Title

Middle Stone Age reduction strategies at the desert's edge: a multi-site comparison across the Gebel Akhdar of northeast Libya

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Abstract

Haua Fteah cave, situated between the Mediterranean coast and the Gebel Akhdar of northeast Libya, preserves rich Middle Stone Age (MSA) and Late Stone Age (LSA) cultural horizons. Excavated in the 1950s and more recently, the richness and time-depth of the cave's archaeological record are unsurpassed by any other site in northern Cyrenaica. As a result, the Haua Fteah sequence has long been used to represent the culture history of the region as a whole. Recent geoarchaeological surveys of the Gebel Akhdar, as well as pre-desert and desert biomes further to the south, have resulted in the discovery of numerous MSA and LSA sites. The vast majority of these sites consist of surface lithics that cannot be dated currently. In contrast, parts of the Haua Fteah sequence have been dated using various chronometric methods. Using data collected through lithic attribute analysis, coupled with various statistical approaches (including Discriminant Function Analysis, or DFA), this paper explores variation in core reduction strategies within Haua Fteah from the early MSA to early LSA. Collections of cores from various sites located throughout the landscape are contrasted against those from Haua Fteah. By comparing undated cores from the landscape with those from different occupation phases at Haua Fteah, DFA classification is tested as a method for imparting an approximate chronology to the former. The results indicate notable variation in reduction strategies within the MSA at Haua Fteah, and notable similarities between early MSA ("Pre-Aurignacian") and early LSA ("early Dabban") core morphologies and technologies. Because of the latter in particular, together with several other factors that may be underpinning spatio-temporal variability in core reduction strategies, caution is recommended in loosely assigning approximate chronologies to surface lithic sites.

Keywords

Haua Fteah; Libya; Middle Stone Age; Late Stone Age; Lithic technology; Discriminant Function Analysis

1. Introduction

The Middle Stone Age (MSA) of North Africa has received greater research attention in recent years. Notable progress has been made towards placing the region, and its hominin fossil and cultural records, more firmly within current models of human biological and behavioural evolution over the last ~200,000 years (~200 kyr) (Barton et al., 2009; Stringer and Barton, 2008; Balter, 2011; Hublin and McPherron, 2012). Building on a long history of research in the region, an important focus of this new work has been to use modern techniques of excavation and analysis to more fully understand previously excavated deep cave sequences. Examples include the cave sites of Haua Fteah in northeast Libya (McBurney, 1967; Barker et al., 2007), and in Morocco, Grotte des Pigeons near Taforalt (Bouzouggar et al., 2007), Dar es-Soltan I (Barton et al., 2009) and Contrebandiers (Dibble et al., 2012). In addition to these sites, there have been advances in our knowledge of the Middle Stone Age of several other North African regions, such as the Jebel Gharbi in northwest Libya (Barich et al., 2006), the central Libyan Sahara (Cremaschi et al., 1998; Cancellieri and di Lernia, 2012; Foley et al., 2013), the Nile Valley (Van Peer et al., 2003, 2010; Olszewski et al., 2010), the Red Sea Mountains (Mercier et al., 1999) and the Eastern Saharan (Western Desert) oases (Smith et al., 2007; Hawkins, 2012; Kleindienst, 2013). At an even broader scale, several multi-regional syntheses and analyses have shed important new light on region-wide changes in North African palaeoenvironments (Smith, 2012; Larrasoaña, 2012), human dispersals across North Africa (Osborne et al., 2008; Drake et al., 2011; Coulthard et al., 2013), and lithic technological diversity and associated demographic processes (Scerri et al., 2014; Van Peer, in press).

As in sub-Saharan Africa (Clark, 1992; McBrearty and Brooks, 2000), the North African MSA shows marked spatio-temporal diversity in lithic technology. This underlies the varied application of the terms Middle Stone Age, Middle Palaeolithic or Mousterian to the North African record. A wide array of terms are also used for presumed cultural variants of the North African MSA (e.g. Sangoan, Lupemban, Levalloiso-Mousterian); some more geographically constrained (e.g. Taramsan, Safahan, Libyan Pre-Aurignacian) than others (e.g. Aterian, Nubian). This MSA technological diversity has been shown to exhibit broad-scale spatial patterning across North Africa (Scerri, 2013; Scerri et al., 2014; Van Peer, in press), and temporal patterning in regions such as the lower Nile valley (Van Peer et al., 2010) and Jebel Gharbi (Barich et al., 2006; Garcea and Giraudi, 2006). The most high resolution but spatially constrained records of temporal variability derive from excavated cave sites, such as Ifri n'Ammar (Richter et al., 2010), Contrebandiers (Dibble et al., 2012), Sodmein Cave (Vermeersch et al., 1994; Mercier et al., 1999) and Haua Fteah (McBurney, 1967). The start of the MSA in North Africa appears to be regionally variable (see Barton et al., 2015). While the MSA may have spanned a period of ~200 kyr or more, the paucity of dated early MSA sites means that the nature and timing of the shift from ESA to MSA technologies across North Africa remains to be clearly defined (Barham and Mitchell, 2008, p. 233). Given this length of time and the dramatic palaeoclimatic, palaeoecological and demographic shifts that occurred during the later Quaternary, as well as associated developments in human evolution, cognition and behaviour, the existence of technological diversity during the MSA is not surprising. The validity of the nomenclature assigned to different North African MSA assemblages has been discussed elsewhere (e.g. McBrearty and Brooks, 2000;

Van Peer and Vermeersch, 2007; Dibble et al., 2013; Van Peer, in press) and recent studies have begun to test the appropriateness of traditional cultural systematics through large-scale analyses of lithic assemblages from sites throughout the region (Scerri, 2013; Scerri et al., 2014).

Northern Cyrenaica in Libya is a good example of an area of North Africa that shows spatio-temporal technological diversity during the Middle Stone Age (Jones et al., in press). Central to this is the deep-time cultural sequence of Haua Fteah cave, located 0.8 km from the present-day Mediterranean coast, at the northern edge of the Gebel Akhdar ("Green Mountain"). Haua Fteah was first excavated by Charles McBurney and colleagues in the 1950s (McBurney, 1967). Excavations to a depth of 14 metres revealed different cultural episodes that spanned the MSA to Historic periods. From oldest to youngest, the Palaeolithic industries were termed 'Libyan Pre-Aurignacian', 'Levalloiso-Mousterian' (both equivalent to the MSA or Middle Palaeolithic), 'Dabban' ('early' and 'late' periods, equivalent to the LSA or Upper Palaeolithic), 'Oranian' and 'Capsian' (equivalent to the LSA or Epi-Palaeolithic). Although the term 'MSA' rather than 'Middle Palaeolithic' is preferred here, McBurney's named industries are retained for cross-communication purposes. Detailed descriptions of lithic artefacts from all cultural periods at Haua Fteah are available in McBurney (1967). More recent studies have been conducted, which have addressed the following: variation within the Levallois-Mousterian (Chazan, 1995); technological changes from the Pre-Aurignacian to Dabban (Moyer, 2003); and, comparisons of the Pre-Aurignacian and Levallois-Mousterian, discussed with reference to similarities with northeast African and Levantine records and the questionable presence of the Aterian at Haua Fteah (Reynolds, 2013). Samples of Levallois-Mousterian lithic artefacts from Haua Fteah have also been included in wider regional comparisons, within North Africa (Scerri, 2013; Scerri et al., 2014) and further afield, incorporating data from Europe, Asia and Australasia (Clarkson et al., 2012). These studies have integrated the Haua material into wider theories regarding *Homo sapiens* population histories and dispersals within North Africa and beyond.

Since 2007, renewed investigations in the cave have provided greater stratigraphic, chronological, palaeoenvironmental and archaeological resolution to the cave's sequence (Barker et al., 2007, 2008, 2009, 2010, 2012; Douka et al., 2013; Rabett et al., 2013; Farr et al., 2014). This work commenced under the Cyrenaican Prehistory Project and was succeeded by the ERC-funded TRANSNAP project (*Cultural Transformations and Environmental Transitions in North African Prehistory*). An important component of this work has been to contextualise the record from Haua Fteah within that of the wider landscape. This has involved geoarchaeological surveys of a large and ecologically diverse study area (~150 x 150 km) that traverses a wide array of habitats, ranging from Mediterranean coast, to forested uplands of the Gebel Akhdar, to semi-desert and desert biomes in the south. These surveys have resulted in the discovery of 181 sites comprised of lithic scatters, many of which are characteristically MSA or LSA on account of various typological and technological features (Barker et al., 2009, 2010; Jones et al., 2011, in press). While McBurney and Hey (1955) had conducted pioneering surveys along the Cyrenaican coast and in the immediate hinterland, the Palaeolithic record of areas further to the south had not been explored previously.

This paper examines the MSA and early LSA lithic record of Haua Fteah, comparing this against lithic artefacts from thirteen sites located across the wider landscape. Lithics from these sites (e.g. bifaces, cores, blanks, retouched blanks) have been studied by the author using attribute analysis, resulting in a database of ~19800 artefacts. A small subset of this dataset is explored in this paper, predominantly comprising discarded cores from Haua Fteah and the landscape sites, as well as unretouched blanks from the Pre-Aurignacian and Levallois-Mousterian layers. Using univariate and multivariate statistical techniques, three questions are addressed through the examination of morphological and technological attributes on these cores and blanks.

1. How did core reduction strategies change during the MSA of Haua Fteah and into the early LSA (or "Dabban")? The aim is to establish the extent of technological variability within the MSA of Haua Fteah, by comparing Pre-Aurignacian and Levallois-Mousterian discarded cores, and to contrast these with those from the Early Dabban.
2. Is it valid to examine core reduction strategies by using data recorded only on cores? The importance of looking at the entire assemblage (i.e. cores and debitage) in order to reconstruct reduction strategies has been raised several times (e.g. Dibble, 1995); this is understandable and is an issue that is discussed in more detail below. In this paper, the validity of applying a cores-only approach to the Haua Fteah record is tested through statistical comparisons of morphological and technological attributes on cores and blanks from the same contexts.
3. The chronology of the different cultural phases at Haua Fteah, particularly those belonging to the later MSA and LSA, is reasonably well understood (Douka et al., 2014). Is it possible to use chronological data for the different cultural phases at Haua Fteah, coupled with technological similarities between cores from these phases and those from undated landscape sites, as a means to impart a chronology on the latter? If so, this would be one of the few ways in which to give an approximate age to surface lithic scatters that cannot be dated directly and rarely can be correlated stratigraphically to otherwise dateable deposits.

2. A cores-only approach to reconstructing reduction strategies

In a study of early Mousterian artefacts from Biache St Vaast, Dibble (1995) compared the results of two different analytical approaches: his approach, which involved an attribute analysis of cores and blanks (including tools) in order to reconstruct how reduction techniques may have varied during the "lifespan" of a core, and Boëda's (1988) analysis that concentrated only on the cores as a means to recognise distinct schemes of reduction. He concluded that a study based on cores alone is problematic for two main reasons. First, he demonstrated that knapping strategies (e.g. flaking patterns) changed during the reduction process (see also Wallace and Shea, 2006; Cochrane, 2014), emphasizing that "The morphology viewed on any given core […] will represent only the last actions that were performed on it" (Dibble, 1995, p. 102). Second, different cores in an assemblage may be discarded at different stages in the reduction sequence (e.g. due to knapping errors, or differences in reduction intensity, occupation intensity or raw material availability). He concluded that the whole industry needs to be studied and not just a selection of it

(Dibble, 1995). This point was recently reiterated in a study of Howiesons Poort cores from Sibudu: “Cores give us a somewhat partial view of the whole technology that must be completed with other technological sources of information (such as trimming and preparation by-products and qualitative blank characteristics)” (de la Peña and Wadley, 2014, p.28).

Although these are important concerns, there have been several recent and notable studies involving comparisons of solely the cores in assemblages. Several of these studies have applied multivariate statistical techniques (e.g. Principle Components Analysis [PCA] and Discriminant Function Analysis [DFA]) to core attribute data to explore patterns of variation (Lycett et al., 2006; Petraglia et al., 2007; Lycett, 2009; Clarkson, 2010; Shott et al., 2011; Clarkson et al., 2012; Haslam et al., 2010; Lycett and von Cramon-Taubadel, 2013, 2015; Shipton et al., 2013; Eren et al., 2014). These studies have made valuable conclusions regarding the factors that underlie variation in core technology. For example, Clarkson (2010) presents the results of a multivariate morphometric analysis of cores from five Howiesons Poort sites using DFA, incorporating variables related to core shape, scar patterning, production technology and reduction intensity. Although Howiesons Poort backed artefacts show strong technological similarities across regions, Clarkson demonstrates that corresponding traditions of core reduction showed regional differentiation. Several reasons are provided to support an analysis that focuses on cores exclusively, but perhaps the most relevant of these relates to the concept of cultural transmission. Clarkson notes that discarded cores preserve a considerable amount of technological information that can be useful for identifying different lines of cultural transmission, which may suggest specific regional cultural traditions. The underlying premise is that methods of core reduction are learnt by knappers through observation and replication. Where variation in core technologies exists, this may indicate different lines of cultural transmission (Clarkson, 2010). This close relationship between core morphologies and cultural transmission is also followed in other studies (Clarkson et al., 2012; Lycett, 2013; Lycett and von Cramon-Taubadel, 2013; Eren et al., 2011).

Factors other than cultural transmission can generate variation in core technologies, such as reduction intensity (Clarkson, 2013), mobility patterns (Wallace and Shea, 2006), or raw material type and availability. Although Clarkson (2010) showed that raw material type contributes somewhat to patterns of variation, geography (i.e. different regional types) was a greater contributor to variation in Howiesons Poort core technologies. Supporting this, knapping experiments have been used to investigate how the properties of different raw materials contribute to handaxe shape (Eren et al., 2014). Through multivariate analyses of shape data (using PCA and MANOVA), raw material type was not a major contributor to handaxe morphology. In an earlier study, also based on knapping experiments but focused on an individual knapper’s increasing replication skills, Eren et al. (2011) demonstrate that skill rather than raw material quality is the predominant factor involved in the knapper achieving particular goals (in their study, Levallois reduction). Like Clarkson (2010), they recognise that raw material properties may have some impact on core morphology, but state that “when evaluating quantifiable differences between lithic assemblages, we should not prematurely assume that raw material quality will necessarily override skill levels, culturally-mediated preferences, and/or culturally-mediated skill levels” (Eren et al., 2011, p.2738). Using archaeological examples and multivariate statistics (MANOVA and DFA), Lycett and von Cramon-Taubadel (2015) explore the different (but not necessarily mutually exclusive) roles of raw material, reduction intensity and culture in handaxe shape variation. While raw material may contribute to morphological variation, cultural factors may also be contributing to handaxe shape. In a separate study of Levallois core morphometrics using PCA, they strongly implicate social transmission in Levallois reduction strategies, where teaching may have been required to maintain stability of such traditions (Lycett and von Cramon-Taubadel, 2013).

Two key points are emphasized following this brief review of previous approaches to the study of cores. First, by focusing on only one technological yet information-rich element of an assemblage, the analysis of only the cores in an assemblage presents a more time-efficient method of exploring technological variation between a large number of sites and/or stratigraphic contexts within sites (e.g. Wallace and Shea, 2006). The studies reported above demonstrate that important conclusions can still be reached by focusing exclusively on cores. Second, raw material, reduction intensity and cultural factors are all famously implicated in patterns of lithic variation (for a review, see Lycett and von Cramon-Taubadel, 2015). These studies of cores (and handaxes) demonstrate the successful application of particular methods for understanding the relative importance of these factors in explaining lithic variation.

3. Sites and samples

The cores examined here (Table 1) derive from a variety of time periods, site types and ecological contexts. They include cores from excavations at Haua Fteah cave and Hajj Creiem, surface and stratified contexts in the Al-Marj basin, and surface lithic scatters in the Gebel Akhdar and pre-desert, near the edge of the Sahara (Fig. 1).

In the 1950s, Haua Fteah was excavated in spits in three nested trenches: an Upper Trench, Middle Trench and Deep Sounding (McBurney, 1967). Upper Trench and Middle Trench spits, but not those of the Deep Sounding, were later assigned to numbered layers in accordance with sedimentological changes. The Haua Fteah MSA and early LSA cores investigated here derive from McBurney's excavations of the Middle Trench and Deep Sounding (Fig. 2). Here, these are divided into four analytical groups of roughly equal sample size, where McBurney's cultural nomenclature is retained: (1) a Pre-Aurignacian group (incorporating cores from spits 68 to 176), representing the cave's lowermost and hence oldest cultural horizon, recovered from the base of the Deep Sounding; (2) a Levallois-Mousterian group, comprising cores from the upper levels of the Deep Sounding and the lower layers of the Middle Trench (layers 26 to 35), and excluding cores from spit 55-46; (3) a subset of Levallois-Mousterian cores from an exceptionally artefact-rich spit that McBurney excavated in the north sector of the Middle Trench (spit 55-46, covering layers 32 and 33); (4) an Early Dabban group (layers 21 to 25).

