An investigation of the flake-based lithic tool morphology using 3D geometric morphometrics: A case study from the Mirak Paleolithic Site, Iran

Seyyed Milad Hashemi, Hamed Vahdati Nasab, Gilles Berillon, Mona Oryat

An Investigation on the Shape of the Flake-based Lithic Tools Using 3-D Geometric Morphometrics; Case study: Mirak Paleolithic Site, Iran

Seyyed Milad Hashemi[1], Hamed Vahdati Nasab[2], Gilles Berillon[3] and Mona Oryat[4]

1. Post-doc fellow, Tarbiat Modares University, Tehran, Iran
2. Associate Professor, Tarbiat Modares University, Tehran, Iran. Corresponding Author: Vahdati@modares.ac.ir
3. UMR 7194 MNHN-CNRS-UPVD/ Département Homme et Environnement, Musée de l'Homme, Paris, France
4. PhD student, Tarbiat Modares University, Tehran, Iran

Abstract

Twenty-first century's archaeologists are increasingly looking for more objective methods for analyzing archaeological remains in order to obtain more reliable results than ever before. To achieve this goal, some methods formerly used in various disciplines are gradually been introduced into archaeology and their effectiveness is being tested; this is also true for archaeological analysis of lithic artifacts. One of such methods (borrowed from evolutionary biology) that has become more and more popular in stone tool archaeology is geometric morphometrics; meaning the application of geometry principles to the statistical study of morphology. The goal of such studies is to raise the information regarding inter- and intra-assemblage morphological variabilities of lithic artifacts and based on that, to inspect the mechanisms and reasons behind in creating such variabilities. 3-D landmark-based geometric morphometrics is used here to study the diachronic changes in the morphology of lithic tools. The materials of this study are some flake lithic tools of Mirak; an open-air Paleolithic site located at the northern fringes of the Iranian Central Desert. The lithics belong to two archaeological layers. Layer 2, which features combination of Middle and Upper Paleolithic lithic materials with the absolute chronologies of 33–26 ka, and layer 3, which consists mainly of Middle Paleolithic materials with the age-range of 55–43 ka. The mentioned layers are of Marine Isotope Stage 3, a time of rapid fluctuations in climatic/environmental characteristics at global scale. The aim here is to investigate any significant morphological differences in the two sets of aformentioned lithic assemblages, and then, to suggest some probable reasons behind the stability or variability in morphology. The results of the analysis indicate that the general morphology of the flake-based lithic tools is not significantly different at the two layers. In order to inspect the rationale for such diachronic stability, the morphology of the original lithic raw materials and population dynamics were studied. It seems at least part of the answer lies in the flow of information and cultural transmission due to the presence of metapopulations in the Iranian Central Plateau during MIS 3. Apart from that, the possibilities of the attribution of the two sets of the lithic tools to different hominins of Late Pleistocene (Neanderthal and modern human) in southwest Asia must be considered as well.

Keywords: Flake-based lithic tools, Mirak Paleolithic site, 3D Geometric Morphometrics, The northern edges of Iranian Central Desert, Environmental change.

1 INTRODUCTION

Similar to biological entities, lithic artifacts change through time. Among the reasons for such changes are including differences in subsistence strategies because of climatic fluctuations (economic reasons: see e.g., de Azevedo et al. 2014), or changes in social (Ericson 1984: 5) or technological organization (see e.g., Andrefsky 2008). In addition to socio-economic reasons, cultural issues or the so-called "history-related inertia" (see Prentiss and Clarke 2008) could also modify or stabilize the structure of the stone artifact assemblages (see e.g., Goodale and Andrefsky, eds. 2015; O'Brien and Lyman 2003; Prentiss and Clarke 2008). Thus, economic and cultural frameworks seem to complement each other for explaining the reasons behind changes or stability in the technological organization.

