A tale of two hearth sites: Neolithic and intermittent mid to late Holocene occupations in the Jubbah oasis, northern Saudi Arabia

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Abstract

Hearth sites are characteristic of Holocene occupation in the Arabian sand seas but remain mostly unstudied. Excavations of two multi-period hearth sites in the Jebel Oraf palaeolake basin, in the oasis of Jubbah, now substantially increase our knowledge of these sites. In total, 17 of 170 identified hearths were excavated at Jebel Oraf 2 (ORF2), an open-air site on the edge of a palaeolake. In addition, 11 hearths were excavated at the stratified site of Jebel Oraf 115 (ORF115), a rockshelter formed by two boulders. Radiocarbon dating and lithic assemblages indicate that the majority of these hearths were in use in the second half of the 6th millennium BC, and that both sites were used sporadically until the recent past. All hearths appear to have been extremely short-lived, and faunal remains suggest they may have been used to cook meat from hunted or trapped wildlife, and occasionally from livestock. The frequent use of grinding stones, often broken into fragments and used to cover hearths is also attested. Evidence for the exceptionally early use of metal from dated occupation deposits as well as from rock art, shows that these short-lived sites were well connected to technological innovations in the wider region.

Key words

Neolithic, settlement, pastoralism, Saudi Arabia, Holocene, climate

1. Introduction

The Neolithic in the Fertile Crescent forms the foundation of our understanding of an economic transition that saw mobile hunter-gatherers become sedentary farmers. However, on the fringes of this Neolithic core area, populations in the more arid environments of northern Arabia had to adapt their subsistence strategies in different ways. This resulted in a trajectory where Neolithic hunting and gathering was supplemented with mobile pastoralism; while sedentism and agriculture are predominantly associated with Bronze Age occupation in the oases, following the onset of desertification in the region.

The Neolithic in the southern Levant is heterogeneous and populations in different areas adopted herding at different rates (see for example Martin and Edwards, 2013 and references therein). In the Badia of eastern Jordan, caprine herding and opportunistic agriculture appeared by the Pre-Pottery Neolithic C (PPNC, 6600-6250 BC), in a complex subsistence strategy combining livestock and hunting that allowed long-term seasonal occupation of marginal environments (Betts et al., 2013; Martin and Edwards, 2013; Miller et al., 2019; Rollefson et al., 2014). In the Jordanian Highlands and the Jordan Valley, sheep and goat herding was practised by the Middle PPNB (8100-7500 BC) (Makarewicz, 2016; Martin and Edwards, 2013). Evidence from ‘Ain Ghazal, in central Jordan, suggests the emergence of a specialised pastoral economy by the early 7th millennium BC, after domestic goats were herded from around 8500 BC, and domestic sheep were introduced around 7500 BC (Wasse, 2002). Despite apparent regional differences in the timing of subsistence changes, Neolithic sites across the steppe and desert areas of the southern Levant are characterised by remains of substantial curvilinear structures that were used as pens, dwellings, and storage facilities. Even mobile populations are known to have occupied substantial dwellings seasonally (Fujii, 2013c; Fujii, 2013a; Henry et al., 2003; Henry et al., 2017; Rollefson et al., 2014; Rollefson et al., 2016; Rowan et al., 2015).

The study of the Neolithic of the Arabian Peninsula is still at a comparatively early stage, and large areas remain unexplored. Archaeological sites containing faunal remains of early domesticates are extremely rare along the west and in the interior of the Peninsula, with most of our understanding of the Neolithization of Arabia coming from a small but growing number of sites excavated along the Gulf coast and in the very south of the Peninsula. Faunal remains from dated contexts on the Arabian Gulf coast suggest that cattle, sheep, and goat had been introduced from the Levant by the end of the 6th millennium BC (Crassard and Drechsler, 2013a; Drechsler, 2007; Uerpmann et al., 2000). Technological and typological similarities in lithic assemblages, suggest that connections between the southern Levant and the Gulf were established by the 7th millennium BC (Drechsler, 2007; Drechsler, 2009). Notably, there appears to be a division between the central Gulf as far south as

Qatar with short (<2cm) winged and tanged arrowheads, similar to those in the Levant, and the southern Gulf around the Musandam peninsula with long (>3cm) foliate, tanged, or trihedral arrowheads akin to those from Yemen (Charpentier and Crassard, 2013; Maiorano et al., 2020; Spoor, 1997). Northern and central Arabia thus appear to have been influenced by regions to the north, while southern Arabia has more idiosyncratic artefact styles. Neolithic settlements in the southern Gulf from the 6th and 5th millennium BC are characterised by structural remains. Round, circular, or D-shaped stone structures were reported from Marawah and Dalma (see for example Beech et al., 2000; Beech et al., 2020), and similar, though less substantial structures were recorded at as-Sabiyah in northern Kuwait (Carter and Crawford, 2003). Numerous post holes were documented at the settlement of Akab in the lagoon of Umm al-Qaiwain (Charpentier and Méry, 2008), although no permanent installations were identified at the broadly contemporary site of Dosariyah (Drechsler, 2011). Remains of boats and of 'Ubaid pottery show that sites along the Gulf were part of a wide-ranging interaction network. Populations along the Gulf had developed a unique blend of local and introduced elements that allowed the successful establishment of permanent settlements, extensive exploitation of maritime resources, and even pearling (Carter, 2006; Drechsler, 2011; Beech et al., 2020). Of these Gulf sites the closest to Jebel Oraf is as-Sabiyah (730km), followed by Dosariyah (900km), and Akab and Marawah (1500km). The Levant, and in particular the Badia of Eastern Jordan, are considerably closer to Jebel Oraf (500km), and interaction may have occurred via the interdune corridors of the Nefud desert (Scerri et al., 2018; Figure 1). Recent research has identified such interactions at a number sites in the region. At Al Jawf, on the north side of the Nefud, Levantine Neolithic lithic types were being produced using the same techniques as in the Levant (Crassard and Hilbert 2019), suggesting either they were made by some of the same people, or that there was close enough contact to directly observe artefact manufacture and not merely emulate end-products. Previous research in the Jubbah oasis identified multiple phases of Levantine lithic types (Crassard et al., 2013; Hilbert et al., 2014; Guagnin et al., 2020). Moreover, zooarchaeological evidence suggests cattle herding was introduced from LPPNB settlements in southern Levant, via the Red Sea coast (Makarewicz, 2020).

To date, only a few faunal remains have been reported from Neolithic contexts in northern Saudi Arabia; including the occupation sites of Jebel Oraf and Alshaba, a stone platform in Dumat al Jandal, and a mustatil in the western Nefud (Guagnin et al., 2017b; Scerri et al., 2018; Groucutt et al., 2020; Munoz et al., 2020). Neolithization models therefore have to infer population dynamics and subsistence changes across vast distances. The process underpinning the spread of the Neolithic and in particular the question of whether the use of domesticated livestock spread together with Levantine stone tool technology thus remains unresolved (see also Makarewicz, 2020). Distance and lack of data also cause considerable uncertainties in the terminology used to characterise Arabian sites and lithic technologies. In northern Arabia, characteristics that are typically used to define the Neolithic, such as sedentism, agriculture, and pottery are only known from Bronze Age and later contexts (Magee, 2014). The presence of domesticated livestock is therefore often used to define the pastoralists of the 6th millennium BC as Neolithic (Crassard and Drechsler, 2013b). In reference to this convention and following Fedele (2008) we use the term 'Neolithic' for the period following the introduction of domesticated livestock, and 'Pre-Neolithic' to describe the preceding period, prior to the adoption of food production, but in which there are apparent cultural links to contemporaneous Levantine Pre-Pottery Neolithic societies (Guagnin et al., 2020).

Recent test excavations of two hearths at Jebel Oraf 2 in the Jubbah oasis have yielded radiocarbon ages between 5200 and 5070 BC, lithics similar to those typical for the Pottery Neolithic (PN) in the Levant, as well as likely remains of domesticated cattle (Guagnin et al., 2017b). The excavated hearths are unusual in that signs of structural remains are completely absent. A similar hearth site has also recently been excavated at Alshabah in the western Nefud Desert (Figure 1) (Scerri et al., 2018; see also Breeze et al., 2017) and a number of unexcavated hearth sites were reported from central Saudi Arabia and the Rub al-Khali (Reeler and Al Shaikh, 2015). This type of site appears to be common in the sand seas of the Arabian Peninsula and may perhaps represent an adaptation to marginal arid environments, although the coastal site of Dosariyah appears to have been a settlement with similarly ephemeral activity (Drechsler, 2011). In eastern Jordan, at the oasis of Azraq (Figure 1), the late Pre-Pottery Neolithic B (PPNB) site Azraq 31 Area A produced a series of superimposed hearths but no evidence for structures (Baird et al., 1992; Betts, 1989). Hearth sites are not known from the higher rainfall regions of the Levant, despite intensive surveys.

Here we report the results of our excavations of two multi-period hearth sites in the Jebel Oraf basin. At Jebel Oraf 2 (ORF2), on the shores of a palaeolake, 15 hearths were excavated in addition to the two reported in Guagnin et al. (2017b), raising the number of excavated hearths to 17 of 170 identified hearths. A further hearth site, Jebel Oraf 115 (ORF115), was discovered inside a small rockshelter formed by two large boulders on the slopes of Jebel Oraf. The site had recently been partially destroyed by looters, but stratified deposits survive on the southern side of the shelter. Both sites form part of a Neolithic landscape in which earlier dune sites in the form of single phase scatters of lithics, charcoal, and bone, were recorded in elevated positions on the slopes of sand dunes; while hearth sites with evidence of repeated occupation over extended periods were recorded on the shores of the Jebel Oraf palaeolake (the Neolithic landscape of the Jebel Oraf basin is reported in Guagnin et al., 2020). Here we describe the results of our excavations, including the characteristics of hearths and lithic assemblages, and present data from faunal remains and phytolith analysis. This new dataset now allows a comparison with contemporary sites in the Levant and other areas of the Arabian Peninsula, and a first significant characterisation of Neolithic settlement and subsistence patterns in northern Saudi Arabia.

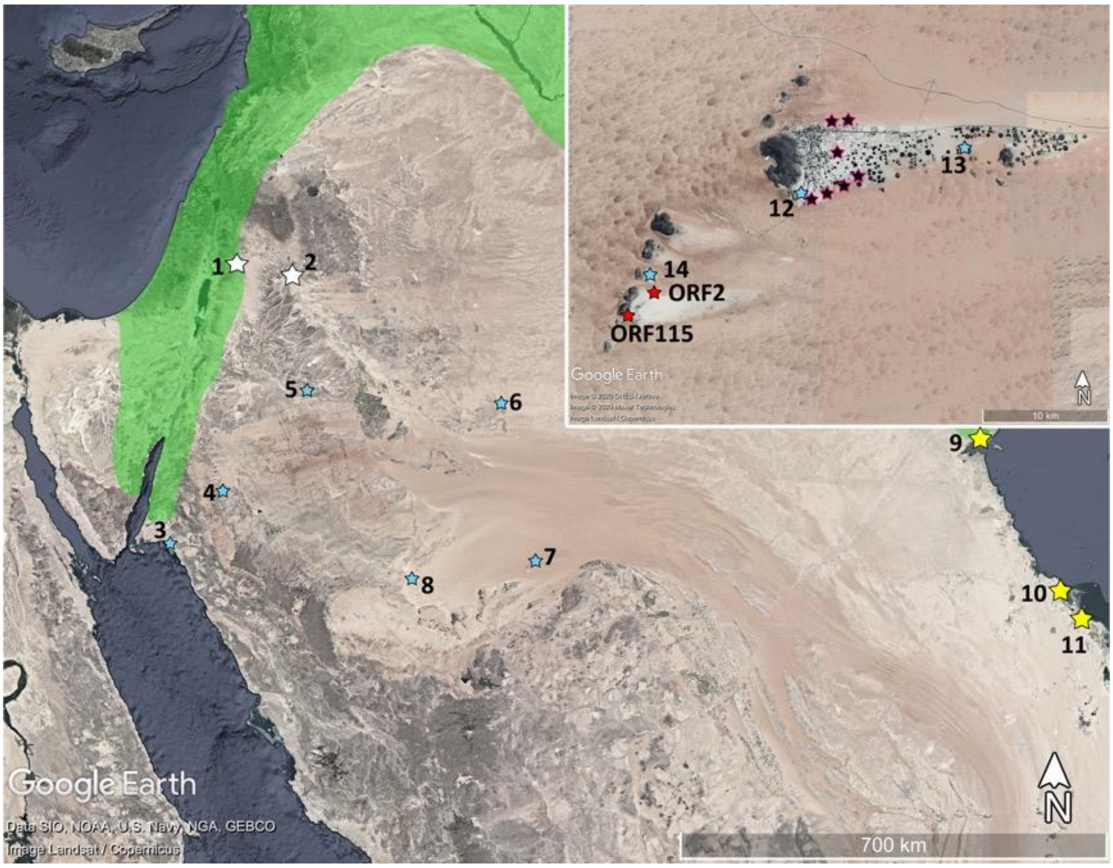

Figure 1 Map showing the Fertile Crescent and sites in northern Arabia mentioned in the text. Inset: Sites in the Jubbah oasis. Large white and yellow stars: Neolithic sites in the Levant and on the Gulf coast (after Drechsler, 2009) with local early evidence of domesticated livestock. Blue: Saudi Arabian sites mentioned in the text. Red: Excavated sites. Black/pink: Neolithic/Chalcolithic sites mapped b. Garrard et al. (1981). 1: 'Ain Ghazal; 2: Azraq 31; 3: Wadi Sharma; 4: al-Aynah; 5: Qulban Beni Mura; 6: Rasif; 7: Jubbah (see also inset); 8: Alshabah; 9: H3/ as-Sabiyah; 10: Abu Khamis, 11: Dosariyah; 12: Al-Rabyah; 13: Jebel Qattar 101; 14: Jebel Katefeh 100.

