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Life-sized Neolithic camel sculptures in Arabia: A scientific assessment of the craftsmanship and age of the Camel Site reliefs

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ABSTRACT

The life-sized, naturalistic reliefs at the Camel Site in northern Arabia have been severely damaged by erosion. This, coupled with substantial destruction of the surrounding archaeological landscape, has made a chronological assessment of the site difficult. To overcome these problems, we combined results from a wide range of methods, including analysis of surviving tool marks, assessment of weathering and erosion patterns, portable X-ray fluorescence spectrometry, and luminescence dating of fallen fragments. In addition, test excavations identified a homogenous lithic assemblage and faunal remains that were sampled for radiocarbon dating. Our results show that the reliefs were carved with stone tools and that the creation of the reliefs, as well as the main period of activity at the site, date to the Neolithic. Neolithic arrowheads and radiocarbon dates attest occupation between 5200 and 5600 BCE. This is consistent with measurements of the areal density of manganese and iron in the rock varnish. The site was likely in use over a longer period and reliefs were re-worked when erosion began to obscure detailed features. By 1000 BCE, erosion was advanced enough to cause first panels to fall, in a process that continues until today. The Camel Site is likely home to the oldest surviving large-scale (naturalistic) animal reliefs in the world.

1. Introduction

The rock art of Saudi Arabia provides a rich record of the region's prehistoric past. Changing climatic conditions are reflected in the depiction of diverse wildlife that once thrived during the Holocene humid period, when increased rainfall supported lakes and grasslands across northern Arabia ca. 8000–4000 BCE (Dinies et al., 2015; Engel et al., 2017; Lézine et al., 2010; Petraglia et al., 2020). Changes in subsistence and technological advances are visible in the form of hunting scenes, the emergence of domesticated livestock, weaponry and

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writing, and chart the progression of prehistoric human populations from the Epi-Palaeolithic/Pre-Neolithic to the Neolithic, Bronze and Iron Ages and into the more recent historic periods (see for examle Aksoy, 2017; Guagnin et al., 2017a; Khan, 2007; Newton and Zarins, 2000). Two sites that have received particular attention are Jubbah and Shuwaymis, where thousands of engravings document Neolithic fauna and lifestyles (Guagnin et al., 2015; Guagnin et al., 2016; Jennings et al., 2013; Jennings et al., 2014; Macholdt et al., 2018).

However, as archaeological research in Arabia intensifies, large numbers of new rock art sites are recorded every year (see for example Arbach et al., 2015; Bednarik and Khan, 2017; Degli Esposti et al., 2020; Monchot and Poliakoff, 2016; Olsen, 2017).

One recently discovered site that stands out in Arabia is the so-called Camel Site, where several life-sized reliefs of camels and equids were reported (Charloux et al., 2018). Based on similarities with the life-sized camel reliefs in the Siq at Petra (Jordan), the site had initially been attributed to the Nabatean period while awaiting a detailed chronological assessment. However, new comparative studies of large naturalistic (two-dimensional) engravings of camels (LNEC) in northern Arabia now suggest that the reliefs of the Camel Site may be a three-dimensional version of a wider reaching Neolithic rock art tradition (Charloux et al., 2020; Charloux and Guagnin, under review). In fact, the only feature that distinguishes LNEC from Camel Site reliefs is the extent to which the image is raised from the background. LNEC in the Sakaka and the Jubbah/Jebel Misma areas not only mirror the reliefs of the Camel Site in their naturalism and detail but also show similarities in engraving technique as some LNEC are partially depicted in low-relief. LNEC distribution also overlaps spatially with the Camel Site and both share a symbolic tradition where engravings and reliefs predominantly show male camels with bulging necklines, a feature that is typical of male camels in rut (Gauthier-Pilters and Dagg, 1981). Camel reliefs and LNEC are usually also depicted with pronounced humps and rounded bellies, signs that they are well fed, and a possible reference to the wet season – a time of year when vegetation was abundant, which would have coincided with the mating season (Gauthier-Pilters and Dagg, 1981).

Here we explore the possibility that the reliefs of the Camel Site may have been created during the Holocene humid period (ca. 8000–4000 BCE). We present data from archaeological excavations, scientific dating and technological analyses to support a Neolithic age for the reliefs. In northern Arabia, characteristics that are typically used to define the Neolithic in the Levantine sphere, 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 BCE as Neolithic (Crassard and Drechsler, 2013). Pastoralism was probably introduced in the region during the 7th millennium BCE (Drechsler, 2007), although the exact timing of this transition from hunting to herding remains unknown. Evidence from excavated sites in the Jubbah oasis suggests that by 6000 BCE onwards domestic cattle were present in Northern Arabia (Guagnin et al., 2021). At present, the archaeological record for the preceding millennia is even more fragmentary, and only a handful of Early Holocene sites are known in the Nefud desert (Guagnin et al., 2020; Hilbert et al., 2014) and close to the modern border with Jordan (Fujii and Al-Mansour, 2018; Gilmore et al., 1982; Ingraham et al., 1981). Recent archaeological research is beginning to identify an increase in human activity towards the end of the Holocene humid period. The frequency of radiocarbon dates appears to increase substantially between 5500 BCE and 4800 BCE, with a peak around 5200 BCE (Groucutt et al., 2020; Guagnin et al., 2017b; Guagnin et al., 2020; Munoz et al., 2020; Scerri et al., 2018; Thomas et al., 2021b; Thomas et al., 2021a) and may correspond to a change in activity patterns, intensification of long-distance interactions, and population increases. A newly documented phenomenon from this period are *mustatil*, large rectangular stone structures that were probably built as communal meeting places for rituals (Groucutt et al., 2020; Thomas et al., 2021a). The increase in activity in the late Neolithic thus appears to relate to a period of increased ritual expression of which the rich body of Neolithic rock art in this region may also have formed a part (Guagnin et al., 2017a; Andreae et al., 2020). Although occupation subsequently appears to have become more sporadic across northern Saudi Arabia, symbolic landscapes continued to form an important part of prehistoric life, whether in the form of megalithic structures, platforms, cairns or rock art sites (Gebel, 2016; Jennings et al., 2013; Munoz et al., 2020). In this broad context, we believe that the exceptional Camel Site, which was very probably a gathering place with important symbolic function (Charloux et al., 2020), brings new insight on the complex societal and ceremonial picture of the prehistoric period in northern Arabia.

To date, evidence for the age of the reliefs at the Camel Site, and indeed the wider tradition of LNEC is largely based on stylistic comparison and a relative chronology based on rare instances of stratigraphic sequences in the rock art. Here we present a technological study and absolute chronological assessment of the Camel Site that support a Neolithic age for the creation of the site. Our research includes tool mark analyses, an assessment of weathering and erosion patterns, newly discovered panels, test excavations and lithic assemblages, rock varnish density measurements, as well as the first radiocarbon ages and OSL dates obtained from the site. These analyses also allow us to place the site into the wider context of Neolithic cultural expression and socio-economic context in the region.

2. Methods

The first two field seasons of the Camel Site Archaeological Project were carried out in October 2018 and October 2019. The main aim of the fieldwork was to carry out an archaeological survey of the site and its surroundings, detailed survey and documentation of all carved surfaces at the site, to establish a protocol for the protection and restoration of the reliefs that are suffering from erosion, and to establish a chronology for the site through test excavations, radiocarbon dating and Optically Stimulated Luminescence (OSL) dating (for a detailed field report see Charloux et al., in press).

Every panel was surveyed in detail and photographed in different light conditions as the visibility of panels and individual carved elements is highly dependent on the position of the sun. Panels were also photographed with artificial light sources at night and were recorded as high-resolution 3D models. Survey of the panels also included the ground below each relief to check for stone tools and fallen fragments, as well as an assessment of the condition and craftsmanship of the relief, an estimate of the weight of the boulder or panel, and an assessment of tool marks, including macro photography. Weight estimates and tool mark analysis are based on the professional experience of a stone mason and a conservator (F. Burgos and F. Dubois). The detailed assessment of panels in different light conditions led to the detection of seven previously unknown life-sized animal reliefs, two scenes with small scale reliefs, as well as two fragments of reliefs in the rubble banks pushed aside by bulldozers.

Due to the advanced state of erosion at the site, many boulders with reliefs have fallen. A total of six boulders are no longer in situ, and five of these have fallen to the ground. Of these, two have subsequently been pushed around and damaged by bulldozing. The present and likely original location was assessed for each panel and forms the basis for an initial assessment of taphonomic processes at the site. This assessment also showed that two fragments of a fallen boulder (panels 5, 6 and 7) have remained in situ, thus providing an opportunity for OSL dating of underlying sand deposits (Fig. SI1).

2.1. Portable X-ray fluorescence spectrometry

Measurements by portable X-Ray Fluorescence Spectrometry (pXRF) were conducted on selected elements at the Camel Site to determine the density of manganese in the rock varnish in order to derive age estimates for the carvings. The technique has been described in detail elsewhere (Macholdt et al., 2018; Macholdt et al., 2019) and will only be outlined briefly here. Measurements were conducted using a Niton XL3 pXRF (Thermo Fisher Scientific) in the "mining" mode. The instrument is equipped with an X-ray source with an energy of 50 keV and a silver anode and has a spot size of 8 mm in diameter. For quality control, the reference materials TILL1 and FeMnOx-1 (GeoReM database, version 25; http://georem.mpch-mainz.gwdg.de; Jochum et al., 2005) were measured before and after each XRF measurement sequence. We made a total of 145 measurements, 55 on intact varnish surfaces and 95 on rock art surfaces. The measurements were converted into areal density values of manganese (Mn), D_{Mn}, in units of μg cm^2 using the calibration curve from Macholdt et al. (2017). Since D_{Mn} can vary substantially due to different growth and erosion conditions even within a given rock art panel, we also calculated the ratio of the measurements on the petroglyph surfaces to that on immediately adjacent intact varnish. This provides a normalized measure, called N_{Mn} (in %), which represents the degree of re-varnishing on the petroglyph surface relative to the surrounding intact varnish. Photographs of all petroglyph measurement positions are provided as supplemental data (Figs. SI23-SI32).

