour emus , macropods and echidnas	N	Chaloupka & Giuliani 1984
117	<i>Gardenia megasperma</i>	Wild Gardenia	plant gum used as binder; consumption of fruit	N	Chaloupka & Giuliani 1984
118	<i>Gardenia sp.</i>	-	wood used for smoking pipes; firesticks	N	Chaloupka & Giuliani 1984
119	<i>Grevillea heliosperma</i>	Rock Grevillea	wood used as firewood; consumption of seeds/nuts	N	Chaloupka & Giuliani 1984
120	<i>Grevillea pteridifolia</i>	Fern-leafed Grevillea	wood used for axe handles, spear thrower; consumption of nectar	N	Chaloupka & Giuliani 1984
121	<i>Grewia latifolia</i>	Turkey Bush	wood used as firesticks; consumption of fruit, leaves used as a tea substitute	N	Chaloupka & Giuliani 1984
122	<i>Grewia multiflora</i>	Bugus	wood used as firesticks; consumption of fruit, leaves used as a tea substitute	N	Chaloupka & Giuliani 1984
123	<i>Grewia retusifolia</i>	Emu Berry	wood used as firesticks; consumption of fruits and leaves as a tea substitute	N	Chaloupka & Giuliani 1984
124	<i>Grewia sp.</i>	-	solution drunk to alleviate symptoms of cold, flu, etc.; consumption of fruits and leaves as a tea substitute	N	Chaloupka & Giuliani 1984

	Plant name	Common name	Plant use	Ground Y/N	Reference(s)
125	<i>Grewia xanthopetala</i>	-	wood used as firesticks; bark used as string; consumption of fruit	N	Chaloupka & Giuliani 1984
126	<i>Gronophyllum ramsayi</i>	Northern Kenitia Palm	old leaf base used to make basket-like water container; consumption of growing tip	N	Chaloupka & Giuliani 1984
127	<i>Gymnanthera lucida</i>	-	seeds, stems and leaves crushed and used as antiseptic	Y	Chaloupka & Giuliani 1984
128	<i>Haemodorum brevicale</i>	-	plant used to make dyes	N	Chaloupka & Giuliani 1984
129	<i>Haemodorum corymbosum</i>	-	plant used to make dyes	N	Chaloupka & Giuliani 1984
130	<i>Hakea arborescens</i>	Yellow Hakea	wood used for making spear heads, digging sticks, fighting sticks, music sticks, axe handles, spear thrower	N	Chaloupka & Giuliani 1984
131	<i>Heteropogon triticeus</i>	Giant Spear Grass	stems used as miniature spears by young boys during mock spear fights; consumption of stems	N	Chaloupka & Giuliani 1984
132	<i>Hibbertia sp. new</i>	-	wood used as firesticks	N	Chaloupka & Giuliani 1984
133	<i>Hyptis suaveolens</i>	Chinese Mint	stems used as miniature spears by young boys during mock spear fights; wood used as firesticks	N	Chaloupka & Giuliani 1984
134	<i>Ipomea abrupta</i>	Bush Potato	consumption of flesh	Y	Chaloupka & Giuliani 1984; Jones & Meehan 1989; Meehan 1989
135	<i>Ipomoea batatas</i>	Sweet Potato Vine	consumption of flesh	Y	Jones & Meehan 1989
136	<i>Ipomoea diversifolia</i>	Morning glory	consumption of flesh	Y	Jones & Meehan 1989
137	<i>Ipomoea gracilis</i>	Sweet Potato	consumption of flesh	Y	Jones & Meehan 1989
138	<i>Ipomoea graminea</i>	Bush Potato	consumption of flesh	Y	Jones & Meehan 1989
139	<i>Ipomoea velutina</i>	-	consumption of flesh	Y	McCarthy & McArthur 1960
140	<i>Ixora tomentosa</i>	-	plant used to make dyes; consumption of fruit	N	Chaloupka & Giuliani 1984
141	<i>Jacksonia dilatata</i>	Jacksonia	bark crushed and used for eye medicine, antiseptic; wood used as firewood; consumption of edible gum	Y	Chaloupka & Giuliani 1984
142	<i>Keraudrenia hookeriana</i>	-	wood used as firesticks	N	Chaloupka & Giuliani 1984
143	<i>Leea rubra</i>	Leea	consumption of fruit	N	Chaloupka & Giuliani 1984
144	<i>Leptocarpus spathacea</i>	-	segments strung to make necklaces and chest ornaments	N	Chaloupka & Giuliani 1984
145	<i>Litsea glutinosa</i>	Soft Bollygum	plants used to make dyes	N	Chaloupka & Giuliani 1984
146	<i>Litsea glutinosa</i>	Bolly Beach	wood used for making spear thrower; plants used to make dyes	N	Chaloupka & Giuliani 1984
147	<i>Livistona humilis</i>	Sand Plum	consumption of growing tip, fruit, trunk pith or palm ; plants used	N	Chaloupka & Giuliani 1984;

	Plant name	Common name	Plant use	Ground Y/N	Reference(s)
			to make dyes		Jones & Meehan 1989
148	<i>Livistona inermis</i>	Wispy Fan Palm	consumption of growing tip	N	Chaloupka & Giuliani 1984
149	<i>Livistona loriphylla</i>	-	wood used as firesticks; consumption of growing tip, fruit	N	Chaloupka & Giuliani 1984
150	<i>Lophopetalum arnhemicum</i>	-	used as firewood	N	Chaloupka & Giuliani 1984
151	<i>Lophostemon lactifluus</i>	Northern Swamp box tree	wood used as burning sticks or fire torches, firewood	N	Chaloupka & Giuliani 1984
152	<i>Lophostemon grandiflora</i>	Brush Box	used as firewood	N	Chaloupka & Giuliani 1984
153	<i>Ludwigia octovalvis</i>	Willow Primrose	stems used as miniature spears by young boys during mock spear fights	N	Chaloupka & Giuliani 1984
154	<i>Ludwigia perennis</i>	Red Leaf	stems used as miniature spears by young boys during mock spear fights	N	Chaloupka & Giuliani 1984
155	<i>Mackinlaya macrosciadea</i>	Blue Umbrella	wood used for smoking pipes	N	Chaloupka & Giuliani 1984
156	<i>Mallotus nesophila</i>	Showy Honey Myrtle	wood used for making spear thrower	N	Chaloupka & Giuliani 1984
157	<i>Maranthes corymbosa</i>	Sea Bean	wood used for making spear thrower, firewood	N	Chaloupka & Giuliani 1984
158	<i>Mecarthuria apetala</i>	-	leaves used to flavour emus , macropods and echidnas	N	Chaloupka & Giuliani 1984
159	<i>Melaleuca argentea</i>	Silver leaved paperback	leaves used to flavour crocodiles, fish and macropods	N	Chaloupka & Giuliani 1984
160	<i>Melaleuca leucadendron</i>	Cajeput Tree	bark and wood used for ground cover, shelters, rafts, water and food containers, as wrappings, fire torch and in assisting fire sticks to ignite, goose whacking sticks, firewood; consumption of nectar	N	Chaloupka & Giuliani 1984
161	<i>Melaleuca magnifica</i>	-	wood used for making spear heads	N	Chaloupka & Giuliani 1984
162	<i>Melaleuca minutifolia</i>	Northern fine-leaved paperback	leaves used to flavour emus and other game; eye medicine	N	Chaloupka & Giuliani 1984
163	<i>Melaleuca punicea</i>	-	wood used for fighting sticks, firewood	N	Chaloupka & Giuliani 1984
164	<i>Melaleuca symphyocarpa</i>	Liniment Tress	wood used for making spear heads, fighting sticks, whacking sticks, music sticks, digging sticks, boomerangs	N	Chaloupka & Giuliani 1984
165	<i>Melaleuca viridifolia</i>	Red Paperbark Tree	bark used to wrap food when cooking and storing; consumption as herbs when cooking game; leaves crushed and soaked and solution drunk as a decongestant	Y	Chaloupka & Giuliani 1984
166	<i>Melastoma polyanthum</i>	Lasiandra	consumption of fruit	N	Chaloupka & Giuliani 1984
167	<i>Microstemma tuberosum</i>	White turnip	consumption of seeds/nuts, roots	N	Chaloupka & Giuliani 1984

	Plant name	Common name	Plant use	Ground Y/N	Reference(s)
168	<i>Mimusops elengi</i>	Red Coondoo	consumption of fruit	N	Meehan 1989
169	<i>Morinda citrifolia</i>	Great Morinda	plants used to make dye, consumption of fruit	Y	Chaloupka & Giuliani 1984; Jones & Meehan 1989; Meehan 1989
170	<i>Murdannia graminea</i>	Grass Lily	consumption of roots	N	Chaloupka & Giuliani 1984
171	<i>Nauclea orientalis</i>	Cheesewood	wood used to make paddles; consumption of fruit	N	Chaloupka & Giuliani 1984
172	<i>Nelumbo nucifera</i>	Pink Water Lily	consumption of rhizomes, seeds, nuts, roots and stems; seeds ground and made into bread	Y	Chaloupka & Giuliani 1984; McArthur 1960
173	<i>Niorinda citrifolia</i>	-	Consumption of fruit	N	McCarthy & McArthur 1960
174	<i>Nymphae gigantea</i>	Blue Water Lily	consumption of rhizomes, root/bulb, seeds and stems	N	McArthur 1960; McCarthy & McArthur 1960
175	<i>Nymphea macrosperma</i>	Water Lily	consumption of seeds/nuts, roots	N	Chaloupka & Giuliani 1984; Jones & Meehan 1989; Meehan 1989
176	<i>Nymphea violacea</i>	Water Pandanus	consumption of roots	N	Chaloupka & Giuliani 1984; Jones & Meehan 1989; Meehan 1989
177	<i>Opilia amentacea</i>	-	plant crushed and used as antiseptic, eye medicine; bark and leaves used; consumption of fruit	Y	Chaloupka & Giuliani 1984
178	<i>Oryza meridionalis</i>	Wild Rice	consumption of seeds	N	Jones & Meehan 1989
179	<i>Oryza perennis</i>	Asian Rice	consumption of seeds/nuts; seeds ground and made into bread	Y	Chaloupka & Giuliani 1984
180	<i>Owenia vernicosa</i>	Candle-stick tree	bark used for string, wood used to make spear thrower, fighting stick	N	Chaloupka & Giuliani 1984
181	<i>Pandanus aquaticus</i>	Water Pandan	wood used to make paint brushes; bark used to make string	N	Chaloupka & Giuliani 1984
182	<i>Pandanus spiralis</i>	Spring Pandanus	consumption of kernels, fruit, seeds, nuts, growing tip, fruit skin; solution applied externally to bruises, sores and swellings; plant used to make dilly bags, baskets, grass mats and mosquito nets	Y	Chaloupka & Giuliani 1984; Jones & Meehan 1989; Meehan 1989; Meehan et al. 1978
183	<i>Passiflora foetida</i>	Pashion Flower	consumption of fruit	N	Chaloupka & Giuliani 1984
184	<i>Persoonia falcata</i>	Milky Plum	wood used to make boomerangs and music sticks; consumption of fruit	Y	Chaloupka & Giuliani 1984; Jones & Meehan 1989
185	<i>Petalostigma pubescens</i>	Quinine Tree	wood used for making spear thrower; firewood	N	Chaloupka & Giuliani 1984
186	<i>Phyllanthus sp.</i>	-	wood used for goose whacking sticks, firesticks	N	Chaloupka & Giuliani 1984

	Plant name	Common name	Plant use	Ground Y/N	Reference(s)
187	<i>Physalis minima</i>	Ground Cherry	consumption of fruit	N	Chaloupka & Giuliani 1984
188	<i>Pityrodia jamessii</i>	Wurrumba	leaves crushed and used to treat colds, headaches, open wounds	Y	Chaloupka & Giuliani 1984
189	<i>Pityrodia sp.</i>	-	colds, headaches, open wounds	N	Chaloupka & Giuliani 1984
190	<i>Planchonella arnhemica</i>	-	wood used for making spear thrower, axe handles, digging sticks, shovel sticks, firesticks, consumption of fruit	N	Chaloupka & Giuliani 1984
191	<i>Planchonia careya</i>	Cocky Apple	bark used as string; plant used to make chest string for women during their first menstruation; consumption of fruit	N	Chaloupka & Giuliani 1984; Jones & Meehan 1989
192	<i>Plympea violacea</i>	-	consumption of seeds/nuts; crafting of wooden implements	N	Chaloupka & Giuliani 1984
193	<i>Potamogeton elongatus</i>	Pond Lily	consumption of roots	N	Chaloupka & Giuliani 1984
194	<i>Pouteria sericea</i>	Wild Prune	wood used for making spear thrower; axe thrower, firewood; consumption of fruit	N	Chaloupka & Giuliani 1984
195	<i>Premna acuminata</i>	-	wood used as firesticks	N	Chaloupka & Giuliani 1984
196	<i>Rauwenhoffia sp. Aff. Leichhardtii</i>	Zig Zag Vine	consumption of fruit	N	Chaloupka & Giuliani 1984
197	<i>Sclerandrium truncatiglume</i>	-	wood used for smoking pipes	N	Chaloupka & Giuliani 1984
198	<i>Securinega melanthesoides</i>	-	wood used as firesticks; consumption of fruit	N	Chaloupka & Giuliani 1984
199	<i>Sesamum indicum</i>	Sesame seeds	wood used as firesticks	N	Chaloupka & Giuliani 1984
200	<i>Smilax australis</i>	Barbed Wire Vine	wood used as firesticks; consumption of fruit	N	Chaloupka & Giuliani 1984
201	<i>Stephania japonica</i>	Snake Vine	consumption of roots	N	Chaloupka & Giuliani 1984
202	<i>Sterculia sp.</i>	-	consumption of fruit	N	Jones & Meehan 1989
203	<i>Sterculia quadrifida</i>		bark strip and string; consumption of seeds/nuts	N	Chaloupka & Giuliani 1984; Jones & Meehan 1989
204	<i>Strychnos lucida</i>	Red-fruited Kurrajong	bark and leaves used; wood used for goose whacking sticks, firewood	N	Chaloupka & Giuliani 1984
205	<i>Syzygium angophoroides</i>	Yarrabah Satinash	consumption of fruit	N	Chaloupka & Giuliani 1984; Jones & Meehan 1989
206	<i>Syzygium armstrongii</i>	Bush Apple	bark used; wood used to make paddles; consumption of fruit	N	Chaloupka & Giuliani 1984; Jones & Meehan 1989
207	<i>Syzygium bleeseri</i>	Black Lillypilly	used as firewood; consumption of fruit	N	Chaloupka & Giuliani 1984
208	<i>Syzygium eucalyptoides</i>	White Apple	consumption of fruit	N	Chaloupka & Giuliani 1984
209	<i>Syzygium operculatum</i>	Obar	consumption of fruit	N	Chaloupka & Giuliani 1984

	Plant name	Common name	Plant use	Ground Y/N	Reference(s)
210	<i>Syzygium rubiginosum</i>	Watergum	wood used to make paddles; consumption of fruit	N	Chaloupka & Giuliani 1984
211	<i>Syzygium suborbiculare</i>	Red Apple	used as firewood; consumption of fruit	N	Chaloupka & Giuliani 1984; McCarthy & McArthur 1960; Meehan 1989
212	<i>Tacca leontopetaloides</i>	Polynesian Arrowroot	consumption of flesh, roots used to treat diarrhoea	N	Chaloupka & Giuliani 1984; Jones & Meehan 1989; Wightman & Andrews 1989
213	<i>Tamarindus indicus</i>	Tamarind	consumption of fruit	N	Meehan 1989
214	<i>Templetonia hookeri</i>	Tropic Templetonia	wood used for spear thrower peg	N	Chaloupka & Giuliani 1984
215	<i>Tephrosia flammea</i>	-	leafy branches used as a fish poison	N	Chaloupka & Giuliani 1984
216	<i>Tephrosia sp.</i>	-	antiseptic, wood and leafy branches used as a fish poison	N	Chaloupka & Giuliani 1984
217	<i>Terminalia carpentariae</i>	Wild Peach	gum used as binder; consumption of fruit, edible gum; wood used for digging sticks, fire sticks	N	Chaloupka & Giuliani 1984; Jones & Meehan 1989
218	<i>Terminalia ferdinandiana</i>	Billygoat Plum	used as firewood; consumption of fruit, edible gum	N	Chaloupka & Giuliani 1984
219	<i>Terminalia grandiflora</i>	Nut tree	wood used for making wooden implements; consumption of seeds/nuts	N	Chaloupka & Giuliani 1984
220	<i>Terminalia pterocarpa</i>	-	wood used for making wooden implements	N	Chaloupka & Giuliani 1984
221	<i>Trema aspera</i>	Poison Peach	wood used for making spear thrower, firesticks	N	Chaloupka & Giuliani 1984
222	<i>Triglochin procera</i>	Water Ribbons	consumption of root/bulb, rhizomes	N	Chaloupka & Giuliani 1984; Jones & Meehan 1989; McCarthy & McArthur 1960
223	<i>Triodia microstachya</i>	-	leaves crushed and soaked with solution applied to bruises, antiseptic	Y	Chaloupka & Giuliani 1984
224	<i>Tinospora smilacina</i>	Snake Vine	stems pounded between stones and used as ligature; roots crushed and used as a solution for skin irritations, inflammation, etc.	Y	Chaloupka & Giuliani 1984
225	<i>Typhonium angustilobum</i>	Fire Lily	consumption of roots	Y	Chaloupka & Giuliani 1984
226	<i>unidentified graminoid</i>	-	leaves/stalks used as a herb when cooking macropods, bandicoots and possums	N	Chaloupka & Giuliani 1984
227	<i>Unona wardiana</i>	-	consumption of fruit	N	Chaloupka & Giuliani 1984
228	<i>Uvaria goezeana</i>	-	consumption of fruit	N	Chaloupka & Giuliani 1984
229	<i>Uvaria membranacea</i>	Pale Green Triangle	consumption of fruit	N	Chaloupka & Giuliani 1984
230	<i>Verticordia decussata</i>	Tottum Poles	wood used for spear thrower peg	N	Chaloupka & Giuliani 1984

	Plant name	Common name	Plant use	Ground Y/N	Reference(s)
231	<i>Verticordia verticillata</i>	Tropical Featherflower	wood used for spear thrower peg	N	Chaloupka & Giuliani 1984
232	<i>Vigna vexillata</i>	Wild Cow Pea	consumption of root/bulb, pith and palm	N	Chaloupka & Giuliani 1984; Jones & Meehan 1989; McCarthy & McArthur 1960
233	<i>Vitex acuminata</i>	Vitex	used as firewood, firesticks, consumption of fruit	N	Chaloupka & Giuliani 1984; Jones & Meehan 1989
234	<i>Vitex glabrata</i>	Smooth Chastetree	wood used as firesticks; consumption of fruit	N	Chaloupka & Giuliani 1984; Jones & Meehan 1990
235	<i>Vitex sp. new</i>	-	used as firewood, firesticks, digging sticks	N	Chaloupka & Giuliani 1984; Jones & Meehan 1991
236	<i>Xanthostemon paradoxus</i>	Very Ripe Fruit	wood used for digging sticks	N	Chaloupka & Giuliani 1984
237	<i>Xanthostemon psidioides</i>	River Penda	wood used for fighting sticks, digging sticks, whacking sticks, decongestant	N	Chaloupka & Giuliani 1984
238	<i>Xanthostemon sp. undescribed</i>	-	wood used for axe handles	N	Chaloupka & Giuliani 1984

References Appendix A

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Appendix B

Experimental grinding stones: raw materials, sampling descriptions and use-wear/residue analysis

Table B1 i–v: Results of XRD analysis: percentage of minerals by weight for each of the five sandstones and relative ranking (as determined by the largest percentage of quartz).

i.

Sandstone:	Jemalong Ridge sandstone		
Collection location:	Jemalong Ridge, NSW		
Hardness rank:	1/5		
Weight of sample:	2.48 g		
<i>mineral no</i>	<i>ID</i>	<i>mineral</i>	<i>weight%</i>
1	1	Quartz	95.7
2	10	Calcite 1	0
3	8240	Kaolin, BISH12	0.9
4	116	Illite 1	3.4
5	8236	Mixed layer illite (MLI)	0

ii.

Sandstone:	Kakadu sandstone/quartzite		
Collection location:	Kadadu National Park, NT		
Hardness rank:	2/5		
Weight of sample:	4.62 g		
<i>mineral no</i>	<i>ID</i>	<i>mineral</i>	<i>weight%</i>
1	1	Quartz	96.9
2	10	Calcite 1	0
3	8240	Kaolin, BISH12	0.2
4	116	Illite 1	2.9
5	8236	MLI	0

iii.

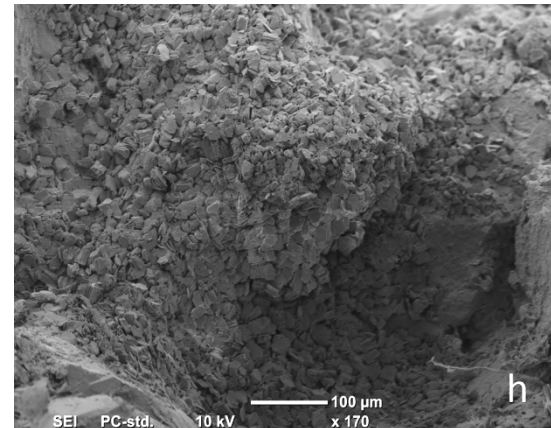
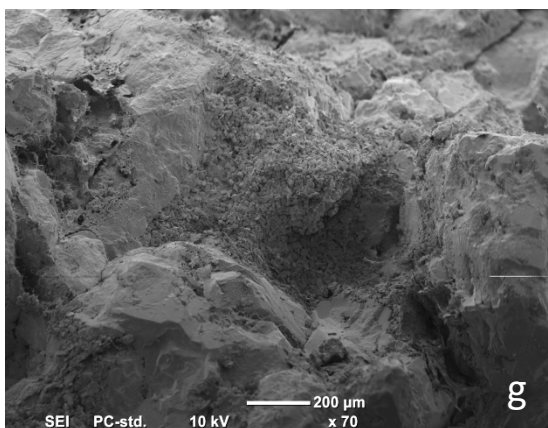
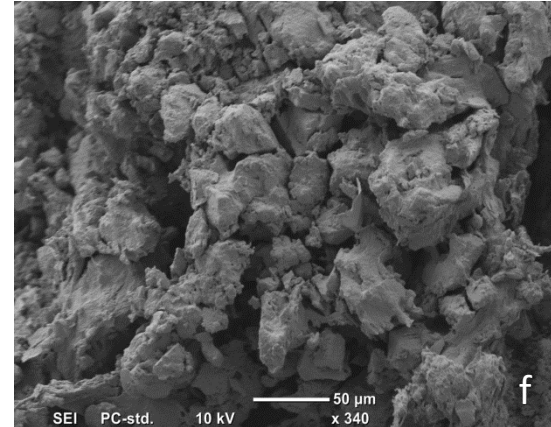
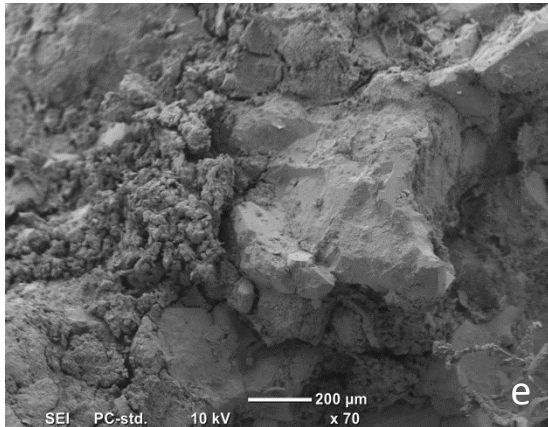
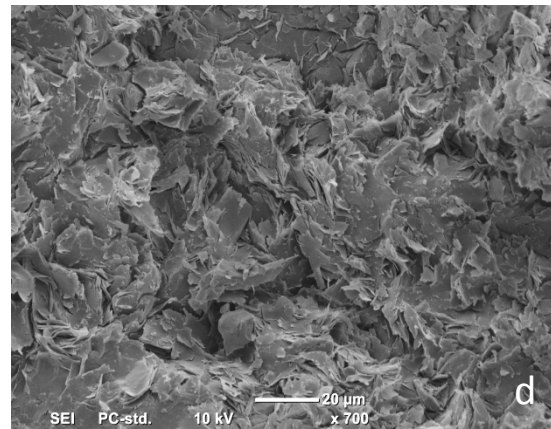
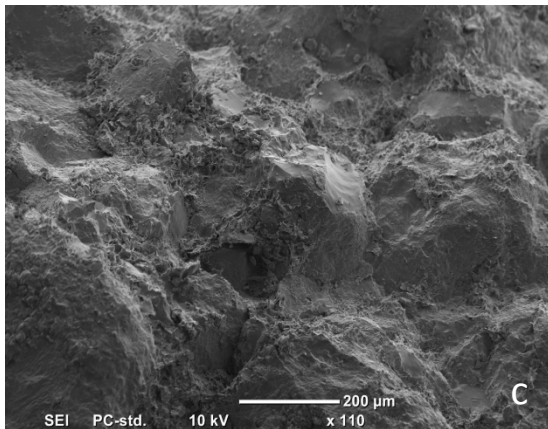
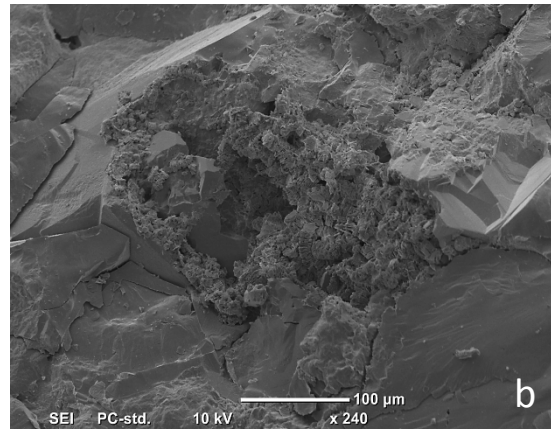
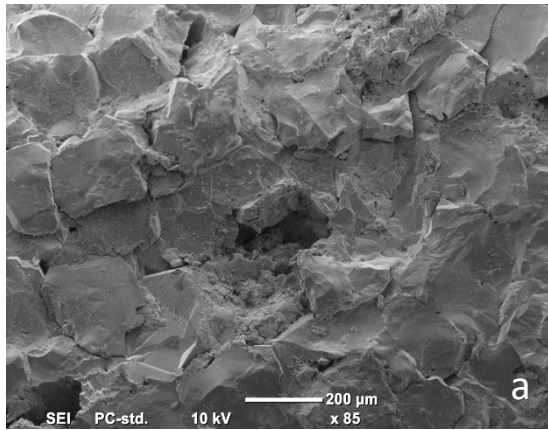
Sandstone:	Hawkesbury sandstone		
Collection location:	Austinmer, NSW		
Hardness rank:	3/5		
Weight of sample:	3.9 g		
<i>mineral no</i>	<i>ID</i>	<i>mineral</i>	<i>weight%</i>
1	1	Quartz	95.4
2	10	Calcite 1	0
3	8240	Kaolin, BISH12	2.6
4	116	Illite 1	1.8
5	8236	MLI	0.2

iv.

Sandstone:	Kimberley sandstone		
Collection location:	Kimberley, WA		
Hardness rank:	4/5		
Weight of sample:	3.4 g		
<i>mineral no</i>	<i>ID</i>	<i>mineral</i>	<i>weight%</i>
1	1	Quartz	90.4
2	10	Calcite 1	0.1
3	8240	Kaolin, BISH12	5.3
4	116	Illite 1	3.9
5	8236	MLI	0.3

v.

Sandstone:	Hawkesbury sandstone		
Collection location:	Bundanoon, NSW		
Hardness rank:	5/5		
Weight of sample:	4.07 g		
<i>mineral no</i>	<i>ID</i>	<i>mineral</i>	<i>weight%</i>
1	1	Quartz	77.7
2	10	Calcite 1	0
3	8240	Kaolin, BISH12	19.7
4	116	Illite 1	2.4
5	8236	MLI	0.2



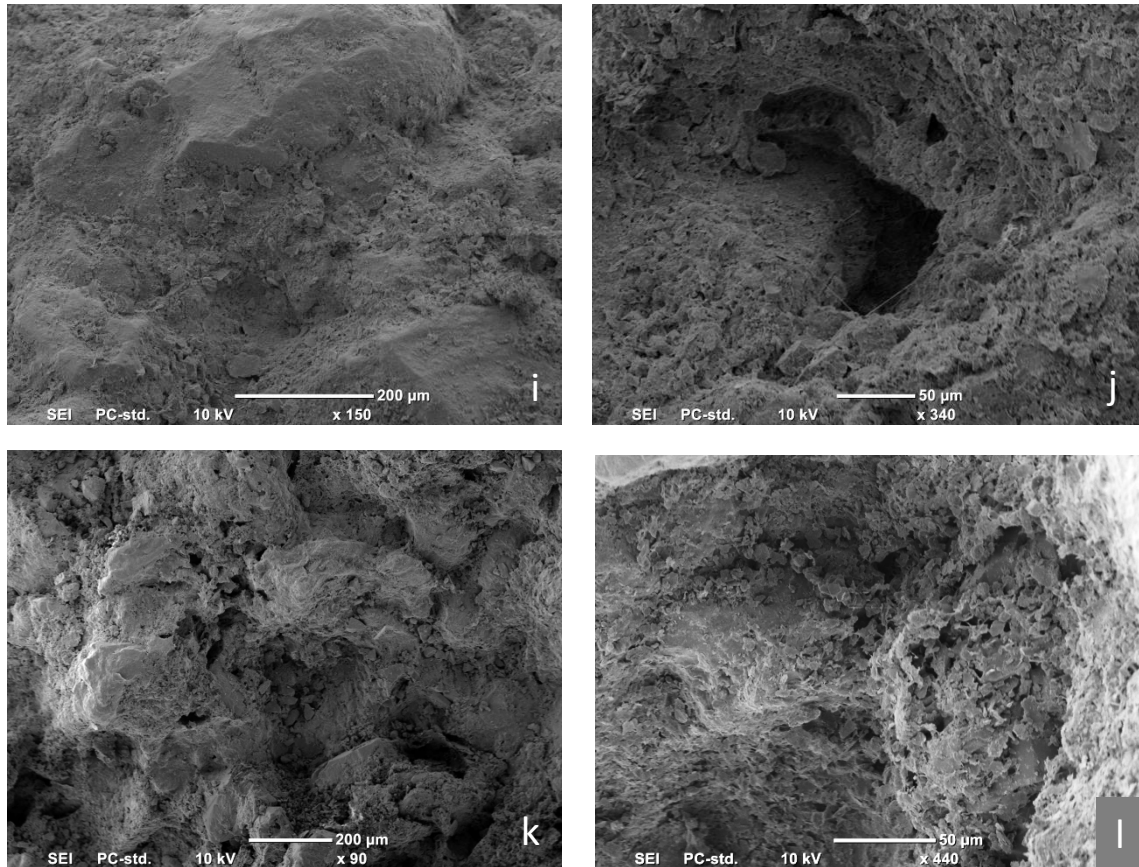


Plate B1a-l: SEM images of unground sandstone surfaces used in the experimental workshop: **a-b)** Jemalong Ridge sandstone, New South Wales: well cemented fine grain quartz with illitic clays (poorly crystalline); **c-d)** Kakadu sandstone/quartzite, Northern Territory: fine-grained quartz grains, illitic clays; **e-h)** Hawkesbury sandstone from the Austinmer region, New South Wales: illitic and kaolinite bundles, poorly sorted quartz; **i)** sandstone from the Kimberley region, Western Australia: poorly crystalline clays, possibly some kaolinite; coarse grained and poorly sorted quartz; **k-l)** Hawkesbury sandstone from Bundanoon, New South Wales: poorly crystalline clays, mostly kaolinites, poorly-sorted quartz.

Exp. grinding stone no	Worked-material	No. of PVS peels sampled	PVS peel intervals (mins)
EGS 1	wheat	3	0,30,75
EGS 2	wood	1	120
EGS 3	bone	1	120
EGS 4	wood	1	120
EGS 5	bone	1	120
EGS 11	coffee	2	0, 20
EGS 12	Warrego grass seeds	5	0, 65, 125, 180, 240
EGS 13 (side 1)	stone (basalt)	3	0, 60, 60
EGS 13 (side 2)	stone (dolerite)	2	80, 80
EGS 15	wheat	3	0,30,75
EGS 16	Kangaroo grass seeds	2	0, 90
EGS 17	Acacia seeds	3	0,45,120
EGS 18	stone (basalt)	2	0,60
EGS 19	Kurrajong seeds	2	0,60
EGS 20	bone	2	0,30
EGS 23	Acacia seeds	2	0,120
EGS 24	Kurrajong seeds	2	0,60
EGS 25	Acacia seeds	3	0,45,120
EGS 28	Warrego grass seeds	5	0, 65, 125, 180, 240
EGS 29	Kangaroo grass seeds	2	0,90
EGS 31	Warrego grass seeds	5	0,20,40,125,150
EGS 32	Acacia seeds	2	0,120
EGS 33	Warrego grass seeds	2	0,85
EGS 34	bone	1	30
EGS 35	haematite	1	10
EGS 36	haematite	0	not sampled
EGS 37	coffee	1	20
EGS 38	stone (sandstone)	0	not sampled
EGS 39	Stone (sandstone)	0	not sampled

Table B3: Use-wear traces as observed on experimental artefacts.

Experimental GS number	Tool Type	Raw material type	processed material	method of processing	Low magnification			High magnification					
					Degree of surface levelling	Degree of grain edge rounding	macro striae	polish morphology	polish brightness	polish coverage	Polish development	fine striae	grain fractures
EGS 1	US	quartzite	wheat	grinding	high	high	Y	reticular	dull	localised	weak	Y	Y
EGS 2	F	quartzite	wood	grinding	mod	high	Y	domed-pitted/reticular	dull	moderate	weak/developed	Y	Y
EGS 3	F	s/stone	bone	grinding	minimal	slight-md	Y	un-diagnostic	dull	localised	weak	Y	N
EGS 4	F	s/stone	wood	grinding	mod	mod	Y	domed/reticular	dull	localised	weak	Y	N
EGS 5	F	quartzite	bone	grinding	minimal	mod-high	Y	smooth-pitted; striated	bright	extensive	developed	Y	Y
EGS 12	LS	s/stone	Warrego grass seed	grinding	high	mod	Y	reticular	bight	extensive	developed	Y	Y
EGS 13 (S1)	F	s/stone	stone (basalt)	grinding	high	absent	N	n/a	n/a	n/a	absent	Y	Y
EGS 13 (S2)	F	s/stone	stone (dolerite)	grinding	high	absent	N	n/a	n/a	n/a	absent	Y	Y
EGS 15	LS	s/stone	Wheat	grinding	high	high	Y	reticular	mod	moderate	moderate	Y	Y
EGS 16	LS	s/stone	Kangaroo grass seed	grinding	min-mod	md-high	Y	reticular	mod	moderate	moderate	Y	Y
EGS 17	LS	s/stone	Acacia seed	grinding (wet)/pounding	minimal	mod	N	reticular	dull	moderate	weak	Y	Y
EGS 18	F	s/stone	stone (basalt)	grinding	high	mod	Y	reticular	bright	extensive	developed	Y	Y
EGS 19	LS	s/stone	Kurrajong seed	pounding	min-md	high	N	un-diagnostic	dull	localised	weak	Y	Y
EGS 20	LS	s/stone	bone	pounding	md	slight-md	Y	Rough-pitted	dull	localised	weak	Y	Y

EGS 23	US	s/stone	Acacia seed	pounding/ milling	md	mod	Y	reticular	mod	moderate	moderate	Y	N
EGS 24	US	s/stone	Kurrajong seed	pounding	slight	absent	N	un-diagnostic	dull	localised	weak	N	Y
EGS 25	US	s/stone	Acacia seed	pounding/ milling	mod	high	Y	reticular	mod	moderate	moderate	Y	Y
EGS 28	US	s/stone	Warrego grass seed	grinding	high	mod	Y	reticular	bright	extensive	well- developed	Y	Y
EGS 29	US	s/stone	Kangaroo grass seed	grinding	high	high	Y	reticular	mod	localised	weak	Y	Y
EGS 31	LS	s/stone	Warrego grass seed	grinding	high	mod	Y	reticular	mod	localised	weak	Y	Y
EGS 32	LS	s/stone	Acacia seed	pounding	minimal	slight-md	N	un-diagnostic	dull	moderate	mod /developed	N	Y
EGS 33	US	s/stone	Warrego grass seed	grinding	absent	slight-md	Y	un-diagnostic	mod	localised	weak	Y	Y
EGS 34	US	quartzite	bone	pounding	high	high	Y	rough	bright	moderate	moderate	Y	Y
EGS 35	F	s/stone	haematite	grinding	high	high	N	un-diagnostic	dull/mod	localised	weak/mod	Y	Y
EGS 36	F	s/stone	haematite	grinding	high	mod	N	undulating	mod	moderate	moderate	Y	Y
EGS 38	US	s/stone	stone (s/stone)	grinding	high	mod	Y	striated	dull/mod	extensive	developed	Y	Y
EGS 39	US	s/stone	stone (s/stone)	grinding	high	mod	Y	striated	dull/mod	extensive	developed	Y	Y

*Tool type: US = *upper stone*; LS = *lower stone*; F = *filing stone*

Table B4: Use-wear traces observed on ethnographic artefacts.

Ethnographic GS number	Tool Type	Raw material type	processed material	<i>Low magnification</i>			<i>High magnification</i>					
				Degree of surface levelling	Degree of grain edge rounding	macro striae	polish morphology	polish brightness	polish coverage	polish development	fine striae	grain fractures
21733	US	indurated sandstone	seeds	high	high	Y	reticular	bright	extensive	well-developed	Y	Y
21736	US	indurated sandstone	seeds	high	high	Y	reticular	bright	extensive	well-developed	Y	Y
21737	US	quartz	seeds	high	high	Y	domed, reticular	moderate – bright	moderate	developed	Y	Y
21738	US	indurated sandstone	seeds	high	high	Y	reticular	bright	extensive	well-developed	Y	Y
21739	US	indurated sandstone	seeds	high	high	Y	reticular	bright	extensive	well-developed	Y	Y
62365	US	indurated sandstone	seeds	high	high	Y	reticular	moderate – bright	extensive	moderate – developed	Y	Y
62378	HS	sandstone	seeds	high	high	Y	reticular	bright	extensive	well-developed	N	Y
62382	US	indurated sandstone	seeds	high	high	Y	reticular	very bright	very extensive	well-developed	Y	Y
62384	US	sandstone	seeds	high	high	Y	reticular	bright	extensive	well-developed	Y	Y
62420	US	indurated sandstone	seeds	high	high	Y	reticular	moderate – bright	extensive	moderate – developed	Y	Y
62421	US	sandstone	seeds	high	high	Y	reticular	bright	extensive	developed	Y	Y
62422	US	sandstone	seeds	high	high	Y	reticular	bright	extensive	developed	Y	Y

Table B5: Observation of surface features as identified on experimental grinding stones comprising the blind tests.

ULg GS no.	Low magnification			High magnification							Interpretation: Worked-material
	Degree of surface levelling	Degree of grain edge rounding	macro striae	polish morphology	polish brightness	polish coverage	Polish development	fine striae	grain fractures	residues (as observed directly from artefact surface)	
1	high	moderate	Y	un-diagnostic	moderate	localised	weak	Y	Y	no organics	stone
2	minimal	minimal	Y	un-diagnostic	dull	localised	weak	N	Y	organic fibres	unknown
3	min - mod	high	N	striated	bright	moderate	developed	Y	Y	white organic material	bone or shell
4	moderate	high	Y	domed/ striated	bright	extensive	mod - developed	Y	N	amorphous white material	bone
5	moderate	high	Y	un-diagnostic	dull	localised	weak	N	Y	-	unknown
6	min - mod	mod - high	Y	undulating	moderate	localised - mod	weak	Y	Y	sediment, plant fibres	unknown
6'	min - mod	high	Y	undulating	moderate	localised - mod	weak	N	Y	sediment	unknown
7	mod - high	mod - high	N	reticular	moderate	moderate	weak - mod	Y	Y	plant material, kernel	plant
7'	mod - high	high	N	reticular	bright	mod - extensive	developed	Y	Y	plant material	plant
8	high	high	Y	reticular	bright	moderate	developed	Y	Y	cellulose fibres	plant
8'	high	high	y	reticular/ flat	bright	extensive	well- developed	Y	N	starch	plant
9	moderate	moderate	N	undulating	bright	mod - extensive	moderate	N	N	red mineral pigment	pigment
9'	minimal	mod - high	N	un-diagnostic	dull - mod	localised	weak	N	Y	red mineral pigment	pigment
10	moderate	moderate	Y	un-diagnostic	dull	localised	weak	N	Y	starch	unknown
10'	high	moderate	Y	domed	bright	localised - mod	moderate	Y	N	-	unknown

Table B6: Material(s) identified on the ground surface of experimental artefacts following water removal and residue examination under transmitted light.