1.1 Archaeological and environmental background

In northern Saudi Arabia, curvilinear structures are known from Neolithic settlements to the north of the Nefud desert. At Wadi Sharma and al-Aynah, clusters of curvilinear structures were dated to the PPNB (Fujii, 2013c). Reconstruction of landscape use in the region of Wadi Sharma and the Jafr Basin in southern Jordan suggests ephemeral occupation by small, more mobile groups during the Late Neolithic, possibly linked to a period of aridification (Fujii, 2013c; Fujii, 2013b). Further east, multi-roomed domestic structures are also known from Late Neolithic levels at Rasif (Zielhofer et al., 2018). Moreover, Neolithic and Chalcolithic occupation in the Jafr area, at Rasif, and at Qulban Beni Mura in Jordan is associated with water management strategies (Fujii, 2013b; Gebel, 2016; Zielhofer et al., 2018). However, sites from the 6th and 7th millennium BC remain largely unknown in the area.

In the Jubbah oasis, on the southern edge of the Nefud Desert, surveys in the 1970s recorded 12 possible Neolithic or Chalcolithic sites (Figure 1). These contained a range of stone tools including tanged arrowheads, blades, and hoes (Garrard et al., 1981; Parr et al., 1978). Recent surveys by the Palaeodeserts Project have identified two further early Holocene sites. At Al-Rabyah, a lithic assemblage with bladelets and geometric microliths akin to the Geometric Kebaran, was attributed to a drier climatic phase around 8000 BC (Hilbert et al., 2014). At Jebel Qattar 101, El-Khiam and Helwan points similar to those characteristic for the PPN in the Levant (where they occur between 10,200 and 6900 BC) were associated with a palaeolake that was dated to 7000-6000 BC (Crassard et al., 2013). However, none of the sites identified in the Jubbah oasis yielded faunal remains, and until the discovery of bone fragments at ORF2 (Guagnin et al., 2017b) the closest sites with domestic fauna remained as far afield as Kuwait, Yemen, and Jordan.

Evidence for Bronze or Iron Age settlements has so far not been identified in Jubbah, likely as a result of the expansion of modern settlement and agriculture. However, Bronze Age motifs have been identified in the rock art and the region is rich in Iron Age imagery and inscriptions (Guagnin et al., 2017a; Guagnin et al., 2020). A shell bead found at a disturbed burial cairn provided a radiocarbon date of 2930-2770 BC (Guagnin et al., 2017a), and many of the cairns visible on the slopes of the Jebels in Jubbah may date to the Bronze Age (Jennings et al., 2013). The practice of constructing burial cairns seems to have begun both locally and regionally in the late Neolithic (Abu-Azizeh et al. 2014; Guagnin et al. 2020), becoming widespread in the Bronze Age, perhaps with the emergence of pastoral elites (Newton and Zarins, 2000). In the oasis of Tayma, on the western edge of the Nefud Desert, cairns are common in the Bronze Age and artefacts recovered from graves suggest wide reaching contacts as far as Syria and the Levant. Circular tombs were constructed throughout the Iron Age. Remains of permanent occupation are identifiable in Bronze Age contexts and the oasis appears to have been continuously occupied since at least the Iron Age (Hausleiter and Eichmann, 2018; Hausleiter and Zur, 2016)

In north-western Saudi Arabia, the Neolithic coincided with the Holocene humid period, when an orbitally-driven enhancement of regional insolation caused a northward shift of the African summer monsoon. In the oasis of Jubbah this increase in precipitation led to elevated groundwater levels, which in turn resulted in the formation of a large lake and a number of smaller outlying lakes (Engel et al., 2017; Guagnin et al., 2020; Parton et al., 2015; Parton et al., 2018). At the site of Al Rabyah, an early phase of lake formation was recorded at ca 10,000 BC. Following a period of lake contraction, a second phase of lake expansion was dated to around

4600 BC. Molluscs and ostracods recovered from these deposits indicate the presence of a shallow freshwater lake surrounded by vegetation (Hilbert et al., 2014). In addition, a smaller lake dated to between 7000 and 6000 BC was identified at Jebel Qattar in the east of the Jubbah basin. The small palaeolake at Jebel Oraf appears to have mirrored the situation of the main basin in the Jubbah oasis, and lake marls at ORF2 record a flooding event during the late 6th millennium BC (Guagnin et al., 2020). Holocene palaeolakes are also known from the oasis of Tayma, on the western side of the Nefud Desert, and from interdune depressions in the western Nefud (Engel et al., 2012; Scerri et al., 2018). This period of climatic amelioration and lake formation and the subsequent return to aridity after 4000 BC forced a series of adaptive responses across Arabia (Petraglia et al., 2020), which form the backdrop to the occupation deposits presented here. Following the onset of desert conditions, populations of the Bronze Age retreated to oases, forming permanent settlements (Hausleiter and Eichmann, 2018: Table 1). The occupation deposits excavated at Jebel Oraf predominantly date to the 6th and early 5th millennium BC and coincide with the end of the Holocene humid period. The late Neolithic period is therefore our primary focus here.

2. Material and Methods

In 2015, the site of ORF2 was explored in two test excavations of hearths visible on the surface; these yielded remains of *Bos* and charcoal dated to the early 5th millennium BC (Guagnin et al., 2017b). In 2016, ORF2 was targeted for further excavations, designed to document the extent of the site, and to sample a larger number of hearths. The site was initially surveyed by walking transects of 2m spacing to locate and document all visible hearths, and any artefacts lying on the surface. Hearths and artefacts were mapped with a Differential Global Positioning System (DGPS) with a precision of up to 1cm, which provided a global anchor for the local grid, and with a total station for higher-precision on-site measurements. Transect-based collection of topographic measurements using the DGPS system were used to map elevation changes across the site (see Figure A1 in the appendix), and the extent of visible lake deposits along the edge of the palaeolake where ORF2 is situated (Figure 2) were also recorded.

At ORF2, trenches were initially laid out to include areas surrounding the hearths, to facilitate the identification of any associated structural remains or post-holes (Figure A2). However, these areas were found to be sterile, with the exception of a few instances where hearths appeared to have been raked out or washed into lake marl. As a consequence, the strategy was changed to target hearths more directly. In total 10 trenches were excavated (Figure A2), containing a total of 16 hearths, including the re-excavation of Hearth 2 and the surrounding area to clarify the hearth's position relative to visible lake marls (Guagnin et al., 2017b; Guagnin et al., 2020). A further small trench was located on the lake marl to sample lake deposits for optically stimulated luminescence dating (Guagnin et al., 2020). Excavation followed the single-context method, with hearths half-sectioned to the natural substrate initially, in order to obtain profiles of any stratigraphic change. Subsequently the remaining half of each hearth was removed to allow full recovery of associated finds, along with samples for microbotanical analyses and dating.

The ORF115 site had been partially destroyed by looters, but some stratified deposits were still preserved on the side of a large robber trench. The face of these remnant in-situ deposits was carefully cleaned and excavated in three trenches (see below). In addition, a number of lithics were recovered from screening the looters' spoil heap.

All excavated deposits from ORF2 and ORF115 were sieved with 5mm, 1mm, and 0.25mm sieves and all artefacts, faunal remains, and macro-botanical remains were recovered. Material was examined using a binocular microscope (<20X magnification). As the contexts were solely comprised of sand and ashy material, flotation was not necessary and may have resulted in the destruction of any charred plant remains surviving in the hyper-arid environment (see for example Arranz-Otaegui et al., 2018, supplementary video). In addition, sediment samples were taken from each excavated hearth deposit for phytolith analysis.

Where possible, charcoal fragments, specific to context, were collected. In addition, ostrich eggshell was collected, and all carbon rich deposits were sampled and submitted for radiocarbon dating in order to define the chronology of human activity at ORF2 and ORF115. Unfortunately, in many cases carbon content was not sufficient for dating and samples had to be abandoned. Radiocarbon dating was predominantly carried out by the Radiocarbon Dating Laboratory at the University of Waikato (sample code Wk), two additional dates were obtained from the Centre for Applied Isotope Studies at the University of Georgia (CAIS, sample code UGAMS).

As part of the pre-treatment processes at Waikato, charcoal samples were cleaned and then washed in hot HCl, and rinsed and treated with multiple hot NaOH washes. The NaOH insoluble fraction was treated with hot HCl, filtered, rinsed and dried. Eggshell (ostrich) samples were cleaned and then acid washed using 0.1N HCl, rinsed and dried. Results were provided as Conventional Age or Percent Modern Carbon (pMC) (following Stuiver and Polach, 1977), based on the Libby half-life of 5568 years with correction for isotopic fractionation applied.

Pre-treatment at CAIS differed slightly. Charcoal samples were treated with a mix of acetone and benzene in Soxhlet apparatus to remove any organic contaminants then they were rinsed with acetone and dried out at 60°C. After that samples were treated with 5% HCl at a temperature of 80°C for 1 hour, then washed with deionized water on a fiberglass filter and rinsed with diluted NaOH to remove possible contamination by humic acids. Samples were then treated with diluted HCL again, washed with deionized water and dried at 60°C. For accelerator mass spectrometry analysis, the cleaned samples were combusted at 900°C in evacuated/ sealed ampoules in the presence of CuO.

Zooarchaeological analysis focused firstly on identifying the animal remains (bones and teeth) retrieved from all contexts, and secondly on recording bone modification data to allow taphonomic assessment to aid understanding of the site-formation processes in and around the hearths. To this end, all bone fragments were recorded to some level, whether identifiable to taxon and element or size-class only (or in some cases, indeterminate size-class and element; Tables A3-A6). Fragments of unidentifiable long-bone, cranium, ribs, and vertebrae were assigned to 'cattle/equid/camel-size', 'sheep/goat/gazelle size', or 'hare/fox size'. In Tables A3-A6 these size classes are coded 7, 3, and 2 respectively.

Bone fragment lengths were recorded to assess comminution, whether by natural, human, or combined factors. Fragments were often very small (1-3 cm) making it impossible to see any signs of intentional breakage. Bone surface weathering was also recorded, developed from Behrensmeyer (1978), where low, moderate, or high weathering can indicate not only degrees of bone exposure but also the stability of the burial environment (Lyman and Fox, 1989). Burning of fragments was recorded by colour, with brown/black indicating lower temperature fire-sources, and white/blues/greys (calcined) indicating higher temperatures (following Shipman et al., 1984), although relationships between bone colour and temperatures are complex. Gnawing on bone was also documented, with the morphology and size of marks indicating whether due to carnivore or rodent activity.

Knapped sharp-edged lithics from each excavation context as well as piece plotted key surface finds were classified by material and weighed. Retouched pieces and cores were assigned to types following Shea (2013). Hammerstones were counted. Grindstones (bottom stones) and mullers (hand stones) were assigned to material, weighed individually, and their number of ground surfaces was counted. In addition, their maximum dimension and thickness was measured, and for mullers their width was also taken. The morphology of the main ground surface was classified as either flat, concave, or convex, and any pecking to rejuvenate ground surfaces was noted. For grindstones the type of edge shaping (unifacial flaking, bifacial flaking, grinding, pecking) if any was recorded.

3. ORF2 Results

Along the northern edge of the Jebel Oraf lake basin, sand dunes gently rise up to a height of about 40m. At the base of these dunes the terrain opens out to form a flat terrace (Figure A1). On the southern edge of this terrace, grey lake marls, deposits of the former palaeolake, are still visible. The hearths recorded at ORF2 all either sit on top of the sand or the lake marl edge of this terrace (Figure 2).

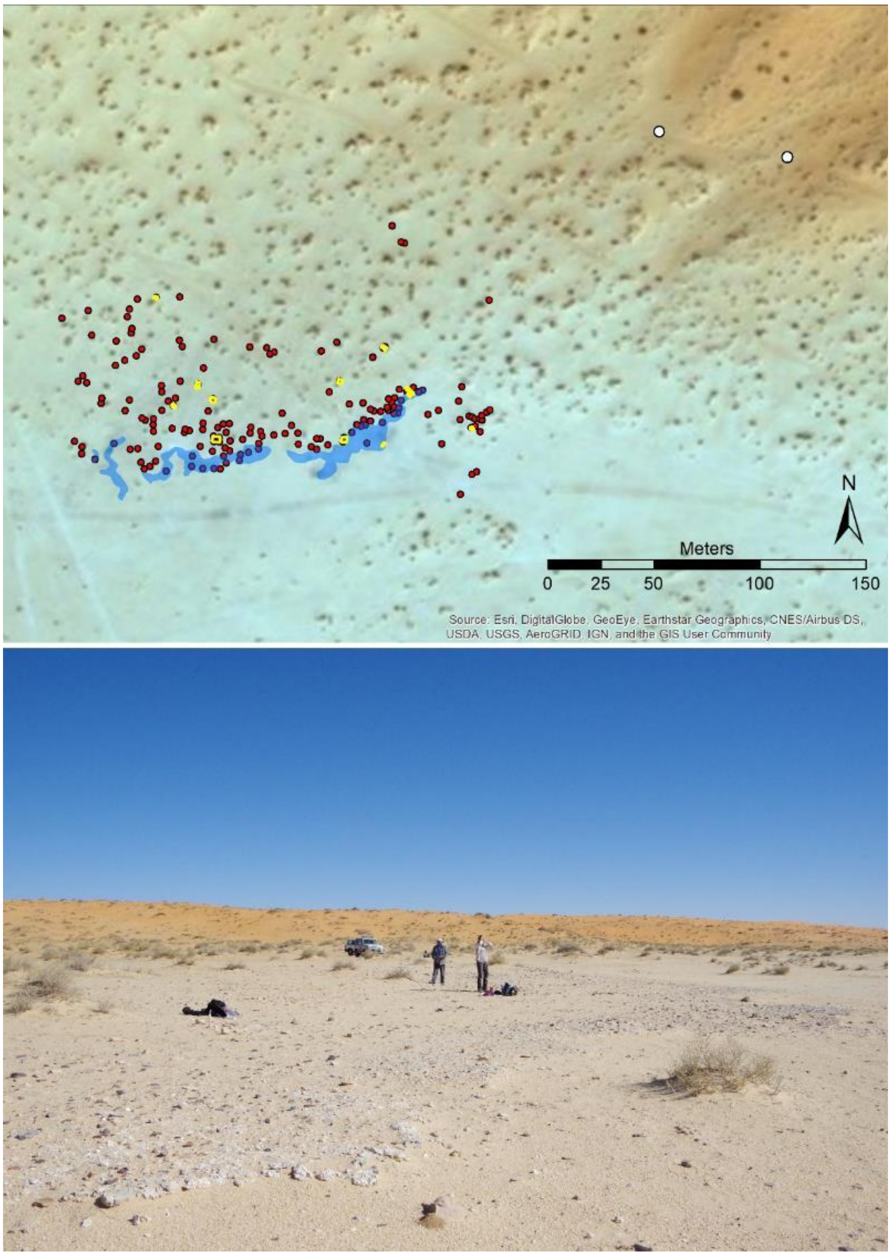

Figure 2 Top: Satellite image showing the location of the majority of hearths recorded at ORF2 at the base of a dune (red dots). Palaeolake deposits visible on the surface are marked in blue. Trenches excavated in 2016 are marked in yellow (trench numbers are shown in Figure A2). Sites with PPN lithics recorded further up the dune are marked in white. Bottom: View of ORF2, showing the lake marl deposit in the foreground.

