Ancient starch analysis of grinding stones from Kokatha Country, South Australia

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ABSTRACT

Identifying the range of plants and/or animals processed by pounding and/or grinding stones has been a rapidly developing research area in world prehistory. In Australia, grinding and pounding stones are ubiquitous across the semi-arid and arid zones and the associated tasks have been mostly informed by ethnographic case studies. More recently, plant microfossil studies have provided important insights to the breadth of plants being exploited in a range of contexts and over long time periods. The preservation of starch and/or phytoliths on the used surfaces of these artefacts is well documented, though the factors determining the survival or destruction of use-related starch residues are still largely unknown. Some of these artefacts have also been used for grinding up small animals and these tasks can be identified by specific staining methods for organic remains such as collagen.

In this study, 25 grinding and pounding stones identified during an archaeological project in arid South Australia, were examined for starch and collagen residues. The artefacts were from 3 locations in central South Australia, all located in exposed settings. Of these localities, Site 11 in the Western Valley near Woomera is an important Aboriginal landscape specifically associated with male ceremonial practice in the recent past. The remaining two sites, one in the adjacent Nurrungar Valley and the other near Andamooka 100 km distant, have unrestricted access and potentially a different suite of residues. The Kokatha Mula Nations, the Traditional Owners of Woomera, requested that this study be undertaken to explore the range of plants that may have been processed here. It provided an opportunity to investigate the preservation potential of starch and collagen on grinding stones; explore the range of taphonomic factors involved in the persistence of residues in extreme environmental conditions; and test the methodological developments in identifying specific plant origin of starch residues. Of the 25 grinding/pounding stones tested, 7 yielded starch grains. Geometric morphometric analysis identified 3 economic grass species, \textit{Crinum flaccidum} (Andamooka Lily) and \textit{Typha domingensis} (Bulrush/ Cumbungi). Folded collagen was identified on one artefact. Oral histories recount the movement between Andamooka and Nurrungar/Western Valley for men’s ceremonies, and documented in the movement of stone resources, e.g. oolitic chert.

The survival of residues in this environment and the identification of economic plant taxa complement the current knowledge of ceremonial activities and the movement of people and resources across significant distances in arid South Australia.

1. Introduction

Grinding technology emerged in the Late Pleistocene across the globe, and the specific tasks associated with these implements varied considerably through time and space (e.g. Piperno et al., 2000; Fullagar, 2006; Fullagar et al., 2008, 2015; Liu et al., 2014; Field et al., 2016; Louderback and Pavlik, 2017; Barton et al., 2018). The distribution varies with environment, and in Australia, while grinding
stones can be found in most environmental zones, they are ubiquitous across the arid and semi-arid regions. Numerous shapes and forms have been described (e.g. Smith, 1999; Smith et al., 2015), and the uses and tasks performed (involving both plants and animals) have been described in the ethnographic literature (e.g. Hayden, 1979; Gould, 1980), or identified in functional studies (e.g. Fullagar et al., 2008).

In arid regions, starch foods prepared from seeds, yams and tubers have always been primary sources of food for Aboriginal people (Clarke, 2013; Pascoe, 2014; Pate and Owen, 2015). Many were prepared by grinding to a paste, followed by roasting or cooking before eating (e.g. Gould, 1980; Clarke, 1978:80). Ethnographic studies have shown that grinding/pounding stones were also used for processing insects, lizards, cats and some small marsupials (Gould, 1980). Non-food materials such as ochre and medicinal plants, e.g. Acacia inaequilateralis (Kanji Bush) and Duboisia hopwoodii (Pituri) have also been recorded as processed in this way (Brokensha, 1978). Preparation with or without water effectively rendered food edible and in a form that could be consumed by elderly or the very young. Toxic starch plants, like Nardoo (Marsilea spp.) and Cycads were prepared by complex processing: baking, pounding/grinding and leaching with water to remove toxins (e.g. Cribb and Cribb, 1974:72 Pedley, 1993; Asmussen, 2011).

Numerous studies in Australia and New Guinea have established that starch survives for many millennia as use-related residues on the surface of stone artefacts (Denham et al., 2003; Fullagar, 2006; Fullagar et al., 2008; Field et al., 2009, 2016). While the specific factors controlling the survival of starch over these time periods have yet to be well defined, it is clear that these plant microfossils can be a resilient record of plant use from the distant past. Preservation of starch is not restricted to particular environments, with starch grains recovered from grinding stones in the rainforests of Far North Queensland, the semi-arid and arid regions of Australia and from flaked and ground stone artefacts in the New Guinea highlands (Field et al., 2016; Fullagar, 2006; Fullagar et al., 2015; Summerhayes et al., 2010). The size and morphology of starch grains can be diagnostic to a particular plant species and are governed by their genetics and physical environments (Field, 2006a). Furthermore, it has also been shown that the local environment can have a significant effect on grain characteristics (Lance et al., 2005), though this appears to usually be only in size. As grinding stones can also be multifunctional in some instances, examining them for evidence of processing small animals is also important. These activities can be inferred by the presence of collagen, a residue that can also be preserved for long periods (Stephenson, 2011, 2015).

In this study, we present the results of a residue analysis of grinding and pounding stones from the arid zone in South Australia. The aim of this study was to investigate the survival of potentially use-related residues, specifically starch, phytoliths and collagen, the last being a likely indicator of multifunctional use. If starch residues did survive could these be attributed to specific plant taxa using the geometric morphometric approach? Importantly for the Kokatha people of the Woomera region, did the potential function of these grinding and pounding stones and the associated residues provide corroboration for the known history of site use?