GS number	Mineral residues	Plant residues	Animal residues	Stain applied	+/-	Interpretation: worked-material
1	quartz crystals	cellulose	-	-		stone (axe grinding)
2	quartz crystals	cellulose	-	-		unused
3	-	-	possible bone, possible shell	Orange G	-	bone
4	-	cellulose	possible bone/collagen	Orange G	+	bone
5	-	starch – n=>1000, size: 20-30µm, shape: elongated/ rounded cellulose	-	-		plant
6	quartz crystals	cellulose, amorphous plant tissue	possible collagen	Orange G	+	animal
6'	quartz crystals	cellulose	possible collagen	Orange G	-	unknown
7	-	starch – n= >20, size: 5-15µm, shape: irregular + round cellulose, amorphous plant tissue	-	-		starchy plant
7'	-	starch – n= 1, size: 5µm, shape: round cellulose	-	-		starchy plant
8	quartz crystals	starch – n= >100, size: 10-20µm, shape: rounded cellulose, amorphous plant tissue, phytoliths, plant cells	-	-		starchy plant
8'	-	starch – n=>100, size: 10-20µm, shape: rounded cellulose	-	-		starchy plant
9	red mineral	cellulose	-	-		pigment
9'	red mineral	cellulose	-	-		pigment
10	-	starch – n=>100, size: 12-30µm, shape: rounded cellulose, plant cells	-	-		starchy plant
10'	-	starch – n=50-100, size: 10-30µm, shape: rounded cellulose, amorphous plant tissue	-	-		starchy plant

Appendix C

Results of functional analyses performed on archaeological tools

Table C1: Details of each grinding stones analysed from MJB and Lake Mungo, including specific location of retrieval from site, raw material type, number of grinding surfaces and size and mass recordings.

Site name	GS number	Spit/ square number	Raw material type	No. of grinding surfaces	Size measurements			
					Mass (g)	Length (mm)	Width (mm)	depth (mm)
MJB	GS 1	D2/5	sandstone	1	700	154	83	27
MJB	GS 2	C3/8	sandstone	2	143	64	51	26
MJB	GS 3	E1/21	sandstone	2	408	123	87	28
MJB	GS 4	E1/21	sandstone	1	323	60	81	40
MJB	GS 5	D2/21	sandstone	1	100	92	66	8
MJB	GS 6	C2/21	sandstone	1	480	98	61	54
MJB	GS 7	C2/22A	quartzite	1	84	55	40	28
MJB	GS 8	D2/8	sandstone	2	530	123	55	42
MJB	GS 9	D2/24	sandstone	1	23	33	27	11
MJB	GS 10	D2/24	sandstone	2	69	48	34	24
MJB	GS 13	D2/25A	sandstone	2	168	79	53	35
MJB	GS 14	D2/26	sandstone	3	64	41	47	18
MJB	GS 15	D2/26	sandstone	1	91	56	60	16
MJB	GS 16	D2/26	sandstone	2	150	51	51	39
MJB	GS 17	D2/26	sandstone	0	194	69	64	43
MJB	GS 18	D3/26	quartzite	2	286	70	56	39
MJB	GS 19	C2/26A	sandstone	1	51	30	30	23
MJB	GS 20	E1/27	sandstone	1	34	59	43	5
MJB	GS 21	E2/28A	sandstone	1	684	112	78	45
MJB	GS 22	D2/28A	sandstone	1	86	42	58	25
MJB	GS 23	D2/28A	sandstone	2	392	87	62	50
MJB	GS 24	E2/28A	sandstone	2	497	109	68	68
MJB	GS 26	C2/28A	sandstone	1	174	60	56	36
MJB	GS 27	C1/28	sandstone	1	208	54	49	52
MJB	GS 28	C1/28	mudstone	1	171	47	58	34
MJB	GS 29	D1/34	sandstone	1	703	106	96	40
MJB	GS 30	D1/34	sandstone	1	137	69	44	22
MJB	GS 31	D1/34	sandstone	1	69	425	29	35
MJB	GS 32	C2-C3/37	sandstone	2	1090	241	230	131
MJB	GS 33	D2/34	sandstone	1	116	62	39	34
MJB	GS 35	D1/34	sandstone	2	113	85	52	16
MJB	GS 36	C1/35	sandstone	2	79	76	60	11
MJB	GS 37	C1/35	sandstone	1	37	46	32	26
MJB	GS 38	C2/37A	sandstone	2	7900	263	171	91
MJB	GS 39	D1/37	sandstone	1	2635	189	135	73

Site name	GS number	Spi/ square number	Raw material type	No. of grinding surfaces	Size measurements			
					Mass (g)	Length (mm)	Width (mm)	depth (mm)
MJB	GS 40	D2/37	sandstone	1	805	122	118	46
MJB	GS 41	D2/38	sandstone	1	237	*	*	*
MJB	GS 42	D2/38	sandstone	0	277	71	49	62
MJB	GS 43	D1/38	sandstone	1	69	66	54	12
MJB	GS 44	D2/39A	sandstone	1	34	58	37	7
MJB	GS 45	D2/39A	sandstone	1	31	35	42	19
MJB	GS 46	D2/39	sandstone	2				
MJB	GS 47	D2/39	sandstone	1	3	31	1.7	4
MJB	GS 48	D2/40A	sandstone	1	330	92	6.5	38
MJB	GS 49	C4/29	sandstone	1	91	65	68	19
MJB	GS 50	C4/45	sandstone	1	118	8.7	57	19
MJB	UP GS 1	No data	sandstone	3	94	46	40	37
MJB	UP GS 2	C2/5	sandstone	1	3	31	17	3
MJB	UP GS 3	D2/10	sandstone	1	43	62	25	22
MJB	UP GS 4	D2/16A	sandstone	1	248	92	73	21
MJB	UP GS 5	B2/21	sandstone	1	36	33	28	23
MJB	UP GS 6	E2/23	sandstone	1	11	39	29	10
MJB	UP GS 7	C2/24A	sandstone	1	14	29	18	19
MJB	UP GS 8	D2/25A	quartzite	0	18	38	38	10
MJB	UP GS 9	D2/25	sandstone	1	7	28	26	7
MJB	UP GS 10	D2/25A	quartzite?	1	11	43	22	4
MJB	UP GS 11	D2/25	sandstone?	1	25	54	50	8
MJB	UP GS 12	D2/26A	sandstone	1	283	84	56	39
MJB	UP GS 13	E1/26	sandstone	0	103	59	70	55
MJB	UP GS 14	E1/26	quartzite	1	15	49	37	05
MJB	UP GS 15	C2/26	sandstone	1	98	55	43	33
MJB	UP GS 16	D2/26	sandstone	3	248	83	71	55
MJB	UP GS 17	C2/26	sandstone	2	46	47	29	25
MJB	UP GS 18	C2/26	sandstone	1	410	76	64	45
MJB	UP GS 19	C2/26	sandstone	1	192	58	39	52
MJB	UP GS 20	C2/26	sandstone	0	97	48	35	400
MJB	UP GS 21	C2/26	sandstone	4	219	68	57	380
MJB	UP GS 22	C2/26	sandstone	2	164	56	60	36
MJB	UP GS 23	D2/28A	sandstone	1	76	62	50	19
MJB	UP GS 24	E3/28	sandstone	1	235	70	43	39
MJB	UP GS 25	C1/29	quartzite	1	25	37	23	21
MJB	UP GS 26	C3/35	Sandstone	1	152	6.2	28	58
MJB	UP GS 27	C1/36	sandstone	1	14	31	24	10
MJB	UP GS 28	C2/29A	sandstone	1	198	78	40	50

Site name	GS number	Spit/ square number	Raw material type	No. of grinding surfaces	Size measurements			
					Mass (g)	Length (mm)	Width (mm)	depth (mm)
MJB	UP GS 29	C2/29A	sandstone	1	353	92	67	41
MJB	UP GS 30	C3/36	sandstone	1	301	74	73	32
MJB	UP GS 31	C2/37A	sandstone	1	279	118	55	36
MJB	UP GS 32	C2/37A	sandstone	1	244	62	54	36
MJB	UP GS 33	C2/39A	sandstone	1	488	109	84	31
MJB	UP GS 34	C2/39A	sandstone	1	231	74	73	20
MJB	UP GS 35	C3/42	sandstone	1	303	101	54	46
MJB	UP GS 36	C3/44	quartzite	1	82	74	46	20
MJB	UP GS 37	E2/28A	volcanic	1	148	69	56	26
MJB	UP GS 38	No data	sandstone	1	3400	253	129	58
MJB	UP GS 39	C2/3	mudstone	5	217	98	50	25
MJB	L49	C2/5	sandstone	1	539	154	113	18
MJB	L52	C3/5	sandstone	2	1051	117	99	49
MJB	L813	D2/23	sandstone	1	383	102	82	26
MJB	L868	E1/24	sandstone	1	13	33	30	11
MJB	L894	C2/25	sandstone	1	14	41	28	06
MJB	L1349	D1/32	sandstone	1	280	70	52	40
MJB	R2	C4/4	quartzite	1	79	92	29	19
MJB	R5	E1/21	sandstone	3	900	115	77	62
MJB	R66	E1/17	sandstone	3	8400	280	198	124
MJB	R68	E1/18	sandstone	2	642	151	88	29
MJB	R69	C2/18	sandstone	1	2792	144	108	85
Mungo	LM GS 1	Unit E	sandstone	2	183	101	88	21
Mungo	LM GS 2	Unit E	sandstone	1	27	26	18	4
Mungo	LM GS 3	Unit E	sandstone	2	65	86	85	10
Mungo	LM GS 4	Unit E	sandstone	1	11	40	32	7
Mungo	LM GS 5	Unit E	sandstone	1	23	56	43	6
Mungo	LM GS 6	Unit E	sandstone	1	15	34	30	6
Mungo	LM GS 7	Unit E	sandstone	1	9	40	26	5
Mungo	LM GS 8	Unit E	sandstone	1	8	37	32	5
Mungo	LM GS 9	Unit E	sandstone	1	7	32	29	7
Mungo	LM GS 10	Unit F	sandstone	2	57	60	40	16
Mungo	LM GS 11	Unit E	sandstone	3	24	39	35	12
Mungo	LM GS 12	Golgol lag	sandstone	2	67	64	46	22
Mungo	LM GS 13	Golgol lag	sandstone	1	22	42	37	14
Mungo	LM GS 14	Unit F	sandstone	2	9	47	16	13
Mungo	LM GS 15	Unit F	sandstone	2	4	24	16	9
Mungo	LM GS 16	Unit F	sandstone	2	18	75	27	8
Mungo	LM GS 17	Golgol lag	sandstone	1	40	66	46	21

Table C2: Table of grinding stone characteristics for MJB and Lake Mungo specimens, including raw material, grinding stone type, completeness, number of grinding surfaces and corresponding surface morphology, likelihood of use, and presence of features such as iron oxide staining (as determined by the presence of a natural red staining of the constituent grains, acquired either before or after use) and pecking. Asterisks within iron oxide stain column indicate iron oxide accretion present on artefact surface.

Site name	GS number	Raw material type	Grinding stone type	Completeness	Grinding surface no.	Use (0-3)	Shape of ground surface	Iron oxide staining	Pecking
MJB	GS 1	sandstone	lower stone	fragment	1	3	F	N	N
MJB	GS 2	sandstone	upper stone	fragment	1	3	CV	N	N
					2	3	CV	N	N
MJB	GS 3	sandstone	filing stone	complete	1	3	F	N	N
					2	3	F	N	N
MJB	GS 4	sandstone	filing stone	fragment	1	3	CV	N	N
MJB	GS 5	sandstone	uncertain	fragment	1	2	F	Y	N
MJB	GS 6	sandstone	uncertain	fragment	1	1	CV	Y*	N
MJB	GS 7	quartzite	upper stone/ hammerstone	fragment	1	2	CV	N	N
MJB	GS 8	sandstone	upper stone	complete	1	3	CC	Y	N
					2	3	CV	Y	N
MJB	GS 9	sandstone	uncertain	fragment	1	3	CV	Y	N
MJB	GS 10	sandstone	filing stone	fragment	1	2	CC	Y	N
					2	3	F	Y	N
MJB	GS 13	sandstone	uncertain	fragment	1	1	F	N	N
					2	1	F	N	N
MJB	GS 14	sandstone	filing stone	fragment	1	3	F	Y	N
					2	3	F	Y	N
					3	3	F	Y	N
MJB	GS 15	sandstone	filing stone	fragment	1	3	F	N	N
MJB	GS 16	sandstone	upper stone	fragment	1	3	F	N	N
					2	3	CV	N	N
MJB	GS 17	sandstone	uncertain	fragment	0	0	n/a	Y	N

Site name	GS number	Raw material type	Grinding stone type	Completeness	Grinding surface no.	Use (0-3)	Shape of ground surface	Iron oxide staining	Pecking
MJB	GS 18	quartzite	upper stone/ hammerstone	complete	1	3	CV	Y	N
					2	3	CV	Y	N
MJB	GS 19	sandstone	filing stone	fragment	1	3	CV	N	N
MJB	GS 20	sandstone	filing stone	fragment	1	3	CC-F	Y	N
MJB	GS 21	sandstone	filing stone	fragment	1	3	F	N	N
MJB	GS 22	sandstone	upper stone	fragment	1	3	CV	N	N
MJB	GS 23	sandstone	filing stone	fragment	1	3	F	N	N
					2	3	CV	N	N
MJB	GS 24	sandstone	upper /filing stone	fragment	1	3	F	Y	N
					2	3	CV	Y	N
MJB	GS 26	sandstone	upper stone	fragment	1	3	CV	Y	N
MJB	GS 27	sandstone	uncertain	fragment	1	2	F	Y	N
MJB	GS 28	mudstone	filing stone	fragment	1	3	CV	N	N
MJB	GS 29	sandstone	lower stone	fragment	1	3	F	N	N
MJB	GS 30	sandstone	lower stone	fragment	1	3	F	N	N
MJB	GS 31	sandstone	filing stone	fragment	1	3	CV	N	N
MJB	GS 32	sandstone	lower stone (mortar)	complete	1	3	CC	Y	N
					2	3	F	Y	N
MJB	GS 33	sandstone	filing stone	fragment	1	3	F	N	N
MJB	GS 35	sandstone	filing stone	fragment	1	3	CC	Y	N
					2	3	F	Y	N
MJB	GS 36	sandstone	filing stone	fragment	1	3	F	Y	N
					2	3	F	Y	N
MJB	GS 37	sandstone	uncertain	fragment	1	3	CV	N	N
MJB	GS 38	sandstone	filing stone	fragment	1	3	F	N	N
					2	3	F	N	N

Site name	GS number	Raw material type	Grinding stone type	Completeness	Grinding surface no.	Use (0-3)	Shape of ground surface	Iron oxide staining	Pecking
MJB	GS 39	sandstone	upper stone	complete	1	3	F-CV	Y	N
MJB	GS 40	sandstone	filing stone	fragment	1	3	F	Y	N
MJB	GS 41	sandstone	filing stone	fragments	1	3	F	Y	N
MJB	GS 42	sandstone	uncertain	fragment	0	0	n/a	Y	N
MJB	GS 43	sandstone	filing stone	fragment	1	3	F	N	N
MJB	GS 44	sandstone	uncertain	fragment	1	3	F	Y	N
MJB	GS 45	sandstone	uncertain	fragment	1	3	F	N	N
MJB	GS 46	sandstone	filing stone	fragment	1	3	F	N	N
					2	3	F	N	N
MJB	GS 47	sandstone	uncertain	fragment	1	3	F	Y	N
MJB	GS 48	sandstone	uncertain	fragment	1	2	F	N	N
MJB	GS 49	sandstone	upper stone	fragment	1	3	CV	N	N
MJB	GS 50	sandstone	uncertain	fragment	1	3	F	Y	N
MJB	UP GS 1	sandstone	upper stone	fragment	1	3	F	Y	N
					2	3	CV	Y	N
					3	3	F	Y	N
MJB	UP GS 2	sandstone	upper stone	fragment	1	3	CV	N	N
MJB	UP GS 3	quartzite	upper stone/filing stone	fragment	1	3	CV	N	N
MJB	UP GS 4	sandstone	filing stone	fragment	1	3	CV	Y	N
MJB	UP GS 5	sandstone	filing stone	fragment	1	3	CV	N	N
MJB	UP GS 6	sandstone	filing stone	fragment	1	3	F	N	N
MJB	UP GS 7	sandstone	filing stone	fragment	1	3	CV	Y	N
MJB	UP GS 8	quartzite	uncertain	fragment	0	0	n/a	Y	N
MJB	UP GS 9	sandstone	upper stone	fragment	1	3	CV	N	N
MJB	UP GS 10	quartzite?	uncertain	fragment	1	2	F	N	N
MJB	UP GS 11	sandstone?	uncertain	fragment	1	3	CV	N	N

Site name	GS number	Raw material type	Grinding stone type	Completeness	Grinding surface no.	Use (0-3)	Shape of ground surface	Iron oxide staining	Pecking
MJB	UP GS 12	sandstone	uncertain	fragment	1	3	F	N	N
MJB	UP GS 13	sandstone	uncertain	fragment	0	0	n/a	Y	N
MJB	UP GS 14	quartzite	uncertain	fragments	1	3	F	N	N
MJB	UP GS 15	sandstone	filing stone	complete	1	3	F	Y	N
MJB	UP GS 16	sandstone	upper stone	fragment	1	3	F-CC	Y	N
					2	3	F-CC	Y	N
					3	3	F	Y	N
MJB	UP GS 17	sandstone	uncertain	fragment	1	3	F	Y	N
					2	3	F	Y	N
MJB	UP GS 18	sandstone	filing stone	fragment	1	3	F	N	N
MJB	UP GS 19	sandstone	filing stone	fragment	1	3	CV	N	N
MJB	UP GS 20	sandstone	uncertain	fragment	0	0	n/a	Y	N
MJB	UP GS 21	sandstone	upper stone/filing stone	complete	1	3	F	Y	N
					2	3	F	Y	N
					3	3	F	Y	N
					4	3	F	Y	N
MJB	UP GS 22	sandstone	filing stone	fragment	1	3	F	N	N
					2	3	F	N	N
MJB	UP GS 23	sandstone	filing stone	fragment	1	3	F	N	N
MJB	UP GS 24	sandstone	filing stone	fragment	1	3	F	N	N
MJB	UP GS 25	quartzite	filing stone	fragment	1	3	CV	N	N
MJB	UP GS 26	Sandstone	upper stone	fragment	1	3	CV	Y	N
MJB	UP GS 27	sandstone	filing stone	fragment	1	3	F	Y	N
MJB	UP GS 28	sandstone	filing stone	fragment	1	3	CV	Y	N
MJB	UP GS 29	sandstone	filing stone	fragment	1	3	F	N	N
MJB	UP GS 30	sandstone	uncertain	fragment	1	3	CV-F	N	N
MJB	UP GS 31	sandstone	filing stone	fragment	1	3	F	N	N

Site name	GS number	Raw material type	Grinding stone type	Completeness	Grinding surface no.	Use (0-3)	Shape of ground surface	Iron oxide staining	Pecking
MJB	UP GS 32	sandstone	uncertain	fragment	1	3	F	N	N
MJB	UP GS 33	sandstone	filing stone	fragment	1	2	F	N	N
MJB	UP GS 34	sandstone	filing stone	fragment	1	3	F	N	N
MJB	UP GS 35	sandstone	filing stone	fragment	1	3	F	Y	N
MJB	UP GS 36	quartzite	filing stone	fragment	1	3	F	N	N
MJB	UP GS 37	volcanic	upper stone	fragment	1	3	CV	N	N
MJB	UP GS 38	sandstone	lower stone	complete	1	3	F	Y	N
MJB	UP GS 39	mudstone	filing stone (whetstone)	fragment	1	3	F	N	N
				fragment	2	3	F	N	N
				fragment	3	3	F	N	N
				fragment	4	3	F	N	N
				fragment	5	3	F	N	N
MJB	L49	sandstone	upper stone	fragment	1	3	CV	N	N
MJB	L52	sandstone	upper stone	complete	1	3	CV	Y	N
					2	3	F	Y	N
MJB	L813	sandstone	filing stone	fragment	1	3	F	Y	N
MJB	L868	sandstone	uncertain	fragment	1	3	CV	Y	N
MJB	L894	sandstone	uncertain	fragment	1	3	F	Y	N
MJB	L1349	sandstone	uncertain	fragment	1	3	F	Y	N
MJB	R2	quartzite	uncertain	fragment	1	3	F	Y*	N
MJB	R5	sandstone	upper stone	complete	1	3	CV	Y	N
					2	3	CV	Y	N
					3	3	F	Y	N
MJB	R66	sandstone	lower stone	complete	1	3	CV	Y	N
					2	3	F	Y	N
					3	3	F	Y	N
MJB	R68	sandstone	uncertain	complete	1	3	CC	Y	N

Site name	GS number	Raw material type	Grinding stone type	Completeness	Grinding surface no.	Use (0-3)	Shape of ground surface	Iron oxide staining	Pecking
					2	3	F	Y	N
MJB	R69	sandstone	filing stone	fragment	1	3	F	Y	N
Mungo	LM GS 1	sandstone	recycled millstone	fragment	1	3	CV	N	N
					2	3	CC	N	N
Mungo	LM GS 2	sandstone	uncertain	fragment	1	3	F	Y	N
Mungo	LM GS 3	sandstone	recycled millstone	fragment	1	3	CV, f	Y	N
					2	3	CC	Y	N
Mungo	LM GS 4	sandstone	uncertain	fragment	1	3	F	Y	N
Mungo	LM GS 5	sandstone	uncertain	Fragment	1	3	F	Y	N
Mungo	LM GS 6	sandstone	uncertain	fragment	1	3	F	Y	N
Mungo	LM GS 7	sandstone	uncertain	fragment	1	3	F	Y	N
Mungo	LM GS 8	sandstone	uncertain	fragment	1	3	F	Y	N
Mungo	LM GS 9	sandstone	uncertain	fragment	1	3	F	Y	N
Mungo	LM GS 10	sandstone	upper (muller)	fragment	1	3	F, f	Y	N
					2	2	F	N	N
Mungo	LM GS 11	sandstone	upper stone	complete	1	3	CV	N	N
					2	3	F	N	N
					3	3	F-CV	N	N
Mungo	LM GS 12	sandstone	lower stone	fragment	1	3	CC	N	N
Mungo	LM GS 13	sandstone	uncertain	fragment	1	1	F	N	N
Mungo	LM GS 14	sandstone	uncertain	fragment	1	3	F	Y	N
					2	3	F	Y	N
Mungo	LM GS 15	sandstone	uncertain	fragment	1	3	F	Y	N
Mungo	LM GS 16	sandstone	lower stone (?)	fragment	1	3	F	Y	N
					2	3	F	N	N
Mungo	LM GS 17	sandstone	uncertain	fragment	1	3	CV	Y	N

Table C3: Use-wear characteristics of MJB grinding stone surfaces as observed at low magnification using a stereomicroscope and high magnification using vertical incident light.

GS number	Ground surface number	Stereomicroscope			Vertical incident light						
		grain levelling	grain edge rounding	macro striae	use-polish morphology	use-polish brightness	use-polish coverage	use-polish development	micro striae	grain fractures	visible residues (as observed directly from ground surface)
GS 1	1 of 1	mod-high	high	Y	reticular	bright	extensive	developed	Y	N	red pigment
GS 2	1 of 2	high	high	N	reticular; striated	bright	extensive	developed	Y	N	plant exudate
	2 of 2	moderate	moderate	N	reticular	bright	extensive	developed	Y	N	plant exudate
GS 3	1 of 2	moderate	moderate	Y	smooth-domed	dull - mod	localised	weak	N	N	red pigment, amorph. organic material
	2 of 2	moderate	slight-mod	Y	un-diagnostic	dull	localised	weak	N	N	-
GS 4	1 of 1	high	high	N	un-diagnostic	moderate	localised	weak - mod	Y	N	red pigment
GS 5	1 of 1	absent	slight	Y	un-diagnostic	dull	localised	very weak	Y	N	red pigment
GS 6	1 of 1	absent	moderate	N	un-diagnostic	dull	localised	weak	Y	N	red pigment
GS 7	1 of 1	minimal	moderate	N	un-diagnostic	moderate	localised	weak - mod	N	Y	red pigment
GS 8	1 of 2	mod-high	high	Y	reticular	bright	extensive	developed	Y	N	red pigment
	2 of 2	mod-high	high	Y	reticular	bright	extensive	developed	Y	N	-
GS 9	1 of 1	minimal	mod-high	N	un-diagnostic	bright	localised	weak	N	Y	red pigment
GS 10	1 of 2	minimal	slight-mod	Y	absent	n/a	absent	n/a	N	Y	hyphae
	2 of 2	minimal	slight-mod	Y	absent	n/a	absent	n/a	N	Y	-
GS 13	1 of 2	absent	slight-mod	Y	un-diagnostic	moderate	localised	weak	N	N	Rootlets, termite contamination
	2 of 2	absent	slight-mod	Y	un-diagnostic	moderate	localised	weak	N	N	-
GS 14	1 of 3	mod-high	moderate	Y	undulating /reticular	moderate	localised	moderate	Y	N	red pigment

GS number	Ground surface number	Stereomicroscope			Vertical incident light						
		grain levelling	grain edge rounding	macro striae	use-polish morphology	use-polish brightness	use-polish coverage	use-polish development	micro striae	grain fractures	visible residues (as observed directly from ground surface)
	2 of 3	mod-high	moderate	Y	undulating /reticular	moderate	localised	moderate	Y	N	red pigment
	3 of 3	mod-high	moderate	Y	undulating /reticular	moderate	localised	moderate	Y	N	red pigment
GS 15	1 of 1	high	high	Y	undulating	moderate	moderate	moderate	Y	N	red pigment
GS 16	1 of 2	high	mod-high	Y	reticular	bright	moderate	moderate	Y	N	-
	2 of 2	high	mod-high	Y	reticular	bright	moderate	moderate	Y	N	-
GS 17	0	absent	absent	N	absent	n/a	absent	n/a	N	N	-
GS 18	1 of 2	mod-high	high	Y	reticular	bright	extensive	w. developed	Y	N	-
	2 of 2	mod-high	high	Y	reticular	bright	extensive	w. developed	Y	N	-
GS 19	1 of 1	mod-high	moderate	Y	undulating /reticular	moderate	moderate	moderate	Y	N	red pigment
GS 20	1 of 1	moderate	moderate	Y	undulating	moderate	moderate	moderate	Y	N	cellulose
GS 21	1 of 1	high	high	Y	undulating /reticular	v. bright	extensive	developed	Y	N	red pigment
GS 22	1 of 1	high	high	Y	un-diagnostic	dull	localised	weak	Y	N	cellulose
GS 23	1 of 2	mod-high	moderate	Y	undulating	moderate	moderate	moderate	Y	Y	-
	2 of 2	mod-high	mod-high	Y	undulating	moderate	moderate	moderate	Y	Y	-
GS 24	1 of 2	moderate	moderate	Y	reticular	bright	moderate	moderate	Y	N	red pigment
	2 of 2	moderate	moderate	Y	reticular	bright	moderate	moderate	Y	N	-
GS 26	1 of 1	moderate	high	Y	un-diagnostic	bright	localised	weak	N	N	-
GS 27	1 of 1	high	moderate	N	un-diagnostic	dull	localised	weak	N	Y	red pigment
GS 28	1 of 1	high	high	Y	undulating /reticular	bright	moderate	developed	Y	N	red pigment
GS 29	1 of 1	high	high	N	reticular	bright	extensive	developed	Y	N	red pigment

GS number	Ground surface number	Stereomicroscope			Vertical incident light						
		grain levelling	grain edge rounding	macro striae	use-polish morphology	use-polish brightness	use-polish coverage	use-polish development	micro striae	grain fractures	visible residues (as observed directly from ground surface)
GS 30	1 of 1	high	high	Y	reticular	bright	extensive	developed	Y	N	red pigment
GS 31	1 of 1	minimal	high	N	undulating	bright	localised	weak - mod	Y	N	red pigment
GS 32	1 of 2	high	high	Y	reticular	bright	moderate	moderate	Y	Y	red pigment
	2 of 2	high	high	Y	un-diagnostic	moderate	localised	weak - mod	N	Y	red pigment
GS 33	1 of 1	high	high	Y	undulating /reticular	moderate	mod-extensive	moderate	Y	N	red pigment
GS 35	2 of 2	minimal	moderate	N	undulating	bright	moderate	moderate	Y	N	red pigment
	1 of 2	minimal	moderate	Y	undulating	bright	moderate	moderate	Y	N	red pigment
GS 36	1 of 2	high	high	Y	undulating	moderate	moderate	weak - mod	Y	N	-
	2 of 2	minimal	slight	N	undulating	moderate	localised	weak - mod	Y	N	red pigment
GS 37	1 of 1	mod-high	high	Y	undulating	bright	moderate	moderate-developed	Y	N	red pigment
GS 38	1 of 2	minimal	moderate	Y	un-diagnostic	dull	localised	weak	N	Y	-
	2 of 2	minimal	moderate	Y	un-diagnostic	dull	localised	weak	N	Y	-
GS 39	1 of 1	high	high	Y	reticular	bright	extensive	developed	Y	N	charcoal, cellulose, termite contamination
GS 40	1 of 1	moderate	moderate	Y	undulating	moderate	moderate	moderate	N	N	red pigment
GS 41	1 of 1	moderate	high	Y	undulating	moderate	moderate	weak	N	N	cellulose
GS 42	0	absent	n/a	N	absent	n/a	absent	n/a	N	N	-
GS 43	1 of 1	high	high	Y	undulating /reticular	moderate	moderate	weak - mod	Y	Y	cellulose
GS 44	1 of 1	minimal	slight-mod	N	rough-domed	bright	extensive	developed	Y	N	-
GS 45	1 of 1	high	high	Y	un-diagnostic	moderate	moderate	weak - mod	Y	N	red pigment
GS 46	1 of 2	minimal	moderate	Y	undulating	moderate	moderate	weak	Y	N	red pigment
	2 of 2	minimal	moderate	N	un-diagnostic	moderate	moderate	weak	Y	N	red pigment

GS number	Ground surface number	Stereomicroscope			Vertical incident light						
		grain levelling	grain edge rounding	macro striae	use-polish morphology	use-polish brightness	use-polish coverage	use-polish development	micro striae	grain fractures	visible residues (as observed directly from ground surface)
GS 47	1 of 1	high	high	Y	un-diagnostic	bright	localised	weak	Y	N	red pigment
GS 48	1 of 1	absent	slight	Y	absent	n/a	absent	n/a	N	N	red pigment
GS 49	1 of 1	high	high	Y	undulating	bright	irregular	moderate	Y	N	red pigment
GS 50	1 of 1	absent	moderate	Y	absent	n/a	absent	n/a	Y	N	possible
L49	1 of 1	high	high	Y	reticular	bright	extensive	developed	Y	N	red and yellow pigment, cellulose
L52	1 of 2	high	high	Y	reticular	bright	extensive	developed	Y	Y	red pigment
	2 of 2	high	high	Y	reticular	bright	moderate	moderate	Y	Y	red and yellow pigment
L813	1 of 1	moderate	moderate	Y	undulating	bright	extensive	developed	Y	N	red mineral pigment
L868	1 of 1	high	high	Y	un-diagnostic	dull-mod	localised	weak - mod	Y	N	red mineral pigment
L894	1 of 1	high	high	Y	undulating	bright	moderate	moderate	Y	N	sediment only
L1349	1 of 1	minimal	moderate	Y	reticular	bright	moderate	moderate	Y	N	sediment only
R2	1 of 1	high	mod-high	N	reticular	bright	extensive	developed	Y	N	red pigment
R5	1 of 3	high	high	Y	reticular	bright	extensive	developed	Y	N	red mineral pigment
	2 of 3	high	high	Y	reticular	bright	localised	weak	Y	N	red mineral pigment
	3 of 3	minimal	high	Y	un-diagnostic	moderate	localised	weak	N	N	sediment only
R66	1 of 3	moderate	moderate	N	reticular	bright	extensive	developed	N	N	sediment only
	2 of 3	moderate	moderate	N	reticular	bright	extensive	developed	N	Y	sediment only
	3 of 3	moderate	moderate	N	reticular	bright	moderate	moderate	N	N	sediment only
R68	1 of 2	minimal	slight	N	absent	n/a	absent	n/a	N	Y	red pigment
R68	2 of 2	high	high	Y	undulating	moderate	moderate	moderate	Y	Y	red pigment
R69	1 of 1	high	high	Y	undulating	moderate	moderate	moderate	Y	N	red pigment

GS number	Ground surface number	Stereomicroscope			Vertical incident light						
		grain levelling	grain edge rounding	macro striae	use-polish morphology	use-polish brightness	use-polish coverage	use-polish development	micro striae	grain fractures	visible residues (as observed directly from ground surface)
UP GS 1	1 of 3	high	high	Y	reticular	bright	moderate	developed	Y	N	-
	2 of 3	high	high	Y	reticular	bright	moderate	developed	Y	N	-
	3 of 3	high	high	Y	reticular	bright	moderate	developed	Y	N	-
UP GS 2	1 of 1	high	high	Y	reticular	bright	extensive	developed	Y	N	red pigment
UP GS 3	1 of 1	high	high	N	absent	n/a	absent	n/a	Y	Y	red pigment, possible bone
UP GS 4	1 of 1	high	high	Y	reticular; striated	bright	extensive	w. developed	Y	N	red pigment
UP GS 5	1 of 1	moderate	high	Y	undulating	bright	moderate	developed	Y	N	-
UP GS 6	1 of 1	moderate	moderate	Y	undulating	moderate	irregular	weak	N	N	red pigment
UP GS 7	1 of 1	moderate	high	Y	un-diagnostic	moderate	localised	weak	N	N	red pigment
UP GS 8	0	absent	absent	N	absent	n/a	absent	n/a	N	N	-
UP GS 9	1 of 1	high	high	Y	reticular	bright	moderate	developed	Y	N	red pigment
UP GS 10	1 of 1	moderate	high	Y	absent	n/a	absent	n/a	N	N	-
UP GS 11	1 of 1	moderate	high	Y	reticular	bright	moderate	developed	Y	Y	red pigment
UP GS 12	1 of 1	moderate	slight	N	un-diagnostic	moderate	localised	weak	N	N	red pigment
UP GS 13	0	absent	absent	N	absent	n/a	absent	n/a	N	N	-
UP GS 14	1 of 1	high	high	N	reticular	bright	extensive	developed	Y	Y	red pigment
UP GS 15	1 of 1	minimal	high	Y	undulating	bright	extensive	w. developed	Y	N	charcoal/termite contamination
UP GS 16	1 of 3	high	high	Y	reticular	bright	extensive	w. developed	Y	N	charcoal, termite contamination
	2 of 3	high	high	Y	reticular	bright	extensive	developed	Y	N	-
	3 of 3	minimal	slight	Y	un-diagnostic	bright	moderate	weak	Y	N	red and yellow pigment

GS number	Ground surface number	Stereomicroscope			Vertical incident light						
		grain levelling	grain edge rounding	macro striae	use-polish morphology	use-polish brightness	use-polish coverage	use-polish development	micro striae	grain fractures	visible residues (as observed directly from ground surface)
UP GS 17	1 of 2	moderate	mod-high	Y	reticular	bright	extensive	w. developed	Y	N	bone
	2 of 2	minimal	moderate	Y	un-diagnostic	bright	moderate	moderate	Y	N	red pigment
UP GS 18	1 of 1	minimal	moderate	Y	un-diagnostic	moderate	localised	weak	Y	N	red pigment
UP GS 19	1 of 1	high	mod-high	Y	un-diagnostic	moderate	moderate	moderate	Y	N	red pigment
UP GS 20	0	absent	absent	N	absent	n/a	absent	n/a	N	N	-
UP GS 21	1 of 4	moderate	high	Y	reticular	bright	extensive	developed	Y	N	bone, vivianite
	2 of 4	moderate	high	Y	reticular; striated	bright	extensive	developed	Y	N	-
	3 of 4	minimal	high	N	reticular	bright	extensive	developed	Y	N	possible bone
UP GS 21	4 of 4	minimal	high	N	reticular	bright	extensive	developed	Y	N	-
UP GS 22	1 of 2	mod-high	high	Y	un-diagnostic	moderate	localised	weak	N	N	-
	2 of 2	mod-high	high	Y	reticular; striated	bright	extensive	developed	Y	N	red and yellow pigment
UP GS 23	1 of 1	moderate	moderate	Y	undulating	mod-bright	moderate	moderate	Y	N	red pigment, hyphae
UP GS 24	1 of 1	absent/ minimal	slight	Y	un-diagnostic	dull	not present	weak	Y	N	red pigment, termite contamination
UP GS 25	1 of 1	high	high	Y	undulating	bright	moderate	moderate	Y	N	red pigment
UP GS 26	1 of 1	high	high	Y	reticular	bright	extensive	w. developed	Y	N	red pigment
UP GS 27	1 of 1	high	high	Y	un-diagnostic	bright	localised	weak	N	N	charcoal
UP GS 28	1 of 1	mod-high	moderate	Y	un-diagnostic	moderate	localised	weak - mod	N	N	red pigment
UP GS 29	1 of 1	high	moderate	Y	undulating	moderate	localised	moderate	Y	Y	sediment only
UP GS 30	1 of 1	moderate	high	Y	un-diagnostic	dull-moderate	moderate	weak	Y	N	waxy coating
UP GS 31	1 of 1	minimal	slight	Y	undulating	bright	localised	weak	Y	N	red pigment

GS number	Ground surface number	Stereomicroscope			Vertical incident light						
		grain levelling	grain edge rounding	macro striae	use-polish morphology	use-polish brightness	use-polish coverage	use-polish development	micro striae	grain fractures	visible residues (as observed directly from ground surface)
UP GS 32	1 of 1	high	high	Y	un-diagnostic	dull	localised	weak	Y	N	red pigment
UP GS 33	1 of 1	moderate	slight-mod	N	un-diagnostic	bright	localised	weak	Y	N	sediment only
UP GS 34	1 of 1	moderate	mod-high	Y	un-diagnostic	dull-moderate	localised	weak	N	N	red pigment
UP GS 35	1 of 1	minimal	slight-mod	Y	un-diagnostic	dull	localised	weak	N	N	red pigment, metal
UP GS 36	1 of 1	high	moderate	Y	un-diagnostic	dull	localised	weak	N	N	red pigment, metal
UP GS 37	1 of 1	absent	absent	Y	undulating	bright	moderate	moderate	Y	N	sediment only
UP GS 38	1 of 1	moderate	mod-high	Y	un-diagnostic	moderate	localised	weak	N	N	sediment, rootlets, metal, red pigment
UP GS 39	1 of 5	high	absent	Y	striated	bright	extensive	w. developed	Y	N	red pigment
UP GS 39	2 of 5	high	absent	Y	undulating; striated	bright	extensive	developed	N	N	red pigment
	3 of 5	high	absent	Y	undulating; striated	bright	extensive	developed	N	N	red pigment
	4 of 5	high	absent	Y	striated	bright	extensive	developed	Y	N	red pigment
	5 of 5	high	absent	Y	striated	bright	extensive	developed	Y	N	red pigment

Table C4: Use-wear characteristics of Lake Mungo grinding stone surfaces as observed at low magnification using a stereomicroscope and high magnification using vertical incident light.