In total, 17 of the 170 recorded hearths were excavated at ORF2. The excavated hearths can be grouped into two distinct types: shallow hearths built by forming a small depression in the sand, and more substantial hearths lined with stones (for a detailed description of each hearth see Table A1, photographs of all trenches and hearths are provided in Figures A3-A8). The shallow hearths were typically ca 15cm deep and filled with ashy/carbon rich deposits. The surface of this type of hearth is frequently covered in grinding stone fragments or small stones, most of which are

~10cm in maximum dimension, reaching up to ~20cm. Some of these grinding stones could be re-fitted, and eight grinding stone fragments show impact scars suggestive of deliberate breakage prior to placement over the hearths.

The second more substantial type of hearth has larger rocks, ~30cm in diameter tightly packed around the perimeter of a fireplace. In our sample all these stone-lined hearths are associated with Late Neolithic/Chalcolithic dates, resulting in a pattern where Neolithic hearths consist of a mixture of stone-lined hearths and shallow hearths, while all three historic radiocarbon ages are associated with shallow hearths (Table A3).

Outside the hearths, archaeological materials such as lithics and bone fragments were only found on the surface, where they could feasibly have moved, or inside the lake marl. Analysis of the lake marl in Trench 7 showed that high stands dated to around 5300 BC must have softened the substrate sufficiently for early hearths to have been destroyed and become mixed in with the marl (Guagnin et al., 2020). For hearths post-dating this event, preservation is relatively good. A number of recent camel and vehicle tracks cross the site and have caused some disturbance (Figure A1). However, the fact that all excavated hearths were intact suggests taphonomic processes have mostly only resulted in small movements of materials on the surface (also confirmed by the taphonomic analysis of faunal remains).

*Table 1 Radiocarbon ages obtained for ORF2, calibrated using OxCal calibration programme (listed in chronological order, latest to earliest) and to 95.4% probability. Three further samples for Hearths 27, 169, and 122 had to be abandoned due to insufficient carbon content. Lab codes marked with * refer to radiocarbon ages obtained from initial test excavations, reported in Guagnin et al. (2017b). + marks ages reported as part of an analysis of the wider Jebel Oraf landscape (Guagnin et al., 2020). At Waikato, the Carbon-13 stable isotope value ($\delta^{13}C$) was measured on prepared graphite using the AMS spectrometer. The radiocarbon date has been corrected for isotopic fractionation, however, the AMS-measured $\delta^{13}C$ value can differ from the $\delta^{13}C$ of the original material and it is therefore not shown.*

Lab code	Trench	Hearth	Material	Context	Description	$\delta^{13}C$,‰	$D^{14}C$,‰	$F^{14}C$,% (pMC)	AMS date	Calibrated date
Wk-45127	2	26/27	Charcoal	200	Sand on surface of Trench 2		-14.9 ± 1.9	98.5 ± 0.2	121±15bp	AD 1682-1930
Wk-44954	3	63	Charcoal	302	Hearth fill		-70.2 ± 2.3	93.0 ± 0.2	585±20bp	AD 1306-1411
Wk-44950	1	90	Charcoal	106	Hearth fill		-125.7 ± 2.2	87.4 ± 0.2	1079±20bp	AD 898-1016
Wk-45128	4	145	Charcoal	401	Hearth fill		-493.5 ± 1.3	50.6 ± 0.1	5465±20bp	4353-4264 BC
UGAMS-44685+	7	2	Charcoal	702	Hearth fill	-20.07			5520±25bp	4447-4333 BC
Wk-45129	6	122	Charcoal	604	Hearth fill		-529.3 ± 1.2	47.1 ± 0.1	6053±20bp	5020-4854BC
Wk-43210*	Test pit	1	Charcoal	n/a	Hearth fill		-535.3 ± 1.7	46.5 ± 0.2	6156±29bp	5220-5020BC
Wk-44951	1	88	Charcoal	109	Hearth fill		-538.9 ± 1.3	46.1 ± 0.1	6218±23bp	5293-5068BC
Wk-44952	1	91	Charcoal	115	Hearth fill		-539.5 ± 1.2	46.0 ± 0.1	6230±20bp	5299-5076BC
Wk-43212*	7		Charcoal	704	Washed hearth in lake marl		-540.3 ± 1.3	46.0 ± 0.1	6242±23bp	5300-5070BC
Wk-44958+	7		Charcoal	708	Sand between upper and lower lake marl		-541.0 ± 1.1	45.9 ± 0.1	6255±20bp	5301-5214BC
Wk-44957+	7	53	Charcoal	703	Hearth fill		-542.3 ± 1.1	45.8 ± 0.1	6278±20bp	5306-5220BC

3.1 Hearths

In total, three stone-lined hearths were excavated (Hearths 88, 122, 145; Figure 3), two of which show clear signs of the stones having been pushed inwards (88 and 145).

Hearth 88 was constructed as a substantial feature built out of large stones, which were probably originally placed upright and later pushed in to lay on top of the black, carbon rich deposit when the hearth was abandoned. At this point, smaller stones were placed on top of the carbon rich deposit, in a possible attempt either to contain the fire or to secure the remaining fuel (Figure 3 and Figure A3 top left). Small charcoal fragments were recovered from the fill of this hearth and radiocarbon dated to the late 6th millennium BC (Table 1).

Hearth 145 is similar in size and was dated to the late 5th millennium BC. It is constructed in concentric rings, with a smaller chamber-like setting in the centre, a ring of upright stones around it, and a further three stones more loosely placed around the hearth (Table A1). The inner rings are tightly packed with a carbon rich deposit that contained fragments of lithics and bones.

The fill of Hearth 122 is similar in age to Hearth 88 (Table 1), but this hearth is constructed in a different manner. Hearth 122 is oval in shape, with two larger stones along the sides, and two or three smaller stones forming shorter, rounded ends. This hearth contained a thick black fill which formed an almost homogenous deposit of fine carbon rich dust mixed with some sand. Before Hearth 122 was abandoned, smaller stones were placed on top of the hearth fill (Figure 3).

Hearth 91 is undated and was built in a shallow pit that appears to have been covered by larger stones, which were subsequently put to one side. This suggests hearths may have been raked out to allow re-use at a later time.

The presence of carbon rich dust was typical of all hearths excavated at ORF2, and only a few very small pieces of charcoal were observed. It is therefore possible that dung was the main fuel used.

Figure 3 ORF2, stone-lined hearths: H88 (plan and section; Trench 1), H122 (Trench 6), H145 (Trench 4), H91 (Trench 1). For radiocarbon ages see Table 1, a full description of each hearth can be found in Table A1.

The remaining 13 of the excavated hearths were all constructed in shallow pits with small stones placed on top. Here we describe a small selection that is representative of this hearth type. Hearth 26 could not be dated directly, and charcoal from the surface of Trench 2 provided a recent radiocarbon age (Table 1). However, the presence of lithics in the fill of Hearth 26, and their absence in the adjacent Hearth 27 indicate an earlier date. Fragments of lithics were also found in between both hearths but had likely originated from hearth materials washed into the underlying lake marl during a flooding event in the late 6th millennium BC (Guagnin et al., 2020).

The shallow pit of Hearth 26 had been dug directly into the lake marl, with the heat of the fire solidifying the marl to form a ridge (Figure 4).

Hearth 53 (late 6th millennium BC) was discovered during excavations in Trench 7 and had not been visible on the surface. It had a small cluster of stones placed on top of a black, carbon rich deposit mixed with sand (Figure 4). Hearth 2 (mid-late 5th millennium BC) is situated ca 1m north in the same trench. Both hearths were placed on top of the lake marl deposit and were surrounded by sand with a high content of ash, which also contained fragments of bones and lithics, including a Neolithic arrowhead (see below). The high ash content indicates that perhaps some of the shallow Neolithic hearths were destroyed or cleared out as others were constructed, and that the occupation of the site may have been more intensive than the surviving Neolithic hearths suggest.

Hearth 90 was dated to the end of the first millennium AD, and shows that the construction of hearths in shallow pits, with stones placed on top of carbon rich deposits, continued for several millennia. Hearth 63 was radiocarbon dated to the 13th century AD, and was covered with 42 grindstone fragments, indicating the re-use of Neolithic materials in intermittent reoccupations of the site.

Figure 4 Examples of hearths constructed in shallow pits excavated at ORF2. Hearths 26, 62, and 63 are shown before excavation (left) and after excavation (right) to show the stones on top of each hearth. Stones can also be seen on the unexcavated half of Hearth 90. An example of black carbon rich deposits can be clearly seen in the section of Hearth 53.

3.2 ORF2 lithics

The great majority of lithics were made on quartz and quartzite pebbles and cobbles which are available in abundance in the Oraf basin. From excavated contexts, 97.7% of artefacts by weight are from these quartz and quartzite pebbles and cobbles (3548.3g), with the ferruginous quartzite favoured in the Middle Palaeolithic (Groucutt et al., 2017) also occasionally exploited (31.5g), as well as exotic chert (50.3g) and chalcedony (1.7g) - particularly for artefacts shaped through retouch.

Core reduction strategies on local quartzitic clasts are expedient, with bipolar (n=2), single platform (n=4), and multiplatform (n=5) examples evident from excavated contexts. Retouched pieces from the excavation include side and end-scrapers and a single sickle insert. Notably, this sickle insert is from Trench 7 which has the earliest dates for ORF2 and may represent some typological continuity with sites higher up on the dunes where sickle blades were present and arrowheads show similarities with the Levantine PPN (Guagnin et al., 2020).

Lithics from ORF2 appear to correspond with the Pottery Neolithic of the Levant. Diagnostic lithics include Ha-Parsa arrowheads (Figure 5) (Figure A9), and a cortical knife (Figure A10). Ha-parsa arrowheads are common in the southern Levant in the late Neolithic, reaching peak frequencies at around 5000 BC (Gopher, 1994). Similarly, cortical knives are a feature of occupation in the Negev Desert of the southern Levant in the late Neolithic (Goring-Morris et al., 1994).

Figure 5 Neolithic chert arrowheads from ORF2. Left: undiagnostic piece (possibly Nizzanim, cf. Figure 7.14v in Shea 2013:247) from Context 151. Middle: Ha-Parsa point with a broken tip from Context 701 (cf. Figure 7.14i in Shea 2013: 247). Right: Ha-Parsa point with a broken tang from context 701 (cf. Figure 7.14h in Shea 2013: 247). Scale is 1cm.

A variety of scrapers were recovered from ORF2 including broad flat fan scrapers (Figure A11) characteristic of the Pottery Neolithic and early Bronze Age in the southern Levant where they were used in skinning, butchery, and shearing (Barket and Bell, 2011; Henry, 1995; Yerkes et al., 2016). One of the most unusual artefacts from ORF2 was a large hinge-terminated chert blade with a further two hinge terminations on its dorsal surface and steep retouch along both edges (Figure A10).

Several groundstone axe and chisel fragments made on exotic igneous materials and chert were found at ORF2 (Figure A9). The small size of the groundstone tools and that some were made on chert/flint allies them to the later Neolithic in the Levant (Barkai and Yerkes, 2008). There is no evidence that these axes were made locally, but axe rejuvenation flakes from the site indicate local use and re-sharpening.

Grindstones were numerous at ORF2, with 143 recovered from excavation and a further 11 collected as isolated surface finds of interest (NB: the local Jubbah museum has several grindstones, some of which may be from the site). The grindstones were nearly all fragmentary, with impact indicating breakage was in many cases deliberate, and ranged in maximum dimension from 19.88mm to 490mm. The great majority of specimens were made on the local tabular sandstone basement rock, with evidence for grindstone production at the site of JKF100 in the neighbouring Jebel Katefeh basin. Two of the surface grindstones collected were of exotic materials, a vesicular basalt piece, and a coarse-grained granite quern (Figure A12). A single other quern was recovered, from Trench 1 (Context 114). Sources of vesicular basalt might occur in the Harrat Hutaymah or Harrat Ithnayn/Khaybar volcanic regions to the south of the Nefud Desert, but known sources of coarse-grained granite that were exploited for making grindstones in the Neolithic are found at Azraq in Jordan (Wright, 2008).

The grindstones ranged in thickness from 2.82mm to 111.32mm, and other than the querns generally had flat surfaces (83%, n=127), or mild concavities (14%, n=22) and convexities (3%, n=5). Of the 98 fragments that preserved part of the original edge of the grindstone, 60 exhibited the unmodified edge of the slab blank, 12 were unifacially flaked, 15 were bifacially flaked, 10 were pecked (including two that were also bifacially flaked), and 5 were ground (including two that were also pecked). Pecking to rough the surface of the grindstones was observed in four cases, and in one instance it was used to make a concavity. No systematic differences were observed between the two trenches with younger dates (2 and 3) and the rest of the excavated assemblage, with flaking, grinding, and pecking evident on examples from both. This suggests that we are dealing with a single assemblage of Neolithic grindstones rather than two phases of grindstone deposition widely separated in time.

The grindstones were unevenly distributed with Trench 3 yielding 45 pieces, six of which were refit sets of up to 12 individual pieces. The young date from Trench 3 indicates that it represents re-use of the ORF2 site, when it seems that many grindstones lying on the surface of ORF2 were gathered up and deposited here. It is possible that the grindstones were re-used at the site to cover the fire (as observed in the stone-lined hearths at ORF2), alternatively, they may have been preferentially selected over the natural flat slabs of sandstone that are available at the site to provide a smooth surface on which to cook.