2.2. Lithics survey

The area immediately surrounding the Camel Site reliefs was surveyed for archaeological remains. As the area is relatively small, transects were not laid out systematically, and instead followed the terrain (Fig. 1). The area is heavily damaged from bulldozing and the top layer of sediment has been removed across most of the site and used to form a barrier that demarcates the boundaries of the field. As a result, lithics predominantly remain where the bedrock is slightly raised and thus protected surface finds from bulldozing. Lithics were found across the site, and in some cases had evidently escaped in between the teeth of the bulldozer bucket (Fig. 1). The site therefore retains a small sample of lithics in reasonable state of preservation, despite the apparent and extensive damage.

2.3. Test excavation

Between the three rock spurs that make up the Camel Site (Fig. 1 and Fig. 2), the terrain rises gently at the base of each outcrop and a low talus slope composed of sandstone debris and aeolian material sits around each of the spurs. This has protected some areas from bulldozing, while others have been destroyed or buried under the debris. Based on this observation an area in front of a small natural rock shelter on the talus slope was chosen for excavation. A series of five 1x1m squares was opened up, following the terrain up the slope, and overall forming a trench of 5x1m. All squares were excavated down to the natural bedrock. The test trench was excavated to assess the preservation of in situ archaeological remains in order to have a representative sample of the material culture used and produced at the site. Our primary aim was to secure datable materials from stratified deposits in order to establish a first radiocarbon chronology for the site.

2.4. Radiocarbon dating

Due to poor preservation of bone collagen in hyper-arid environments, conventional radiocarbon dating was not possible. However, samples from arid environments such as the Arabian Peninsula have good preservation of the mineral fraction of skeletal remains (carbonate hydroxyapatite, or bioapatite), which has been shown to be a reliable material to date skeletal remains (Zazzo and Saliège, 2011) and has been successfully employed in the region (see for example Guagnin et al., 2021; Hausleiter and Zur, 2016; Guagnin et al., 2020). Four samples were chosen for radiocarbon dating, covering a range of different depths in the test excavation, as well as remains of a hearth (Table 4). Samples were sent to the Centre for Applied Isotope Studies (CAIS) at the

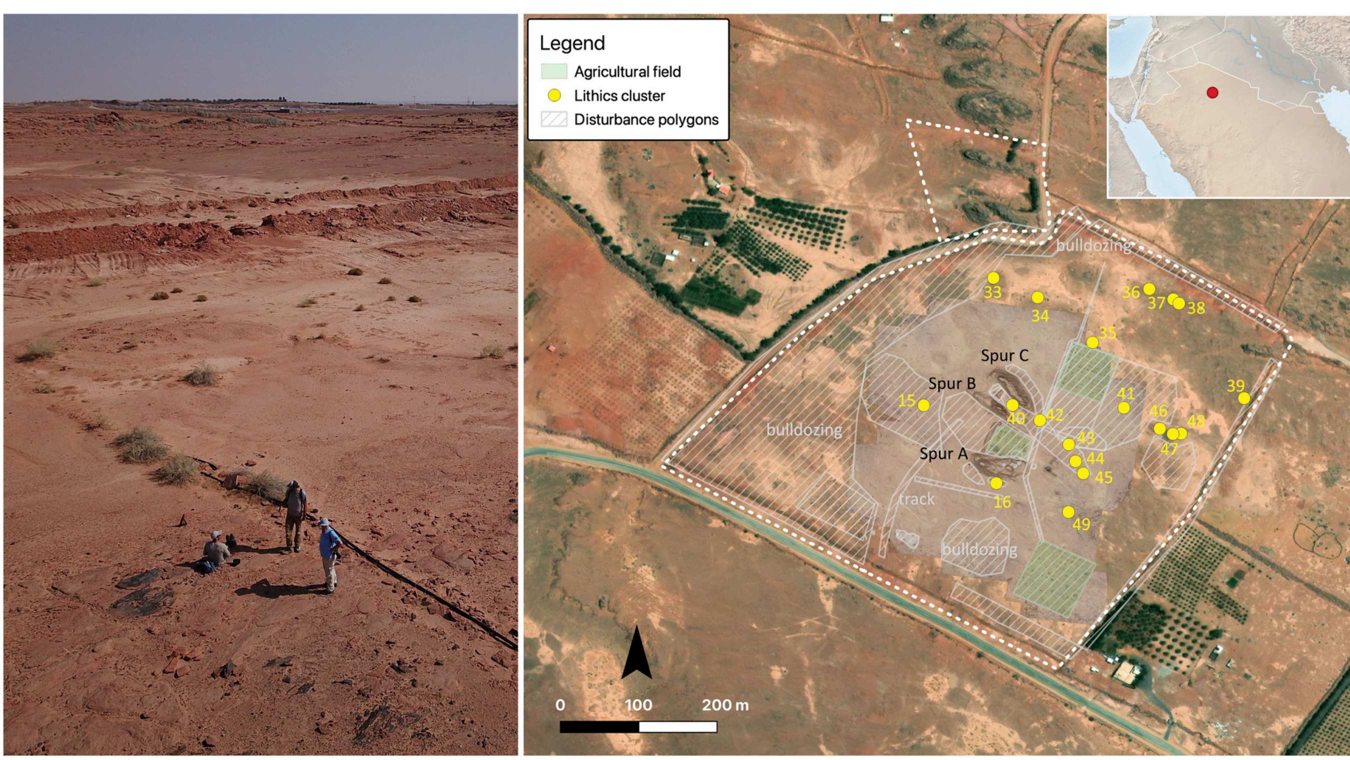

Fig. 1. Left: View across the field surrounding the Camel Site spurs during the lithics survey. The barrier created by bulldozing surface sand and rocks can be seen in the background. Right: Bing Virtual Earth satellite image showing the location of lithic scatters, damage from bulldozing and agricultural activities with a terrain model overlay to show more clearly the three spurs that make up the site. White dashed line shows the perimeter of the field and the archaeological site. Inset shows the location of the Camel Site in northern Saudi Arabia © M. Guagnin, P. Flohr and G. Charloux.

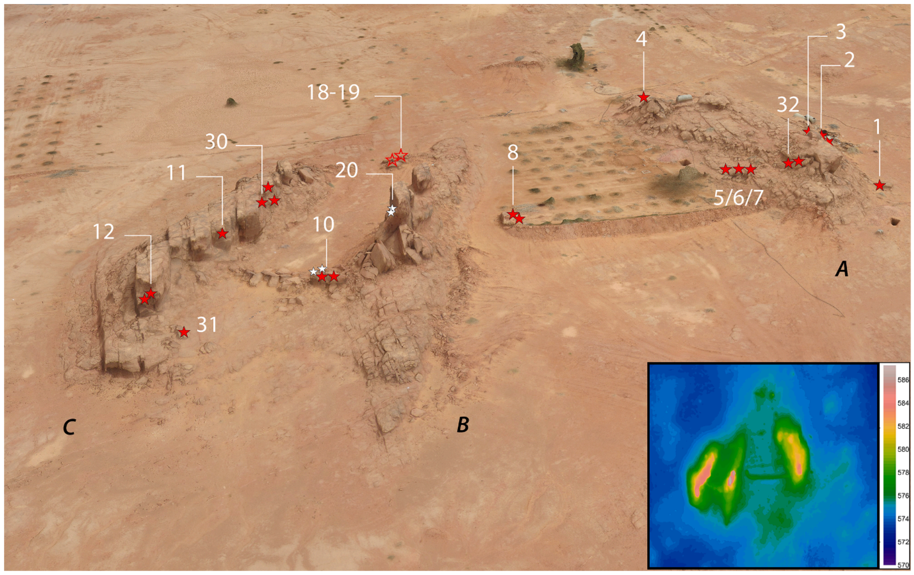

Fig. 2. Oblique view of a 3D model of the Camel Site, viewed from north-west, showing the position of all large reliefs (red stars), small reliefs (white stars) and large fragments (stars with red outline). © G. Charloux & M. Guagnin, R. Schwerdtner. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

University of Georgia for bioapatite radiocarbon dating to allow good comparison with ages previously obtained in the region. Additional information on the radiocarbon methodology is provided in the SI document.

2.5. OSL methodology

Two rock fragments were targeted for OSL dating of samples retrieved from a layer of sand, that touched the underside of each rock fragment, and was sandwiched between the loose and friable bedrock and the rock fragments themselves. In addition, a piece of the rock was collected that was directly in contact with the sampled sand. To prevent exposure to sunlight, sampling was carried out at night using red light.

In the laboratory, the grains-size 100–150 µm was gained by sieving, followed by decarbonisation (20% HCl). A K-feldspar and quartz fraction were enriched by density separation, the latter etched in 40% HF for 60 min. The dried grains were mounted on stainless steel discs (2 mm stamp of silicon oil). Measurement of equivalent dose (D_e) was done on a Freiberg Instruments *Standard* device (Richter et al., 2013). For quartz, green light optical stimulation (OSL: 525 nm, 90 mW cm^{-2}, 60 s) with detection in the near UV was used (Hamamatsu 7360–02 PMT, 3 mm Schott BG-3 and 5 mm Delta-BP 365/50 interference filter). For K-feldspar, we applied IR stimulation (IRSL: 850 nm, 200 mW cm^{-2}, 90 s) with detection in the blue range (3 mm Schott BG-39 and HC 414/46 interference filter). The Single Aliquots Regenerative Dose protocol was used with preheat (10 s)/cutheat of 220 °C/160 °C for quartz. Preheating at 180 °C (10 s) was applied for the K-feldspar post-IR Infrared Stimulated Luminescence (IRSL) protocol (150 °C; Reimann and Tsukamoto, 2012). The overall performance was good and cross-checked by a dose recovery test.

