Middle Palaeolithic raw material procurement and early stage reduction at Jubbah, Saudi Arabia

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Abstract

Several hundred Middle Palaeolithic (MP) archaeological sites have now been identified in the Arabian Peninsula. However, the study of lithic raw material properties and related procurement behaviours is still in its infancy. Here we describe raw material procurement and early stage lithic reduction at MP sites in the Jubbah palaeolake basin, in the Nefud Desert, northern Saudi Arabia. We describe the sites identified during our surveys, and we use petrographic studies to demonstrate that MP assemblages were mostly produced from differing forms of ferruginous quartzite. These raw materials do not substantially vary in composition, although they are not identical in terms of factors such as grain size and the proportion of iron oxide. We then describe the lithic technology at these sites, with a particular focus on the largest assemblage identified, Jebel Katefeh-12 (JKF-12), which provides detailed information on lithic reduction at a quartzite source. Analyses from this site are then considered together with data from other MP sites in the Jubbah basin, where similar raw material was used. The results indicate that factors such as initial clast size/shape and reduction intensity play important roles in influencing aspects of morphological and technological variability. Our results suggest that incursions of MP populations into northern Arabia were probably temporally limited, as might be expected in a marginal and generally arid region. MP raw material procurement sites provide a highly visible signal of these ephemeral incursions, providing information on the ways that human populations adapted to the challenging conditions of the Saharo-Arabian arid belt.

1. Introduction

Archaeologists have paid considerable attention to lithic raw material procurement, stone tool reduction, and landscape behaviours (e.g. Andrefsky 2005; Doronicheva et al., 2016; Ekshtain et al., 2016; Ferris, 2015; Garvey, 2015; Odell, 2000; Will and Mackay, 2016). Raw material availability and quality, as well as clast shape and size play important roles in the technological and organisational strategies of hunter-gatherer populations. Relatively little research on this topic has been conducted on Middle Palaeolithic (MP) sites in much of southwest Asia.

In part this reflects a focus on cave and rockshelter sites, which often preserve dateable Pleistocene sediments, but also reflects the influence of the notion of 'embedded procurement' (Binford, 1979), which suggests that raw material procurement was essentially subsumed within other subsistence activities (see also Brantingham, 2003). However, the idea of 'embedded procurement', was developed from the ethnographic study of sledge and metal tool using groups and therefore caution must be exercised when applying it to MP populations. Indeed, raw material procurement can be an energetically costly activity (e.g. Kuhn, 1995; Amick, 2007; Wilson, 2007) and the uneven distribution of raw material resources led hominins to develop specific provisioning systems (e.g. Kelly, 1988; Kuhn, 1995; Mackay et al., 2014; Wilson and Brown, 2014). Therefore, Binford's (1979, 259) argument that logical foragers would not make "express and exclusive" trips to raw material sources aside from exceptional circumstances, because there are "few or no direct costs" of procurement, must be evaluated in light of the evidence that raw material procurement can actually be extremely costly. Similarly, the record of areas such as Southwest France, where high quality chert is widely available, has led to the notion that MP hominins rarely transported lithic materials for long distances. Such conclusions are questioned by findings of regular long distance transport in areas such as East Africa (Negash et al., 2011) and the Caucasus (Doronicheva and Shackley, 2014).

Cave and rockshelter excavations in Southwest Asia have produced important behavioural findings, but offer only partial insights into spatially and technically fragmented and complex lithic reduction processes and mobility strategies. It has been argued, for instance, that many Levantine MP sites represent the provisioning of places (*sensu* Kuhn, 1995; e.g. Hovers, 2009; Hovers and Belfer-Cohen, 2013). Along with factors such as high levels of reduction intensity in many caves and rockshelters, it is clear that factors such as provisioning of places will have important consequences for the technological character of those assemblages. It is therefore necessary to understand behaviour at a landscape level, and particularly to integrate data from raw material procurement localities where the early stages of lithic reduction were conducted. Such sites may lack the stratigraphic integrity of caves and rockshelters, but provide a key and often overlooked element of lithic technology and human behaviour.

Sites in Egypt and Sudan show raw material extraction extending back to the Acheulean (Vermeersch and Paulissen, 1997). MP raw material extraction from pits is documented at sites such as Arkin 5 (Chmielewski, 1968), where a series of artificial pits, each around 3.5 metres in diameter, are interpreted as evidence for 'mining' ferruginous quartzite/ferricrete sandstone. In one case it appears that a wall had been strengthened with slabs of stone. A number of other sites along the Nile demonstrate the quarrying of raw materials such as ferruginous quartzite (e.g. Marks, 1968). Several sites show hominin procurement of chert cobbles by often extensive ancient excavations (e.g. Otte et al., 2002). It is estimated that the total area exploited by MP hominins to access sub-surface raw materials at the Egyptian sites of Nazlet Safaha and Taramsa I is around 10,000m^3, producing millions of chert cobbles (Van Peer, 1998). At Taramsa a series of occupations associated with raw material procurement cover more than 100,000 years (Van Peer et al., 2010). Phase IV (~60-55 thousand years ago [henceforth ka]) at Taramsa is characterised by an intensification of raw material procurement, perhaps reflecting population concentration close to the Nile in an otherwise arid region. The lithic technology is characterised by the 'Taramsan' core reduction method, the steeper lateral preparation of which allows more continuous, and therefore perhaps less wasteful, production compared to Levallois reduction. The Taramsan, which has been described as transitional to the Upper Palaeolithic (Van Peer et al., 2010, p. 234), demonstrates the interacting influences of demography, mobility strategies, technology, and raw material factors.

In the Levant the best understood localities are occupations in caves and rockshelters, in contrast to open-air procurement and early stage reduction sites. The chronology of the latter is currently problematic, but the presence of handaxes and Levallois technologies suggests that they date to the Acheulean and Middle Palaeolithic, as well as being used more recently (Finkel et al., 2016). In the case of Mt. Pua there are around 1500 tailing piles, some over fifteen meters across and three meters in height (Gopher and Barkai, 2014). In contrast to traditional views where hominins simply embedded raw material procurement within subsistence activities, and hence left the landscapes in which they lived almost unaltered, localities such as Mt. Pua and others such as Sede Ilan indicate a much more intensive approach to raw material procurement (see e.g. Barkai and Gopher, 2009; Barkai et al., 2006). Test excavations at these localities demonstrate that a variety of tools, such as basalt and limestone wedges, were imported to the sites from elsewhere as part of organised, long term quarrying activities, creating 'industrial areas' and extensive modification of the landscape. The tailing piles were deliberately positioned so as to not impede future extractions. For example, at Sede Ilan some of the highest quality chert in the landscape occurs in the bedrock. Here exhausted extraction fronts were backfilled, seemingly to stabilize the walls and allow continued and future extraction. Reduction to produce handaxes and Levallois flakes was conducted on top of the tailing piles. Piles of limestone, lacking the flint and basalt in the main activity zones, may even represent topographic/stratigraphic markers placed during an early phase of site use (Barkai et al., 2006), suggesting that the early hominins had a good understanding of the geology and landscape. The discovery of two lithic 'caches' has even been claimed to indicate symbolic behaviours associated with raw material procurement behaviours (see Barkai and Gopher, 2011 for details). Elsewhere in the Levant, studies of the cosmogenic beryllium isotope ^{10}Be have suggested that by the late Middle Pleistocene some raw material was being acquired from deeply buried sources (Boaretto et al., 2009).