Figure 6 Near complete refitting grindstone with bored holes from ORF2 Trench 3. Note that the largest fragment on the right was found some distance away from the hearth on which the rest of the fragments were deposited and bears no evidence of fire discolouration unlike many of the others.

The most complete grindstone from ORF2 is also the most elaborate (Figure 6): A refit of 12 pieces, 11 of which come from Trench 3, but the largest piece was found ~20m away and does not have the same ash staining as those from Hearth 63 (Figure A5), indicating the placement of fragments on the fire occurred after the initial discard of this piece. This near-complete grindstone is 430mm long, made of sandstone, with a rounded edge around the entire circumference created by bifacial flaking and pecking. It is concave, and, while 31mm thick at the edge, it was so heavily used on both surfaces that it has worn through at the centre. It contains two bored holes at either end of one of the long edges. Two other grindstones similarly featured these bored holes; the vesicular basalt piece from the surface of ORF2 and a thin sandstone fragment from ORF206 (Figure A12). Grindstones with bored holes are known from Jordanian Neolithic sites such as Early/Middle PPNB site of Jilat 7

(Wright, 2008). Such bored grindstones are unusual and may reflect a portability adaptation so that the grindstone could be tied on to something.

In addition to the grindstones from ORF2, 11 mullers were recovered as isolated surface finds from the site, with a further one from Trench 10 (Context 152; Figure A13). These artefacts were made on both local quartzite and sandstone as well as three exotic pieces on vesicular basalt and two in a non-local quartzite. Two of the specimens are broken, with the complete ones ranging in length from 82.1mm to 108.5mm, and in weight from 175g to 571g. It appears that the corners on some pieces have been deliberately rounded through pecking, while a broad surface on one also appears to have been pecked, perhaps to rejuvenate it. Two of the mullers may also have been used as mortars as they exhibit battering on their ends. The ground surfaces are either convex or flat and are well worn, with the number of ground surfaces per specimen ranging from one to four. Their presence at ORF2 indicates that grinding took place on site prior to the breakage and discard of the grindstones.

A broken half of a small sandstone palette with a ground concave surface was found at ORF2 (Figure A14). Although this fragment did not have a bored hole, at Neolithic sites in the Levant complete examples of such artefacts have holes and are known as pendant palettes. A small broken muller ground all over and with a comparable convex surface was also found on the surface of ORF2 and was likely used with such small palettes. The size of these items suggests they were not used for grain, with pigment a possible alternative function. A fragment of a limestone bracelet of 4cm diameter was found on the surface at ORF2 (Figure A14). Such artefacts are known from Levantine Neolithic sites such as ‘Ain Gazal in Jordan (Rollefson, 1984).

Several quartz and quartzite pebbles recovered from ORF2 exhibited extensive battering (Figure A15), including one from Trench 1 (Context 105). The frequency with which such battered stones occur at the site is surprising given the rarity of hammerstones at Middle Palaeolithic sites in Jubbah (Groucutt et al., 2017). The battering on these stones is also too extensive for it to have resulted from either the creation of the small quartz and quartzite flakes, or the occasional edge modification seen on the grindstones. Instead, it is likely that many of these were used as pecking stones to create the numerous examples of Neolithic petroglyphs in the Jubbah area.

Unfortunately, the recovered grindstones and grindstone fragments were all found either on the surface or just below and none were retrieved from a sealed context. As such, none could be sampled for residue or phytolith analysis as the risk of contamination (especially from camel dung and modern campfires, both evident across the oasis) was very high.

3.3 ORF2 Faunal remains

Across all ORF2 trenches >1800 mammal bone/tooth fragments were recorded (Table A3). Bone survives relatively well but is highly fragmented. Most fragments fall in the 1-3cm range, with fewer up to 4cms (many bone lengths in Table A3 are recorded as n/a, where encrustations prevented exact measurements). This very high fragmentation leads to extremely low identification rates, with only 14 bones being identifiable to taxon.

There are some hints as to the causes of bone fragmentation: in Trenches 1 and 7 the smallest fragments are in topsoil contexts, which may link to poor preservation. Bone weathering is not high, which would be expected if surface exposure or deflation had affected bone. Carnivore gnawing, seemingly by a small fox-sized carnivore, was identified on only 10 specimens (Table A3). These animals may have been attracted to the site to scavenge from human refuse, meaning some bone loss may be expected. There is very little evidence of rodent activity, and no suggestion of bioturbation. Burning of bone when visible (often obscured by encrustation on surfaces) is seen mostly in the ashy fills of hearths (e.g. Trench 1, Context 109), surfaces around hearths (e.g. Trench 2, Context 203), or in charcoal layers (e.g. Trench 7, Context 703 in Hearth 53). This burning, therefore, appears to be directly associated with the actual use of the hearths, suggesting discarded bone became incorporated into burning events. That most bone is not burnt, however, is not surprising, since grilling or roasting tends not to lead to direct burning of bone joints, but only occasional singed bone ends (Gifford-Gonzalez, 1989).

Identifiable specimens and undiagnostic bone fragments (Tables A3 and A4)

Trenches 5 and 10 (both undated) contained no bone. Others, such as Trenches 4 and 6 (both prehistoric) contained very few fragments, and the undated hearths in Trenches 8 and 9 both had small samples. Discussion therefore centres around Trenches 1 and 7 (late 6th millennium) and Trenches 2 and 3 (historic dates).

Overall, across all trenches and hearths, the 14 diagnostic bones constitute less than 1% of the total fragment count. Additionally, seven of the 14 diagnostic specimens derive from surface contexts (Trenches 2, 3, 7) and so should be treated with caution.

Of the two prehistoric trenches which produced bone (Trenches 1 and 7) it is notable that Trench 1 has no cattle/equid/camel-sized fragments but does contain sheep/goat/gazelle-sized fragments (Table A3). The much larger samples from Trench 7 contain 17 cattle/equid/camel-sized fragments, but a far higher number (n=274) of sheep/goat/gazelle-sized fragments. Cattle/equid/camel-sized animals are therefore poorly represented compared with smaller sheep/goat/gazelle-sized mammals in the prehistoric deposits.

In the later period hearths (Trenches 2 and 3), Trench 2 shows similar numbers of cattle/equid/camel-sized - and sheep/goat/gazelle-sized fragments, while Trench 3 contains only remains of the latter. Combining the two, there is more of a balance of larger and smaller mammals in the historical period.

Turning to diagnostic animal bone (Table A4), the Neolithic hearths (Trenches 1 and 7 - Hearth 88 and Hearth 53) contain a total of five identified specimens – four gazelle (a mandible fragment, a proximal metatarsal, and two phalanges), and a single incisor identified to cattle, *Bos* sp. This picture generally mirrors the size classes seen in undiagnostic fragments, with cattle and cattle-sized bone less common in Neolithic hearth deposits. Sheep/goat/gazelle-sized bone is frequent, albeit only remains of gazelle have been securely identified. There is therefore no evidence for domestic sheep or goats from the prehistoric hearths.

Hearth 88 in Trench 1 is one of the large stone-lined hearths. The two gazelle bones and one cattle incisor from here are from the well-stratified Context 109 - the ashy fill of Hearth 88; all three diagnostic specimens are burnt, tying them in well with use of the hearth.

The two diagnostic bones from Trench 7 (both gazelle) are from deposits close to the surface (contexts 700 and 701). Context 700 is the sandy surface deposit, while the underlying context 701 is an ashy deposit containing the Neolithic-dated shallow Hearth 53, and is rich in bone, which appears closely associated with the hearth.

Later period hearths (in Trench 2 and 3, Hearths 26, 27, and Hearth 63 respectively) show nine diagnostic elements, of which three are identified as gazelle, and six are cattle teeth. Five of these cattle teeth are from the surface topsoil in Trench 2 (Context 200); both maxillary and mandibular teeth are present, but it can’t be discounted that they may derive from jaws of the same individual (or even the same maxilla in the case of the four maxilla tooth fragments).

4. ORF115 Results

The site of ORF115 was discovered during a survey of the rock art along the slopes of Jebel Oraf. Within a cluster of large boulders that is densely covered in rock art, two boulders form a shelter. The shelter had recently been looted, with a large trench dug in what would have been the main occupation area. However, a substantial deposit remained on the southern side of the shelter (Figure 7). The loose backfill of the robber trench was cleared out and the intact deposit gently cleaned. The open face of the deposit was then excavated in three small trenches (1-3), to achieve a straight section across the remaining deposit (Figure 7). Each layer therefore has multiple context numbers as they stretch across the trenches, with the first digit of the three-letter context code indicating the trench. Context 117, for example, is the same as Context 214 and 309 (see Figure 8). Trench 4 was designed to investigate the top of the section - particularly a large groove in the side of the boulder - and was excavated down to the top of the Chalcolithic/Early Bronze Age layer (Figure 8, Context 303/204).

Due to the layout of the shelter, the occupation deposits show additional layers towards the front of the sheltered area, which are also disturbed by a small, historic trench that probably once accommodated a wall (Context 403). Layers at the back of the shelter were more protected and tend to be thicker. Due to these disturbances and different depositional histories in the centre and at the edge of the shelter, particularly the upper layers could not always be reconciled; Contexts 209 and 208 appear to be younger than Contexts 114 and 112 (Figure 8).

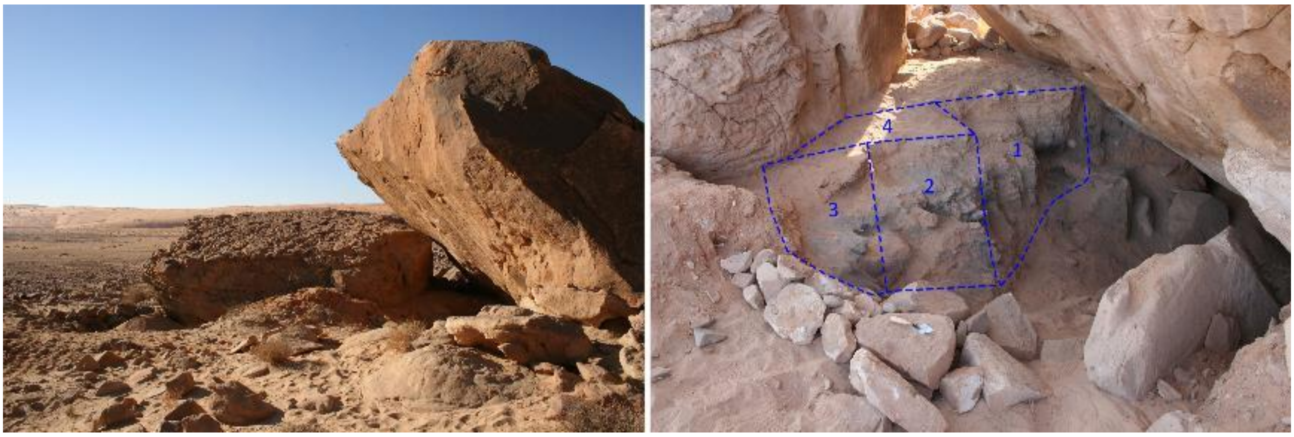

Figure 7 Setting of ORF115, where two large boulders form a small shelter. Left: the southern side of the palaeolake basin is visible in the background. Right: ORF115 before excavation. Robbers had dug a substantial hole, exposing the stratigraphy of the site along the side (centre of image). On the left edge of the image the robber's spoil heap is visible. Trenches from excavation are outlined with blue dashed lines.

Radiocarbon dates from the occupation layers that remain in the shelter indicate that ORF115 was first occupied around 6000 BC. Although all boulders in the vicinity are densely covered in rock art, no rock art was found below the occupation layers, where the shelter ceiling would have been relatively low and awkward to access. In total, Neolithic layers amount to a height of 60-70cm in the cave, followed by ca. 8cm of Chalcolithic/Early Bronze Age occupation, and a thin occupation layer from the Late Bronze Age. It has not been possible to obtain radiocarbon ages for the layers at the very top of the sequence, but artefacts such as pottery suggest historic occupation.

Table 2 Radiocarbon ages obtained for ORF115, calibrated using OxCal calibration programme (listed in chronological order, latest to earliest) and to 95.4% probability. Three further samples (Contexts 116, 206 (Hearth 6), and 408) had to be abandoned due to insufficient carbon content. The date marked with #is too young for the stratigraphic position of the context, possibly due to bioturbation caused by an animal burrow (snake hole). At Waikato, the Carbon-13 stable isotope value ($\delta^{13}C$) was measured on prepared graphite using the AMS spectrometer. The radiocarbon date has been corrected for isotopic fractionation, however, the AMS-measured $\delta^{13}C$ value can differ from the $\delta^{13}C$ of the original material and it is therefore not shown.