The concentration of dose rate relevant elements (K, Th, U) was determined by high-resolution gamma spectrometry at VKTA Rossendorf e.V., Dresden. Due to the complex situation, two rock samples were measured in addition to the sampled sand layer. A layer model in ADELEv2017 (Degering and Degering, 2020) was used to calculate the annual dose rate (Top layer = 15 cm rock, sampled layer = 10 cm sediment, bottom layer = >30 cm of rock), assuming an average water content of 3 ± 3%, an internal K-content of 12.5 ± 0.5% and a-value for K-feldspar of 0.07 ± 0.02. Cosmic dose rate was corrected for geographic position.

3. Results

3.1. Tool marks and engraving process

A detailed assessment of the engraving techniques and taphonomic processes that underpinned the creation and subsequent partial destruction of each relief provides some insight into the original layout and use of the site. Although all reliefs have lost a substantial proportion of their original mass, and the original carved surfaces only remain in few locations, the remaining surfaces and three-dimensional sculped shapes still retain some information on the tools and carving processes used at the site.

Here we focus on the life-sized reliefs recorded at the Camel Site, as they distinguish the site from the numerous other rock art sites known from Arabia and likely also relate to the site's original purpose and use. The presence of two-dimensional engravings in the vicinity of the site is discussed elsewhere (Charloux et al., 2020). The core area of the Camel Site, which extends around three rock spurs (Fig. 2), contains 12 known panels with the remains of 21 life-sized animal reliefs (Fig. 2). In addition, two large fragments of life-sized reliefs (18 and 19) were recorded, as well as four small camels in bas relief and three small equids in high relief. All details were assessed visually by an experienced stonemason and conservator (Fig. 3 and Fig. 4). Of the 12 panels with life-sized reliefs, tool marks are still identifiable on 8 of the panels and allow conclusions on the tools and methods used in the carving process (Table 1). The process of carving the reliefs would need to have been done in two stages. In an initial stage the rock was shaped to bring out the relief, and on most reliefs a substantial volume of rock was removed, particularly below the abdomen and between the legs of the animals. This process was particularly time consuming for high-reliefs such as Panel 1, Panel 5, and Panel 11 where the body of the animal is raised substantially compared to the surrounding rock surface and more rock volume had to be removed (detailed Figures for each panel are provided in the SI – Figs. SI2-SI15). This initial preparatory phase is most clearly visible in Panel 4, where a carving of a camel was outlined and abandoned without having been completed (Fig. 3). A pecking technique was used to create small but deep holes that separate the relief from the rock surface that was to be removed. The removal of sandstone was likely done using large scrapers or hammers with stone chisels. In a second stage the relief was shaped and the finer detail was carved. Where the

Fig. 3. Panel 4 being inspected by P. Flohr and F. Dubois (who is standing on the former working platform). Right (top and bottom): close up photographs show a technique where a pick was used to create small but deep holes to separate the relief from the rock surface that was to be removed. Although erosion has removed original tool marks, the holes themselves are still clearly visible. © M. Guagnin.

rock surface is preserved, the reliefs show a surprising amount of detail and naturalism. This was achieved through the use of smaller and possibly hafted chisels as well as abrasive stones for smoothing surfaces. All traces suggest that carving was done with stone tools, no evidence for the use of metal tools was found on any of the reliefs.

The creation of the reliefs was a time-consuming process, and particularly the creation of more complex panels with two animal reliefs or of particularly deep reliefs is estimated to have taken around 10 to 15 days to carve (Panels 1, 2, 5, 10, 11, 12, 31 and 32). Simpler panels and panels with single animals may have taken fewer days (Panel 3, 8, 31). If we assume an average of 12 days for complex panels, and 8 days for simpler panels, the known panels at the site would have taken a combined 120 person days to produce. It is possible that two carvers may have worked together, with one (perhaps less experienced) carver removing the bulk of the rock, and a second carver shaping and polishing the final relief. This may have reduced the time it took to produce a relief, although given the nature of both tasks, any overlap would have been limited (given that the task of the second carver can only begin in earnest once the task of the first carver is complete). The attention to detail and the carving skill evident in the remaining surface areas suggest that the final reliefs had a polished and homogenous look, which would have required a single, skilled individual to carry out the shaping and polishing of the reliefs.

Given the difference in technique, stylistic considerations and skill evident in the panels, it appears that the different panels (and in fact different reliefs within a panel) were produced by different carvers, likely at different times. This is particularly evident in Panel 8 and Panel 31, which have been carved in bas-relief rather than high relief.

The difference in 'hand' is most clearly visible in the camel and equid reliefs on Panel 2 (Fig. 4). The head of the camel appears to be extremely naturalistic, with the nostril visible, the lips and even the muscles of the jaw, as well as a bulging neckline, as is typical for male camels in rut. Interestingly, the lips and chin of the camel are slightly differently shaped to (most) modern camels, resulting in a more triangular profile of the head, and it is not clear to what extent this may be the result of erosion (the lips are certainly somewhat flattened by erosion), artistic expression, or perhaps a phenotypic change resulting from domestication and breeding. Unfortunately, the eye of the camel has eroded away and can no longer be assessed. The relief of the camel appears to be more three dimensional, with the muzzle of the camel closer to the rock surface, while the head protrudes more in a depiction of a dynamic upward motion. The wild ass, on the right of the panel is more stylised in outline, seemingly with the entire body raised to the same level from the rock surface. Its outline and surface are less detailed, with the ear depicted in relatively simple lines. A faded depression of the original eye is still visible and appears to have been naturalistic. A fresh eye was incised or chiselled with a hard stone at a later date and was placed too high on the forehead, probably to avoid the slight depression from the original eye. This gives the equid an even more stylised impression. Peck marks in front of the original eye suggest that a third attempt at recreating the eye was undertaken, although it is not clear if this was before or after the incised eye (Fig. 4). Overall, it appears that the characteristics of the relief that are still visible today were the result of one or more re-engraving episodes that re-shaped the body outline as well as the head, with the original having been more naturalistic. While erosion prevents a similarly detailed analysis of other panels, re-engraving events are also common within the wider tradition of Large Naturalistic Camel Engravings (LNEC) (Charloux et al., 2020).

Long-term interaction with the reliefs is also evident in multiple grooves visible on Panels 1 and 3 (Fig. 5 and Fig. 6). The grooves were created after completion of the panel and probably for the purpose of generating and removing sandstone powder (see Discussion). The overlapping nature of the grooves, and the difference in depth and shape (particularly the deep, circular hollow on Panel 3) suggest activity by

Fig. 4. Tool marks on Panel 2 being inspected by F. Burgos. A: Detail photograph of the head of the young equid, showing the original, faded eye (1), a later eye chiselled in an incorrect anatomic position (2), and an aborted, later attempt to create a fresh eye (3). B: chiselling marks above the equid's nose. C: Polished lips, and peck and chisel marks around the muzzle of the camel. © M. Guagnin and G. Charloux.

different individuals and over prolonged time periods. Evidence of re-working is only visible on Spur A, although it is not clear if that is a result of better preservation or if this indicates an activity reserved for specific reliefs.

3.2. *Weathering and erosion*

A thorough site condition assessment revealed the main drivers of erosion at the site. While the whole area has been extensively damaged by bulldozing, agricultural landscaping and irrigation, the reliefs have predominantly been damaged by wind erosion and the effects of salt and moisture, with the latter likely caused by temperature differences and

Table 1
List of panels with observed tool marks and evidence for engraving processes. In total the Camel Site has 21 large animals in relief (numbers prefixed with 'A' in the last column), of which 17 are camels, 2 equids, and 1 could be either a camel or an equid. Small scale reliefs are not numbered here. The continuous numbering of newly discovered panels follows the initial numbering in Charloux et al. (2018).

Panel No	Original position	Tool marks	Engraving process	Animal reliefs
1	Boulder – fallen from above Panel 2	Tool marks visible on belly (dimples) and thigh; no indication of metal use – most likely carved using lithics.	Fractured along outline, making it impossible to identify re-engraving events. Grooves, covered in thick, dark varnish, were likely created for the purpose of dislodging portable or even ingestible sand from the panel and suggest substantial and longer-term interaction with the finished panel.	A1 (camel)
2	In situ on cliff	Traces around the heads of the animals show chiselling and direct pecking. Eye of equid chiselled or scratched with hard stone. No indication of metal use – most likely carved using lithic tool. Lips may have been polished with a stone tool.	Style, representation and tools/techniques used suggest equid and camel were carved by different individuals. May not have been created simultaneously but clearly reference each other. Eye of equid re-worked twice once engravings were sufficiently old for the original eye to have faded. Hind and head of the equid show evidence of re-engraving.	A2 (equid) & A3 (camel)
3	Boulder slipped sideways – initially closer to Panel 2	No visible tool marks, although some eroded 'dimples' suggest faded peck marks.	Technique of creating outline and tool used to shape the body suggest similarities with Panel 1. Outline re-worked at least once. Hind-legs not rendered in 3D. Grooves and deep hollow indicates continued interaction with the panel.	A4 (equid)
4	In situ on cliff	Very eroded and tool marks no longer visible but technique identifiable.	The engraving is unfinished and shows the first step in the engraving process: the tracing of the outline that achieves an initial raising of the animal against the rock surface, although the removal of rock surface to create depth never took place. On this panel the rock still forms a work platform in front of the panel – similar platforms may have existed at some of the other panels but were probably lost to erosion. The finished engraving would have been smaller than life-sized.	A5 (camel)
5, 6 & 7	Boulders have fallen and broken apart - initially part of one block from near the top of Spur A	Tool marks eroded and not clearly visible but appear to have been made with indirect percussion, possibly using a hafted lithic tool.	Engravings on 2 (and possibly 3) sides. Main engraving shows a large camel. On the short side of the block legs of an unidentified, smaller animal can be seen. The back of the block with the front legs appears to have extremely faded remnants of an additional engraving. The carving of the camel removed a considerable quantity of rock and would have required substantial effort. Carving may have been done by two people – with one doing the coarser removal of rock and one the finer shapes of the relief.	A6 (camel in 3 separate fragments: belly & hind legs, front legs and hump) A7 (uncertain [legs]), A8 (uncertain [outline])
8	Boulder has fallen from higher up on the southern side of spur B	Tool marks eroded but must have initially been very finely pecked. Tool marks around the head of the remaining camel stem from a lithic chisel.	Camels are worked in bas relief. Head is naturalistic but more stylised than the camel on Panel 2 (A3). Technique and artistic quality different to other panels at the site, and likely carried out by a different person.	A9 (camel) & A10 (camel)
10	Boulder has fallen from the western end of spur B	Tool marks visible along the outlines of the legs clearly show the use of a lithic chisel and a hammer, as well as a scraper to polish the rock. Pecking visible in the hollowed area beneath the abdomen.	Two life sized camels were engraved high up on spur B. At a later point, before the fall of the panel, two small camels were added in bas-relief.	A11 (camel), A12 (camel), & 2 small camels
11	In situ on cliff	Tool marks visible below the abdomen and along the legs.	Position of the panel would have required a working platform or rigging so the engravers could reach.	A13 (camel)
12	In situ on cliff	Tool marks visible on the legs, as well as the rock surface where volume was removed to create the relief. Striations still visible on the rock surface are eroded tool marks. All remaining traces are indicative of lithic tools.	Life-sized adult camel with either a young camel or a young equid. Likely engraved at the same time, as both figures make space for each other. Similar techniques evident on both animals, suggesting they were made by the same carver. Legs are very wide (unlike other more naturalistic carvings at the site) and suggest a less skilled carver. Carving would have required scaffolding/rigging or platform.	A14 (large camel), A15 (small equid/camel)
18 & 19	Boulders had fallen from original position and were recently moved by bulldozer	Weathered tool marks visible on both blocks but difficult to identify.	18: possible hump of camel or pointed area between legs. 19: part of a leg. Unclear where the fragments come from – possibly	Not identifiable