2. Background

2.1. Site setting

The Woomera and Andamooka region of South Australia (Fig. 1) is home to the Kokatha people and represented by the Kokatha Aboriginal Corporation (KAC). Between 2011 and 2017, an archaeological and anthropological project was undertaken by Godden Mackay Logan Heritage consultants (GML) in collaboration with the KAC (GML Heritage, 2018). The artefacts examined in this study were from Site 11 in the Western Valley (13 grinding stones), a habitation site in the adjacent Nurrungar Valley near Woomera (8 grinding stones), and a habitation site near Andamooka (4 grinding stones), 100 km north of Site 11.

Site 11 is located in a small closed valley (the Western Valley) which is remote, extremely dry and wind-swept. The landscape is largely devoid of vegetation except for patchy areas of low salt bush on the valley floor. The valley is oriented east-west, as is the associated ephemeral creek system. No standing or running water is normally present. The Western Valley is bordered by north and south facing slopes, with ancient eroded surfaces of hardened Corroberra sandstone (Pwc) consisting of red-brown, silty sandstone and flakey, micaceous siltstones. A single quartzite outcrop is located on the northern valley slope. The valley floor comprises colluvial and alluvial silts, with pockets of aeolian sands and silts, creating a flat soft surface in the absence of a ground covering surface geology.

The Western Valley is associated with Kokatha Dreaming and male ceremonies, traditions that are still practiced by Kokatha Watis (initiated males). While the Western Valley’s northern slope is associated with the Kokatha male ceremony, the valley floor is a ‘staging area’ and is the location of Site 11, an area 1 km long by approximately 400 m wide. The valley floor is littered with stone artefacts, including numerous grinding stones. Density mapping undertaken in the survey has estimated that around 120,000 lithics are present on the surface – all of which must have been transported from a stone quarry, around 5 km distant. In 2016, approximately 30,000 of these lithics were collected and submitted to a technological analysis (GML Heritage, 2018). The period of site use is not known, but estimates, based on stone artefact technology indicate the late Holocene, possibly within the last 2000–3000 years.

The Nurrungar Valley is a large north-south oriented valley with an ephemeral drainage system that runs into a nearby large salt lagoon. It is an open setting, significantly larger than the Western Valley and is unrestricted in access.

Andamooka is set within gently undulating quaternary sand dunes, with open sites positioned in the swales of the dune field. The setting is generally open, and unrestricted in access.

2.2. Cultural traditions

Traditional knowledge documented in the GML study (GML Heritage, 2018), describes the local Watis inviting men from neighbouring and distant clans/tribes to participate in male ceremonies. These men brought stone materials for ceremonies, manufacture/use and trade, and food for consumption during the journey to, and during, ceremonies. Ceremonies occur during the hottest and driest months of the year: January and February. The environmental conditions across the region during these months is extreme, with day time temperatures exceeding 40°C. With little available shade, endurance becomes a component of the ceremony.

The Kokatha recount that all food and water is taken to Site 11 at the start of the ceremony, and processed and consumed during the ceremony. Outside the ceremonial period this small valley is closed to all Kokatha people, except the senior Watis. All Kokatha men know not to enter the area, and the area is never visited by Kokatha women because of traditional gender restrictions.

To that end, the grinding stones analyzed for this study are most likely to be connected with ceremonial times. These artefacts are manufactured from sandstone and quartzite, both of which are available from nearby outcrops. The grinding stones are not (known to be) removed post ceremony or used for purposes outside the ceremony. Given the exclusive nature of these ceremonial activities, and the isolated and sparsely vegetated status of the Western Valley, any residues present are most likely to originate from use at these times.

Please note that detailed maps and photographs of the Western Valley are not included due to cultural restrictions.
2.3. The grinding stone assemblage

Across the north of Kokatha Country, grinding stones are regularly identified in ‘living’ or ‘habitation’ sites, as described by local Aboriginal people. These sites are associated with flaked stone tools, hearths (fireplaces), and other ‘secret/sacred’ culture. Kokatha living sites are frequently connected with specific landscape locations, for example, in association with sources of water, dune fields and food sources (Hughes et al., 2011; GML Heritage, 2018).

The grinding/pounding stones from Kokatha Country have been classified in the artefact manual created for the ‘Olympic Dam’ (OXD) project, which is nearby and are summarized below (Hiscock, Undated:10) (Tables 1 and 2). The grinding stones examined in this study commonly have one or more smoothed or polished surfaces. Some may also have been used for pounding stones and have pitted surfaces. Grinding/pounding stones are divided into several groups:

1. Grinding dishes (or millstones). These are flat, thin slabs of sandstone or quartzite ground smooth on one or both sides, with distinct abraded surfaces typically elongated in shape and often concave in cross-section. These are usually found as broken fragments and complete specimens are rare in the OXD region.
2. Flat grinding stones are often quite thick on parallel-sided slabs, with a flat, approximately circular area of abrasion on one or more faces. The ground surfaces may be slightly concave but are often flat with only a light polish.
3. Top stones (mullers) are used on top of grinding dishes or flat grinding stones. These have flat or slightly convex ground surfaces that often extend to the edge of the specimen. They can be variable in form: sometimes a large cobble which may also be used as a pounding stone, and some are reworked from a broken dish or flat grinding stone.
4. Other grinding stones are those that do not fit within the above categories.