GS number	Ground surface number	Stereomicroscope			Vertical incident light						
		grain levelling	grain edge rounding	macro striae	polish morphology	polish brightness	polish coverage	polish development	micro striae	grain fractures	visible residues (as observed directly from ground surface)
LM GS 1	1 of 2	moderate	mod-high	Y	reticular	bright	extensive	developed	Y	N	rootlet
LM GS 1	2 of 2	moderate	mod-high	Y	reticular	bright	extensive	developed	Y	N	plant material
LM GS 2	1 of 1	minimal	slight	N	reticular	bright	extensive	developed	Y	N	plant material
LM GS 3	1 of 2	moderate	mod	N	reticular	bright	extensive	developed	Y	N	plant material
LM GS 3	2 of 2	minimal	mod	Y	reticular	bright	extensive	developed	Y	N	plant material
LM GS 4	1 of 1	minimal	slight	N	reticular	bright	extensive	developed	Y	N	plant material
LM GS 5	1 of 1	minimal	mod	N	reticular	bright	extensive	developed	Y	N	plant material
LM GS 6	1 of 1	minimal	slight	N	reticular	bright	extensive	developed	Y	N	plant material
LM GS 7	1 of 1	minimal	mod	N	reticular	bright	extensive	developed	Y	N	plant material
LM GS 8	1 of 1	minimal	mod	N	reticular	bright	extensive	developed	Y	N	plant material
LM GS 9	1 of 1	minimal	slight	N	reticular	bright	extensive	developed	Y	N	plant material
LM GS 10	1 of 2	moderate	high	Y	reticular	bright	extensive	developed	Y	N	-
LM GS 10	2 of 2	minimal	slight	N	un-diagnostic	dull	localised	mod	Y	N	-
LM GS 11	1 of 3	high	high	Y	reticular	bright	extensive	developed	Y	N	-
	2 of 3	high	high	Y	reticular	bright	extensive	developed	Y	N	-
	3 of 3	high	high	Y	reticular	bright	extensive	developed	Y	N	-
LM GS 12	1 of 2	moderate	mod	Y	un-diagnostic	mod	extensive	mod	Y	Y	sediment, charcoal
	2 of 2	minimal	slight	N	un-diagnostic	dull	localised	mod	Y	N	lichen
LM GS 13	1 of 1	absent	slight	N	absent	n/a	n/a	n/a	N	N	lichen
LM GS 14	1 of 2	high	high	Y	reticular	bright	extensive	w. developed	Y	N	-
LM GS 14	2 of 2	minimal	high	Y	reticular	bright	extensive	w. developed	Y	N	-

GS number	Ground surface number	Stereomicroscope			Vertical incident light						
		grain levelling	grain edge rounding	macro striae	polish morphology	polish brightness	polish coverage	polish development	micro striae	grain fractures	visible residues <i>(as observed directly from ground surface)</i>
LM GS 15	1 of 2	moderate	high	Y	reticular	bright	extensive	developed	Y	N	-
LM GS 15	2 of 2	minimal	slight	N	un-diagnostic	mod	localised	weak	N	N	-
LM GS 16	1 of 2	moderate	mod	Y	reticular	bright	extensive	developed	Y	N	-
LM GS 16	2 of 2	minimal	slight	N	un-diagnostic	mod	localised	weak	Y	N	-
LM GS 17	1 of 1	high	high	Y	reticular	bright	extensive	developed	Y	N	plant fibres

Table C5: Materials identified within extracted residue samples from each of the MJB and Lake Mungo grinding surfaces, extracted via sonication and pipette removals. . Green coloured squares indicate recognised plant material, yellow squares indicate identified animal material, red squares indicates pigment and blue squares indicate minerals.

Artefact	Surface	ORGANIC										INORGANIC				Other
		Plant						Animal				Pigment		Mineral		
		Cellulose	Lignin	Starch	Phytolths	Raphides	Resin	Collagen	Bone	Hair	Feather	Red	Yellow	Round	Angular	
GS 01	1 of 1	+	+	+	+	+						+	+		+	rootlets (contamination); charcoal
GS 02	1 of 2	+					+					+			+	
	2 of 2	+													+	
GS 03	1 of 2	+	+	+	+			+				+		+	+	
	2 of 2	+	+	+	+							+		+	+	plant sheath
GS 04	1 of 1	+	+		+		+					+		+	+	rootlets; sieve cell, perforation plate
GS 05	1 of 1	+												+		charcoal
GS 06	1 of 1	+										+		+	+	
GS 07	1 of 1	+						+				+		+		trichome
GS 08	1 of 2	+										+		+	+	
	2 of 2	+					+					+		+	+	
GS 09	1 of 1	+						+		+				+	+	
GS 10	1 of 2	+												+		hyphae
	2 of 2	+												+		hyphae
GS 13	1 of 2	+												+	+	hyphae; charcoal
	2 of 2													+	+	
GS 14	1 of 3	+	+					+				+			+	
	2 of 3	+										+			+	
	3 of 3	+										+			+	
GS 15	1 of 1											+		+	+	
GS 16	1 of 2	+	+											+	+	

Artefact	Surface	ORGANIC										INORGANIC				Other
		Plant						Animal				Pigment		Mineral		
		Cellulose	Lignin	Starch	Phytolths	Raphides	Resin	Collagen	Bone	Hair	Feather	Red	Yellow	Round	Angular	
	2 of 2	+	+											+	+	charcoal
GS 18	1 of 2	+	+									+		+	+	
	2 of 2	+	+									+		+	+	
GS 19	1 of 1	+										+		+	+	
GS 20	1 of 1	+												+	+	
GS 21	1 of 1	+										+		+	+	
GS 22	1 of 1	+												+	+	bacterial contam.; yellow minerals
GS 23	1 of 2	+	+									+		+	+	
	2 of 2	+	+									+		+	+	
GS 24	1 of 2		+											+	+	
	2 of 2		+									+		+	+	
GS 26	1 of 1	+	+											+	+	
GS 27	1 of 1	+	+									+		+	+	
GS 28	1 of 1	+	+					+							+	hyphae
GS 29	1 of 1	+	+	+	+									+	+	hyphae
GS 30	1 of 1	+	+									+		+	+	
GS 31	1 of 1	+	+									+		+	+	
GS 32	1 of 2	+	+	+			+					+		+	+	purple fibre
	2 of 2	+	+		+							+		+	+	
GS 33	1 of 1													+	+	
GS 35	2 of 2	+	+					+				+		+	+	
	1 of 2	+	+					+						+	+	animal fat*, blood?
GS 36	1 of 2	+												+	+	
	2 of 2	+												+	+	charcoal

Artefact	Surface	ORGANIC										INORGANIC				Other
		Plant						Animal				Pigment		Mineral		
		Cellulose	Lignin	Starch	Phytolths	Raphides	Resin	Collagen	Bone	Hair	Feather	Red	Yellow	Round	Angular	
GS 37	1 of 1	+	+					+						+	+	
GS 38	1 of 2	+			+									+	+	lichen spores
	2 of 2	+												+	+	
GS 39	1 of 1	+	+	+										+	+	hyphae; charcoal
GS 40	1 of 1	+										+		+	+	
GS 41	1 of 1	+										+		+	+	
GS 43	1 of 1	+												+	+	hyphae; charcoal; red mineralsl
GS 44	1 of 1	+	+					+			+			+	+	
GS 45	1 of 1	+	+									+			+	
GS 46	1 of 2											+			+	synthetic fibre
	2 of 2											+			+	
GS 47	1 of 1			+								+		+	+	
GS 48	1 of 1	+										+		+	+	
GS 49	1 of 1	+													+	
GS 50	1 of 1	+										+		+	+	
L49	1 of 1	+	+	+	+							+	+		+	
L52	1 of 2	+	+	+								+	+		+	perforation plate
	2 of 2	+										+			+	
L813	1 of 1	+	+	+	+	+	+					+			+	hyphae
L868	1 of 1		+	+	+			+				+			+	
L894	1 of 1	+										+		+	+	
L1349	1 of 1	+	+	+				+						+	+	decaying root; charcoal
R2	1 of 1	+	+	+	+			+						+	+	
R5	1 of 3	+	+	+	+		+					+		+	+	perforation plate; charcoal

Artefact	Surface	ORGANIC										INORGANIC				Other
		Plant						Animal				Pigment		Mineral		
		Cellulose	Lignin	Starch	Phytolths	Raphides	Resin	Collagen	Bone	Hair	Feather	Red	Yellow	Round	Angular	
	2 of 3	+												+	+	
	3 of 3	+					+							+	+	charcoal
R66	1 of 3	+	+	+						+				+	+	hyphae
R66	2 of 3	+												+	+	
	3 of 3	+												+	+	
R68	1 of 2	+					+	+				+	+	+	+	hyphae
	2 of 2	+			+							+		+	+	hyphae
R69	1 of 1	+	+									+			+	hyphae
UP GS 01	1 of 3	+	+		+			+							+	
	2 of 3	+	+					+							+	
	3 of 3	+	+					+							+	
UP GS 02	1 of 1	+		+	+	+						+			+	sieve cell
UP GS 03	1 of 1	+	+					+				+			+	
UP GS 04	1 of 1	+		+			+					+	+		+	
UP GS 05	1 of 1	+										+		+	+	hyphae
UP GS 06	1 of 1	+										+			+	
UP GS 07	1 of 1											+			+	calcite crust
UP GS 09	1 of 1	+						+				+		+	+	charcoal
UP GS 10	1 of 1	+										+			+	
UP GS 11	1 of 1	+												+	+	
UP GS 12	1 of 1	+	+	+								+			+	fungal spores
UP GS 14	1 of 1	+		+								+		+	+	
UP GS 15	1 of 1	+										+		+	+	
UP GS 16	1 of 3	+	+									+			+	charcoal; hyphae

Artefact	Surface	ORGANIC										INORGANIC				Other
		Plant						Animal				Pigment		Mineral		
		Cellulose	Lignin	Starch	Phytolths	Raphides	Resin	Collagen	Bone	Hair	Feather	Red	Yellow	Round	Angular	
	2 of 3	+		+								+			+	
	3 of 3	+	+									+	+		+	
UP GS 17	1 of 2	+						+							+	
	2 of 2	+					+	+			+	+		+	+	blood or resin
UP GS 18	1 of 1	+					+					+			+	hyphae; resin?
UP GS 19	1 of 1													+	+	
UP GS 21	1 of 4	+	+		+				+			+			+	vivianite
	2 of 4	+						+	+						+	
	3 of 4	+							+			+			+	vivianite
	4 of 4	+										+			+	rootlet
UP GS 22	1 of 2	+												+	+	
	2 of 2	+										+	+	+	+	
UP GS 23	1 of 1											+			+	
UP GS 24	1 of 1	+										+		+	+	white mineral; charcoal
UP GS 25	1 of 1	+	+									+		+	+	
UP GS 26	1 of 1	+	+	+	+			+				+		+	+	hyphae
UP GS 27	1 of 1	+													+	metal; charcoal
UP GS 28	1 of 1	+	+												+	sieve cell
UP GS 29	1 of 1														+	
UP GS 30	1 of 1	+												+	+	
UP GS 31	1 of 1	+										+		+		charcoal
UP GS 32	1 of 1	+										+			+	
UP GS 33	1 of 1	+	+												+	plant cells
UP GS 34	1 of 1	+						+				+		+	+	

Artefact	Surface	ORGANIC										INORGANIC				Other
		Plant						Animal				Pigment		Mineral		
		Cellulose	Lignin	Starch	Phytolths	Raphides	Resin	Collagen	Bone	Hair	Feather	Red	Yellow	Round	Angular	
UP GS 35	1 of 1	+										+			+	metal
UP GS 36	1 of 1												+			+
UP GS 37	1 of 1	+													+	hyphae
UP GS 38	1 of 1	+			+							+			+	metal; rootlets
UP GS 39	1 of 5	+						+	+			+				bacterial contamination, pollen?
	2 of 5	+						+				+				
	3 of 5	+										+			+	
	4 of 5	+										+			+	
	5 of 5	+										+				
LM GS 1	1 of 2	+						+							+	rootlet
	2 of 2	+													+	
LM GS 3	1 of 2	+												+		
	2 of 2	+		+			+									
LM GS 5	1 of 1	+					+				+			+	+	
LMGS 10	1 of 2	+		+												
LMGS 11	1 of 3	+	+				+									
LMGS 12	1 of 3	+												+		lichen
LMGS 13	1 of 1														+	lichen
LMGS 14	1 of 3	+													+	
LMGS 15	1 of 3															
LMGS 16	1 of 3	+					+	+								
LMGS 17	1 of 1	+		+												

Table C6: Staining agents used on each artefact extractions (pipette only): L-R- Congo Red for the identification of gelatinised/damaged starch (bright red) and cellulose (dark red), IKI for the identification of intact starch, Methylene Blue for the identification of cellulose, Orange G for the identification of collagen, Phloroglucinol for the identification of lignin, Rhodamine B for the identification of keratin and collagen, Safranin for the identification of lignin, and Sudan IV, for the identification of fats. Grey negative squares indicate where the stain was applied with no identification; coloured squares indicate residue confirmation. Blank squares indicate no stain applied.

Artefact	Staining agent							
	<i>Congo Red*</i>	<i>IKI</i>	<i>Methylene Blue</i>	<i>Orange G</i>	<i>Phloro-gluconol</i>	<i>Rhodamine B</i>	<i>Safranin</i>	<i>Sudan IV</i>
GS 1	+	-					+	
GS 2	+	-		-			-	
GS 3	+	+		+			+	
GS 4	+	-					+	
GS 5	+	-						
GS 6	+	-						
GS 7	+	-		+				
GS 8	+	-		-				
GS 9	+	-		+		+		
GS 10	+	-						
GS 13	+	-						
GS 14	+	-		+	+		+	-
GS 15	-	-						
GS 16	+	-		-	+		+	
GS 17								
GS 18	+	-		-	-		+	-
GS 19	+	-		-				
GS 20	+	-		-				
GS 21	+	-		-				
GS 22	+	-	+	-			-	
GS 23	+	-		-			+	
GS 24	-	-			-		+	
GS 26	+	-			+			
GS 27	+	-		-			+	
GS 28	+	-		+			+	
GS 29	+	-		-			+	
GS 30	+	-		-			+	
GS 31	+	-					+	
GS 32	+	-		-			+	
GS 33	-	-						
GS 35	+	-		+			+	+
GS 36	+	-		-				

Artefact	Staining agent							
	<i>Congo Red*</i>	<i>IKI</i>	<i>Methylene Blue</i>	<i>Orange G</i>	<i>Phloro-gluconol</i>	<i>Rhodamine B</i>	<i>Safranin</i>	<i>Sudan IV</i>
GS 37	+	-	+		+	+		
GS 38	+	-		-				
GS 39	+	-		-			+	
GS 40	+	-	+	-			-	
GS 41	+	-	+					
GS 42	+	-						
GS 43	+	-	+					
GS 44	+	-			+	+		
GS 45	+	-			+			
GS 46	-	-				-		
GS 47	-	-						
GS 48	+	-	+					
GS 49	+	-		-				
GS 50	+	-						
L49	+	-	+	-			+	
L52	+	-		-			+	
L813	+	+	+	-			+	
L868	+	-		+			+	
L894	+	-						
L1349	+	-		+			+	
R2	+	-		+			+	
R5	+	+					+	
R66	+	-	+	+		+	+	
R68	+	-	+	+			-	
R69	+	-		+			+	
UP GS 1	+	-		+		-	+	
UP GS 2	+	-	+	+				
UP GS 3	+	-		+			+	
UP GS 4	+	-					-	
UP GS 5	+	-		+				
UP GS 6	+	-	+	+				
UP GS 7	-	-						
UP GS 8								
UP GS 9	+	-		+				
UP GS 10	+	-	+	-				
UP GS 11	+	-	+	-				
UP GS 12	+	-	+	-			+	
UP GS 13								
UP GS 14	+	-		-			-	
UP GS 15	+	-		-				

Artefact	Staining agent							
	<i>Congo Red*</i>	<i>IKI</i>	<i>Methylene Blue</i>	<i>Orange G</i>	<i>Phloro-gluconol</i>	<i>Rhodamine B</i>	<i>Safranin</i>	<i>Sudan IV</i>
UP GS 16	+	-	+	-			+	
UP GS 17	+	-	+	-		+		
UP GS 18	+	-		-				-
UP GS 19	-	-						
UP GS 20								
UP GS 21	+	-	+	+			+	
UP GS 22	+	-		-				
UP GS 22	+	-						
UP GS 23	-	-						
UP GS 24	+	-						
UP GS 25	+	-					-	
UP GS 26	+	-		+			+	-
UP GS 27	+	-						
UP GS 28	+	-	+	-			+	-
UP GS 29	-	-						
UP GS 30	+	-						
UP GS 31	+	-						
UP GS 32	+	-						
UP GS 33	+	-					+	
UP GS 34	+	-		+				
UP GS 35	+	-						-
UP GS 36	-	-						
UP GS 37	+	-						
UP GS 38	+	-		-			-	
UP GS 39	+	-	+	+				-
LM GS 1	-	-		+				
LM GS 3	-	-		-				
LM GS 4	-	-						
LM GS 5	-	-						
LM GS 10	-	-						
LM GS 11	-	-					+	
LM GS 12	-	-	-	-				
LM GS 13	-	-						
LM GS 14	-	-						
LM GS 15	-	-						
LM GS 16	-	-	+	+			-	
LM GS 17	-	+		-				

Table C7: Results of Hemastix testing conducted on pipette extractions from one ground and un-ground surface for each artefact with and without the addition of a chelating agent EDTA. Score of 0 indicate no trace of haem, 1-2 indicates trace amounts, and 3-5 indicate larger amounts. Blank squares indicate samples not analysed.

Artefact number	ground surface		un-ground surface	
	Hmstix score	Hmstix EDTA	Hmstix score	Hmstix EDTA
GS 1	0			
GS 2	0			
GS 3	0			
GS 4	3	2	0	
GS 5	0			
GS 6	0			
GS 7	1	0	0	
GS 8	0			
GS 9	1	0	1	0
GS 10	3	2	4	0
GS 13	3	0	4	0
GS 14	4	2	3	0
GS 15	0			
GS 16	1	0	1	0
GS 18	0			
GS 19	3	0	4	0
GS 20	3	0	3	0
GS 21	0			
GS 22	2	0	2	0
GS 23	3	0	3	0
GS 24	0			
GS 26	0			
GS 28	0			
GS 29	0			
GS 30	0			
GS 31	3	0	0	
GS 32	0			
GS 33	1	0	0	
GS 35	3	0	1	0
GS 36	3	0	3	0
GS 37	0			
GS 38	3	0	1	0
GS 39	3	0	3	0
GS 40	2	0	1	0
GS 41	0			

Artefact number	ground surface		un-ground surface	
	Hmstix score	Hmstix EDTA	Hmstix score	Hmstix EDTA
GS 47	0			
GS 48	0			
GS 49	0			
GS 50				
UP GS 1	0			
UP GS 2	0			
UP GS 3	2	0	0	
UP GS 4	0			
UP GS 5	2	0	2	0
UP GS 6	3	0	0	
UP GS 7	0			
UP GS 9	0			
UP GS 10	0			
UP GS 11	0			
UP GS 12	0			
UP GS 14	3	0	3	0
UP GS 15	0			
UP GS 16	1	0	0	
UP GS 17	0			
UP GS 18	1	0	0	
UP GS 19	0			
UP GS 21	1	0	0	
UP GS 22	0			
UP GS 23	0			
UP GS 24	0			
UP GS 25	0			
UP GS 26	3	0	1	0
UP GS 27				
UP GS 28	3	0	1	0
UP GS 29	0			
UP GS 30	0			
UP GS 31	0			
UP GS 32	0			
UP GS 33	0			
UP GS 34	0			

Artefact number	ground surface		un-ground surface	
	Hmstix score	Hmstix EDTA	Hmstix score	Hmstix EDTA
GS 42	0			
GS 43	3	0	4	0
GS 44	3	1	3	0
GS 45	3	0	3	0
GS 46	0			
L49	0			
L52	0			
L813	0			
L868	0			
L894	0			
L1349	0			
R2	0			
R5	0			
R66	2	0	3	0
R68	0			
R69	0			
LM GS 1	0			

Artefact number	ground surface		un-ground surface	
	Hmstix score	Hmstix EDTA	Hmstix score	Hmstix EDTA
UP GS 35	0			
UP GS 36	0			
UP GS 37	0			
UP GS 38	0			
UP GS 39	1	0	0	
LM GS 2				
LM GS 3	0			
LM GS 4				
LM GS 5	0			
LM GS 6				
LM GS 7				
LM GS 8				
LM GS 10	0			
LM GS 11	0			
LM GS 13	0			
LM GS 15	0			
LM GS 17	0			

Table C8: Results of biochemical testing for MJB residue samples (pipette only). Plus signs indicate positive readings, single plus for trace amounts and double plus for higher readings, as tested against a standard of known quantity. Negative signs indicate a negative result for sample readings; a blank square indicates no analysis undertaken.

Artefact	Surface	Biochemical test					
		Bradford Assay	Diphenyl-amine	Falholt	PSA	Hemastix	IKI
GS 01	1 of 1	-	++	-	++	-	++
	sediment sample	+	-	-			+
GS 02	1 of 2	+	+	-	++	-	++
	2 of 2			-			
	sediment sample	-	-	-			++
GS 03	1 of 2	-	++	++	++	-	++
	2 of 2	-	++	-	+	-	++
	sediment sample	++	-	-			++
GS 04	1 of 1	-	++	+	++	++	++
	sediment sample	-	-	-			++
GS 05	1 of 1	-	-	-	+	-	+
	sediment sample	-	-	-			+

Artefact	Surface	Biochemical test					
		Bradford Assay	Diphenyl-amine	Falholt	PSA	Hemastix	IKI
GS 06	1 of 1	-	-	++	-	-	-
	sediment sample	-	-	++			+
GS 07	1 of 1	-	-	++	-	+	-
	sediment sample	-	-	-			-
GS 08	1 of 2	-	-	++	-	-	-
	2 of 2			-			
	sediment sample	-	-	-			+
GS 09	1 of 1	++	-	+	-	+	-
	sediment sample	-	-	-			-
GS 10	1 of 1	-	-	-	-	++	+
	sediment sample	-	-	-			-
GS 13	1 of 1	++	-	-	-	++	-
	sediment sample	-	-	-			+
GS 14	1 of 3	-	-	-	-	++	-
	2 of 3						
	3 of 3						
	sediment sample	-	-	-			++
GS 15	1 of 1	-	-	-	-	-	-
	sediment sample	-	-	-			-
GS 16	1 of 2	++	++	-	-	+	+
GS 16	2 of 2			-			
	sediment sample	++	-	-	-	-	-
GS 18	1 of 2	-	-	++	+	-	++
	2 of 2	+	++	-	++	+	+
GS 19	1 of 1	-	-	-	-	++	-
	sediment sample	-	-	-			+
GS 20	1 of 1	++	++	+	++	++	++
	sediment sample	-	-	-			+
GS 21	1 of 1	+	++	++	++	-	++
	sediment sample	++	-	-	-	-	++
GS 22	1 of 1	++	++	++	++	+	++
	sediment sample	-	-	-			++
GS 23	1 of 2	++	++	++	++	++	++
	2 of 2			++			
	unused surface	+	+	++	++	++	++
GS 24	1 of 2			-			
	2 of 2	++	+	-	++	-	++
	sediment sample	-	-	-			++

Artefact	Surface	Biochemical test					
		Bradford Assay	Diphenyl-amine	Falholt	PSA	Hemastix	IKI
GS 26	1 of 1 sediment sample	-	-	-	+	-	+
		-	-	-			-
GS 27	1 of 1 sediment sample	-	-	-	+	-	++
		-	-	-			+
GS 28	1 of 1 sediment sample	-	-	++	-	-	-
		-	-	-			-
GS 29	1 of 1 sediment sample	+	+	++	-	-	+
		-	-	-			-
GS 30	1 of 1 sediment sample	++	++	++	++	-	-
		-	-	-			-
GS 31	1 of 1 sediment sample	-	-	++	-	++	-
		+	-	-			-
GS 32	1 of 2 2 of 2 sediment sample	-	++	++	++	-	++
				+			
		-	-	-			-
GS 33	1 of 1 sediment sample	-	-	++	-	+	+
		-	-	-			+
GS 35	1 of 2 2 of 2 sediment sample	-	-	++	-	++	-
		-	++	++	-	++	+
		-	-	-			+
GS 36	1 of 2 2 of 2 sediment sample	-	-	++	-	++	+
		++	++	-	++	++	++
		-	-	-			-
GS 37	1 of 1 sediment sample	-	-	-	-	-	-
		-	-	-			+
GS 38	1 of 2	++	++	-	++	++	++
GS 38	2 of 2 sediment sample	++	++	++	++	++	++
		++	++	-			+
GS 39	1 of 1 sediment sample	+	++	++	++	++	++
		-	+	-			++
GS 40	1 of 1 sediment sample	++	+	++	++	+	++
		++	-	-			+
GS 41	1 of 1 sediment sample	-	-	++	-	-	+
		-	++	-			++
GS 42	1 of 1 sediment sample	-	-	-	-	-	-
		-	-	-			++
GS 43	1 of 1 sediment sample	-	-	-	+	++	+
		-	-	-			-

Artefact	Surface	Biochemical test					
		Bradford Assay	Diphenyl-amine	Falholt	PSA	Hemastix	IKI
GS 44	1 of 1 sediment sample	-	-	-	-	++	-
		-	-	-			+
GS 45	1 of 1 sediment sample	-	-	++	-	++	-
		-	-	-			+
GS 46	1 of 2	-	-	-	-	-	-
	2 of 2			+			
	sediment sample	-	-	-			+
GS 47	1 of 1	-	+	+	-	-	-
	unused surface	++	-	-		-	++
GS 48	1 of 1 sediment sample	-	++	++	-	-	-
		-	+	-			+
GS 49	1 of 1 sediment sample	-	-	++	-	-	-
			-	-			-
GS 50	1 of 1 sediment sample	-	-	++	++	?	-
		-	-	-			-
L49	1 of 1	-	-	-	-	-	+
	sediment sample	++	-	-			+
L52	1 of 2	+	-	-	+	-	+
	2 of 2			-			
	sediment sample	++	-	-	-	-	++
L813	1 of 1	+	++	-	++	-	++
	sediment sample	-	-	-			+
L868	1 of 1	-	-	-	-	-	-
	sediment sample	-	-	-			-
L894	1 of 1	-	-	-	-	-	+
	sediment sample	-	-	-			-
L1349	1 of 1	++	+	-	++	-	++
	sediment sample	-	-	-			++
R2	1 of 1	++	++	-	+	-	+
	sediment sample	-	-	-			-
R5	1 of 3	++	++	-	++	-	++
	2 of 3			-			
	3 of 3	-	+	-	++	-	++
	sediment sample	-	-	-			-
R66	1 of 3	-	-	-	++	+	+
	2 of 3				++		
	3 of 3						
	sediment sample	-	-	-			+

Artefact	Surface	Biochemical test					
		Bradford Assay	Diphenyl-amine	Falholt	PSA	Hemastix	IKI
R68	1 of 2	-	-	-	++	-	+
	2 of 2			-	++		
	sediment sample	-	-	-			+
R69	1 of 1	-	-	-	++	-	-
	sediment sample	-	-	-			+
UP GS 01	1 of 3			-			
	2 of 3	-	++		-	-	+
	3 of 3			++			
	sediment sample	-	++	-		-	++
UP GS 02	1 of 1	-	-	++	++	-	+
	unused surface	-	-	-			+
UP GS 03	1 of 1	-	+	+	-	+	+
	unused surface	-	-	-	-	-	++
UP GS 04	1 of 1	++	++	++	++	-	-
	sediment sample	-	-	-			-
UP GS 05	1 of 1	+	++	++	++	+	+
	sediment sample	-	-	-			-
UP GS 06	1 of 1	++	-	++	-	++	+
	sediment sample	-	-	-			-
UP GS 07	1 of 1	-	-	++	-	-	-
	sediment sample	-	-	-			+
UP GS 09	1 of 1	++	++	++	++	-	++
	unused surface	++	++	-			++
UP GS 10	1 of 1	-	-	++	-	-	-
	sediment sample	+	-	-			+
UP GS 11	1 of 1	-	-	++	++	-	+
UP GS 11	sediment sample	-	-	-			++
UP GS 12	1 of 1	+	++	-	++	-	++
	sediment sample	-	-	-			++
UP GS 14	1 of 1	++	++	-	++	++	++
	sediment sample	-	-	-			++
UP GS 15	1 of 1	+	-	++	++	-	+
	unused surface	++	-	-			+
UP GS 16	1 of 3	++	++	-	++	+	++
	2 of 3	-	-	-	++	-	++
	3 of 3			-			
	sediment sample	-	-	-			-
UP GS 17	1 of 2	-	-	+	++	-	+
	2 of 2			-			

Artefact	Surface	Biochemical test					
		Bradford Assay	Diphenyl-amine	Falholt	PSA	Hemastix	IKI
	unused surface	-	-	-			-
UP GS 18	1 of 1	-	-	-	-	+	+
	sediment sample	-	-	-			++
UP GS 19	1 of 1	-	-	++	-	-	+
	sediment sample	-	-	-			-
UP GS 21	1 of 4	-	-	++	-	+	-
	2 of 4			-			
	3 of 4						
	4 of 4						
	sediment sample	-	-	-			-
UP GS 22	1 of 2	-	-	-	-	-	-
	2 of 2			++			
	sediment sample	-	-	-			-
UP GS 23	1 of 1	-	-	-	++	-	++
	sediment sample	-	-	-			+
UP GS 24	1 of 1	-	-	++	-	-	+
	sediment sample	-	-	-			-
UP GS 25	1 of 1	-	-	++	+	-	+
	sediment sample	-	-	-	-	-	+
UP GS 26	1 of 1	++	-	++	++	++	+
	sediment sample	-	-	-			+
UP GS 27	1 of 1			++			
	sediment sample	-	-	-			-
UP GS 28	1 of 1	-	-	++	-	++	-
	sediment sample	-	-	-			+
UP GS 29	1 of 1	++	-	++	-	-	-
	unused surface	-	-	-			-
UP GS 30	1 of 1	-	-	++	-	-	+
UP GS 30	unused surface	++	-	-			-
UP GS 31	1 of 1	-	-	++	-	-	-
	unused surface	-	-	-			+
UP GS 32	1 of 1	-	-	++	-	-	-
	unused surface	-	-	-			+
UP GS 33	1 of 1	-	+	++	-	-	-
	unused surface	-	-	-			-
UP GS 34	1 of 1	-	-	-	-	-	+
	unused surface	-	-	-			-
UP GS 35	1 of 1	-	-	-	-	-	+
	unused surface	-	-	++			-
UP GS 36	1 of 1	++	-	-	++	-	+

Artefact	Surface	Biochemical test					
		Bradford Assay	Diphenyl-amine	Falholt	PSA	Hemastix	IKI
	unused surface	-	-	-			-
UP GS 37	1 of 1	-	-	-	-	-	+
	sediment sample	-	-	-			+
UP GS 38	1 of 1	-	-	-	-	+	-
	sediment sample	+	-	-			+
UP GS 39	1 of 5	++	-	-	-	+	-
	2 of 5			-			
	3 of 5			-			
	4 of 5						
	5 of 5			-			
	sediment sample	-	-	-			+
Total surfaces w positive readings		34	38	58	51	26	67
Total sediment samples with positive readings		16	7	3	1	<i>not measured</i>	56

Table C9: Results of biochemical testing for Lake Mungo residue samples (pipette only). Plus signs indicate positive readings, single plus for trace amounts and double plus for higher readings. Negative signs indicate a negative result for sample readings; a blank square indicates no analysis undertaken.

Artefact	Surface	Biochemical test					
		Bradford Assay	Diphenyl-amine	Falholt	PSA	Hemastix	IKI
LM GS 1	1 of 1	-	-	-	-	-	++
	1 of 2	-	-	-	-	-	-
LM GS 3	1 of 1	-	-	-	+	-	-
	1 of 2	-	++	-	-	-	+
LM GS 5	1 of 1	-	-	-	-	-	-
LM GS 10	1 of 2	-	-	-	-	-	-
	2 of 2						
LM GS 11	1 of 3			-			
	2 of 3	-	-	-	-	-	+
	3 of 3						
LM GS 12	1 of 1	+	-	-	-	-	+
LM GS 13	1 of 1	-	-	-	-	-	-

Artefact	Surface	Biochemical test					
		Bradford Assay	Diphenyl-amine	Falholt	PSA	Hemastix	IKI
LM GS 14	1 of 2	-	-	-	-	-	-
	2 of 2						
LM GS 15	1 of 1	-	-	-	-	-	-
LM GS 16	1 of 1	++	++	-	++	-	++
	1 of 2						
LM GS 17	1 of 1	++	++	-	++	-	++
Total surfaces w positive readings		3	3	0	3	0	6
Total sediment samples with positive readings		<i>not measured</i>	<i>not measured</i>	<i>not measured</i>	<i>not measured</i>	<i>not measured</i>	<i>not measured</i>

Table C10: Summary of residues identified on the MJB and Lake Mungo artefacts, as determined from GC-MS analyses, where NDR indicates “no residues detected” and unknown refers to residues in which compounds have been identified but are not specific to plant, animal or mineral. The specific compounds for each residue mixture are listed in Table E1 and E2, Appendix E. Chromatographs for each residue sample are presented in Appendix E, Figures E1-E92.

GS number	Residues identified on (ground) artefact surfaces		handling residues?	Residues in soil
GS 01	plant	leaf, seed	N	NRD
GS 02	plant	non-descript	Y	plant
GS 03	plant, animal	blood, non-descript plant	N	NRD
GS 04	plant	non-descript	Y	NRD
GS 05	plant	wood, fruit (Ficus?)	N	NRD
GS 06	NRD	–	Y	NRD
GS 07	plant	nut, seed, leaf, honey	Y	handling
GS 08	plant	seeds, leaf (toxic?)	Y	NRD
GS 09	plant	leaf, nut, seed	N	handling
GS 10	plant	leaf, nut, seed	Y	NRD
GS 13	plant	roots, seeds, leaves	N	NRD
GS 14	plant	roots	Y	NRD
GS 15	plant (very limited)	non-descript	Y	NRD
GS 16	plant	non-descript	N	NRD
GS 18	plant	seeds, nuts, roots	Y	NRD
GS 19	plant	seeds, nuts, roots	N	NRD
GS 20	plant	seeds, nuts, roots	Y	NRD
GS 21	plant	seeds, nuts, roots	Y	plant
GS 22	plant	seeds, nuts, roots	N	NRD

GS number	Residues identified on (ground) artefact surfaces		handling residues?	Residues in soil
GS 23	plant	seed	N	plant
GS 24	plant	roots, nuts, seeds	N	NRD
GS 26	plant	nuts, seed	N	NRD
GS 27	plant	non-descript	N	unknown
GS 28	plant (limited)	non-descript	N	unknown
GS 29	plant (limited)	non-descript	N	NRD
GS 30	plant	seed?	N	NRD
GS 31	plant	non-descript	Y	NRD
GS 32	plant	non-descript	N	NRD
GS 33	plant (limited)	non-descript	N	NRD
GS 35	plant (limited)	non-descript	N	NRD
GS 36	plant	seed, nut	N	NRD
GS 37	plant	root, seed, nut	N	NRD
GS 38	unknown	–	N	NRD
GS 39	plant	burnt and unburnt wood, seed, nut, tuber	N	NRD
GS 40	unknown	–	N	NRD
GS 41	unknown	–	N	NRD
GS 42	unknown	–	N	plant, handling
GS 43	unknown	–	N	NRD
GS 44	unknown	–	N	unknown
GS 45	NRD	–	N	unknown
GS 46	plant	non-descript	N	unknown
GS 47	plant (limited)	non-descript	N	not sampled
GS 48	NRD	–	N	NRD
GS 49	unknown	–	N	NRD
GS 50	NRD	–	N	plant (limited)
L 49	plant	non-descript	N	NRD
L 52	unknown	–	N	NRD
L 813	unknown	–	N	NRD
L 868	plant	non-descript	N	NRD
L 894	NRD	–	N	NRD
L 1349	plant	non-descript	N	NRD
R 2	unknown	–	N	NRD
R 5	unknown	–	N	NRD
R 66	NRD	–	N	NRD
R 68	unknown	–	N	unknown
R 69	NRD	–	N	unknown
UP GS 1	NRD	–	N	unknown
UP GS 2	NRD	–	N	not sampled
UP GS 3	unknown	–	N	NRD
UP GS 4	unknown	–	N	NRD
UP GS 5	unknown	–	N	not sampled

GS number	Residues identified on (ground) artefact surfaces		handling residues?	Residues in soil
UP GS 6	plant	root, tuber, seed	N	unknown
UPGS 7	NRD	–	N	NRD
UP GS 9	Unknown	–	N	NRD
UP GS 10	NRD	–	N	insect, plant, bacteria
UP GS 11	plant	seed, nut, root	N	NRD
UP GS 12	NRD	–	N	NRD
UP GS 14	plant	non-descript	N	NRD
UP GS 15	NRD	–	N	not sampled
UP GS 16	unknown	–	N	NRD
UP GS 17	unknown	–	N	not sampled
UP GS 18	plant	burnt wood	N	NRD
UP GS 19	not sampled	–	N	NRD
UP GS 21	plant, possible animal	nut, seed	N	NRD
UP GS 22	plant	non-descript	N	NRD
UP GS 23	unknown	–	Y	NRD
UP GS 24	plant	seed, nut	N	NRD
UP GS 25	plant	root, seed, nut	N	NRD
UP GS 26	unknown	–	N	plant (seed)
UP GS 27	NRD	–	N	NRD
UP GS 28	NRD	–	N	NRD
UP GS 29	plant	seed, nut, root	N	not sampled
UP GS 30	unknown	–	N	not sampled
UP GS 31	NRD	–	N	not sampled
UP GS 32	unknown, possibly animal	–	Y	not sampled
UP GS 33	NRD	–	N	not sampled
UP GS 34	unknown	–	N	not sampled
UP GS 35	NRD	–	N	not sampled
UP GS 36	NRD	–	N	not sampled
UP GS 37	NRD	–	N	NRD
UP GS 38	unknown	–	N	NRD
UP GS 39	plant	non-descript	N	NRD
LM GS 1	plant	non-descript	N	not sampled
LM GS 2	not sampled	–	–	not sampled
LM GS 3	plant	non-descript	N	not sampled
LM GS 4	not sampled	–	–	not sampled
LM GS 5	plant	non-descript	Y	not sampled
LM GS 6	not sampled	–	–	not sampled
LM GS 7	not sampled	–	–	not sampled
LM GS 8	not sampled	–	–	not sampled
LM GS 9	NRD	–	N	not sampled
LM GS 10	unknown	–	N	not sampled

GS number	Residues identified on (ground) artefact surfaces		handling residues?	Residues in soil
LM GS 11	unknown	–	N	not sampled
LM GS 12	NRD	–	N	not sampled
LM GS 13	NRD	–	N	not sampled
LM GS 14	unknown	–	Y	not sampled
LM GS 15	NRD	–	N	not sampled
LM GS 16	NRD	–	N	not sampled
LM GS 17	NRD	–	N	not sampled

Table C10: Listing of grinding stone type and probable function for MJB and Lake Mungo grinding stones. Conclusions are based on weighted evidence following morphological characterisation and the recognition of specific use-wear and residue features.