Dates have yet to be published for the Deep Sounding, but the earliest Pre-Aurignacian occupation of the cave likely extends back to the humid period of Marine Isotope Stage 5e (MIS 5e, which begins c.130 ka) (MacDonald, 1997; Barker et al., 2012; Rabett et al., 2013; Farr et al., 2014), and probably not as early as MIS 7 (Moyer, 2003, p. 37). The Pre-Aurignacian and Levallois-Mousterian groups are separated by approximately 3.2 m of more or less horizontally layered red clay-silts

(McBurney, 1967: fig. I.9; Farr et al., 2014: fig. 7). The possibility that cores from the Pre-Aurignacian have been reworked into the Levallois-Mousterian layers can be excluded. In this paper, the Levallois-Mousterian cores are separated into two analytical groups as a means to explore the degree of variability amongst cores in these layers. This is because the Levallois-Mousterian covered a broad time-frame of approximately 30,000 years, from ~74-43 ka. Cores from spit 55-46 belong to a more constrained time-frame and date to early MIS 4. The Early Dabban cores derive from layers dating to ~43-38 ka. These ages are taken from a recent study that has provided new dates for the Haua Fteah sediments, based on ^{14}C, OSL, ESR and tephra dates, and Bayesian modelling (Douka et al., 2014). McBurney (1967, p. 135) placed the start of the Early Dabban in the upper part of layer 25, and his stratigraphic placement for the transition between the Levallois-Mousterian and Early Dabban is followed here. The nature of this cultural transition remains to be defined clearly, in particular whether it was abrupt or gradual. McBurney (1967) favoured the latter, and preliminary findings from recent excavations of Haua Fteah suggest that the transition was complex and not abrupt (Rabett et al., 2013). Because of this, it is possible that some lithic artefacts assigned to the end of the Levallois-Mousterian may be better placed in the Early Dabban, or vice versa. Yet, in terms of the analytical groups of cores explored statistically below, there is good separation between the Levallois-Mousterian and Early Dabban samples. This is because there are no cores that derive exclusively from layer 25. Furthermore, exceptionally few cores were excavated from the overlying and underlying levels (Fig. 2).

These cores from Haua Fteah are compared with those from sites in the wider landscape. This includes cores from Hajj Creiem, the only landscape assemblage derived from archaeological excavations. A 40 m^2 area of this site, located in Wadi Gahham, was excavated in 1947 and 1948, producing ~1500 lithic artefacts confined to a thickness of <0.5 m (McBurney and Hey, 1955). The site was situated adjacent to a former lake that had built up against a tufa dam in nearby Wadi Derna. The artefacts were discovered in association with numerous faunal remains (e.g. zebra and Barbary sheep), suggested to preserve evidence of hunting activity. This "ancient camp site" may have been used for a few seasons or possibly only a few days or weeks (McBurney and Hey, 1955: 143). Sequential flake refits have been identified at the site, supporting primary flaking activities. The artefacts, defined as classical Mousterian, have been compared metrically with several European Mousterian assemblages (McBurney and Hey, 1955). McBurney (1967, p. 129) suggested that the Hajj Creiem assemblage correlates both stratigraphically (on account of similar sediments denoting humid and cold conditions) and technologically with layers 32 or 33 in Haua Fteah. This is the same context as the cores from spit 55-46, dated to early MIS 4.

Cores from the Al-Marj basin, site CPP8009 in the Baltat ar Ramlah palaeolake, and sites in the Upper Gebel and North Gebel groups were collected during geoarchaeological surveys in 2009 and 2010. Al-Marj is located in a topographic depression within the western Gebel Akhdar, where artefacts occur in section and surface exposures in association with a canal cutting that bisects part of the basin. Sites in the North Gebel are located to the south of Haua Fteah, and those from the Upper Gebel are found at higher elevations even further south. Site CPP8009 is an area of raised land (a 'palaeo-island') within the Baltat ar Ramlah palaeolake and preserves a dense scatter of lithics on its surface. This is the southernmost site and lies in a very different ecological context from the others, located in the pre-desert region near the northernmost edge of the present-day Sahara. The majority of cores derive from surface lithic scatters, with the exception of some of the Al-Marj cores that were found within exposed sections. These sites, as well as the artefacts from them, are described in detail elsewhere (Barker et al., 2009, 2010; Jones et al., 2011, in press).

Table 1. Contextual and sample size information for each analytical group of cores from Haua Fteah and sites across the wider landscape.

Analytical group	**Site(s)**	**Contexts**	**Distance from Haua Fteah (km)**	**Number of cores**	**Number of core fragments**	**Number of cores-on-flakes[1]**
PA (Pre-Aurignacian)	Haua Fteah	Spits 68-176	0	41	9	5
LM (Levallois-Mousterian, excluding spit 55-46)	Haua Fteah	Layers 26-35	0	46	12	2
55-46 (Levallois-Mousterian from spit 55-46)	Haua Fteah	Layers 32-33	0	46	10	4
Early Dabban	Haua Fteah	Layers 21-25	0	31	3	1
Hajj Creiem	Hajj Creiem	Not specified	57	15	4	11
Al-Marj	EM4, EM21 (sections); EM105, EM113, EM122, EM124, EM125, EM126, EM131 (surface)	Surface and stratified	108	16	0	0
North Gebel	CPP sites: 8103, 8104, 8109, 8111, 8116, 8117, 8118, 8119	Surface	6-15	32	7	0
Upper Gebel	CPP sites: 8112, 8113,	Surface	22-25	12	2	0
Baltat ar Ramlah	CPP8009	Surface	100	43	6	0

[1] Includes complete and broken cores-on-flakes

4. Methodology

The lithic dataset derives from an analysis of core and blank attributes. Metric and non-metric traits were recorded that provide information about size, morphology and technology. Attribute analysis is an objective methodology for comparing the distribution of data between assemblages given that each attribute is recorded in the same way on different artefacts. Depending on which attributes are recorded, it is also ideal for detecting small-scale technological differences between assemblages that otherwise appear similar. Because of the type of data recorded, it is an optimal methodology for using statistical techniques to test specific hypotheses regarding past technologies and behaviours. It is also an effective way of handling large lithic datasets. This paper focuses on metric and non-metric attributes recorded on cores from Haua Fteah and the landscape sites, as well as two subsets of attribute data recorded on complete and unretouched blanks from Haua Fteah. Metric attributes are either considered individually (e.g. mass), or two or more attributes are combined to create a new variable (e.g. core elongation). Not all core and blank attributes recorded during data collection are included in the analyses below, only those pertinent to the three research questions are explored (these are defined in Tables A.1 and A.2). Together, these variables describe artefact size, shape, platform characteristics, reduction intensity, and scar features (i.e. size, shape and flaking pattern).

Univariate and multivariate statistical tests (conducted using SPSS Version 21) are used to interrogate quantitative and qualitative data generated through attribute analysis. These are used to: (1) compare levels of statistical similarity and difference between the four analytical groups from Haua Fteah; (2) to compare cores in each of the five landscape groups to each of the four Haua Fteah groups of cores. Detailed descriptions of the statistical procedures used are provided in Appendix A and summarised briefly here. Univariate statistical tests consisted of parametric tests (ANOVA) and non-parametric tests (Kruskal-Wallis, Mann Whitney U) of quantitative data, and Pearson's chi-square and Fisher's exact tests of categorical data. Discriminant Function Analysis (DFA) is a multivariate statistical technique used here to identify: (1) which core attributes have the greatest power at discriminating between the four groups of Haua Fteah cores; (2) how the variables separate the four groups. The latter is determined by examining the relationship between functions and group centroids, and the correlations between variables and each statistically significant function. DFA classification ("jack-knife") results are interpreted to determine the accuracy with which the DFA classifies each core back into its own group. Classification procedures are also used to classify cores from four landscape groups (Al Marj, Upper Gebel, North Gebel and Hajj Creiem) into any one of three Haua Fteah groups (Pre-Aurignacian, Levallois-Mousterian, Early Dabban). The probabilities of group membership are used to give a measure of the strength of these group predictions. All the assumptions of DFA are met in the analyses reported here (see Appendix A for details).

5. Results

5.1 An examination of MSA and early LSA reduction strategies in Haua Fteah using core attribute data

The results of univariate statistical comparisons of lithic attribute data recorded on cores in the four Haua Fteah groups are summarised in Table 2 (Table A.3 provides detailed results). The four groups, Pre-Aurignacian, Levallois-Mousterian (excluding cores from spit 55-46), Levallois-Mousterian cores from spit 55-46 and Early Dabban, are hereafter referred to as PA, LM, 55-46 and ED respectively. Photographed examples of cores in each of the four groups are provided in figure 4. Knapping behaviours are examined with respect to reduction intensity, core surface and platform maintenance, and cultural tradition.

Table 2. Results of univariate statistical comparisons of cores from Haua Fteah. These are in four analytical groups: PA (Pre-Aurignacian); LM (Levallois-Mousterian, excluding cores from spit 55-46); 55-46 (Levallois Mousterian cores from spit 55-46); ED (Early Dabban). Refer to Table A.3 for detailed results.

Group 1	**Group 2**	**Statistically significant differences between Groups 1 and 2 (with reference to Group 1)**	**Percentage difference between groups[1]**
PA	LM	Heavier; thicker; fewer total scars; more scars with non-feather terminations; more single conchoidal platforms; lower faceting rates; more elongated last scars and cores; higher frequency of unidirectional, bidirectional and random flaking patterns; lower frequencies of discoidal, Levallois (including recurrent Levallois) cores.	67%
PA	55-46	Heavier; larger last scars; thicker; fewer total and major scars; more single conchoidal platforms; lower faceting rates; more elongated last scars and cores; higher frequency of unidirectional, bidirectional and random flaking patterns; lower frequencies of discoidal, Levallois (including recurrent Levallois) cores.	72%
PA	ED	Heavier; larger last scars; fewer total and major scars; less elongated last scars and cores; higher frequency of cores with random flaking patterns.	39%
LM	55-46	Heavier; larger last scars; fewer major flake scars.	17%
LM	ED	Flatter; larger last scars; more invasive last scars (by area); more total scars; more multi-conchoidal platforms; lower last platform angle; higher faceting rates; less elongated last scars and cores; higher frequency of radial flaking patterns; higher frequencies of discoidal, Levallois (including recurrent Levallois) cores.	61%
55-46	ED	Lighter; flatter; more invasive last scars (by area); more total scars; higher faceting rates; less elongated last scars and cores; higher frequency of radial flaking patterns; higher frequencies of discoidal, Levallois (including recurrent Levallois) cores.	72%

[1] The percentage difference between the each pair of groups is the percentage of the total number of tests that gave a statistically significant result.

5.1.1 Reduction intensity

Are any of the inter-group differences a result of differential reduction intensity? If not, then what other factors may be driving technological differences? Core size, the size of the last blank removed, frequency of scars with non-feather terminations, amount of cortex remaining and number of flake scars can be useful indicators of reduction intensity (for additional methods to examine reduction intensity, see Clarkson, 2013). The premise here is that heavier and thicker cores with greater amounts of cortex, larger blank removals, fewer scars and mainly scars with feather terminations are less reduced that smaller and thinner cores with less cortex, smaller blank removals, more scars and more non-feather terminations (i.e. stepped, hinged or overshot). Although these variables might also explain differences in other aspects of core technology (e.g. culturally specific traditions), and not just reduction intensity, these attributes do give an approximate measure of differential reduction intensity.

Statistical comparisons between the four analytical groups indicate that differential reduction intensity is unlikely to be a notable cause of variation between these assemblages. Five key points are made in support of this: (1) the four groups do not differ in the amount of cortex remaining on the cores; (2) PA cores are larger with lower scar counts but there are no differences in cortex coverage and the frequency of non-feather terminations (it is expected that the latter would be respectively higher and lower if PA cores were, as a whole, less reduced than those in the other groups); (3) ED cores show more intensive flaking than PA cores, with significantly more scars, suggestive of only marginally higher reduction intensity given the lack of difference in cortex coverage and frequency of non-feather terminations; (4) overall levels of reduction intensity do not appear to differ between ED and the two Levallois-Mousterian groups; (5) 55-46 cores may be a slightly more reduced subset of the general population of LM cores.

5.1.2 Variability within the Levallois-Mousterian

The few differences between the LM and 55-46 groups appear to lie in different measures of reduction intensity, with no differences in aspects of cultural tradition, platform preparation and core surface management. 55-46 cores are lighter, the last blanks removed are smaller, and they have a higher number of major flake scars (but there is no difference between groups in the total number of scars). Scar counts suggest that similar methods of core preparation were practiced but that multiple smaller flake removals in 55-46 predominated before discard, possibly indicative of core exhaustion. In other words, 55-46 cores became too small for the removal of large preferential flakes (due to surface area covered, the latter would reduce scar counts). While 55-46 cores may suggest higher reduction intensity than LM cores, there are no differences in core thickness (similarly flat cores predominate), frequency of scars with non-feather terminations and cortex coverage.

5.1.3 Comparison of the different MSA variants: Pre-Aurignacian and Levallois-Mousterian

Ruling out differential reduction intensity as a notable cause of variation between the analytical groups, how do MSA cores vary in terms of platform maintenance, core surface management and indicators of cultural tradition? There are some notable differences as well as similarities between PA and both groups of Levallois-Mousterian cores (LM and 55-46). Levallois-Mousterian cores show higher rates of faceting, marked also by more PA cores with platforms consisting of a single conchoidal flake scar as opposed to more Levallois-Mousterian cores with platforms exhibiting multiple flake scars. PA cores are significantly more elongated and thicker than Levallois-Mousterian cores and the last blanks removed from PA cores are more elongated. The latter were not more invasive across the last flaked face surface, however, indicating that PA core surfaces were not being prepared for more invasive blank removals. The greatest differences between PA and Levallois-Mousterian cores are reflected in scar patterning, demonstrating key differences in the frequency of different knapping behaviours. Unidirectional, bidirectional and random patterns of flake removals are significantly more common in PA cores, whereas radial methods are prevalent in Levallois-Mousterian cores (Fig. 5). This shows not only differences in core surface management between these two phases of occupation in the cave but may also suggest different cultural traditions. This pattern is also reflected in the significantly higher proportion of discoidal and Levallois cores in the Levallois-

Mousterian. Discoidal cores and Levallois cores are still present in the Pre-Aurignacian but in lower numbers; 13% of PA cores are Levallois cores, compared to 45% of Levallois-Mousterian cores. Instead, the PA group preserves a greater range of different core types, where multiplatform and irregular-shaped cores are more common (Table A.4). Perhaps this reflects an increase in technological specialisation, conservatism, and recursive or culturally transmitted behaviours during the Levallois-Mousterian.

Not only do Levallois cores occur at high frequencies in the Levallois-Mousterian but different types are present, including: Levallois cores with secondary retouch, possibly as result of their use as scrapers; preferential Levallois cores to produce flakes mostly but also points; and various types of recurrent Levallois cores, such as those with bidirectionally opposed Levallois blank removals (e.g. fig. 5: no. 17). An additional type, termed here preferential bifacial Levallois core (e.g. fig. 5: nos. 19, 20), has only been encountered in the Levallois-Mousterian layers of Haua Fteah (n=3, layers 32-34). Technically, this type defies certain strict principles of the Levallois system, specifically the notion of two hierarchically organised core surfaces. These cores, however, show faceted platforms, preparation of surface convexities on both faces and preferential Levallois blank removals across both faces of the core.

5.1.4 A comparison of MSA and Early Dabban cores.

A notable outcome of these results concerns the degree of similarity between PA and ED cores; only 39% of statistical tests provide a significant result. In fact, they are more similar to each other than either group is to either LM or 55-46 (see Table 2 for percentage of differences between groups). Many of the differences that exist between cores in both LM groups and PA and ED cores are similar. Faceting is more common in LM and 55-46 than in ED, as are radial methods of flaking (unidirectional and bidirectional methods are more common in ED). This is correlated with a significantly higher frequency of discoidal and Levallois cores in LM and 55-46, although these types are not absent from ED (Table A.4). In addition to different methods of platform and core surface preparation, ED cores are significantly thicker and more elongated, where the last blanks removed are more elongated yet less invasive across the surface area of the core. Together, these suggest a notable change in knapping traditions and blank preference in the Early Dabban.

Comparisons of PA and ED cores indicate that three out of the seven statistically significant differences between the two groups lie in indicators of reduction intensity. Size is one of the major differences between the two groups; ED cores are lighter and the last blanks removed are smaller. Another key difference is elongation, where ED cores and the last blanks are more elongated. While unidirectional and bidirectional flaking methods predominate in both, randomly orientated flake removals are present in PA but not ED. The differences between the two groups clearly lie in the more frequent and intensive production of smaller and more elongated flakes in the Early Dabban, perhaps coupled with a narrower range of core reduction strategies. Both groups, however, share an emphasis on elongated blank production (albeit more elongated in ED) through unidirectional and bidirectional flaking, together with similarly thick cores, high frequencies of single conchoidal platforms, and low frequencies of faceting and discoidal and Levallois reduction methods.

5.1.5 Discriminant Function Analysis of Haua Fteah cores

Two DFAs of the four core groups were conducted. DFA 1 examines which variables are the most powerful at discriminating between these groups, and explores patterns of core misclassifications. DFA 2 determines the effect of size on core classification. Seven normally distributed and uncorrelated variables with significantly different group means were included in DFA 1: mass, last scar elongation index, core elongation, last scar area invasiveness (all of which had undergone log10 transformations), total number of scars, core flatness and last platform angle. Inspection of the squared Mahalanobis distances (D^2) revealed no multivariate outliers. While Box's M (214.180, $p<0.001$) indicates inequality of covariance matrices, separate group bivariate scatterplots of canonical discriminant functions 1 and 2 reveal approximate equality in size (Tabachnick and Fidell, 2014, p. 427); therefore, classification based on this DFA is appropriate (Appendix A). The first two functions are significant (both $p<0.001$); function 1 explains 79.6% of the variance and function 2 explains 18.8%. Function 1 separates PA and ED cores from LM and 55-46 cores, where structure correlations (discriminant loadings with values >0.3) indicate that more elongated cores with more elongated scars are negatively correlated with flatter cores possessing higher scar counts. Core mass is positively correlated with both functions but it is most strongly correlated with function 2. This function separates PA from ED in particular and to a lesser extent LM from 55-46, where heavier cores with scars that are more invasive across the last flaked core face distinguish PA and LM from ED and 55-46 (Fig. 3). Last platform angle contributes very little to either function.