(*continued on next page*)

Table 1 (*continued*)

Panel No	Original position	Tool marks	Engraving process	Animal reliefs
			fragments of Panel 10, Panel 30 or an unknown and now fully destroyed additional panel.	
20A	In situ, high up on spur B	Tool marks visible but difficult to assess due to height and inaccessibility of the panel.	Ledge that likely served as a working platform has eroded and broken away. Similarity of the equid carvings suggests they may have been created by the same carver. Left most equid may have been partially unfinished, potentially due to the difficulty in accessing the location. Remaining parts of the relief suggests it was carved in high-relief, and likely by a different carver to the camels in 20B.	3 small equids
20B	In situ high up on spur B	Tool marks visible but difficult to assess due to height and inaccessibility of the panel.	Ledge that likely served as a working platform has eroded and broken away. Two camels appear to have been carved by the same person (in bas-relief) and post-date the engraving of the ibex.	2 small camels
30	In situ but extremely eroded	Some tool marks visible along the legs and neck of the camel on the right (SI Fig. 13C, D and E).	Position of camels suggests that at best very small working platforms existed beneath each relief, and carving would have required some additional support. Proportions of the body, leg position, body shape and volume, and outline of the hump are almost identical to Panel 11. The remains of the legs on Panel 30 suggest that the bone structure may have been more pronounced. Panel 30 may have been produced at the same time/by the same carver(s) as Panel 11.	A16 (camel), A17 (camel), A18 (camel?)
31	Boulder fragments below Panel 12, now horizontal, but their original position may have been more vertical. Original position likely below and to the right of Panel 12	Tool marks very eroded, no sign of metal tools (all grooves very smooth).	Likely position suggests the panel was probably engraved without the need for a support platform. Bas-relief very different and more simplistic than the other reliefs at the site – less skilled carving but in the regional tradition of large naturalistic camel engravings.	A19 (camel)
32	Boulder has fallen from western end/ top of Spur A	Tool marks very eroded and not all lines clearly recognizable.	Possibly one of the first panels that fell – shortly after the fall of Panel 5/6/7. May have been next to or even below the original position of Panel 5/6/7.	A20 (camel), A21 (camel)

sporadic rainfall. When the varnish formed on the rock surface it caused the sandstone to harden and protected the carvings for millennia, a phenomenon called case hardening (Dorn et al., 2017). Once the outer, harder layer of rock is removed by wind erosion, the internal, softer sandstone quickly erodes, leaving only an outer shell that is prone to collapse (Fig. 6). On numerous panels this had the result that the surface facing the wind eroded first, followed by a hollowing of the rock which left a thin layer containing the original carved panel. This is particularly evident on Panel 4 (Fig. SI16), but also on Panel 3, where the whole boulder has shifted as a result of hollowing, and a fall of the panel is imminent (Fig. 6).

Similar patterns of wind erosion could also be observed on a smaller scale within individual reliefs, where parts of the reliefs are being hollowed out, causing the loss of fragments. Loss of fragments has caused significant damage to Panels 2, 11, 12 and 30, while the fall of boulders has been the main cause of damage for Panels 1, 3, 5/6/7, 8, 10 and 32 (a detailed assessment of each panel and photographs of each relief are provided in the SI document). The taphonomic process is thus partly driven by the stability of the original rock substance and its likelihood to remain in situ while sustaining extensive damage to the surface, or to fall.

Fallen boulders have predominantly been damaged by bulldozing (Panels 1, 8 and fragments 18 & 19) and in the case of Panel 8 even a 20-ton boulder was not safe from being moved. In addition, fallen boulders were damaged by moisture rising from the ground, either after rains or as a result of agricultural irrigation in the area. The latter led in turn to salt efflorescence causing yet further damage (See Table S1).

As a result of the extensive erosion at the site, Panels 1, 5/6/7 and 32 have fallen from the top of Spur 1 (Fig. 1). The site would thus originally have consisted of at least two tiers of carvings.

The assessment indicates that accelerating erosion is likely a more recent phenomenon at the site and that the panels likely survived for a substantial amount of time before sustaining extensive damage. The drivers of these erosion processes, and the extent to which they were driven by changes in climate, wind regimes or water availability needs to be addressed in further analyses in the future.

3.3. Luminescence dating

Two OSL samples were recovered from below the fallen fragments of Panel 5/6/7, the only fragments to have remained in situ, and given its position likely one of the first panels to have fallen. The two samples investigated show a quite different behaviour with regard to the distribution of individual D_e values (Figs. SI17-SI22). Sample CS-2Q shows a quite narrow distribution around the zero value. Hence, this sample is considered to be of modern age. For sample CS-1, both quartz and K-feldspar show a wide distribution that is interpreted to reflect differential bleaching of the luminescence signal prior to deposition. This is typical for water-lain (fluvial) sediments. In addition, there are apparent outliers at the lower edge of the distribution. These could reflect post-deposition mixing (bioturbation?). Mean burial dose (D_e) was calculated using the Minimum Age Model of Galbraith et al. (1999) after removing outliers at the lower edge (4 aliquots of CS1-Q and 6 aliquots of CS1-F) and assuming a sigma_b value of 0.15. The mean D_e decreases

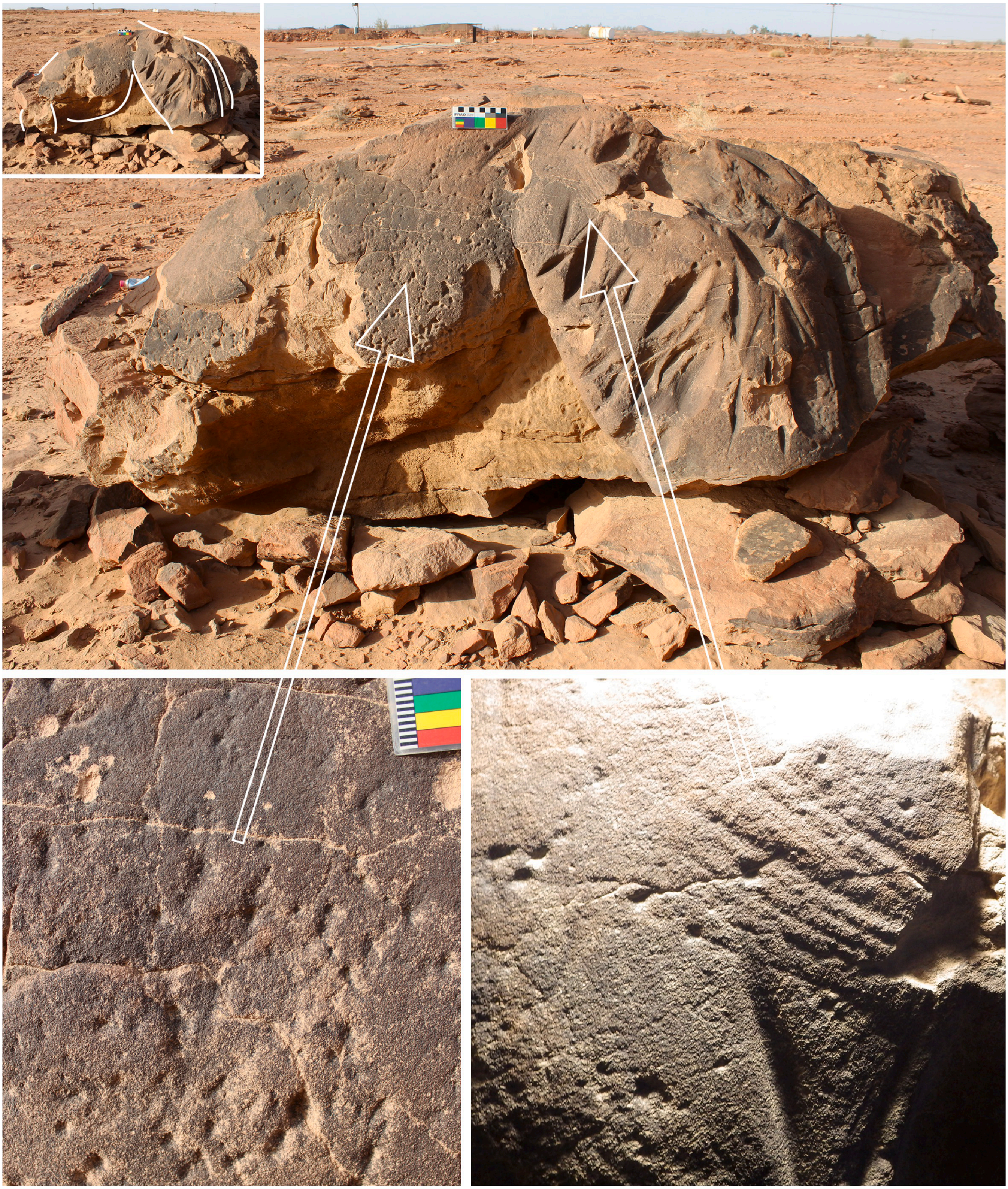

Fig. 5. Panel 1 showing the belly, thigh and upper tail of a camel. Tool marks can be seen on the lower abdomen and the upper thigh, as well as a series of deep grooves. Detail photographs are shown on the lower left and lower right. © M. Guagnin & G. Charloux.

to 9.53 ± 0.74 Gy when using a sigma_b of 0.10, and increased to 10.31 ± 1.08 Gy when sigma_b = 0.20 (these appear reasonable minimum and maximum estimates). This results in consistent OSL and IRSL ages of about 3000 years, and a higher pIR age of 4200 years (Table 2). The latter may reflect partial bleaching in the sample that is not compensated for by the use of the Minimum Age Model.