Table 1

<table>
<thead>
<tr>
<th>Site 11</th>
<th>Technological type</th>
<th>L (mm)</th>
<th>W (mm)</th>
<th>T (mm)</th>
<th>Used surfaces (n)</th>
<th>Raw material</th>
<th>Residues (BS)</th>
<th>Starch (SL/JF)</th>
</tr>
</thead>
<tbody>
<tr>
<td>GS 01</td>
<td>Complete cobble</td>
<td>140</td>
<td>120</td>
<td>110</td>
<td>1 ground</td>
<td>Sandstone</td>
<td>Plant fibres</td>
<td>n</td>
</tr>
<tr>
<td>GS 02</td>
<td>Slab fragment</td>
<td>120</td>
<td>130</td>
<td>70</td>
<td>1 ground</td>
<td>Sandstone</td>
<td>Plant fibres</td>
<td>y</td>
</tr>
<tr>
<td>GS 03</td>
<td>Complete cobble</td>
<td>80</td>
<td>65</td>
<td>60</td>
<td>2 ground</td>
<td>Sandstone</td>
<td>Plant fibres</td>
<td>n</td>
</tr>
<tr>
<td>GS 05</td>
<td>Slab fragment</td>
<td>300</td>
<td>200</td>
<td>60</td>
<td>1 ground</td>
<td>Sandstone</td>
<td>Sandstone</td>
<td>y</td>
</tr>
<tr>
<td>GS 06</td>
<td>Complete cobble</td>
<td>170</td>
<td>120</td>
<td>100</td>
<td>1 ground, 2 pitted</td>
<td>Quartzite</td>
<td>Plant fibres</td>
<td>y</td>
</tr>
<tr>
<td>GS 07</td>
<td>Slab fragment</td>
<td>200</td>
<td>150</td>
<td>70</td>
<td>1 ground</td>
<td>Sandstone</td>
<td>Sandstone</td>
<td>y</td>
</tr>
<tr>
<td>GS 08</td>
<td>Complete cobble</td>
<td>110</td>
<td>110</td>
<td>80</td>
<td>1 ground</td>
<td>Sandstone</td>
<td>Plant fibres</td>
<td>n</td>
</tr>
<tr>
<td>GS 10</td>
<td>Complete cobble</td>
<td>130</td>
<td>100</td>
<td>90</td>
<td>1 ground</td>
<td>Quartzite</td>
<td>Plant fibres</td>
<td>y</td>
</tr>
<tr>
<td>GS 11</td>
<td>Complete cobble (muller)</td>
<td>100</td>
<td>70</td>
<td>90</td>
<td>1 ground, 1 pitted</td>
<td>Quartzite</td>
<td>None</td>
<td>n</td>
</tr>
<tr>
<td>GS12</td>
<td>Cobble fragment</td>
<td>150</td>
<td>100</td>
<td>120</td>
<td>2 ground</td>
<td>Sandstone</td>
<td>Amorphous cellulose</td>
<td>n</td>
</tr>
<tr>
<td>GS13</td>
<td>Cobble fragment</td>
<td>70</td>
<td>70</td>
<td>70</td>
<td>2 ground</td>
<td>Sandstone</td>
<td>Plant fibres</td>
<td>n</td>
</tr>
<tr>
<td>GS14</td>
<td>Complete Cobble</td>
<td>190</td>
<td>120</td>
<td>100</td>
<td>1 ground, 1 pitted</td>
<td>Quartzite</td>
<td>Plant fibres</td>
<td>n</td>
</tr>
<tr>
<td>GSN53</td>
<td>Slab Fragment (cf. millstone)</td>
<td>200</td>
<td>110</td>
<td>70</td>
<td>1</td>
<td>Sandstone</td>
<td>Plant fibres</td>
<td>n</td>
</tr>
</tbody>
</table>
2.4. Use related residues

Plants with starchy seeds or tubers may need preparation before being ground and in the case of grass seeds, it is threshing and winnowing. Because of the grinding/pounding process, some of the starchy material is retained on the implements used to prepare them often in interstitial spaces or cracks and are referred to as ‘use-related’ residues. Other use-related residues from processing animal and insects may also be preserved and can include blood, collagen, and plant related non-starchy materials such as bark or ash (Brokensha, 1978; McBryde, 1987; Stephenson, 2011). It is these residues that are being examined in this study.

2.5. Ancient starch analysis

A note on methods of starch identification is needed here because of the various approaches used by researchers to the problem. It is widely acknowledged that it can be challenging to attribute starch grains to their origin plant taxa even when undertaken by an expert: most commonly using a visual comparison involving identification of unique morphological features and maximum length measurements. The issues around identification mainly arise because there can be greater morphological variation observed within a species than there is between species. Some plants produce very diagnostic grains, e.g. the small freshwater fern Nardoo ( Marsilea drummondii ), and the Hairy Yam ( Dioscorea bulbifera ), (Fig. 2a, b) while others are difficult to discriminate on a visual basis because of the redundancy of shapes between species (e.g. Cycas media and Beilschmiedia bancroftii, Fig. 2c, d). For this reason, we use a shape analysis, population approach known as geometric morphometric analysis (Coster and Field, 2015). It is a method that provides a higher level of confidence than previous more subjective comparative methods mentioned above (and discussed in Fullagar et al., 2008). No method appears to be fool proof as some species can be particularly difficult to separate and not all starch under examination can be attributed to a specific plant taxa (Field et al., 2016).

Study of plant microfossils is grounded in a comprehensive modern comparative reference collection compiled of known economic and non-economic starchy plants for the area under study (Field, 2006a,b). Lists of potential economic taxa for the Woomerina region were compiled following GML Heritage (2017) and Luu et al. (2015). Secondary sources included Australia’s Virtual Herbarium (2017), Clarke (2013), Latz (1986), Low (1991), Zola and Gott (1992). Australia’s Virtual Herbarium (Australia’s Virtual Herbarium, 2017) was used to verify the presence of a particular species within this region. Tables 3 and 4 and Fig. 3 present the reference taxa used in this study.