DFA 1 classification results reveal that 60% of cores are correctly classified back into their own group through cross-validated (jack-knife) classification. This 'hit ratio' of 60% is higher than what would be expected by chance and therefore these results are acceptable; however, there are some noteworthy misclassifications. First, while 60% of PA cores are classified back into their own group, 25% are misclassified as ED, 12.5% as LM, and 2.5% as 55-46. Second, 67% of ED cores are classified back into their own group, but 20% are misclassified as PA. These both demonstrate a notable overlap between PA and ED core attributes, also indicated by the results of the univariate statistical comparisons. Third, 71% of 55-46 cores are classified correctly but 4% are classified as ED and 24% are misclassified as LM. The latter is expected given that spit 55-46 is part of the Levallois-Mousterian. Fourth, 43% of LM are classified correctly but 36% are misclassified as 55-46, 16% as PA and 7% as ED. This greater number of misclassifications of LM cores into PA and ED, when compared to the number of misclassifications of 55-46 into these two groups, highlights greater variation in LM core forms in comparison to those in 55-46. This is unsurprising given that the LM group encapsulates a broader time-frame (i.e. where LM encompasses ten of McBurney's stratigraphic layers, and 55-46 covers only two of these) (see also fig. 2).

In DFA 2, the variables are the same as in DFA 1 except that core mass is excluded (all other size-related variables are inputted as ratios, one method of correcting for size). Functions 1 ($p<0.001$) and 2 ($p=0.015$) are significant, explaining 88.3% and 10.3% of variance respectively (Fig. A.1). The variables most strongly correlated with function 1 are last scar elongation, core elongation and core flatness. The variables most strongly correlated with function 2 are total scar count and, to a lesser extent, last scar invasiveness (by area). Function 1 separates ED and PA from LM and 55-46.

Function 2 pulls apart ED and PA cores only, indicating that what distinguishes these two groups is higher scar counts and less invasive last scars in ED when compared to PA. Excluding size has an impact on the classification statistics, where the hit ratio is only 47%, less than that expected by chance. Most of the misclassifications are divided between LM and 55-46 as the smaller size of 55-46 cores is one of few variables that distinguishes them from the LM cores as a whole. Once size is removed, the proportion of PA cores misclassified as ED (25%) remains the same as in DFA 1, but an additional 7% of ED cores are misclassified as PA (total of 27%). This shows that both groups overlap to a similar degree even after core size is controlled for, yet the smaller size of ED cores is, to a certain extent, of importance in accurately affiliating cores with the Early Dabban. This point becomes relevant later when predicting group membership of cores from across the landscape.

5.2 An examination of the debitage: assessing the validity of using only core data to reconstruct reduction strategies in Haua Fteah

Blanks from PA and 55-46, deriving from the same contexts as the cores in these groups, are used to test the validity of an exclusive focus on discarded cores from Haua Fteah as a means to reconstruct reduction strategies. Debitage from 55-46 is examined rather than that from LM for two reasons: (1) 55-46 occupies a more constrained time range; (2) to explore further the possibility that 55-46 cores may signify higher reduction intensities than PA cores. Two issues are addressed here through an analysis of morphological and technological attributes on cores and blanks. First, attributes that are directly comparable on cores and blanks within each group are tested for statistical similarity to establish if key information about reduction trajectories is expressed by the debitage and not by the cores. If blanks and cores within each group are similar with respect to comparable variables then focusing solely on the cores is a reasonable approach. Second, blanks in both groups are compared to determine if they mirror the patterns seen when equivalent variables on the cores from each group are compared. If they do, then core attributes alone are a good reflection of inter-group differences.

5.2.1 Intra-group core and blank comparisons

There are remarkably few differences between cores and blanks within each group with respect to those core and blank variables that can be compared directly. Findings are based on analyses of complete cores (including cores-on-flakes) and complete unretouched blanks. There are no statistically significant differences between PA cores (n=47) and blanks (n=1223), and between 55-46 cores (n=48) and blanks (n=1516) with respect to the following: (1) last scar surface area and its equivalent, flake surface area; (2) scar count; (3) scar pattern; (4) frequency of Levallois products. This means that cores in each group provide a good representation of product size, flaking intensity, flaking patterns, and frequency of Levallois. The statistical differences that do exist concern the frequencies of different platform preparation techniques ($p<0.001$ in both PA and 55-46) and blank elongation in 55-46 only (measured on blanks and the last scars on cores).

In both groups, faceting is observed more frequently on the cores than on the blanks, yet overhang removal is slightly more visible on the blanks. This imbalance between cores and blanks is just a matter of proportions: there are far more blanks than cores and careful platform preparation though faceting is expected to occur at much lower frequencies in the former. Overhang removal is more common on blanks than cores because most, if not all, of the traces of this preparation technique would be removed from the core face along with blank removal. Conversely, remnants of faceting on core platforms are often retained after blank removal. These factors likely explain the discrepancy in the frequency of the different platform preparation techniques between cores and blanks in each group.

55-46 blanks are significantly more elongated than the last scars on 55-46 cores ($p=0.015$); therefore, the production of more elongated flakes is not reflected in the discarded cores yet is apparent in the debitage. As discussed, 55-46 cores appear to be a more reduced subset of the Levallois-Mousterian cores as a whole. It appears that the relatively exhausted nature of the often small and flat discoidal and Levallois cores, which largely make up 55-46, obscure earlier stages of reduction where more elongated blanks were being produced. The extensive debitage from 55-46 does appear to represent various stages along the reduction continuum; for example, the blanks that preserve cortex are larger than those without ($p<0.001$), suggesting that initial decortification of 55-46 cores took place within the excavated area. Consequently, the data were explored further to establish if production strategies shifted during the course of reduction from earlier large blade to smaller flake production. The results do show an earlier period of larger blade production that is not reflected in the cores; more elongated blanks (with an elongation index of ≥ 2) have a significantly higher mean mass ($p=0.045$) than the less elongated blanks (elongation index of <2). As well as being heavier, the more elongated blanks also have larger amounts of cortex remaining than the less elongated blanks ($p=0.004$). However, large blank production was not restricted to the manufacture of elongated blanks. Further investigation reveals that Levallois flakes were produced at the beginning as well as at the end of reduction. Blanks classified as Levallois flakes are significantly heavier than all other flakes ($p<0.001$), yet there is also a high frequency of small Levallois cores in this group (50% of 55-46 cores are Levallois cores). There is a significant difference, however, in dorsal scar pattern between more and less elongated blanks ($p<0.001$), as would be expected given differences in blank shape. The major differences do not lie in the frequencies of unidirectional or bidirectional dorsal scar patterns; these are only marginally higher in the elongated blanks. Instead, the differences lie in the higher frequency (61% versus 47%) of radial flaking in the less elongated blanks, and the higher frequency (16% versus 8%) of elongated blanks that show removals from the dorsal ridge.

Irrespective of blank elongation, the blanks that show ridge-derived removals are also significantly larger ($p<0.001$) than those that show all other dorsal scar patterns, except those preserving bidirectional removals. Interestingly, there is no significant difference in the size of blanks with bidirectional or radial scar patterns; together with ridge-derived scar patterns, these have the highest mean mass. This lends support to the finding that radial flaking methods (including Levallois) persisted at various stages throughout the reduction sequence. The smallest blanks are those with unidirectional (linear and convergent) scar patterns derived from the proximal end, as well as those with scars derived from the left or right margins. This relationship is suggestive of both discoidal reduction and Levallois core surface and platform preparation, and is consistent with the high frequency of small discoidal and Levallois cores within the 55-46 group. Together, these findings suggest that: (1) given these relationships between size, shape (elongation), cortex coverage and ridge-derived scar patterns, a key purpose of large elongated blank production was directed at early core management, perhaps to create appropriate surface convexities; (2) radial (including Levallois) methods of core reduction took place throughout the reduction continuum and not just towards the end. The absence of larger Levallois and discoidal cores in 55-46 suggest that there was a tendency towards exploiting the selected chert nodules to exhaustion. To summarise, the blanks from 55-46 provide additional complexity to our understanding of the reduction sequence than is revealed by the cores alone.

5.2.2 Inter-group blank comparisons

Comparisons between PA and 55-46 blanks reveal the same similarities and differences with respect to equivalent variables as shown when PA and 55-46 cores are compared (Table 3). There is only one exception: while there is no difference between the two groups in the frequency of cores with cortex remaining on the surface, significantly more PA blanks (29%) have cortex present when compared to 55-46 blanks (25%) (p=0.012). Not only is there a higher frequency of PA blanks with cortex present but mean cortex percentage is also significantly higher (p=0.002). This supports observations that 55-46 cores are relatively more reduced than PA cores. Whilst taking into account this discrepancy, the blanks reveal the same patterns as the cores in all other respects where equivalent variables can be explored.

Table 3. Results of statistical comparisons between PA (Pre-Aurignacian) and 55-46 (Levallois-Mousterian spit 55-46) blank attributes. These are contrasted with the results of statistical analyses of equivalent attributes recorded on cores in these two groups.

Core comparisons			**Do blank comparisons show the same relationship?**	**Blank comparisons**		
PA cores	**55-46 cores**	**P-value**		**PA blanks**	**55-46 blanks**	**P-value**
Larger last scar surface area	Smaller last scar surface area	p=0.002	Yes	Larger surface area	Smaller surface area	p<0.001
Lower scar count	Higher scar count	p<0.001	Yes	Lower dorsal scar count	Higher dorsal scar count	p<0.001
More elongated last scars	Fewer elongated last scars	p<0.001	Yes	More elongated	Less elongated	p<0.001
More unidirectional and bidirectional flaking	More radial flaking	p<0.001	Yes	More unidirectional and bidirectional scar patterns	More radial scar patterns (and scars removed from dorsal ridge)	p<0.001
More single conchoidal[1] platforms	More multi-conchoidal[2] platforms	p<0.001	Yes	More single conchoidal[1] platforms	More multi-conchoidal[2] (including dihedral) platforms	p<0.001
Faceting uncommon	Faceting common	p<0.001	Yes	Lower rates of faceting	Higher rates of faceting (including	p<0.001

					heavy faceting)	
Fewer Levallois cores	More Levallois cores	$p<0.001$	Yes	Lower frequency of Levallois	Higher frequency of Levallois	$p<0.001$
No difference in cortex coverage		Not significant	No	More blanks with cortex present (29%)	Fewer blanks with cortex present (25%)	$p=0.012$

[1] Platforms consisting of a single flake scar.

[2] Platforms consisting of multiple flake scars.

An analysis of blank attributes together with core attributes can undoubtedly add greater complexity to our understanding of core reduction strategies. Illustrated here, however, a focus on cores alone can give a reasonably accurate account of core reduction strategies where patterns seen in the cores remain largely the same when blanks are also considered. This is the case at least for the two analytical groups explored in detail here. It does not follow that the same can be said of every site, or assemblage within a site, but it adds legitimacy to the following cores-only based analysis where cores from a range of landscape sites are contrasted with those from Haua Fteah.

5.3 Comparisons between cores from landscape sites and those from Haua Fteah

Using a series of univariate statistical tests applied to metric and non-metric traits, cores from the landscape (Fig. 1) were compared to the four Haua Fteah assemblages in turn. Results show the extent to which each of the landscape sites (Hajj Creiem and CPP8009) and site clusters (Al-Marj, North Gebel and Upper Gebel) are different from each of the four Haua Fteah groups. Figure 6 illustrates the extent of statistical differences between assemblages by combining the results of all tests (for details, refer to Table A.5). Scar pattern analysis also highlights similarities and differences between assemblages (Fig. 5).

Discriminant function analysis is used to predict the group of cores from Haua Fteah that cores from the landscape are most closely affiliated with (at least according to those variables used to calculate the discriminant functions). While univariate tests give an account of overall inter-group differences, DFA classification provides the probability that an individual core is a member of either the PA or LM or ED group. Landscape cores are entered into the DFA as ungrouped cases; therefore, the attributes of the landscape cores are not involved in the calculation of the discriminant functions. Instead, their squared Mahalanobis distances from group centroids are used to calculate probabilities of group membership (Table A.6). Cores from spit 55-46 are excluded for two reasons. First, combining 55-46 and LM cores into a single group results in large inter-group differences in sample size, which can impact classification accuracy. By excluding 55-46 cores, group sizes remain similar. Second, the 55-46 group is an artificial grouping within the Levallois-Mousterian, and the separate inclusion of two highly similar groups (i.e. LM and 55-46) would bias classification. Given that a higher number of misclassifications in DFA 2 involved the two Levallois-Mousterian groups, the exclusion of 55-46 from the DFA used to classify landscape cores increases the hit ratio considerably, where 64% of cross-validated grouped cases are correctly classified (in contrast to 47 % in DFA 2). Classification of landscape cores is based on DFAs that exclude cores-on-flakes and use the same variables as in DFA 2; therefore, size is controlled for in classifications.

5.3.1 Baltat ar Ramlah, site CPP8009

Site CPP8009 cores are included in univariate comparisons but not in DFA classification because these were analysed during an earlier field season when fewer attributes were recorded, including several of those used in DFA. Where differences are apparent between CPP8009 and Haua Fteah cores, these can all be explained by differential reduction intensity. The former are representative of relatively earlier stages in the reduction sequence. The site is situated immediately adjacent to low quality chert outcrops, and thus material quality, as well as immediate proximity to source material, may also be underlying some of these differences and obscuring any potential cultural affiliations with the Haua Fteah cores. Furthermore, the potential role of very different ecological contexts (an open site in a pre-desert environment versus a cave near the Mediterranean coast) as an underlying cause of core variation must be considered seriously. Typologically, CPP8009 cores share the greatest affinities with LM and PA cores; however, the site is a palimpsest and the presence of artefact recycling suggests that the area was repeatedly revisited (Jones et al., 2011), both meaning that more specific assertions regarding age would be too speculative.

5.3.2 Al-Marj

The lithic artefacts recovered during surveys of Al-Marj are exceptional for the region. This is on account of the large number of bifaces (predominantly handaxes at various stages of reduction) found during surveys of the canal cutting. Previously, only very occasional handaxes have been reported in northern Cyrenaica (Reynolds, 2013). Bifaces (including bifacial foliates and bifacial cores) are also very rare in Haua Fteah. These are confined to the lowermost Levallois-Mousterian layers and to older contexts within a small artefact concentration in the middle of McBurney’s Deep Sounding, located above and separate from the artefact-rich Pre-Aurignacian layers.

The Al-Marj cores included in analyses here (handaxes are excluded) represent a range of core types (Table A.4). In terms of scar pattern (Fig. 5) and high scar counts, they share the greatest affinities with the Levallois-Mousterian cores from Haua Fteah, and the greatest differences with the PA and ED cores. Like those from CPP8009, Al-Marj core attributes are suggestive of lower reduction intensity than those from all Haua Fteah groups. Chert sources, of a similar high quality to the cherts encountered in Haua Fteah, are exposed in the canal cutting and in the immediate vicinity of the cores described here. Cores (as well as bifaces) at various stages of reduction were identified during surveys. An affiliation between Al-Marj and LM cores is supported by DFA classification results (Table A.6); 60% are classified as LM, where 33% have a $\geq$0.7 probability of belonging to this group. Other cores align more closely with the PA group (27%, but with varying levels of certainty) and ED group (13%). Only two cores were classified as ED, a single platform blade core and a bidirectional bladelet core, and the probabilities that they belong in this group are high at 0.78 and 0.9 respectively. These results, together with the presence of a broad range of core and retouched tool types in the area, suggest that there were multiple phases of occupation in the Al-Marj basin during the MSA and early LSA. It is also possible that Al-Marj preserves lithic technologies from time periods that have no equivalent samples in the Haua Fteah sequence. There were substantial periods of time when very few artefacts were discarded in Haua Fteah; in particular, between the artefact-dense Pre-Aurignacian and Levallois-Mousterian layers and during the late Levallois-Mousterian and earliest Dabban. Furthermore, the technologies of northern Cyrenaica that precede the Pre-Aurignacian are unknown currently.

5.3.3 Upper Gebel

Lithic artefacts from Upper Gebel sites, at high elevations in the Gebel Akhdar, have been previously aligned with LSA technologies (Barker et al., 2010; Jones et al., in press). DFA classifications contradict this slightly, yet the results of univariate statistical tests do not. If the DFA used to predicted group membership excludes core mass, then 58% of Upper Gebel cores are classified as PA and only 33% as ED. Yet if mass is included, only 17% are classified as PA and 58% as ED. Uncertainties in the probabilities of group membership reflect the technological similarities between PA and ED cores, and these are clearly impacting landscape core classifications. As shown, core size is an important variable for discriminating between PA and ED cores. Arguably, the incorporation of mass in classification of the Upper Gebel cores provides more accurate results. Two discoidal cores from CPP8113 are classified as ED and LM; the latter is the only Upper Gebel core classified as LM (the results remain the same after correcting for size). The probability that this discoidal core belongs to LM is poor (<0.44), whereas the probability that the other discoidal core belongs to ED is high (0.7, includes core mass). Discoidal cores and occasional Levallois cores are present in the Early Dabban layers at Haua Fteah so this result is not surprising. While there are some inconsistencies in the classification of Upper Gebel cores, particularly in distinguishing between PA and ED group predictions, the results of univariate tests firmly align the Upper Gebel cores with the Early Dabban. These consider more variables than DFA classifications and inter-group comparisons of 16 variables show that Upper Gebel cores are statistically indistinguishable from ED cores and are most different from LM cores (Figs. 5 and 6).