One of the topics addressing frequently in the archaeology of stone artifacts is the form (shape+size; following Needham's Equation (1950) mentioned in Borel et al. 2017) and its variabilities. In addition, attempts are made to explain the reasons for such variabilities (see e.g., Archer et al. 2015; Lycett 2015). Various methods have been developed to study the morphological variability of stone artifacts through space and time; one of them is called geometric morphometrics (henceforth, GM), meaning the application of the geometrical principles to the statistical study of morphology (Lycett and Chauhan 2010: 14). This analysis, which is borrowed from evolutionary biology and biological anthropology (see Bookstein 1978; Bookstein et al. 1985; Vahdati Nasab and Clark 2014b) provides the foundations for more objective interpretations of archaeological artifacts than ever before. In one of the three general modes of GM, called landmark-based GM, the shape of artifacts is examined using comparable landmark and semilandmark points created on the Cartesian coordinate system. Such points, created on a two- or three-dimensional images of stone artifacts could help to grasp the inter- and intra-assemblage shape variabilities via the help of multivariate statistics. As a result, the researcher could be able to address the variables involved in creating various shapes (e.g., the impact of platform attributes on flake size and shape: Archer et al. 2017; or the impact of lithic raw material on hand axe morphology: Herzlinger and Grosman 2018; or the relationship between technology, function and morphology: Chacón et al. 2016). The basis of this method of GM is to standardize lithic artifacts (eliminate the effect of size in calculations) in such a way that the shape differences will be only depended on the morphology and not the size, position, and the direction of artifacts (Webster and Sheets 2010: 163, 164). The ultimate goal of such studies is to illuminate inter- and intra-assemblage morphological variabilities and based on that, to inspect the mechanisms and reasons behind in creating such variabilities; among them are stochasticity, the original shape and type of the lithic raw material, reduction intensity and technique, function, ecology, cultural traditions and biomechanical and cognitive differences (Lycett and Chauhan 2010: 14).

One of the central themes in GM is the concept of homology. Homology here means "the features being measured in one specimen are directly analogous to those measured in another: Lycett and Chauhan 2010: 16". It is only in the presence of such condition that statistical analyses would be meaningful. It is not difficult to consider such interspecific corresponding points in biological entities and on the living organs (for instance, the tendon-bone junction points in corresponding bones of various mammals; for pioneering works on the homologous landmarks see e.g., Bookstein 1991); however, applying such method on stone artifacts is very difficult and sometimes a subjective job. That is why, finding corresponding or identical points in archaeological materials is done using a procedure called semilandmark configuration in which the direction, position, and the scale of the display of lithic artifacts will be standardized (Slice 2007). It is only after performing such step that the dependent variables to morphology could be used in multivariate statistical analysis. The homologous points (called semilandmarks) are then selected using several protocols defined for stone artifacts (Lycett and Chauhan 2010: 16). These semilandmarks, which are borrowed from the third type of landmarks in Fred Bookstein's definitions (Bookstein 1991: 63–66), are points that are defined by the rules of geometry and do not necessarily make sense in the world outside of statistical shape analysis (see Fig. 5). Nowadays, such an approach is gaining more and more popularity among archaeologists (see Okumura and Araujo 2019 for a review of the applications of GM in material culture studies, discussions on key concepts, and some critical commentary. Some instances of landmark-based GM research in lithic archaeology are as the following: Archer et al. 2015, 2017; Buchanan and Collard 2010; Lycett and von Cramon-Taubadel 2013; Monnier and McNulty 2010).

Despite the worldwide prevalence of GM studies in bological anthropology and in the archaeological studies of stone artifacts, so far, except for a few cases[1], no archaeological research in Iran is conducted using this method. Therefore, this research could be somehow considered a pilot study in this field in Iran. One of the most important strengths of this method is the more objectivity surrounding the results than the classical lithic techno-typological studies in which the results are significantly more subjective (see e.g., Cardillo 2010; Chacón et al. 2016; Shott and Trail 2010). As the title of the research suggests, the ultimate goal here is to assess the possibility of correlating possible diachronic changes in the morphology of the lithic tools with possible changes in subsistence/adaptive strategies as a result of climatic/environmental fluctuations. Simply put, the aim is first to investigate any possible significant differences in the morphology of the two sets of lithic tools from one archaeological site, and if it is the case, its probable relationship to the modifications in adaptive strategies will be discussed. Additionally, the affinity of each set to the different species of humans (Neanderthals or modern human) or various modern human population groups will be considered. Thus, the intensity of change or stability in the lithic tools's shape in the two different time periods may imply that the assemblages belong to one or more population groups or a modification in adaptive strategies of the human populations present in the landscape. In addition to what discussed, the use of 3-d methods may also have implications for the role of lithic raw materials in shaping the characteristics of the technological complexes.