The above data indicate that by the MP a variety of methods of extraction were being used, including energetically costly extraction of raw material from sediments and, to a lesser extent, from bedrock. Aside from offering insights into hominin behaviour (technology, forward planning, etc.), it can be argued that evidence for the intensity of raw material procurement and lithic reduction provide an approximate (relative) indicator of demography. This takes the form of both the number of lithics on a landscape (e.g. Foley and Mirazón-Lahr, 2015) and of energetically expensive procurement behaviours indicating pressure on resources. Given the importance of considering raw material procurement, an aim here is to examine the MP of Arabia, analysing how raw material was accessed and its implications concerning mobility strategies and technological variation. Here we will place particular attention on recent research conducted in the Jubbah Oasis, in the Nefud Desert of Saudi Arabia.

2. Background

2.1 Raw material procurement and the Middle Palaeolithic of Arabia

The majority of identified MP sites in Arabia are located directly on, or close to raw material sources (e.g. Groucutt and Petraglia, 2012; Delagnes et al., 2012; Usik et al., 2013). This, together with analyses of their technology, indicates that most of these sites can be described as raw material procurement localities where early stage lithic reduction was carried out. Consequently, understanding technological variation in Arabia is dependent on understanding the different characteristics of raw material sources, and how these relate to factors such as mobility strategies.

In Yemen, 94% of the raw material used at Shi'bat Dihya 1 (SD-1) consists of locally procured rhyolite that was abundantly available both on the surface and in alluvial deposits proximal to the site (Delagnes et al, 2012). The rhyolite was acquired in the form of cobbles of desirable morphologies, which consequently required little in the way of preparation of convexities to produce blades and pointed flakes. Clasts of these suitable morphologies were particularly abundant where steep tributaries joined the main wadi, in contrast to more rounded morphologies elsewhere. Delagnes et al. (2012) discuss the relationship between the limited preparation of striking platforms and the physical properties of rhyolite as a raw material. Their knapping experiments show that the rhyolite has reasonable properties of conchoidal fracture, but it needs to be struck very forcibly, which they suggest may explain the lack of faceting at SD-1. Likewise, the abundance of raw material may explain the short production sequences, with little evidence for the re-preparation of debitage surface convexity or platform surfaces. Perhaps at least in part as a result of these raw material factors, the site of SD-1 is unlike other known assemblages either in Arabia or in surrounding regions.

Further east, chert is abundant in many areas of Yemen and Oman. Crassard (2008), for instance, describes numerous sites associated with high quality chert sources in Hadramawt. Crassard (2009) correlates this with aspects of the technology observed, namely the rarity of recurrent Levallois methods and the dominance of preferential methods, which he sees as reflecting the intimate proximity of workshop sites to high quality raw material sources. In Oman, abundant chert sources are associated with hundreds of MP sites (Usik et al., 2013). The highest quality chert in Dhofar occurs as large slabs in the Mudayy member (Usik et al., 2013). The highest identified density of MP sites occurs around the village of Mudayy, where fluvial and aeolian erosion led to the repeated exposure of fresh chert. This has led to the presence of several sites preserving a 'lateral stratigraphy' reflecting the repeated use of fresh chert by hominins, with the older material extending further away from the current exposures (Usik et al., 2013). Similar situations have been described elsewhere, with the inselbergs of Nubia for instance (Guichard and Guichard, 1965). However, in the Nubian case, the steep slopes of the inselbergs lead to complex situations where much of the earlier material is concealed beneath colluvial sediments and rockfalls. In the Huqf region of Oman, chert is abundant and associated with Palaeolithic raw material procurement and early stage reduction, although the chronology and cultural affiliations of such assemblages are currently unclear. In many cases these are vast sites, and while not definitively MP give an indication of the density of Palaeolithic occupations in certain areas. Jagher et al., (2011) describe an example of a site (no. 318) that covers an area of around 800,000 m^2 with an average density of 300-400 lithics per square metre (or around 280 million lithics in total).

In the United Arab Emirates, identified MP sites are also typically associated with chert sources. Scott-Jackson and colleagues (2009) describe a series of hill top MP sites associated with raw material procurement and early stage reduction, as do Wahida et al. (2009) for the Jebel Barakah sites. Jebel Faya contains abundant local chert, which Marks (2009, p. 305) links to the "significant workshop component" of the MP assemblages at the Jebel Faya (FAY-NE1) site.

In Saudi Arabia, the Comprehensive Survey of the Kingdom beginning in the 1970s found that MP sites were frequently associated with raw material sources (see Petraglia and Alsharekh, 2003; Groucutt and Petraglia, 2012). This has been confirmed by more recent research (Groucutt et al., 2015a). For example, sites near Al Kharj have been found to be associated with sandstone and quartzite outcrops (Crassard and Hilbert, 2013). At Jubbah, MP sites were initially identified in association with quartzite sources on Jebel Umm Sanman (Garrard et al., 1981). Several seasons of recent fieldwork, the latter under the aegis of the Palaeodeserts Project, were conducted at Jubbah in the Nefud Desert of northern Saudi Arabia between 2010 and 2013. These resulted in the discovery of a number of MP sites (Petraglia et al., 2011; 2012; Groucutt et al., 2015b). Our initial attention focussed on the excavation of the MP sites of Jebel Qatar-1 (JQ-1), Jebel Umm Sanman-1 (JSM-1), and Jebel Katefeh-1 (JKF-1). Work at other sites, such as Jebel Katefeh-12 (JKF-12) consisted of collecting a small sample of artefacts (Groucutt et al., 2015b). Scerri et al. (2014a) included JSM-1, JKF-1 and a sample of the JKF-12 material in a comparative analysis of MP technology. This research makes Jubbah a uniquely important area in Arabia, containing almost half of the excavated Pleistocene sites of the peninsula. The position of Jubbah, as an oasis with lithic raw materials, as well as floral and faunal resources, also makes a good case study, as such resources, at least in the case of raw material, appear to be scarce for dozens of kilometres from Jubbah in every direction owing to the presence of a large sand sea.

Given these observations it is somewhat problematic that most research on the MP of Arabia has focussed on techno-typological comparisons with surrounding regions in order to address population dispersals, with little consideration of the influence of raw material factors. The importance of considering the influence of raw materials is confirmed by the characteristics of recently identified sites that are located further from raw material sources. In the case of Mundafan Al Buhayrah, in the Empty Quarter, chert appears to have been imported from several kilometres away, and the assemblage features high levels of recurrent Levallois reduction and high frequencies of retouch compared to other Arabian assemblages (Groucutt et al., 2015c). In Dhofar, TH-69 is about 1 km from the nearest raw material source, in contrast to almost all other identified sites (Usik et al., 2013), and the assemblage features smaller and more heavily reduced lithics than similar sites, and has the highest percentage (>90%) of beaked (or 'Nubian') Levallois cores of any reported site in the region. These observations suggest that more concerted research is needed to understand relationships between raw materials, technological variation and mobility strategies.

2.2 The geology of the Jubbah Basin

In broad terms the Arabian Peninsula can be divided into a western area consisting of a Precambrian basement (the Arabian shield) and an eastern area of Mesozoic and younger geology (the Arabian shelf). Between these zones there exists a relatively narrow exposure of Palaeozoic rocks, extending primarily north-south for the length of Saudi Arabia (see e.g. Bassis et al., 2016). The Jubbah area is situated with this Palaeozoic sequence. The geology of the Jubbah area was mapped (at 1:250,000 scale) and described by Ekren and colleagues (1986).

The study area is located just north of the transition from the Proterozoic Arabian shield, characterised by igneous rocks, to the Palaeozoic succession as seen at Jubbah and elsewhere in the southern Nefud desert, primarily consisting of sandstone. The Palaeozoic sequence appears to have begun during the transition from the Proterozoic to the Cambrian (the Yatib Formation), overlain by the Risha and Sajir members of the Cambrian/early Ordovician Saq sandstone. The younger part of the sequence consists of the Qasim formation, itself featuring several subdivisions and extending into the late Ordovician, and finally the Sarah formation which dates to the terminal Ordovician/early Silurian period. This long accumulation reflects changing conditions from fluviatile to marine for the Saq sandstone, through to late Ordovician glacial advance leading to the deposition of tillite and related rocks in the Sarah formation. The latest views on this sequence are given by Bassis and colleagues (2016).