5.3.4 North Gebel

Cores in the North Gebel cluster of sites, located only 6-15 km from Haua Fteah, show mixed predicted memberships to the three Haua groups. As the univariate tests conflate cores from eight separate locations into one larger group, DFA classification results enable more precise interpretations. Both methods show close affiliations between the North Gebel cluster and the Pre-Aurignacian, where 52% of cores are classified as PA. This is particularly the case at CPP8119, where 56% of cores are classified as PA, 22% as LM and 22% as ED. This site provides the strongest evidence to date for a Pre-Aurignacian presence beyond the cave. The artefacts derive from ploughed red-brown soils that had been levelled for agriculture, disturbing older buried material. Clearly younger material was observed in the western part of the site, including backed pieces and a bidirectional bladelet core, classified here as ED (0.69 probability). To different degrees, all sites in the North Gebel cluster appear to contain material of different ages.

5.3.5 Hajj Creiem

Unlike cores from the other landscape sites, the excavated artefacts from Hajj Creiem derive from a highly restricted time range (McBurney and Hey, 1955, p. 143). This is well reflected in the results of the univariate tests and DFA classifications. There is an unequivocal affiliation between the Hajj Creiem cores and those from the Levallois-Mousterian layers of Haua Fteah. They are almost statistically indistinguishable from one another. The main characteristic that sets Hajj Creiem apart is the presence of a high number of cores-on-flakes. These comprise 56% (n=14) of the total number of complete cores and are represented by several different types of cores-on-flakes: nine are Kombewa cores (where the flake bulb has been removed), three are discoidal cores-on-flakes, and two are unidirectionally and radially flaked truncated faceted pieces. Cores-on-flakes are encountered throughout the Haua Fteah sequence but at much lower frequencies than at Hajj Creiem. Inclusion of cores-on-flakes bias DFA classifications as seven cores-on-flakes are classified as PA and seven as LM. This is a misnomer as the typically low scar counts on the core-on-flakes is resulting in them being grouped with PA. A far more accurate picture of assemblage affiliations is gained if cores-on-flakes are excluded from classification, where 91% of cores are classified into LM with high probabilities ranging from 0.54 to 1 (73% have >0.7 probability of belonging to LM). One discoidal core is classified as PA, but it is in an earlier stage of reduction that the other cores and its lower scar count and greater thickness are perhaps the leading variables that are grouping it with PA. Discoidal cores and Levallois cores (preferential, and radially and bidirectionally recurrent) and the aforementioned cores-on-flakes are the only core types recorded at Hajj Creiem. This represents a low diversity of types when compared with those from the MSA layers of Haua Fteah. This could be a reflection of either the lower sample size of cores from Hajj Creiem or a shorter period of occupation of the site, perhaps geared towards more task-specific activities.

6. Discussion

Three main questions have been addressed in this paper: how core reduction strategies in Haua Fteah changed from the earliest MSA to the early LSA; if this can be determined by considering only the cores and not the entire assemblage; and the extent to which cores from sites in the landscape can be correlated with different phases of occupation at Haua Fteah. With respect to the first of these, it has been shown that differential reduction intensity does not underlie any major differences between assemblages. Nor do raw material type, quality and availability; the vast majority of cores in all assemblages are made on medium and high quality cherts that are readily available locally. This means that factors related to cultural tradition underlie the differences in reduction strategies between the three major phases of human presence in Haua Fteah examined here. Are these cultural changes stochastic (i.e. due to chance), or are they explained by human adaptation to different ecological conditions and resources, or by demographic shifts in the region (e.g. population growth, extinctions, replacements), or by a combination of these different factors? McBurney (1967) certainly favoured demographic explanations as a cause of cultural change throughout the Haua sequence. On the basis of similarities in lithic technologies, he looked to southwest Asia in particular as the source of the Pre-Aurignacian, Levallois-Mousterian and Dabban, relating them to population "incursions" rather than indigenous developments from one industry to the next (e.g. McBurney, 1967, p. 326). Here, it is iterated strongly, however, that the factors that explain these cultural changes in Haua Fteah cannot be answered by an examination of the lithic artefacts alone (and certainly not of just the cores). Additional datasets need to be incorporated to address this (e.g. palaeoclimatic, palaeontological, palaeobotanical, genetic, etc.) and this is beyond the scope of this paper.

One of the surprising results of this study is that the Pre-Aurignacian cores as a whole are more similar to the Early Dabban cores than they are to those from the Levallois-Mousterian when each core is essentially stripped down to the same set of recorded attributes. This is one of the benefits of attribute analysis as an objective procedure as it avoids preconceived notions that may bias interpretations. In spite of the similarities between the Pre-Aurignacian and Early Dabban, there are some key differences (the latter are smaller, more elongated and more intensively flaked), and the Haua Pre-Aurignacian is certainly not an Upper Palaeolithic or Late Stone Age industry. Levallois technologies are part of the Pre-Aurignacian (Moyer, 2003; but contra McBurney, 1967, p. 325) but by no means to the same prolific extent to which they are present in the Levallois-Mousterian. An argument for close cultural connections between populations that produced technologies termed "Pre-Aurignacian" in the Levant and in Haua Fteah was proposed (McBurney, 1967, pp. 97, 326) and followed (Moyer, 2003, p. 35). Yet, this has little chronological support (see section 3) and has not been tested through thorough comparative technological analyses. Instead, it is more plausible that the Haua Pre-Aurignacian is simply comparable to one of the many earlier Middle Palaeolithic and Middle Stone Age assemblages where blade production occurred in differing frequencies at sites in Europe, western Asia and Africa during the later Middle Pleistocene and early Upper Pleistocene. Furthermore, these early blade-based technologies were practiced by different hominin species and cannot be associated with any particular species, such as *Homo sapiens* (for a comprehensive review, see Bar-Yosef and Kuhn, 1999). McBurney referred to the Libyan Pre-Aurignacian as a "highly idiosyncratic material culture" (McBurney, 1967, p. 90). This now remains to be confirmed; perhaps if it is similar to several other early MSA (or Middle Palaeolithic) blade-based industries then it is not so idiosyncratic.

Bar-Yosef and Kuhn (1999, p. 329) have noted, "In most regions, including the Levant, southern Africa, and Europe, the use of blade technologies waxes and wanes markedly over time, and early blade-based assemblages are subsequently replaced by flake-based Middle Paleolithic or Middle Stone Age industries". This is certainly the case in Haua Fteah. Given the high frequency of Levallois and discoidal cores in the Levallois-Mousterian layers, Levallois and discoidal reduction methods become engrained in knapping behaviours during this period. In many ways, Pre-Aurignacian knapping traditions were more varied and opportunistic, yet those in the Levallois-Mousterian were relatively culturally conservative, perhaps reflecting more established lines of cultural transmission, where knapping behaviours were taught, learnt and passed on.

Analyses of cores and blanks in two of the analytical groups have demonstrated that the cores reflect almost exactly the same patterns as the blanks. Conclusions based on the cores alone are therefore reasonable; however, there is no doubt that information from the blanks (unretouched and retouched) would add further detail and resolution to these observations. For example, comparisons of Pre-Aurignacian and Early Dabban blanks and tools would presumably tease apart these industries considerably (the relatively high frequency of backing in the latter but not the former is one of several examples). Furthermore, cores throughout the sequence occur at substantially lower frequencies than blanks, which is why cores from several different contexts have been grouped together here to ensure that statistical comparisons are viable. Where individual layers have produced large enough samples of blanks, then analyses of the debitage provide greater resolution. For example, analyses of blank attributes can explain variability in reduction strategies within the Levallois-Mousterian and within the Pre-Aurignacian. In this way, more specific hypotheses can be tested more effectively, such as those regarding cultural continuity and social transmission during the MSA at Haua Fteah.

While comparisons of cores in the four Haua Fteah groups have provided useful information regarding broad-scale changes in reduction methods throughout the MSA and early LSA sequence, the incorporation of cores from landscape sites has also produced some interesting results. In this study, as well as others, Discriminant Function Analysis has been shown to be a useful method for exploring morphological and technological variation between different groups of cores. Here, it has also been used to determine how reliably individual cores from the landscape can be classified into each of the three main Haua Fteah cultural periods investigated here. The outcome of this method is dictated by the variables that are entered into the analysis (and not all recorded variables can be included for reasons already explained); therefore, the inclusion of different variables may or may not produce different results and this is something that would be interesting to test in the future. Using DFA to classify cores from landscape sites surpasses the problem of palimpsest assemblages, typical of surface lithic scatters. This is because it classifies single cores, not the collection within which they occur, and can even be used to estimate the extent to which cores in a surface assemblage are chronologically mixed. While the univariate tests used here have considered more variables than the discriminant analyses, cores discarded during different time periods are conflated into artificial groups (with the exception of Hajj Creiem); however, the results of multivariate and univariate approaches have been shown to complement one another.

Haua Fteah provides the only well dated Palaeolithic cultural sequence in northeast Libya (McBurney, 1967; Douka et al., 2014) and we are therefore reliant on this site for chronometric ages for different cultural episodes. A principal aim behind using DFA to classify cores was to investigate if morphological and technological similarities between undated landscape cores and those from the Haua sequence could be used to impart an approximate chronology on the former. The success of this approach is mixed and several general points need to be made. First, not all cores from the Haua Fteah excavations have been included here, such as those from Oranian, Capsian and Neolithic occupation phases. It is quite possible that some of the cores from the Upper Gebel in particular, as well as those from some sites in the North Gebel, may align more closely (i.e. classify with higher probabilities) to these cultural periods. This could be tested through further data collection.

Second, Hajj Creiem is exceptional, as the cores from this excavated site can be equated with a considerable degree of certainty with the Haua Levallois-Mousterian cores. In contrast, there may be cores that were discarded at landscape sites during periods that have no temporal equivalent at Haua Fteah. This may include cores discarded earlier than the first evidence for hominins at Haua Fteah, or during periods when there is little sign of human habitation in the cave. Based on both core traits and DFA classifications, it is suspected that this may be the case for some (but not all) of the analysed cores from Al-Marj, as these appear to represent multiple time periods, albeit predominantly MSA. Some are very similar to the Levallois-Mousterian cores, yet it is tentatively suggested that some Al-Marj cores and bifaces may correspond chronologically to a fairly discrete occupation phase preserved in the middle of the Deep Sounding. This is an exceptionally small artefact concentration, situated stratigraphically in between the Pre-Aurignacian and Levallois-Mousterian phases of occupation, and includes evidence of bifacial cores (possibly core-axes) and broken bifacial foliates.

Third, given the similarities between Pre-Aurignacian and Early Dabban cores, caution is recommended in loosely assigning lithic artefacts from surface sites to particular cultural phases. The results of intra-site comparisons of the Haua Fteah cores (DFA 1 and DFA 2) show that a proportion of Early Dabban cores are misclassified as Pre-Aurignacian and a proportion of Pre-Aurignacian cores are misclassified as Early Dabban. Similar misclassifications have likely occurred when landscape cores have been assigned to the different cultural phases at the Haua Fteah. Where misclassifications are suspected, then an examination of other artefact types found at a site (e.g. backed blades or bladelets, chamfered blades, etc.) can help to discriminate between possible cultural periods represented. For example, this has enabled sites in the Upper Gebel to be more firmly associated with LSA occupation. In addition, the geological context of some surface sites can occasionally provide important information regarding approximate age. For example, both core classifications and geological context at site CPP8119 suggest that this is the first known manifestation of the Pre-Aurignacian in an open setting outside Haua Fteah.

Fourth, classifications of cores into the Haua Fteah groups could be confounded by several environmental factors that may be driving core reduction strategies alongside cultural tradition. These include, for example, factors related to site type (e.g. cave versus lake margin), microclimate, ecological setting (e.g. coast versus mountain) and resources (e.g. distance to and availability of potable water, terrestrial and aquatic animals and plants, lithic raw materials). It is plausible that the period of human occupation at Hajj Creiem is contemporary with one of the phases of Levallois-Mousterian occupation at Haua Fteah; however, there are minor technological differences between these sites that might be explained by one or more of these environmental factors. Although cores from CPP8009 in the Baltat ar Ramlah palaeolake in the pre-desert region were not included in DFA classifications, it is clear from other statistical comparisons that lower reduction intensity and raw material factors (immediate proximity to raw materials of poorer quality) are major causes of differences between CPP8009 and Haua Fteah cores, possibly together with several other factors (e.g. the site's location in a very different ecological setting).

To conclude, there are multiple and often intimately correlated factors that may underlie intra- and inter-site variation in core reduction strategies. These factors, that are not necessarily mutually exclusive, fall under three main umbrellas relating to time, people and the environment. Several environmental causes of lithic variation have been highlighted above, with reference to specific sites, yet there are numerous factors broadly relating to climate, geography, geology and ecology that may also be relevant. Time is another major contributor to lithic variation, with its obvious association with cultural change, including fluctuations through time in similar cultural expressions (e.g. as with blade production in the Pre-Aurignacian and Early

Dabban). Time is also associated with the creation of the archaeological record and its later investigation. For example, comparisons between artefacts from discrete knapping events and palimpsest surfaces should reveal different patterns of variation, as may artefacts derived from different excavation years, especially if these have involved disparate sampling and storage procedures. As has been done here, many of the factors relating to the environment and creation and sampling of the archaeological record can be recognized and assessed in terms of how strongly they are contributing to intra- and inter-site core variation. These are the factors, however, that are the easiest to assess. It is the factors relating to the people that actually reduced the cores that remain far more elusive. For example, it is far easier to determine proximity between a site and raw material source and use this to explain differences in core reduction strategies than it is to establish if technological differences may have been caused by geographical isolation of human groups undergoing cultural drift. Furthermore, past demographic processes may have influenced core reduction strategies in certain places during certain periods; yet in others, lithic technological stasis may have prevailed even when demographic shifts were occurring. The spatio-temporal similarities and differences in core reduction strategies described in this paper cannot be used on their own to reconstruct past demographic processes but they can be used to generate hypotheses regarding these. An example would be to hypothesize that the human groups that occupied Hajj Creiem and the MIS 4 Levallois-Mousterian contexts at Haua Fteah were part of the same general population. A second hypothesis may be that there was population continuity in the Gebel Akhdar region from the Pre-Aurignacian to the Levallois-Mousterian. In order to test any hypotheses regarding past demographic processes in the region, the incorporation of high-resolution multiple lines of evidence is essential. Specifically, these include more extensive lithic datasets, detailed chronostratigraphic data, palaeoclimatic reconstructions, and palaeobotanical and zooarchaeological datasets. These have been collected during the course of the TRANS-NAP project, of which the research presented here forms a part, and are being integrated in order to address hypotheses about past population dynamics in the Gebel Akhdar from the MSA onwards.

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Title

Middle Stone Age reduction strategies at the desert's edge: a multi-site comparison across the Gebel Akhdar of northeast Libya

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APPENDIX A

Table A.1. Definitions of quantitative and qualitative variables used in statistical analyses of cores. To take measurements, cores are orientated by the last major flake scar removed from the core, with the last core platform at the top and the distal end (base) of the core at the bottom. Here, the last flaked face is abbreviated and referred to as "plane 1", where the opposite flaked face (viewed after rotating the core 180° around its length axis) is referred to as "plane 2". Examples are given for categorical variables rather than all possible outcomes.

Attribute category	**Variable**	**Definition**
Cortex	Cortex %	Percentage of cortex remaining on the core.
Size	Mass	Mass of core (g).
Shape	Core elongation	Ratio of core length to medial core width. Core length is measured from the point on the platform edge from where the last major blank was detached (along the axis of percussion) to the distal end of the core. Medial core width is measured perpendicular to and at the midpoint of core length.
	Core flatness	Ratio of medial core width to medial core thickness. As with medial core width, medial core thickness is taken at the midpoint of core length.
Platform features	Platform surface	e.g. cortical, crushed, single conchoidal (comprised of a single flake scar), multi-conchoidal (comprised of multiple flake scars).
	Platform preparation	e.g. faceting, overhang removal.
	Last platform angle	Angle (in degrees) created between the platform and the last blank (i.e. last scar) removed from that platform.
Scar features	Number of major scars	Number of scars that extend over more than one third of the length of the core.
	Total number of scars	Total number of scars across all core surfaces. This does not include platform preparation scars, created by faceting or overhang removal, or core retouch scars (e.g. present on core scrapers).
	Number of scars on plane 1	Number of scars on the last flaked face of the core (plane 1).
	Number of scars on plane 2	Number of scars on the opposite surface to the last flaked face (plane 2).
	Number of non-feather terminations	Number of major scars that end in non-feather terminations (i.e. step, hinge, overshot/plunging terminations).