3.4. Areal density of manganese and iron in the rock varnish

Our approach to obtaining rock art age estimates from pXRF

Fig. 6. Extensive damage visible on Panel 3. Top: re-fitting of a fragment of the tail found below the panel with a traced outline of the equid (for an untraced image see SI2). Bottom: hollowed out rock – the equid engraving can be seen on the right surface of the rock. © M. Guagnin.

Table 2
Summary data of luminescence dating with sampling depth, concentration of dose rate relevant elements (k, Th, U), total dose rate, number of measured/accepted aliquots, mean Equivalent dose and resulting age.

Sample	Depth (cm)	K (Bq kg-1)	Th (Bq kg-1)	U (Bq kg-1)	D (Gy ka^{-1})	N	od	D_e (Gy)	Age (a)
CS-1 Rock	15	500 ± 50	30.4 ± 1.9	14.5 ± 1.0	–	–	–	–	–
CS-1 Quartz	10	720 ± 70	41.3 ± 2.6	21.7 ± 1.3	3.40 ± 0.36	50/50	0.64	9.93 ± 0.90	2920 ± 305
CS-1 Feldspar IR	10	720 ± 70	41.3 ± 2.6	21.7 ± 1.3	3.96 ± 0.46	39/39	0.79	12.07 ± 1.26	3050 ± 355
CS-1 Feldspar pIR	10	720 ± 70	41.3 ± 2.6	21.7 ± 1.3	3.96 ± 0.46	39/38	0.74	16.74 ± 1.74	4230 ± 490
CS-2 Rock	15	560 ± 60	26.7 ± 1.8	15.1 ± 1.0	–	–	–	–	–
CS-2 Quartz	10	820 ± 50	66.0 ± 4.0	31.8 ± 1.9		39/39	n.a.	zero	modern

Table 3
D_{Mn} and N_{Mn} data and age estimates for the rock art elements. The age estimates are subject to an uncertainty of about 40%. [n: number of measurements. Avg.: arithmetic average, S.D.: standard deviation].

Element ID	Motif	n	D_{Mn} [μg cm^{-2}]		N_{Mn} [%]		Age estimate [ka]	
			Avg.	S.D.	Avg.	S.D.	from D_{Mn}	from N_{Mn}
CS1-1a	Camel, right	3	223	1.2	91	10	–	–
CS1-1c	Camel, grooved area	3	216	20	88	12	–	–
CS1-1d	Camel, center	3	207	15	84	11	–	–
CS1-1f	Camel, left	3	235	11	96	11	–	–
CS1-1g	Camel, far left	3	246	24	100	14	–	–
CS1-1	Camel, avg. of above	15	226	16	92	6	8.1	6.4
CS1-1b	Camel, eroded surface	3	116	29	47	13	–	–
CS1-1e	Recently chiseled	3	1.4	0.7	0.6	0.3	–	–
CS2-1a	Equid, ear	3	192	10	106	8	6.9	7.3
CS2-1b	Equid, near eye	3	94	19	51	11	3.3	3.6
CS2-2	Wasm	8	17	3.7	12.1	2.6	0.6	0.8
CS2-3	Arabic insc., 1979 CE	6	3.8	0.7	3.5	0.6	0.1	0.2
CS14-1	MSH inscription	9	55	20	33	12	2.0	2.3
CS14-2	Small camel	9	58	16	30	8.3	2.1	2.1
CSH-1	MSH inscription	11	57	21	34	13	2.0	2.4

measurements is based on the fact that, in order to create the image, the artist removes the rock varnish that existed on the original surface, thereby producing a virgin surface on which varnish will regrow over time. If the rate of varnish growth is known, the age of a rock art element can be estimated by dividing the varnish density on the element by the varnish growth rate. Variability of varnish density caused by factors other than age, such as rainfall, dust fall, slope angle, substrate durability, surface runoff, etc. can be compensated at least in part by normalizing the varnish density on the element to that of the surrounding intact varnish (for a detailed discussion see Macholdt et al., 2019). The varnish density is represented by the areal density of manganese (Mn), D_{Mn}, and its normalized equivalent, N_{Mn}. The average D_{Mn} on the intact varnish at the Camel Site, 172 ± 50 μg cm^{-2}, is in the range typical of northern Arabian varnish (Andreae et al., 2020; Andreae et al., 2021; Macholdt et al., 2018). We calculated the rate of Mn accumulation on the rock art surfaces by dividing D_{Mn} and N_{Mn} measured on Hismaic and Mixed Safaitic/Hismaic (MSH) inscriptions by the age of these scripts, ca. 2.0 ± 0.3 ka (Macdonald, 2004; Norris, 2018). To obtain a representative average, we used data from both the Sakaka and Kilwa areas for this purpose (Andreae et al., 2020). The resulting absolute and normalized accumulation rates are $R_{Mn} = 28 \pm 11$ μg cm^{-2} ka^{-1} (95% confidence interval: 18–38 μg cm^{-2} ka^{-1}) and $R_{NMn} = 14.4 \pm 6.1$ % ka^{-1} (95% confidence interval: 9.4–19.3 % ka^{-1}), which are the values that we used as the basis for our estimates of rock art ages.

The objective of our pXRF measurements at the Camel Site was to obtain data from rock art elements with a presumed wide range of ages, in order to support a chronology of rock art creation at the site. Regarding the high relief camel images, our selection was constrained by the very advanced degree of erosion of many of the reliefs and by the difficulty of access to the reliefs on the high cliffs. We chose Panel 1 (CS1-1, Fig. SI23), a fallen boulder that was originally above Panel 2 and showed a reasonably well preserved part of the body of a camel, and the head of the equid on Panel 2 (CS2-1, Fig. SI25), which could be reached from above. On the north side of Spur A, we measured on some wusum (CS2-2, Fig. SI27), a type of tribal property and territorial marking used by the inhabitants of Arabia for millennia (Bednarik and Khan, 2005; McCorriston and Martin, 2010) and a recent Arabic inscription (CS2-3, Fig. SI28) containing the date 1399 (AH, 1979 CE). A two-dimensional camel image on the north side of Spur B (CS14-2, Figs. SI29 and SI31) was selected as it resembled elements that had been dated to the historic period elsewhere, as well as an MSH inscription on the same panel to provide an age reference. An additional age reference was provided by measurements on an MSH inscription on a small outcrop 650 m north–north-east of the Camel Site. The results of the measurements are given in Table 3.

In Fig. 7, we show the D_{Mn} values measured on Panel 1 at the measurement spots. The two points on the right appear to be on intact varnish, without any evidence of tool use. Four spots on the camel surface gave only slightly lower values on average (207, 223, 235, and 246 μg cm^{-2}), indicating a long period of revarnishing since their creation. The spot in the grooved area yielded a similar D_{Mn} (216 μg cm^{-2}), suggesting that the grooving was done at a time not very long after the creation of the camel. A visibly eroded spot gave a lower value (116 μg cm^{-2}), and a very low value was obtained from a recent chisel mark (1.4 μg cm^{-2}). From these data, age estimates can be obtained in two ways. If we assume that the spots to the right are in fact intact varnish, we can apply the normalization method, which would yield a mean N_{Mn} of 92 ± 6 % for the measurements on the camel (excluding the eroded spot), corresponding to an age estimate of 6.4 ± 2.5 ka (the error estimate includes the uncertainties from the pXRF measurements as well as from the accumulation rate). It is, however, possible that the presumably intact spots on the right have actually been worked on as part of phase 1 of the sculpting of the camel and are thus coeval with the camel. In this case, we can use the absolute Mn density (226 ± 16 μg cm^{-2}) and accumulation rate to obtain an age estimate of 8.1 ± 3.2 ka.

The measurements on Panel 2 (Fig. 7) yielded a D_{Mn} value of 192 μg cm^{-2} on the ear of the equid and 93 μg cm^{-2} on a spot just above the more recently chiseled eye. The age estimates from the ear are 6.9 ± 2.7 ka using D_{Mn} and 7.3 ± 2.9 using N_{Mn}. For the spot above the eye we obtain much lower estimates, 3.3 ± 1.3 and 3.6 ± 1.4 ka, respectively. This may be the result of erosion at this exposed spot or of reworking when the new eye was added. Overall, these results clearly indicate a Neolithic age for the high relief camel and equid images. These age estimates are very similar to those of the very realistic, slightly three-dimensional camel images on the Horsfieldberg at Kilwa, which are thought to represent wild camels and are stylistically very different from the domestic camel images produced starting in the Late Bronze Age (Andreae et al., 2020).