3. Materials and methods

A total of 25 grinding stones were collected from three separate locations (Fig. 1) Site 11 in the Western Valley; AS11, a habitation site in the Nurrunga Valley (3 km east of Site 11), and a habitation site at Andamooka (Tables 1, 2). All grinding stones were either sandstone or quartzite, and a range of flat stones and top stones were sampled. All artefacts had evidence for either grinding or pounding and a number also had evidence for pitting.

Samples from Site 11 (in the Western Valley), which was directly connected with male ceremony, were collected from the northern edge of the valley floor. The assemblage comprised thirteen grinding stones samples GS1 to GS3, GS5 to GS14 and GS53 (Fig. 4). Any residues on these samples were likely to be the resultant of processing of plants brought into the Western Valley.

The habitation site within the Nurrunga Valley was also sampled. This site was culturally unrestricted, used by family groups, adjacent to a semi-permanent water hole, with food plants and small trees bearing edible seeds or fruit known to be present. Eight grinding stones were selected from a location where other cultural finds were also found (stone tools and a hearth). The eight grinding stones – samples GS15 to GS22 – would have been used at the site, and may have documented plants available locally.

The site sampled in this study was also a culturally unrestricted habitation site in the dune fields near Andamooka, 100 km north from the Nurrunga Valley. Four grinding stones were sampled from this location – GS23 to GS26. These artefacts were associated with two separate lithic densities located in a vegetated dune system, described by the Kokatha as living areas. These grinding stones were included to provide a comparative sample from a location with a contrasting environmental context and thus food resources.

3.1. Sample processing

Each grinding stone was photographed in situ, then placed in a sealed and separate plastic bag to reduce handling. The grinding stones were taken to a temporary artefact recording area in Woomera for residue sampling. The ground surfaces of the 25 grinding stones were sampled for use-related residues. Samples were collected using a variable volume pipette, and approximately 300μl of distilled water. A single sample was collected from each stone. The distilled water was applied to areas with evidence of smoothing (polishes), pits and crevices, as these locations, in our experience, hold the greatest potential for residue survival (Dubreuil et al., 2015; Fullagar, 2006; Fullagar et al., 2006, 2008). The surface was scraped with a nylon pipette tip to help dislodge residues before the water plus sample was removed and transferred to a 1.5 ml centrifuge tube. Samples were subsequently split into two and processed to recover ancient starch and phytoliths (by Luu, Field and Coster) and to assay for collagen (Stephenson).

The sample size was relatively small as the grinding stones could not be moved to a larger laboratory where would normally use a ultrasonic bath and centrifugation. As a result, we predicted a smaller number of microfossils were likely to be recovered. As requested by the

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**Table 2**

Descriptions of grinding stones from the ‘habitation sites’ at Nurrungar Valley (15–22) and Andamooka (23–26) plus residue observations (with initials of authors).

<table>
<thead>
<tr>
<th>Site 11</th>
<th>Technological type</th>
<th>L (mm)</th>
<th>W (mm)</th>
<th>T (mm)</th>
<th>Used surfaces (n)</th>
<th>Stone raw material</th>
<th>Residues (RS)</th>
<th>Starch (SL/JF)</th>
</tr>
</thead>
<tbody>
<tr>
<td>GS 19</td>
<td>Cobble fragment</td>
<td>140</td>
<td>100</td>
<td>100</td>
<td>2 ground</td>
<td>Quartzite</td>
<td>Plant fibres</td>
<td>n</td>
</tr>
<tr>
<td>GS 20</td>
<td>Slab fragment</td>
<td>140</td>
<td>90</td>
<td>70</td>
<td>2 ground</td>
<td>Quartzite</td>
<td>Folded collagen</td>
<td>n</td>
</tr>
<tr>
<td>GS 21</td>
<td>Slab fragment</td>
<td>150</td>
<td>220</td>
<td>90</td>
<td>1 ground</td>
<td>Sandstone</td>
<td>Plant fibres</td>
<td>n</td>
</tr>
<tr>
<td>GS 22</td>
<td>Complete lower slab (cf. millstone)</td>
<td>280</td>
<td>140</td>
<td>50</td>
<td>1 ground</td>
<td>Sandstone</td>
<td>Plant fibres</td>
<td>n</td>
</tr>
<tr>
<td>GS 23</td>
<td>Lower slab fragment (cf. millstone)</td>
<td>100</td>
<td>90</td>
<td>70</td>
<td>1 ground</td>
<td>Sandstone</td>
<td>Plant fibres</td>
<td>n</td>
</tr>
<tr>
<td>GS 24</td>
<td>Complete cobble</td>
<td>80</td>
<td>80</td>
<td>80</td>
<td>1 ground</td>
<td>Quartzite</td>
<td>-</td>
<td>n</td>
</tr>
<tr>
<td>GS 25</td>
<td>Slab fragment</td>
<td>200</td>
<td>180</td>
<td>60</td>
<td>1 ground and pitted</td>
<td>Sandstone</td>
<td>Starch</td>
<td>y</td>
</tr>
<tr>
<td>GS 26</td>
<td>Complete cobble</td>
<td>80</td>
<td>50</td>
<td>50</td>
<td>1 ground, 1 possible ground</td>
<td>Quartzite</td>
<td>Starch</td>
<td>y</td>
</tr>
</tbody>
</table>
Kokatha representatives, following sampling all grinding stones were returned to their original locations. Processing of the residues samples for the starch analysis was undertaken in the School of Biological, Earth and Environmental Sciences at the University of New South Wales. Each sample collected in the field was split into two, one for the starch analysis and one for the collagen analysis (see below).