Site name	GS number	Grinding stone type	MF ?	Function
MJB	GS 1	coupled stone (lower)		plant processing (hard seed)
MJB	GS 2	coupled stone (upper)		plant processing (hard seed)
MJB	GS 3	filing stone	Y	plant processing (soft and starchy plant); animal processing
MJB	GS 4	filing stone; coupled stone	Y	pigment processing; plant processing
MJB	GS 5	filing stone		plant processing (wood or fruit)
MJB	GS 6	uncertain/unused		unknown/unused
MJB	GS 7	coupled stone (upper)/ hammerstone		plant processing
MJB	GS 8	coupled stone (upper)		plant processing (seed)
MJB	GS 9	uncertain	Y	plant processing; possible animal processing
MJB	GS 10	uncertain		plant processing
MJB	GS 13	uncertain		plant processing
MJB	GS 14	coupled stone		plant processing
MJB	GS 15	filing stone		pigment processing
MJB	GS 16	coupled stone (upper)		plant processing (seed)
MJB	GS 17	uncertain/unused		unknown/unused
MJB	GS 18	coupled stone (upper)/ hammerstone	Y	plant processing (seed); flake manufacture
MJB	GS 19	coupled stone		plant processing
MJB	GS 20	coupled stone (lower)		plant processing
MJB	GS 21	filing stone; coupled stone	Y	pigment processing; plant processing (seed)
MJB	GS 22	coupled stone (upper)		plant processing
MJB	GS 23	uncertain		plant processing
MJB	GS 24	coupled stone (upper)		plant processing (seed, nut, roots)
MJB	GS 26	coupled stone (upper)		plant processing (nuts, seeds)
MJB	GS 27	uncertain		unknown

Site name	GS number	Grinding stone type	MF ?	Function
MJB	GS 28	coupled stone (upper)		plant processing
MJB	GS 29	coupled stone (lower)		plant processing
MJB	GS 30	coupled stone (lower)		plant processing (seed)
MJB	GS 31	uncertain		plant processing
MJB	GS 32	coupled stone (lower): pitted anvil stone/mortar		plant processing
MJB	GS 33	filing stone; coupled stone	Y	pigment processing; possible plant processing
MJB	GS 35	uncertain		unknown, possible plant processing
MJB	GS 36	coupled stone		plant processing
MJB	GS 37	coupled stone (upper)		plant processing
MJB	GS 38	filing stone		unknown, possibly for stone processing (axe manufacture)
MJB	GS 39	coupled stone (upper)		plant processing (burnt plant, including seed, nut, tuber, wood)
MJB	GS 40	filing stone		pigment processing
MJB	GS 41	filing stone		pigment processing
MJB	GS 42	uncertain/unused		unknown/unused
MJB	GS 43	filing stone		pigment processing
MJB	GS 44	uncertain		unknown
MJB	GS 45	uncertain		unknown
MJB	GS 46	uncertain		plant processing
MJB	GS 47	uncertain		unknown; possible plant processing
MJB	GS 48	uncertain		unknown
MJB	GS 49	coupled stone (upper)		unknown
MJB	GS 50	uncertain		unknown
MJB	L49	coupled stone (upper)		plant processing (starchy plant, tubers, underground storage organs, seed)
MJB	L52	coupled stone (upper)		plant processing (seed)
MJB	L813	filing stone		pigment processing
MJB	L868	uncertain		unknown
MJB	L894	uncertain		unknown
MJB	L1349	uncertain		plant processing
MJB	R2	uncertain		plant processing
MJB	R5	coupled stone (upper)		plant processing (seed)
MJB	R66	coupled stone (lower)	Y	plant processing; possible stone processing (axe manufacture)
MJB	R68	uncertain		unknown
MJB	R69	filing stone		Pigment processing
MJB	UP GS 1	coupled stone (upper)		plant processing
MJB	UP GS 2	coupled stone (upper)		plant processing (starchy plant)
MJB	UP GS 3	uncertain		unknown
MJB	UP GS 4	filing stone		manufacture-ground
MJB	UP GS 5	filing stone		unknown

Site name	GS number	Grinding stone type	MF ?	Function
MJB	UP GS 6	uncertain		plant processing
MJB	UP GS 7	filing stone		pigment processing
MJB	UP GS 8	uncertain/unused		unknown/unused
MJB	UP GS 9	coupled stone (upper)		plant processing (hard seed)
MJB	UP GS 10	uncertain		unknown
MJB	UP GS 11	coupled stone		plant processing
MJB	UP GS 12	uncertain		unknown
MJB	UP GS 13	uncertain/unused		unknown/unused
MJB	UP GS 14	uncertain	Y	pigment processing; plant processing
MJB	UP GS 15	filing stone		pigment processing
MJB	UP GS 16	coupled stone (upper)		plant processing
MJB	UP GS 17	uncertain	Y	plant processing; possible animal processing
MJB	UP GS 18	filing stone		plant processing (wood)
MJB	UP GS 19	coupled stone (upper)		plant processing
MJB	UP GS 20	uncertain/unused		unknown/unused
MJB	UP GS 21	filing stone; coupled stone (upper)	Y	animal processing (bone); plant processing (seed)
MJB	UP GS 22	coupled stone		plant processing
MJB	UP GS 23	filing stone		pigment processing
MJB	UP GS 24	filing stone		unknown, possibly plant processing
MJB	UP GS 25	filing stone; coupled stone (upper)	Y	pigment processing; plant processing
MJB	UP GS 26	coupled stone (upper)		plant processing (seed)
MJB	UP GS 27	filing stone		unknown
MJB	UP GS 28	filing stone		unknown
MJB	UP GS 29	filing stone		unknown
MJB	UP GS 30	uncertain		unknown
MJB	UP GS 31	filing stone		unknown
MJB	UP GS 32	uncertain		unknown
MJB	UP GS 33	filing stone		unknown
MJB	UP GS 34	uncertain		unknown
MJB	UP GS 35	filing stone		unknown, possible pigment processing
MJB	UP GS 36	filing stone		pigment processing
MJB	UP GS 37	uncertain		unknown
MJB	UP GS 38	filing stone		unknown
MJB	UP GS 39	filing stone		metal axe and stone axe sharpening
Mungo	LM GS 1	coupled stone: recycled millstone / muller		plant processing (seed)
Mungo	LM GS 2	coupled stone (upper)		plant processing (seed)
Mungo	LM GS 3	coupled stone: recycled millstone/ muller		plant processing (seed)
Mungo	LM GS 4	coupled stone (lower)		plant processing (seed)
Mungo	LM GS 5	coupled stone (lower)		plant processing (seed)

Site name	GS number	Grinding stone type	MF ?	Function
Mungo	LM GS 6	coupled stone (lower)		plant processing (seed)
Mungo	LM GS 7	coupled stone (lower)		plant processing (seed)
Mungo	LM GS 8	coupled stone (lower)		plant processing (seed)
Mungo	LM GS 9	coupled stone (lower)		plant processing (seed)
Mungo	LM GS 10	coupled stone (upper, muller)		plant processing (seed)
Mungo	LM GS 11	coupled stone (upper)		plant processing
Mungo	LM GS 12	uncertain		uncertain
Mungo	LM GS 13	uncertain/unused		uncertain
Mungo	LM GS 14	uncertain		plant processing (seed)
Mungo	LM GS 15	uncertain		plant processing (seed)
Mungo	LM GS 16	coupled stone (lower)		plant processing (seed)
Mungo	LM GS 17	coupled stone (lower)		plant processing (seed)

Table C11: residues identified by three analysts using various methods of extraction (at different locations of the stones) and identification (such as stains).

Artefact number	Analyst	Collagen	Plant (e.g. cellulose)	Starch	Mineral	Other
LMGS1	EH	+	+	+	-	gelatinised starch
LMGS1	BS	+	+	+	-	lichen
LMGS1	JF			+		
LMGS2	BS	-	+	-	-	feather barbule
LMGS3	EH	-	+	-	+	
LMGS3	BS	-	+	-	-	lichen
LMGS3	JF			+		
LMGS5	EH	-	+	-	-	
LMGS5	BS	-	+	-	+	
LMGS7	BS	-	+	+	+	
LMGS10	EH	-	+	-	-	
LMGS10	BS	-	+	-	+	hyphae, feather barb.
LMGS10	JF			+		
LMGS11	EH	-	+	-	-	
LMGS11	BS	-	+	+	-	
LMGS11	JF			+		
LMGS12	EH	-	+	-	+	
LMGS12	BS	-	+	-	+	
LMGS12	JF			+		
LMGS13	JF			+		
LMGS14	EH	-	+	-	-	
LMGS14	BS	-	+	-	+	
LMGS14	JF			+		
LMGS15	EH	-	-	-	-	

LMGS15	JF			+		
LMGS16	EH	+	+	+	-	gelatinised starch
LMGS16	BS	-	-	-	-	
LMGS16	JF			+		
LMGS17	EH	-	+	+	-	
LMGS17	BS	+	+	+	+	
LMGS17	JF			+		

Table C12: Number of samples collected from the Lake Mungo grinding stones

<i>Artefact number</i>	<i>total residue lifts</i>	<i>E:W:A lifts</i>	<i>water lifts</i>	<i>In situ/ field lifts</i>	<i>PVS peels</i>
<i>Lake Mungo</i>					
LMGS1	5	2	3		
LMGS2	2	1	1		
LMGS3	4	2	2		
LMGS4	2	1	1		
LMGS5	3	1	2		
LMGS6	2	1	1		
LMGS7	2	1	1		
LMGS8	2	1	1		
LMGS9	2	1	1		
LMGS10	3	1	2		
LMGS11	3	2	1		
LMGS12	3	1	2		
LMGS13	2	1	1		
LMGS14	2	1	1		
LMGS15	2	1	1		
LMGS16	3	1	2		
LMGS17	3	1	2		
TOTAL	45	20	25	0	0
No of artefacts sampled	17	17	17	0	0

Table C13: Number of samples collected from each MJB grinding stone

<i>Artefact number</i>	<i>total residue lifts</i>	<i>E:W:A lifts</i>	<i>water lifts</i>	<i>In situ/ field lifts</i>	<i>PVS peels</i>
<i>Madjedbebe</i>					
GS 1	4	2	2		
GS 2	4	2	2		
GS 3	5	2	3	3	
GS 4	4	2	2		
GS 5	4	2	2		2
GS 6	2		2		1
GS 7	4	2	2		
GS 8	4	2	2		1
GS 9	3	1	2		
GS 10	3	1	2		
GS 13	3	1	2		
GS 14	4	2	2		
GS 15	4	2	2		
GS 16	4	2	2		
GS 18	3	3			1
GS 19	3	1	2		
GS 20	3	1	2		
GS 21	4	2	2		
GS 22	4	2	2		1
GS 23	4	2	2		
GS 24	3	1	2		
GS 26	4	2	2		
GS 27	2	1	1		

<i>Artefact number</i>	<i>total residue lifts</i>	<i>E:W:A lifts</i>	<i>water lifts</i>	<i>In situ/ field lifts</i>	<i>PVS peels</i>
<i>Madjedbebe (cont.)</i>					
GS 29	4	2	2		
GS 30	3	1	2		
GS 31	3	1	2		
GS 32	6	3	3	3	6
GS 33	3	1	2		
GS 35	5	2	3		
GS 36	5	2	3		
GS 37	2	1	1		
GS 38	4	2	2		4
GS 39	4	2	2		2
GS 40	3	1	2		
GS 41	2	1	1		
GS 42	2	1	1		
GS 43	3	1	2		
GS 44	3	1	2		
GS45	3	1	2		
GS46	4	2	2		
GS47	2	1	1		
GS48	2	1	1		
GS49	3	1	2		
GS50	2	1	1		
L49	4	2	2		
L52	4	2	2		

<i>Artefact number</i>	<i>total residue lifts</i>	<i>E:W:A lifts</i>	<i>water lifts</i>	<i>In situ/ field lifts</i>	<i>PVS peels</i>
GS 28	5	3	2		
L868	2	1	1		
L894	2	1	1		
L1349	3	1	2		
R2	4	2	2		
R5	6	3	3		
R66	5	2	3		6
R68	4	2	2		
R69	3	1	2		1
UP GS 1	4	2	2		
UP GS 2	2	1	1		
UP GS 3	3	1	2		
UP GS 4	5	2	3	3	
UP GS 5	3	1	2		
UP GS 6	2	1	1		
UP GS 7	2	1	1		
UP GS 9	3	1	2		
UP GS 10	2	1	1		
UP GS 11	3	2	1		
UP GS 12	3	1	2		
UP GS 14	3	1	2		
UP GS 15	2	1	1		
UP GS 16	5	3	2		
UP GS 17	4	2	2		

<i>Artefact number</i>	<i>total residue lifts</i>	<i>E:W:A lifts</i>	<i>water lifts</i>	<i>In situ/ field lifts</i>	<i>PVS peels</i>
L813	3	1	2		
UP GS 21	4	2	2		
UP GS 18	3	1	2		
UP GS 19	2	1	1		
UP GS 22	4	2	2		
UP GS 23	2	1	1		
UP GS 24	3	1	2		
UP GS 25	2	1	1		
UP GS 26	5	3	2		
UP GS 27	2	1	1		
UP GS 28	3	1	2		
UP GS 29	2	1	1		
UP GS 30	2	1	1		
UP GS 31	2	1	1		
UP GS 32	2	1	1		
UP GS 33	2	1	1		
UP GS 34	2	1	1		
UP GS 35	2	1	1		
UP GS 36	2	1	1		
UP GS 37	2	2			
UP GS 38	6	2	4	4	2
UP GS 39	6	4	2		
TOTAL	301	139	162	13	27
Total number of artefacts sampled:					
	92	91	90	4	11

Appendix D

Gas Chromatography Mass Spectrometry data and chromatographs

Table D1: Compounds detected within the residue mixtures sampled from the ground and unground surfaces of the MJB grinding stones, where *n*= number of grinding surfaces (ground + unground) with compound present.

Compound detected	Origin	n=	Reference(s)
(1,1,2-trimethylpropyl)-benzene	contamination	1	
(2,8,12,18-tetraethyl-3,7,13,17-tetramethyl-21H, 23H-porphinato(2-)-N21,N22,N23,N24)-, (SP-4-1)-	degraded porphyrin (haemaglobin, myoglobin)	1	
(4-hydroxyphenyl)-(2-hydroxyphenyl)-methane		3	
1-(3-methylbutyl)-2,3,5-trimethylbenzene		2	
1,1'-(3,3-dimethyl-1-butenylidene)bis-benzene		1	
1,1',2,2'-tetrahydro-1,1'-dimethoxy-carotene		3	
1,1'-biphenyl, 4,4'-dinitro-	plant residue, bioactive properties	1	
1,2,4-trimethylbenzene	contamination	1	
1,2-benzisothiazol-3-amine	plant (bioactive)	1	Priyanka <i>et al.</i> 2014
1,2-propanediol, 3-(octadecyloxy)- acetate		1	
1,2-propanediol, 3-(octadecyloxy)- diacetate		1	
1,3-dioxane, 4-(hexadecyloxy)-2-pentadecyl-	plant	1	Salem <i>et al.</i> 2011
1,5-cyclooctadiene, 3,4,7,8-tetrakis(1-methylethylidene)-		6	
10-methylundecanoic acid, methyl ester	plant	1	Williams 1993, Azmat. <i>et al.</i> 2010
11-cis-octadecenoic acid	animal, plant (incl root, seed - Asclepias and macadamia), bacterial	1	Chisholm & Hopkins 1960, Denev <i>et al.</i> 2011, Holloway & Wakil 1964, Kumar <i>et al.</i> 2014, Miyatani <i>et al.</i> 2001, Sağlik <i>et al.</i> 2002, Shibahara <i>et al.</i> 1986, Ugoeze. <i>et al</i> 2014
11-norcannabinol-9-carboxylic acid	plant (bioactive)	5	Aneela <i>et al.</i> 2014
15-isopropenyl-oxacyclopentadecan-2-one		1	
17-octadecynoic acid	plant <i>Indigofera</i>	1	Deshpande <i>et al.</i> 2013, Reddy <i>et al.</i> 2014
1-acetyl-4-amino-5-ethyl-2,5-dihydro-1H-pyrrole-3-carbonitrile		1	
1-cyclohexenol		1	
1-ethyl-4-methylbenzene	plant residue, seed and/or nut; plant <i>Vitex</i>	19	Ciganek <i>et al.</i> 2007, de Lacy Costello <i>et al.</i> 2001, Janakiraman <i>et al.</i> 2012, Omikorede <i>et al.</i> 2012
1-heptadecanol acetate	plant	1	Wesołowska <i>et al.</i> 2011

Compound detected	Origin	n=	Reference(s)
1-hexacosene	hexacos-1-ene, Burnt Plant Material	3	Kaal <i>et al.</i> 2008
1H-indene, 2,3-dihydro-1,1,3-trimethyl-3-phenyl-	plant	1	
. 1H-indole-2-carboxylic acid, 3-methyl-4-oxo-6-(3,4,5-trimethoxyphenyl)-4,5,6,7-tetrahydro-, ethyl ester		1	
1-hydroxy-4-hydroxymethyl-phenol		1	
1-monolinoleoylglycerol	Plant <i>Calophyllum</i>	2	Bhuiyan <i>et al.</i> 2009, Lakshmi & Rajalakshmi 2011, Merlin <i>et al.</i> 2009, Malarvizhi & Ramakrishnan 2011, Murugesan & Panneerselvam 2013, Sheela & Uthayakumari 2013
2-(1,1-dimethylethyl)-4-(1-methyl-1-phenylethyl)-phenol		8	
2(3H)-naphthalenone, 3-hydroxy-4,4a,5,6,7,8-hexahydro-1,4a-dimethyl-7-(1-methylethenyl)-, (3S-(3.alpha.,4a.alpha.,7.alpha.))-		1	
2-(4-methoxy-phenyl)-6-p-tolyl-pyridine		1	
2-(hydroxymethyl)phenol	salicylic alcohol (Bioactive)	2	
2,2,4-trimethyl-4-(4'-oxyphenyl)chromane		2	
2,3-dihydroxybutane		1	
2,4,4,6-tetramethyl-6-phenyl-1-heptene	(2,4,4,6-Tetramethyl-6-hepten-2-yl)benzene	1	
2,4,6-trimethyldecane	tridecanes (13 Carbons), Burnt Plant material	1	Kaal <i>et al.</i> 2008, 2009
2,4,6-trimethyloctane	undecanes (11 Carbons), Burnt plant material	1	Kaal <i>et al.</i> 2008
2,4,7,14-tetramethyl-4-vinyl-tricyclo(5.4.3.0(1,8))tetradecan-6-ol		1	
2,4-bis(1-methyl-1-phenylethyl)-phenol		21	
2,4-bis(dimethylbenzyl)-6-t-butylphenol	plant	43	Castrejón <i>et al.</i> 2003
2,4-dihydroxy-3-methylbenzoic acid		1	
2,4-dintrophenyl-arginine	amino acid derivative	1	
2,4-diphenyl-4-methyl-2E-pentene	plant residue, seed and/or nuts	43	
2,4-imidazolidinedione, 5-(3,4-dihydroxy-phenyl)-3-methyl-5-phenyl-		9	
2,6,10,15-tetramethyl-heptadecane	heneicosanes (21 Carbons), Burnt plant material, beeswax	6	Kaal <i>et al.</i> 2008, Lakshmi prava <i>et al.</i> 2012, Maia & Nunes 2013

Compound detected	Origin	n=	Reference(s)
2,6,10-trimethyl-tetradecane	tridecanes (13 Carbons), Burnt Plant material	5	Kaal <i>et al.</i> 2008, 2009
2,6,11-trimethyl-dodecane	heptadecanes (17 Carbons), Burnt plant material, beeswax	1	Kaal <i>et al.</i> 2008, 2009, Maia & Nunes 2013, Regert <i>et al.</i> 2001
2,6-bis(1,1-dimethylethyl)-4-(1-methyl-1-phenylethyl)-phenol	pentadecanes (15 Carbons), Burnt plant material, beeswax; plant residue, nuts and/or seed	41	Kaal <i>et al.</i> 2008, 2009, Lakshmi prava <i>et al.</i> 2012
2,6-dihydroxy-4-methylphenol	plant	1	Chowdhury <i>et al.</i> 2013
2',6'-dihydroxyacetophenone	plant	2	Cecilia <i>et al.</i> 2012
2,6-dihydroxybenzoic acid	fungal mycobiont	1	Takenaka <i>et al.</i> 2011
2,6-dimethyl-4,4-tetramethylene-1,4-dihydropyridine-3,5-dicarbonitrile		1	
2,6-dimethyl-heptadecane	nonadecanes (19 Carbons), Burnt plant material, beeswax	2	Kaal <i>et al.</i> 2008, 2009, Lakshmi prava <i>et al.</i> 2012
2,6-di-tert-butyl-4-(2,4-dimethylbenzyl)phenol		3	
2,6-ditertbutylphenol	contamination	2	
2-amino-1-(4-methoxyphenyl)-5-phenyl-1H-pyrrole-3,4-dicarbonitrile		1	
2-ethyl-2-methyl-tridecanol	algae, plant	1	Ololade & Olawore 2013, Sathya <i>et al.</i> 2012, Al-Mazroa <i>et al.</i> 2015
2-ethylhexanoic acid	plant, honey	13	Fiehn <i>et al.</i> 2000, Hammami <i>et al.</i> 2011, Jerković & Marijanović 2010, Wang <i>et al.</i> 2012
2H,8H-benzo(1,2-b:5,4-b')dipyran-10-propanol, 5-methoxy-2,2,8,8-tetramethyl-		1	
2-hexadecanoic acid glycerol	2-monopalmitin - plant	1	Gutiérrez <i>et al.</i> 1999, Perumal & Mahmud 2013
2-hydroxy-2-cyclopenten-1-one		1	
2-hydroxy-3-methyl-benzoic acid	3-methylsalicylic acid, plant (Bioactive)	1	Zulfiqar 1998
2-hydroxy-4-hydroxymethyl-phenol		1	
2-hydroxy-ethanoic acid	glycolic acid	2	
2-hydroxymethylfuran	furfuryl alcohol	1	
2-hydroxymethyl-phenol	salicyl alcohol, plant (Bioactive)	6	Mahdi 2010
2-hydroxypropanoic acid	lactic acid	15	
2-hydroxypropanol	unknown	1	

Compound detected	Origin	n=	Reference(s)
2-methoxy-3-methyl-phenol	burning of biomass	1	Roggero <i>et al.</i> 2011
2-methoxyphenol	Guaiacol, wood, fruit <i>Ficus</i> (antimicrobial)	1	van Bergen & Poole 2002, Ragasa <i>et al.</i> 2014, Saravanan et al 2014
2-methyl-2-phenyl-tridecane	unknown	1	
2-methylbenzoic acid anhydride	unknown	1	
2-methyl-butan-1,4-diol	unknown	1	
2-methyl-eicosane	plant	1	Santhosh Kumar <i>et al.</i> 2014, Siddiquee <i>et al.</i> 2012
2-methylnonadecane	icosanes (20 carbons), Plant, Burnt Plant Material	1	Kaal <i>et al.</i> 2008, Wang <i>et al.</i> 2006
2-naphthol, 1-(4-dimethylaminophenyl)azo-	plant	1	Gutiérrez <i>et al.</i> 1999
2'-oxophenyl-4'-oxophenyl-methane	unknown	1	
2-oxo-propanoic acid	unknown	1	
2-phenyl-2-oxphenyl-propane	plant (Bioactive)	19	
2-tert-butyl-4-methyl-6-(a-methylbenzyl)phenol	unknown	4	
3,4-dihydroisoquinoline, 1-(3-hydroxybenzyl)-6-methoxy-	alkaloid (Bioactive)	1	
3,5-bis(4-(1,1-dimethylethyl)phenyl)-2,3-dihydro-1H-indene-1-one	unknown	1	
3,5-dimethoxy-4-hydroxybenzoate	unknown	1	
3,5-dimethoxy-4-hydroxy-cinnamaldehyde	Sinapaldehyde - plant (Bioactive)	1	Cabrita <i>et al.</i> 2012, Gopalakrishnan & Vadivel 2011, Heigenmoser <i>et al.</i> 2013
3,9.beta.;14,15-diepoxy-pregn-16-en-20-one, 3,11.beta.,18-triacetoxy-	unknown	1	
3-methyl-2-hydroxy-2-butenic acid	2-Hydroxy-3-methylbutyric acid	1	
3-phenyl-2-propenol	cinnamyl alcohol - plant	1	de Vega <i>et al.</i> 2013, Wang <i>et al.</i> 2013
3-phenyl-prop-2-ene	unknown	1	
4-(1,1,3,3-tetramethylbutyl)phenol	unknown	1	
4-(hydroxymethyl)phenol	gastrodigenin, leaves or twigs of <i>Aptenia cordifolia</i> (Bioactive)	1	Della Greca <i>et al.</i> 2007
4,4'-(1-methylethylidene)bis(2,6-dimethyl-phenol)	unknown	4	
4,6-bis(t-butyl)-2-(dimethylbenzyl)phenol	unknown	1	

Compound detected	Origin	n=	Reference(s)
4,6-dimethyl-2-thioxo-1,2-dihydro-3-pyridinecarbonitrile	unknown	5	
4H-1-benzopyran-4-one, 5,7-dihydroxy-2-(3,4,5-trimethoxyphenyl)-	flavone	1	
4-hydroxybenzaldehyde	plant <i>Mimusops</i> , <i>Solanum</i> (bioactive-medicinal)	1	Rao <i>et al.</i> 2012, Ren <i>et al.</i> 2009, Kuo <i>et al.</i> 2008
5-(3-benzylamino-2-hydroxypropoxy)naphtho(1,2-b)thiophene	unknown	1	
5,8,11,14-eicosatetraynoic acid	unknown	1	
5,8,11-eicosatriynoic acid	unknown	5	
5,8-diethyldodecane	hexadecanes (16 Carbons), burnt plant material	1	Kaal <i>et al.</i> 2008
5-allyl-1-methoxy-2,3-dihydroxybenzene	unknown	1	
5-hydroxy-3-amino-indolepropionate	unknown	1	
5-hydroxy-5-methyl-2-phenyl-3-isoxazolidinone	unknown	1	
5-methyl-2-phenylindolizine	plant <i>Cissus</i>	1	Rosy & Rosakutty 2012
5-methyl-tetradecane	pentadecanes (15 Carbons), burnt plant material, beeswax	2	Kaal <i>et al.</i> 2008, 2009, Lakshmi prava <i>et al.</i> 2012
6-(7-nitrobenzofurazan-4-yl)amino-morphinan-4,5-epoxy-3,6-di-ol	unknown	2	
7aH-cyclopenta(a)cyclopropa(f)cycloundecene-2,4,7,7a,10,11-hexol, 1,1a,2,3,4,4a,5,6,7,10,11,11a-dodecahydro-1,1,3,6,9-pentamethyl-, 2,4,7,10,11-pentaacetate	unknown	1	
7-dehydrocholesteryl isocaproate	animal, skin, milk	1	
7-methylhexadecane	heptadecanes (17 Carbons), Burnt plant material, beeswax	1	Kaal <i>et al.</i> 2008, 2009, Maia & Nunes 2013, Regert <i>et al.</i> 2001
9-(methoxyimino)-11,15-dihydroxy-Prost-13-en-1-oic acid	linolenic acid - plant (seed)	1	Liu <i>et al.</i> 2000, Minzangi <i>et al.</i> 2011, Xue <i>et al.</i> 2008
9,12,15-octadecatrenoic acid glycerol	Linoleic acid - propolis, plant (seed), animal <i>Macadamia</i>	1	Abirami & Rajendran 2011, Abozid <i>et al.</i> 2013, Choudhari & Kareppa 2013, Chaudhary <i>et al.</i> 2014, Ertas <i>et al.</i> 2014, Malainey <i>et al.</i> 1999, Krishna <i>et al.</i> 2012, Sáez <i>et al.</i> 2014
9,12-octadecadienoic acid	unknown	3	
9-desoxo-9-x-acetoxy-3,8,12-tri-O-acetylingol	plant (esssential oil of <i>Mikania scanden</i>) (Bioactive)	2	Remya & Saj 2013
acetamide	unknown	3	

Compound detected	Origin	n=	Reference(s)
androst-2-en-17-amine, 4,4-dimethyl-N-(2-phenylethyl)-, (5.alpha.)-	unknown	1	
androst-4-ene-3,20-dione, 11,16,22-triacetoxy-	unknown	1	
androst-5,7-dien-3-ol-17-one, acetate	unknown	2	
androsta-3,5-dien-3-ol	(Bioactive)	2	
azelaic acid	aged oxidation of large fatty acids (rancidity), acne cream, plant, animal	46	Al-Shammari <i>et al.</i> 2012, Eerkins 2002, Garelnabi <i>et al.</i> 2010, Nicolet & Liddle 1916
benz(a)anthracene-7-carbonitrile	unknown	1	
benzenepropanoic acid, .beta.,.beta.-dimethyl-. Methyl ester	unknown	1	
benzhydrazide, 4-(4-(4-methoxyphenyl)-5-methylthiazol-2-ylamino)-	unknown	2	
benzo(b)thiophene-4-acetic acid	unknown	1	
benzoic acid	plant (antibacterial) <i>Petalostigma</i> , <i>Ficus</i>	9	Cock & Kalt 2012, Fountain <i>et al.</i> 1995, Kalt & Cock 2014, Jeong <i>et al.</i> 2014, Saravanan <i>et al.</i> 2014
Bis(4-hydroxyphenyl)propane	plant (bioactive)	21	Kim <i>et al.</i> 2004
butylphosphonic acid, pentyl 4-(2-phenylprop-2-yl)phenyl ester	plant (antioxidant)	1	Kumar & Bhaskar 2012
cholestan-8,24-dien-3-ol, 4-methyl-, (3.beta.,4.alpha.)-	unknown	3	
cis-10-heptadecenoic acid	animal fat	1	
cyclohexylamine	unknown	1	
cyclopentanol	plant	1	Hadi <i>et al.</i> 2013, Helen <i>et al.</i> 2011, Jerkovic & Mastelic. 2001, Ramesh <i>et al.</i> 2014
decanedioic acid	sebacic acid - plant, contamination, honey	1	Byrdwell & Neff 1998, Eerkins 2002, Lachman <i>et al.</i> 2010, Senanayake 2006
D-homo-24-nor-17-oxachola-20,22-diene-3,7,16-trione, 14,15:21,23-diepoxy-4,4,8-trimethyl-, (5.alpha.,13.alpha.,14.beta.,15.beta.,17a.alpha.)-	unknown	1	
dibenzo(b,f)1,5-dioxacyclooctane, 4-methoxy-6,12-(ethylideno)-	unknown	1	
docosahexanoic acid, 1,2,3-propanetriyl ester	plant	1	Olutayo <i>et al.</i> 2013
docosanoic acid	Behenic acid - plant (seed) <i>Macadamia</i>	1	Ertas <i>et al.</i> 2014, Gaikwad <i>et al.</i> 2011, Igwe & Okwu 2013, Makhija <i>et al.</i> 2010, Sáez <i>et al.</i> 2014
dodecandioic acid	plant	1	Chinwe <i>et al.</i> 2014

Compound detected	Origin	n=	Reference(s)
dodecanedioic acid	sebacic acid - plant, contamination, honey	1	Byrdwell & Neff 1998, Eerkens 2002, Lachman <i>et al.</i> 2010, Senanayake 2006
dodecanoic acid, 2,3-bis(acetyloxy)propyl ester	plant	1	Sodipo <i>et al.</i> 2012
dodecanol	plant	1	Faridah <i>et al.</i> 2010, Sharopov <i>et al.</i> 2010, Soleimani <i>et al.</i> 2009
eicosane	(20 carbons), Plant, Burnt Plant Material	2	Kaal <i>et al.</i> 2008, Senthilkumar <i>et al.</i> 2012
eicosanoic acid	Arachidic acid - propolis, plant seed <i>macadamia</i> , animals	2	Abozid <i>et al.</i> 2013, Alhassanm <i>et al.</i> 2014, Gaikwad <i>et al.</i> 2011, Igwe & Okwu 2013, Refaat <i>et al.</i> 2013, Sáez <i>et al.</i> 2014, Suseno <i>et al.</i> 2014
eicosanol	Arachidyl Alcohol - plant	2	Kether <i>et al.</i> 2012, Josewin <i>et al.</i> 1999, Manavalan 2014, Ramasamy prava & Sen & Batra 2012, Sombié <i>et al.</i> 2013
ethanediol	ethylene glycol	10	
ethyl iso-allocholate	plant (Bioactive) <i>Ficus</i>	1	Sarada <i>et al.</i> 2011, Saravanan <i>et al.</i> 2014
glycerol	unknown	2	
Glycine, N-((3.alpha.,5.beta.,7.alpha.,12.alpha.)-24-oxo-3,7,12-trihydroxy-cholan-24-yl)-, methyl ester	amino acid derivative	3	
Glycocholic acid	unknown	1	
glyoxylic acid	unknown	1	
heptadecanoic acid, heptadecyl ester	plant	1	Bharathy & Uthayakumari 2013, Tyagi & Sharma 2014
heptanedioic acid	pimelic acid	1	
heptanoic acid	enanthic acid	4	
hexadecane	hexadecanes (16 Carbons), plant <i>Indigofera</i> , Burnt Plant Material	3	Deshpande <i>et al.</i> 2013, Kaal <i>et al.</i> 2008
hexadecanoic acid	Plant, animal, beeswax, handling, contamination	40	Abozid <i>et al.</i> 2013, Al-Shammari <i>et al.</i> 2012, Croxton <i>et al.</i> 2010, Gutiérrez <i>et al.</i> 1999, Lakshmi prava <i>et al.</i> 2012, Michalski <i>et al.</i> 2013, Maia & Nunes 2013, Malainey <i>et al.</i> 1999, Malarvizhi & Ramakrishnan 2011, Regert <i>et al.</i> 2001
hexadecanoic acid 1,1-dimethylethyl ester	plant	1	Prakash <i>et al.</i> 2011
hexadecanoic acid butyl ester	plant	4	Igwe & Okwu 2013, Sujatha <i>et al.</i> 2014
hexadecanoic acid, 1,1-dimethylethyl ester	plant	2	Prakash <i>et al.</i> 2011
hexadecanoic acid, 1-hydroxymethyl-1,2-ethanediyl ester	Plant - seed <i>Cassia</i> , leaf <i>Ormocarpum</i>	1	Kumar <i>et al.</i> 2013, Sivakumar & GajaLakshmi prava 2014
hexadecanoic acid, butyl ester	plant	3	Igwe & Okwu.2013, Sujatha <i>et al.</i> 2014
hexanedioic acid	Plant, animal, beeswax, handling,	1	Croxton <i>et al.</i> 2010, Lakshmi prava <i>et al.</i> 2012, Maia & Nunes

Compound detected	Origin	n=	Reference(s)
	contamination		2013, Malainey <i>et al.</i> 1999, Michalski <i>et al.</i> 2013, Regert <i>et al.</i> 2001
hexylmalonic acid	adipic acid, aged lipids (rancidity)	1	Mzé-Ahmed <i>et al.</i> 2011, Obenland <i>et al.</i> 2012
hydrazine, N-(3-methylbenzoyl)-N'-(2-nitrobenzoyl)-	unknown	1	
hydroxylamine, O-decyl-	plant	1	Senthilkumar <i>et al.</i> 2012
isopropylbenzene	cumene	3	
lactic acid	unknown	1	
levoglucosan	burnt organics	1	Kehrwald <i>et al.</i> 2012, Latif <i>et al.</i> 2012
methanesulfonylacetic acid	unknown	1	
monoamidoethylmalonic acid	plant	4	Zhang <i>et al.</i> 2010
monolinoleoylglycerol	plant	15	Bhuiyan <i>et al.</i> 2009, Lakshmi prava & RajaLakshmi prava 2011, Malarvizhi & Ramakrishnan 2011, Merlin <i>et al.</i> 2009, Murugesan & Panneerselvam 2013, Sheela & Uthayakumari 2013
monostearin	unknown	1	
N-(2-hydroxyethyl)-9-methyl-4-methylthio-1,2-carbazoledicarboximide	unknown	1	
N-(2-methyl-1-oxo-2-propenyl)-N-glycine	amino acid derivative	2	
naphthalene-2,6-dicarboxylic acid, pentyl ester 4-pentyl-phenyl ester	unknown	1	
narcissidine-7-one, 1,3-diacetyl-4,12-dihydro-, (1.alpha.,2.beta.,3.alpha.)-	alkaloid, plant (Bioactive)	2	de Andrade <i>et al.</i> 2012, Bastida <i>et al.</i> 2011, Santana <i>et al.</i> 2008
N-dodecylmethylamine	unknown	1	
nonanoic acid	plant, industrial use	2	Knudsen <i>et al.</i> 1993
N-tert-butylacetamide	unknown	2	
octadecandioic acid	handling, plant <i>Pandanus</i>	1	Judefeind <i>et al.</i> 2008, Mahalingam <i>et al.</i> 2012
octadecanoic acid	Plant, animal, beeswax, handling, contamination	31	Abirami & Rajendran 2011, Croxton <i>et al.</i> 2010, Gutiérrez <i>et al.</i> 1999, Malainey <i>et al.</i> 1999, Michalski <i>et al.</i> 2013, Regert <i>et al.</i> 2001
octadecanoic acid 2-methylpropyl ester	contamination	1	Stringer <i>et al.</i> 2000
octadecanoic acid butyl ester	plant	4	Nayak <i>et al.</i> 2014
octadecanoic acid, (2-phenyl-1,3-dioxolan-4-yl)methyl ester	plant	1	Hassan <i>et al.</i> 2014

Compound detected	Origin	n=	Reference(s)
octadecanoic acid, 2-methylpropyl ester	possible contamination	2	Bai <i>et al.</i> 2014
octadecanoic acid, ethyl ester	plant <i>Cissus</i> , insects	1	Babu <i>et al.</i> 2014, Kumar <i>et al.</i> 2012, Lacheva 2014, Sivagurunathan 2014
octadecanol	unknown	4	
octanedioic acid	suberic acid - plant	6	Eerkins 2002, Ertas <i>et al.</i> 2014, Yayli et al 2001
octanol	unknown	1	
oxalic acid	plant	1	Haytowitz & Matthews 1984
oxanilic acid	unknown	5	
oxirane, 2,2'-((1-methylethylidene)bis(4,1-phenyleneoxymethylene))bis-	unknown	7	
pentadecan-2-ol	unknown	1	
phenol	plant <i>Ficus</i>	8	Saravanan <i>et al.</i> 2014
phenylalanine, 4-amino-N-t-butyloxycarbonyl-, t-butyl ester	amino acid derivative	3	
phenylpropylamine, N-acetyl-3,4-dimethoxy-	unknown	1	
phosphate	unknown	16	
phthalic acid, 6-ethyl-3-octyl isobutyl ester	plant	2	Renjie <i>et al.</i> 2010
phthalic acid, butyl 2-methylpropyl ester	unknown	1	
phthalic acid, butyl decyl ester	plant	2	Ranganathan 2014
phthalic acid, butyl dodecyl ester	unknown	2	
phthalic acid, butyl hexyl ester	plant	1	Dev <i>et al.</i> 2011, Hossain <i>et al.</i> 2011
phthalic acid, butyl nonyl ester	contamination	2	
phthalic acid, butyl tetradecyl ester	unknown	1	
phthalic acid, butyl undec-2-en-1-yl ester	unknown	2	
phthalic acid, butyl undecyl ester	unknown	1	
phthalic acid, decyl 2-ethylhexyl ester	unknown	1	
phthalic acid, decyl hex-2-yn-4-yl ester	unknown	1	
phthalic acid, dibutyl ester	Plant, contamination	1	Al-Shammari <i>et al.</i> 2012, Prasad & Suresh 2012, Zhao & Yang 2008
phthalic acid, isobutyl octadecyl ester	plant <i>Solanum</i>	1	Chen-xing <i>et al.</i> 2014, Kaushik <i>et al.</i> 2014, Ren & Tian 2012
phthalic acid, isodecyl octyl ester	unknown	1	

Compound detected	Origin	n=	Reference(s)
phthalic acid, octyl tridec-2-yn-1-yl ester	plant	2	Senthilkumar <i>et al.</i> 2012
Pregan-20-one, 2-hydroxy-5,6-epoxy-15-methyl-	propolis-beeswax (Bioactive)	5	Abozid <i>et al.</i> 2013, Shubharani <i>et al.</i> 2014
propylbenzene	unknown	2	
propylene glycol	unknown	1	
prosta-5,13-dien-1-oic acid, 9,11,15-trihydroxy-, (5Z,9.alpha.,11.alpha.,13E, 15S)-	unknown	1	
Rhizoxin	fungus	1	Partida-Martinez & Hertweck 2005
scopoletin	a coumarin found in plant roots and tubers (bioactive)	1	Darmawan <i>et al.</i> 2012, Hisham <i>et al.</i> 2010, Malik <i>et al.</i> 2011, Rani <i>et al.</i> 2011, Ren <i>et al.</i> 2009, , Vipul <i>et al.</i> 2013
serine, N,O-bis(m-toluoyl)-, methyl ester	amino acid derivative	1	
serverogenin acetate	plant, e.g., <i>Trichilia</i> sp.	5	Senthilkumar <i>et al.</i> 2012
sulphur	unknown	1	
tetradecan-3-ol	unknown	1	
tetradecan-6-ol	unknown	1	
tetradecanoic acid	Myristic acid, plant <i>Calophyllum</i> , plant oils and animal fats	1	Abirami & Rajendran 2011, Al-Shammari <i>et al.</i> 2012, Azmat <i>et al.</i> 2010, Ertas <i>et al.</i> 2014, Fievez <i>et al.</i> 2011, Gnanamuthu & Rameshkumar 2014, Gutiérrez <i>et al.</i> 1999, Kale <i>et al.</i> 2011, Malarvizhi & Ramakrishnan 2011, Maruthupandian & Mohan 2011, Maya <i>et al.</i> 2006, Ogunlesi <i>et al.</i> 2010, Saravanan <i>et al.</i> 2013, Sutha <i>et al.</i> 2011
trans-1,1'-bibenzoindanylidene	unknown	1	
tridecan-2-ol	bacteria, plant, insect	2	Bruschini <i>et al.</i> 2006, Chikhi <i>et al.</i> 2012, Weise <i>et al.</i> 2012
tridecanol	plant	1	Wanzala <i>et al.</i> 2014, Kuljanabhagavad <i>et al.</i> 2010
Tyramine	alkaloid - plant (Toxic) <i>Acacia</i> , <i>Phalaris</i>	1	Adams & Camp 1966, Camp & Norvell 1966, Clement <i>et al.</i> 1998, Culvenor <i>et al.</i> 2005

Table D2: Compounds detected within the residue mixtures sampled from the ground and unground surfaces of the Lake Mungo grinding stones, where n = number of grinding surfaces (ground + unground) with compound present.