The small 2D camel, CS14-2, has a varnish density very similar to the MSH inscriptions, suggesting a similar age, around 2 ka. The wusum have D_{Mn} and N_{Mn} suggesting an age of 0.7 ± 0.3 ka, within the age range of wusum we measured in the Hima and Ha'il areas (0.2 to 3 ka) (Macholdt et al., 2018; Macholdt et al., 2019). The low D_{Mn} on both the Arabic inscription CS2-3 (3.8 ± 0.8 μg cm^{2}) and the chisel marks on Panel 1 (1.4 ± 0.7 μg cm^{2}) clearly are consistent with being recent additions.

3.5. Test excavation, finds and radiocarbon dating

A small test trench (1 m × 5 m; Camel Site Trench 1: Fig. 8) was excavated under a short overhang below Panel 20 between spurs B and C. Despite extensive bulldozing at the site, archaeological deposits have survived in this area and small hearths were discovered (burnt and ashy layers) as well as faunal remains, lithic artefacts and beads made of various materials.

Camel Site Trench 1 yielded a thin stratigraphy of a cemented to heavily-cemented brown–red to brown-grey sandy sediment layers. Along a slight slope of a talus abutting the sandstone overhang, a series of five one-square-metre squares were excavated from Square 1 at the upper part of the talus, to Square 5 at its lowest part. The remaining

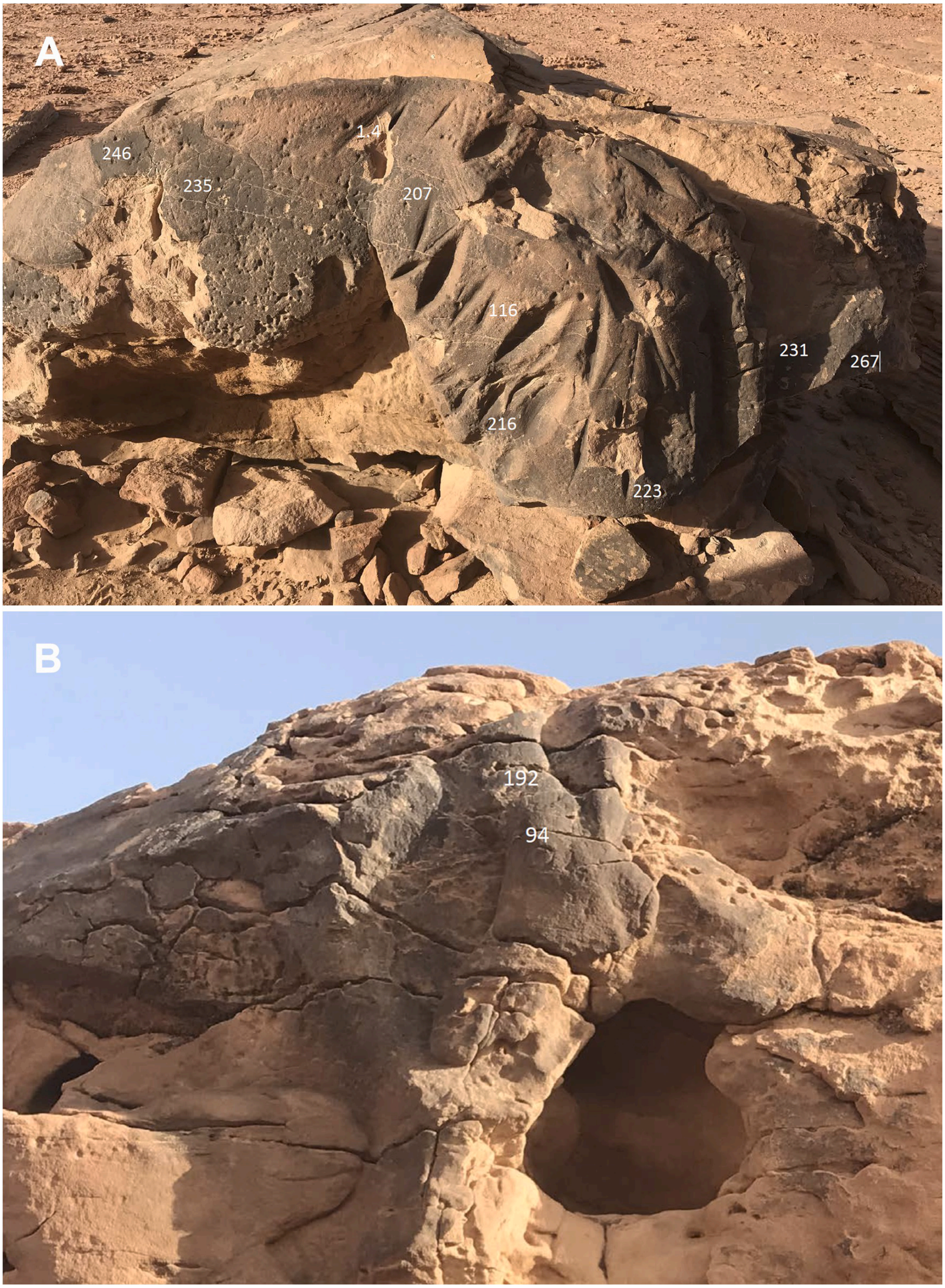

Fig. 7. D_{Mn} values measured on Panel 1 (A) and Panel 2 (B) at the measurement spots. © C.M. Andreae and M.O. Andreae

sediment accumulation at the trench ranges from a few centimetres of yellow sand lying directly on the bedrock surface, to 40 cm at its deepest point (Fig. 9).

Bone fragments from three different depths were selected for bioapatite dating and all provided Neolithic ages (Table 4). Radiocarbon dating obtained from archaeological deposits within the test trench thus all fall within two to three centuries in the mid-sixth millennium BCE, with a much later hearth placed over the top of the deposits.

The trench yielded a rather rich and homogeneous assemblage of lithics and other artefact types. In total, 706 artefacts were found (Table 5), including a majority of debitage (chert and quartzite flakes) and rare cores. Lithic retouched tools are ubiquitous, although made of fine-grained chert and most probably Neolithic in age considering their freshness and retouch specificities (fine retouch, sometimes by pressure technique). A series of eight arrowheads (Fig. 10) and arrowhead fragments are typical of the short transverse arrowhead type (Gopher, 1989;

Fig. 8. Position of the test trench under spur B, photo taken mid-excavation with the upper squares in the process of being cleaned. Squares were 1x1m and were numbered from the base of the spur downwards and varied in depth depending on the underlying bedrock. © G. Charloux.

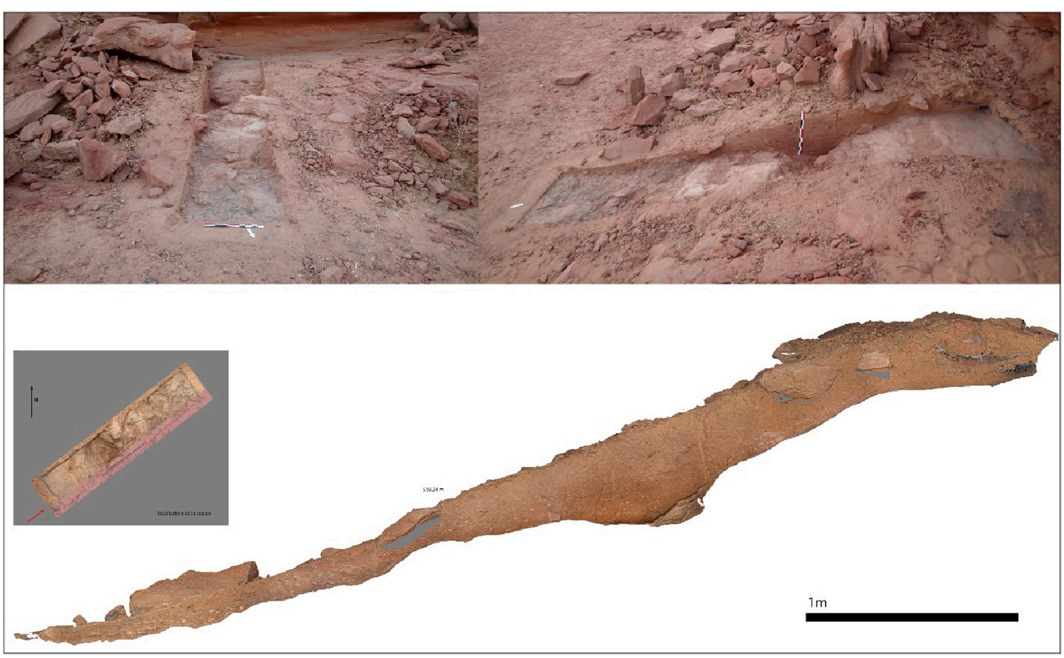

Fig. 9. Camel Site Trench 1 after excavation. Top: two general views of the trench; bottom: orthophotography of the south profile of the trench (0.4 mm per pixel). © R. Crassard and P. Mora.

Gopher, 1994) already known from surface and stratified contexts from the southern Levant and Jordan. This type of projectile is very specific, as a larger active extremity of the tool is left unretouched, using a natural edge of a flake (or blade or bladelet) as the projectile tip, being transverse to the general axis of the elongated piece. The rest of the arrowhead is finely and bifacially pressure-retouched along a tang that served as a hafting zone.

The dates obtained from Trench 1 coincide with the chronology of the transverse arrowheads known from sites in Israel and north-eastern Jordan. Rosen (Rosen, 1984; Rosen, 2011), dates transverse arrowheads

Table 4
Radiocarbon ages obtained from different deposits in the test trench and calibrated using CALIB REV 7.1.0 with 95.4% (2 sigma) probability.

Sample number	Field ID	Material	Depth	Square	δ13C,‰	δ18O,‰ 14C	14C age years, BP	Calibrated age, BCE	Median probability
UGAMS 46509	Sample 1	bioapatite	20–30 cm	3	−7.42	6.05	6680 ± 25	5641–5555 BCE	5598 cal BC
UGAMS 46510	Sample 2	bioapatite	30–40 cm	2	−6.95	5.60	6340 ± 25	5373–5226 BCE	5323 cal BC
UGAMS 46511	Sample 3	bioapatite	0–5 cm	4	−6.44	4.21	6500 ± 25	5517–5380 BCE	5477 cal BC
UGAMS 46512	Sample 4	charcoal	0–5	5	−11.35	n/a	280 ± 20	1521–1661 CE	1587 cal AD

Table 5
Breakdown of the archaeological artefacts retrieved from stratified deposits in the test trench (Camel Site Trench 1).