In our experience, the yield of starch grains was likely to be small and the samples were mounted with minimal treatment to preserve any plant microfossils that may have been present. Negative controls were processed in parallel with the archaeological samples to assay for contaminating starch. Each sample was spun at 6000 RPM for five minutes and the supernatant was discarded. The samples were then re-suspended in c. 30 μl of distilled water and transferred to a glass microscope slide and mounted in a 50:50 water:glycerol solution with a glass coverslip and sealed with nail varnish.

The preparation of each sample for collagen and other organic residues followed a modified Picro-Sirius Red (PSR) staining protocol (Stephenson, 2015) and was undertaken at the University of Queensland. The preparation of each sample for the collagen study used a modified Picro-Sirius Red (PSR) staining protocol (Stephenson, 2015). The sample was transferred to a glass slide and allowed to dry overnight. A drop of freshly prepared 0.25% PSR solution was applied to the slide. After an hour, two drops of acidified water was applied to wash out excess PSR stain. Coverslips were placed over the stained areas, and the slides scanned.

3.2. Microscopy

Microscopy was undertaken with a Zeiss Axioskop II transmitted light microscope fitted with Nomarski optics, Zeiss HRC digital camera and AxioVision software (ver 4.8.3.0; Carl Zeiss 2006–2011). Total slide scans were completed using partially cross-polarised light to ensure the maximum number of starch grains was identified. The preparation was examined at an effective 1000× magnification (using a 63× Oil Immersion objective, with additional 1.6× magnification and 10× oculars).

The PSR stained slides were examined using a Leitz Dialux 22 bright-field transmitted light microscope fitted with polarising filters.

Table 3

<table>
<thead>
<tr>
<th>Family</th>
<th>Genus, species</th>
<th>Common name</th>
<th>Plant part used</th>
<th>Reference</th>
<th>Grains in reference set</th>
</tr>
</thead>
<tbody>
<tr>
<td>Amaryllidaceae</td>
<td>Crinum flaccidum</td>
<td>Andamooka Lily</td>
<td>Corm (medicinal)</td>
<td>Latz (1986), Fennell and van Staden (2001)</td>
<td>116</td>
</tr>
<tr>
<td>Fabaceae</td>
<td>Acacia aneura</td>
<td>Mulga</td>
<td>Seeds</td>
<td>Latz (1986), Low (1991)</td>
<td>105</td>
</tr>
<tr>
<td>Fabaceae</td>
<td>Acacia tetragonophylla</td>
<td>Kurara</td>
<td>Seeds</td>
<td>Latz (1986)</td>
<td>157</td>
</tr>
<tr>
<td>Fabaceae</td>
<td>Acacia victoria</td>
<td>Bramble wattle</td>
<td>Seeds</td>
<td>Latz (1986), Low (1991)</td>
<td>121</td>
</tr>
<tr>
<td>Marsileaceae</td>
<td>Marsilea drummondi</td>
<td>Nardoo</td>
<td>Sporocarps</td>
<td>Low (1991), Zola and Gott (1992)</td>
<td>102</td>
</tr>
<tr>
<td>Poaceae</td>
<td>Dasyloctenium radulans</td>
<td>Button grass</td>
<td>Seeds</td>
<td>Latz (1986)</td>
<td>215</td>
</tr>
<tr>
<td>Poaceae</td>
<td>Panicum millioiumentum</td>
<td>Proso millet</td>
<td>Seeds</td>
<td>Low (1991)</td>
<td>128</td>
</tr>
<tr>
<td>Poaceae</td>
<td>Paspalidium jubatum</td>
<td>Warrego Summer Grass</td>
<td>Seeds</td>
<td>Clarke (2013)</td>
<td>139</td>
</tr>
</tbody>
</table>
Table 4
Ethnobotany of plant taxa included in the ancient starch and collagen analysis of grinding stones from the Australian arid zone.

<table>
<thead>
<tr>
<th>Plant</th>
<th>Known distribution</th>
<th>Common name</th>
<th>Identified traditional aboriginal use</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Panicum miliaceum</em></td>
<td>Near Andamooka</td>
<td>French Millet Broom Millet</td>
<td>Seed was collected and winnowed before being pounded into an edible substance. These bulbs were harvested from the plant and pounded to make a paste with water. Well known to be used for medicinal purposes in Central Australia and as a topical treatment for sores and boils. Flowers in summer to early autumn.</td>
</tr>
<tr>
<td><em>Crinum flaccidum</em></td>
<td>Near Woomera</td>
<td>Andamooka Lily</td>
<td>A widely used food plant, growing in the lake. The underground stem (rhizome) is rich in starch, and also is a source of strong fibre for string-making. The young flowering stems were eaten raw and the leaves were used to make baskets (Gott, 1999).</td>
</tr>
<tr>
<td><em>Typha domingensis</em></td>
<td>Near Andamooka</td>
<td>Southern Cattail Narrow-leaf Cumbungi</td>
<td></td>
</tr>
<tr>
<td><em>Eragrostis eriopoda</em></td>
<td>Near Woomera</td>
<td>Woolybutt grass</td>
<td>&quot;A food source: the seedheads are rubbed off, and then separated from the seeds by pounding, singeing, winnowing and ‘yandying’. The seeds are then ground to a flour and water added to produce a runny mix, which is cooked in sand, ashes and coals to produce a traditional bread or nyuma, wanytji.&quot; (Goddard et al., 2002:102). Body decoration: “in central Australia, decorations were obtained from the heads of Wollybutt grass” (Clarke, 2013:214). Modern use: “During the last decade, Pilbara and Western Desert women have produced baskets and sculptures made from desert grasses, using the coiled bundle technique. The main species involved are long greybeard grass and Woollybutt grass” (Clarke, 2013:246).</td>
</tr>
<tr>
<td><em>Panicum decompositum</em></td>
<td>Near Woomera</td>
<td>Australian Millet Native Millet Umbrella Grass</td>
<td>One of the most important native food plants, the seeds being ground between stones, made into a paste and baked in the ashes (Cribb and Cribb, 1974:102). Other varieties of panic grass have been utilised by women in the north Wellesley islands as a source of fibre for making cord/string. Other varieties were used in Arnhem land for necklaces (Clarke, 2013:184, 219). Not recorded as used.</td>
</tr>
<tr>
<td><em>Paspalidium jubiflorum</em></td>
<td>Near Woomera</td>
<td>Warrego Summer Grass</td>
<td></td>
</tr>
</tbody>
</table>
and photographed using a Tucsen ISH 500 video camera at varying magnifications.