Lab code	Trench	Material	Context	Description	$\delta^{13}C$,‰	$D^{14}C$,‰	$F^{14}C$,% (pMC)	AMS date	Calibrated date
Wk-44942	1	Ostrich eggshell	106	Firm sand with occasional pebbles and charcoal fragments	-9.5 ± 0.3	-328.4 ± 1.6	67.2 ± 0.2	3198±20bp	1504-1430 BC
Wk-45124	1	Ostrich eggshell	111	Pale brown sand with gravel		-445.0 ± 1.0	55.5 ± 0.1	4730±15bp	3631-3381 BC
Wk-44943	1	Ostrich eggshell	107	Hearth fill (Hearth 1)	-9.3 ± 0.3	-445.6 ± 1.4	55.4 ± 0.1	4738±20bp	3634-3382 BC
UGAMS-44679	2	Charcoal	208	Silty sand with moderate amounts of lithics and bone	-24.03			5690±25bp	4582-4459 BC
Wk-44948#	2	Charcoal	214	Sand with lithics and bone fragments		-533.3 ± 1.2	46.7 ± 0.1	6122±20bp	5208-4988BC
Wk-45126	2	Charcoal	211/115	Hearth fill with rocks (Hearth 3)		-540.5 ± 1.2	46.0 ± 0.1	6246±22bp	5307-5081BC
Wk-44947	2	Charcoal	209/305	Silty sand with frequent lithics, bone and pieces of sandstone		-540.6 ± 1.1	45.9 ± 0.1	6248±20bp	5304-5209BC
Wk-45125	1	Charcoal	114	Silty sand with frequent lithics and bone and some charcoal pieces; cowrie shell		-556.6 ± 1.2	44.3 ± 0.1	6533±22bp	5531-5472BC
Wk-45784	1	Charcoal	112	Silty sand with frequent charcoal and occasional stones, often heat altered; small arrowhead		-559.7 ± 0.9	44.0 ± 0.1	6590±17bp	5610-5480BC
Wk-45785	1	Charcoal	118	Basal occupation deposit, sitting on top of sterile sand. Occasional lithics and bone.		-585.4 ± 0.8	41.5 ± 0.1	7073±17bp	6010-5900BC

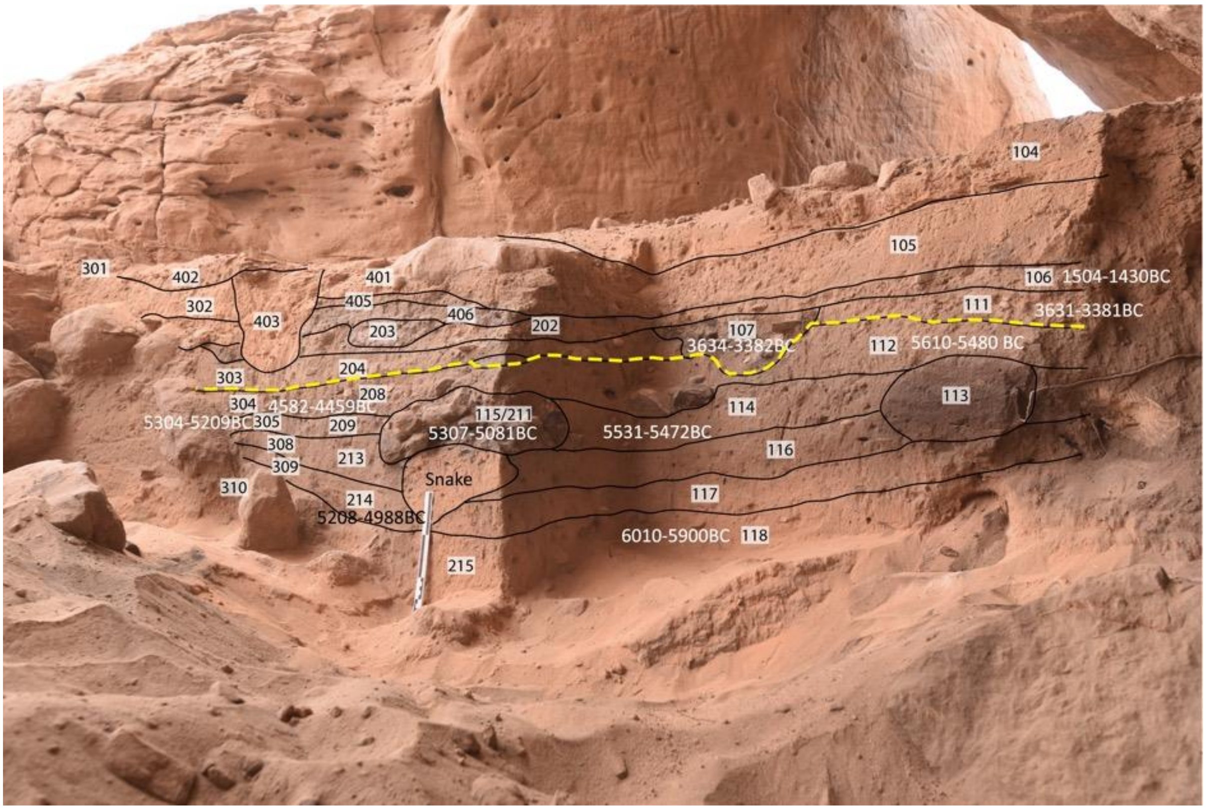

Figure 8 Section of ORF115 after the excavation of Trenches 1,2 and 3. Context numbers are indicated in white boxes, and radiocarbon ages are listed in each dated context. One radiocarbon date (in black font) is too young for the stratigraphic position of this context, possibly as a result of bioturbation caused by a snake hole. The yellow line marks the top of the more frequently occupied Neolithic sequence, occupation above this line appears much more sporadic.

A total of 11 hearths were identified at ORF 115 (Table A2). The majority of these were placed in shallow pits. However, one Neolithic hearth (Hearth 3, Context 211) was lined with stones around its perimeter, and had further stones placed on top. A Chalcolithic hearth (Hearth 1, Context 107; following the chronological sequence established at Tayma by Hausleiter and Eichmann (2018)) had a base lined with stones, and a further Neolithic hearth (Hearth 8, Context 306) was placed into a cluster of large stones (Figure 9). While some of the shallow hearths consist of small lenses suggestive of a single burning event, the size and carbon accumulation within Hearth 2 (Figure 9) suggests prolonged or perhaps repeated use, yet there is no evidence of a stone lining.

Other than the historic wall at the top of the sequence, the shelter contains no evidence of structural remains.

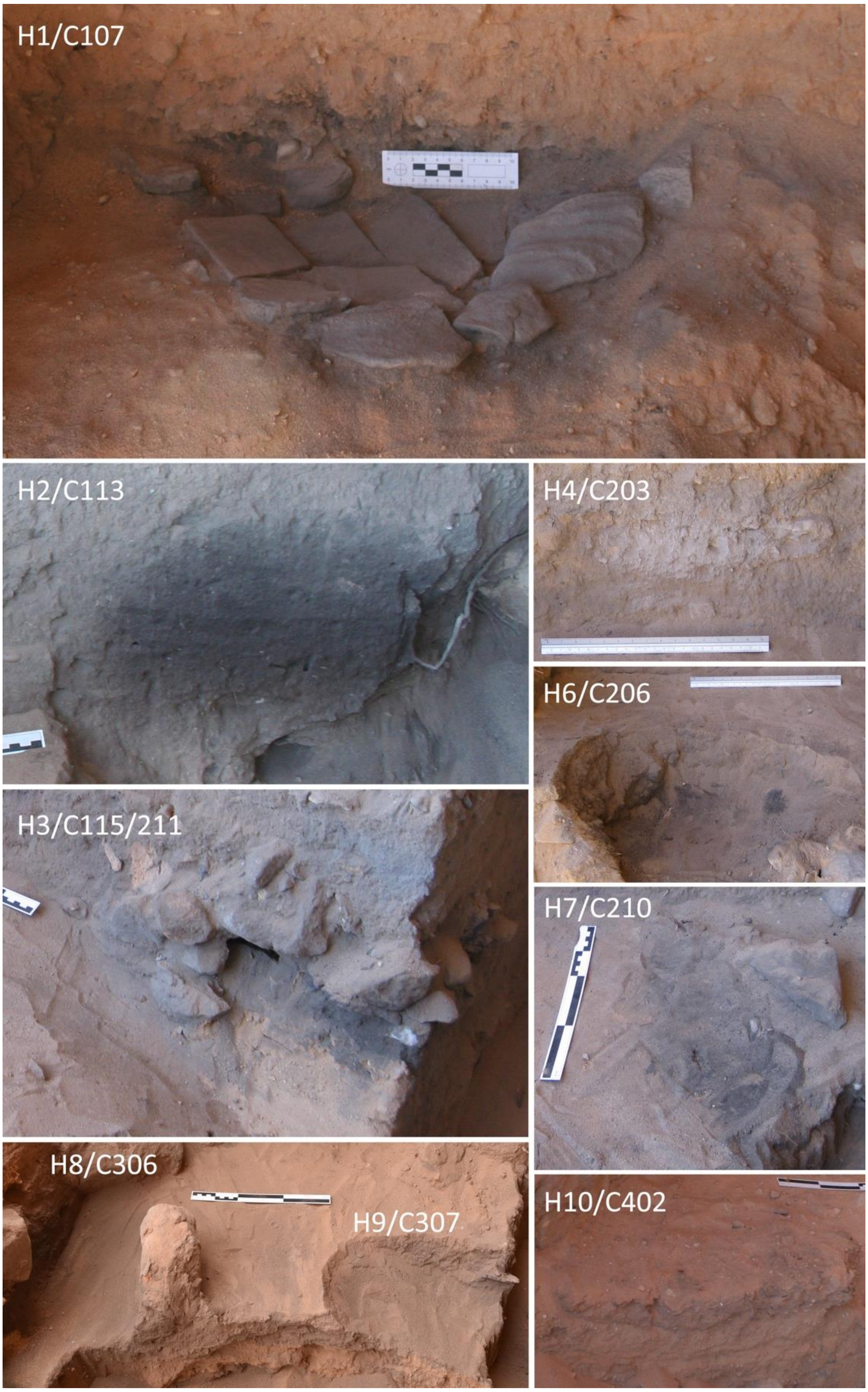

Figure 9 Selection of hearths from ORF115. For Hearths 6 and 9 the cut is shown to illustrate their size. Descriptions of the hearths are provided in Table A2.

4.1 Neolithic occupation

The three oldest layers of occupation (Contexts 116, 117, and 118) had relatively low densities of lithics (320.1g). Of the seven hearths associated with the Neolithic occupation of ORF115, four were placed onto Context 116. High concentrations of bone fragments and artefacts were recorded in the layer above them (Context 114/209/305), with 2627.2g of lithics. Contexts 112 and 208, dating to the Late Neolithic and early Chalcolithic respectively (again following Hausleiter and Eichmann, 2018), maintained a high density of lithics (1228.5g). The two hearths with the highest concentrations of lithics, Hearth 5 (Context 205, 150g) and Hearth 6 (Context 206, 201g), were constructed on top of Context 112, with a Neolithic arrowhead found in Context 206 indicating they were part of the Neolithic occupation of the shelter. Of the Neolithic hearths only one (Hearth 3) contained stones, and, unlike the chalcolithic hearth where the stones were at the base, these were placed around the sides with larger stones placed on top like in many of the hearths at ORF2. Hearth 8 was placed into a space surrounded by stones, reminiscent of the constructed hearths at ORF2.

4.2 Chalcolithic/Early Bronze Age occupation

The main Chalcolithic/Early Bronze Age occupation of the shelter was documented in Context 111/204/303. Concentrations of lithics are lower than in the final Neolithic, with a total of 668.7g across the layer. Hearth 1 (Context 107, 56g of lithics) is cut into the Chalcolithic/Early Bronze Age occupation, with a radiocarbon date obtained from a piece of ostrich eggshell (3634-3382 BC) indicating a similar age as the surrounding layer. This hearth was lined with eight pieces of sandstone (Figure 9), and a small piece of gold wire was found between the stones (Figure 11, right). The date of this context makes this the oldest gold artefact in Arabia yet known.

The oldest gold artefacts in the Levant were found in a Chalcolithic cemetery in Nahal Kana Cave (Gopher et al., 1990; Gopher and Tsuk, 1996) and were associated with radiocarbon ages of ca 4000 BC. In Egypt, gold artefacts remained relatively rare in the Pre-Dynastic and Early Dynastic periods, up until the middle of the 3rd millennium BC (Klemm and Klemm, 2013). In Mesopotamia, gold is not commonly found until the Late Uruk period, at the end of the 4th millennium BC (Stein, 1994), although a gold wire has been reported from a late Ubaid context at Ur, and gold beads from Tepe Gawra XII have been dated to the late 5th millennium BC (Moorey, 1994: 221).

Chalcolithic/Early Bronze Age occupation of ORF115 can also be linked to a rock art panel recorded 350m south of the rock shelter. This panel shows two human figures depicted with features typical of the 'Jubbah style' that is usually attributed to the Neolithic period (Guagnin et al., 2015; see for example Khan, 2007: 28-32)(Figure

10). Both figures have angular shoulders, very thin arms and legs facing to one side in a twist of perspective from the frontal perspective of the elongated upper body. This type of human figure is frequently found in Pre-Neolithic hunting scenes and Neolithic cattle herding imagery (Guagnin et al., 2017a). However, classic Jubbah style human figures are typically depicted with penis sheaths and indistinct headdresses. In the case of panel ORF131A, both human figures appear to have been engraved with a sharp tool, possibly metal, which creates sharper edges and allows the depiction of thinner lines. This is particularly evident in the headdresses of both figures, which appear to represent long ostrich feathers. However, the most marked distinction is the depiction of metal daggers held at the waist of each figure, with the elongate blade and the hilt clearly visible and likely engraved with a metal tool. The depictions thus reference a Neolithic engraving style but also the use of metal, and may therefore relate to the late Chalcolithic/Early Bronze Age occupation recorded at ORF115.

Figure 10 Above: Panel ORF131A, showing an African Wild Ass with shoulder stripe, surrounded by human figures. Below: Close up of the two human figures with metal daggers secured on their waist, and long feathers on their heads.

4.3 Late Bronze Age occupation

The Late Bronze Age occupation of the shelter was only documented in a single layer, Context 106/202, although it is possible that Hearth 4 (Context 203) also dates to this period. Lithics were still present with Context 202 producing 39.6g, Context 106 186g, and Hearth 4 165.8g. In addition, a small, hook-shaped piece of metal was found in Hearth 4 (Figure 11, left). XRF analysis indicates that the metal is highly oxidized, and the copper content suggests a Bronze alloy. Fragments of bones were also recovered from all contexts.

Figure 11 Left: hook-shaped object found in Hearth 4 (Context 203), XRF analysis suggests a bronze alloy. Right: small wire found in Hearth 1 (Context 107) identified as gold using XRF analysis. The scale shows units of 1mm.

4.4 Historic/Iron Age occupation

A wall on the outside of the shelter was cut into Context 106/202 (Figure A16). Above this context layers inside the shelter do not line up with layers outside the wall (Figure 8). We can therefore assume that the wall was built after the Late Bronze Age. It disintegrated or was removed before the deposition of Context 402, an area where high ash content suggests a hearth (Figure 8). The wall was thus probably built during the Iron Age or Early Islamic period.

In general, all contexts at the top of the sequence have a very low density of lithics, with about 30 to 50g of lithics fragments per context and in many cases less than 10g. Only Context 302 contained 94.3g, and Context 406 244.2g. This suggests that some knapping did occur during the later occupation of the shelter, and the location of these contexts suggests that this was predominantly done in front of, or directly inside the wall.