Artefact type	Count
Chert flakes	606
Quartzite flakes	58
Chert cores	3
Quartzite core	1
Arrowheads	8
Retouched tools	22
Hammerstone	1
Engraving tool (to be confirmed with use-wear analysis)	1
Beads / beads fragments / shell fragments	5
Stone vessel fragment	1
Artefacts total from Camel Site Trench 1	**706**

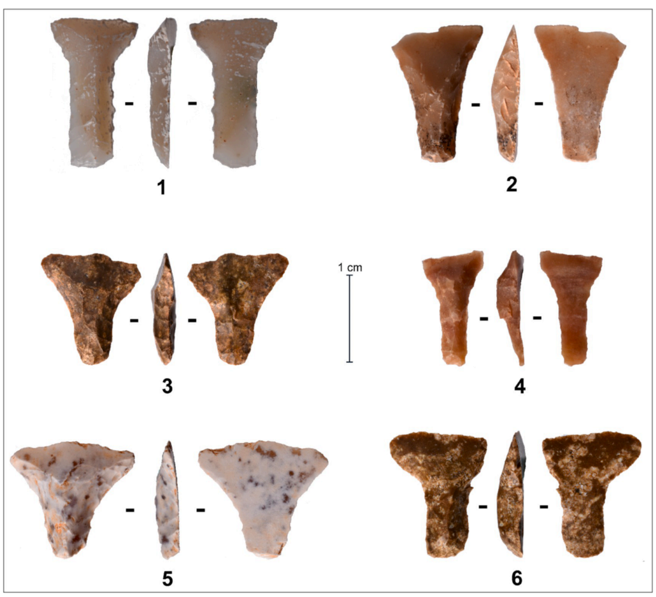

Fig. 10. Complete transverse arrowheads from Camel Site Trench 1. © R. Crassard.

to a later phase of the southern Levant chronology, i.e. Chalcolithic/ Bronze Age I, from 5000 to 3000 cal. BC. This assumption is mainly based on surface collections from undated desert surface scatters. However, transverse arrowheads are well documented from secure contexts and radiocarbon dated to around 6500–6000 cal. BC in north-eastern Jordan, most notably from the Wisad Pools sites (Rollefson et al., 2011; Rollefson et al., 2013; Rollefson et al., 2014; Rowan et al., 2015). With other similar discoveries in the north-eastern Jordanian Badia and Harra areas, this earlier date has become more widely accepted, and transverse arrowheads are generally attributed to the local Late Neolithic (Betts, 1993; McCartney and Betts, 1998; Betts et al., 2013), extending this chronological consensus to sites in Palestine/Israel (e.g. Wadi Rabah Culture; Gopher, 1989; Gopher, 1994; Goring-Morris, 1993).

3.6. *Lithic assemblages from surface sites found at the Camel Site and its immediate surroundings*

Although much of the area in the immediate vicinity of the reliefs has been obliterated by bulldozing, some raised, rocky areas have apparently escaped total destruction and have yielded lithics presenting diagnostic technological and typological characteristics, making a chrono-cultural attribution of these finds possible. Two clusters in particular are noteworthy here, namely #33 and #34, located in the northern area of the site, and #46, #47 and #48, which are located towards the eastern section. Both clusters are located on aforementioned ridges, just outside the bulldozed area surrounding the sandstone spurs.

Surface scatters #33 and #34, located to the north of the reliefs, are palimpsests and present two different groups of stone tool artefacts. The lithic scatters are relatively well delimited with a relatively low density of less than two artefacts per square meter. Four flat, bidirectional, and unidirectional cores with simple faceted striking platforms (Fig. 11) stand out from the majority of the observed surface finds in this cluster. These show extensive rounding comparable to those observed in Middle Palaeolithic occurrences in the area (Adams et al., 1977; Hilbert et al., 2017; Hilbert and Crassard, 2020; Parr et al., 1978). Most of the artefacts from the #33 and #34 clusters, however, are classified as blades and endscrapers made on blades (Fig. 12). The artefacts show extensive edge damage and battering, likely the result of substantial post-depositional displacement/transport. The raw material used is mostly fine-grained chert with different textures and gradations, most of the observed tools are made on fine-grained banded grey chert, which crops out 15 km to the west of Dumat al-Jandal, along the contact of the sandstone and limestone formation (Crassard and Hilbert, 2020; Hilbert and Crassard, 2020). The raw material used, the weathering observed on the artefacts and the technological characteristics of the blade production systems is comparable to that of the DAJ-112 and DAJ-125 sites located to the west and may indicate Early Holocene human occupation or activities (Crassard and Hilbert, 2020).

The lithic clusters identified in the western area of the site, #46, #47 and #48, are unlike the blade industry and are characterized by small flakes made of different fine-grained chert and flint, quartz and silcrete materials. These show little evidence of chemical and mechanical weathering, tools are rare and mostly retouched flakes and piercers were identified. No ceramics have been found in association with any of the lithic scatters during the 2019 survey. The configuration of the flake assemblages and the ad-hoc character of the lithics, may be held indicative for a later, possibly Mid to Late Holocene occupation at the Camel Site.

In addition, multiple stone tools were recovered from the base of reliefs and show visible signs of intense abrasion. These have been collected and their locations plotted; traceological (use-wear) analysis of these possible engraving tools is planned. This will provide a better understanding of the function of these tools. The raw material (a coarse-grained silicified sandstone) does not outcrop within a 15 km radius of the site, providing evidence for the extent of planning and logistics that was involved in the production of these tools. An exploratory experiment with stone tools was conducted to create a reference collection for the traceological analysis. This will give a comparative dataset that records the types of damage resulting from the use of stone tools to carve sandstone.

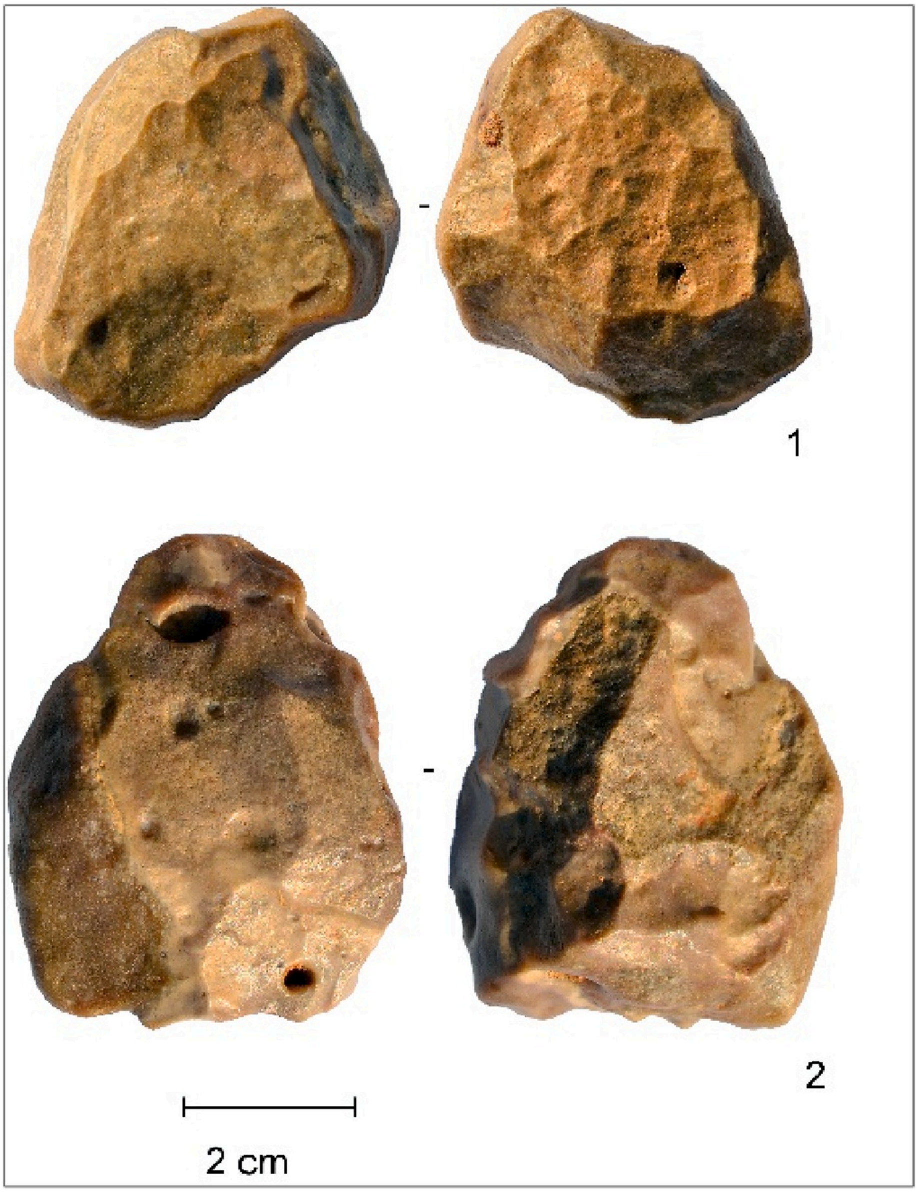

Fig. 11. Heavily rolled and weathered Middle Palaeolithic cores from the Camel Site. © Y.H. Hilbert.

4. Discussion

Our detailed chronological assessment of the Camel Site reliefs has identified multiple strands of evidence that all indicate a Neolithic age for the initial creation of the rock art site. Moreover, the erosion patterns visible at the site, pXRF analysis of rock varnish, OSL age estimates of fallen fragments, lithic analysis and identification of the engraving and re-engraving processes evident at the site have provided important new insights into the site's creation, chronology and taphonomic history. Three distinct phases can now be identified: a long period of creating, re-engraving and interacting with the panels, followed by a period when the site fell out of use, and finally an acceleration of erosion leading to the destruction of reliefs and the fall of entire panels. For the first time since their discovery, the Camel Site reliefs can be contextualised within the cultural and environmental record of the region, and in establishing the age and taphonomic history of the site we can begin to identify the challenges that lie ahead in the protection and conservation of the site.