3.3. Geometric morphometric analysis

Digital images (JPEG) of starch grains in the archaeological sample preparations and the modern comparative reference collection were imaged via brightfield differential interference contrast microscopy. Digitisation of these images was completed by tracing using a graphical user interface (GUI) developed in MATLAB (MATLAB Release 2014b, The MathWorks, Inc., Natick, MA, USA), and a WACOM Intuos Pen Tablet (CTH-480). The starch grain outline is referred to as the region of interest (ROI), and if there were more than one grain per field of view, they were numbered sequentially. The location of the hilum position was also marked, fissures, faceting and presence or absence of lamellae were routinely noted.

An algorithm was developed for the analysis of starch grains (Coster and Field, 2015). Application of the algorithm to the co-located reference grains results in a classifier constructed to predict the plant species that produced the starch grain. The grains analysed include those from the reference set of known species and those of unknown species, i.e. the archaeological residue sample. These grains can be characterised in terms of geometric morphometric measures determined from digitised images (see above).

The attributes (or predictor variables) used in this study were:

- Hilum position as an offset from the centre of mass of the grain,
- Perimeter,
- Area,
- Maximum length through the hilum, and the
- Fourier signature of the grain outline (a decomposition of the shape into radial basis components) (Coster and Field, 2015).

The predictor variables were used to build a classifier for the reference set of grains; those species which are possible origin species for the unknown grains. Different classifiers, employing all combinations of the predictor variables were assessed to find an optimal classifier for the reference set which was composed of all potential species (Coster and Field, 2015). The number of individual grains of the reference species is also considered and it is estimated that the within-species variations should be adequately represented by ≥100 starch grains.

The optimum classifier to discriminate the reference plant species was a quadratic discriminant, with a voted output for the predictor variables area, perimeter, circularity and Fourier signature (components 0–5) (following Coster and Field (2015), Field et al. (2016)). This classifier was optimal both for the prediction of the reference starch grains used in its construction and also by cross-validation, where a subset of grains from known species is withheld from the classifier construction and subsequently used to test the classifier performance.

3.4. Results

More than 62 starch grains were identified on seven of the 25 grinding stones submitted for analysis (some clumping prevented an accurate total count). Most grains were intact and undamaged and S3 were digitized for the geometric morphometric analysis. Those not included were damaged and were not suitable for this study. Crinum flaccidum and Typha domingensis were identified on five of the seven grinding stones and two grinding stones had 3 species of grasses identified (Table 5). Other residues were also documented (Tables 1 and 2).

In summary, the analyses of the grinding stones have shown the following:

1. Seven of the 25 artefacts sampled retained starch on their used surfaces (Table 1). Five of the grinding stones were from Site 11; the other two from the habitation site near Andamooka. The Nurrungar Valley habitation site grinding stones did not yield any starch grains.
2. Starch was recovered from a range of upper and lower grounding stone implements (Tables 1, 2; Figs. 4, 5 a–c).
3. Collagen (Fig. 5d), diatoms and phytoliths (silica skeletons of plants) were identified in the slide preparations on some grinding stones (Tables 1 and 2).
4. The results suggest that starch may survive, even if in reduced frequencies, on the used surfaces of grinding stones in open, and environmentally harsh settings.

Of the 13 grinding stones sampled within the Western Valley five yielded starch grains (Tables 1 and 2). Interestingly all grinding stones with residues had starch grains from more than one species: GS5, GS6 and GS7 (situated near each other) had two species each, GS2 had four
species and GS10 had five different plant taxa present. The assemblage was dominated by two species – *Typha domingensis* (Bulrush), a food source; and *Crinum flaccidum* (Andamooka Lily), a medicinal plant. Notably, the analyses by AC/SL/JF and BS were undertaken independently and their separate results agreed on the presence or absence of starch on grinding stones.

A low density of collagenous residues was noted across GS18, as identified by the collagen specific Picro-Sirius Red stain (Stephenson, 2015). These included folded collagen and fine collagen fibres (Fig. 5d), which are commonly associated with skin. As such, the low density and isolated nature of these residues suggest that the collagen is likely to be a contaminant and may be the result of handling. Collagen is mostly found in fibrous tissues such as tendons, ligaments and skin (Di Lullo et al., 2012). It consists of amino acids wound together to form triple-helices which then form elongated fibrils. The Picro-Sirius Red stain is specific for collagen and the adapted staining protocol used here can differentiate Types I, II and III collagen in archaeological contexts (Stephenson, 2015). Importantly, handling experiments investigating the transference of skin, oils, lipids and collagen have been documented in laboratory trials at the University of Queensland and in experiments carried out in the Western Desert Ranger workshops (B. Stephenson, unpublished results). The densities of collagen observed in this study are exceptionally low when compared with animal processing events.