4.5 ORF115 lithics

From the lower (Neolithic) part of the sequence (Contexts 112, 206, 211, 113, 117, 118, 214, 215) as well as the robber trench spoil, diagnostic artefacts include Ha-Parsa and Herzliya arrowheads, as well as two retouched possible sickle blades (Figure 12 and A17). These artefacts were made on a variety of exotic cherts and flint. As at ORF2 though, the great majority of lithics (93.6%) from the Neolithic levels at ORF115 were made on local rounded clasts of quartz and quartzite (5382.67g). There was also occasional exploitation of bedded ferruginous quartzite (107.9g), a single artefact of yellow silcrete from Jebel Umm Sanman (0.2g), and a selection of exotic materials including rhyolite (195.3g), chert/flint (58.5g), and chalcedony (2.6g). The only known source for these exotics is the rhyolite, which is found on the southern edge of the Nefud at a dyke near the Qana oasis ~60km from Jebel Oraf, and was also exploited by the Middle Palaeolithic occupants of neighbouring Jebel Katefeh (Groucutt et al., 2015). Reduction techniques were represented by expedient bipolar (n=5), single platform (n=4), multiplatform (n=5), and semi-discoidal (n=1) cores, although a single example of a chert ridge blade from Context 211 suggests blade technology was also known to the occupants. An unusual retouched artefact with a deeply notched tang was found in the robber spoil (Figure A18), and may share some affinity with the deeply notched tanged scrapers from the nearby site of Jebel Qattar 101 (Crassard et al., 2013).

Eleven grindstones made of sandstone were recovered from the Neolithic layers (Contexts 211, 114, 117, 118, 214) and the robber backfill at ORF115. Thicknesses ranged from 9.37mm to 96.3mm. Two of these grindstones were complete, with the largest being 471mm in length. Edge modifications included examples of unifacial flaking, grinding, and pecking, while an impact scar and a flake suggest some deliberate breakage as at ORF2. Seven mullers were found at ORF115, three of which from excavated contexts (209 and 118). The mullers were made on local sandstone (n=5) and quartzite (n=2), they had between 1 and 2 grinding surfaces, and all but one were complete. The complete specimens ranged in length from 74.5mm to 160.24mm, and in weight from 189g to 917g. The two largest mullers which had been extensively shaped through pecking were deposited beside each other in what appeared to be a cache in Context 118. These two were both made out of the same reddish sandstone but were very different in morphology with one being a mortar with a very convex relatively small main grinding surface and the other an oval piece with two large flat grinding surfaces (Figure A19). Although sample sizes are small at ORF115, in comparison to ORF2 there are more complete grindstones, an absence of unused grindstones, and a higher ratio of mullers to grindstones. This is perhaps because ORF115 is further away from Jebel Katefeh, where grindstones were being manufactured, than ORF2.

The upper part of the sequence at ORF115 has a considerably impoverished assemblage of stone tools in comparison to the Neolithic levels. Quantities of flaked stone artefacts are lower (1925.4g versus 5750.27g), and there are no grindstones, mullers, sickle blades, or arrowheads. The proportion of imported material is lower (1.8% versus 6.4%), with a large proportion of this (13.5g) being the yellow silcrete that is found at nearby Jebel Umm Sanman. The remainder of the imported material is chert (20.2g), with the exotic silcrete, rhyolite, and chalcedony no longer represented. However, there is continuity in the expedient manner in which the local pebbles were flaked, with bipolar (n=2), single platform (n=3), and multiplatform cores (n=1).

Figure 12 Chert Late Neolithic arrowheads from ORF115. Top left - Herzilya point from Context 113 (cf. Figure 7.14l in Shea (2013: 247); Top right – Ha-Parsa point from Context 112 (cf. Figure 7.14c in Shea (2013: 247) (note that this piece appears to have an impact fracture on its tip); Bottom left – broken Ha-Parsa point from Context 117 (cf. Figure 7.14h in Shea (2032: 247); Bottom right – small tanged point from Context 206. Scale is 1cm.

4.6 ORF115 Faunal remains

At ORF115, 2362 fragments of animal bone were recorded across the four excavated trenches, indicating generally good bone preservation throughout the long time-depth represented at the site from the Neolithic to Historic periods (Table A5). Fragmentation however, as with ORF2, is very high with bone fragments mostly in the 1-3cm range (only two Historic/Iron Age deposits in Trench 4 show larger fragments), again leading to low identification rates. The near-absence of gnawing observed on bone surfaces – except for one rodent and one small carnivore-gnawed fragment in Context 405 – suggests that bone deposits were neither carnivore deposited or disturbed; and general moderate surface weathering indicates that animal bones were not exposed for long periods in the open, but were buried relatively quickly. It is notable from Table A5 that there are high densities of bone in and around the Neolithic hearth deposits in Trenches 1, 2 and 3, and the high proportion of burnt bone in those deposits suggests a close association between the hearths and the faunal material around them.

The bulk of the animal bone throughout the sequence is clearly 'undiagnostic' (2262 fragments versus 100 diagnostics), meaning identifiable bones/NISPs make up only 4% of the total. Within the undiagnostic category the vast majority of bone fragments are sheep/goat/gazelle sized, with far fewer cattle/equid/camel-sized, and very few fox/hare sized throughout the stratigraphic sequence (Table A5). Neolithic deposits in particular have very few cattle/equid/camel-sized fragments, being instead dominated by sheep/goat/gazelle sized-animals.

Table A6 shows diagnostic elements (NISPs) organized by archaeological period, with the earliest part of the sequence (Neolithic) at the base and most recent (Historical/Iron Age) at the top. From Neolithic deposits, there are 35 identifiable fragments: 20 are from medium ungulates, either sheep, goats or gazelle, but too fragmented to distinguish which; four lower limb elements (metacarpal, phalanges, and astragalus fragments) are firmly identified to sheep/goat, but can't be narrowed down further. It should be noted that the sheep/goat category could include wild ibex (*Capra ibex*) and so does not necessarily reflect herded domesticates; nevertheless, the presence of any sheep/goat of whatever status the *Capra* may be is interesting at ORF115 since the Neolithic deposits at ORF2 did not produce any identified caprine bone at all. There are also three gazelle elements from ORF115 Neolithic deposits – two phalanges and a mandible fragment - which as with ORF2 could belong to any of the Arabian gazelle species (*G. dorcas, G. gazella,* G. *subgutturosa marica*, or the now-extinction *G. bilkis*). Two tooth fragments are tentatively assigned to cattle (*Bos* spp.), in each case these are small (1-2cm) fragments of tooth enamel, but their size and morphology is strongly suggestive of *Bos*. These identifications support those from ORF2 (above, and Guagnin et al., 2017b) and argue for the presence of herded cattle in the area in the Neolithic. A single oryx bone (astragalus) comes from Context 112 in Trench 1, which is the first faunal representation of *Oryx leucoryx* at Jebel Oraf. In addition, there are four fragments of ostrich (*Struthio camelus*) eggshell from the Neolithic deposits. Ostriches were common across the open lands of the Arabian Peninsula until their local extinction in the mid 20th century, and their eggs can serve many uses (i.e., as artefacts as well as for food). A single other small bird bone (coracoid) was identified from the Neolithic deposits.

The deposits dating to the Chalcolithic/Early Bronze Age have produced only ostrich eggshell fragments, and only one Iron Age deposit (Context 202) yielded any other faunal material: three tooth fragments from either sheep/goat or gazelle and four bird long bone fragments which lack diagnostic ends.

The majority of diagnostic animal remains from ORF115 (n=52) derive from upper Iron Age or Historical era deposits, potentially covering long time-periods. Identifiable specimens include a *Bos* (cattle) mandible fragment; a goat (whether *C. hircus* or *ibex*) horncore fragment; a number of long bone, phalanx, and carpal fragments of indeterminate sheep/goat/gazelle; two small felid metacarpals (cat?); and numerous ostrich eggshell fragments which are often burnt/charred (whether incidentally or as part of cooking). While this later period material cannot be treated as an 'assemblage' as such, it's interesting to note the long-term continuity in animal representation at the ORF115 rockshelter location, with evidence for cattle, caprines, ostrich eggs, and likely gazelles as well, being consumed from the Neolithic to more recent times.

5. Phytoliths (ORF2 and ORF115)

Despite extensive sieving for macrobotanical remains using a 0.25mm mesh, no plant seeds were recovered from either ORF2 or ORF115. Only low numbers (<10) of small charcoal pieces (0.5-1mm in size) were recovered from any of the contexts at either site, including hearth deposits. This is most likely due to poor preservation within the extremely arid environment of Jebel Oraf. While plant material was likely burnt within the hearths excavated at the sites, the lack of macrobotanical remains means that it is impossible to say whether the fuel used at ORF2 and ORF115 was either wood, dung, a mixture of both, or something else entirely. Equally, in the absence of burnt food plants and plant foods, and with such poor preservation of plant material, it is not possible to determine to what extent the humans who used ORF2 and ORF115 used plant-based foods.

The preservation of phytoliths was also very poor. Initially, five 1g samples from ORF2 and three 1g samples from ORF115 were processed following Rosen's method (Ramsey et al., 2016; Rosen, unpublished protocol). These produced very low quantities of phytoliths and it was decided that processing further samples was not profitable. The limited phytoliths recovered from both sites show the presence of grasses and cyperaceae in the area (Table A7 and A8). This ties in with the expectation of the existence of wetter lake side grasslands and sedge lands during the Neolithic. No evidence for crop plants was recovered, although several fragments of unidentifiable grass husk multi-cell were identified.

6. Discussion

The radiocarbon dates obtained from ORF2 and ORF115 suggest that the two hearth sites were repeatedly occupied during the second half of the 6th millennium BC, with more sporadic occupation in later millennia (Figures A20 and A21). Moreover, a high content of ash and carbon, fragments of charcoal and bone, as well as lithics in the lake marl deposit at ORF2 suggests that numerous additional hearths from the 6th millennium BC may have been destroyed in flooding events. However, even generous estimates of the total number of Neolithic hearths that might once have been present at ORF2 and ORF115 fall far short of one per year between 5500 and 5000BC. Occupation of ORF2 and ORF115 was therefore far from regular, even during their most frequent period of use. The question remains whether additional visits to the Jebel Oraf basin occurred in as of yet unexplored hearth sites, or if visits to the Jebel Oraf basin were limited to particularly dry years, when vegetation had to be exploited in a wider area, or perhaps during particularly wet years, when vegetation and water availability may have made the Jebel Oraf basin more attractive compared to the larger palaeolake in the Jubbah basin.

Archaeological surveys in the southern Levant have shown a population increase after 5500BC, with 50% of nomadic camp sites associated with the Chalcolithic and Early Bronze Age (Abu-Azizeh, 2013). However, reconstruction of landscape use in the Wadi Sharma area and in the Jafr Basin also suggests more ephemeral occupation during the (Levantine) Pottery Neolithic (Fujii, 2013b; Fujii, 2013c). The occupation pattern at Jebel Oraf shows a slightly different pattern, with a peak in occupation during the 6th millennium BC and only sporadic occupation during the Chalcolithic and Early Bronze Age, likely due to limited water availability after the end of the Holocene humid period in this area. The presence of hearth sites dating to the late 6th and late 5th millennium BC in the western Nefud desert (Scerri et al., 2018) suggests increasing aridification or population expansion at the end of the Holocene humid period did not necessarily lead to a congregation of populations in oases such as Jubbah, but that populations across the Nefud Desert adopted patterns of landscape use that were highly mobile. In south-eastern Arabia lithic point type diversity suggests high levels of connectivity across the region in the late 6th and early 5th millennium BC, but decreasing in the millennia after (Maiorano et al., 2020).

No structural remains were identified at ORF2 or in the Neolithic contexts of ORF115, and no post holes were visible in the exposed areas of lake marl in Trenches 2 and 7 at ORF2. The small size of the hearths at ORF2, the ephemeral character of the shallow pit hearths, and the absence of substantial deposits of bones and artefacts thus make the use of huts unlikely at Jebel Oraf. Domestic architectural remains were also not identified during extensive surveys of the slopes of Jebel Oraf, and of the surface and area around ORF2 (Guagnin et al., 2020). For some reason shelters were either not used or were extremely light. This absence of shelters raises the question whether occupation occurred during a season when protection from the sun or wind/sand was necessary. While the boulders at ORF115 would have provided some shade, a gap between both boulders (Figure 7) would have left the site exposed to wind.

Of the excavated hearths, the more elaborate stone-lined hearths are only known from the Neolithic. While this may be a result of sample bias, environmental records attest to the existence of lakes and vegetation in the Jubbah oasis in the early and middle Holocene. In addition, the flooding events recorded in the lake marls of ORF2 (Guagnin et al., 2020) indicate that water was available in the Jebel Oraf basin, and would have supported vegetation. Environmental conditions could therefore have allowed longer occupation by pastoralists, who may have come with their herds, attracted by water and pastures in the Jebel Oraf basin, and potentially by wildlife for hunting. After the onset of aridification, use of the landscape likely changed, although the sporadic presence of human populations is documented in later hearths, and in the rock art. Human groups may have continued to visit the area to exploit raw materials, or to hunt arid adapted species, such as wild camels, ibex, wild equids and gazelles.

The faunal remains from the Neolithic hearths and associated deposits at ORF2 provide evidence for hunted gazelle being processed, presumably cooked and deposited around them, and also evidence – albeit from one diagnostic element – of cattle. This confirms our earlier reported results (Guagnin et al., 2017b) of the presence of cattle in the late 6th millennium at ORF2, where we argued from combined evidence that cattle are likely to be herded domesticates. The picture is now complicated by the presence of gazelle bones. These could belong to any of the Arabian gazelle species and clearly represent hunted wildlife. It is not uncommon for prehistoric pastoralist sites to contain sometimes abundant remains of wild animals alongside domestic stock (e.g. Martin, 1999, for Neolithic sites in the Jordanian steppe/deserts; Beech et al., 2020, for examples from the Gulf region), particularly if domestic livestock was being kept primarily for breeding, secondary products, and exchange. The tentative picture emerging from ORF2 of herder-hunters could be augmented in future by identifying samples of undiagnostic fragments through zooarchaeology by mass spectrometry (ZooMS).