	Last scar elongation index	Ratio of last scar length to last scar medial width. Last scar length is taken from the point of percussion along a line perpendicular to the platform to the distal termination of the scar. Medial scar width is taken perpendicular to and at the midpoint of scar length.
	Last scar surface area	The product of last scar length and medial scar width.
	Last scar invasiveness (by area)	Ratio of last scar surface area to last core face area. Last core face area is the product of core length and medial core width.
	Last scar invasiveness (by length)	Ratio of last scar length to last scar face length. Last scar face length is taken along the same line as last scar length but the measurement terminates at the distal end of the core rather than at the distal end of the last scar.
Scar pattern	Flaking pattern	e.g. unidirectional, bidirectional, radial, random.
	Number of scars at 0° (plane 1)	The number of scars that show blank removals initiated from a direction of 0° on plane 1. As the core is orientated by the last scar removed and with the platform at the top, then the last scar will always be removed from a 0° angle (see Fig. 5). For example, if flaking is unidirectional from a single flat platform, then all blanks will have been detached from 0°.
	Number of scars at 45° (plane 1)	The number of scars that show blank removals initiated from a direction of 45° on plane 1.
	Number of scars at 90° (plane 1)	The number of scars that show blank removals initiated from a direction of 90° on plane 1.
	Number of scars at 135° (plane 1)	The number of scars that show blank removals initiated from a direction of 135° on plane 1.
	Number of scars at 180° (plane 1)	The number of scars that show blank removals initiated from a direction of 180° on plane 1.
	Number of scars at 225° (plane 1)	The number of scars that show blank removals initiated from a direction of 225° on plane 1.
	Number of scars at 270° (plane 1)	The number of scars that show blank removals initiated from a direction of 270° on plane 1.
	Number of scars at 315° (plane 1)	The number of scars that show blank removals initiated from a direction of 315° on plane 1.
	Number of flaking directions on plane 1	The total number of flaking directions on the last flaked face. This figure can range from 1-8. For example, if blank removals are initiated from 0°, 45°, 90°, 135°, 180°, 225°, 270° and 315° then the number of flaking directions will be 8 but if blanks are only removed from 0°, then the number of flaking directions will be 1.
Typology	Discoidal core	i.e. discoidal, not discoidal.
	Levallois core (preferential)	i.e. preferential Levallois, not preferential Levallois.
	Levallois core (recurrent)	i.e. recurrent Levallois, not recurrent Levallois.

Table A.2. Definitions of quantitative and qualitative variables used in statistical analyses of unretouched and unbroken blanks.

Attribute category	**Variable**	**Definition**
Cortex	Cortex presence	i.e. cortex present, cortex absent.
	Cortex %	Percentage of cortex remaining on the flake dorsal surface and/or platform.
Size	Mass	Mass of blank (g).
	Surface area	Product of flake length and flake medial width. Flake length is taken along the axis of percussion and perpendicular to the platform edge, from the point of percussion to the distal end of the flake. Flake medial width is taken perpendicular to and at the midpoint of flake length.
Shape	Elongation index	Ratio of flake length to flake medial width.
Scar features	Dorsal scar count	Number of scars on the dorsal surface (not including scars formed by retouch or edge damage).
	Dorsal scar pattern	e.g. from proximal, from left, from right, bidirectional, radial, crested.
Platform features	Platform preparation	e.g. faceting, overhang removal.
	Platform type	e.g. cortical, punctiform, single conchoidal, dihedral, multiple conchoidal.
Typology	Levallois blank	i.e. Levallois, not Levallois.

Description of statistical techniques

Univariate statistical tests

Univariate statistical tests used in this paper consist of parametric tests (ANOVA) and non-parametric tests (Kruskal-Wallis, Mann Whitney U) of quantitative data, and Pearson's chi-square test and Fisher's exact test of categorical data. Normality tests (Kolmogorov-Smirnov and Shapiro-Wilk) and histograms are used to examine the distribution of scale variables within each analytical group. Several variables become normalised following log10 transformations. Group means of normally distributed untransformed and transformed data are compared using ANOVA. Where ANOVA tests give a statistically significant result (alpha level, $p \leq 0.05$), post hoc tests are used to examine inter-group relationships. If homogeneity of variance can be assumed (determined using Levene's test), Gabriel post hoc tests are interpreted. Where variances are found to be unequal, the results of Games Howell post hoc are followed. Non-parametric tests are used to examine variables that cannot be normalised. Kruskal-Wallis tests are used to examine the distribution of data across three or more groups. If a significant result is obtained, a Kruskal-Wallis test is followed by pairwise comparisons using Mann Whitney U tests. The latter determine between which groups the significant difference(s) exists. Where multiple pairwise comparisons are made, the significance level is adjusted accordingly using a Bonferroni correction; this reduces the likelihood of Type 1 errors (i.e. falsely rejecting the null hypothesis).

Discriminant Function Analysis (DFA)

Discriminant function analysis is a multivariate statistical technique that is employed here for two purposes. First, the standardized canonical discriminant function coefficients are used to determine which variables have the greatest power at discriminating between the pre-defined analytical groups of cores. Structure matrix correlations (only those with values ≥ 0.3 are interpreted) are used to establish the strength and direction of the relationship between variables and statistically significant functions. The latter are determined using Wilk's lambda test. Second, classification is an important and useful component of DFA. Here, canonical discriminant functions are used to predict the analytical group to which each core most likely belongs, on the basis of those variables inputted into the analysis. Of particular interest is the frequency at which the Haua Fteah cores in the four analytical groups are misclassified into a different group. High rates of misclassification can be used to identify similarities between particular groups of cores, at least in terms of those variables included in the model. DFA is not only used here to examine misclassification rates but it is also used as a tool to classify ungrouped cores from the landscape into any one of three groups of cores from Haua Fteah. Classification procedures are discussed further below, but first the validity of the discriminant analyses reported here are subject to meeting a number of conditions.

Various assumptions need to be met for a DFA to be viable. The continuous variables included in the analysis must display multivariate normality, which can be assessed by conducting normality tests on the distribution of each variable within each group. To meet this assumption, several variables had to be transformed (typically using log10 transformations) to ensure that the relevant data was normally distributed within each group. Where it was not possible to normalise data for certain variables, these were excluded from the analysis. Normally distributed variables (mostly transformed) were entered into the analysis and group mean comparisons were made using ANOVA tests. Variables that gave insignificant results were excluded and the analysis repeated.

The extent of collinearity needs to be taken into account, where predictor variables should not be highly correlated (e.g. Hair et al., 2010, pp. 165). Correlated variables were identified by examining the pooled within-groups correlation matrix. Those that are deemed highly correlated have correlations of ≥0.8 (Field, 2005, pp. 175). None of the variables included in any of the discriminant analyses even approached values this high; therefore, collinearity was not a problem.

The classification procedure is sensitive to sample size, outliers and homogeneity of variance-covariance matrices. The number of cases in each group should be greater than the number of predictor variables (Tabachnick and Fidell, 2014, pp. 425), and each group should contain at least 20 cases. In terms of overall sample size (i.e. the total number of cores across all groups included in the analysis), there should ideally be 20 or more cores per predictor variable (Hair et al., 2010, pp. 353). All discriminant analyses reported here meet these sample size criteria. In the classification procedure, prior probabilities were set to consider all groups as equally likely, rather than computing from group sizes. This is because the different sample sizes of the different analytical groups are simply the random result of the sampling procedure during excavation or survey. By using this method, the classification coefficients are not weighted to take into account the number of cores within each analytical group and the classification results are not biased by different sample sizes.

DFA can be very sensitive to the presence of outliers. Multivariate outliers were identified by checking the squared Mahalanobis distances against the appropriate critical chi-square value for the number of variables in the analyses. The latter was calculated at the 0.05 probability level; in other words, outliers are identified as those cores whose probability of belonging to the group to which it is most closely affiliated is ≤0.05. If present, any outliers were excluded from the analysis.

Equality of group covariance matrices can be determined using Box's test, where a significant value indicates unequal group covariance matrices. This test, however, is frequently reported as being overly sensitive, often producing significant results (Tabachnick and Fidell, 2014, pp. 426; Hair et al., 2010, pp. 355, 440). An alternative assessment of homogeneity of variance-covariance matrices can be made by examining the bivariate scatterplots of scores for the first two functions for each group. Approximately equal distributions of data amongst the separate groups is deemed sufficient evidence for homogeneity of variance-covariance matrices (Tabachnick and Fidell, 2014, pp. 426). Furthermore, DFA is robust to violation of the assumption of equal variance-covariance matrices when group sample sizes are approximately equal (where, largest group size ÷ smallest group size is <1.5) (Hair et al., 2010, pp. 459). This condition is met because of the similar sample sizes of the different analytical groups used here.

To assess group predictions, the cross-validated ("jack-knifed") classification procedure is used as this provides the most accurate method for predicting the group into which a core most likely belongs. The 'hit ratio' gives the percentage of cores correctly classified by the discriminant analysis; an acceptable hit ratio is 25% larger than that due to chance. For example, ≥50% is an acceptable hit ratio where there are four pre-defined groups in the analysis where prior probabilities were set to consider all groups as equally likely. DFA is used to classify cores from the landscape sites into one of three Haua Fteah analytical groups. Cores from each landscape site (or group of multiple sites) are entered into the analysis as ungrouped cases. The probabilities of group membership, squared Mahalanobis distances and territorial map, are examined as a means to specify the group to which each landscape core most likely belongs.

Table A.3. Results of statistical comparisons of cores from Haua Fteah, divided into four analytical groups: PA (Pre-Aurignacian); LM (Levallois-Mousterian, excluding cores from spit 55-46); 55-46 (Levallois-Mousterian cores from spit 55-46); ED (Early Dabban). Samples include all complete cores (cores-on-flakes are excluded from analyses). The number of cores (n) within each group is provided for each test.

Comparison of Pre-Aurignacian cores and Levallois-Mousterian cores (excluding spit 55-46)

Variable	**PA**	**LM**	**Statistical test**[1]	**P-value**
Mass (log10)	Heavier (n=40)	Lighter (n=46)	ANOVA (Games-Howell)	p=0.003
Core elongation (log10)	More elongated cores (n=41)	Less elongated cores (n=46)	ANOVA (Gabriel)	p=0.004
Core flatness	Thicker (n=41)	Flatter (n=46)	ANOVA (Games-Howell)	p=0.002
Platform surface	More single conchoidal platforms (n=38)	More multi-conchoidal platforms (n=41)	Pearson Chi-Square	p=0.001
Platform preparation	Lower frequency of faceting (n=36)	Higher frequency of faceting (n=46)	Pearson Chi-Square	p<0.001
Total number of scars	Fewer scars (n=40)	More scars (n=45)	ANOVA (Games-Howell)	p<0.001
Number of non-feather scars	More non-feather terminations (n=40)	Fewer non-feather terminations (n=45)	Mann Whitney U	p=0.007
Last scar elongation index (log10)	More elongated last scars (n=40)	Less elongated last scars (n=46)	ANOVA (Games-Howell)	p<0001
Flaking pattern	More unidirectional, bidirectional and random flaking scar patterns (n=41)	More radial scar patterns (n=46)	Pearson Chi-Square	p<0.001
Discoidal core?	Fewer discoidal cores (n=41)	More discoidal cores (n=46)	Pearson Chi-Square	p=0.023
Levallois core?	Fewer Levallois cores (n=41)	More Levallois cores (n=46)	Pearson Chi-Square	p<0.001
Recurrent Levallois core?	Fewer recurrent Levallois cores (n=41)	More recurrent Levallois cores (n=46)	Pearson Chi-Square	p=0.004

No statistically significant differences in:
Cortex %
Last platform angle
Number of major scars
Last scar surface area
Last scar invasiveness by area
Last scar invasiveness by length

Comparison of Pre-Aurignacian cores and Levallois-Mousterian cores from spit 55-46

Variable	**PA**	**55-46**	**Statistical test**	**P-value**
Mass (log10)	Heavier (n=40)	Lighter (n=45)	ANOVA (Games-Howell)	p<0.001
Core elongation (log10)	More elongated cores (n=41)	Less elongated cores (n=46)	ANOVA (Gabriel)	p<0.001
Core flatness	Thicker (n=41)	Flatter (n=46)	ANOVA (Games-Howell)	p<0.001
Platform surface	More single conchoidal platforms (n=38)	More multi-conchoidal platforms (n=46)	Pearson Chi-Square	p<0.001

Platform preparation	Lower frequency of faceting (n=36)	Higher frequency of faceting (n=43)	Pearson Chi-Square	p<0.001
Number of major scars	Fewer major flake scars (n=41)	More major flake scars (n=46)	ANOVA (Gabriel)	p<0.001
Total number of scars	Fewer scars (n=40)	More scars (n=45)	ANOVA (Games-Howell)	p<0.001
Last scar elongation index (log10)	More elongated last scars (n=40)	Less elongated last scars (n=46)	ANOVA (Games-Howell)	p<0001
Last scar surface area (log10)	Larger last scars (n=40)	Smaller last scars (n=46)	ANOVA (Gabriel)	p=0.002
Flaking pattern	More unidirectional, bidirectional and random flaking (n=41)	More radial flaking (n=46)	Pearson Chi-Square	p<0.001
Discoidal core?	Fewer discoidal cores (n=41)	More discoidal cores (n=46)	Pearson Chi-Square	p=0.001
Levallois core?	Fewer Levallois cores (n=41)	More Levallois cores (n=46)	Pearson Chi-Square	p<0.001
Recurrent Levallois core?	Fewer recurrent Levallois cores (n=41)	More recurrent Levallois cores (n=46)	Pearson Chi-Square	p=0.004
No statistically significant differences in: Cortex % Last platform angle Number of non-feather scars Last scar invasiveness (by area) Last scar invasiveness (by length)				
Comparison of Pre-Aurignacian cores and Early Dabban cores				
Variable	**PA**	**ED**	**Statistical test**	**P-value**
Mass (log10)	Heavier (n=46)	Lighter (n=31)	ANOVA (Games-Howell)	p=0.001
Core elongation (log10)	Less elongated cores (n=41)	More elongated last scars (n=31)	ANOVA (Gabriel)	p=0.034
Number of major scars	Fewer major flake scars (n=41)	More major flake scars (n=31)	ANOVA (Gabriel)	p=0.001
Total number of scars	Fewer scars (n=40)	More scars (n=31)	ANOVA (Games-Howell)	p=0.02
Last scar elongation index (log10)	Less elongated last scars (n=40)	More elongated last scars (n=31)	ANOVA (Games-Howell)	p=0.044
Last scar surface area (log10)	Larger last scars (n=40)	Smaller last scars (n=31)	ANOVA (Gabriel)	p<0.001
Flaking pattern	More random flake removals but unidirectional and bidirectional flaking predominates (n=41)	No cores with random flake removals (but unidirectional and bidirectional flaking predominates (n=31)	Pearson Chi-Square	p=0.045
No statistically significant differences in: Cortex % Core flatness (similarly thick) Platform surface Frequency of faceting Last platform angle Number of non-feather terminations Last scar invasiveness by area Last scar invasiveness by length				

Frequency of discoidal cores Frequency of Levallois cores Frequency of recurrent Levallois cores				
Comparison of Levallois-Mousterian cores (excluding spit 55-46) and Levallois-Mousterian cores from spit 55-46				
Variable	**LM**	**55-46**	**Statistical test**	**P-value**
Mass (log10)	Heavier (n=46)	Lighter (n=45)	ANOVA (Games-Howell)	p<0.001
Number of major scars	Fewer major flake scars (n=46)	More major flake scars (n=46)	ANOVA (Gabriel)	p=0.007
Last scar surface area (log10)	Larger last scars (n=46)	Smaller last scars (n=46)	ANOVA (Gabriel)	p=0.009
No statistically significant differences in: Cortex % Core elongation Core flatness (similarly flat) Platform surface Frequency of faceting Last platform angle Total number of scars Number of non-feather terminations Last scar elongation index Last scar invasiveness by area Last scar invasiveness by length Flaking pattern (radial flaking predominates) Frequency of discoidal cores Frequency of Levallois cores Frequency of recurrent Levallois				
Comparison of Levallois-Mousterian cores (excluding spit 55-46) and Early Dabban cores				
Variable	**LM**	**ED**	**Statistical test**	**P-value**
Core elongation (log10)	Less elongated cores (n=46)	More elongated cores (n=31)	ANOVA (Gabriel)	p<0.001
Core flatness	Flatter (n=46)	Thicker (n=31)	ANOVA (Games-Howell)	p<0.001
Platform preparation	Higher frequency of faceting (n=46)	Lower frequency of faceting (n=27)	Pearson Chi-Square	p<0.001
Total number of scars	More scars (n=46)	Fewer scars (n=31)	ANOVA (Games-Howell)	p=0.001
Last scar elongation index	Less elongated last scars (n=46)	More elongated last scars (n=31)	ANOVA (Games-Howell)	p<0.001
Last scar surface area (log10)	Larger last scars (n=46)	Smaller last scars (n=31)	ANOVA (Gabriel)	p=0.001
Last scar invasiveness by area (log10)	Last scars more invasive by area (n=46)	Last scars less invasive by area (n=31)	ANOVA (Games-Howell)	p=0.004
Flaking pattern	More radial flaking (n=46)	More unidirectional and bidirectional flaking (n=31)	Pearson Chi-Square	p<0.001
Discoidal core?	More discoidal cores (n=46)	Fewer discoidal cores (n=31)	Fisher’s Exact Test	p=0.042
Levallois core?	More Levallois cores (n=46)	Fewer Levallois cores (n=31)	Pearson Chi-Square	p<0.001