The lithic tools that are subject of the present study are recovered from Mirak archaeological site. Located at about 16 km south of the city of Semnan (220 km east of Tehran) with a mean elevation of 1030 m asl., Mirak is an open-air Middle and Upper Paleolithic site comprising of some nebkha mound clusters in an arid plain landscape as part of the belt of the northern fringes of the Iranian Central Desert (hereafter, ICD; Fig. 1). The site consists of at least three cultural deposits/layers belonging to Marine Isotope Stages (MIS) 3–2 (Fig. 3; Hashemi et al., 2018; Heydari et al. 2020; Vahdati Nasab et al. 2019)[2]. According to the OSL chronology (Heydari et al. 2020), the oldest layer (3) is of 55–43 kya, the middle one (layer 2) is in the age-range of 33–26 kya, and the upper layer (1) is of 28–21 kya. It should be noted that due to severe erosion in the layer 1, which is of Upper Paleolithic Period (see Akhavan Kharazian et al. 2018; Jamet et al. 2018), its cultural remains are not the subject of study in this paper and thus, only the stone artifacts recorded from the layers 2 and 3 are examined here. Thus, the materials correspond more or less to the MIS 3[۳]. MIS 3 is a stage with frequent and relatively rapid climatic fluctuations even on millennial and centennial scales (see e.g., Cserkész-Nagy and Sztanó 2016; Dansgaard et al. 1993; Siddall et al. 2008). It seems that these frequent fluctuations had influenced the landscapes of the Iranian Central Plateau (hereafter, ICP[۴]; see Hashemi et al. 2018 for rationale behind such claim). Climatic fluctuations could potentially lead to changes in environmental characteristics and as a result, alterations in spatio-temporal distribution of resources across the landscapes (see e.g., Hetherington and Reid 2010: part II; Pecl et al. 2017). Such an instability could potentially be considered as a factor triggering modifications in technological organization (see e.g., Morisaki et al., 2015; Robinson and Sellet eds., 2018). Part of the study of changes in technological organization is the investigation on morphological changes of a specific group of lithic artifacts through time.

Based on the chronology, the lithic assemblage of the layer 3 of Mirak is attributed to the Middle Paleolithic Period (Vahdati Nasab et al. 2019). Contrary to the Levant, where the Middle Paleolithic lithic manufacturers could be both Neanderthals and modern humans (see e.g., Shea 2003; Vandermeersch, ed. 1981), or Africa and the Arabian Peninsula with evidence in favor of modern humans (see e.g., Groucutt et al. 2018; Richter et al. 2017), because of absence of any hominid remains in the northern ICD (Mirak), it is not possible at the moment to recognize the true biological nature of the Mirak's flintknappers (either Neanderthals and modern humans are good candidates). Although the direct attribution of the lithic industries to any human species is not certain due to the lack of fossil evidence in the regions such as Iran (Dennell 2020: 229); nevertheless, the recovery of Neanderthal fossil remains from the Zagros (Trinkaus 1983; Trinkaus and Biglari 2006; Zanolli et al. 2019), and most likely, in the western part of the ICP (Vahdati Nasab et al., in press) and also in Central Asia (Gunz and Bulygina 2012; Krause et al. 2007) in association with Mousterian industries could imply the presence of Neanderthals in the ICP and in particular, Mirak. In addition to what mentioned, according to the Neanderthal extinction chronology around 40 kya (see e.g., Higham et al. 2014), the layer 2 of Mirak cannot easily be considered a Neanderthal-related deposit, and a more logical approach is to attribute that to modern humans (although much more recent dates for the presence of Neanderthals are suggested based solely on Mousterian industry; for instance, about 28 kya for Gibraltar: Delson and Harvati 2006 or about 34–31 kya for the northern Ural Mountains in the Arctic latitudes of Russia: Slimak et al. 2011, they all lack fossil evidence).