Compound detected	Origin	n=	Reference(s)
15-isopropenyl-oxacyclopentadecan-2-one	unknown	1	
1-ethyl-4-methylbenzene	plant residue, seed and/or nut; plant <i>Vitex</i>	5	Ciganek <i>et al.</i> 2007, de Lacy Costello <i>et al.</i> 2001, Janakiraman <i>et al.</i> 2012, Omikorede <i>et al.</i> 2012
2-hydroxypropanoic acid	lactic acid	2	
4,6-dimethyl-2-thioxo-1,2-dihydro-3-pyridinecarbonitrile	unknown	1	
azelaic acid	degraded fatty acids	4	
benzo(b)thiophene-4-acetic acid	unknown	1	
benzoic acid	plant (antibacterial) <i>Petalostigma</i> , <i>Ficus</i>	1	Cock & Kalt 2012, Fountain <i>et al.</i> 1995, Kalt & Cock 2014, Jeong <i>et al.</i> 2014, Saravanan <i>et al.</i> 2014
heptanoic acid	enanthic acid	1	
hexadecanoic acid	Plant, animal, beeswax, handling, contamination	4	Abozid <i>et al.</i> 2013, Al-Shammari <i>et al.</i> 2012, Croxton <i>et al.</i> 2010, Gutiérrez <i>et al.</i> 1999, Lakshmi prava <i>et al.</i> 2012, Michalski <i>et al.</i> 2013, Maia & Nunes 2013, Malainey <i>et al.</i> 1999, Malarvizhi & Ramakrishnan 2011, Regert <i>et al.</i> 2001
isopropylbenzene	cumene	1	
monoamidoethylmalonic acid	plant	1	Zhang <i>et al.</i> 2010
monolinoleoylglycerol	plant	2	Bhuiyan <i>et al.</i> 2009, Lakshmi prava & RajaLakshmi prava 2011, Malarvizhi & Ramakrishnan 2011, Merlin <i>et al.</i> 2009, Murugesan & Panneerselvam 2013, Sheela & Uthayakumari 2013
octadecanoic acid	Plant, animal, beeswax, handling, contamination	1	Abirami & Rajendran 2011, Croxton <i>et al.</i> 2010, Gutiérrez <i>et al.</i> 1999, Malainey <i>et al.</i> 1999, Michalski <i>et al.</i> 2013, Regert <i>et al.</i> 2001
oxanilic acid	unknown	1	

Table D3: Compounds detected within the residue mixtures sampled from the MJB grinding stones

GS no	Surface no	GC-MS lab no	sampling solvent	Compounds detected	Interpretation	Figure no.
GS 1	1	EH1 (run1)	EWA	Glycocholic acid Glycine, N-((3.alpha.,5.beta.,7.alpha.,12.alpha.)-24-oxo-3,7,12-trihydroxy-cholan-24-yl)-, methyl ester 9-desoxo-9-x-acetoxy-3,8,12-tri-O-acetylingol 7aH-cyclopenta(a)cyclopropa(f)cycloundecene-2,4,7,7a,10,11-hexol, 1,1a,2,3,4,4a,5,6,7,10,11,11a-dodecahydro-1,1,3,6,9-pentamethyl-, 2,4,7,10,11-pentaacetate Glycine, N-((3.alpha.,5.beta.,7.alpha.,12.alpha.)-24-oxo-3,7,12-trihydroxy-cholan-24-yl)-, methyl ester 3,9.beta.;14,15-diepoxy pregn-16-en-20-one, 3,11.beta., 18-triacetoxy-2,4-imidazolidinedione, 5-(3,4-dihydroxy-phenol)-3-methyl-5-phenyl-hexadecanoic acid, 1-hydroxymethyl-1,2-ethanediyl ester hexadecanoic acid, 1-hydroxymethyl-1,2-ethanediyl ester	plant residue may be from leaf and/or seed (Bioactive)	E1.1
	1	EH1 (run2)	EWA	acetamide ethanediol ethanediol 2-hydroxy-3-methyl-benzoic acid phosphate N-dodecylmethylamine 2-(hydroxymethyl)phenol 4-(hydroxymethyl)phenol 3-methyl-12-pyridin-2-yl-8,9,10,12-tetragydro-7H-benzo(b)(4,7)phenanthroline-11-one 2,6-ditertbutylphenol 2(3H)-naphthalenone, 3-hydroxy-4,4a,5,6,7,8-hexahydro-1,4a-dimethyl-7-(1-methylethenyl)-, (3S-(3.alpha.,4a.alpha.,7.alpha.))- 2-phenyl-2-oxophenyl-propane 2-hydroxypentadecane 2,4-diphenyl-4-methyl-2E-pentene 2-phenyl-2-oxophenyl-propane monolinoleoylglycerol 11-norcanabinol-9-carboxylic acid hexadecanoic acid 2,2,4-trimethyl-4-(4'-oxyphenol)chromane Bis(4-hydroxyphenyl)methane 2,6-bis(1,1-dimethylethyl)-4-(1-methyl-1-phenylethyl)-phenol	plant residue may be from leaf and/or seed (Bioactive)	–

GS no	Surface no	GC-MS lab no	sampling solvent	Compounds detected	Interpretation	Figure no.
GS 1 (cont).	1	EH1 (run2) (cont).	EWA	1,1',2,2'-tetrahydro-1,1'-dimethoxy-carotene Bis(4-hydroxyphenyl)methane 6-(7-nitrobenzofurazan-4-yl)amino-morphinan-4,5-epoxy-3,6-di-ol 5,8,11-eicosatriynoic acid octadecanoic acid 2-methoxy-3-methyl-phenol butylphosphonic acid, pentyl 4-(2-phenylprop-2-yl)phenyl ester 2,4-bis(dimethylbenzyl)-6-t-butylphenol 2,4-diphenyl-4-methyl-2(E)-pentene	plant residue may be from leaf and/or seed (Bioactive)	
	1	EH2	EWA	2,4-diphenyl-4-methyl-2(E)-pentene	residue not identifiable	E1.2
	1	EH174	water	–	no residue detected	E1.3
	soil	EH268	–	–	no residue detected	E1.4
GS 2	1	EH3	EWA	2-ethylhexanoic acid oxalic acid 2-naphthol, 1-(4-dimethylaminophenyl)azo- 1H-indene, 2,3-dihydro-1,1,3-trimethyl-3-phenyl- 2,4-diphenyl-4-methyl-2(E)-pentene 2-phenyl-2-oxophenyl-propane octadecanoic acid, (2-phenyl-1,3-dioxolan-4-yl)methyl ester hexadecanoic acid oxirane, 2,2'-((1-methylethylidene)bis(4,1-phenyleneoxymethylene))bis- Bis(4-hydroxyphenyl)methane 2,6-bis(1,1-dimethylethyl)-4-(1-methyl-1-phenylethyl)-phenol cholesta-8,24-dien-3-ol, 4-methyl-, (3.beta.,4.alpha.)- Rhizoxin	plant residue	E2.1
	2	EH4	EWA	methanesulfonylacetic acid 2,4-diphenyl-4-methyl-2(E)-pentene phthalic acid, 6-ethyl-3-octyl isobutyl ester phthalic acid, butyl dodecyl ester 2,6-bis(1,1-dimethylethyl)-4-(1-methyl-1-phenylethyl)-phenol 2,4-bis(dimethylbenzyl)-6-t-butylphenol	plant residue	E2.2
	1	EH175	water	–	no residue detected	E2.3

GS no	Surface no	GC-MS lab no	sampling solvent	Compounds detected	Interpretation	Figure no.
GS 2 (cont).	soil	EH269	water	phosphate azelaic acid hexadecanoic acid 1-monolinoleoylglycerol octadecanoic acid N-tert-butylacetamide	plant residue, decaying fatty acids, handling residue	E3.4
GS 3	2	EH5	EWA	2-ethylhexanoic acid 2,4-diphenyl-4-methyl-2(E)-pentene 2-phenyl-2-oxophenyl-propane hexadecanoic acid cholesta-8,24-dien-3-ol, 4-methyl-, (3.beta.,4.alpha.)- 2,4-bis(dimethylbenzyl)-6-t-butylphenol N-tert-butylacetamide	plant residue	E3.1
	2	EH6	EWA	4-(1,1,3,3-tetramethylbutyl)phenol 2-phenyl-2-oxophenyl-propane dodecandioic acid	plant residue, animal residue traces of highly degraded blood, degraded fatty acids (plant or animal)	E3.2
				(2,8,12,18-tetraethyl-3,7,13,17-tetramethyl-21H, 23H-porphinato(2-)-N21,N22,N23,N24)-, (SP-4-1)- 2,4-diphenyl-4-methyl-2(E)-pentene cis-10-heptadecenoic acid hexadecanoic acid butyl ester		
	1	EH176	water	–	no residue detected	E3.3
	2	EH177	water	–	no residue detected	E3.4
	soil	EH270	–	–	no residue detected	E3.5
GS 4	1	EH7	EWA	ethanediol ethanediol ethanediol cyclohexylamine 1-cyclohexenol 2-hydroxypropanoic acid 2-ethylhexanoic acid benzoic acid phosphate 2-(hydroxymethyl)phenol 2-phenyl-2-oxophenyl-propane	plant residue, handling residues	E4.1

GS no	Surface no	GC-MS lab no	sampling solvent	Compounds detected	Interpretation	Figure no.
GS 4 (cont).	1	EH7 (cont).	EWA	hexadecanoic acid oxirane, 2,2'-((1-methylethylidene)bis(4,1-phenyleneoxymethylene))bis-Bis(4-hydroxyphenyl)methane 2,6-bis(1,1-dimethylethyl)-4-(1-methyl-1-phenylethyl)-phenol Bis(4-hydroxyphenyl)methane octadecanoic acid 2,4-imidazolidinedione, 5-(3,4-dihydroxy-phenol)-3-methyl-5-phenyl-1-hydroxy-4-hydroxymethyl-phenol 2,4-bis(dimethylbenzyl)-6-t-butylphenol	plant residue, handling residues	E4.1
	1	EH8	EWA	2,6-dihydroxybenzoic acid 2,4-dihydroxy-3-methylbenzoic acid 2-ethylhexanoic acid benzoic acid 2-phenyl-2-oxophenyl-propane oxirane, 2,2'-((1-methylethylidene)bis(4,1-phenyleneoxymethylene))bis-	plant residue, handling residues	E4.2
	1	EH178	water	–	no residue detected	E4.3
	soil	EH271	–	–	no residue detected	E4.4
GS 5	1	EH9	EWA	2-ethylhexanoic acid benzoic acid 2-phenyl-2-oxophenyl-propane 2,4,6-trimethyldecane 5-methyl-2-phenylindolizine dodecanol 5,8-diethyldodecane 2-phenyl-2-oxophenyl-propane phenylpropylamine, N-acetyl-3,4-dimethoxy- 2-phenyl-2-oxophenyl-propane hexadecanoic acid 2,2,4-trimethyl-4-(4'-oxyphenol)chromane Bis(4-hydroxyphenyl)methane 2,6-bis(1,1-dimethylethyl)-4-(1-methyl-1-phenylethyl)-phenol 1,1',2,2'-tetrahydro-1,1'-dimethoxy-carotene Bis(4-hydroxyphenyl)methane octadecanoic acid 2,4-bis(dimethylbenzyl)-6-t-butylphenol	plant residue (Bioactive)	E5.1

GS no	Surface no	GC-MS lab no	sampling solvent	Compounds detected	Interpretation	Figure no.
GS 5 (cont).	1	EH10	EWA	ethanediol phenol phenol 2-hydroxy-ethanoic acid 2-hydroxy-ethanoic acid 2-ethylhexanoic acid benzoic acid glycerol 2-methoxyphenol 2,6,10-trimethyl-tetradecane 2,6-dimethyl-heptadecane octanol 2,4-bis(dimethylbenzyl)-6-t-butylphenol 2-phenyl-2-oxophenyl-propane 2-tert-butyl-4-methyl-6-(a-methylbenzyl)phenol serverogenin acetate phthalic acid, butyl nonyl ester hexadecanoic acid (4-hydroxyphenyl)(2-hydroxyphenyl)methane 2,6-bis(1,1-dimethylethyl)-4-(1-methyl-1-phenylethyl)-phenol Bis(4-hydroxyphenyl)methane acetonitrile octadecanoic acid 2,4-bis(dimethylbenzyl)-6-t-butylphenol	plant residue, including wood or fruit (<i>Ficus</i> sp.?)	E5.2
	1	EH179	water	–	no residue detected	E5.3
	soil	EH272	–	–	no residue detected	E5.4
GS 6	1	EH180	water	hexadecanoic acid octadecanoic acid	handling residue	E6.1
	soil	EH273		–	no residue detected	E6.2
GS 7	1	EH11	EWA	phenol 2-ethylhexanoic acid benzoic acid 2-phenyl-2-oxophenyl-propane nonanoic acid 2-hydroxymethylphenol hexadecane 17-octadecynoic acid	plant residue, possibly honey (propolis), bark, seed or leaf	E7.1

GS no	Surface no	GC-MS lab no	sampling solvent	Compounds detected	Interpretation	Figure no.
GS 7 (cont).	1	EH11 (cont).	EWA	2,4-diphenyl-4-methyl-2(E)-pentene 2-phenyl-2-oxophenyl-propane hexadecanoic acid oxirane, 2,2'-((1-methylethylidene)bis(4,1-phenyleneoxymethylene))bis-(4-hydroxyphenyl)(2-hydroxyphenyl)methane 2,6-bis(1,1-dimethylethyl)-4-(1-methyl-1-phenylethyl)-phenol Pregan-20-one, 2-hydroxy-5,6-epoxy-15-methyl- 5,8,11-eicosatriynoic acid Bis(4-hydroxyphenyl)methane 5,8,11-eicosatriynoic acid 2,4-bis(dimethylbenzyl)-6-t-butylphenol	as above	E7.1
	1	EH12	EWA	2-ethylhexanoic acid 2-ethylhexanoic acid hydroxylamine, O-decyl- 10-methylundecanoic acid, methyl ester 2,4-diphenyl-4-methyl-2(E)-pentene 2-methylbenzoic acid anhydride 2,4-diphenyl-4-methyl-2(E)-pentene Glycine, N-((3.alpha.,5.beta.,7.alpha.,12.alpha.)-24-oxo-3,7,12-trihydroxy-cholan-24-yl)-, methyl ester 2-tert-butyl-4-methyl-6-(a-methylbenzyl)phenol phthalic acid, butyl undec-2-en-1-yl ester phthalic acid, decyl hex-2-yn-4-yl ester 2-(1,1-dimethylethyl)-4-(1-methyl-1-phenylethyl)-phenol 2,6-bis(1,1-dimethylethyl)-4-(1-methyl-1-phenylethyl)-phenol 2-(1,1-dimethylethyl)-4-(1-methyl-1-phenylethyl)-phenol ethyl iso-allocholate 9-(methoxyimino)-11,15-dihydroxy-Prost-13-en-1-oic acid serine, N,O-bis(m-toluoyl)-, methyl ester 2,4-bis(dimethylbenzyl)-6-t-butylphenol 2,4-bis(1-methyl-1-phenylethyl)-phenol	plant residue, high amino acid content which might be nut or seed	E7.2
	1	EH181	water	hexadecanoic acid octadecanoic acid	handling residues	E7.3
	soil	EH274	–	hexadecanoic acid octadecanoic acid	handling residues	E7.4

GS no	Surface no	GC-MS lab no	sampling solvent	Compounds detected	Interpretation	Figure no.
GS 8	1	EH13	EWA	1,1'-biphenyl, 4,4'-dinitro- 2-hydroxy-2-cyclopenten-1-one phenol 2-hydroxypropanoic acid 2-ethylhexanoic acid benzoic acid phosphate 2-hydroxymethyl-phenol 2-methylnonadecane 4-hydroxybenzaldehyde 2,4-diphenyl-4-methyl-2(E)-pentene 2-phenyl-2-oxophenyl-propane serverogenin acetate hexadecanoic acid 11-norcannabinol-9-carboxylic acid Bis(4-hydroxyphenyl)methane 2,6-bis(1,1-dimethylethyl)-4-(1-methyl-1-phenylethyl)-phenol Bis(4-hydroxyphenyl)methane Tyramine hexadecanoic acid, 1,1-dimethylethyl ester octadecanoic acid serverogenin acetate 2-hydroxy-4-hydroxymethyl-phenol 2,4-bis(dimethylbenzyl)-6-t-butylphenol	plant residue, possibly seeds; bioactive properties and possible toxic substances	E8.1
	2	EH14	EWA	1H-indene, 2,3-dihydro-1,1,3-trimethyl-3-phenyl- 2,4-diphenyl-4-methyl-2(E)-pentene phthalic acid, octyl tridec-2-yn-1-yl ester 2,6,10,15-tetramethyl-heptadecane 2-(1,1-dimethylethyl)-4-(1-methyl-1-phenylethyl)-phenol 2,6-bis(1,1-dimethylethyl)-4-(1-methyl-1-phenylethyl)-phenol hexadecanoic acid, butyl ester heptadecanoic acid, heptadecyl ester 2,6,10,15-tetramethyl-heptadecane 2,6,10,15-tetramethyl-heptadecane 2,4-bis(dimethylbenzyl)-6-t-butylphenol 2,4-bis(1-methyl-1-phenylethyl)-phenol 1,2-propanediol, 3-(octadecyloxy)- acetate	plant residue, leaf is more likely as it contains a high number of hydrocarbons commonly found in leaf wax and seed husks	E8.2

GS no	Surface no	GC-MS lab no	sampling solvent	Compounds detected	Interpretation	Figure no.
GS 8 (cont).	1	EH182	water	hexadecanoic acid octadecanoic acid	handling residues	E8.3
	soil	EH275	–	–	no residue detected	E8.4
GS 9	1	EH15	EWA	2,6,10-trimethyl-tetradecane 1H-indene, 2,3-dihydro-1,1,3-trimethyl-3-phenyl-4,4'-(1-methylethylidene)bis(2,6-dimethyl)-phenol phthalic acid, butyl tetradecyl ester 2-ethyl-2-methyl-tridecanol phenylalanine, 4-amino-N-t-butyloxycarbonyl-, t-butyl ester hexadecanoic acid 2-(1,1-dimethylethyl)-4-(1-methyl-1-phenylethyl)-phenol 2-methyl-eicosane 1,1',2,2'-tetrahydro-1,1'-dimethoxy-carotene hexadecanoic acid butyl ester 2,6,10,15-tetramethyl-heptadecane eicosane eicosane 2,6,10,15-tetramethyl-heptadecane octadecanol 2,4-bis(dimethylbenzyl)-6-t-butylphenol 2,6,10,15-tetramethyl-heptadecane	plant residue, amino acids present high number of hydrocarbons, leaf and nut or seed	E9.1
	1	EH183	water	–	no residue detected	E9.2
	soil	EH276	–	hexadecanoic acid octadecanoic acid	handling residues	E9.3
GS 10	1	EH16	EWA	1H-indene, 2,3-dihydro-1,1,3-trimethyl-3-phenyl-2,4-diphenyl-4-methyl-2(E)-pentene phthalic acid, butyl undecyl ester 2-(1,1-dimethylethyl)-4-(1-methyl-1-phenylethyl)-phenol 2,6-bis(1,1-dimethylethyl)-4-(1-methyl-1-phenylethyl)-phenol hexadecanoic acid, butyl ester octadecanoic acid, 2-methylpropyl ester 2,4-bis(dimethylbenzyl)-6-t-butylphenol 2,4-bis(1-methyl-1-phenylethyl)-phenol 1-hexacosene	plant residue, high hydrocarbons, leaf, seed and/or nut	E10.1

GS no	Surface no	GC-MS lab no	sampling solvent	Compounds detected	Interpretation	Figure no.
GS 10 (cont).	1	EH184	water	azelaic acid hexadecanoic acid octadecanoic acid	handling residues, degraded fatty acid, unknown sources	E10.2
	soil	EH277	–	–	no residue detected	E10.3
GS 13	1	EH17	EWA	2,6,10-trimethyldecane 1H-indene, 2,3-dihydro-1,1,3-trimethyl-3-phenyl- 2,4-diphenyl-4-methyl-2(E)-pentene phthalic acid, octyl tridec-2-yn-1-yl ester phthaic acid, butyl hexyl ester 2-(1,1-dimethylethyl)-4-(1-methyl-1-phenylethyl)-phenol 2,6-bis(1,1-dimethylethyl)-4-(1-methyl-1-phenylethyl)-phenol hexadecanoic acid, butyl ester 1-hexacosene octadecanoic acid, 2-methylpropoyl ester 2,4-bis(dimethylbenzyl)-6-t-butylphenol phthalic acid, 2-ethylhexyl neopentyl ester	plant residue, carbohydrate and hydrocarbons, roots, seeds or leaves	E11.1
	1	EH185	water	–	no residue detected	E11.2
	soil	EH278	–	–	no residue detected	E11.3
GS 14	1	EH18	EWA	1H-indene, 2,3-dihydro-1,1,3-trimethyl-3-phenyl- 2,4-diphenyl-4-methyl-2(E)-pentene naphthalene-2,6-dicarboxylic acid, pentyl ester 4-pentyl-phenyl ester 2-tert-butyl-4-methyl-6-(a-methylbenzyl)phenol 2-(1,1-dimethylethyl)-4-(1-methyl-1-phenylethyl)-phenol 2,6-bis(1,1-dimethylethyl)-4-(1-methyl-1-phenylethyl)-phenol 2,4-bis(dimethylbenzyl)-6-t-butylphenol 2,4-bis(1-methyl-1-phenylethyl)-phenol	plant residue, carbohydrates, roots	E12.1
	1	EH19	EWA	phenol 2-hydroxymethylphenol 5-methylpentadecane 1-acetyl-4-amino-5-ethyl-2,5-dihydro-1H-pyrrole-3-carbonitrile 2,4-diphenyl-4-methyl-2(E)-pentene 2-phenyl-2-oxophenyl-propane 11-norcanabinol-9-carboxylic acid Bis(4-hydroxyphenyl)methane 2,6-bis(1,1-dimethylethyl)-4-(1-methyl-1-phenylethyl)-phenol Bis(4-hydroxyphenyl)methane 5,8,11,14-eicosatetraynoic acid	plant residue (Bioactive)	E12.2

GS no	Surface no	GC-MS lab no	sampling solvent	Compounds detected	Interpretation	Figure no.
GS 14 (cont).	1	EH19 (cont).	EWA	hexadecanoic acid, 1,1-dimethylethyl ester docosahexanoic acid, 1,2,3-propanetriyl ester 2,4-bis(dimethylbenzyl)-6-t-butylphenol 2,4-bis(1-methyl-1-phenylethyl)-phenol 2,4-bis(1-methyl-1-phenylethyl)-phenol	plant residue (Bioactive)	E12.2
	1	EH186	water	2-hydroxypropanoic acid hexadecanoic acid octadecanoic acid	residue not identifiable, handling residue	E12.3
	soil	EH279	–	–	no residue detected	E12.4
GS 15	1	EH20	EWA	4,6-dimethyl-2-thioxo-1,2-dihydro-3-pyridinecarbonitrile 2,4-diphenyl-4-methyl-2(E)-pentene 2,6-bis(1,1-dimethylethyl)-4-(1-methyl-1-phenylethyl)-phenol 2,4-bis(dimethylbenzyl)-6-t-butylphenol 2,4-bis(1-methyl-1-phenylethyl)-phenol 2,4-bis(1-methyl-1-phenylethyl)-phenol	plant residue (very limited)	E13.1
	1	EH187	water	hexadecanoic acid octadecanoic acid	handling residues	E13.2
	soil	EH280	–	–	no residue detected	E13.3
GS 16	2	EH21	EWA	1,2-benzisothiazol-3-amine phenol phosphate 2,4,6-trimethyloctane dodecanedioic acid 2,4-diphenyl-4-methyl-2(E)-pentene tetradecanoic acid narcissidine-7-one, 1,3-diacetyl-4,12-dihydro-, (1.alpha.,2.beta.,3.alpha.)-	plant residue (bioactive), alkaloids	E14.1
	1	EH22	EWA	2,6,10-trimethyltetradecane 1H-indene, 2,3-dihydro-1,1,3-trimethyl-3-phenyl- 2,4-diphenyl-4-methyl-2(E)-pentene 2,6-bis(1,1-dimethylethyl)-4-(1-methyl-1-phenylethyl)-phenol Pregan-20-one, 2-hydroxy-5,6-epoxy-15-methyl- 9-desoxo-9-x-acetoxy-3,8,12-tri-O-acetylingol 2,4-bis(dimethylbenzyl)-6-t-butylphenol 2,4-bis(1-methyl-1-phenylethyl)-phenol 2,4-bis(1-methyl-1-phenylethyl)-phenol	plant residue (Bioactive)	E14.2
	1	EH188	water	–	no residue detected	E14.3

GS no	Surface no	GC-MS lab no	sampling solvent	Compounds detected	Interpretation	Figure no.
GS 16	soil	EH281	–	–	no residue detected	E14.4
GS 18	1	EH23	EWA	2,4-diphenyl-4-methyl-2(E)-pentene phthalic acid, dibutyl ester 2,6-bis(1,1-dimethylethyl)-4-(1-methyl-1-phenylethyl)-phenol hexadecanoic acid butyl ester 1-hexacosene octadecanoic acid butyl ester 2,4-bis(dimethylbenzyl)-6-t-butylphenol 2,4-bis(1-methyl-1-phenylethyl)-phenol	plant residue, seed and/or nuts	E15.1
	2	EH24	EWA	ethanediol phenol 2-hydroxypropanoic acid glycerol 2-hydroxymethylphenol 2,6-ditertbutyl-phenol 2,4-diphenyl-4-methyl-2(E)-pentene 2-phenyl-2-oxophenyl-propane D-homo-24-nor-17-oxachola-20,22-diene-3,7,16-trione, 14,15:21,23-diepoxy-4,4,8-trimethyl-, (5.alpha.,13.alpha.,14.beta.,15.beta.,17a.alpha.)- phthalic acid, butyl dodecyl ester oxirane, 2,2'-((1-methylethylidene)bis(4,1-phenyleneoxymethylene))bis- oxirane, 2,2'-((1-methylethylidene)bis(4,1-phenyleneoxymethylene))bis- 2'-oxophenyl-4'-oxophenyl-methane 2,6-bis(1,1-dimethylethyl)-4-(1-methyl-1-phenylethyl)-phenol Bis(4-hydroxyphenyl)methane 2,4-bis(dimethylbenzyl)-6-t-butylphenol	plant residue (Bioactive)	E15.2
	1	EH25	EWA	1H-indene, 2,3-dihydro-1,1,3-trimethyl-3-phenyl- 2,4-diphenyl-4-methyl-2(E)-pentene 2,6-bis(1,1-dimethylethyl)-4-(1-methyl-1-phenylethyl)-phenol 1,5-cyclooctadiene, 3,4,7,8-tetrakis(1-methylethylidene)- 1,5-cyclooctadiene, 3,4,7,8-tetrakis(1-methylethylidene)- hydrazine, N-(3-methylbenzoyl)-N'-(2-nitrobenzoyl)- 2,4-bis(dimethylbenzyl)-6-t-butylphenol 2,6-bis(1,1-dimethylethyl)-4-(1-methyl-1-phenylethyl)-phenol	plant residue, seed and/or nut, roots	E15.3
GS 19	1	EH26	EWA	1H-indene, 2,3-dihydro-1,1,3-trimethyl-3-phenyl- 2,4-diphenyl-4-methyl-2(E)-pentene 2,6-bis(1,1-dimethylethyl)-4-(1-methyl-1-phenylethyl)-phenol	plant residue, seed and/or nut, roots	E16.1

GS no	Surface no	GC-MS lab no	sampling solvent	Compounds detected	Interpretation	Figure no.
GS 19 (cont).	1	EH26 (cont).	EWA	1,5-cyclooctadiene, 3,4,7,8-tetrakis(1-methylethylidene)-hexadecanoic acid butyl ester 1-heptadecanol acetate octadecanoic acid butyl ester octadecanoic acid 2-methylpropyl ester 2,4-bis(dimethylbenzyl)-6-t-butylphenol 2,6-bis(1,1-dimethylethyl)-4-(1-methyl-1-phenylethyl)-phenol	plant residue, seed and/or nut, roots	E16.1
	1	EH189	water	–	no residue detected	E16.2
	soil	EH282	–	–	no residue detected	E16.3
GS 20	1	EH27	EWA	phenol 2-hydroxymethylphenol 2,6,10-trimethyltetradecane 2,4-diphenyl-4-methyl-2(E)-pentene 4,4'-(1-methylethylidene)bis(2,6-dimethyl-phenol) (1,1,2-trimethylpropyl)-benzene 2,4-diphenyl-4-methyl-2(E)-pentene 2,4,7,14-tetramethyl-4-vinyl-tricyclo(5.4.3.0(1,8))tetradecan-6-ol 2-phenyl-2-oxophenyl-propane 2-tert-butyl-4-methyl-6-(a-methylbenzyl)phenol phthalic acid, isobutyl octadecyl ester oxirane, 2,2'-((1-methylethylidene)bis(4,1-phenyleneoxymethylene))bis-Bis(4-hydroxyphenyl)methane 2,6-bis(1,1-dimethylethyl)-4-(1-methyl-1-phenylethyl)-phenol dibenzo(b,f)1,5-dioxacyclooctane, 4-methoxy-6,12-(ethylideno)- 1,5-cyclooctadiene, 3,4,7,8-tetrakis(1-methylethylidene)- hexadecanoic acid, 1,1-dimethylethyl ester 2,4-bis(dimethylbenzyl)-6-t-butylphenol 2,4-bis(1-methyl-1-phenylethyl)-phenol	plant residue, seed and/or nut, root (Bioactive)	E17.1
	1	EH190	water	monolinoleoylglycerol hexadecanoic acid monolinoleoylglycerol octadecanoic acid	plant residue, handling residue	E17.2
	soil	EH283	–	–	no residue detected	E17.3
GS 21	1	EH28	EWA	7-methylhexadecane 1H-indene, 2,3-dihydro-1,1,3-trimethyl-3-phenyl-serverogenin acetate 2,4,4,6-tetramethyl-6-phenyl-1-heptene	Plant residue, nut or seed	EH18.1

GS no	Surface no	GC-MS lab no	sampling solvent	Compounds detected	Interpretation	Figure no.
GS 21 (cont).	1	EH28 (cont).	EWA	2,4-diphenyl-4-methyl-2(E)-pentene androst-5,7-dien-3-ol-17-one, acetate Pregan-20-one, 2-hydroxy-5,6-epoxy-15-methyl-phthalic acid, butyl tridec-2-yn-1-yl ester phenylalanine, 4-amino-N-t-butyloxycarbonyl-, t-butyl ester 4,6-bis(t-butyl)-2-(dimethylbenzyl)phenol 2,6-bis(1,1-dimethylethyl)-4-(1-methyl-1-phenylethyl)-phenol 1,5-cyclooctadiene, 3,4,7,8-tetrakis(1-methylethylidene)- 2,6-dimethyl-4,4-tetramethylene-1,4-dihydropyridine-3,5-dicarbonitrile 2,4-bis(dimethylbenzyl)-6-t-butylphenol 2,6-bis(1,1-dimethylethyl)-4-(1-methyl-1-phenylethyl)-phenol	plant residue, nut or seed	E18.1
	1	EH29	EWA	1H-indene, 2,3-dihydro-1,1,3-trimethyl-3-phenyl- 2,4-diphenyl-4-methyl-2(E)-pentene 2,6-bis(1,1-dimethylethyl)-4-(1-methyl-1-phenylethyl)-phenol androst-5,7-dien-3-ol-17-one, acetate 2,4-bis(dimethylbenzyl)-6-t-butylphenol 2,6-bis(1,1-dimethylethyl)-4-(1-methyl-1-phenylethyl)-phenol	plant residue, roots, seeds and/or nuts	E18.2
	1	EH191	water	hexadecanoic acid octadecanoic acid	handling residue	E18.3
	soil	EH284	–	phthalic acid, butyl 2-methylpropyl ester 1,3-dioxane, 4-(hexadecyloxy)-2-pentadecyl-	plant residue	E18.4
GS 22	1	EH30	EWA	1H-indene, 2,3-dihydro-1,1,3-trimethyl-3-phenyl- 2,4-diphenyl-4-methyl-2(E)-pentene 2,6-bis(1,1-dimethylethyl)-4-(1-methyl-1-phenylethyl)-phenol 1H-indole-2-carboxylic acid, 3-methyl-4-oxo-6-(3,4,5-trimethoxyphenyl)-4,5,6,7-tetrahydro-, ethyl ester 2,4-bis(dimethylbenzyl)-6-t-butylphenol 2H,8H-benzo(1,2-b:5,4-b')dipyran-10-propanol, 5-methoxy-2,2,8,8-tetramethyl- 2,4-bis(1-methyl-1-phenylethyl)-phenol	plant residue, seeds, nuts or roots	E19.1
	1	EH31	EWA	hexadecane 1H-indene, 2,3-dihydro-1,1,3-trimethyl-3-phenyl- 2,4-diphenyl-4-methyl-2(E)-pentene 2,6-bis(1,1-dimethylethyl)-4-(1-methyl-1-phenylethyl)-phenol 2,4-bis(dimethylbenzyl)-6-t-butylphenol	plant residue	E19.2
	1	EH192	water	–	no residue detected	E19.3

GS no	Surface no	GC-MS lab no	sampling solvent	Compounds detected	Interpretation	Figure no.
GS 22 (cont).	soil	EH285	–	–	no residue detected	E19.4
GS 23	1	EH32	EWA	5-methyl-tetradecane 1H-indene, 2,3-dihydro-1,1,3-trimethyl-3-phenyl-benzenepropanoic acid 2,4-diphenyl-4-methyl-2(E)-pentene 2,6-bis(1,1-dimethylethyl)-4-(1-methyl-1-phenylethyl)-phenol cholestan-8,24-dien-3-ol, 4-methyl-, (3.beta.,4.alpha.)- Pregan-20-one, 2-hydroxy-5,6-epoxy-15-methyl-6-(7-nitrobenzofurazan-4-yl)amino-morphinan-4,5-epoxy-3,6-di-ol 2,4-bis(dimethylbenzyl)-6-t-butylphenol 2,4-bis(1-methyl-1-phenylethyl)-phenol	plant residue, possibly propolis	E20.1
	1	EH33	EWA	2,6-dimethyl-heptadecane 2,4-diphenyl-4-methyl-2(E)-pentene 4,4'-(1-methylethylidene)bis(2,6-dimethyl-phenol) phthalic acid, butyl nonyl ester 11-norcanabinol-9-carboxylic acid 2,6-bis(1,1-dimethylethyl)-4-(1-methyl-1-phenylethyl)-phenol 4H-1-benzopyran-4-one, 5,7-dihydroxy-2-(3,4,5-trimethoxyphenyl)- trans-1,1'-bibenzoindanylidene 1,2-propanediol, 3-(octadecyloxy)- diacetate serverogenin acetate 2,4-bis(dimethylbenzyl)-6-t-butylphenol 2,4-bis(1-methyl-1-phenylethyl)-phenol	plant residue, Bioactive, flavones	E20.2
	1	EH193	water	phosphate heptanedioic acid octanedioic acid azelaic acid decanedioic acid 5,8,11-eicosatriynoic acid hexadecanoic acid androst-4-ene-3,20-dione, 11,16,22-triacetoxy- 9,12-octadecadienoic acid octadecanoic acid 9,12-octadecadienoic acid 9,12-octadecadienoic acid	plant residue, seed	E20.3

GS no	Surface no	GC-MS lab no	sampling solvent	Compounds detected	Interpretation	Figure no.
GS 23 (cont).	1	EH193 (cont).	water	eicosanol eicosanoic acid octadecandioic acid docosanoic acid monostearin	plant residue, seed	E20.3
	soil	EH286	–	octadecanol hexadecanoic acid, 1,1-dimethylethyl ester tetradecan-6-ol	plant residue	E20.4
GS 24	1	EH34	EWA	2,4-diphenyl-4-methyl-2(E)-pentene 2-(1,1-dimethylethyl)-4-(1-methyl-1-phenylethyl)-phenol 2,6-bis(1,1-dimethylethyl)-4-(1-methyl-1-phenylethyl)-phenol 2,4-bis(dimethylbenzyl)-6-t-butylphenol 2,4-bis(1-methyl-1-phenylethyl)-phenol	plant residue	E21.1
	2	EH35	EWA	4,6-dimethyl-2-thioxo-1,2-dihydro-3-pyridinecarbonitrile 2,4-diphenyl-4-methyl-2(E)-pentene 2,6-bis(1,1-dimethylethyl)-4-(1-methyl-1-phenylethyl)-phenol 2,4-bis(dimethylbenzyl)-6-t-butylphenol 2,4-bis(1-methyl-1-phenylethyl)-phenol	plant residue, roots, nuts and/or seed	E21.2
	2	EH194	water	phosphate octanedioic acid azelaic acid	plant residue	E21.3
	soil	EH287	–	–	no residue detected	E21.4
GS 26	1	EH36	EWA	1H-indene, 2,3-dihydro-1,1,3-trimethyl-3-phenyl- 2,4-diphenyl-4-methyl-2(E)-pentene 2,6-bis(1,1-dimethylethyl)-4-(1-methyl-1-phenylethyl)-phenol 2,4-bis(dimethylbenzyl)-6-t-butylphenol 2,4-bis(1-methyl-1-phenylethyl)-phenol	plant residue	E22.1
	1	EH37	EWA	2,6,11-trimethyl-dodecane hexadecane 1H-indene, 2,3-dihydro-1,1,3-trimethyl-3-phenyl- 2,4-diphenyl-4-methyl-2(E)-pentene 2,6-bis(1,1-dimethylethyl)-4-(1-methyl-1-phenylethyl)-phenol 2,4-bis(dimethylbenzyl)-6-t-butylphenol 2,4-bis(1-methyl-1-phenylethyl)-phenol	plant residue, nuts and/or seed	E22.2
	1	EH195	water	azelaic acid	degraded fatty acid, unknown source	E22.3

GS no	Surface no	GC-MS lab no	sampling solvent	Compounds detected	Interpretation	Figure no.
GS26	soil	EH288	–	–	no residue detected	E22.4
GS 27	1	EH38	EWA	2-hydroxymethylphenol 2,4-diphenyl-4-methyl-2(E)-pentene 7-dehydrocholesteryl isocaproate Pregan-20-one, 2-hydroxy-5,6-epoxy-15-methyl- 2-phenyl-2-oxophenyl-propane phenylalanine, 4-amino-N-t-butyloxycarbonyl-, t-butyl ester narcissidine-7-one, 1,3-diacetyl-4,12-dihydro-, (1.alpha.,2.beta.,3.alpha.)- 11-norcannabinol-9-carboxylic acid Bis(4-hydroxyphenyl)methane 2,6-bis(1,1-dimethylethyl)-4-(1-methyl-1-phenylethyl)-phenol 2,4-bis(dimethylbenzyl)-6-t-butylphenol	plant residue, possibly propolis, bioactive As above	E23.1 E23.1
	soil	EH289	–	octadecanol octadecanoic acid	residue not identifiable	E23.2
GS 28	1	EH39		2,4-diphenyl-4-methyl-2(E)-pentene 2,4-diphenyl-4-methyl-2(E)-pentene 2,6-bis(1,1-dimethylethyl)-4-(1-methyl-1-phenylethyl)-phenol 2,4-bis(dimethylbenzyl)-6-t-butylphenol 2,4-bis(1-methyl-1-phenylethyl)-phenol	plant residue (limited)	E24.1
	unground surface	EH40	–	–	no residue detected	E24.2
	1	EH41		2,4-diphenyl-4-methyl-2(E)-pentene 2,6-di-tert-butyl-4-(2,4-dimethylbenzyl)phenol 2,4-bis(dimethylbenzyl)-6-t-butylphenol	plant residue (limited abundance)	E24.3
	1	EH196	water	phosphate octanedioic acid azelaic acid	plant residue (limited abundance)	E24.4
	soil	EH290		octadecanoic acid	residue not identifiable	E24.5
GS 29	1	EH42	EWA	1H-indene, 2,3-dihydro-1,1,3-trimethyl-3-phenyl- 2,4-diphenyl-4-methyl-2(E)-pentene 2,6-bis(1,1-dimethylethyl)-4-(1-methyl-1-phenylethyl)-phenol 2,4-bis(dimethylbenzyl)-6-t-butylphenol 2,4-bis(1-methyl-1-phenylethyl)-phenol	plant residue	E25.1
	1	EH43	EWA	–	no residue detected	E25.2
	1	EH197	water	azelaic acid	degraded fatty acid, unknown source	E25.3

GS no	Surface no	GC-MS lab no	sampling solvent	Compounds detected	Interpretation	Figure no.
GS 29	soil	EH291	–	–	no residue detected	E25.4
GS 30	1	EH44	EWA	2,4-diphenyl-4-methyl-2(E)-pentene 2,6-bis(1,1-dimethylethyl)-4-(1-methyl-1-phenylethyl)-phenol hexadecanoic acid, 1,1-dimethylethyl ester 2,4-bis(dimethylbenzyl)-6-t-butylphenol	plant residue, seed?	E26.1
	1	EH198	water	azelaic acid	degraded fatty acid, unknown source	E26.2
GS 30	soil	EH292	–	–	no residue detected	E26.3
GS 31	1	EH45	EWA	2,4-diphenyl-4-methyl-2(E)-pentene 2,6-di-tert-butyl-4-(2,4-dimethylbenzyl)phenol 2,4-bis(dimethylbenzyl)-6-t-butylphenol	plant residue (limited abundance)	E27.1
	1	EH199	water	1-ethyl-4-methylbenzene tetradecan-3-ol 5-hydroxy-5-methyl-2-phenyl-3-isoxazolidinone azelaic acid hexadecanoic acid octadecanoic acid	degraded fatty acid, handling residues	E27.2
	soil	EH293	–	–	no residue detected	E27.3
GS 32	1	EH 47	EWA	1H-indene, 2,3-dihydro-1,1,3-trimethyl-3-phenyl- 2-methyl-2-phenyl-tridecane 2,4-diphenyl-4-methyl-2(E)-pentene octadecanoic acid, ethyl ester 2,6-di-tert-butyl-4-(2,4-dimethylbenzyl)phenol 1,5-cyclooctadiene, 3,4,7,8-tetrakis(1-methylethylidene)- 2,4-bis(dimethylbenzyl)-6-t-butylphenol	plant residue	E28.1
	1	EH48	EWA	1H-indene, 2,3-dihydro-1,1,3-trimethyl-3-phenyl- 1,1'-(3,3-dimethyl-1-butenylidene)bis-benzene 2,6-bis(1,1-dimethylethyl)-4-(1-methyl-1-phenylethyl)-phenol	plant residue	E28.2
	2	EH49	EWA	–	no residue detected	E28.3
	1	EH201	water	azelaic acid	degraded fatty acid, unknown source	E28.4
	1	EH202	water	azelaic acid	degraded fatty acid, unknown source	E28.5