The sand sea of the Nefud desert today covers most of the area, with the Palaeozoic succession visible in the form of isolated eminences (jebels), such as those at Jubbah. The sandstone at Jubbah belongs to the upper part of the Sajir member of the Saq sandstone, capped by the Qasim and Sarah formations atop Jebel Umm Sanman. Ekren et al. (1986) describe the upper part of the Sajir member as being impregnated in places by siliceous and ferruginous cement, of meteoric origin and probably forming during several periods between the Cretaceous and the Quaternary. The ferruginous aspect is particular clear, and reflects the movement of iron rich waters into the sandstone. The result are beds of white to beige sandstone alternating with occasional ferruginised horizons (see for example figure 6). These ferruginised horizons, which have also been described as quartzites owing to their modified state, were the main source of lithic raw material for hominins at Jubbah, but have not previously been described in detail. They could also be termed ferruginous/ferrocrete sandstone, quartzitic ironstone, or quartzitic sandstone, but are referred to hereafter simply as (ferruginous) quartzites. These often occur at transitions within and between beds, such as at the top of the Saq formation, as seen on Jebel Umm Sanman (figure 3). The raw material source at JSM-1, described below, also reflects cementation of sediments, but in this case of a non-ferruginous form. Finally, occasional conglomeritic beds occur within the Palaeozoic sequence. At Jubbah these are predominantly characterised by small quartz pebbles, as seen around Jebel Qattar and just below JKF-12, but those of the Sarah formation at the top of Jebel Umm Sanman also contain other lithologies of basement (igneous) rock.

3 Materials and methods

3.1 Field methods

Fieldwork for the present study consisted of pedestrian surveys to identify MP sites and clarify raw material availability across the Jubbah Basin. Surveys between 2010 and 2013 crossed all of the major jebels (rock eminences) at Jubbah (the term being used here to cover the main Jubbah basin and immediately adjacent basins to the southwest). At the identified sites an initial analysis of the lithics was conducted, focussing on determining the core reduction methods employed; samples were collected for more detailed technological and petrographic analysis, as described below. At JKF-12, the largest raw material procurement and early stage reduction site identified, a systematic collection of lithics was collected in 2013 from a 4 x 4 metre grid square and from a shallow excavation in part of the square, to collect a complete and representative sample. The systematic collection at JKF-12 was supplemented by the collection of additional cores and other particularly technologically informative pieces from within fifteen metres of the grid square.

3.2 Lithic analysis methods

The collected samples were subsequently analysed in detail to describe a series of morphological and technological features, following the definitions and approaches outlined elsewhere (Scerri et al., 2014a,b; Groucutt et al., 2015b, c). Selected examples were chosen for illustration and photography. Analyses combined qualitative and quantitative approaches, with the former focussing on factors such as the recording of the direction and chronology of scars, and the latter on the recording a variety of measurements and attribute states as defined in the above references. These measures allow us to describe the lithic assemblages identified, while we use measures such as Scar Density Index measures, following Clarkson (2013), to bring a quantitative aspect to comparisons between the assemblages.

3.3 Geological description methods

Geological observations were made during the pedestrian surveys, along with inspection of available geological maps and their accompanying descriptions. To understand raw material properties in more detail, samples of the materials used for lithic reduction were selected for petrographic description and analysis from the most important raw material procurement sites discovered. Samples were selected to be as representative as possible of the material used at each site, with petrographic analysis aiming to describe in detail the characteristics of each sample. Petrographic thin sections were prepared following standard protocols at the Department of Earth Sciences, University of Oxford where they were also subsequently analysed.

The thin sections were examined with a Nikon Optiphot Pol geological microscope using a ×4 objective lens. The slides were inspected under both plane and cross-polarized light. Photomicrographs were made using a Qimaging QICAM Fast 1394 digital camera. Quartz is identified under the microscope as colourless (analyser out), low relief, low order interference colours, with occasional fluid inclusion trails, showing either straight or strained extinction. Muscovite is recognised as a colourless mineral with a single cleavage, moderate relief and high order interference colours, showing straight extinction under crossed polarized light. Zircon is distinguished as a high relief mineral with high order interference colours and exhibits a well-rounded shape in sedimentary rocks. Calcite in thin section is typically colourless but turbid showing two intersecting cleavages and high order interference colours. Amphiboles are greenish and pleiochroic in colour, with two cleavages, high relief and moderate interference colours.

4. Results

Survey results were obtained from four areas in the Jubbah basin (figure 1). These are described below where for each area we outline in turn the characteristics of the site, the analysis of geological samples collected and finally the analysis of lithic artefacts collected.

4.1 Jebel Ghawtar

Jebel Ghawtar is a large jebel, with small subsidiary eminences in the dunes to the south. The jebel covers an area of ~1.6 km north to south and 1.3 km east to west, with a maximum altitude of 1082 m above sea level. This margins of Jebel Ghawtar were systematically surveyed over several days by a large team and on top of the jebel, transects were employed. While a large number of Holocene archaeological sites (particularly rock art) were identified, only two or three possible MP flakes were recognised, probably related to the fact that suitable quartzite raw material appears to be sparse or absent at this end of the Jubbah basin.

figure 1 hereabouts

4.2 Jebel Qattar

Jebel Qattar is small, measuring 0.5 x 0.4 km, with a maximum altitude of 907 m. Surveys conducted along its margins resulted in the discovery of the site of Jebel Qattar-1 (JQ-1). Two MP assemblages were identified at JQ-1, one dating to ~ 75 ka and the other to at least ~211 ka (Petraglia et al., 2011; 2012). Here we report a survey for raw material in the environs of the site. The survey of Jebel Qattar and neighbouring small jebels revealed a paucity of suitable raw materials. Small quartz pebbles can be found in the area, present both as pebbles within the bedrock and eroded onto the surface. In some cases *in situ* quartz pebbles in bedrock bear evidence of having been struck. This quartz material was, however, rarely used by the MP knappers of JQ-1.

Four extremely small beds of quartzite were identified around the southeastern corner of Jebel Qattar, for example at JQ-D (28.1039 N, 41.0642 E) shown in figure 2. Two of these, labelled JQ-A (figure 2c) and JQ-B, consist of low quality quarztitic sandstone. At the base of these seams, an abundance of weathered material was observed, but these clasts are small in size owing to their natural facture, which along with the coarseness of the rock makes it of low suitability for lithic manufacture. JQ-D (figure 2D) and JQ-E are horizontally bedded, and more ferruginous. Both are thin (~3-4 cm), but are of relatively high quality. Both of these beds appear to have been knapped directly, but no lithic artefacts were identified adjacent to them, indicating that these extremely small sources were not utilised to any great extent. It may just be that a single flake was struck from them. Therefore, while it is possible that some of the quartzite used at JQ-1 came from JQ-D and JQ-E, the small size of these sources and lack of lithics around them suggests that the raw material may have been brought into the area from the sources in the western part of Jubbah described below. Neighbouring jebels to the south revealed evidence for small quartz pebbles within and below bedrock, but no quartzite of suitable quality for knapping was identified.