The small sample of diagnostic bones from Neolithic ORF115 hints at different types of human-animal interaction: the oryx and gazelle represent hunted wildlife; the sheep/goat bones might represent hunted ibex, but could also come from herded domestic caprines. The cattle teeth are likely to reflect herded livestock (although *Bos primigenius* cannot be discounted), following our arguments for contemporaneous pastoral encampments at nearby ORF2, where cattle teeth have also been found. In addition, Neolithic ORF115 sees the collection of ostrich eggs presumably for food, alongside the hunting or trapping of another small bird species. For such a small assemblage, the deposits reflect diverse animal-food procurement activities, and probably herding alongside hunting and collecting, in a subsistence pattern that appears to have continued for millennia, until the recent past.

The lithic industry at both hearth sites shows a similar pattern to that previously observed at the older sites of Al-Rabyah (Epipalaeolithic), JQ101 (early Neolithic), and ORF207 (early Neolithic), where lithic types show connections to the Levant (Crassard et al., 2013; Hilbert et al., 2014). Long distance contact must therefore have been maintained over several millennia and led to the regular transmission of lithic styles and perhaps even the transfer of materials (see also Guagnin et al., 2020). The occurrence of grinding stones at Jebel Oraf is striking, particularly in the context of extremely ephemeral sites. In the absence of evidence for plant use, a wide range of interpretations for the function of the grindstones is available. Perhaps they were used to grind grain for flour, to process edible sedge tubers that may have grown around the lake margins of Jebel Oraf, or perhaps they were used to process pigments to be used in rock art? Use-wear analysis is now underway to identify their primary functions. However, evidence from ORF2 shows that grinding stones were subsequently intentionally broken and used in many of the hearths, perhaps to cook meat or to contain the embers of the fire, a secondary function that was practised until the recent past.

The presence of pecking stones at Jebel Oraf, and depictions of metal daggers in the vicinity of ORF115 now provides multiple links between different occupation deposits and continued phases of rock art production, adding to earlier correlations between changes in rock art content and subsistence shifts from hunting to herding (Guagnin et al., 2017a; Guagnin et al., 2018). Moreover, predictions of high frequencies of gazelle in the early- and mid- Holocene landscapes of northern Saudi Arabia that were based on prey biomass reconstructions from the rock art in Shuwaymis (Guagnin et al., 2016), can now be confirmed in the limited identifiable specimens in the ORF2 and ORF115 faunal assemblages.

The discovery of a very small piece of gold wire in a deposit radiocarbon dated to 3634-3382 BC is exceptional and is, to our knowledge, the oldest gold artefact found on the Arabian Peninsula to date. It is not known if the gold was sourced and processed locally or traded from the Levant. Nevertheless, its presence in a location so remote from population centres shows that the pastoralists of the 6th millennium BC were well connected and had access to emerging technologies, despite – or perhaps because of – their highly mobile lifestyles.

7. Conclusion

The hearths sites of ORF2 and ORF115 provide a valuable contribution for our understanding of Neolithic occupation patterns and subsistence strategies. Although there is some evidence of the use of domesticated livestock, the hunting of wildlife, the collection of ostrich eggs, and the trapping of small bird species continued to form an important source of protein in all occupation phases. This is also reflected in the recurrence of arrowheads in Neolithic deposits. Moreover, all faunal remains show strong links with the use of hearths. Considering the ephemeral nature of the hearths and the absence of architectural remains or shelters, this suggests that visits to the Jebel Oraf basin were short-lived and involved the consumption of meat. Despite extensive sieving and sampling for phytoliths, we were not able to identify use of wild or domestic plants at Jebel Oraf, though numerous grindstones in the Neolithic are suggestive of plant processing and perhaps seed consumption. Occupation and subsistence patterns at Jebel Oraf are therefore markedly different from the Levant, where clustered enclosures are typical for Neolithic sites and domesticated livestock quickly became a major source of protein. These differences also extend to sites along the Gulf coast, where a mixture of marine exploitation and herding was practiced, but generally coupled with substantial structural remains. Notable also is that the subsistence and occupation patterns observed at Jebel Oraf appear to have remained largely unchanged over several millennia, spanning the Holocene humid period as well as subsequent periods of aridification and desertification. The fact that occupation appears to have peaked during the second half of the 6th millennium BC, and coincides with a lake high stand, suggests that the area on the periphery of the larger Jubbah palaeolake/oasis was visited during wetter years, presumably to exploit increases in vegetation and wildlife. This knowledge of the landscape appears to have been passed on from one generation to the next even after the onset of aridity, when wet seasons became exceptional events.

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9. References

ABU-AZIZEH, W. 2013. The South-Eastern Jordan's Chalcolithic-Early Bronze Age Pastoral Nomadic Complex: Patterns of Mobility and Interaction. *Paléorient,* 39**,** 149-176.

ARRANZ-OTAEGUI, A., GONZÁLEZ CARRETERO, L., ROE, J. & RICHTER, T. 2018. "Founder crops" v. wild plants: Assessing the plant-based diet of the last hunter-getherers in southwest Asia. *Quaternary Science Reviews,* 186**,** 263-283.

BAIRD, D., GARRARD, A., MARTIN, L. & WRIGHT, K. I. 1992. Prehistoric environment and settlement in the Azraq Basin: an interim report on the 1989 excavation season. *Levant,* 24**,** 1-31.

BARKAI, R. & YERKES, R. W. 2008. Stone Axes as cultural markers: technological, functional and symbolic changes in bifacial tools during the transition from hunter-gatherers to sedentary agriculturalists in the Southern Levant. *In:* LONGO, L. & SKAKUN, N. (eds.) *"Prehistoric Technology" 40 years later: functional studies and the Russian legacy.* Oxford: Archaeopress.

BARKET, T. M. & BELL, C. A. 2011. Tabular scrapers: Function revisited. *Near Eastern Archaeology,* 74**,** 56-59.

BEECH, M., ELDERS, J. & SHEPHERD, E. 2000. Reconsidering the 'Ubaid of the Southern Gulf: new results from excavations on Dalma Island, U.A.E. *Proceedings of the Seminar for Arabian Studies,* 30**,** 41-47.

BEECH, M., CUTTLER, R., AL KAABI, A. K., EL FAKI, A. A., MARTIN, J., AL HAMELI, N. H., ROBERTS, H. M., SPENCER, P., TOMASI, D., BRUNET, O. & CRASSARD, R. 2020. Excavations at MR11 on Marawah Island (Abu Dhabi, UAE): new insight into the architecture and planning of Arabian Neolithic settlements and early evidence for pearling. *Arabian archaeology and epigraphy,* 31**,** 19-31.

BEHRENSMEYER, A. K. 1978. Taphonomic and ecologic information from bone weathering. *Paleobiology,* 4**,** 150-162.

BETTS, A., MARTIN, L. & MCCARTNEY, C. 2013. Background and Methodology. *In:* BETTS, A. V. G., CROPPER, D., MARTIN, L. & MCCARTNEY, C. (eds.) *The Later Prehistory of the Badia. Excavations and Surveys in Eastern Jordan.* Oxford: Oxbow Books.

BETTS, A. V. G. 1989. The Pre-Pottery Neolithic B Period in Eastern Jordan. *Paléorient,* 15**,** 147-153.

BREEZE, P. S., GROUCUTT, H. S., DRAKE, N. A., LOUYS, J., SCERRI, E. M. L., ARMITAGE, S. J., ZALMOUT, I. S. A., MEMESH, A. M., HAPTARI, M. A., SOUBHI, S. A., MATARI, A. H., ZAHIR, M., AL-OMARI, A., ALSHAREKH, A. M. & PETRAGLIA, M. D. 2017. Prehistory and palaeoenvironments of the western Nefud Desert, Saudi Arabia. *Archaeological Research in Asia,* 10**,** 1-16.

CARTER, R. & CRAWFORD, H. 2003. The Kuwait-British Archaeological Expedition to As-Sabiyah: Report on the Fourth Season's Work. *Iraq,* 65**,** 77-90.
CARTER, R. 2006. Boat remains and maritime trade in the Persian Gulf during the sixth and fifth millennia BC. *Antiquity,* 80**,** 52-63.
CHARPENTIER, V. & MÉRY, S. 2008. A Neolithic settlement near the Strait of Hormuz: Akab Island, United Arab Emirates. *Proceedings of the Seminar for Arabian Studies,* 38**,** 83-102.
CHARPENTIER, V. & CRASSARD, R. 2013. Back to Fasad... and the PPNB controversy. Questioning a Levantine origin for Arabian Early Holocene projectile points technology. *Arabian archaeology and epigraphy,* 24**,** 28-36.
CRASSARD, R. & DRECHSLER, P. 2013a. Towards new paradigms: multiple pathways for the Arabian Neolithic. *Arabian archaeology and epigraphy,* 24**,** 3-8.
CRASSARD, R. & DRECHSLER, P. 2013b. Invited editors' preface. *Arabian archaeology and epigraphy,* 24**,** 1-2.
CRASSARD, R., PETRAGLIA, M. D., PARKER, A. G., PARTON, A., ROBERTS, R. G., JACOBS, Z., ALSHAREKH, A., AL-OMARI, A., BREEZE, P., DRAKE, N. A., GROUCUTT, H. S., JENNINGS, R., REGAGNON, E. & SHIPTON, C. 2013. Beyond the Levant: first evidence of a pre-pottery Neolithic incursion into the Nefud Desert, Saudi Arabia. *PLoS One,* 8**,** e68061.
DRECHSLER, P. 2007. The Neolithic dispersals into Arabia. *Proceedings of the Seminar for Arabian Studies,* 37**,** 93-109.
DRECHSLER, P. 2009. *The Dispersal of the Neolithic over the Arabian Peninsula,* Oxford, Archaeopress.
DRECHSLER, P. 2011. Places of contact, spheres of interaction. The Ubaid phenomenon in the central Gulf area as seen from a first season of reinvestigations at Dosariyah (Dawsāriyyah), Eastern Province, Saudi Arabia. *Proceedings of the Seminar for Arabian Studies,* 41**,** 69-82.
ENGEL, M., BRÜCKNER, H., PINT, A., WELLBROCK, K., GINAU, A., VOSS, P., GROTTKER, M., KLASEN, N. & FRENZEL, P. 2012. The early Holocene humid period in NW Saudi Arabia – Sediments, microfossils and palaeo-hydrological modelling. *Quaternary International,* 266**,** 131-141.
ENGEL, M., MATTER, A., PARKER, A. G., PARTON, A., PETRAGLIA, M. D., PRESTON, G. W. & PREUSSER, F. 2017. Lakes or wetlands? A comment on 'The middle Holocene climatic records from Arabia: Reassessing lacustrine environments, shift of ITCZ in Arabian Sea, and impacts of the southwest Indian and African monsoons' by Enzel et al. *Global and Planetary Change,* 148**,** 258-267.
FEDELE, F. G. 2008. Wādī at-Tayyilah 3, a Neolithic and Pre-Neolithic occupation on the eastern Yemen Plateau, and its archaeofaunal information. *Proceedings of the Seminar for Arabian Studies,* 38**,** 153-172.
FUJII, S. 2013a. Jawf/Tabuk Archaeological Project (JTAP). A Brief Report of the Third Field Season, 2013. http://jswaa.org/en_expeditions/: College of Human and Social Sciences, Kanazawa University.
FUJII, S. 2013b. Chronology of the Jafr Prehistory and Protohistory: a Key to the Process of Pastoral Nomadization in the Southern Levant. *Syria,* 90**,** 49-125.
FUJII, S. 2013c. Jawf/Tabuk Archaeological Project (JTAP). A Brief Report of the Second Field Season, 2013. http://jswaa.org/en_expeditions/: School of Humanities, Kanazawa Univversity.

GARRARD, A., HARVEY, C. P. D. & SWITSUR, V. R. 1981. Environment and Settlement during the Upper Pleistocene and Holocene at Jubba in the Great Nefud, Northern Arabia. *Atlal,* 5**,** 137-148.

GEBEL, H. G. K. 2016. The Socio-Hydraulic Foundations of Oasis Life in NW Arabia: The 5th Millennium BCE Shepherd Environs of Rajajil, Rasif and Qulban Beni Murra. *In:* LUCIANI, M. (ed.) *The Archaeology of North Arabia. Oases and Landscapes.* Vienna: Austrian Academy of Sciences Press.

GIFFORD-GONZALEZ, D. 1989. Ethnographic analogues for interpreting modified bones: some cases from East Africa. *In:* BONNICHSEN, R. & SORG, M. H. (eds.) *Bone Modification.* Orono: University of Maine.

GOPHER, A., TSUK, T., SHALEV, S. & GOPHNA, R. 1990. Earliest Gold Artifacts in the Levant. *Current Anthropology,* 31**,** 436-443.

GOPHER, A. 1994. *Arrowheads of the Neolithic Levant. A Seriation Analysis,* Winona Lake, Indiana, Eisenbrauns.

GOPHER, A. & TSUK, T. 1996. *The Nahal Qanah Cave. Earliest Gold in the Southern Levant,* Tel Aviv, Institute of Archaeology, Tel Aviv University.

GORING-MORRIS, A. N., GOPHER, A. & ROSEN, S. 1994. The Neolithic Tuwailan Cortical Knife Industry of the Negev. *In:* GEBEL, H. G. K. & KOZŁOWSKI, S. K. (eds.) *Neolithic Chipped Stone Industries of the Fertile Crescent. Studies in Early Near Eastern Production, Subsistence, and Environment I.* Berlin: Ex Oriente.

GROUCUTT, H. S., SHIPTON, C., ALSHAREKH, A., JENNINGS, R. P., SCERRI, E. M. L. & PETRAGLIA, M. D. 2015. Late Pleistocene lakeshore settlement in northern Arabia: Middle Palaeolithic technology from Jebel Katefeh, Jubbah. *Quaternary International,* 382**,** 215-236.

GROUCUTT, H. S., SCERRI, E. M. L., AMOR, K., SHIPTON, C., JENNINGS, R. P., PARTON, A., CLARK-BALZAN, L., ALSHAREKH, A. & PETRAGLIA, M. D. 2017. Middle Palaeolithic raw material procurement and early stage reduction at Jubbah, Saudi Arabia. *Archaeological Research in Asia,* 9**,** 44-62.