GS no	Surface no	GC-MS lab no	sampling solvent	Compounds detected	Interpretation	Figure no.
GS 32	soil	EH295	–	–	no residue detected	E28.6
GS 33	1	EH46	EWA	2,4-diphenyl-4-methyl-2(E)-pentene 2,6-bis(1,1-dimethylethyl)-4-(1-methyl-1-phenylethyl)-phenol 2,4-bis(dimethylbenzyl)-6-t-butylphenol	plant residue (limited abundance)	E29.1
	1	EH200	water	phosphate azelaic acid	degraded fatty acid, unknown source	E29.2
	soil	EH294		–	no residue detected	E29.3
GS 35	1	EH50	EWA	–	no residue detected	E30.1
	2	EH51	EWA	2-phenyl-2-oxophenyl-propane hexadecanoic acid pentadecan-2-ol (4-hydroxyphenyl)-(2-hydroxyphenyl)-methane Bis(4-hydroxyphenyl)methane androsta-3,5-dien-3-ol 3,5-bis(4-(1,1-dimethylethyl)phenyl)-2,3-dihydro-1H-indene-1-one 2,4-imidazolidinedione, 5-(3,4-dihydroxy-phenyl)-3-methyl-5-phenyl- 2,4-bis(dimethylbenzyl)-6-t-butylphenol	plant residue, bioactive	E30.2
	1	EH203	water	Bis(4-hydroxyphenyl)methane azelaic acid	plant residue (Bioactive) (very limited abundance)	E30.3
	2	EH205	water	azelaic acid	degraded fatty acid, unknown source	E30.4
	soil	EH296	–	–	no residue detected	E30.5
	1	EH52	EWA	–	sample not analysed*	–
GS 36	2	EH53	EWA	acetamide 5-(3-benzylamino-2-hydroxypropoxy)naphtho(1,2-b)thiophene 1-ethyl-2-methyl-benzene 1-ethyl-4-methyl-benzene phosphate 2,4-imidazolidinedione, 5-(3,4-dihydroxy-phenyl)-3-methyl-5-phenyl- octanedioic acid azelaic acid 2,4-imidazolidinedione, 5-(3,4-dihydroxy-phenyl)-3-methyl-5-phenyl- 4,4'-(1-methylethylidene)bis(2,6-dimethyl-phenol) hexadecanoic acid	plant residue, seed or nut (Bioactive)	E31.1

GS no	Surface no	GC-MS lab no	sampling solvent	Compounds detected	Interpretation	Figure no.
GS 36 (cont).	2	EH53 (cont).	EWA	3,9.beta.;14,15-diepoxypregn-16-en-20-one, 3,11.beta.,18-triacetoxy-2-(4-methoxy-phenyl)-6-p-tolyl-pyridine androsta-3,5-dien-3-ol octadecanoic acid eicosanol eicosanoic acid 1-monolinoleoylglycerol 5,8,11-eicosatriynoic acid	as above	E31.1
	2	EH206	water	azelaic acid	degraded fatty acid, unknown source	E31.2
	soil	EH297	–	–	no residue detected	E31.3
GS 37	1	EH54	EWA	2-ethylhexanoic acid azelaic acid monolinoleoylglycerol hexadecanoic acid monolinoleoylglycerol monolinoleoylglycerol monolinoleoylglycerol octadecanoic acid 2',6'-dihydroxyacetophenone	plant residue, root seed and/or nut	E32.1
	soil	EH298	–	–	no residue detected	E32.2
GS 38	1	EH55	EWA	azelaic acid	degraded fatty acid, unknown sources	E33.1
	2	EH56	EWA	–	no residue detected	E33.2
	1	EH207	water	azelaic acid	degraded fatty acid, unknown source	E33.3
	2	EH208	water	azelaic acid	degraded fatty acid, unknown source	E33.4
	soil	EH299	–	–	no residue detected	E33.5
GS 39	1	EH57	EWA	acetamide propylbenzene 1-ethyl-2-methyl-benzene isopropylbenzene 2-hydroxypropanoic acid octadecanoic acid	plant residue, wood/burnt wood, also consistent with seed, nut, tuber	
	1	EH58	EWA	–	no residue detected	

GS no	Surface no	GC-MS lab no	sampling solvent	Compounds detected	Interpretation	Figure no.
GS39 (cont).	1	EH209	water	–	no residue detected	
	soil	EH300		–	no residue detected	
GS 40	1	EH59	EWA	–	no residue detected	E34.1
	soil	EH301		–	no residue detected	E34.2
GS 41	1	EH60	EWA	–	no residue detected	E35.1
	1	EH210	water	–	no residue detected	E35.2
	soil	EH302		–	no residue detected	E35.3
GS 42	1	EH127	EWA	phosphate	residue not identifiable	E36.1
	soil	EH303	–	hexadecanoic acid, 1,1-dimethylethyl ester octadecanoic acid butyl ester phthalic acid, decyl 2-ethylhexyl ester	plant residue, handling residue	E36.2
GS 43	1	EH61	EWA	–	no residue detected	E37.1
	1	EH211	water	–	no residue detected	E37.2
	soil	EH304		–	no residue detected	E37.3
GS 44	1	EH65	EWA	–	no residue detected	E38.1
	1	EH214	water	azelaic acid	degraded fatty acid, unknown source	E38.2
	soil	EH307	–	azelaic acid	degraded fatty acid, unknown source	E38.3
GS 45	1	EH62	EWA	–	no residue detected	E39.1
	1	EH212	water	–	sample not analysed*	–
	soil	EH305	–	Bis(4-hydroxyphenyl)propane azelaic acid	degraded fatty acid, unknown source	E39.2
GS 46	1	EH63	EWA	–	no residue detected	E40.1
	2	EH64	EWA	–	no residue detected	E40.2
	1	EH213	water	benzoic acid azelaic acid hexadecanoic acid	plant residue	E40.3
	soil	EH306	–	azelaic acid	degraded fatty acid, unknown source	E40.4
GS 47	1	EH128	EWA	Bis(4-hydroxyphenyl)methane	plant residue (Bioactive) (very limited)	E41.1

GS no	Surface no	GC-MS lab no	sampling solvent	Compounds detected	Interpretation	Figure no.
GS 48	1	EH129	EWA	phosphate	no residue detected	E42.1
	soil	EH308		–	no residue detected	E42.2
GS 49	1	EH66	EWA	–	no residue detected	E43.1
GS 49 (cont).	1	EH215	water	azelaic acid	degraded fatty acid, unknown source	E43.2
	soil	EH309	–	–	no residue detected	E43.3
GS 50	1	EH130	EWA	–	no residue detected	E44.1
	soil	EH310	–	dodecanoic acid, 2,3-bis(acetyloxy)propyl ester	plant residue (very limited)	E44.2
UPGS 1	1	EH67	EWA	–	no residue detected	E45.1
	3	EH68	EWA	–	no residue detected	E45.2
	2	EH216	water	–	no residue detected	E45.3
	soil	EH311	–	azelaic acid	degraded fatty acid, unknown source	E45.4
UPGS 2	1	EH131	EWA	–	no residue detected	E46.1
UPGS 3	1	EH69	EWA	–	no residue detected	E47.1
	1	EH217	water	azelaic acid	degraded fatty acid, unknown source	E47.2
UPGS 4	1	EH70	EWA	–	no residue detected	E48.1
	1	EH74	EWA	azelaic acid	degraded fatty acid, unknown sources	E48.2
	soil	EH312		–	no residue detected	E48.3
UPGS 5	1	EH72	EWA	–	no residue detected	E49.1
	1	EH220	water	azelaic acid	degraded fatty acid, unknown source	E49.2
UPGS 6	1	EH73	EWA	scopoletin <i>Morinda, Solanum</i> 3,4-dihydroisoquinoline, 1-(3-hydroxybenzyl)-6-methoxy- azelaic acid 3,5-dimethoxy-4-hydroxybenzoate 5-allyl-1-methoxy-2,3-dihydroxybenzene benzhydrazide, 4-(4-(4-methoxyphenyl)-5-methylthiazol-2-ylamino)-	plant residue, root, tuber, seed (bioactive)	E50.1

GS no	Surface no	GC-MS lab no	sampling solvent	Compounds detected	Interpretation	Figure no.
UPGS 6 (cont).	1	EH73 (cont).	EWA	N-(2-hydroxyethyl)-9-methyl-4-methylthio-1,2-carbazoledicarboximide 3,5-dimethoxy-4-hydroxy-cinnamaldehyde hexadecanoic acid benzhydrazide, 4-(4-(4-methoxyphenyl)-5-methylthiazol-2-ylamino)- 2,4-imidazolidinedione, 5-(3,4-dihydroxy-phenyl)-3-methyl-5-phenyl- 2,4-imidazolidinedione, 5-(3,4-dihydroxy-phenyl)-3-methyl-5-phenyl- 11-cis-octadecenoic acid octadecanoic acid	as above	E50.1
	soil	EH314		azelaic acid	degraded fatty acid, unknown source	E50.2
UPGS 7	1	EH132	EWA	–	no residue detected	E51.1
	soil	EH315		–	no residue detected	E51.2
UPGS 9	1	EH74	EWA	–	no residue detected	E52.1
	1	EH221	water	azelaic acid	degraded fatty acid, unknown source, unknown source	E52.2
UPGS 10	1	EH75	EWA	–	no residue detected	E53.1
	soil	EH316	–	tridecan-2-ol	Generic compound found in insect, plant and bacteria	E53.2
UPGS 11	1	EH133	EWA	2-hydroxypropanoic acid 2-ethylhexanoic acid benzoic acid phosphate 2,4-imidazolidinedione, 5-(3,4-dihydroxyphenyl)-3-methyl-5-phenyl- prosta-5,13-dien-1-oic acid, 9,11,15-trihydroxy-, (5Z,9.alpha.,11.alpha.,13E, 15S)- levoglucosan benz(a)anthracene-7-carbonitrile monolinoleoylglycerol phthalic acid, butyl decyl ester hexadecanoic acid octadecanol hexadecanoic acid 1,1-dimethylethyl ester octadecanoic acid monolinoleoylglycerol octadecanoic acid butyl ester phthalic acid, isodecyl octyl ester monolinoleoylglycerol	plant residue, seed, nut and/or root	E54.1

GS no	Surface no	GC-MS lab no	sampling solvent	Compounds detected	Interpretation	Figure no.
UPGS 11	2	EH134	water	–	no residue detected	E54.2
	soil	EH317	–	–	no residue detected	E54.3
UPGS 12	1	EH222	water	–	no residue detected	E55.1
	soil	EH218	–	–	no residue detected	E55.2
UPGS 14	1	EH76	EWA	sulphur propylbenzene 1-ethyl-2-methyl-benzene isopropylbenzene heptanoic acid glyoxylic acid azelaic acid hexadecanoic acid octadecanoic acid	plant residue	E56.1
	1	EH223	water	–	no residue detected	E56.2
	soil	EH319	–	–	no residue detected	–
UPGS 15	1	EH135	EWA	–	no residue detected	–
UPGS 16	1	EH77	EWA	–	no residue detected	E57.1
	2	EH78	EWA	propylene glycol	Residue not identifiable	E57.2
	3	EH79	EWA	2,3-dihydroxybutane	Residue not identifiable	E57.3
	1	EH224	water	–	no residue detected	E57.4
	2	EH225	water	azelaic acid	degraded fatty acid, unknown source	E57.5
	soil	EH320	–	–	no residue detected	E57.6
UPGS 17	1	EH80	EWA	3-phenyl-prop-2-ene	residue not identifiable	E58.1
	2	EH81	EWA	–	no residue detected	E58.2
	1	EH226	water	azelaic acid	degraded fatty acid, unknown source	E58.3
UPGS 18	1	EH82	EWA	1-ethyl-3-methyl-benzene 1-ethyl-4-methy-benzene oxanilic acid	plant residue, burnt wood	E59.1

GS no	Surface no	GC-MS lab no	sampling solvent	Compounds detected	Interpretation	Figure no.
UPGS 18 (cont).	1	EH136	water	–	no residue detected	E59.2
	unground surface	EH227	water	–	no residue detected	E59.3
	soil	EH321	–	–	no residue detected	E59.4
UPGS 19	soil	EH322		–	no residue detected	E60.1
UPGS 21	1	EH83	EWA	monoamidoethylmalonic acid	plant residue (very limited evidence)	E61.1
	2	EH84	EWA	1-ethyl-4-methylbenzene 1-ethyl-2-methylbenzene 3-methyl-2-hydroxy-2-butenic acid N-(2-methyl-1-oxo-2-propenyl)-N-glycine hexadecanoic acid	plant residue, nut and/or seed	E61.2
	1	EH228	water	–	no residue detected	E61.3
	soil	EH323	–	–	no residue detected	–
UPGS 22	2	EH85	EWA	1-ethyl-4-methylbenzene 1-ethyl-4-methylbenzene cyclopentanol oxanilic acid 4,6-dimethyl-2-thioxo-1,2-dihydro-3-pyridinecarbonitrile hexadecanoic acid	plant residue	E62.1
	1	EH86	EWA	–	no residue detected	E62.2
	1	EH229	water	–	no residue detected	E62.3
	soil	EH324	–	–	no residue detected	E62.4
UPGS 23	1	EH173	EWA	2-hydroxypropanoic acid hexadecanoic acid octadecanoic acid	residue not identifiable, handing residues	E63.1
	soil	EH235	–	–	no residue detected	E63.2
UPGS 24	1	EH87	EWA	1-ethyl-2-methyl-benzene oxanilic acid N-(2-methyl-1-oxo-2-propenyl)-N-glycine	plant residue, seed and/or nut	E64.1
	1	EH230	water	–	no residue detected	E64.2
	soil	EH326	–	–	no residue detected	E64.3

GS no	Surface no	GC-MS lab no	sampling solvent	Compounds detected	Interpretation	Figure no.
UPGS 25	1	EH137	EWA	2-hydroxypropanoic acid phosphate monolinoleoylglycerol azelaic acid monolinoleoylglycerol monolinoleoylglycerol hexadecanoic acid octadecanoic acid	plant residue root, seed and/or nut	E65.1
	soil	EH327	–	–	no residue detected	E65.2
UPGS 26	2	EH88	EWA	ethanediol 2-hydroxypropanol	residue not identifiable	E66.1
	1	EH89	EWA	–	no residue detected	E66.2
	1	EH90	EWA	–	no residue detected	E66.3
	3	EH231	water	–	no residue detected	E66.4
	soil	EH238	–	9,12,15-octadecatrienoic acid glycerol	plant residue - seed	E66.5
UPGS 27	1	EH91	EWA	–	no residue detected	E67.1
	soil	EH329		–	no residue detected	E67.2
UPGS 28	1	EH92	EWA	–	no residue detected	E68.1
	1	EH232	water	–	no residue detected	E68.2
	soil	EH330	–	–	no residue detected	E68.1
UPGS 29	1	EH138	EWA	2-hydroxypropanoic acid nonanoic acid hexadecanoic acid monolinoleoylglycerol 2-amino-1-(4-methoxyphenyl)-5-phenyl-1H-pyrrole-3,4-dicarbonitrile octadecanoic acid	plant residue, seed, nut and/or root	E69.1
UPGS 30	1	EH139	EWA	1-(3-methylbutyl)-2,3,5-trimethylbenzene 1-(3-methylbutyl)-2,3,5-trimethylbenzene	residue not identifiable	E70.1
UPGS 31	1	EH140	EWA	–	no residue detected	E71.1
UPGS 32	1	EH141	EWA	2-hydroxypropanoic acid 2,4-dinitrophenyl-arginine hexadecanoic acid	residue not identifiable but possibly proteinaceous; handling residues	E72.1

GS no	Surface no	GC-MS lab no	sampling solvent	Compounds detected	Interpretation	Figure no.
				octadecanoic acid		
UPGS 33	1	EH142	EWA	–	no residue detected	E73.1
UPGS 34	1	EH143	EWA	2-hydroxypropanoic acid hexadecanoic acid androst-2-en-17-amine, 4,4-dimethyl-N-(2-phenylethyl)-, (5.alpha.)- octadecanoic acid	residue not identifiable, may be plant or animal origin	E74.1
UPGS 35	1	EH144	EWA	–	no residue detected	E75.1
UPGS 36	1	EH145	EWA	–	no residue detected	E76.1
UPGS 37	1	EH160	water	–	no residue detected	E77.1
	soil	EH345		–	no residue detected	E77.2
UPGS 38	1	EH97	EWA	–	no residue detected	E78.1
	1	EH98	EWA	–	no residue detected	E78.2
	1	EH234	water	azelaic acid	degraded fatty acid, unknown source	E78.3
	soil	EH332	–	–	no residue detected	E78.4
UP GS 39	2	EH93	EWA	ethanediol 3-phenyl-2-propenol	plant residue	E79.1
	3	EH94	EWA	–	no residue detected	E79.2
	1	EH95	EWA	–	no residue detected	E79.3
	5	EH96	EWA	–	no residue detected	E79.4
	1	EH233	water	–	no residue detected	E79.5
	soil	EH331	–	–	no residue detected	E79.6
L49	1	EH99	EWA	lactic acid oxanilic acid	residue not identifiable	E80.1
	1	EH100	EWA	2-ethylhexanoic acid	plant residue	E80.2
	1	EH235	water	–	no residue detected	E80.3
	soil	EH333		–	no residue detected	E80.4
L52	2	EH101	EWA	4,6-dimethyl-2-thioxo-1,2-dihydro-3-pyridinecarbonitrile	residue not identifiable	E81.1

GS no	Surface no	GC-MS lab no	sampling solvent	Compounds detected	Interpretation	Figure no.
L52 (cont).	1	EH102	EWA	heptanoic acid	residue not identifiable	E81.2
	1	EH236	water	–	no residue detected	E81.3
	soil	EH334		–	no residue detected	E81.4
L813	1	EH103	EWA	–	no residue detected	E82.1
	1	EH237	water	phosphate azelaic acid	degraded fatty acid, unknown source	E82.2
	soil	EH335	–	–	no residue detected	E82.3
L868	1	EH146	EWA	Bis(4-hydroxyphenyl)methane monoamidoethylmalonic acid tridecan-2-ol monolinoleoylglycerol hexadecanoic acid 15-isopropenyl-oxacyclopentadecan-2-one octadecanoic acid monolinoleoylglycerol	plant residue (Bioactive)	E83.1
L894	1	EH147	EWA	–	no residue detected	E84.2
	soil	EH336	–	–	no residue detected	E84.2
L1349	1	EH104	EWA	1-ethyl-4-methylbenzene 1-ethyl-2-methylbenzene 2-hydroxypropanoic acid oxanilic acid 4,6-dimethyl-2-thioxo-1,2-dihydro-3-pyridinecarbonitrile monoamidoethylmalonic acid hexadecanoic acid	plant residue	E85.1
	1	EH238	water	–	no residue detected	E85.2
	soil	EH337	–	–	no residue detected	E85.3
R2	1	EH105	EWA	–	no residue detected	E86.1
	1	EH106	EWA	–	no residue detected	E86.2
	1	EH239	water	azelaic acid	degraded fatty acid, unknown source	E86.3
	soil	EH338	–	–	no residue detected	E86.4
R5	1	EH107	EWA	–	no residue detected	E87.1

GS no	Surface no	GC-MS lab no	sampling solvent	Compounds detected	Interpretation	Figure no.
R5 (cont).	2	EH108	EWA	1-ethyl-4-methylbenzene 1-ethyl-4-methylbenzene 2-hydroxypropanoic acid heptanoic acid hexadecanoic acid	residue not identifiable, fatty acids present but not specific to plant or animal	E87.2
	3	EH109	EWA	–	no residue detected	
	1	EH240	water	–	no residue detected	E87.3
	soil	EH339	–	–	no residue detected	E87.4
R66	1	EH110	EWA	–	no residue detected	E88.1
	2	EH111	EWA	–	no residue detected	E88.2
	1	EH242	water	–	no residue detected	E88.3
	soil	EH340	–	–	no residue detected	E88.4
R68	1	EH112	EWA	–	no residue detected	E89.1
	2	EH113	EWA	isopropylbenzene 1-ethyl-4-methylbenzene benzo(b)thiophene-4-acetic acid	residue not identifiable	E89.2
	1	EH243	water	benzoic acid azelaic acid hexadecanoic acid	plant residue	E89.3
	soil	EH341		azelaic acid	degraded fatty acid, unknown source	E89.4
R69	1	EH114	EWA	–	no residue detected	E90.1
	1	EH244	water	–	no residue detected	E90.2
	soil	EH342	–	azelaic acid	degraded fatty acid, unknown source	E90.3

Table D4: Compound detected within the residue mixtures sampled from Lake Mungo

GS no	surface no	GC-MS lab no	sampling solvent	compounds present	Interpretation	Fig. no.
LM GS 1	1	EH115	EWA	-	no residue detected	E91.1
	2	EH116	EWA	tridecanol	plant residue	E91.2
	1	EH245	water	-	no residue detected	E91.3
	2	EH246	water	-	no residue detected	E91.4
LM GS 3	1	EH117	EWA	1,2,4-trimethylbenzene 1-ethyl-2-methylbenzene heptanoic acid	plant residue	E92.1
	2	EH118	EWA	-	no residue detected	E92.2
	1	EH247	water	-	no residue detected	E92.3
	2	EH248	water	-	no residue detected	E92.4
LM GS 5	1	EH119	EWA	1-ethyl-2-methyl-benzene 1-ethyl-2-methyl-benzene 2-hydroxypropanone monoamidoethylmalonic acid 1,2-dihydroxycyclohexene hexadecanoic acid octadecanoic acid	plant residue; handling residue	E93.1
	1	EH249	water	-	no residue detected	E93.2
LM GS 9	1	EH120	EWA	-	no residue detected	E94.1
LM GS 10	1	EH121	EWA	azelaic acid	degraded fatty acids	E95.1
	1	EH250	water	-	no residue detected	E95.2
LM GS 11	2	EH251	water	-	no residue detected	E96.1
	2	EH122	EWA	-	no residue detected	E96.2
	1	EH123	EWA	azelaic acid	degraded fatty acids	E96.3
LM GS 12	1	EH253	water	-	no residue detected	E97.1
LM GS 13	1	EH148	EWA	-	no residue detected	E98.1

GS no	surface no	GC-MS lab no	sampling solvent	compounds present	Interpretation	Fig. no.
LM GS 14	1	EH149	EWA	2-hydroxypropanoic acid 5-hydroxy-5-methyl-2-phenyl-3-isoxazolidinone phosphate hexylmalonic acid hexadecanoic acid octadecanoic acid	residue not identifiable, handling residues	E99.1
LM GS 15	1	EH150	EWA	-	no residue detected	E100.1
LM GS 16	1	EH254	water	-	no residue detected	E101.1
	1	EH125	EWA	-	no residue detected	E101.2
LM GS 17	1	EH126	EWA	-	no residue detected	E102.1
	1	EH252	EWA	-	no residue detected	E102.2

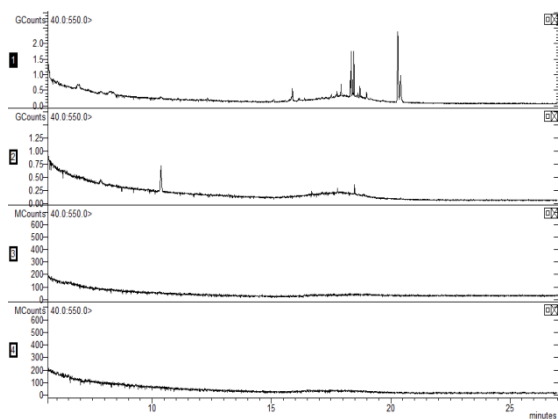


Figure D1: GC-MS chromatograph of residue mixtures sampled from GS 1. **1-2)** compounds detected from the EWA lift from the ground surface; **3)** compounds detected from the water lift from the ground surface; **4)** compounds detected from the sediment sample.

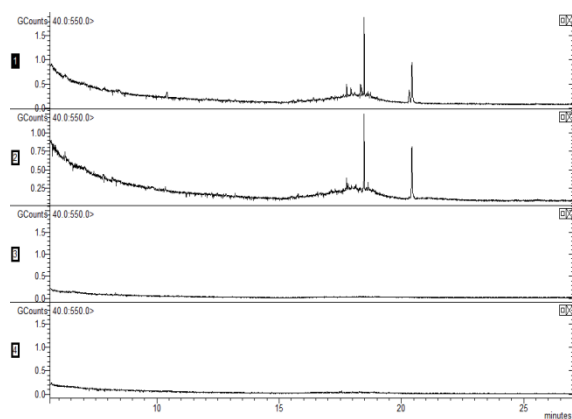


Figure D2: GC-MS chromatograph of residue mixtures sampled from GS 2. **1)** compounds detected from the EWA lift from Surface 1; **2)** compounds detected from the EWA lift from Surface 2; **3)** compounds detected from the water lift from Surface 1; **4)** compounds detected from the sediment sample.

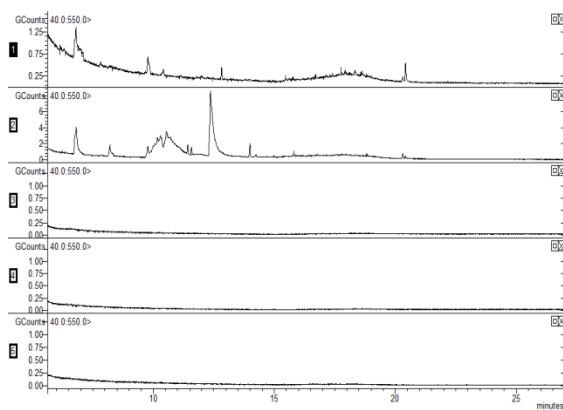


Figure D3: GC-MS chromatograph of residue mixtures sampled from GS 3. **1-2)** compounds detected from the EWA lift from Surface 2; **3)** compounds detected from the water lift from Surface 2; **4)** compounds detected from the water lift from Surface 1; **5)** compounds detected from the sediment sample.

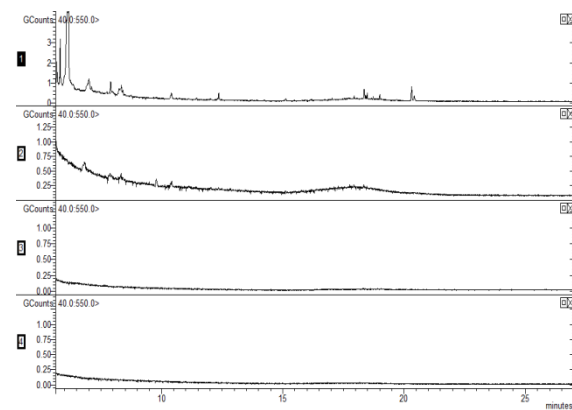


Figure D4: GC-MS chromatograph of residue mixtures sampled from GS 4. **1-2)** compounds detected from the EWA lift from the ground surface; **3)** compounds detected from the water lift from the ground surface; **4)** compounds detected from the sediment sample.

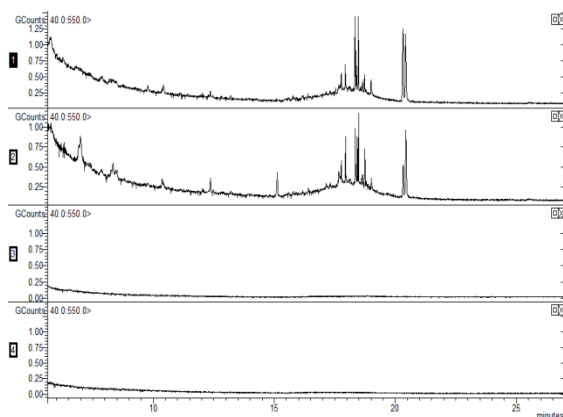


Figure D5: GC-MS chromatograph of residue mixtures sampled from GS 5. **1-2)** compounds detected from the EWA lift from the ground surface; **3)** compounds detected from the water lift from the ground surface; **4)** compounds detected from the sediment sample.

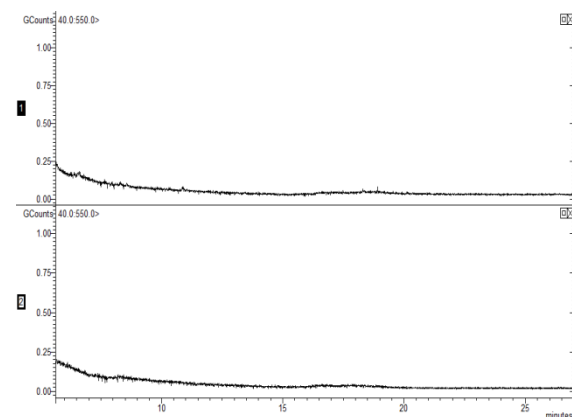


Figure D6: GC-MS chromatograph of residue mixtures sampled from GS 6. **1)** compounds detected from the water lift from the ground surface; **2)** compounds detected from the sediment sample.

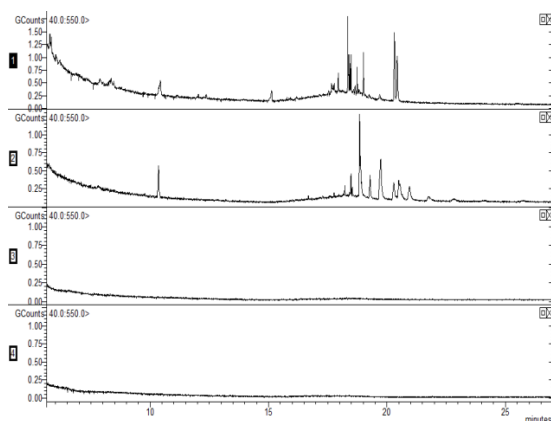


Figure D7: GC-MS chromatograph of residue mixtures sampled from GS 7. **1-2)** compounds detected from the EWA lift from the ground surface; **3)** compounds detected from the water lift from the ground surface; **4)** compounds detected from the sediment sample.

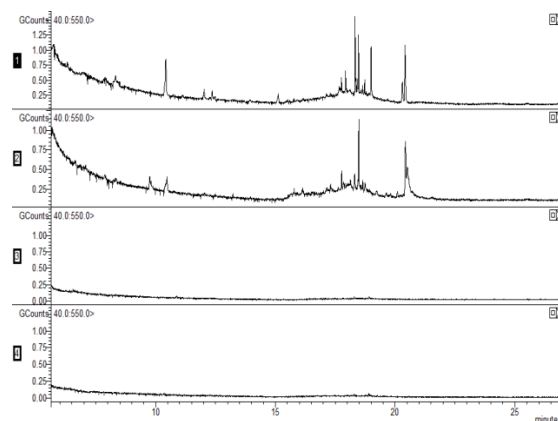


Figure D8: GC-MS chromatograph of residue mixtures sampled from GS 8. **1)** compounds detected from the EWA lift from Surface 1; **2)** compounds detected from the EWA lift from Surface 2; **3)** compounds detected from the water lift from Surface 1; **4)** compounds detected from the sediment sample.

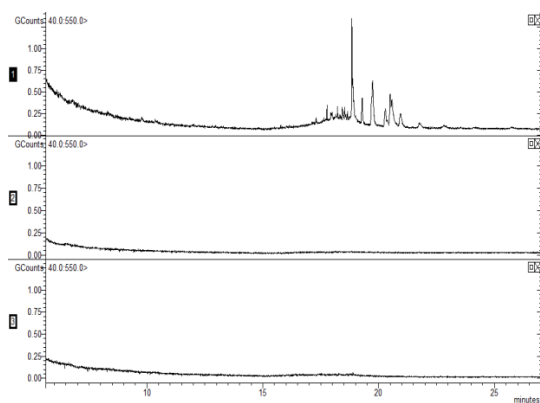


Figure D9: GC-MS chromatograph of residue mixtures sampled from GS 9. **1)** compounds detected from the EWA lift from the ground surface; **2)** compounds detected from the water lift from the ground surface; **3)** compounds detected from the sediment sample.

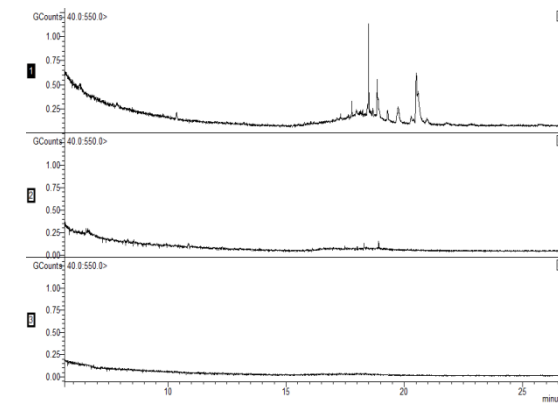


Figure D10: GC-MS chromatograph of residue mixtures sampled from GS 10. **1)** compounds detected from the EWA lift from the ground surface; **2)** compounds detected from the water lift from the ground surface; **3)** compounds detected from the sediment sample.

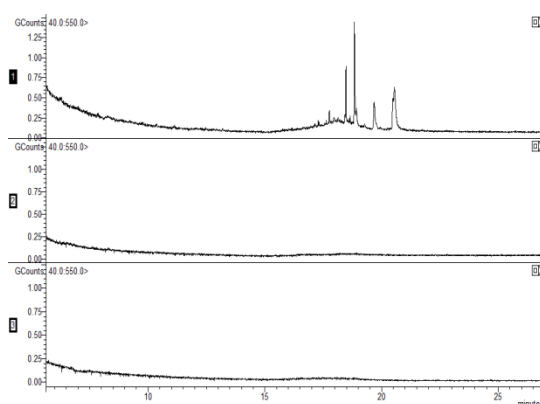


Figure D11: GC-MS chromatograph of residue mixtures sampled from GS 13. **1)** compounds detected from the EWA lift from the ground surface; **2)** compounds detected from the water lift from the ground surface; **3)** compounds detected from the sediment sample.

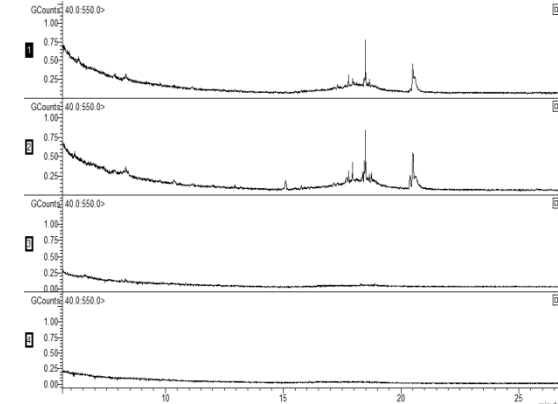


Figure D12: GC-MS chromatograph of residue mixtures sampled from GS 14. **1-2)** compounds detected from the EWA lift from the ground surface; **3)** compounds detected from the water lift from the ground surface; **4)** compounds detected from the sediment sample.

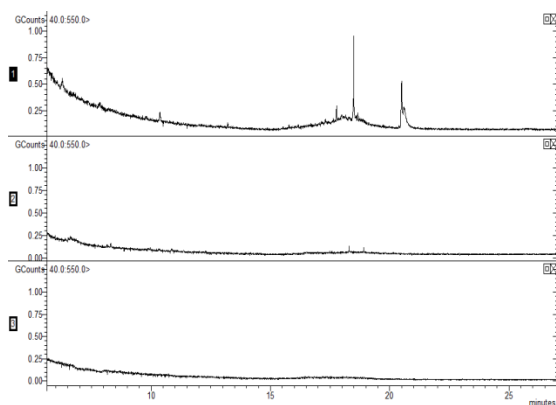


Figure D13: GC-MS chromatograph of residue mixtures sampled from GS 15. **1)** compounds detected from the EWA lift from the ground surface; **2)** compounds detected from the water lift from the ground surface; **3)** compounds detected from the sediment sample.

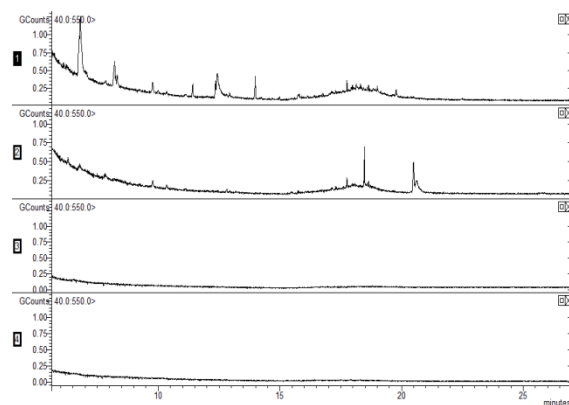


Figure D14: GC-MS chromatograph of residue mixtures sampled from GS 16. **1)** compounds detected from the EWA lift from Surface 2; **2)** compounds detected from the EWA lift from Surface 1; **3)** compounds detected from the water lift from Surface 1; **4)** compounds detected from the sediment sample.

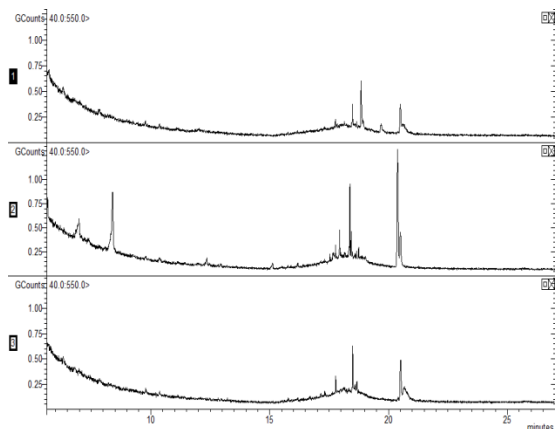


Figure D15: GC-MS chromatograph of residue mixtures sampled from GS 18. **1)** compounds detected from the EWA lift from Surface 1; **2)** compounds detected from the EWA lift from Surface 1; **3)** compounds detected from the sediment sample.

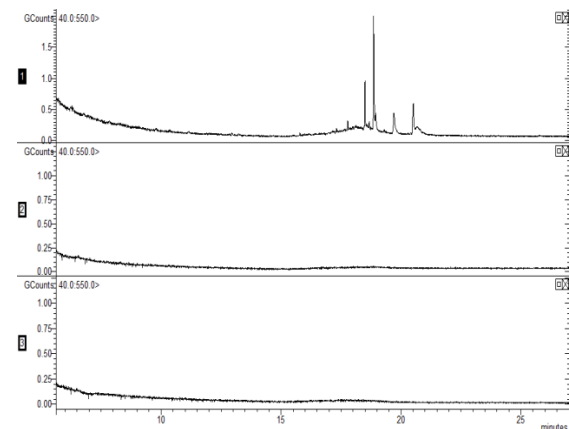


Figure D16: GC-MS chromatograph of residue mixtures sampled from GS 19. **1)** compounds detected from the EWA lift from the ground surface; **2)** compounds detected from the water lift from the ground surface; **3)** compounds detected from the sediment sample.

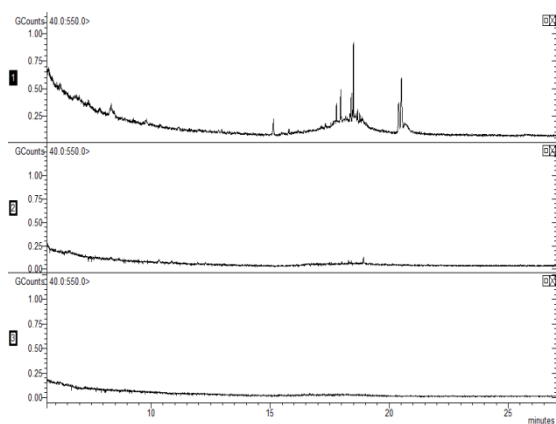


Figure D17: GC-MS chromatograph of residue mixtures sampled from GS 20. **1)** compounds detected from the EWA lift from the ground surface; **2)** compounds detected from the water lift from the ground surface; **3)** compounds detected from the sediment sample.

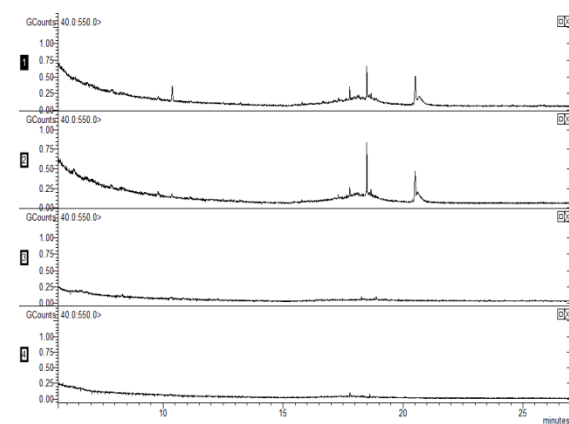


Figure D18: GC-MS chromatograph of residue mixtures sampled from GS 21. **1-2)** compounds detected from the EWA lift from the ground surface; **3)** compounds detected from the water lift from the ground surface; **4)** compounds detected from the sediment sample.