Recurrent Levallois core?	More recurrent Levallois cores (n=46)	No recurrent Levallois cores (n=31)	Pearson Chi-Square	p<0.001
No statistically significant differences in: Cortex % Size Platform surface Last platform angle Number of major flake scars Number of non-feather terminations Last scar invasiveness by length				
Comparison of Levallois-Mousterian cores from spit 55-46 and Early Dabban cores				
Variable	**55-46**	**ED**	**Statistical test**	**P-value**
Mass (log10)	Lighter (n=45)	Heavier (n=31)	ANOVA (Games-Howell)	p<0.001
Core elongation (log10)	Less elongated cores (n=46)	More elongated cores (n=31)	ANOVA (Gabriel)	p<0.001
Core flatness	Flatter (n=46)	Thicker (n=31)	ANOVA (Games-Howell)	p<0.001
Platform surface	More multi-conchoidal platforms (n=46)	More single conchoidal platforms (n=29)	Fisher's Exact test	p=0.023
Platform preparation	Higher frequency of faceting (n=43)	Lower frequency of faceting (n=27)	Pearson Chi-Square	p=0.001
Last platform angle	Lower last platform angle (n=46)	Higher last platform angle (n=30)	ANOVA (Gabriel)	p=0.044
Total number of scars	More scars (n=45)	Fewer scars (n=31)	ANOVA (Games-Howell)	p<0.001
Last scar elongation index (log10)	Less elongated last scars (n=46)	More elongated last scars (n=31)	ANOVA (Games-Howell)	p<0.001
Last scar invasiveness by area (log10)	Last scars more invasive by area (n=46)	Last scars less invasive by area (n=31)	ANOVA (Games-Howell)	p=0.022
Flaking pattern	More radial flaking (n=46)	More unidirectional and bidirectional flaking (n=31)	Pearson Chi-Square	p<0.001
Discoidal core?	More discoidal cores (n=46)	Fewer discoidal cores (n=31)	Pearson Chi-Square	p=0.002
Levallois core?	More Levallois cores (n=46)	Fewer Levallois cores (n=31)	Pearson Chi-Square	p<0.001
Recurrent Levallois core?	More recurrent Levallois cores (n=46)	No recurrent Levallois cores (n=31)	Pearson Chi-Square	p<0.001
No statistically significant differences in: Cortex % Number of major flake scars Number of non-feather terminations Last scar surface area Last scar invasiveness by length				

[1] *Where ANOVA tests are conducted, the results of Gabriel post hoc tests are reported where variances are equal and Games-Howell post hoc tests where variances are unequal.*

Table A.4. Basic typology of cores in each group from Haua Fteah and the wider landscape (rows include complete and broken cores and bifaces[1]).

	Haua Fteah				**Landscape**				
	Pre-Aurignacian	**Levallois-Mousterian**	**Levallois-Mousterian spit 55-46**	**Early Dabban**	**Hajj Creiem**	**Al Marj**	**North Gebel**	**Upper Gebel**	**CPP 8009**
Typology	**n**	**n**	**n**	**n**	**n**	**n**	**n**	**n**	**n**
Levallois core (flake)	5	26	27	2	6	9			4
Levallois core (blade)	2						2		
Levallois core (point)		1	1			1			
Discoidal core	2	15	22	3	9	7		4	8
Multiplatform core (flake)	16	12	3	2		3	8	4	4
Multiplatform core (blade/bladelet)	1			5			4		
Single platform core	7	1		2		2	7	1	1
Single platform core (blade/bladelet)	1			4		1	5	1	1
Bidirectional core	4			1		2	2	1	2
Bidirectional core (blade/bladelet)	2			10		1	3	3	
Core-on-flake	7	2	4	6	15		1		
Bifacial core[2]	1	1				4	1		5
Biface[3]		3		1		31			
Unspecified (mostly core fragments)	7	2	3			1	5		24
Total number	**55**	**63**	**60**	**36**	**30**	**62**	**38**	**14**	**49**

[1] Bifacial cores are included in the samples analyzed in this paper but bifaces are excluded. For interest, biface numbers are included in this table.

[2] Bifacial cores exhibit alternating flake removals from two core faces. These are usually thick, asymmetrical in plan and profile, with or without cortex, and with flake removals that may or may not extend around the entire core circumference.

[3] Here, bifaces include handaxes and bifacial foliates. To differing degrees, these are relatively symmetrical in plan and profile and exhibit a variety of shapes and sizes.

Table A.5. Results of univariate statistical comparisons[a] *between cores from the landscape sites and those in four analytical groups from Haua Fteah: Pre-Aurignacian (PA), Levallois-Mousterian excluding cores from spit 55-46 (LM), Levallois-Mousterian cores from spit 55-46 (55-46) and Early Dabban (ED). The results are expressed with reference to the landscape sites. Core fragments are excluded from analyses of quantitative variables. Cores-on-flakes are included in all analyses, except where comparisons between Hajj Creiem and the four Haua Fteah groups are repeated without cores-on-flakes.*

CPP 8009[b]	**Compared to PA**	**Compared to LM**	**Compared to 55-46**	**Compared to ED**
Statistical differences	More cortex (p<0.001) Fewer major scars (p<0.001) Fewer scars with non-feather terminations (p<0.035) More discoidal cores (p=0.001)	More cortex (p<0.001) Heavier (p<0.001) Fewer major scars (p<0.001) More single conchoidal and fewer multi-conchoidal platforms (p<0.001) Higher platform angle (p=0.005) Fewer Levallois cores (p=0.002)	More cortex (p<0.001) Heavier (p<0.001) Fewer major scars (p<0.001) More single conchoidal and fewer multi-conchoidal platforms (p<0.001) Higher platform angle (p<0.001) Fewer Levallois cores (p=0.001)	More cortex (p<0.001) Heavier (p<0.001) Fewer major scars (p<0.001)
No statistical differences	Mass; platform surface; last platform angle; frequency of Levallois cores	% non-feather scar terminations; frequency of discoidal cores	% non-feather scar terminations; frequency of discoidal cores	Platform surface; last platform angle; % non-feather scar terminations; frequency of Levallois cores; frequency of discoidal cores
Al-Marj[c]	**Compared to PA**	**Compared to LM**	**Compared to 55-46**	**Compared to ED**
Statistical differences	More scars on plane 1 (p=0.003) More flaking directions on plane 1 (p=0.002)	Heavier cores (p<0.001) More single conchoidal and fewer multi-conchoidal platforms (p=0.012)	More cortex (p=0.002) Heavier cores (p<0.001) More single conchoidal and fewer multi-conchoidal platforms (p=0.003) Fewer major scars (p=0.006)	Heavier cores (p<0.001) Cores less elongated (p=0.009) Last scars less elongated (p=0.017) More flaking directions on plane 1 (p=0.002)
No statistical differences	Cortex %; mass; core elongation; core flatness; platform surface; last platform angle; number of major scars; number of scars on plane 2; % non-feather scar terminations; last scar elongation index; last scar surface area; last scar invasiveness (by area)	Cortex %; core elongation; core flatness; last platform angle; number of major scars; number of scars on plane 1; number of scars on plane 2; % non-feather scar terminations; last scar elongation index; last scar surface area; last scar invasiveness (by area); number of	Core elongation; core flatness; last platform angle; number of scars on plane 1; number of scars on plane 2; % non-feather scar terminations; last scar elongation index; last scar surface area; last scar invasiveness (by area); number of flaking directions on plane 1	Cortex %; core flatness; platform surface; last platform angle; number of major scars; number of scars on plane 1; number of scars on plane 2; % non-feather scar terminations; last scar surface area; last scar invasiveness (by area)

		flaking directions on plane 1		
Upper Gebel	**Compared to PA**	**Compared to LM**	**Compared to 55-46**	**Compared to ED**
Statistical differences	Lighter cores (p<0.001) Smaller last scar surface area (p<0.001) Higher frequency of discoidal cores (p=0.013)	Fewer scars on plane 2 (p<0.001) More elongated last scars (p=0.007) Smaller last scar surface area (p=0.002) Fewer flaking directions on plane 1 (p<0.001) Lower frequency of Levallois cores (p=0.001)	Fewer scars on plane 2 (p<0.001) More elongated last scars (p=0.006) Fewer flaking directions on plane 1 (p<0.001) Lower frequency of Levallois cores (p<0.001)	
No statistical differences	Cortex %; core elongation; core flatness; platform surface; last platform angle; number of major scars; number of scars on plane 1; number of scars on plane 2; % non-feather scar terminations; last scar elongation index; last scar invasiveness (by area); number of flaking directions on plane 1; frequency of Levallois cores	Cortex %; mass; core elongation; core flatness; platform surface; last platform angle; number of major scars; number of scars on plane 1; % non-feather scar terminations; last scar invasiveness (by area); frequency of discoidal cores	Cortex %; mass; core elongation; core flatness; platform surface; last platform angle; number of major scars; number of scars on plane 1; % non-feather scar terminations; last scar surface area; last scar invasiveness (by area); frequency of discoidal cores	Cortex %; mass; core elongation; core flatness; platform surface; last platform angle; number of major scars; number of scars on plane 1; number of scars on plane 2; % non-feather scar terminations; last scar elongation index; last scar surface area; last scar invasiveness (by area); number of flaking directions on plane 1; frequency of discoidal cores; frequency of Levallois cores
North Gebel	**Compared to PA**	**Compared to LM**	**Compared to 55-46**	**Compared to ED**
Statistical differences	Thicker cores (p=0.027)	Thicker cores (p<0.001) More single conchoidal and fewer multi-conchoidal platforms (p=0.004) Higher platform angle (p=0.008) Fewer scars on plane 2 (p<0.001) Last scars more elongated (p=0.019) Fewer flaking directions on plane 1 (p<0.001) Lower frequency of discoidal cores	Heavier cores (p<0.001) Thicker cores (p<0.001) More single conchoidal and fewer multi-conchoidal platforms (p=0.001) Higher platform angle (p<0.001) Fewer scars on plane 2 (p<0.001) Last scars more elongated (p=0.016) Fewer flaking directions on plane 1	Less elongated cores (p=0.004) Last scars less elongated (p=0.018)

		(p<0.001) Lower frequency of Levallois cores (p<0.001)	(p<0.001) Lower frequency of discoidal cores (p<0.001) Lower frequency of Levallois cores (p<0.001)	
No statistical differences	Cortex %; mass; core elongation; platform surface; last platform angle; % non-feather scar terminations; number of major scars; number of scars on plane 1; number of scars on plane 2; last scar elongation index; last scar surface area; last scar invasiveness (by area); number of flaking directions on plane 1; frequency of discoidal cores; frequency of Levallois cores	Cortex %; mass; core elongation; number of major scars; number of scars on plane 1; % non-feather scar terminations; last scar surface area; last scar invasiveness (by area)	Cortex %; core elongation; number of major scars; number of scars on plane 1; % non-feather scar terminations; last scar surface area; last scar invasiveness (by area)	Cortex %; mass; core flatness; platform surface; last platform angle; number of major scars; number of scars on plane 1; number of scars on plane 2; % non-feather scar terminations; last scar surface area; last scar invasiveness (by area); number of flaking directions on plane 1; frequency of discoidal cores; frequency of Levallois cores
Hajj Creiem (including cores-on-flakes)	**Compared to PA**	**Compared to LM**	**Compared to 55-46**	**Compared to ED**
Statistical differences	Lighter cores (p<0.001) Less elongated cores (p=0.014) Flatter cores (p<0.001) More multi-conchoidal and fewer single conchoidal platforms (p=0.001) Higher frequency of faceting (p<0.001) Fewer major scars (p=0.023) Fewer scars with non-feather terminations (p=0.002) Higher frequency of discoidal cores (p<0.001)	Flatter cores (p<0.001) Fewer major scars (p<0.001) Lower frequency of Levallois cores (p=0.022)	Heavier cores (p=0.003) Flatter cores (p<0.001) Fewer major scars (p<0.001) Fewer scars on plane 2 (p=0.004) Lower frequency of Levallois cores (p=0.007)	Less elongated cores (p<0.001) Flatter cores (p<0.001) Higher frequency of faceting (p=0.001) Fewer major scars (p<0.001) Less elongated last scars (p<0.001) Larger last scar surface area (p=0.034) Higher frequency of discoidal cores (p=0.003)
No statistical differences	Cortex %; last platform angle; number of scars on plane 1; number of scars on plane 2; last scar elongation index; last scar surface area;	Cortex %; mass; core elongation; platform surface; frequency of faceting; last platform angle; number of scars on plane 1; number of scars on plane 2; %	Cortex %; core elongation; platform surface; frequency of faceting; last platform angle; number of scars on plane 1; % non-feather scar	Cortex %; mass; platform surface; last platform angle; number of scars on plane 1; number of scars on plane 2; % non-feather scar terminations; last

	last scar invasiveness (by area); number of flaking directions on plane 1; frequency of Levallois cores	non-feather scar terminations; last scar elongation index; last scar surface area; last scar invasiveness (by area); number of flaking directions on plane 1; frequency of discoidal cores cores	terminations; last scar elongation index; last scar surface area; last scar invasiveness (by area); number of flaking directions on plane 1; frequency of discoidal cores	scar invasiveness (by area); number of flaking directions on plane 1; frequency of Levallois cores
Hajj Creiem (excluding cores-on-flakes)	**Compared to PA**	**Compared to LM**	**Compared to 55-46**	**Compared to ED**
Statistical differences	Lighter cores (p=0.001) Flatter cores (p=0.038) More multi-conchoidal and fewer single conchoidal platforms (p=0.002) Higher frequency of faceting (p<0.001) More scars on plane 1 (p=0.01) More scars on plane 2 (p<0.001) More flaking directions on plane 1 (p<0.001) Higher frequency of discoidal cores (p<0.001) Higher frequency of Levallois cores (p=0.028)	Higher frequency of discoidal cores (p=0.028)	Heavier cores (p=0.01) Fewer major scars (p<0.001)	Flatter cores (p=0.018) Less elongated cores (p=0.004) Higher frequency of faceting (p<0.001) Fewer major scars (p=0.003) More scars on plane 2 (p<0.001) Less elongated last scars (p<0.001) More flaking directions on plane 1 (p<0.001) Higher frequency of discoidal cores (p=0.001) Higher frequency of Levallois cores (p=0.013)
No statistical differences	Cortex %; core elongation; last platform angle; number of major scars; % non-feather scar terminations; last scar elongation index; last scar surface area; last scar invasiveness (by area)	Cortex %; mass; core elongation; core flatness; platform surface; frequency of faceting; last platform angle; number of major scars; number of scars on plane 1; number of scars on plane 2; % non-feather scar terminations; last scar elongation index; last scar surface area; last scar invasiveness (by area); number of flaking directions on plane 1; frequency of Levallois cores	Cortex %; core elongation; core flatness; platform surface; frequency of faceting; last platform angle; number of scars on plane 1; number of scars on plane 2; % non-feather scar terminations; last scar elongation index; last scar surface area; last scar invasiveness (by area); number of flaking directions on plane 1; frequency of discoidal cores; frequency of Levallois cores	Cortex %; mass; platform surface; last platform angle; number of scars on plane 1; % non-feather scar terminations; last scar surface area; last scar invasiveness (by area)

[a] ANOVA tests were used to compare group means where data was normally distributed within each group. Gabriel post hoc tests were used where variances were equal between groups, and Games-Howell post hoc tests where variances were unequal. Kruskal-Wallis tests were applied to non-parametric data, which were followed by four pair-wise Mann Whitney U tests if the former gave a significant result. To avoid Type 1 errors, a Bonferroni correction was applied when considering the outcome of the Mann Whitney U tests. Here, the alpha level was adjusted to p=0.013. Otherwise, the alpha level is always p=0.05. For categorical data, Fisher's Exact Test was used for 2 x 2 contingency tables and Pearson's chi-square for contingency tables with more than two groups.

[b] Fewer variables are explored for CPP 8009 because fewer core attributes were recorded during the 2009 TRANS-NAP field season in Libya.

[c] Frequencies of discoidal cores and Levallois cores are excluded from comparisons between Al-Marj and the four Haua Fteah groups as this surface collection was partly biased towards the collection of Levallois cores and discoidal cores, and bifaces in particular.

Table A.6. Predicted group memberships for cores from the landscape sites. Discriminant Function Analysis is used to classify individual (ungrouped) cores from the landscape into one of three Haua Fteah analytical groups: Pre-Aurignacian or Levallois-Mousterian (excluding cores from spit 55-46) or Early Dabban. Unless otherwise stated, classification is based on DFAs that exclude mass as a variable and cores-on-flakes from the sample. In order to give a measure of the confidence with which cores are assigned to the relevant Haua Fteah group, probabilities of group membership have been assigned to three classes: <0.5; ≥0.5 to <0.7; ≥0.7.