Because no unmodified clasts were found at JQ-1 no thin sections were made, as this would have involved destruction of artefacts. However, visual inspection indicates that the dominant raw material at JQ-1 consists of relatively fine grained and highly ferruginous quartzite, similar to that found at the sites to the west and southwest of Jubbah described below.

figure 2 hereabouts

4.3 Jebel Umm Sanman

Jebel Umm Sanman is by far the largest jebel in the Jubbah area, measuring ~7 km x 3 km and with a maximum altitude of 1264 m, towering over the town of Jubbah and with the main basin in its lee. Three key raw material procurement and early stage reduction localities atop and on the margins of Jebel Umm Sanman were identified; JSM-1, JSM-15 and JSM-18, as well as several smaller scatters. JSM-1 consists of a MP assemblage from both surface and subsurface contexts, adjacent to a distinctive seam of raw material (described below), which was used for the manufacture of almost all of the lithic artefacts at the site (Petraglia et al., 2012). This is the only location in the Jubbah area where this particular raw material has been recognised in a bedrock context.

figure 3 hereabouts

Survey atop Jebel Umm Sanman identified six MP sites: JSM-11 (28.003 N, 40.912 E), JSM-12 (28.003 N, 40.916 E), JSM-14 (27.999 N, 40.915 E), JSM-15 (27.996 N, 40.915 E), JSM-17 (27.9974 N, 40.9163 E) and JSM-18 (27.998 N, 40.918 E). Quartzite raw material present at these sites occurred as largely horizontal exposures, weathering into clasts of various sizes. JSM-15 (fig. 3) and JSM-18 are the largest sites identified on this jebel, with the others representing small scatters. JSM-15 is a moderate density MP assemblage, spread across two quartzite terraces with the lower (more southerly) terrace having more artefacts. JSM-18 is a denser MP raw procurement and early stage reduction site at the head of a small wadi (valley) on the eastern side of the plateau, overlooking the town of Jubbah. There is about 20-30 cm of sandy sediment underlying the surface of JSM-18, perhaps indicating the potential for buried and dateable lithics at such localities. In general, the lithics from the Jebel Umm Sanman plateau are in a fresh condition.

4.3.1. Jebel Umm Sanman geological samples

Two samples from JSM-1 (figure 6A,B) reflect sandstone/quartzite-like rock formed by the cementation of sediment in a fissure. The first (figure 4A) is a banded and millimetre-laminated, grey sediment which can be described as an argillaceous sandstone/quartzite. It is very poorly sorted with the grain size ranging from clay or very fine silt to coarse sand. The mineralogy is almost exclusively quartz with a rare green pleochroic amphibole. Some layers have little clay sized fraction and range from very fine silt to coarse sand. The sand grains are rounded to angular. The laminations suggest that at times the fissure in which the rock formed must have been water filled and the sediment a combination of slurried detritus, infilling from the fissure wall and windblown sand. The second sample (figure 4B) is a very poorly sorted milky white argillaceous sandstone/quartzite, ranging in grain size from clay to very coarse sand and composed predominantly of rounded to angular quartz grains some having silica overgrowths. No sedimentary structures are visible in the sample.

Three samples of quartzite from JSM-15 and JSM-18, located atop Jebel Umm Sanman, were analysed. The sample from JSM-18 (figures 4C,D) is weakly laminated on a centimetre to millimetre scale and varies from a moderately to poorly sorted, fine grained, very iron rich, brown, quartzite. The millimetre scale laminations are composed of fine to very fine sand. It has predominantly quartz (>99%) mineral grains that are angular to subrounded in cross section, occasionally spherical, but mostly oblate. Some laminations show an alignment of oblate grains. The quartz grains have a narrow fringe of siliceous cement and overgrowths, and contacts show evidence of pressure dissolution. The pore spaces between grains are filled by an iron oxide (now haematite) and the grain surface of the quartz shows some corrosive etching, now infilled by haematite. Some areas have a younger, patchy calcitic cement with occasional dolomite rhombs, and are associated with an iron oxide infilled burrow. Additionally, the specimen contains rare zircon crystals and a green pleiochroic amphibole (< 1%).

figure 4 hereabouts

The first of two samples from JSM-15 (figure 4E) is a silty ferruginous quartzite ranging in grain size from coarse silt to fine sand, although moderately well sorted. Predominantly oblate angular to subrounded quartz grains are surrounded by an iron oxide (haematitic) matrix that shows some botryoidal growths infilling pore spaces. In thin section the iron oxide shows a patchy distribution. There are occasional grain to grain contacts with pressure dissolution, although the rock is mostly matrix supported. The specimen contains about 1% authigenic muscovite, frequently in aligned laminations and curved around quartz grains. The second JSM-15 sample (figure 4F) is a very fine grained, well-sorted, brown ferruginous quartzite. Quartz grains appear as angular to subangular, oblate and elongated shards some with a local quartz overgrowth. Relict sedimentary laminations were also identified, represented by layers richer in sand grain clusters and picked out by discontinuous laminations of wavy muscovite. The specimen also contains rare pleiochroic amphibole and authigenic muscovite and biotite set into a haematitic matrix. The iron oxide is frequently intimately associated and intergrown with the mica. The matrix exhibits a microcrystalline botryoidal haematitic infilling of the pore space between the quartz grains.

4.3.2. Jebel Umm Sanman lithic technology

At JSM-18 many of the quartzite lithics are rather crudely flaked, with cores perhaps representing Levallois 'rough outs'. Other, more finely prepared, examples represent both recurrent and preferential centripetal Levallois cores, as well as discoidal cores (figure 5). It is interesting to note that even at such sites, located directly on raw material sources, small cores (Levallois and discoidal) are relatively abundant. These small cores are ca. 50 x 40 x 30 mm in size. The presence of small cores where there is abundant quartzite, including as relatively large but also highly weathered clasts, may indicate that the raw material has been thermally or otherwise damaged, so knappers focussed on reducing particular clasts with more predictable flaking. The surfaces of quartzite clasts at these sites certainly appear more weathered than at localities such as JKF-12, described below.

figure 5 hereabouts

JSM-15 features similar lithic technology to JSM-18, with a core and flake technology consisting of a mixture of centripetal Levallois cores (both preferential and recurrent) and smaller numbers of discoidal cores (figure 5). The cores at JSM-15 vary from around 85 x 80 x 40 mm for the larger examples, down to ca. 45 x 40 x 20 mm for small cores. The presence of small cores is again notable. Most cores have a cortical base and flakes were struck from faceted platforms. While JSM-15 and JSM-18 are similar in terms of technology, there are differences in terms of the character of the quartzite used, with JSM-15 being more ferruginous.

A small stone tool assemblage from JSM-1 was previously described by Petraglia and colleagues (2012). Subsequently, a much larger assemblage has been collected and excavated. This will be described in detail elsewhere. For now, it suffices to emphasise the dominant character of core reduction at the site. This is heavily centripetal Levallois, with the preferential method dominant, but with recurrent methods also being used. Most examples have a dominantly cortical lower (platform) surface. This reflects the narrow thickness of the seam from which the argillaceous sandstone/quartzite was acquired. As with other raw material procurement sites in the Jubbah area, Levallois flakes are under-represented compared to the number of Levallois cores. Similarly to other raw material procurement and early stage reduction sites at Jubbah, retouched flakes are rare at JSM-1.