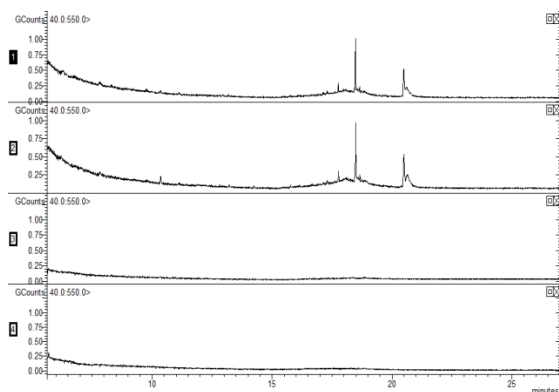


Figure D19: GC-MS chromatograph of residue mixtures sampled from GS 22. **1-2)** compounds detected from the EWA lift from the ground surface; **3)** compounds detected from the water lift from the ground surface; **4)** compounds detected from the sediment sample.

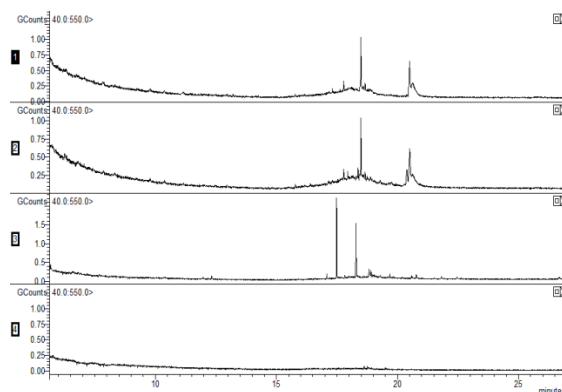


Figure D20: GC-MS chromatograph of residue mixtures sampled from GS 23. **1-2)** compounds detected from the EWA lift from the ground surface; **3)** compounds detected from the water lift from the ground surface; **4)** compounds detected from the sediment sample.

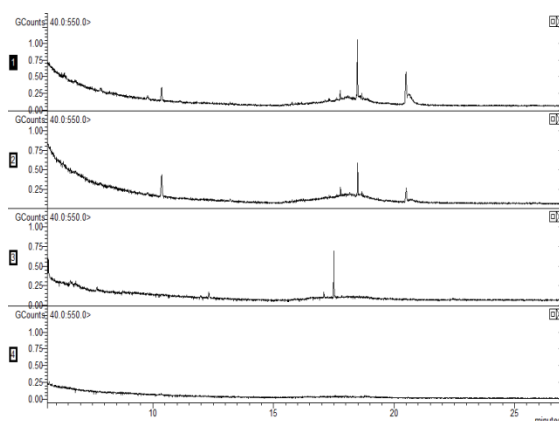


Figure D21: GC-MS chromatograph of residue mixtures sampled from GS 24. **1)** compounds detected from the EWA lift from Surface 1; **2)** compounds detected from the EWA lift from Surface 2; **3)** compounds detected from the water lift from Surface 2; **4)** compounds detected from the sediment sample.

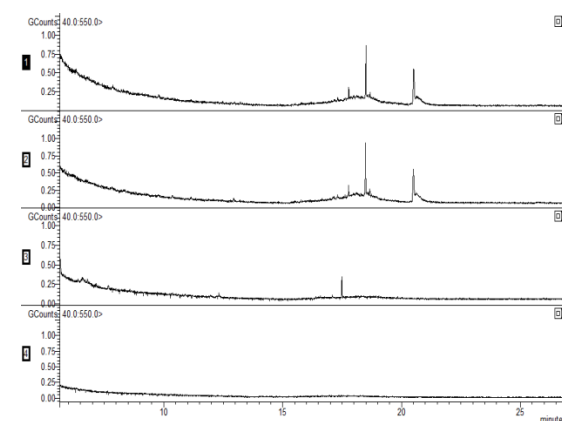


Figure D22: GC-MS chromatograph of residue mixtures sampled from GS 26. **1-2)** compounds detected from the EWA lift from the ground surface; **3)** compounds detected from the water lift from the ground surface; **4)** compounds detected from the sediment sample.

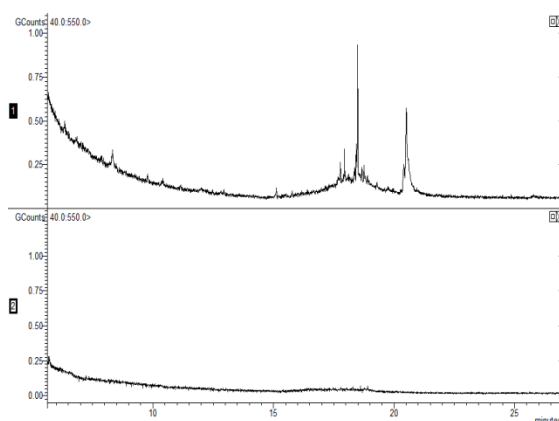


Figure D23: GC-MS chromatograph of residue mixtures sampled from GS 27. **1)** compounds detected from the EWA lift from the ground surface; **2)** compounds detected from the sediment sample.

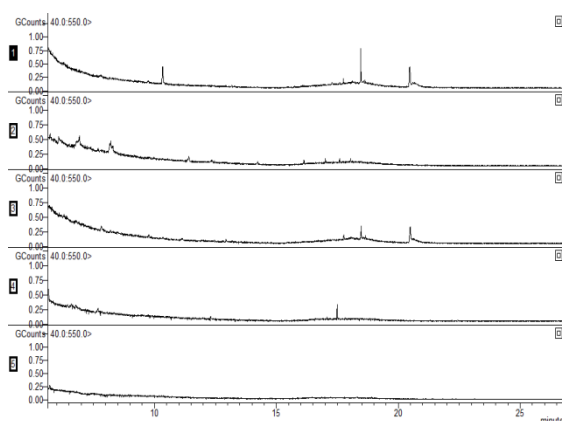


Figure D24: GC-MS chromatograph of residue mixtures sampled from GS 28. **1)** compounds detected from the EWA lift from the ground surface; **2)** compounds detected from the water lift from the unground surface; **3)** compounds detected from the EWA lift from the ground surface; **4)** compounds detected from the water lift from ground surface; **5)** compounds detected from the sediment sample.

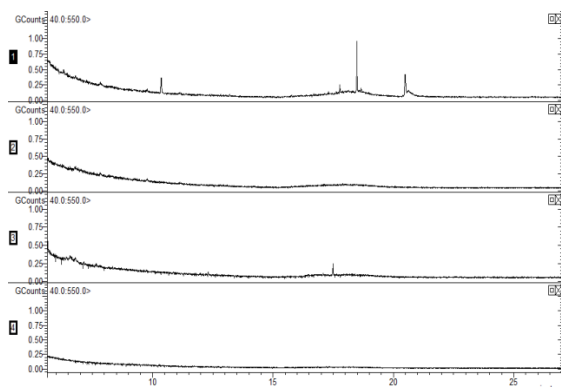


Figure D25: GC-MS chromatograph of residue mixtures sampled from GS 29. **1-2)** compounds detected from the EWA lift from the ground surface; **3)** compounds detected from the water lift from the ground surface; **4)** compounds detected from the sediment sample.

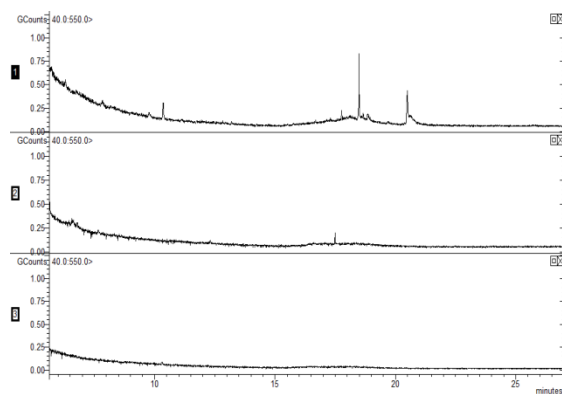


Figure D26: GC-MS chromatograph of residue mixtures sampled from GS 30. **1)** compounds detected from the EWA lift from the ground surface; **2)** compounds detected from the water lift from the ground surface; **3)** compounds detected from the sediment sample.

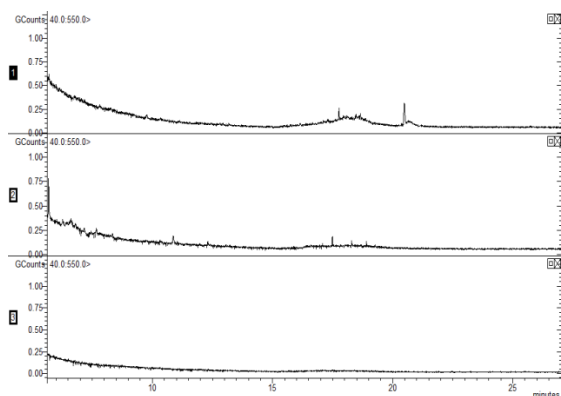


Figure D27: GC-MS chromatograph of residue mixtures sampled from GS 31. **1)** compounds detected from the EWA lift from the ground surface; **2)** compounds detected from the water lift from the ground surface; **3)** compounds detected from the sediment sample.

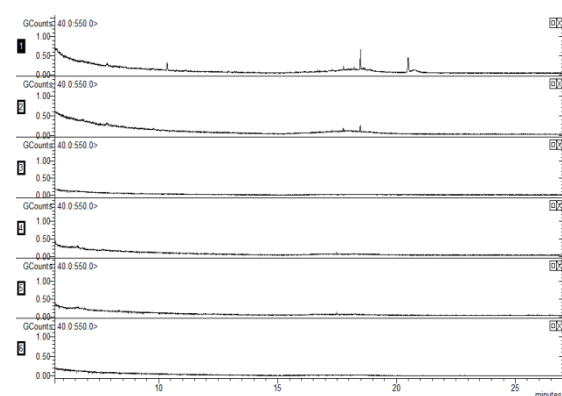


Figure D28: GC-MS chromatograph of residue mixtures sampled from GS 32. **1-2)** compounds detected from the EWA lift from Surface 1; **3)** compounds detected from the EWA lift from the Surface 2; **4-5)** compounds detected from the water lift from Surface 1; **6)** compounds detected from the sediment sample.

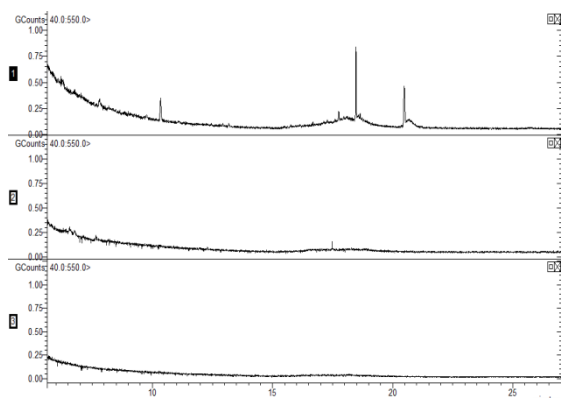


Figure D29: GC-MS chromatograph of residue mixtures sampled from GS 33. **1)** compounds detected from the EWA lift from the ground surface; **2)** compounds detected from the water lift from the ground surface; **3)** compounds detected from the sediment sample.

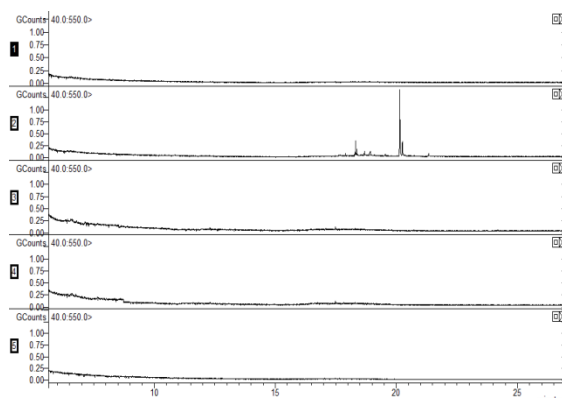


Figure D30: GC-MS chromatograph of residue mixtures sampled from GS 35. **1)** compounds detected from the EWA lift from Surface 1; **2)** compounds detected from the EWA lift from Surface 2; **3)** compounds detected from the water lift from Surface 1; **4)** compounds detected from the water lift from Surface 2; **5)** compounds detected from the sediment sample.

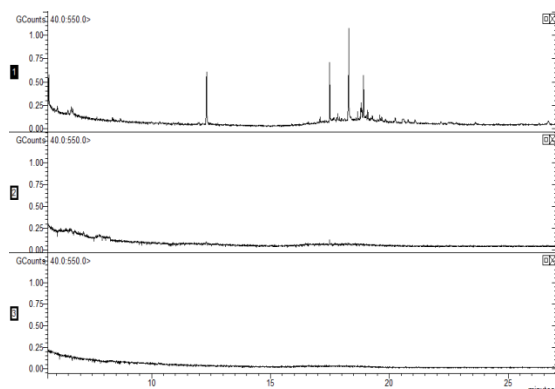


Figure D31: GC-MS chromatograph of residue mixtures sampled from GS 36. **1)** compounds detected from the EWA lift from Surface 2; **2)** compounds detected from the water lift from the Surface 2; **3)** compounds detected from the sediment sample.

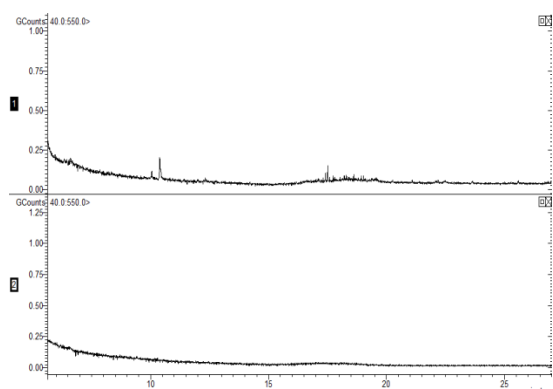


Figure D32: GC-MS chromatograph of residue mixtures sampled from GS 37. **1)** compounds detected from the EWA lift from the ground surface; **2)** compounds detected from the sediment sample.

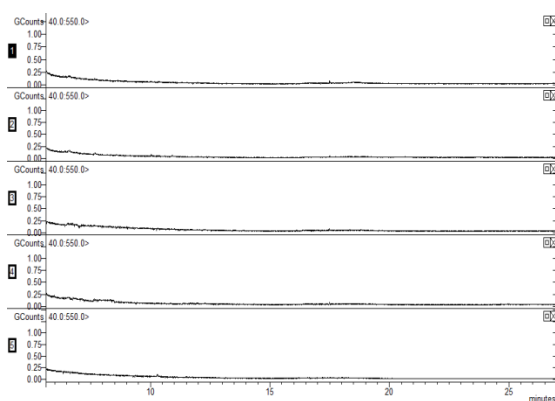


Figure D33: GC-MS chromatograph of residue mixtures sampled from GS 38. **1)** compounds detected from the EWA lift from Surface 1; **2)** compounds detected from the EWA lift from Surface 2; **3)** compounds detected from the water lift from Surface 1; **4)** compounds detected from the water lift from Surface 2; **5)** compounds detected from the sediment sample.

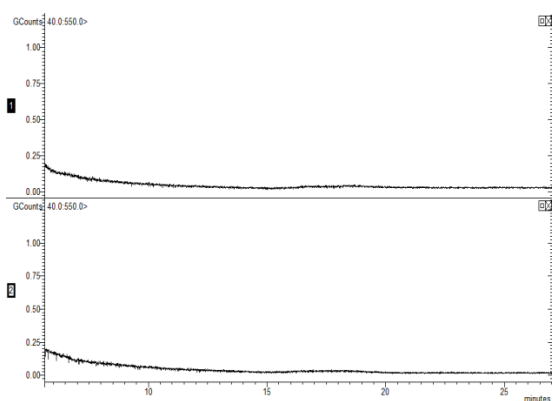


Figure D34: GC-MS chromatograph of residue mixtures sampled from GS 40. **1)** compounds detected from the EWA lift from the ground surface; **2)** compounds detected from the sediment sample.

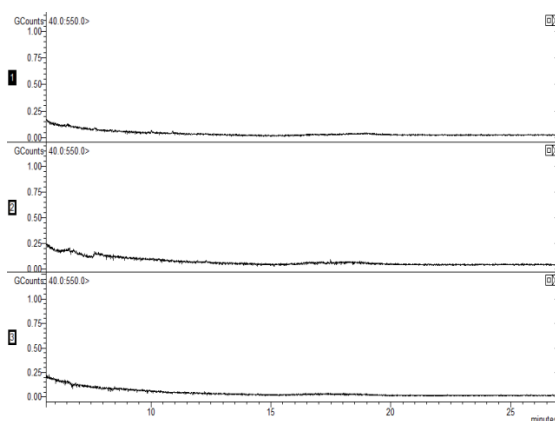


Figure D35: GC-MS chromatograph of residue mixtures sampled from GS 41. **1)** compounds detected from the EWA lift from the ground surface; **2)** compounds detected from the water lift from the ground surface; **3)** compounds detected from the sediment sample.

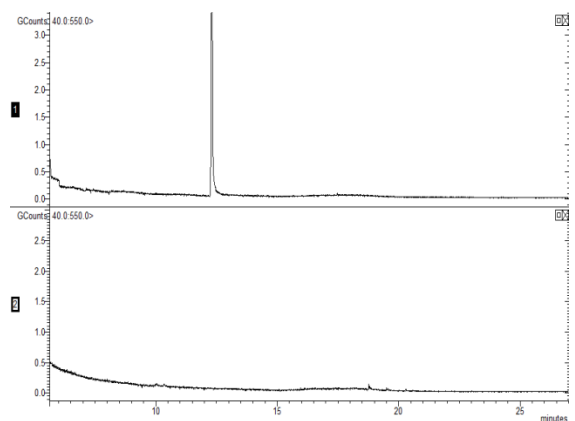


Figure D36: GC-MS chromatograph of residue mixtures sampled from GS 42. **1)** compounds detected from the EWA lift from the ground surface; **2)** compounds detected from the sediment sample.

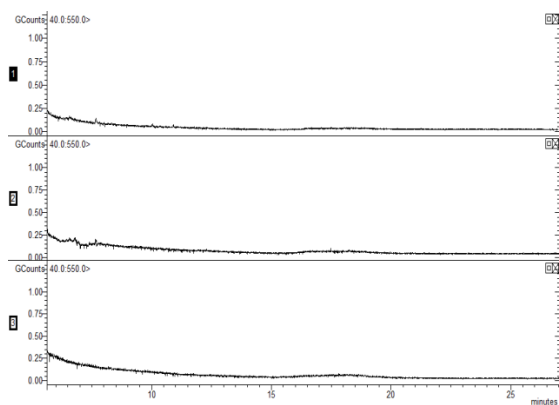


Figure D37: GC-MS chromatograph of residue mixtures sampled from GS 43. **1)** compounds detected from the EWA lift from the ground surface; **2)** compounds detected from the water lift from the ground surface; **3)** compounds detected from the sediment sample.

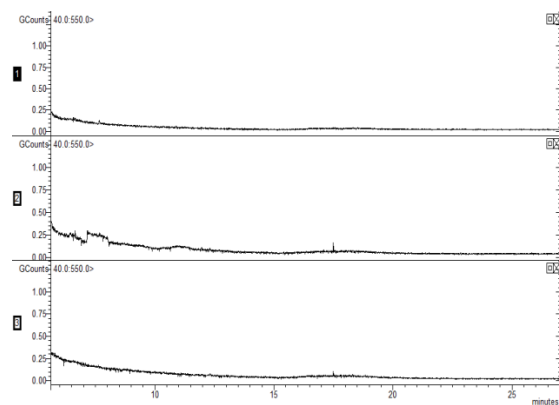


Figure D38: GC-MS chromatograph of residue mixtures sampled from GS 44. **1)** compounds detected from the EWA lift from the ground surface; **2)** compounds detected from the water lift from the ground surface; **3)** compounds detected from the sediment sample.

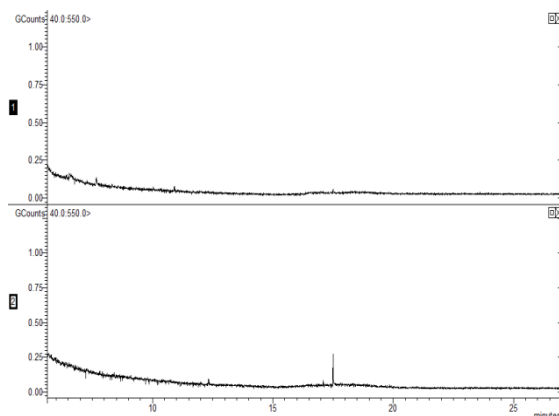


Figure D39: GC-MS chromatograph of residue mixtures sampled from GS 45. **1)** compounds detected from the EWA lift from the ground surface; **2)** compounds detected from the sediment sample.

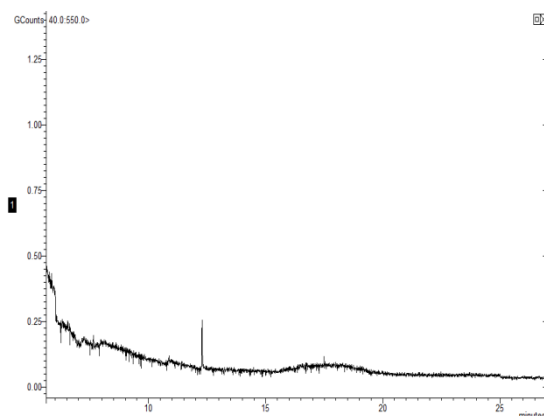


Figure D40: **1)** GC-MS chromatograph of residue mixtures sampled from the ground surface of GS 47 with EWA solvent.

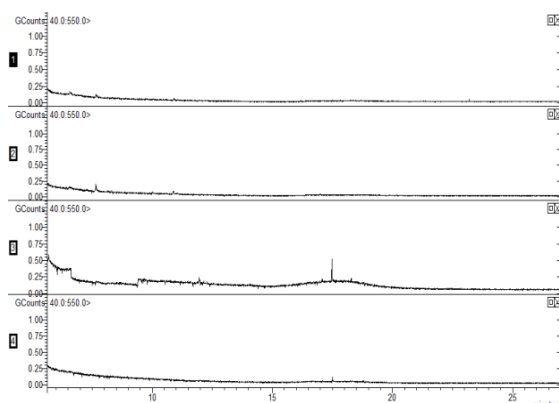


Figure D41: GC-MS chromatograph of residue mixtures sampled from GS 46. **1)** compounds detected from the EWA lift from Surface 1; **2)** compounds detected from the EWA lift from Surface 2; **3)** compounds detected from the water lift from the ground surface; **4)** compounds detected from the sediment sample.

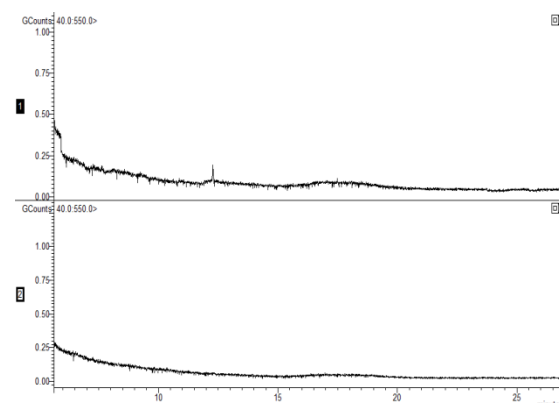


Figure D42: GC-MS chromatograph of residue mixtures sampled from GS 48. **1)** compounds detected from the EWA lift from the ground surface; **2)** compounds detected from the sediment sample.

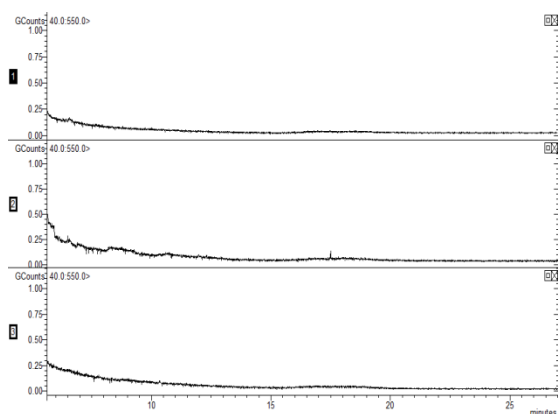


Figure D43: GC-MS chromatograph of residue mixtures sampled from GS 49. **1)** compounds detected from the EWA lift from the ground surface; **2)** compounds detected from the water lift from the ground surface; **3)** compounds detected from the sediment sample.

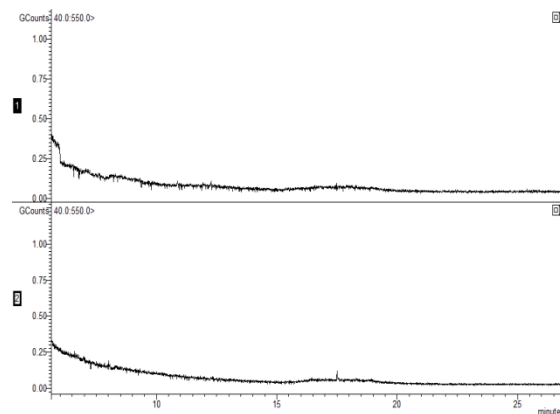


Figure D44: GC-MS chromatograph of residue mixtures sampled from GS 50. **1)** compounds detected from the EWA lift from the ground surface; **2)** compounds detected from the sediment sample.

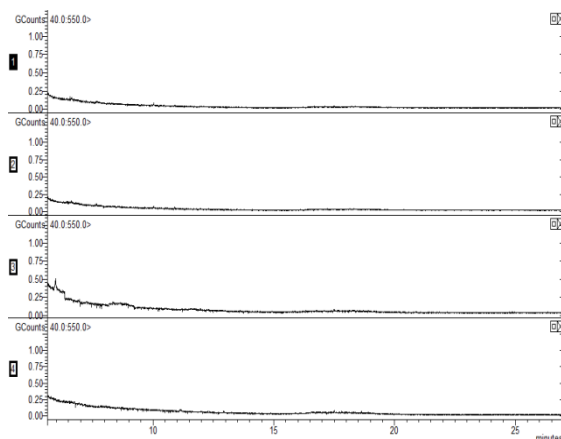


Figure D45: GC-MS chromatograph of residue mixtures sampled from UP GS 1. **1)** compounds detected from the EWA lift from Surface 1; **1)** compounds detected from the EWA lift from Surface 3; **3)** compounds detected from the water lift from Surface 2; **4)** compounds detected from the sediment sample.

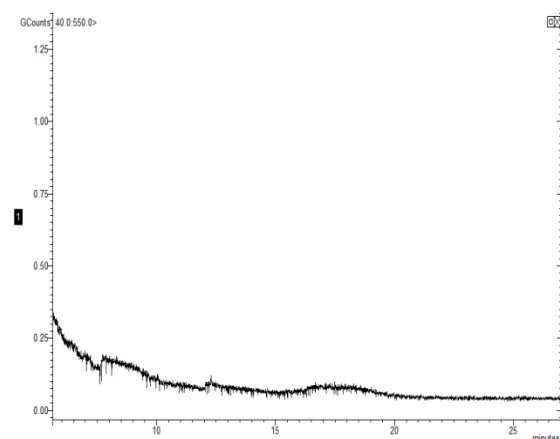


Figure D46: **1)** GC-MS chromatograph of residue mixtures sampled from the ground surface of UP GS 2 with EWA solvent.

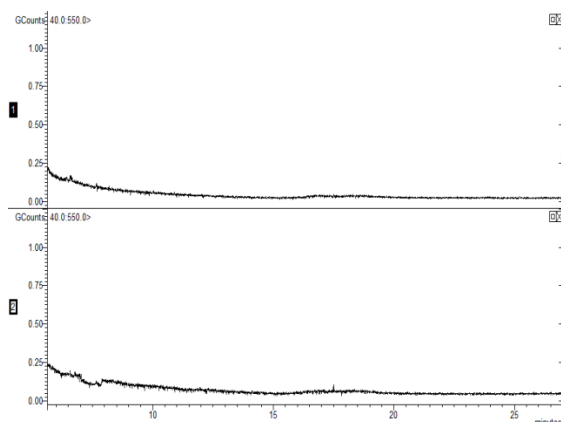


Figure D47: GC-MS chromatograph of residue mixtures sampled from UP GS 3. **1)** compounds detected from the EWA lift from the ground surface; **2)** compounds detected from the water lift from the ground surface.

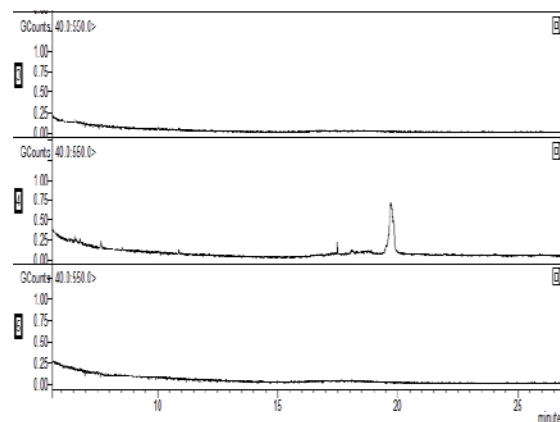


Figure D48: GC-MS chromatograph of residue mixtures sampled from UP GS 4. **1-2)** compounds detected from the EWA lift from the ground surface; **3)** compounds detected from the sediment sample.

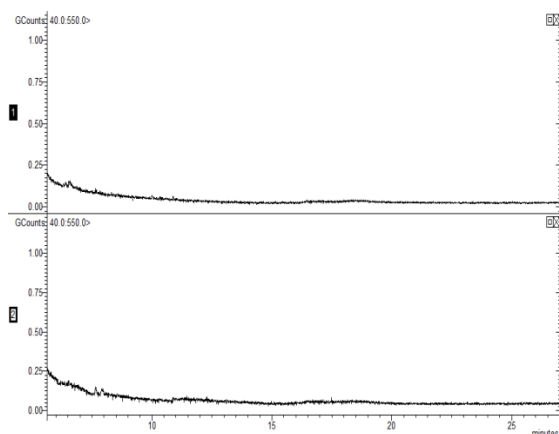


Figure D49: GC-MS chromatograph of residue mixtures sampled from UP GS 5. **1)** compounds detected from the EWA lift from the ground surface; **2)** compounds detected from the water lift from the ground surface.

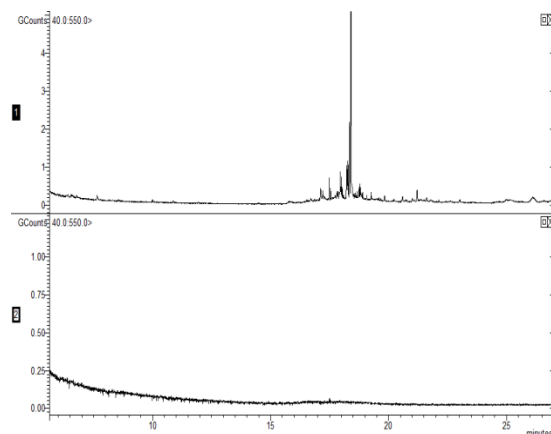


Figure D50: GC-MS chromatograph of residue mixtures sampled from UP GS 6. **1)** compounds detected from the EWA lift from the ground surface; **2)** compounds detected from sediment sample.

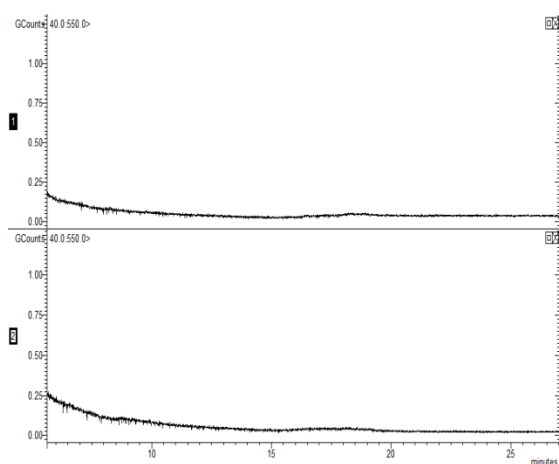


Figure D51: GC-MS chromatograph of residue mixtures sampled from UP GS 7. **1)** compounds detected from the EWA lift from the ground surface; **2)** compounds detected from sediment sample.

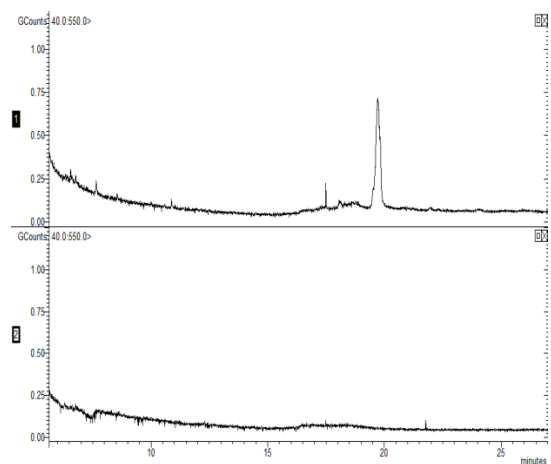


Figure D52: GC-MS chromatograph of residue mixtures sampled from UP GS 9. **1)** compounds detected from the EWA lift from the ground surface; **2)** compounds detected from the water lift from the ground surface.

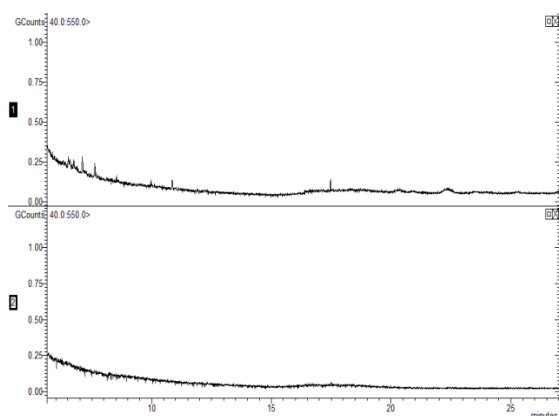


Figure D53: GC-MS chromatograph of residue mixtures sampled from UP GS 10. **1)** compounds detected from the EWA lift from the ground surface; **2)** compounds detected from sediment sample.

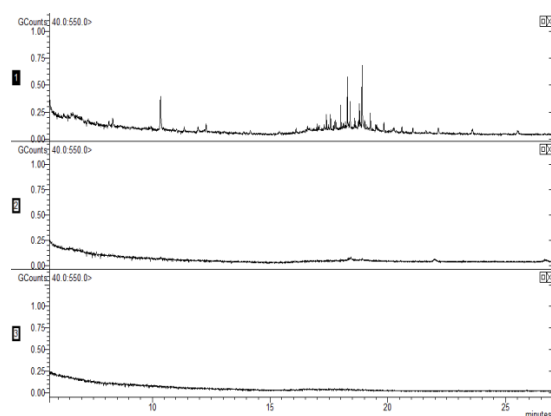


Figure D54: GC-MS chromatograph of residue mixtures sampled from UP GS 11. **1)** compounds detected from the EWA lift from the ground surface; **2)** compounds detected from the water lift from the ground surface; **3)** compounds detected from the sediment sample.

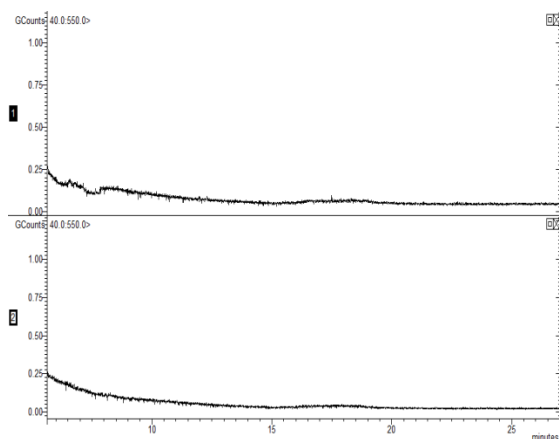


Figure D55: GC-MS chromatograph of residue mixtures sampled from UP GS 12. **1)** compounds detected from the EWA lift from the ground surface; **2)** compounds detected from the sediment sample.

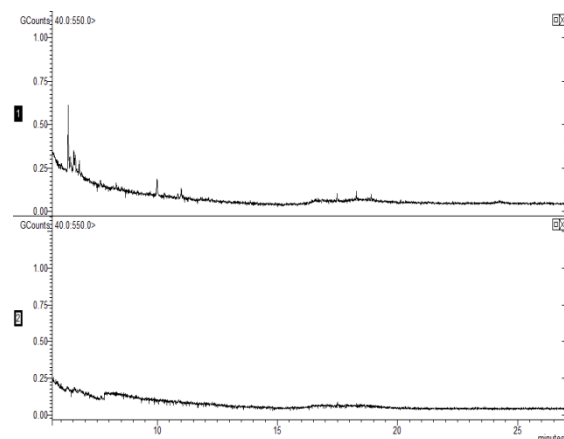


Figure D56: GC-MS chromatograph of residue mixtures sampled from UP GS 14. **1)** compounds detected from the EWA lift from the ground surface; **2)** compounds detected from the water lift from the ground surface.

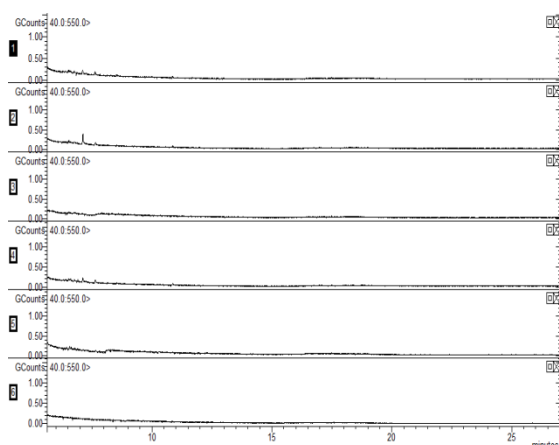


Figure D57: GC-MS chromatograph of residue mixtures sampled from UP GS 16. **1)** compounds detected from the EWA lift from Surface 1; **2)** compounds detected from the EWA lift from Surface 2; **3)** compounds detected from the EWA lift from Surface 3; **4)** compounds detected from the water lift from the Surface 1; **5)** compounds detected from the water lift from Surface 2; **6)** compounds detected from the sediment sample.

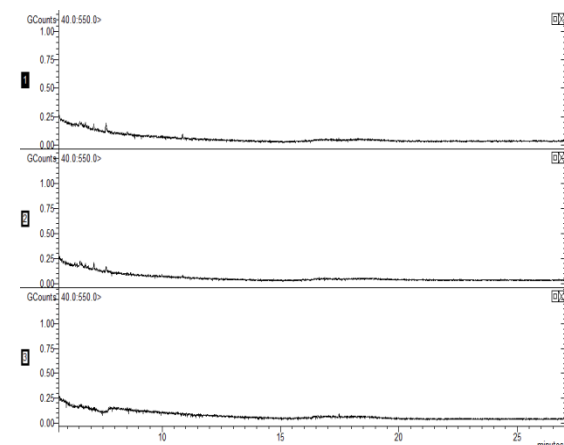


Figure D54: GC-MS chromatograph of residue mixtures sampled from UP GS 17. **1)** compounds detected from the EWA lift from the Surface 1; **2)** compounds detected from the water lift from Surface 2; **3)** compounds detected from the water lift from Surface 1.

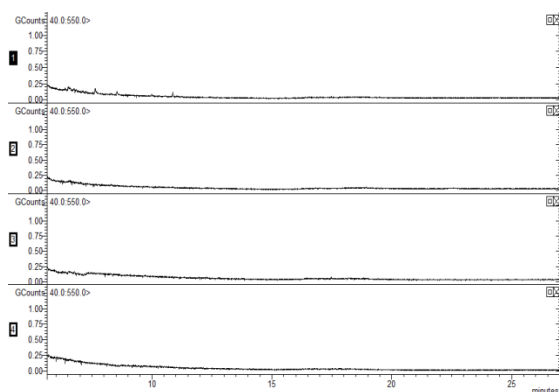


Figure D59: GC-MS chromatograph of residue mixtures sampled from UP GS 18. **1)** compounds detected from the EWA lift from the ground surface; **2)** compounds detected from the EWA lift from the ground surface; **3)** compounds detected from the water lift from the unground surface; **4)** compounds detected from the sediment sample.

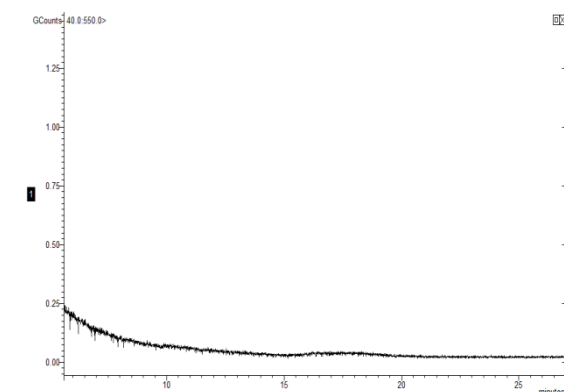


Figure D60: **1)** GC-MS chromatograph of residue mixtures detected from within the sediment sample supplied for UP GS 19.