	Probability of membership to Pre-Aurignacian			**Probability of membership to Levallois-Mousterian**			**Probability of membership to Early Dabban**			
Landscape sites	**<0.5**	**≥0.5 to <0.7**	**≥0.7**	**<0.5**	**≥0.5 to <0.7**	**≥0.7**	**<0.5**	**≥0.5 to <0.7**	**≥0.7**	**Number of cores**
Al Marj	1	2	1	1	3	5	0	0	2	15
	7%	13%	7%	7%	20%	33%	0%	0%	13%	
Upper Gebel[a]	3	3	1	1	0	0	0	3	1	12
	25%	25%	8%	8%	0%	0%	0%	25%	8%	
Upper Gebel[b]	0	2	0	2	1	0	1	2	4	12
	0%	17%	0%	17%	8%	0%	8%	17%	33%	
North Gebel										
CPP8103	0	1	0	0	0	0	0	0	0	1
	0%	100%	0%	0%	0%	0%	0%	0%	0%	
CPP8104	0	2	0	0	0	0	0	1	0	3
	0%	67%	0%	0%	0%	0%	0%	33%	0%	
CPP8109	0	0	1	0	0	0	0	0	0	1
	0%	0%	100%	0%	0%	0%	0%	0%	0%	
CPP8111	1	1	0	2	0	0	0	1	3	8
	13%	13%	0%	25%	0%	0%	0%	13%	38%	
CPP8116	0	1	0	0	0	0	0	0	0	1
	0%	100%	0%	0%	0%	0%	0%	0%	0%	
CPP8117	0	2	1	0	1	0	0	0	0	4
	0%	50%	25%	0%	25%	0%	0%	0%	0%	
CPP8118	0	0	0	0	0	0	0	2	0	2
	0%	0%	0%	0%	0%	0%	0%	100%	0%	
CPP8119	1	3	1	0	1	1	1	0	1	9
	11%	33%	11%	0%	11%	11%	11%	0%	11%	
Hajj Creiem[c]	0	1	0	0	2	8	0	0	0	11
	0%	9%	0%	0%	18%	73%	0%	0%	0%	
Hajj Creiem[d]	2[e]	4[f]	2[g]	0	4[h]	13[i]	0	0	0	14
	8%	16%	8%	0%	16%	52%	0%	0%	0%	

[a] DFA classification excludes core mass.

[b] DFA classification includes core mass.

[c] DFA classification excludes cores-on-flakes from the sample.

[d] DFA classification includes cores-on-flakes in the sample.

[e] Includes one Kombewa core.

[f] Includes three Kombewa cores and one truncated-faceted flake.

[g] Includes two Kombewa cores.

[h] Includes one Kombewa core.

[i] Includes three discoidal cores-on-flakes, two Kombewa cores and one truncated-faceted flake.

Figure Captions: for main text

Figure 1

Location of Haua Fteah, Hajj Creiem and sites recorded during geoarchaeological surveys of the TRANS-NAP project study region. The map covers the Gebel Akhdar of northern Cyrenaica in northeast Libya, as well as pre-desert and desert ecological zones to the far south. Specific sites referred to in the text are labelled (white circles) and sites in the Al Marj basin consist of a cluster of findspots located along the canal (map after Jones et al., in press: fig. 5.2).

Figure 2

Bar chart (left) indicates the numbers of cores (complete cores and core fragments) recovered from each spit during the 1955 excavation season (some cores from spits excavated in 1952 are also included). From bottom to top (oldest to youngest), spits are in chronological order for the Deep Sounding (spits 55-176 to 55-49) and approximate chronological order for the Middle Trench as some spits overlap stratigraphically. This is because the Middle Trench was excavated in four smaller trenches (north and south sectors in 1955, a 1952 trench, and a 1951 trench). A 3-D diagram (right) of the Haua Fteah excavations depicts McBurney's trenches and the location of the recent TRANS-NAP trenches (M, D and S). The approximate stratigraphic locations of the core samples used in this analysis are indicated (Pre-Aurignacian, Levallois-Mousterian, spit 55-46 and Early Dabban).

Figure 3

Results of Discriminant Function Analysis 1 (DFA 1), expressed as a bivariate scatterplot of function 1 scores (x-axis) against function 2 scores (y-axis).

Figure 4

Photographs of cores from Haua Fteah (scale: 5cm). Numbers 1-10: Early Dabban cores from spit 55-93. Numbers 11-16: Levallois-Mousterian cores from spit 55-46. Numbers 17-21: Levallois-Mousterian cores. Numbers 23-30: Pre-Aurignacian cores. Early Dabban cores: (1, 4, 7) single platform bladelet cores; (2, 6) multiplatform bladelet cores; (3, 5) bidirectional bladelet cores; (8) bidirectional blade core; (9) Levallois core (preferential); (10) bidirectional bladelet core-on-flake. Spit 55-46 cores: (11, 13) discoidal cores; (12) Levallois core (recurrent); (14, 15, 16) Levallois cores (preferential). Levallois-Mousterian cores: (17) Levallois core (recurrent), spit 52-33; (18) Levallois core (preferential), spit 52-33; (19) Levallois core (bifacial preferential), spit 52-31; (20) Levallois core (bifacial preferential), spit 55-110; (21) Levallois core (preferential), spit 55-110; (22) Levallois core (preferential), spit 55-109. Pre-Aurignacian cores: (23) exhausted Levallois core, spit 55-68; (24) discoidal core, spit 55-170; (25) Levallois core (recurrent), spit 55-174; (26) atypical Levallois blade core, spit 55-173; (27) single platform core, spit 55-172; (28) multiplatform core, spit 55-172; (29) Levallois core (recurrent), spit 55-175; (30) bidirectional blade core, 55-174.

Figure 5

Scar pattern analysis for core assemblages from Haua Fteah and the landscape sites. (a) Depiction and description of the method of recording flaking direction on the last flaked core face. (b) Proportion of blanks removed from each direction (as recorded on the visible remaining scars) within each core assemblage: PA (Pre-Aurignacian);

LM (Levallois-Mousterian, excluding cores from spit 55-46); 55-46 (Levallois-Mousterian cores from spit 55-46); ED (Early Dabban). (c) As above in (b) for landscape core assemblages from: AM (Al-Marj); HC (Hajj Creiem, excludes cores-on-flakes); NG (North Gebel); UG (Upper Gebel).

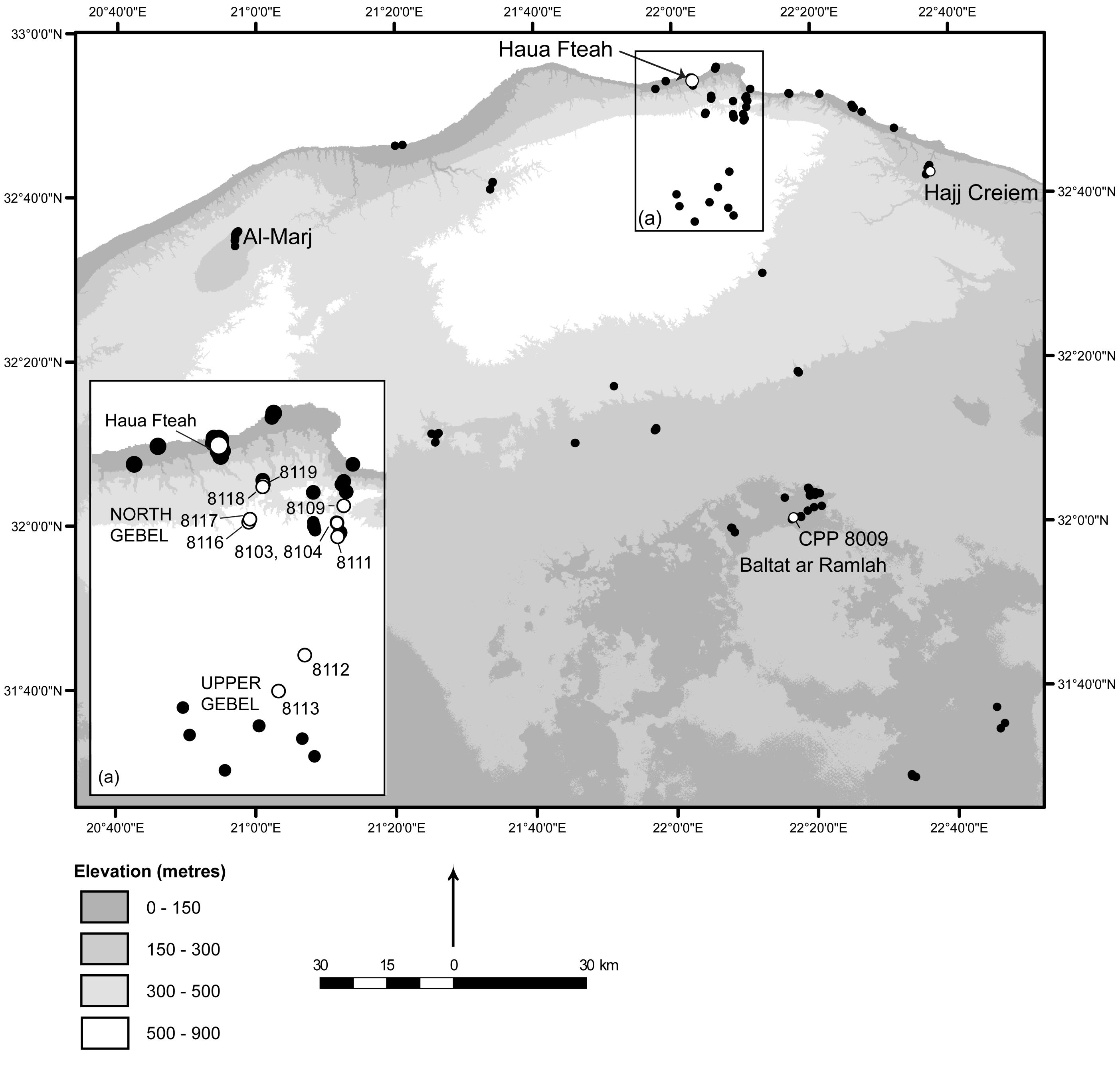
Figure 6

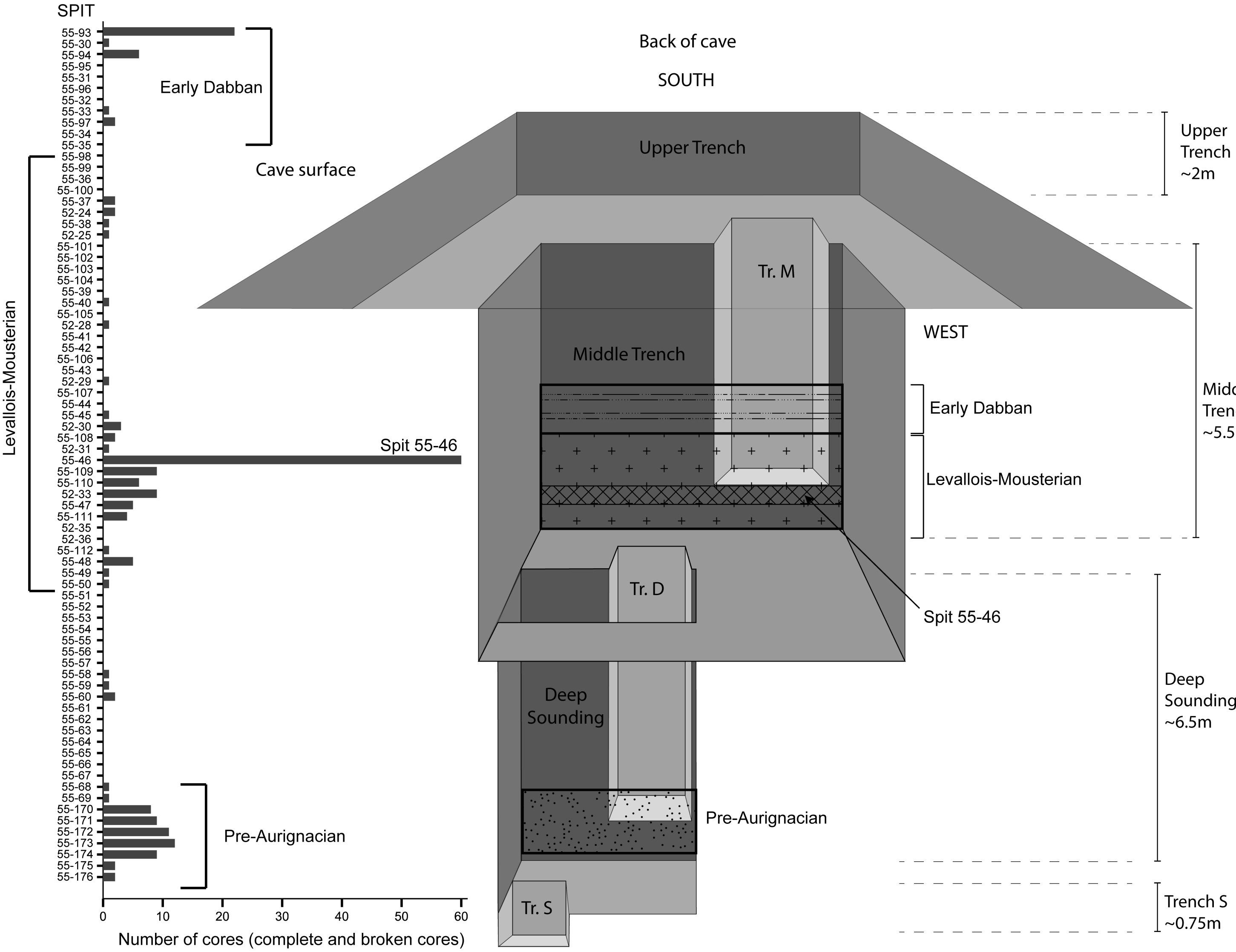
Schematic depiction of the proportion of statistically significant differences between cores from each landscape site (or cluster of sites) and each of the four Haua Fteah core assemblages. The length of the line between two groups represents the proportion of the total number of univariate statistical tests that produced a statistically significant result (i.e., those that indicate a significant difference between assemblages). The longer this line, the greater the difference between two groups of cores. See Table A.5 for details of the tested variables and corresponding p-values. Cores-on-flakes are excluded. Abbreviations as in Figure 5.