Tool marks and engraving process show that a substantial amount of effort was invested in the creation of the site. Although the reliefs are in an advanced state of erosion, and not much of the original surfaces remains, all surviving tool marks are consistent with the use of stone tools in the carving of reliefs. We found no evidence for the use of metal tools. Multiple stone tools that were recovered from the base of reliefs show visible signs of intense abrasion and were likely used as engraving tools. Coupled with the fact that raw material for these carving tools would have had to be sourced from over 15 km away, and that carving of the deeper reliefs is estimated to have required 10 to 15 days, the logistic effort in the creation of the panels was likely substantial. The extent of planning involved, and the time and effort invested clearly sets the Camel Site apart from other rock art sites in Arabia.

Stylistic and technical differences visible in the reliefs suggest that the reliefs were created by a range of different people and probably over a long period of time. This is particularly evident in Panels 8 and 31, which were carved in low relief rather than high relief. However, it cannot be determined whether these differences reflect artistic choice, or changes in stylistic preferences over time. A difference in "hand" is also visible in the camel and equid reliefs on Panel 2 (Fig. 4). Here, a very dynamic depiction of a camel, where a lower relief of the head suggests movement towards/into the rock face, is juxtaposed with a more static representation of a young equid. Once some of the originally

Fig. 12. Artefacts from surface clusters #33 and #34. 1: Mesial blade fragment with inverse nibbling retouch; 2: truncated blade with lateral retouch; 3–9: endscrapers made on blades. Note the high amount of edge damage and rounding on both ventral and dorsal surfaces of the artefacts. © Y.H. Hilbert.

detailed features of the equid had been lost to erosion, its eye was re-carved in different locations and styles during at least two separate occasions. Long-term interaction with reliefs is also evident in numerous deep grooves visible on Panels 1 and 3 (Fig. 5 and Fig. 6). Similar practices are known from ancient Egypt (Traunecker, 1987) and from historic ethnographic records in the Sahara (Le Quellec, 2004), where sandstone powder generated from rock art panels or limestone statues was believed to have magical properties (see also Charloux et al., 2020). The overlapping nature of the grooves, and the difference in depth and shape (particularly the deep, circular hollow on Panel 3) suggest activity by different individuals and over prolonged time periods after completion of the relief. Moreover, pXRF readings on Panel 1 (CS1, Table 3) suggest that the areal density of manganese inside the grooves is within the range of other areas measured on the camel relief, and that the grooves are thus of a similar age. Our evidence therefore shows that re-engraving and interaction with the reliefs appears to have been practised shortly after their completion (Panels 1 and 3) as well as once erosion was more advanced (Panel 2). Re-working thus appears to have been an integral part of the life of the reliefs, and suggests that they retained their symbolic function over long time periods. Our analyses cannot identify why grooves were only found on two panels and it is possible that this practise was reserved for specific panels, or that the practise belongs to an earlier period of use at the site and was later abandoned in favour of other interactions with the reliefs. Nevertheless, to enable these long-term interactions, the reliefs must have retained their original form and general aesthetic for a prolonged period of time – a conclusion that requires particular emphasis given the current state of extremely advanced erosion at the site.

Our analyses of the weathering and erosion patterns visible at the Camel Site are consistent with this interpretation. Although the sandstone appears to be extremely soft today, especially after rainfall, the formation of varnish and the resulting case hardening protected the rock surfaces for a substantial period. In fact, in two of the panels (Panels 3 and 4) case hardening is all that remains, with the original rock hollowed out to the extent that all that survives is the external layer, with a thickness of ca. 10 cm, which contains the original carving. Consequently, the extreme damage from erosion is likely to have been a more recent phenomenon that accelerated once the case-hardened rock surfaces began to be breached by wind erosion. This proposed timing of gradual destruction of the site by erosion is supported by evidence from OSL dating of a fallen boulder fragment that forms part of the cluster containing Panel 5/6/7. Sample 1 provided a minimum age of 3000 BP and likely belongs to one of the first panel fragments that collapsed and fell. The extreme deterioration and fall of the panels therefore likely began during the Late Holocene and may have been accelerated by Holocene climatic changes and the onset of desert conditions in the region. A more detailed investigation of the environmental drivers of sandstone deterioration at the site is now needed to answer these questions. Although the OSL age estimate obtained from Panel 5/6/7 can only provide a minimum age for the reliefs, it is evident that the creation of the panel must have occurred considerably earlier, to allow sufficient time for its erosion and consequent fall.

The pXRF analysis of the rock varnish suggests that the carved surfaces on Panel 1 (where varnish preservation is best) may be up to 8.1 ± 3.2 ka old. The measurements from the ear of the equid on Panel 2 provided slightly younger age estimates with 6.9 ± 2.7 ka using D_{Mn} and 7.3 ± 2.9 using N_{Mn}. The measurements, varnish accumulation rates and age estimates obtained from both panels are consistent with similar studies at Kilwa, Jubbah and Shuwaymis (Macholdt et al., 2018; Andreae et al., 2020) and are also confirmed in measurements from younger, datable engravings in the vicinity of the Camel Site, which included North Arabian Scripts as well as a carved Arabic date. Overall, the results of the pXRF analysis clearly indicate a Neolithic age for the camel and equid reliefs in Panels 1 and 2. Given the advanced erosion evident at the Camel Site, it is likely that the measured surfaces have lost some of their original varnish, and the pXRF measurements may therefore represent minimum ages. Panels 2 was thus likely carved before the late 6th millennium BCE. These results correlate well with the radiocarbon dates and the lithic assemblage obtained from a test trench, both of which place the main period of occupation in the Neolithic period. However, the possibility remains that some of the panels with more advanced erosion were carved at an earlier or perhaps also a later date.

The preliminary interpretation of the lithic analysis from the stone tools found on the few intact areas of the Camel Site's surface, coupled with the radiocarbon ages and stratified lithic artefacts, provide an insight to the prehistoric human occupation of this emblematic site. The less weathered and relatively homogenous assemblages of cores, flakes, endscrapers and blades with lateral retouch and truncated distal terminations found at scatters #33 and #34 are unlike the assemblage excavated from the test trench. The former are larger and show a lamellar habitus, while the stratified lithics show a low incidence of this type of technology. Due to similar raw material and weathering patterns, an association of the lithics from scatters #33 and #34 with the bidirectional industry from DAJ-112 and DAJ-125 and an approximate age of 8000 to 6500 BCE is suggested. Comparable endscrapers, blades and other possibly Early Holocene artefacts from the area surrounding the panels with the camel reliefs are missing. The endscrapers found at #33 and #34 show no signs of being used in engraving activities. Material from surface lithic scatters found to the southwest of the site are likely considerably younger based on the primarily flake-oriented technology, the ad-hoc morphology of the retouched pieces and lack of diagnostic projectiles. Radiocarbon ages and lithics obtained from the test excavation (Trench 1), are indicative of a six millennium BCE occupation, with a homogeneous lithic assemblage that directly relates to the Jordanian and southern Levantine Late Neolithic.

The bulk of the lithic material secured at the Camel site can be typologically associated with the Late Neolithic period. Although neither the Neolithic occupation identified in Trench 1, nor the lithics from surface scatters can be associated with the reliefs with certainty, they nevertheless identify the main periods of activity at the site. However, it remains uncertain whether these activities related to the initial carving of the reliefs or a subsequent phase of interaction with the site, that is documented in the grooves and re-shaping of some reliefs. A Neolithic occupation of the site is also congruent with pXRF analysis of the rock varnish and the fact that the reliefs have been shown to be part of a wider Neolithic rock art tradition (Charloux et al., 2020). Crucially, no pottery fragments or other evidence for a later occupation of the site have been discovered despite intensive surveys. Given that Middle Palaeolithic cores have survived in surface scatters at the Camel Site we suppose that this absence of evidence of later periods is likely an evidence of absence.

5. Conclusion

Despite the well-known difficulty in dating engraved rock art (Macholdt et al., 2018 and references therein), the combined evidence from an analysis of weathering and erosion patterns, surviving tool marks, pXRF analysis of rock varnish, OSL dating of fallen fragments, and the main period of occupation documented in lithic assemblages and in the radiocarbon ages obtained in a test trench all suggest a Neolithic age for the reliefs at the Camel Site and it is likely that some, if not all of the reliefs had been carved by the late 6th millennium BCE. This supports an earlier assessment based on stylistic comparison with and stratigraphic sequences within the LNEC tradition. The Camel Site reliefs are thus likely the oldest preserved large-scale animal reliefs known in the world.

Based on this chronological assessment and our reconstruction of taphonomic processes at the site we can now estimate that the panels at the Camel Site probably began to fall some 4–5000 years after their initial creation and presumably several millennia after use of the site had stopped (depending on how long the original use of the site, and interaction with reliefs in the form of re-engraving and re-shaping continued). It is likely that the reliefs retained their original form and aesthetic for a substantial proportion of this time. By 1000 BCE the condition of the site had deteriorated substantially, and the first panels began to fall. This acceleration of erosion may have been driven by environmental factors and continues until today.

Author contributions

M.G., G.C. and A.M.A. directed the research project in the field. M.G. and G.C. designed the research strategy and M.G. wrote the manuscript with contributions from G.C. and A.M.A. Specialist research contributions were provided by R.C. and Y.H.H. (lithics and excavation), M.O.A. and A.A. (rock varnish analysis), F.P. (OSL dating), F.D. (analysis of erosion and conservation strategy), F.B. (stone masonry and tool marks), P.F. (heritage management), P.M. (photography and 3D modelling), A. AQ. and Y.AA. (technical and logistic support in the field). All authors collected data in the field and contributed to data interpretation.

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Appendix A. Supplementary data

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