GROUCUTT, H. S., BREEZE, P. S., GUAGNIN, M., STEWART, M., DRAKE, N., SHIPTON, C., ZAHRANI, B., AL OMARI, A., ALSHAREKH, A. M. & PETRAGLIA, M. D. 2020. Monumental landscapes of the Holocene humid period in Northern Arabia: The mustatil phenomenon. *The Holocene,* 30**,** 1767-1779.

GUAGNIN, M., JENNINGS, R. P., CLARK-BALZAN, L., GROUCUTT, H. S., PARTON, A. & PETRAGLIA, M. D. 2015. Hunters and herders: Exploring the Neolithic transition in the rock art of Shuwaymis, Saudi Arabia. *Archaeological Research in Asia,* 4**,** 3-16.

GUAGNIN, M., JENNINGS, R., EAGER, H., PARTON, A., STIMPSON, C., STEPANEK, C., PFEIFFER, M., GROUCUTT, H. S., DRAKE, N. A., ALSHAREKH, A. & PETRAGLIA, M. D. 2016. Rock art imagery as a proxy for Holocene environmental change: A view from Shuwaymis, NW Saudi Arabia. *The Holocene,* 26**,** 1822-1834.

GUAGNIN, M., SHIPTON, C., AL-RASHID, M., MOUSSA, F., EL-DOSSARY, S., SLEIMAH, M. B., ALSHAREKH, A. & PETRAGLIA, M. 2017a. An illustrated prehistory of the Jubbah oasis: Reconstructing Holocene occupation patterns in north-western Saudi Arabia from rock art and inscriptions. *Arabian Archaeology and Epigraphy,* 28**,** 138-152.

GUAGNIN, M., SHIPTON, C., MARTIN, L. & PETRAGLIA, M. 2017b. The Neolithic site of Jebel Oraf 2, northern Saudi Arabia: First report of a directly dated site with faunal remains. *Archaeological Research in Asia,* 9**,** 63-67.

GUAGNIN, M., SHIPTON, C., EL-DOSSARY, S., AL-RASHID, M., MOUSSA, F., STEWART, M., OTT, F., ALSHAREKH, A. & PETRAGLIA, M. D. 2018. Rock art provides new evidence on the biogeography of kudu (Tragelaphus imberbis), wild dromedary, aurochs (Bos primigenius) and African wild ass (Equus africanus) in the early and middle Holocene of north-western Arabia. *Journal of Biogeography,* 45**,** 727-740.

GUAGNIN, M., BREEZE, P., SHIPTON, C., OTT, F., STEWART, M., BATEMAN, M., MARTIN, L., GRAHAM, L., EL-DOSSARY, S., KINGWELL-BANHAM, E., ZAHRANI, B., AL-OMARI, A., ALSHAREKH, A. & PETRAGLIA, M. 2020. The Holocene Humid Period in the Nefud Desert: Hunters and Herders in the Jebel Oraf Palaeolake Basin, Saudi Arabia. *Journal of Arid Environments,* 178.

HAUSLEITER, A. & ZUR, A. 2016. Taymā in the Bronze Age (c. 2,000 BCE): Settlement and Funerary Landscapes. *In:* LUCIANI, M. (ed.) *The Archaeology of North Arabia - Oases and Landscapes.* Vienna: Austrian Academy of Sciences.

HAUSLEITER, A. & EICHMANN, R. 2018. The Archaeological Exploration of the Oasis of Taymāʾ. *In:* HAUSLEITER, A., EICHMANN, R. & AL-NAJEM, M. H. (eds.) *Taymāʾ I. Archaeological Exploration Palaeoenvironment Cultural Contacts.* Oxford: Archaeopress.

HENRY, D. O. 1995. The Timnian and Pastoral Nomadism in the Chalcolithic. *Prehistoric Cultural Ecology and Evolution: Insights from Southern Jordan.* Boston, MA: Springer.

HENRY, D. O., CORDOVA, C. E., WHITE, J. J., DEAN, R. M., BEAVER, J. E., EKSTROM, H., KADOWAKI, S., MCCORRISTON, J., NOWELL, A. & SCOTT-CUMMINGS, L. 2003. The Early Neolithic Site of Ayn Abu Nukhayla, Southern Jordan. *Bulletin of the American Schools of Oriental Research,* 330**,** 1-30.

HENRY, D. O., CORDOVA, C. E., PORTILLO, M., ALBERT, R.-M., DEWITT, R. & EMERY-BARBIER, A. 2017. Blame it on the goats? Desertification in the Near East during the Holocene. *The Holocene,* 27**,** 625-637.

HILBERT, Y. H., WHITE, T. S., PARTON, A., CLARK-BALZAN, L., CRASSARD, R., GROUCUTT, H. S., JENNINGS, R. P., BREEZE, P., PARKER, A., SHIPTON, C., AL-OMARI, A., ALSHAREKH, A. M. & PETRAGLIA, M. D. 2014. Epipalaeolithic occupation and palaeoenvironments of the southern Nefud desert, Saudi Arabia, during the Terminal Pleistocene and Early Holocene. *Journal of Archaeological Science,* 50**,** 460-474.

JENNINGS, R., SHIPTON, C., AL-OMARI, A., ALSHAREKH, A., CRASSARD, R., GROUCUTT, H. S. & PETRAGLIA, M. D. 2013. Rock art landscapes beside the Jubbah palaeolake, Saudi Arabia. *Antiquity,* 87**,** 666-683.

KHAN, M. 2007. *Rock art of Saudi Arabia across twelve thousand years,* Riyadh, Deputy Ministry of Antiquities and Museums.

KLEMM, R. & KLEMM, D. 2013. Archaeological Chronology of Gold Mining in Ancient Egypt and Nubian Sudan. *Gold and Gold Mining in Ancient Egypt and Nubia.* Berlin, Heidelberg: Springer.

LYMAN, R. L. & FOX, G. L. 1989. A critical evaluation of bone weathering as an indication of bone assemblage formation. *Journal of Archaeological Science,* 16**,** 293-317.

MAGEE, P. 2014. *The Archaeology of Prehistoric Arabia. Adaptation and Social Formation from the Neolithic to the Iron Age,* New York, Cambridge University Press.

MAIORANO, M. P., CRASSARD, R., CHARPENTIER, V. & BORTOLINI, E. 2020. A quantitative approach to the study of Neolithic projectile points from south-eastern Arabia. *Arabian archaeology and epigraphy,* 31**,** 151-167.

MAKAREWICZ, C. 2020. The adoption of cattle pastoralism in the Arabian Peninsula: A reappraisal. *Arabian archaeology and epigraphy,* 31.

MAKAREWICZ, C. A. 2016. Caprine husbandry and initial pig management east of the Jordan Valley: Animal exploitation at Neolithic Wadi Shu'eib, Jordan. *Paléorient,* 42**,** 151-168.

MARTIN, L. 1999. Mammal remains from the eastern Jordanian Neolithic, and the nature of caprine herding in the steppe. *Paléorient,* 25**,** 87-104.

MARTIN, L. & EDWARDS, Y. 2013. Diverse Strategies: Evaluating the Appearance and Spread of Domestic Caprines in the Southern Levant. *In:* COLLEDGE, S., CONOLLY, J., DOBNEY, K. & MANNING, K. (eds.) *Origins and Spread of Domestic Animals in Southwest Asia and Europe.* California: Left Coast Press.

MILLER, H., BAIRD, D., PEARSON, J., LAMB, A. L., GROVE, M., MARTIN, L. & GARRARD, A. 2019. The origins of nomadic pastoralism in the eastern Jordanian steppe: a combined stable isotope and chipped stone assessment. *Levant,* 50**,** 281-304.

MOOREY, P. R. S. 1994. *Ancient Mesopotamian Materials and Industries. The Archaeological Evidence,* Oxford, Clarendon Press.

MUNOZ, O., COTTY, M., CHARLOUX, G., BOUCHAUD, C., MONCHOT, H., MARQUAIRE, C., ZAZZO, A., CRASSARD, R., BRUNET, O., BOSCHLOOS, V. & AL-MALKI, T. 2020. Marking the sacral landscape of a north Arabian oasis: a sixth-millennium BC monumental stone platform and surrounding burials. *Antiquity,* 94**,** 601-621.

NEWTON, L. S. & ZARINS, J. 2000. Aspects of Bronze Age art of southern Arabia: The pictorial landscape and its relation to economic and socio-political status. *Arabian archaeology and epigraphy,* 11**,** 154-179.

PARR, P. J., ZARINS, J., IBRAHIM, M., WAECHTER, J., GARRARD, A., CLARKE, C., BIDMEAD, M. & AL BADR, H. 1978. Preliminary report on the second phase of the Northern Province Survey 1397/1977. *Atlal,* 2**,** 29-50.

PARTON, A., WHITE, T. S., PARKER, A., BREEZE, P. S., JENNINGS, R., GROUCUTT, H. S. & PETRAGLIA, M. D. 2015. Orbital-scale climate variability in Arabia as a potential motor for human dispersals. *Quaternary International,* 382**,** 82-97.

PARTON, A., CLARK-BALZAN, L., PARKER, A. G., PRESTON, G. W., WAI SUNG, W., BREEZE, P. S., LENG, M. J., GROUCUTT, H. S., WHITE, T. S., ALSHAREKH, A. & PETRAGLIA, M. D. 2018. Middle-late Quaternary palaeoclimate variability from lake and wetland deposits in the Nefud Desert, Northern Arabia. *Quaternary Science Reviews,* 202**,** 78-97.

PETRAGLIA, M. D., GROUCUTT, H. S., GUAGNIN, M., BREEZE, P. S. & BOIVIN, N. 2020. Human responses to climate and ecosystem change in ancient Arabia. *PNAS,* 117**,** 8263-8270.

RAMSEY, M. N., MAHER, L. A., MACDONALD, D. A. & ROSEN, A. 2016. Risk, Reliability and Resilience: Phytolith Evidence for Alternative 'Neolithization' Pathways at Kharaneh IV in the Azraq Basin, Jordan. *PLoS One,* 11**,** e0164081.

REELER, C. & AL SHAIKH, N. 2015. A discussion of Neolithic settlement patterns in Saudi Arabia and Bahrain during the Holocene Pluvial Period. *Proceedings of the Seminar for Arabian Studies,* 45**,** 1-16.

ROLLEFSON, G. 1984. 'Ain Ghazal: An Early Neolithic Community in Highland Jordan, near Amman. *Bulletin of the American Schools of Oriental Research,* 255**,** 3-14.

ROLLEFSON, G., ROWAN, Y. & WASSE, A. A. 2014. The Late Neolithic colonization of the Eastern Badia of Jordan. *Levant,* 46**,** 285-301.

ROLLEFSON, G. O., ROWAN, Y., WASSE, A., HILL, A. C., KERSEL, M. M., LORENTZEN, B., AL-BASHAIREH, K. & RAMSAY, J. 2016. Investigations of a Late Neolithic Structure at Mesa 7, Wadi al-Qattafi, Black Desert, 2015. *Neo-Lithics,* 1/16**,** 1-12.

ROSEN, A. Phytolith Protocol.

ROWAN, Y. M., ROLLEFSON, G. O., WASSE, A., ABU-AZIZEH, W., HILL, A. C. & KERSEL, M. M. 2015. The “land of conjecture:” New late prehistoric discoveries at Maitland’s Mesa and Wisad Pools, Jordan. *Journal of Field Archaeology,* 40**,** 176-189.

SCERRI, E. M. L., GUAGNIN, M., GROUCUTT, H. S., ARMITAGE, S. J., PARKER, L. E., DRAKE, N., LOUYS, J., BREEZE, P. S., ZAHIR, M., ALSHAREKH, A. & PETRAGLIA, M. D. 2018. Neolithic pastoralism in marginal environments during the Holocene humid period, northern Saudi Arabia. *Antiquity,* 92**,** 1180-1194.

SHEA, J. J. 2013. *Stone Tools in the Palaeolithic and Neolithic Near East: A Guide,* Cambridge, Cambridge University Press.

SHIPMAN, P., FOSTER, G. & SCHOENINGER, M. 1984. Burnt bones and teeth: an experimental study of color, morphology, crystal structure and shrinkage. *Journal of Archaeological Science,* 11**,** 307-325.

SPOOR, R. H. 1997. Human population groups and the distribution of lithic arrowheads in the Arabian Gulf. *Arabian archaeology and epigraphy,* 8**,** 143-160.

STEIN, G. 1994. Economy, Ritual, and Power in 'Ubaid Mesopotamia. *In:* STEIN, G. & ROTHMAN, M. S. (eds.) *Chiefdoms and Early States in the Near East: the Organizational Dynamics of Complexity.* Madison: Prehistory Press.

STUIVER, M. & POLACH, H. 1977. Discussion Reporting of 14C Data. *Radiocarbon,* 19**,** 355-363.

UERPMANN, M., UERPMANN, H.-P. & JASIM, S. A. 2000. Stone Age nomadism in SE-Arabia - palaeo-economic considerations on the neolithic site of Al-Buhais 18 in the Emirate of Sharjah, U.A.E. *Proceedings of the Seminar for Arabian Studies,* 30**,** 229-234.

WASSE, A. 2002. Final Results of an Analysis of the Sheep and Goat Bones from Ain Ghazal, Jordan. *Levant,* 34**,** 59-82.

WRIGHT, K. I. 2008. Craft Production and the Organization of Ground Stone Technologies. *In:* ROWAN, Y. M. & EBELING, J. R. (eds.) *New Approaches to Old Stones. Recent Studies of Ground Stone Artifacts.* London: Equinox Archaeology Books.
YERKES, R. W., BARKAI, R., GOPHER, A. & ZUTOVSKI, K. 2016. The use of fan scrapers: Microwear evidence from Late Pottery Neolithic and Early Bronze Age, Ein Zippori, Israel. *Journal of Lithic Studies,* 3**,** 185-205.
ZIELHOFER, C., WELLBROCK, K., AL-SOULIMAN, A. S., VON GRAFENSTEIN, M., SCHNEIDER, B., FITZSIMMONS, K., STELE, A., LAUER, T., VON SUCHODOLETZ, H., GROTTKER, M. & GEBEL, H. G. K. 2018. Climate forcing and shifts in water management on the Northwest Arabian Peninsula (mid-Holocene Rasif wetlands, Saudi Arabia). *Quaternary International,* 473**,** 120-140.