### 4. Discussion

#### 4.1. Residue preservation

The number of grinding stones with preserved starch grains (and near-absence of other residues) reflects the relatively poor residue retention generally observed in surface collections from exposed contexts in marginal environments such as Woomera. The impacts of wind, surface water, rain, other weathering forces, temperature fluctuations as well as UV radiation can result in the removal/degradation of residues on artefact surfaces. Storage and handling of implements following recovery, may also impact on the range and types of residues subtracted from or added to the used surfaces.

Numerous studies have shown that the destruction or removal of use-related residues can be effected by mechanical actions and microbial activity (Barton and Matthews, 2006; Carbone and Keel, 1985; Table 5

Plant taxa identified using the geometric morphometric analysis of starch grains from the seven grinding stones in the Woomera region. Note, not all starch grains identified were digitized for this study due to physical damage.

<table>
<thead>
<tr>
<th>Ground stone ID</th>
<th>Site name</th>
<th># Starch grains</th>
<th>Panicum miliaceum</th>
<th>Crinum flaccidum</th>
<th>Typha domingensis</th>
<th>Eragrostis triopoda</th>
<th>Panicum decompositum</th>
<th>Paspalidium jubiflorum</th>
</tr>
</thead>
<tbody>
<tr>
<td>GS 02</td>
<td>Site 11</td>
<td>19</td>
<td>1</td>
<td>5</td>
<td>12</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>GS 05</td>
<td>Site 11</td>
<td>10</td>
<td>1</td>
<td>6</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>GS 06</td>
<td>Site 11</td>
<td>3</td>
<td>2</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>GS 07</td>
<td>Site 11</td>
<td>17</td>
<td>4</td>
<td>10</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>GS 10</td>
<td>Site 11</td>
<td>10</td>
<td>1</td>
<td>3</td>
<td>3</td>
<td>1</td>
<td></td>
<td>2</td>
</tr>
<tr>
<td>GS 25 Andamooka</td>
<td>Site 11</td>
<td>1</td>
<td></td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>GS 26 Andamooka</td>
<td>Site 11</td>
<td>4</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Totals</td>
<td></td>
<td>62</td>
<td>2</td>
<td>16</td>
<td>32</td>
<td>1</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Percentage</td>
<td></td>
<td>13% unidentfied</td>
<td>3%</td>
<td>26%</td>
<td>52%</td>
<td>2%</td>
<td>2%</td>
<td>3%</td>
</tr>
</tbody>
</table>

Fig. 5. Examples of starch grains isolated from grinding stones examined in this study. (a) An undamaged starch grain from GS10; (b) Clump of starch grains from GS7; (c) Damaged starch grains from GS26, because they were clearly damaged, these were excluded from the geometric morphometric analysis. (d) Folded collagen in an extraction from GS 18 and stained with Picro-Sirius Red (Photographs: (a), (b), (c) Sindy Luu; (d) B. Stephenson).
Haslam, 2004). Nonetheless, many surface collections have been shown to preserve residues (Cooper and Nugent, 2011; Field et al., 2009), as demonstrated here. It is possible that the landscape location and orientation of the artefacts, e.g. used surfaces face down or up, and/or the relatively sheltered location near the base of the northern slope, contributed to the retention of some starch.

A range of taphonomic factors may dictate the persistence of residues on an artefact surface. Some of these are mentioned above and relate to pre- and post-collection handling and in the latter case storage. As far as has been possible, the handling and storage of these artefacts have been mitigated (handling with plastic gloves, storage in plastic bags, etc.). Furthermore, the negative control that was run in parallel with the samples to detect any contaminating starch had no starch present.

4.2. Grinding stone use

The study of use-related residues on grinding stones can provide insights to prehistoric subsistence strategies; plant exploitation and use; and the multifunctional nature of ’formal’ implements (Dickau et al., 2012; Fullagar et al., 2008, 2015; Liu et al., 2014). Furthermore, these studies can potentially identify plant taxa that may have fallen out of use and consequently not within the living memory of modern-day communities, as well as economic plants that may have been transported (Field et al., 2009, 2016). In this study, the highest frequencies of starch grains were documented on lower grinding stones (GS2 and GS7). The residue sample volumes were very conservative and a larger volume of solvent applied to the stone surface is highly likely to have yielded a larger sample of grains.

The two species that were present on 6 of the 7 grinding stones that yielded starch residues were Crinum flaccidum (Andamooka Lily) and Typha domingensis (Bulrush). Notably, these plants either emerge after rain or require wet conditions (a soak or spring) to proliferate (Table 2). As the starch derives from subsurface components of each plant, it is considered unlikely to form an aerial contaminant. Crinum flaccidum has various common names including Andamooka Lily (Sandover Lily and Darling Lily), and is widespread across most environmental zones in the eastern half of the Australian continent. It grows on sandy floodplains, grassy turnout and ephemeral swampy areas, and persists subsurface as a tunicate, or onion like, bulb. The leaves emerge several days after rain, followed by white flowers (Cunningham et al., 1981).

Crinum flaccidum is widely known as a medicinal plant in Central Australia and as a topical treatment for sores and boils in semi-arid areas (Latz, 1986). It has also been reported as an analgesic and recent pharmacological research into the Amaryllidaceae family has identified alkaloids that are considered antiviral, anti-tumour and anticholinergic (Fennell and van Staden, 2001). Crinum has also been reported as prepared for consumption in the semi-arid regions of western NSW (Local Land Services NSW, 2017). The starchy tunicate bulb is made into a gruel, of which pounding can be part of the preparation procedure (Usher, 1974; Latz, 1986:152,Fennell and van Staden, 2001).