4.4 Jebels southwest of the main Jubbah basin.

Several jebels, and associated basins in their lee, occur a few kilometres to the southwest of the main Jubbah basin. The largest of these, and the closest to Jubbah, is Jebel Sataihah, which measures 1.7 x 1.8 km and has a height of 1125 m. A desert pavement-like distribution of quartzite occurs from the eastern flank of Jebel Sataihah, extending for around one kilometre (figure 2 A,B). This desert pavement is truncated in places by shallow stream channels. Low density lithics are found across this surface (SAT-1). In general, those further from the jebel are of Lower Palaeolithic character and are more heavily weathered, while those closer to the jebel base are assigned to the MP and have a fresher appearance (Shipton et al., 2014). A similar, but smaller and low density MP assemblage (SAT-2) was identified to the south (27.953 N, 40.821 E). Small lithic samples were collected from these low-density sites for typological and technological characterisation. These sites are of interest as they represent the use of 'secondary' quartzite clasts, which appear to have originated from atop the jebels and then moved downslope and gathered around the base of jebels as scree-like deposits. Other sites at Jubbah are associated with 'primary' quartzite sources, in the form of beds of the material occurring as bedrock. On Jebel Dohaya (1.6 x 0.8 km, 1153m in height), the next jebel to the south, the MP site of DHY-2 (27.9446 N, 40.8117 E) was identified. The site consists of two moderately high density and spatially restricted MP knapping scatters. The quartzite used at Jebel Dohaya 2 (DHY-2) seems to represent a mix of, firstly, that similar to the Jebel Sataihah sites, consisting of moderately coarse grained dark brown/blueish quartzite, and, secondly, of more fine grained brown/reddish quartzite, similar to that found at JKF-12 to the south. The underside of most cores from DHY-2 have cortex. In some cases cortex is also retained on the upper surface of the core, showing that the raw material was sometimes relatively thin and only ca. 20 mm thick. Even the thickest cores at DHY-2 are only ca. 35 mm thick.

figure 6 hereabouts

Further south, the site of JKF-12 – the largest identified quartzite exposure in the Jubbah area – was investigated in detail. JKF-12 is located on the eastern margin of Jebel Katefeh (0.9 x 0.5 km, 1043 m in height). Extensive survey of JKF-12 revealed spatial variation across the site, both in terms of the bedrock and associated archaeology. Lithics occur at variable density across the site, with two particular concentrations of interest. The area focussed on here is JKF-12a, where the highest density of lithics is found. This is the more northern scatter, and occurs immediately beneath and downslope of an eroding quartzite bed (fig. 6). JKF-12b is at the southern end of JKF-12, where a moderate density of MP artefacts was identified. At JKF-12a, all lithics inside a 4 x 4 metre grid square were collected (figure 7A,B). While much of JKF-12a consists of clast immediately overlying bedrock, an excavation in the grid square demonstrated the presence of buried lithics, extending to a depth of ca. 40 cm in places. Additionally, quartz pebbles of both greater size and considerably greater density than seen anywhere else in the Jubbah area, were identified in bedrock in the eastern part of JKF-12 (figure 7D). It is from the erosion of such beds that a dense abundance of quartz also occurs across the basin to the east. Along with the quartzite from sources such as JKF-12, the quartz pebbles were used by the makers of the JKF-1 assemblage, located around 800 meters to the east (Petraglia et al., 2012; Groucutt et al., 2015b).

figure 7 hereabouts

4.4.1 Geological samples from Jebel Sataihah and Jebel Katefeh

Three samples of ferruginous quartzite were collected from the jebels to the southwest of the main Jubbah basin, while a quartz pebble from the site of JKF-1, of very similar morphology to those knapped on site, was sampled to provide a description of such material.

The sample from SAT-1 (figure 8A) is a medium grained, moderately well sorted, brown, iron rich quartzite. The hand specimen is massive and exhibits no sedimentary textures. It is comprised predominantly of quartz with rare green pleiochroic amphibole, zoned zircons and phosphate grains. The quartz is set in a haematitic matrix coating the grains and showing some botryoidal infilling of pore space. There is a rare, patchy, calcitic cement seen in places. A few of the quartz grains appear to be fractured *in situ* with the cracks now infilled by the iron oxide. Both samples from JKF-12 (figures 8B,C) are massive, brown, fine grained, moderately well sorted, ferruginous quartzite with subrounded to subangular sand grains, frequently fringed by a silica cement. They also contain minor biotite and muscovite and rare green pleiochroic amphibole. The iron oxide matrix is mostly haematite and contains rare patches of radiating microcrystalline silica cement that intermingles with the haematite. One sample (Figure 8C) contains a minor calcite vein.

figure 8 hereabouts

The quartz sample from JKF-1 (figure 8D) is coarse grained, milky white, vein quartz comprised of up to 4mm diameter interlocking quartz crystals. The quartz crystals contain minor mineral inclusions and some have an undulating extinction in cross polarized light. This is a post-sedimentation diagenetic feature often associated with igneous intrusions.

4.4.2 Jebel Sataihah and Jebel Dohaya lithic technology

The MP lithics from SAT-1 are manufactured on a moderately coarse textured greyish brown quartzite. Cores are predominantly centripetal Levallois, with preferential and recurrent methods approximately equally represented. Examples of discoidal cores are also present, seemingly at greater frequencies than the other sites. The cores are relatively large, mostly around 80 mm long, 70 mm wide and 35 mm thick. Most examples have faceted platforms and reserve cortex on the lower surface. A classic example of a centripetally prepared preferential Levallois core from the site is illustrated in figure 9C. One core from the site also shows a beaked or 'Nubian'-like preparation (figure 9D). In both of these cases, it should be noted that residual cortex remains on the striking platforms, indicating a lack of re-preparation and extended reduction.

At SAT-2 virtually all of the cores are Levallois in character, some grading into discoidal. The cores are mostly of recurrent centripetal Levallois character, but some may be unstruck preferential cores. Most of the cores have cortex on the lower surface. They are simply knapped, with many featuring step and hinge terminations. The lithics are made of different colours and granularities of quartzite, which appear to have been gathered at the base of the jebel. The larger cores are around 100 mm long, 75 mm wide and 30 mm thick, but several small cores are also present which average ~50 x 40 x 15 mm.

figure 9 hereabouts

The DHY-2 assemblage is dominated by Levallois cores and flakes at a fairly low density. As with the Sataihah sites, centripetally flaked recurrent and preferential Levallois cores are present in approximately equal numbers, some of the former blending into discoidal cores (figure 8). This is a feature found at several sites, and appears to reflect the difficulty of convexity management on thin clasts of quartzite. Many of the flake removals are therefore not perfectly in plane with the central plane dividing the two hemispheres, as in the strict sense of Levallois. The cores though are virtually all hierarchical, with cortex on the base with platform preparation typically extending around most of the core but not extending far onto the lower surface. The cores at DHY-2 are generally quite small, at around 75 x 60 x 20 mm. One hammerstone was collected at the site (figure 8H).

5. JKF-12 lithic technology

JKF-12 represents the densest concentration of lithic artefacts at a raw material source in the Jubbah area. The quartzite bed at the site is the thickest identified in the area. It is also significant that this bed, and clasts coming from it, is being exposed by erosion of a slope, in contrast to sources such as JSM-15 and 18 which are entirely exposed from above and form parts of flat plateaus. As a result, at JKF-12 large, angular and relatively fresh clasts are exposed, making the site an excellent raw material source for Middle Palaeolithic hominins. In order to understand reduction of the quartzite at JKF-12, a systematic collection was made. Our description focusses on JKF-12a, but we note the essentially similar technology at JKF-12b (see figure 9A,B). Firstly, we describe the results from the systematic collection square, and then the sample focussing on technologically informative pieces such as cores from the surroundings of the latter. The systematic collection from JKF-12 is particularly informative on the flake component of the assemblage, providing information on the trajectories of reduction employed, and the latter on the core forms, giving insights into the later stage of reduction.

5.1 The systematic JKF-12a collection

The systematic 4 x 4 m collection resulted in the recovery of a total of 358 flakes, 9 cores, 1 retouched flake, and one possible hammerstone. All lithics have a similar (moderate) state of weathering. All lithics from JKF-12a and its immediate surroundings are made on ferruginous quartzite, from the seam which is located ~10 metres up a gentle slope, other than the one retouched piece (a fine grained igneous material) and the possible hammerstone (quartz).