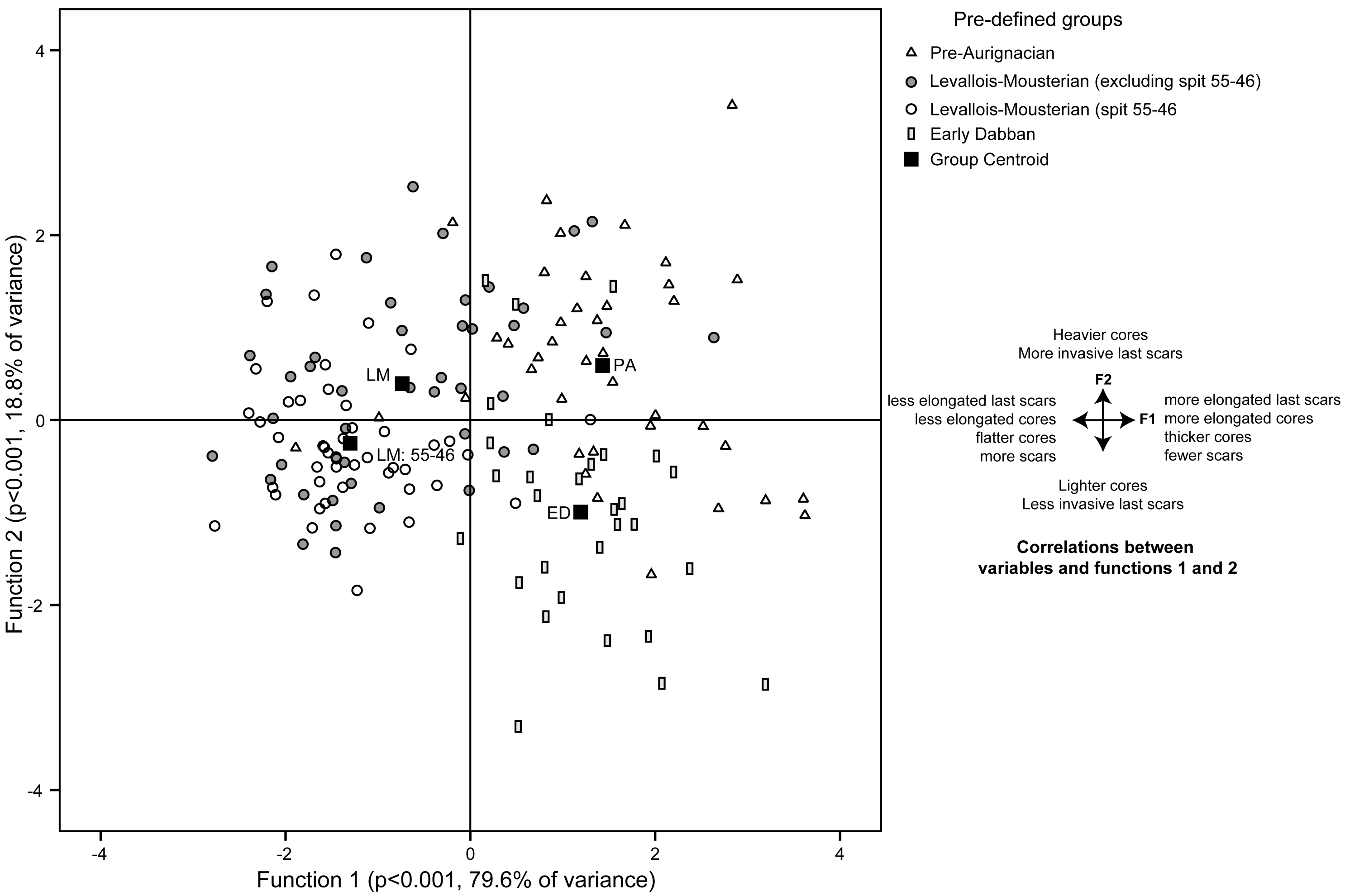
Figure Captions: for Appendix A

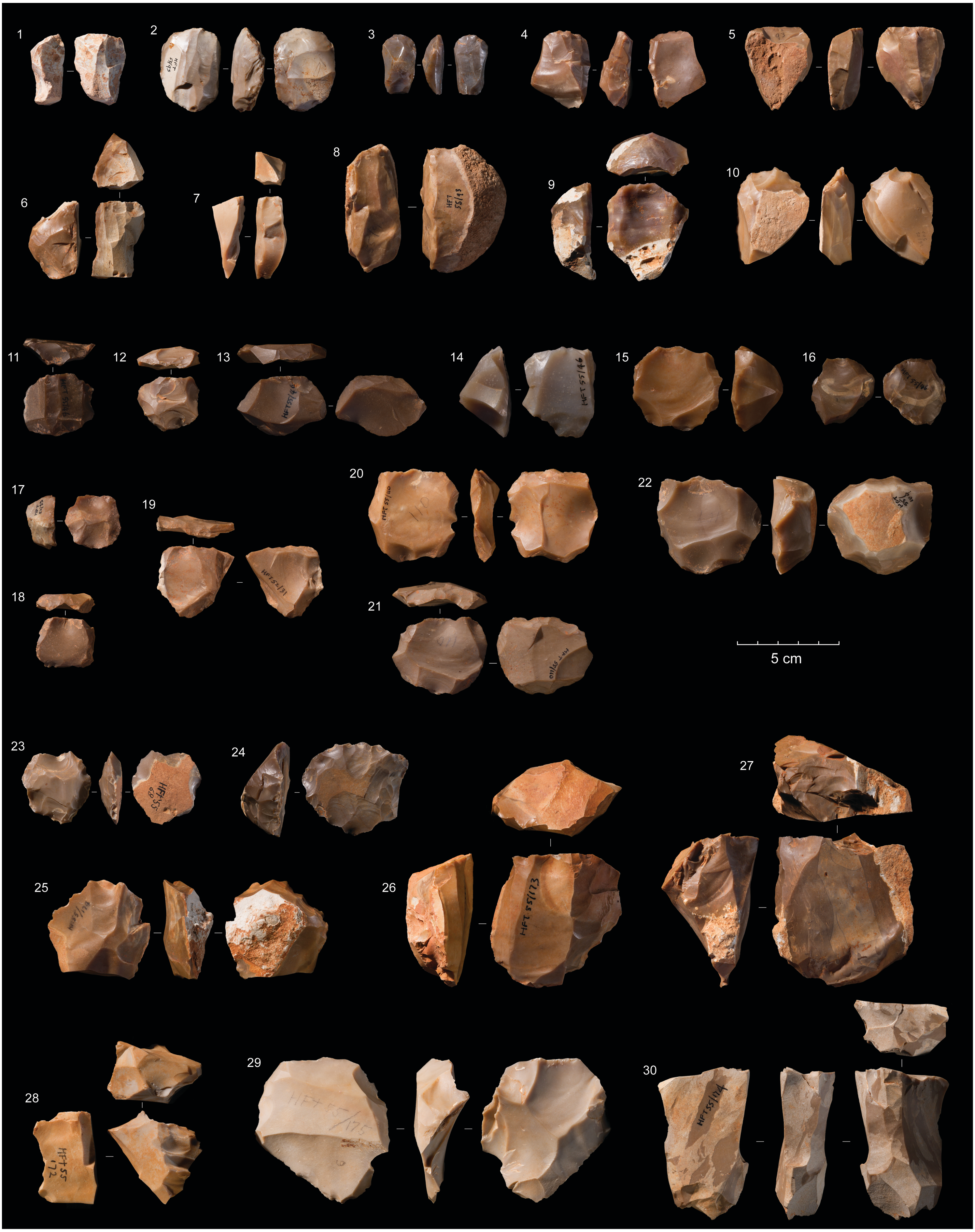
Figure A.1

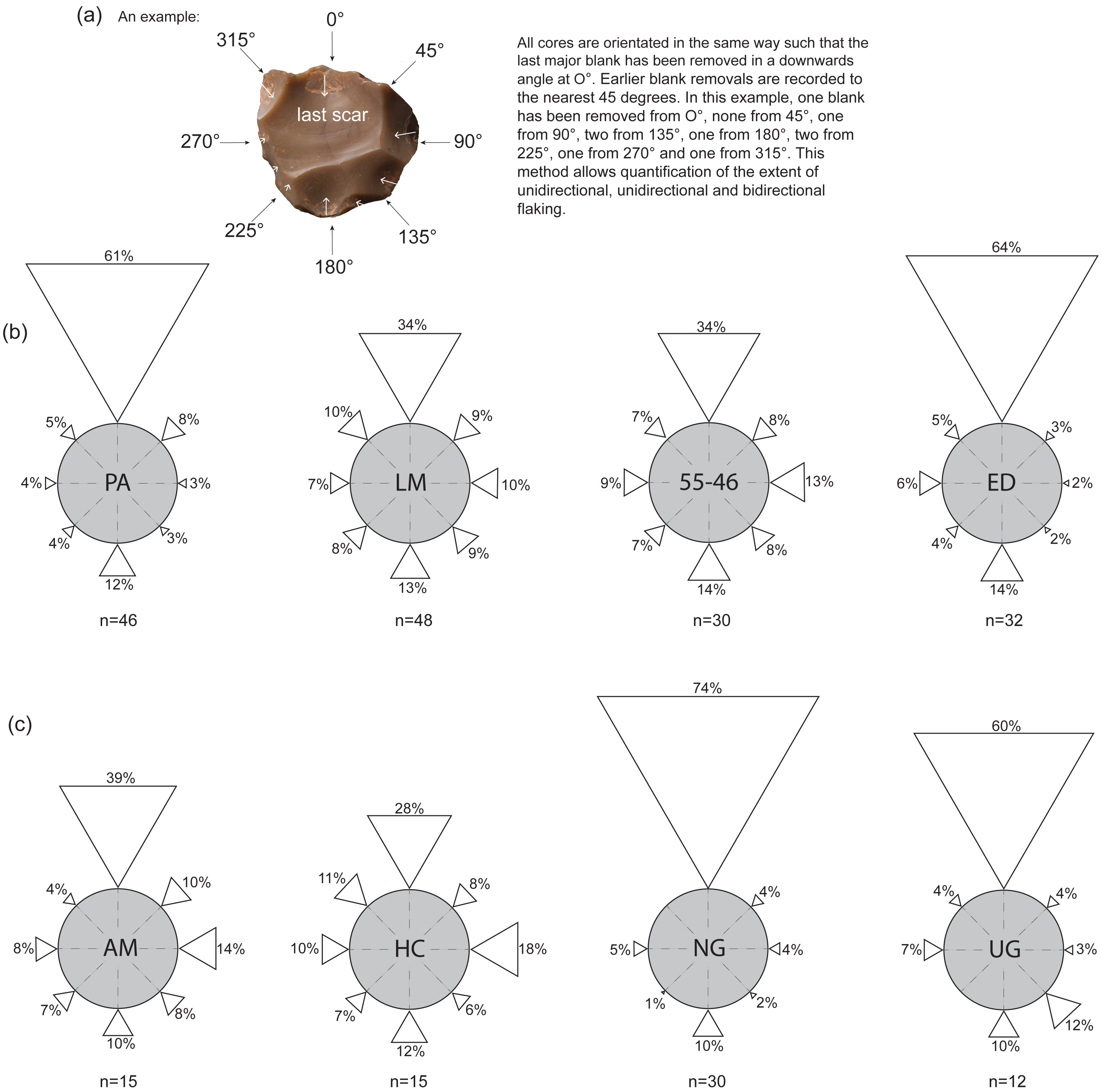
Results of Discriminant Function Analysis 2 (DFA 2), expressed as a bivariate scatterplot of function 1 scores (x-axis) against function 2 scores (y-axis). DFA 2 uses the same variables as DFA 1 but excludes core mass.


20°40'0"E
21°0'0"E
21°20'0"E
21°40'0"E
22°0'0"E
22°20'0"E
22°40'0"E
33°0'0"N
32°40'0"N
32°20'0"N
32°0'0"N
31°40'0"N
Haua Fteah
Hajj Creiem
Al-Marj
CPP 8009
Baltat ar Ramlah
(a)
Haua Fteah
NORTH GEBEL
UPPER GEBEL
8119
8118
8117
8116
8109
8103, 8104
8111
8112
8113
(a)
Elevation (metres)
0 - 150
150 - 300
300 - 500
500 - 900
30
15
0
30 km

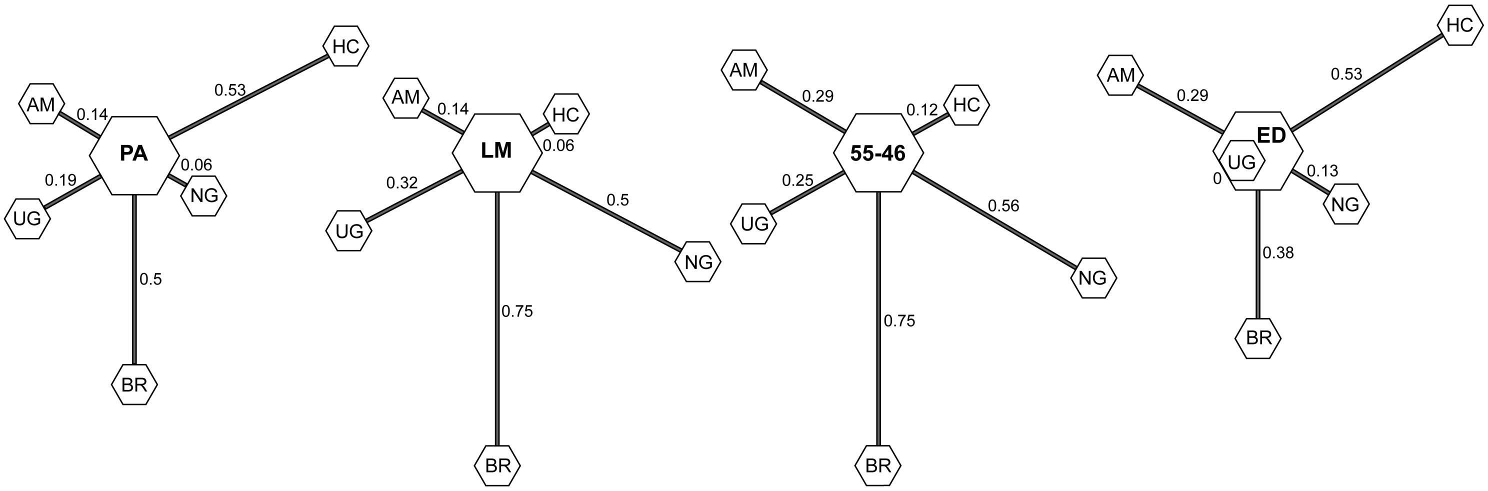

SPIT
55-93
55-30
55-94
55-95
55-31
55-96
55-32
55-33
55-97
55-34
55-35
55-98
55-99
55-36
55-100
55-37
52-24
55-38
52-25
55-101
55-102
55-103
55-104
55-39
55-40
55-105
52-28
55-41
55-42
55-106
55-43
52-29
55-107
55-44
55-45
52-30
55-108
52-31
55-46
55-109
55-110
52-33
55-47
55-111
52-35
52-36
55-112
55-48
55-49
55-50
55-51
55-52
55-53
55-54
55-55
55-56
55-57
55-58
55-59
55-60
55-61
55-62
55-63
55-64
55-65
55-66
55-67
55-68
55-69
55-170
55-171
55-172
55-173
55-174
55-175
55-176
0
10
20
30
40
50
60
Number of cores (complete and broken cores)
Early Dabban
Levallois-Mousterian
Spit 55-46
Pre-Aurignacian
Cave surface
Back of cave
SOUTH
Upper Trench
Tr. M
Middle Trench
WEST
Early Dabban
Levallois-Mousterian
Spit 55-46
Tr. D
Deep Sounding
Pre-Aurignacian
Tr. S
Upper Trench ~2m
Middle Trench ~5.5m
Deep Sounding ~6.5m
Trench S ~0.75m

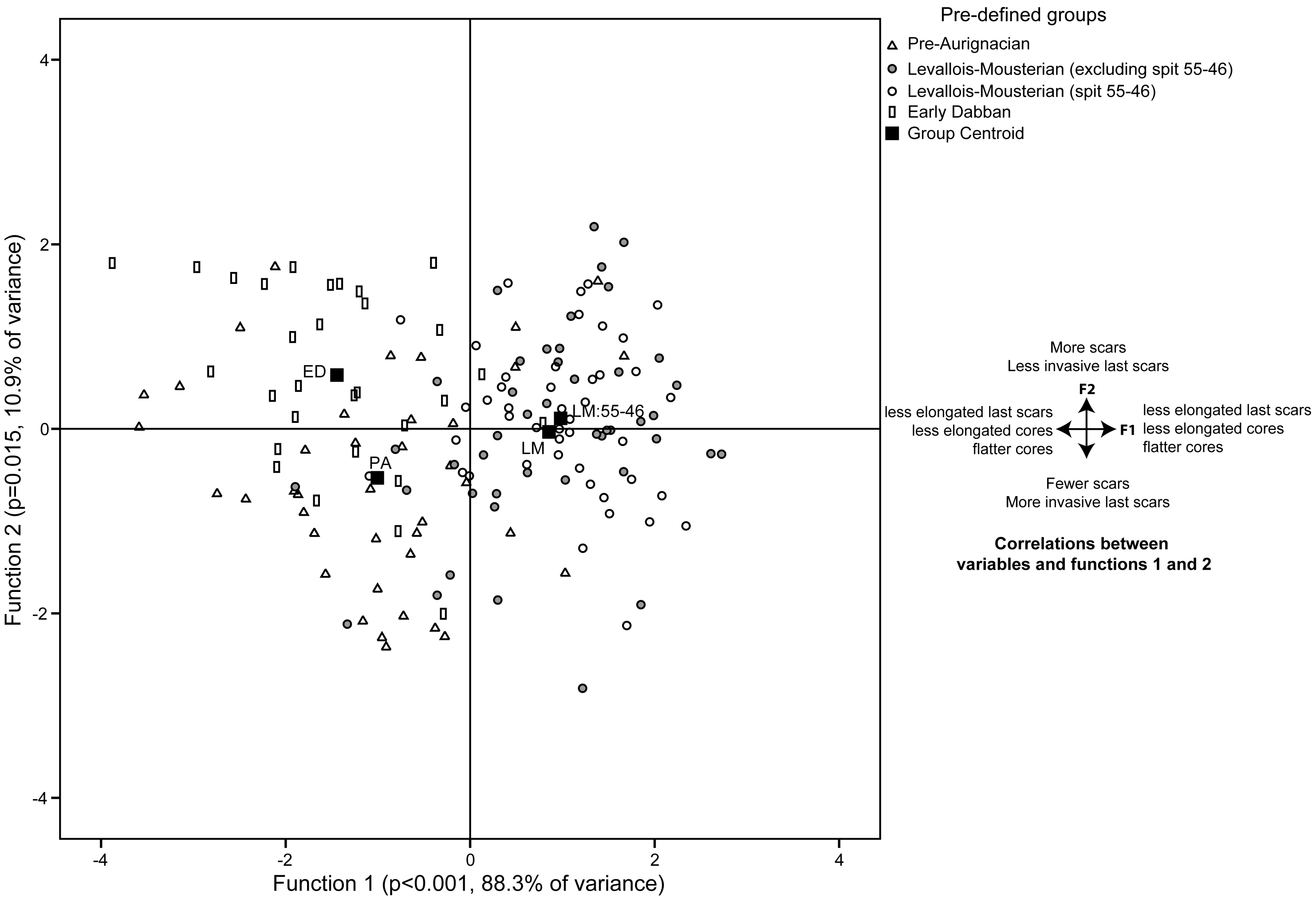

Pre-defined groups
Pre-Aurignacian
Levallois-Mousterian (excluding spit 55-46)
Levallois-Mousterian (spit 55-46
Early Dabban
Group Centroid
LM
PA
LM: 55-46
ED
Function 2 (p<0.001, 18.8% of variance)
Function 1 (p<0.001, 79.6% of variance)
4
2
0
-2
-4
-4
-2
0
2
4
Heavier cores
More invasive last scars
F2
less elongated last scars
less elongated cores
flatter cores
more scars
F1
more elongated last scars
more elongated cores
thicker cores
fewer scars
Lighter cores
Less invasive last scars
Correlations between
variables and functions 1 and 2


1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
5 cm



All cores are orientated in the same way such that the last major blank has been removed in a downwards angle at O°. Earlier blank removals are recorded to the nearest 45 degrees. In this example, one blank has been removed from O°, none from 45°, one from 90°, two from 135°, one from 180°, two from 225°, one from 270° and one from 315°. This method allows quantification of the extent of unidirectional, unidirectional and bidirectional flaking.


PA
AM
0.14
HC
0.53
UG
0.19
NG
0.06
BR
0.5
LM
AM
0.14
HC
0.06
UG
0.32
NG
0.5
BR
0.75
55-46
AM
0.29
HC
0.12
UG
0.25
NG
0.56
BR
0.75
ED
AM
0.29
HC
0.53
UG
0
NG
0.13
BR
0.38



Correlations between variables and functions 1 and 2