Crinum flaccidum starch grains were present on all the artefacts where starch was found. Subsequent archaeological surveys have identified Crinum flaccidum flowering within 2 km of Site 11, which suggests a local source if collected and used during the period of flowering summer to early autumn. The traditional use of Crinum flaccidum is associated with the male ceremonies, and as reported previously - the medical treatment of sores - potentially incurred by men travelling substantial distances for ceremonial purposes, during the hottest months of the year. The flowering cycle of Crinum flaccidum (summer to early autumn) coincides with the season where male ceremony occurred in the Western Valley.

Typha domingensis or Bulrush Typha is one species that is very well known across Aboriginal Australia for its economic uses, including producing fibre for string and edible basal stems (starch rich rhizomes) (Clarke, 2013; Gott, 1999). These require some processing: after cooking they are chewed to produce string, but may also be prepared by pounding.

Typha domingensis was identified on all grinding stone extractions with starch from Site 11, and none were identified on the Andamooka artefacts. Two of the Site 11 grinding stones have higher numbers of Typha domingensis, one being a lump of starch grains that we could not completely visualise. These are the same artefacts that had slightly higher numbers of Crinum flaccidum starch grains as well. Typha is recorded as growing in Andamooka (Table 4, Australia’s Virtual Herbarium, 2017), and could have been brought to the Western Valley with stone materials that were unavailable locally. The wider Nurrungar Valley contains several large ephemeral waterholes where Typha could have grown, but there is no evidence that it has occurred there recently.

The four grass species identified occurred in very small numbers. Their presence on these artefacts could well be from use, or alternatively as aerial contaminants. A detailed usewear study would provide more detail on silica polish but we could not follow this through at the time. Three of the four are well documented economic plant species, but the frequencies are too low to make a call on whether they are use-related.

The low density of collagenous residues noted on one grinding stone sample (GS18, Table 2; Fig. 5d) included folded collagen and fine collagen fibres, and are commonly associated with skin. As such, the low density and isolated nature of these residues suggest the collagen is likely to be a contaminant and may be the result of handling.

4.3. Cultural interpretations

The Kokatha Watis describes traditional ceremonial practice at Site 11 occurring over several days, where those entering the valley needed to bring food for the duration. The presence of economic plant taxa on grinding stones at Site 11 provides insight into the plant use associated with the male ceremony.

During ceremonial times, we argue that the grinding stones in Site 11 were used to prepare medicines and probably food, notably from seeds and underground storage organs. The medicinal plants needed complex processing. Grass seeds also require pounding before roasting. Indications are that food provisioning occurred elsewhere and was brought into the Western Valley, from as far as 100 km away. The traditional Aboriginal economic systems for long distance stone movement into the Western Valley, has parallels with plant movement, notably Typha domingensis and Panicum miliaceum. Across south-eastern Australia, the Bulrush Typha is a common feature in late Holocene living sites (Gott, 1999). It has been a consistent and reliable food, which was relatively simple to prepare and yields large amounts of starch from its rhizomes.

It appears that medicinal treatment for men coming to the ceremony may have been commonplace. All the grinding stones with starch from Site 11 yielded starch from the Andamooka Lily, Crinum flaccidum, a species that spends most of its life cycle as a subterranean tunicate bulb, and its presence is only evident when it sends up leaves and flowers during late summer and early Autumn. As such the emergence of the Andamooka Lily coincides with the men’s ceremonial activities in the Western Valley around this time, as documented in the Kokatha project by GML (GML Heritage, 2017) and suggested by the starch evidence presented in this study.

5. Conclusions

Evaluating the survival of use-related residues on the surfaces of stone artefacts varies considerably with environmental conditions and is rarely predictable. In this pilot study, evaluating the persistence of ancient starch and other residues has resulted in the identification of a number of economic plant taxa as well as collagen in one instance.
**Crinum flaccidum** and *Typha domingensis* are well known as important economic plants across the eastern half of Australia, and in this study, have been recovered from grinding stones in a marginal environmental setting of the Australian arid zone.

Importantly, grinding stones from open sites may retain residues in these arid zone contexts. Tying these residues to function and use needs to be evaluated and as such would benefit from a complete functional analysis. Linking technology, use traces and residue studies will provide a robust hierarchical approach to the identification of the last uses of these implements before discard (Fullagar et al., 1996). This study has shown that residue analyses provide important insights to plant exploitation and potential uses of one of the most ubiquitous artefacts types found across the Australian arid landscape.

The few preserved starch grains on these grinding stones (and near-absence of other organic residues), reflect the relatively poor preservation conditions generally observed in surface collections from exposed site contexts such as Woomera. The impacts of a range of weathering forces can result in the destruction or removal of residues from artefact surfaces, yet in many instances plant material like starch survives, even if in low concentrations. Residue removal is mostly mediated by mechanical actions and microbial activity (Barton and Matthews, 2006; Carbone and Keel, 1985; Haslam, 2004). Nonetheless, many surface collections have been shown to preserve organic residues (Cooper and Nugent, 2011; Field et al., 2016), as was demonstrated here. As such there is considerable potential for future investigations of Australian assemblages (Cooper and Nugent, 2011; Fanning and Holdaway, 2001).

The study of residues on grinding stones can provide additional insights to prehistoric subsistence strategies (e.g. Pate and Owen, 2015); plant exploitation and use; and the multifunctional nature of many ‘formal’ implement artefacts (see Dickau et al.; 2012; Fullagar et al., 2008, 2015; Liu et al., 2014; Field et al., 2016). Valuable scenarios include identifying the use of plant species that have fallen out of use and not currently known by the modern-day communities, as well as identifying plant species that may have been transported into the area (Field et al., 2009). The study has revealed the potential links between archaeological and ethnobotanical studies, where local Aboriginal traditional knowledge can describe the mechanisms for the movement of people, materials, food and intangible cultural heritage across large areas of their country.

**Acknowledgements**

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**References**