Seven of the nine cores are complete, with an average weight of 553 g (σ 486.0), but a considerable range of variation in size. The mean of the maximum linear dimension is 116.3 mm (σ 42.2). The mean angle between the dominant scar and the striking platform is 78° (σ 5.6), while the length and width respectively of the dominant/final scars are 69.1 mm and 55.3 mm (σ 37.3, 11.0). Technologically, aside from one indeterminate (broken) example, the cores belong to the following types: Levallois preform (n=1), single platform cores (n=2), and Levallois cores (n=5). The Levallois cores include both recurrent and preferential exploitation, and unidirectional convergent, bidirectional and centripetal preparation. At least two have some beaked-core characteristics, in the form of having something of a small median distal ridge. Only two of the cores have evidence for faceting, the other examples feature unprepared striking platforms. Most examples likewise feature the extensive use of natural surfaces to guide convexity. Given the small sample size of cores, we will focus our technological description on these in the following section with the enlarged sample. The systematic collection, however, is important in showing: 1) the generally large size of the cores, 2) the dominance of Levallois reduction, alongside a single platform component, and 3) the paucity of striking platform preparation, alongside a general use of natural clasts of a suitable shape.

figure 10 hereabouts

table 1 hereabouts

A basic typological division of the JKF-12a systematic collection is shown in table 1. Most of the assemblage is dominated by flakes, with slightly more than half having cortex. Débordant flakes for the control of convexity are common. In contrast to the Levallois core evidence, Levallois flakes are rare, and only four were classified as being Levallois flakes. Other flakes appear to have been struck from 'almost-Levallois' debitage surfaces (see e.g. figure 10I-K), and while appearing similar to Levallois flakes still appear to be debitage surface preparation flakes. In terms of the completeness of flakes, 62.7% are whole, 9.2% are proximal fragments, 11.7% are distal fragments, 6.1% longitudinal (lateral) fragments and 9.2% are unidentifiable fragments.

Most flakes at JKF-12 have cortex on their surface (table 2), although there was some difficulty in distinguishing cortical and non-cortical surfaces with this quartzite must be borne in mind. The figures for complete flakes are perhaps more informative, and in this regard an even smaller proportion of flakes have no cortex. The character of the distal terminations is shown in table 3, with 71.2% being feathered, indicating good flaking control over the material.

table 2 hereabouts

table 3 hereabouts

Dorsal scar patterns on flakes are widely regarded as being highly informative about reduction processes. As shown in table 4, JKF-12 flakes are dominated by 'from proximal' (unidirectional) scar patterns, with bidirectional scars also well represented. Other scar patterns are present in small frequencies, with for example only 1.9% of flakes having centripetal scar patterns. Compared to other Saharo-Arabian MP assemblages sampled, these are high levels of unidirectional flaking and low frequencies of centripetal reduction (e.g. Scerri et al., 2014b).

table 4 hereabouts

Striking platform types on JKF-12 flakes can be classified as plain (42.2%), cortical (25.3%), dihedral (10.6%) and faceted (9.5%), while 11.4% are indeterminate (due to factors such as weathering and breakage).

Table 5 summarises data on JKF-12 flake size and shape. This shows that JKF-12 flakes are typically large, weighing almost 70 g on average. The convergence values are quite low, indicating many broadly parallel sided flakes. The flattening index shows that flakes at JKF-12 are typically quite thick.

table 5 hereabouts

Finally, only a single retouched flake was found in the JKF-12a systematic collection (figure 10G). This is also the single find from the site made on non-local raw material (a fine grained igneous material). It is steeply retouched and notched along the length of both laterals and appears to have been heavily reduced.

5.2 JKF-12a surrounding sample

Given the presence of only nine cores in the systematic grid sample, a supplementary sample was made from within 15 metres of the collection square, focussed on the recovery of cores. The aim was to add specific information on the reduction methods employed and to supplement the general information derived from the debitage. The following information describes a total sample of 41 cores (39 complete), including the 9 from the systematic collection describe above. An interesting feature of JKF-12 is the presence of several very large cores. One was found just outside our collection area at JKF-12a and so not included in the descriptive statistics. Given the technological interest of such pieces, however, we describe this example of a large core in qualitative terms at the end of this section.

With respect to typology, aside from two incomplete specimens, the cores can be described as single platform cores (n=3), Levallois 'preforms' (n=4), Levallois cores (n=32) and indeterminate (n=2). The Levallois cores are almost all preferentially exploited, with a single removal made from a debitage surface shaped by unidirectional convergent, bidirectional or centripetal preparation (table 6). In summary, in terms of the margins of preferential removals from these cores, the majority of the shape is defined by the unidirectional convergent removals, but in terms of overall core geometry, the centripetal removals are also playing a role (e.g. Figure 11c). An example of a recurrent Levallois core is shown in figure 11a. In this case, centripetal preparation, and the use of natural convexity on the left lateral surface, has been followed by a series of parallel unidirectional removals from the same prepared striking platform.

figure 11 hereabouts

figure 12 hereabouts

table 5 hereabouts

table 6 hereabouts

Table 7 summarises morphological and technological data on the JKF-12 cores. The average weight of 440.1 g, but with some weighing over 1 kg, makes them heavy for the MP. JKF-12 cores are also large in their metric dimensions. The last/dominant scar indices indicate a focus on producing preferential flakes that are slightly elongated and with a trend towards convergence (i.e. point production).

table 7 hereabouts

The cores demonstrate reduction methods making extensive use of natural surfaces and convexities, reflecting the selection and use of suitably shaped clasts. For example, the striking platform angle on unprepared striking platforms (n=12, mean 74.1°) is almost the same as that on facetted striking platforms (n=26, mean 76.9°). Many of the cores also feature the retention of natural surfaces giving suitable convexity on the debitage surface. Features such as the latter, and the large size of the cores, indicate the lack of intensive reduction and re-preparation. The impression from the cores is that reduction processes were relatively short-term, and focussed on producing perhaps a single, often convergently shaped, preferential flake.

table 8 hereabouts

table 9 hereabouts

The lack of intensive reduction at JKF-12 means that the assemblage provides information on the early stage of reduction. In contrast, at many other sites the morpho-technological aspects in part reflect reduction intensity (e.g. Groucutt et al., 2015b). An interesting feature of the JKF-12 cores is the combination of unidirectional-convergent preparation of lateral convexities with additional attention given to the distal end of the core (figures 11 and 12). In some cases the latter approaches the formation of a median-distal ridge, the characteristic feature of 'Nubian' technology (e.g. Usik et al., 2013), which can also, following Seligman's (1921) original description be described as 'beaked' Levallois (Groucutt et al., 2015a). The beak refers to the median distal ridge that is the prominent and defining feature of this technology. While lacking median distal ridges as sharply defined as those in areas with highly quality chert available, 14 of the JKF-12 cores feature some form of median distal ridge. Of these, the angle of the ridge is on average 91° (σ 25.6, range 40-125) and the thickness of the ridge a mean of 26.5 mm (σ 8.2). There may well be a size factor stimulating knappers to produce median distal ridges, with it perhaps hard to produce pointed flakes solely by unidirectional-Levallois preparation on large cores of this raw material. Some examples show the formation of a median distal ridge on an otherwise single platform core with natural lateral convexities (figure 10a). In other cases, where dorsal surface preparation is primarily unidirectional convergent, a supplementary removal from the distal creates a less sharply defined median distal ridge (e.g. figure 11C).

Alongside the numerically dominant forms of cores described above, an important feature is the presence of extremely large (for the MP) cores at JKF-12. These are of different forms, with some being Levallois-like, while the example shown in figure 13 representing a non-Levallois approach to reduction. In this example, there are distinct platform and debitage surfaces, and a series of large flakes have been removed from the debitage surface at a relatively steep angle. This example shows that a large number of well-shaped flakes were produced using a non-Levallois method, and there were no major knapping errors. There is considerable mass left in this core that has not been used, consistent with the abundance of raw material at the site.