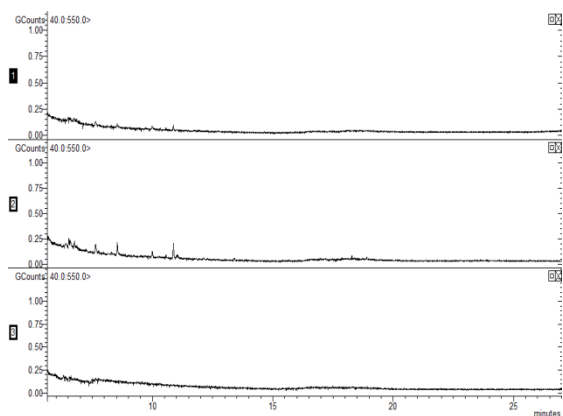


Figure D61: GC-MS chromatograph of residue mixtures sampled from UP GS 21. **1)** compounds detected from the EWA lift from the ground surface; **2)** compounds detected from the water lift from the ground surface; **3)** compounds detected from the sediment sample.

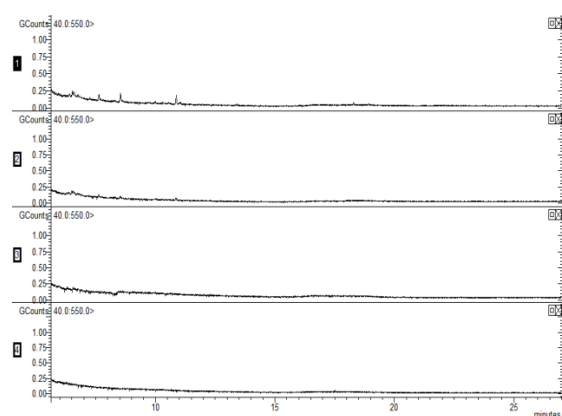


Figure D62: GC-MS chromatograph of residue mixtures sampled from UP GS 22. **1)** compounds detected from the EWA lift from Surface 2; **1)** compounds detected from the EWA lift from Surface 1; **3)** compounds detected from the water lift from Surface 2; **4)** compounds detected from the sediment sample.

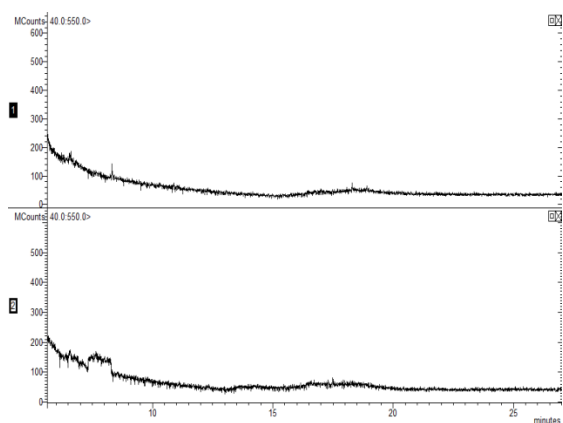


Figure D63: GC-MS chromatograph of residue mixtures sampled from UP GS 23. **1)** compounds detected from the EWA lift from the ground surface; **2)** compounds detected from sediment sample.

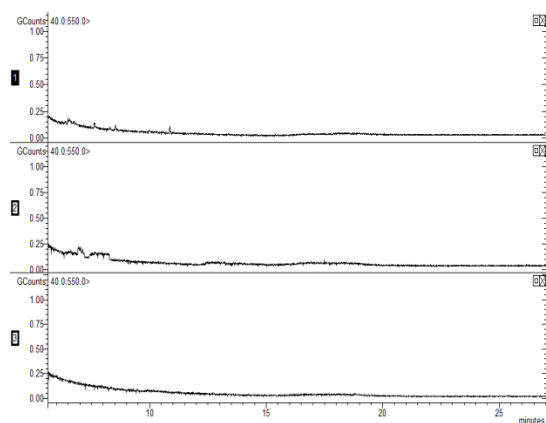


Figure D64: GC-MS chromatograph of residue mixtures sampled from UP GS 24. **1)** compounds detected from the EWA lift from the ground surface; **2)** compounds detected from the water lift from the ground surface; **3)** compounds detected from the sediment sample.

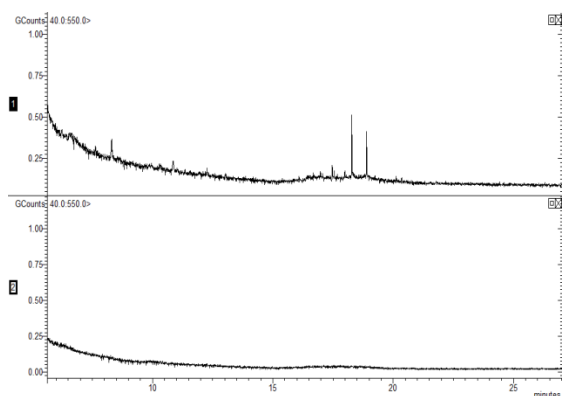


Figure D65: GC-MS chromatograph of residue mixtures sampled from UP GS 25. **1)** compounds detected from the EWA lift from the ground surface; **2)** compounds detected from sediment sample.

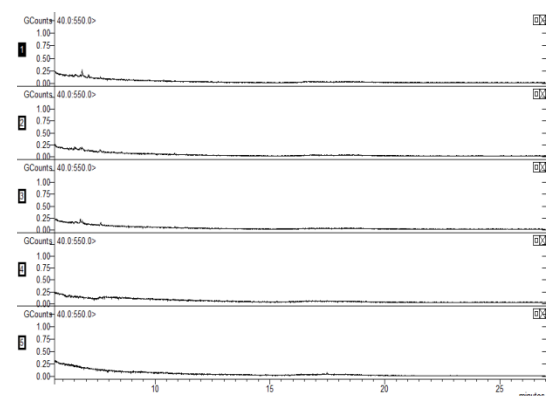


Figure D66: GC-MS chromatograph of residue mixtures sampled from UP GS 26. **1)** compounds detected from the EWA lift from Surface 2; **2-3)** compounds detected from the EWA lift from Surface 1; **4)** compounds detected from the water lift from Surface 3; **5)** compounds detected from the sediment sample.

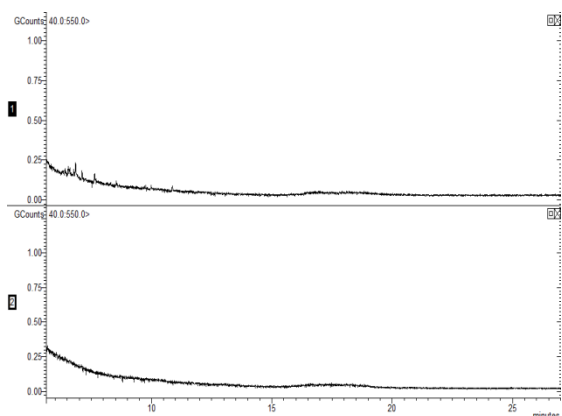


Figure D67: GC-MS chromatograph of residue mixtures sampled from UP GS 27. **1)** compounds detected from the EWA lift from the ground surface; **2)** compounds detected from sediment sample.

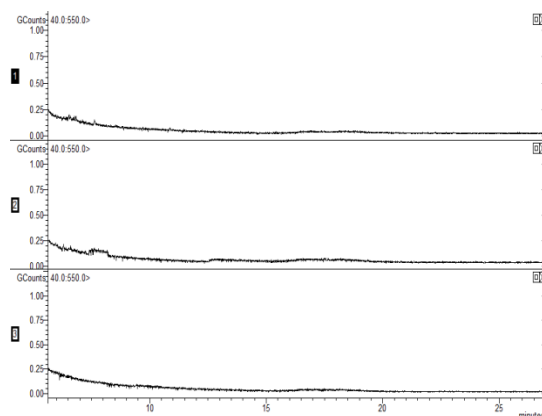


Figure D68: GC-MS chromatograph of residue mixtures sampled from UP GS 28. **1)** compounds detected from the EWA lift from the ground surface; **2)** compounds detected from the water lift from the ground surface; **3)** compounds detected from the sediment sample.

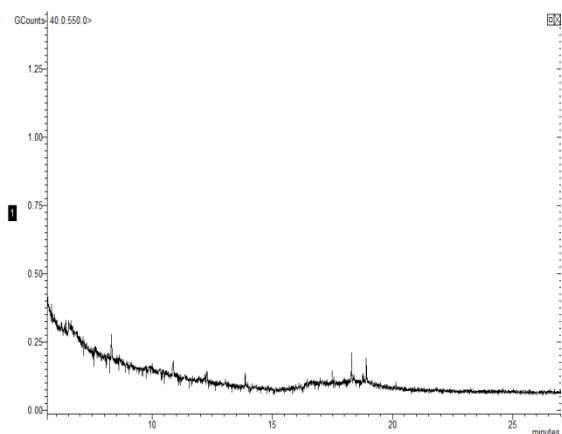


Figure D69: 1) GC-MS chromatograph of residue mixtures sampled from the ground surface of UP GS 29 with EWA solvent .

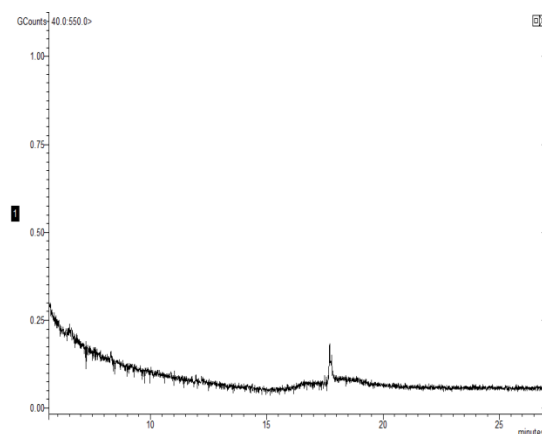


Figure D70: 1) GC-MS chromatograph of residue mixtures sampled from the ground surface of UP GS 30 with EWA solvent .

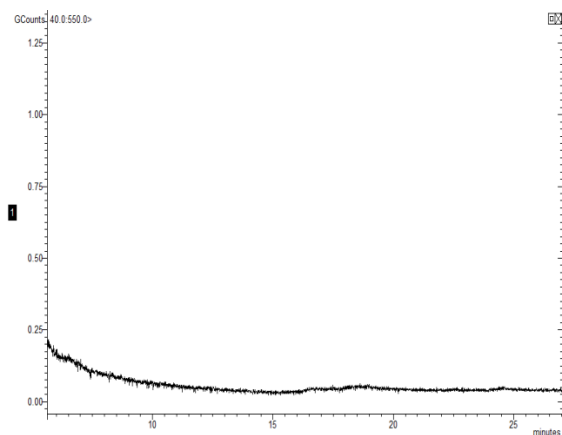


Figure D71: 1) GC-MS chromatograph of residue mixtures sampled from the ground surface of UP GS 31 with EWA solvent .

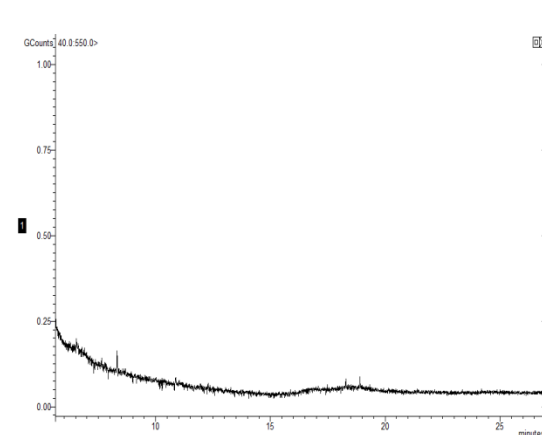


Figure D72: 1) GC-MS chromatograph of residue mixtures sampled from the ground surface of UP GS 32 with EWA solvent .

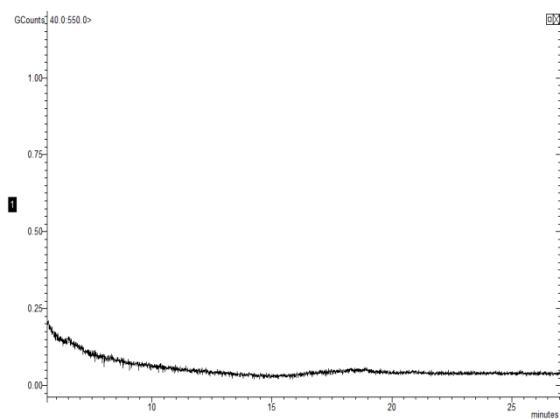


Figure D73: 1) GC-MS chromatograph of residue mixtures sampled from the ground surface of UP GS 33 with EWA solvent .

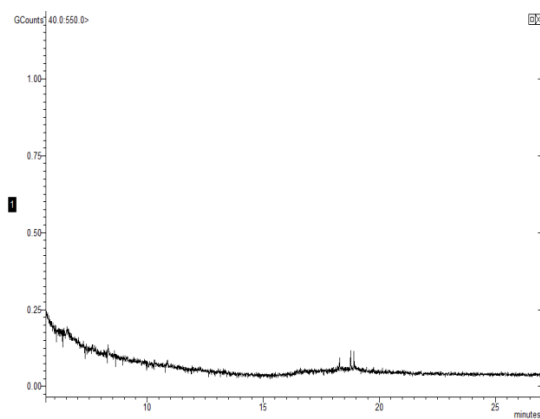


Figure D74: 1) GC-MS chromatograph of residue mixtures sampled from the ground surface of UP GS 34 with EWA solvent .

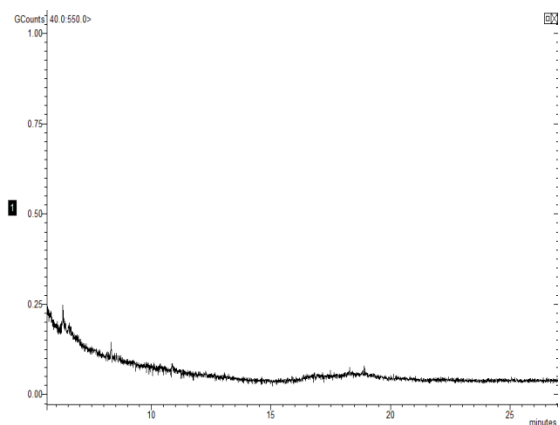


Figure D75: 1) GC-MS chromatograph of residue mixtures sampled from the ground surface of UP GS 35 with EWA solvent .

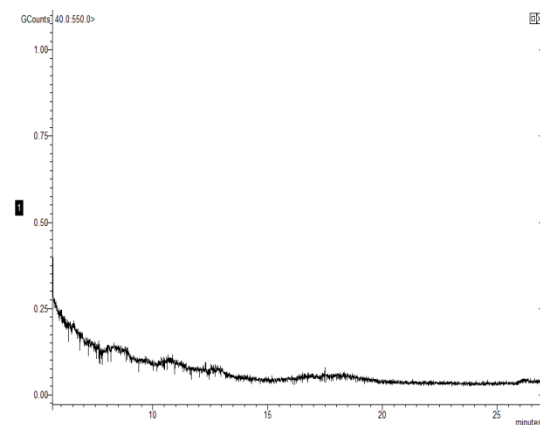


Figure D76: 1) GC-MS chromatograph of residue mixtures sampled from the ground surface of UP GS 36 with EWA solvent .

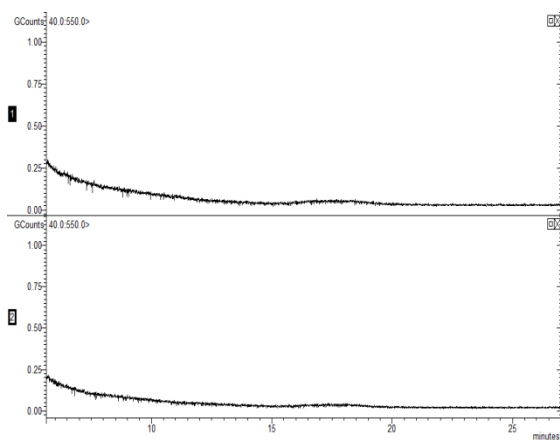


Figure D77: GC-MS chromatograph of residue mixtures sampled from UP GS 37. **1)** compounds detected from the EWA lift from the ground surface; **2)** compounds detected from sediment sample.

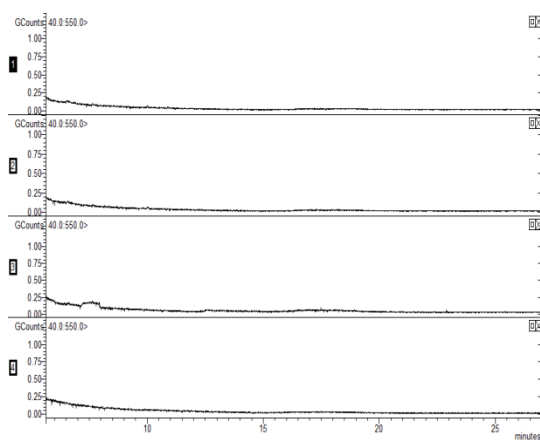


Figure D78: GC-MS chromatograph of residue mixtures sampled from UP GS 38. **1-2)** compounds detected from the EWA lift from the ground surface; **3)** compounds detected from the water lift from the ground surface; **4)** compounds detected from the sediment sample.

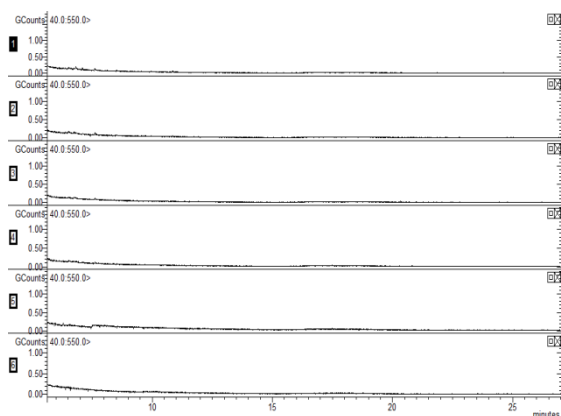


Figure D79: GC-MS chromatograph of residue mixtures sampled from UP GS 39. **1)** compounds detected from the EWA lift from Surface 2; **2)** compounds detected from the EWA lift from Surface 3; **3)** compounds detected from the EWA lift from Surface 1; **4)** compounds detected from the EWA lift from the Surface 5; **5)** compounds detected from the water lift from Surface 1; **6)** compounds detected from the sediment sample.

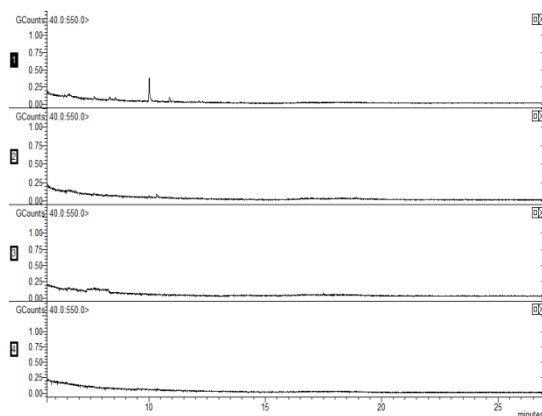


Figure D80: GC-MS chromatograph of residue mixtures sampled from L49. **1-2)** compounds detected from the EWA lift from the ground surface; **3)** compounds detected from the water lift from the ground surface; **4)** compounds detected from the sediment sample.

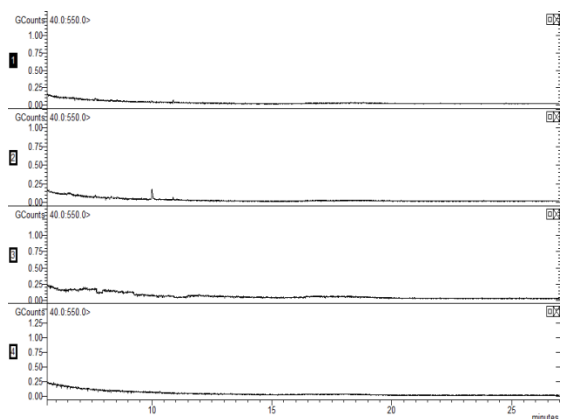


Figure D81: GC-MS chromatograph of residue mixtures sampled from L52. **1)** compounds detected from the EWA lift from Surface 2; **2)** compounds detected from the EWA lift from Surface 1; **3)** compounds detected from the water lift from Surface 1; **4)** compounds detected from the sediment sample.

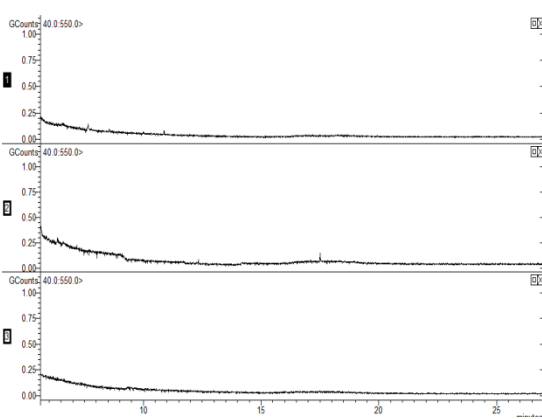


Figure D82: GC-MS chromatograph of residue mixtures sampled from L813. **1)** compounds detected from the EWA lift from the ground surface; **2)** compounds detected from the water lift from the ground surface; **3)** compounds detected from the sediment sample.

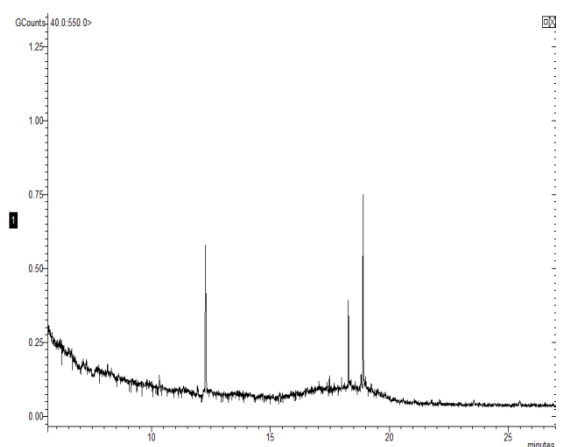


Figure D83: 1) GC-MS chromatograph of residue mixtures sampled from the ground surface of L868 with EWA solvent .

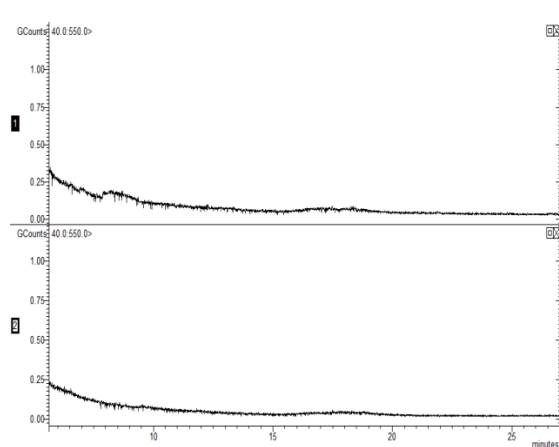


Figure D84: GC-MS chromatograph of residue mixtures sampled from L894. **1)** compounds detected from the EWA lift from the ground surface; **2)** compounds detected from sediment sample.

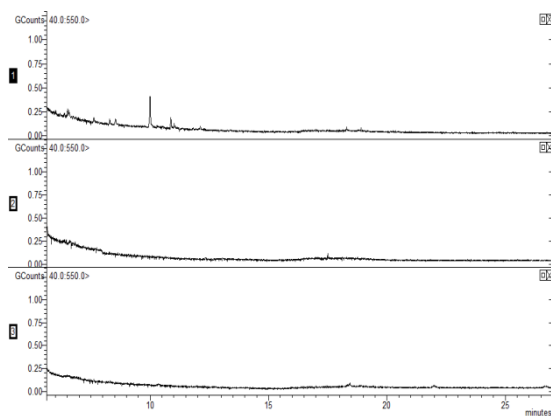


Figure D85: GC-MS chromatograph of residue mixtures sampled from L1349. **1)** compounds detected from the EWA lift from the ground surface; **2)** compounds detected from the water lift from the ground surface; **3)** compounds detected from the sediment sample.

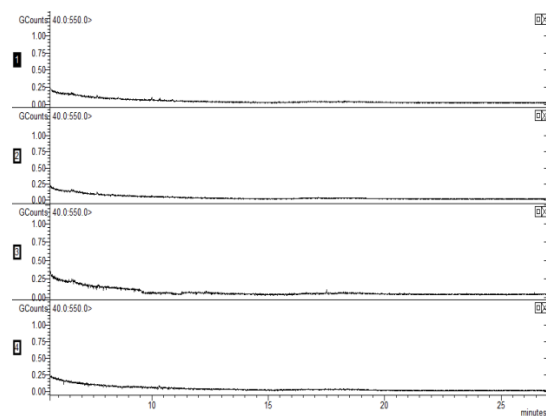


Figure D86: GC-MS chromatograph of residue mixtures sampled from R2. **1-2)** compounds detected from the EWA lift from the ground surface; **3)** compounds detected from the water lift from the ground surface; **4)** compounds detected from the sediment sample.

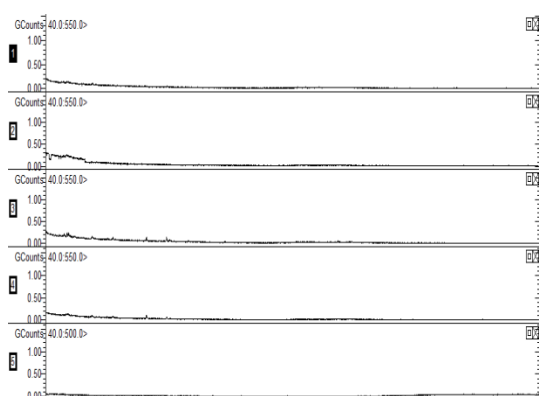


Figure D87: GC-MS chromatograph of residue mixtures sampled from R5. **1)** compounds detected from the EWA lift from Surface 1; **2)** compounds detected from the EWA lift from Surface 2; **3)** compounds detected from the EWA lift from Surface 3; **4)** compounds detected from the water lift from the Surface 1; **5)** compounds detected from the sediment sample.

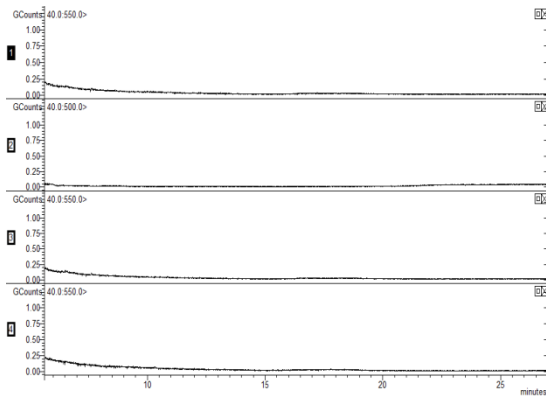


Figure D88: GC-MS chromatograph of residue mixtures sampled from R66. **1)** compounds detected from the EWA lift from Surface 1; **2)** compounds detected from the EWA lift from Surface 2; **3)** compounds detected from the water lift from Surface 1; **4)** compounds detected from the sediment sample.

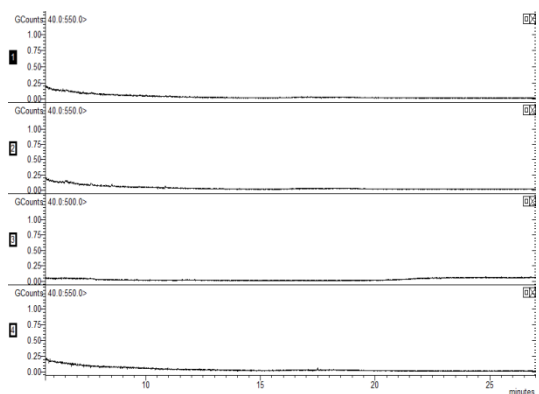


Figure D89: GC-MS chromatograph of residue mixtures sampled from R68. **1)** compounds detected from the EWA lift from Surface 1; **2)** compounds detected from the EWA lift from Surface 2; **3)** compounds detected from the water lift from Surface 1; **4)** compounds detected from the sediment sample.

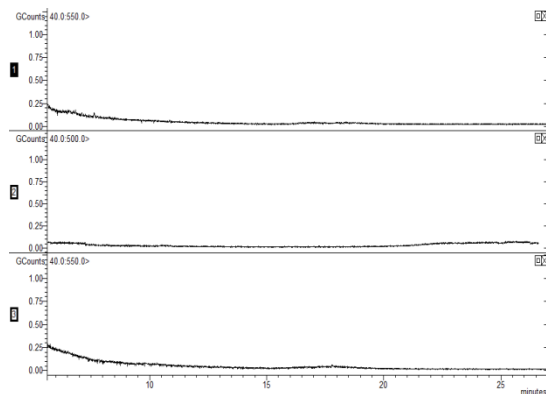


Figure D90: GC-MS chromatograph of residue mixtures sampled from R69. **1)** compounds detected from the EWA lift from the ground surface; **2)** compounds detected from the water lift from the ground surface; **3)** compounds detected from the sediment sample.

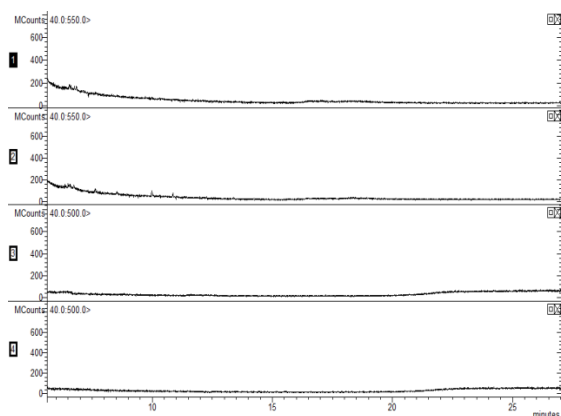


Figure D91: GC-MS chromatograph of residue mixtures sampled from LM GS 1. **1)** compounds detected from the EWA lift from Surface 1; **2)** compounds detected from the EWA lift from Surface 2; **3)** compounds detected from the water lift from Surface 2; **4)** compounds detected from the water lift from Surface 2.

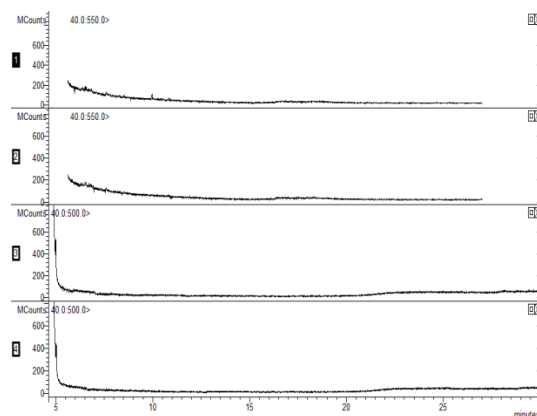


Figure D92: GC-MS chromatograph of residue mixtures sampled from LM GS 3. **1)** compounds detected from the EWA lift from Surface 1; **2)** compounds detected from the EWA lift from Surface 2; **3)** compounds detected from the water lift from Surface 1; **4)** compounds detected from the water lift from Surface 2.

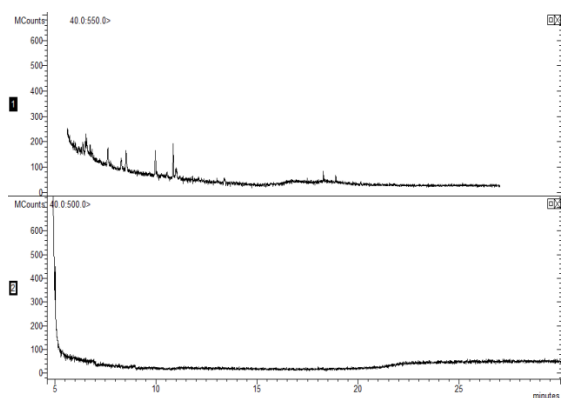


Figure D93: GC-MS chromatograph of residue mixtures sampled from LM GS 5. **1)** compounds detected from the EWA lift from the ground surface; **2)** compounds detected from the water lift from the ground surface.

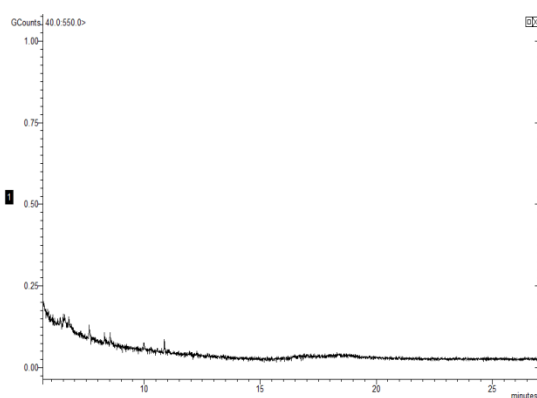


Figure D94: **1)** GC-MS chromatograph of residue mixtures sampled from the ground surface of LM GS 9 with EWA solvent.

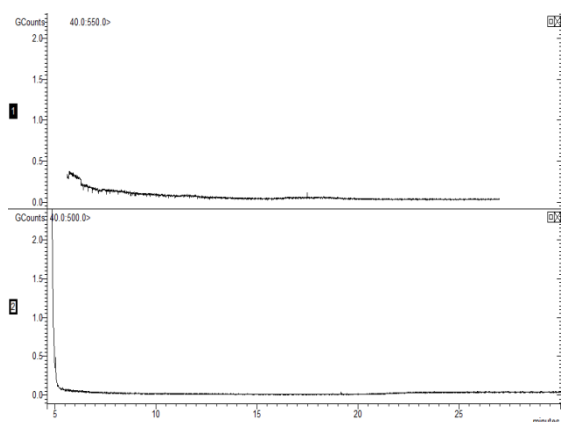


Figure D95: GC-MS chromatograph of residue mixtures sampled from LM GS 10. **1)** compounds detected from the EWA lift from the ground surface; **2)** compounds detected from the water lift from the ground surface.

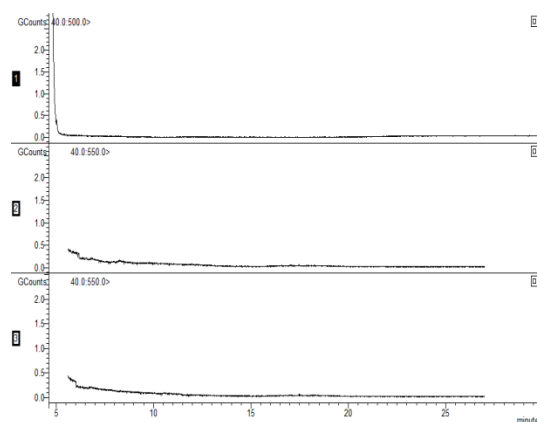


Figure D96: GC-MS chromatograph of residue mixtures sampled from LM GS 11. **1)** compounds detected from the water lift from Surface 2; **2)** compounds detected from the EWA lift from Surface 2; **3)** compounds detected from the EWA lift from Surface 1.

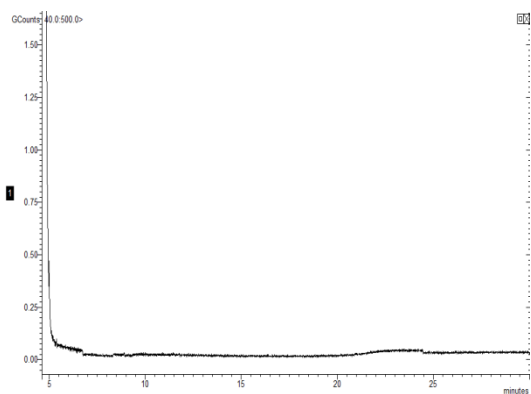


Figure D97: 1) GC-MS chromatograph of residue mixtures sampled from the ground surface of LM GS 12 with water solvent.

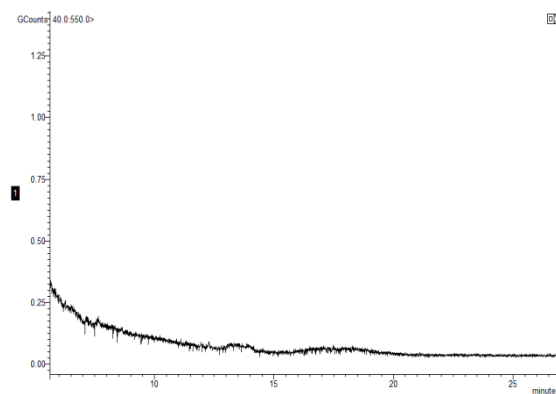


Figure D98: 1) GC-MS chromatograph of residue mixtures sampled from the ground surface of LM GS 13 with EWA solvent.

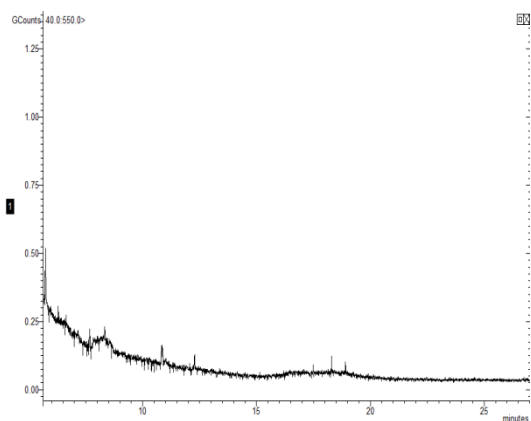


Figure D99: 1) GC-MS chromatograph of residue mixtures sampled from the ground surface of LM GS 14 with water solvent.

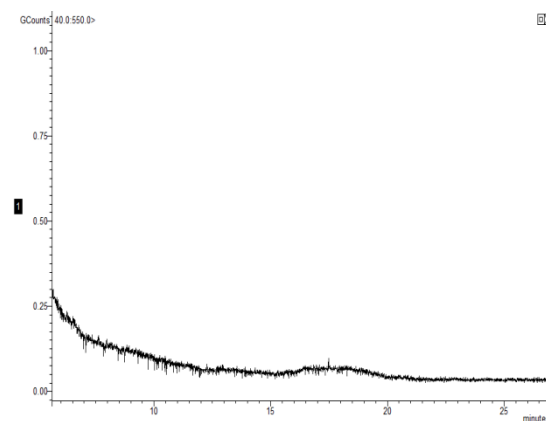


Figure D100: 1) GC-MS chromatograph of residue mixtures sampled from the ground surface of LM GS 15 with EWA solvent.

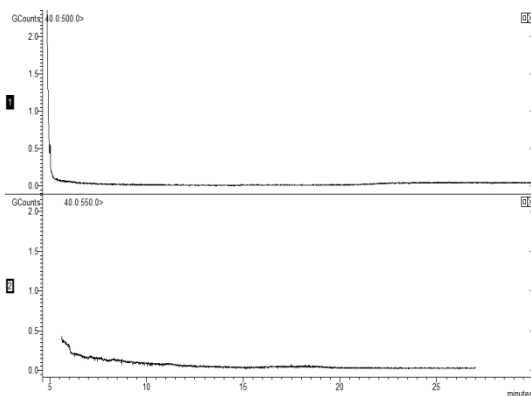


Figure D101: GC-MS chromatograph of residue mixtures sampled from LM GS 16. **1)** compounds detected from the water lift from the ground surface; **2)** compounds detected from the EWA lift from the ground surface.

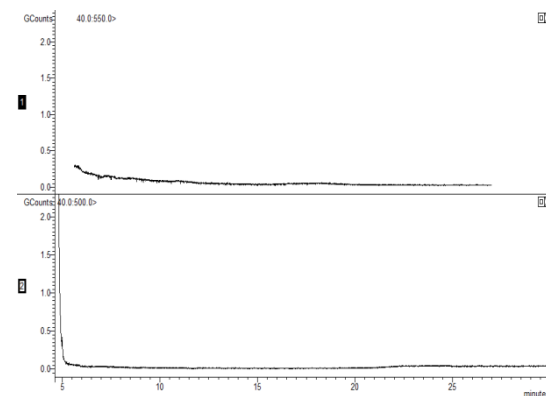


Figure D102: GC-MS chromatograph of residue mixtures sampled from LM GS 17. **1-2)** compounds detected from the EWA lift from the ground surface.

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Appendix E

Publications

Articles below removed for copyright reasons, please refer to the citation:

- Clarkson, C., Smith, M., Marwick, B., Fullagar, R., Wallis, L. A., Faulkner, P., Manne, T., Hayes, E., Roberts, R. G., Jacobs, Z., Carah, X., Lowe, K. M., Matthews, J. & Florin, S. Anna. (2015). The archaeology, chronology and stratigraphy of Madjedbebe (Malakunanja II): a site in northern Australia with early occupation. *Journal of Human Evolution*, 83 46-64.
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