5.3 Summary of the reduction process at JKF-12

The above data suggest the use of four main core reduction methods:

1. The reduction of single platform cores (e.g. figure 10C). These have steep margins and produced elongated and somewhat pointed flakes (e.g. figure 10D,E).
2. The reduction of cores morphologically similar to Levallois cores, but with considerable use of natural convexities and striking platforms (e.g. figure 10A; producing debitage like figure 9B). Preparatory knapping was done in specific places to aid convexity, such as beaked-core like preparation (figure 10A).
3. The reduction of genuinely Levallois cores (figures 11 and 12), with faceted platforms, and a variety of patterns of dorsal surface preparation – but generally a focus on unidirectional-convergent preparation with supplementary lateral and distal removals – to produce quite varied end products, but with many having a broadly pointed shape.
4. The reduction of very large cores, these are 'Levallois-like' to varying levels. The example shown in figure 13 shows a highly productive reduction, by a non-Levallois method. The extremely large débordant flake (figure 10F) shows convexity management on a large core surface.

The similar patterns of weathering associated with the cores and products of these reduction systems likely indicates a limited temporal span of the material. It is unclear to what extent the different reduction 'methods' described above represent different phases of reduction intensity, with single platform cores representing an earlier phase of reduction to Levallois cores. We hypothesise that both differential reduction intensity and deliberately different methods explain the variation.

Figure 13 hereabouts

6. Middle Palaeolithic variability in the Jubbah Basin

The identification of a number of MP sites in the Jubbah area provides an opportunity to make inter-assemblage comparisons between raw material procurement sites and other 'types' of sites in the vicinity. For instance, comparisons can be made between JKF-12 (at raw material source, low reduction intensity), JKF-1 (~800 meters in a straight line to raw material source, moderate reduction intensity), and JQ-1 (seemingly >15 km to significant raw material sources, no major local raw material sources identified, heavily reduced).

table 10 here

table 11 here

A variety of measures indicate that morphological and technological features change in tandem with the distance from the raw material sources and increased reduction intensity. Variables reflecting such correlation include the frequency of cortical cover (table 8) and various aspects of size and shape. These consistent patterns show that lithics further from the raw material sources tend to be smaller, and more intensively flaked. There is, however, more variation in terms of shape indices such as convergence and platform flattening. If the main source for JQ-1 quartzite was local we would expect high levels of cortex, while if imported then reduced levels of cortex would be expected. As shown in table 8, cortical cover is low at JQ-1, consistent with our 'mobility hypothesis'.

Another feature of the Jubbah assemblages that shows considerable variation is the pattern of dorsal scars. Table 10 compares unidirectional and centripetal scar patterns, and shows how the former decreases and the latter increases markedly with distance from the raw material sources. This changing frequency of scar patterns reflects greater reduction intensity and a shift to centripetal methods. In contrast the frequencies of different forms of striking platform do not vary significantly (table 11). These patterns show how knappers attempted to produce broadly similar flakes, and primarily reacted to reduced core size and the impact of previous flaking by emphasising more centripetal reduction.

Table 12 presents further such examples, showing the correlation of morphological (e.g. weight) and other features at Jubbah. At primary sources such as JKF-12, there are large numbers of flakes per core, suggesting either extensive reduction on site and/or the removal of a large number of cores from the site. JQ-1 is currently a unique site in the Jubbah basin in having a relatively high frequency of retouched flakes, suggesting an attempt to prolong the use life of flakes along with the extensive reduction of cores. While JKF-12a and JKF-1 both primarily reflect preferential Levallois reduction, JQ-1 shows a focus on discoidal and recurrent centripetal Levallois methods consistent with both raw material economisation and as a way around knapping 'errors', such as the obstruction of the debitage surface with aberrant terminations.

The survey indicated limited raw material sources in the Jebel Qattar area. The dominant raw material at JQ-1 is a ferruginous quartzite similar to that at sites further west in Jubbah, and more fine-grained than the local sources at JQ-A and JQ-B. The small size and heavily reduced nature of the JQ-1 lithics may theoretically reflect small initial clast size. Alternatively, or in addition, it may reflect greater reduction intensity of raw materials brought in from further west at Jubbah. One way to explore such hypotheses is to compare Scar Density Index (SDI) figures – the ratio of the number of scars to the surface area of cores (Clarkson, 2013) – as previously applied to MP sites in the region by Groucutt and colleagues (2015b). As shown in figure 14 and table 12, SDI (a ratio of the number of scars to the surface area of cores) values for complete quartzite cores from JQ-1, JKF-1 and JKF-12 match previously discussed indications of greater reduction intensity at JQ-1 compared to the other sites. Cores at JQ-1 have almost four times as many scars relative to surface area as do cores from JKF-12. Therefore, while JKF-12 has the characteristics expected of a raw material procurement locality, JQ-1 represents a different form of site, not associated with raw material procurement, while JKF-1 falls between the two. We hypothesise that the great reduction at JQ-1 reflects curation of cores brought to the site rather than the use of small local clasts, although further work is needed to test this.

While we do not completely discount the possibility that small local clasts may a role in determining the characteristics of the JQ-1 assemblage, we highlight the relative prevalence of ‘exotic’ raw materials at the site as an independent measure consistent with our ‘mobility’ hypothesis. Exotic raw materials at Jubbah consist of cherts and fine grained igneous materials. They make up 11% of the JQ-1 assemblage, in contrast to just 0.03% of the JKF-12a assemblage and 2% of the JKF-1 assemblage (table 12). This is consistent with our model for MP variation at Jubbah, and while it does not disprove an important role of putative quartzite sources close to JQ-1 (not identified during intensive survey of the area), it is not what would be expected in such a model.

table 12 hereabouts

figure 14 hereabouts

7. Discussion and conclusions

In the long debate on the meaning of MP variability, raw material influences in stone tool manufacture have either been viewed as paramount (e.g. Clark and Riel-Salvatore, 2006; Mellars et al., 2013) or of little consequence, the latter arguably leading to the “tyranny of the emic goal” (Tostevin, 2011, p. 355). The reality, of course, is that the factors influencing lithic morphology, typology, and technology are complex and variable. While the results of experimental studies and inter-assemblage lithic comparisons indicate that the influence of raw material has often been overstated (Eren et al., 2014; Scerri et al., 2014b; Scerri et al., 2016), it is also clear that raw material form still sometimes plays a role, particularly in the early stages of reduction (Scerri et al., 2016). Raw material variability does not simply reflect ‘quality’, in terms of aspects such as mineralogical homogeneity, but also factors such as clast size and shape, and the distribution of the material in the landscape. It is important to understand how such factors interact with aspects of mobility and technology.

Survey results indicate that raw material suitable for lithic reduction is mainly found at the western end of the Jubbah palaeolake, both as bedrock sources and in scree deposits. MP sites such as JKF-12 are associated with these sources, and clearly represent localities where raw material was procured and early stage reduction/short reduction cycles were conducted. Other sites in the area demonstrate the transport of lithic materials, and therefore begin to provide insights into the mobility and technological strategies employed by MP hominins.

The dominant raw material used by MP hominins at Jubbah consists of ferruginous quartzite, which occurs as beds within the Palaeozoic sandstone succession. While there are minor variations in factors such as the size of grains and the proportion of iron in the quartzites, they have broadly similar structures. These materials are fairly fine grained and homogenous, making them suitable for knapping. Due to their relatively great age (Palaeozoic) they are well cemented and indurated, and so are hard wearing. Our surveys suggest than an important level of variation between the sources and associated lithic technology does not reflect mineralogical variation between quartzite beds, but rather the character of erosion and weathering of clasts at the different sources, as well as clast size. Sources such as JSM-15 and JSM-18 high on Jebel Umm Sanman form a horizontal plateau, and are as a result extensively weathered and available as generally small clasts. In contrast, at JKF-12 the quartzite bed is both thicker than the jebel-top sites and less weathered, as it has been exposed by aeolian erosion of the softer underlying sandstone bed. Hence while JKF-12 and JSM-15 are more similar to each other in terms of factors such as grain size than either are to JSM-18, in technological terms JSM-15 and JSM-18 are very similar (such as being focussed on centripetal Levallois reduction) and different to JKF-12. At JSM-1, a very thin bed of argillaceous sandstone was reduced by overwhelmingly centripetal methods. The same was found elsewhere, for example the core in figure 5C from DHY-2 shows cortical surfaces on both sides of a thin slab of raw material.

Along with the importance of clast morphology and condition, our data suggest an important role for differential reduction intensity, as can be seen by comparing the characteristics of sites such as JKF-12 and JQ-1. It therefore appears that in parallel with clast variability, differential reduction intensity, which itself seems to correlate with distance from raw material sources, also plays a role in influencing MP variability. At JKF-12 reduction was predominantly unidirectional, with short reduction sequences and limited re-preparation, while at JQ-1, cores were highly reduced, by centripetal methods, and retouch was much more common.

The MP record of Jubbah, and the Nefud Desert more widely, suggests that hominin occupations were short-lived and relatively ephemeral (see also e.g. Scerri et al., 2015). These sites are characterised by small and low-density lithic assemblages, in contrast to a much more abundant record in areas such as southern Arabia and the Nile Valley. At Jubbah, hominins used a variety of raw material sources, which were exploited in a limited and un-invasive manner. JKF-12, for instance, represents one of the largest and highest quality raw material sources at Jubbah, and therefore within dozens of kilometres in all directions. It is located on the edge of a basin that held a palaeolake. Yet the number of lithics here is relatively limited. We estimate that in total there are at most a few thousand lithics at JKF-12. This is in contrast to areas like the Nile Valley where large scale quarrying of raw materials occurred, presumably demonstrating relatively high population density.

The paucity of Levallois flakes, which scars on cores show were produced at raw material procurement sites, demonstrates that these were removed from the sites. There is likewise a paucity of clear hammerstones, again suggesting that these were curated objects. The high number of cores to flakes at JKF-12 suggests that cores were also removed from sites. The production and removal of preferential flakes may suggest a strategy of provisioning individuals. Such a strategy is also indicated by the import of smaller cores to JKF-1, probably from JKF-12, and perhaps their import all the way to JQ-1. Provisioning of individuals also fits with a relatively mobile and transient population who were exploiting raw material sources only ephemerally. High levels of technological investment in Levallois cores also suggest high levels of mobility in which large and standardized flakes could be relied upon for relatively long use-lives (Kuhn 1995; Shott 1989; Shipton et al., 2013).

There is a need to avoid both 'raw material tyranny' (the notion that lithic variability is overwhelmingly driven by raw material factors) and 'emic tyranny' (that virtually all variability reflects cultural design) in lithic analysis. While we have emphasised the importance of the parallel processes of, firstly, aspects of clast morphology, size, and weathering and, secondly, differential reduction intensity (which itself seems to broadly correlate with distance from raw material sources), we are by no means stating that these are the only factors driving technological variability. There are of course important aspects of technological variability in a cultural sense, which may in part reflect chronological variability between the sites. Neglecting any aspect of the complex web of factors influencing lithic variability will lead to incomplete understandings, and in that regard developing insights into raw material procurement and early stage reduction offer promising avenues for future research.

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Figure captions

Figure 1 – The Jubbah palaeolake basin, showing the distribution of jebels (sandstone outcrops) and Middle Palaeolithic sites. The western jebels contain quartzite raw material sources. Notably, JSM-15 and JSM-18 are procurement sites on Jebel Umm Sanman, and JKF-12 is one of the densest concentrations of lithic artefacts at a quartzite source.

Figure 2. Examples of quartzite sources in the Jubbah basin. A,B: SAT-1; A: looking down from jebel showing extensive pavement like surfaces of sandstone and quartzite, partly dissected and shielded by the incisions of minor fluvial channels. Note vehicles at top left for scale. B: looking up towards the base of the jebel showing the dense accumulation of both lithics and natural clasts. C,D: Spatially limited sources of quartzitie on Jebel Qattar. At C, the bedrock shows evidence of having being flaked.

Figure 3. JSM-15; quartzite raw material source and Middle Palaeolithic site high on Jebel Umm Sanman, looking to the south. Note fractured and weathered nature of the quartzite. This site offers panoramic views over the palaeolake basin and the surrounding dunefields (Photo: Rémy Crassard).

Figure 4. Microscopic photographs of raw material samples from Jebel Umm Sanman Middle Palaeolithic sites. A-F clockwise from top left. A,B: JSM-1, C,D: JSM-18, E,F: JSM-15. All ferruginous quartzite, except A,B: argillaceous sandstone

Figure 5. Examples of lithic artefacts associated with quartzite raw material procurement localities in the Jubbah area. A: JSM-15, B,D,E: JSM-18, C,F-H: DHY-2. A: recurrent centripetal Levallois core, B, G: preferential Levallois cores, C: thin centripetally flaked core ('radial core'), note cortex on both faces, D,E: flakes, F: Levallois flake, H: hammerstone.

Figure 6. Two views of part of the quartzite source at JKF-12. Here the ferruginous quartzite occurs as thick bedrock slabs. Note the large and highly angled clasts, which provide excellent forms for lithic reduction. Scale is 10 cm long.

Figure 7. Views of JKF-12. A,B: the 4x4 m systematic lithic collection showing its position amid a dense accumulation of natural clasts and lithic artefacts. C: example of the surface at JKF-12, showing both natural clasts and lithics (e.g. the three long flakes), D: bedrock source of small quartz pebbles a few metres downslope from JKF-12. Pebbles from such beds are found in abundance in the lower part of the Katefeh basin.

Figure 8. Microscopic photos of raw material samples from Jubbah Middle Palaeolithic sites. A-D clockwise from top left. A: SAT-1, B,C: JKF-12, D: JKF-1. All ferruginous quartzite, except F: quartz.

Figure 9. Quartzite Levallois cores from Jubbah Middle Palaeolithic localities, A,B: JKF-12b, C,D: SAT-1. A: preferential Levallois core with predominantly unidirectional convergent preparation. B,C:

preferential Levallois core with centripetal preparation, note cortex on debitage surface of B indicating a short reduction sequence and a lack of re-preparation. D: Preferential Levallois core on a thick flake. Note how lateral and distal preparation have formed a median distal ridge making this core similar to 'beaked' (Nubian) Levallois cores.

Figure 10. Quartzite artefacts from JKF-12a. A,C,L: cores. B,D-F,H-K: flakes, F is a débordant flake. G: retouched flake. Note that dorsal surface without arrows showing directions of removals are cortical surfaces. A,B: reduction method of predominantly single platform cores with minor preparation of convexity, C-E: single platform reduction method production thick blades and points, often highly cortical, I-L: Levallois reduction method.

Figure 11. Quartzite Levallois cores with faceted platforms from JKF-12a. A: recurrent unidirectional Levallois core. B,C,: preferential Levallois cores with predominantly unidirectional convergent preparation and supplementary removals from the laterals and distal. Examples such as C have median distal ridges and are therefore reminiscent of beaked ('Nubian') Levallois cores.

Figure 12. Quartzite preferential Levallois cores with faceted platforms from JKF-12a showing variations in convexity management. All can be classified as centripetally prepared, although A presents an example where the immediate outlines of the preferential removal were shaped by unidirectional-convergent preparation, with the wider shaping of the core produced by centripetal preparation

Figure 13. Large quartzite core from JKF-12 (25 x 21 cm). The productive core produced a large number of large flakes by a non-Levallois method.

Figure 14. Boxplot of Scar Density Index for JQ-1, JKF-1 and JKF-12 Middle Palaeolithic sites. Scar density index expresses the ratio of the number of scars to the surface area of cores, indicating how intensively they are flaked. This shows that JKF-12 has low flaking intensity, JKF-1 low to moderate, while JQ-1 is intensively flaked.