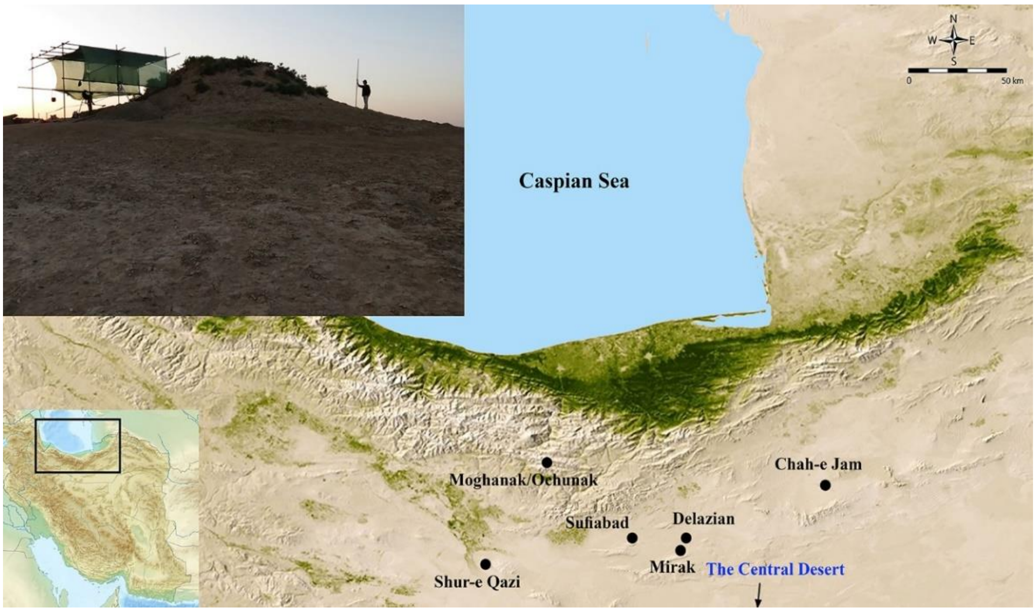

Figure 1. The location of Mirak and some other Paleolithic sites mentioned in the text in the northern fringes of the ICD; inset: a view of the mound 8 of Mirak which was subjected to the systematic excavation (raw image from NASA/NOAA).

As mentioned earlier, one of the aims of this paper is to assess the probability of attribution of the two sets of stone tools in the statistical population to two different human species (Neanderthals and modern humans) or to different population groups of one species (modern human). In doing so, three preliminary scenarios could be proposed here, as the following: assuming the morphological difference between the two sets as a result of the present investigation, such difference could be correlated to the presence of the two different human species mentioned (scenario I). The scenario II is that despite the techno-typological and morphological differences between the two sets of flake tools recovered from the layers 2 and 3, such differences are only indicative of various adaptive strategies in coping with environmental change and modifications in resource distribution patterns and not different species. Thus, the scenario I could be called "species distinction scenario" while the second one could be known as "dissimilar adaptations scenario". Finally, if the morphological differences between the two sets of lithic tools are not significant, it will be possible to talk about the flow and survival of information and the existence of large networks of populations (metapopulations) in the region or similar adaptations to the surrounding environment in two different time periods (scenario III). In addition, the role of the original shape of identical lithic raw materials in determining the morphology of the cores and flake blanks in two different time periods will be examined (in scenario III).

2 MATERIALS AND METHODS

2-1 The statistical Population

As mentioned, the materials studied in this research are the stone tools recovered from the two seasons of excavation in the eastern trench of Mirak during 2016–17 (see Vahdati Nasab et al. 2019). The statistical population is composed of the flake-based scraper types, points, and the retouched pieces which do not show any traces of breakage (hence containing the complete original morphology), and were recovered from the layers 2 and 3 of the eastern trench of Mirak (Fig. 3). Since, in general, retouching is not long or invasive in Mirak lithic tools[۵] (Vahdati Nasab et al. 2019), the original form of the flake blanks has not undergone fundamental changes after being used as tools (retouching in them do not pass the area with a score of 0.5 in none of the specimens selected, and a considerable number of them feature no retouches in most of the 16 zones defined on the flake surfaces: see Clarkson 2002). As a result, it seems there is no significant obstacle to compare the form of the tools to the original flake blanks before undergoing retouching. It should be noted that few number of flake tools such as bifaces and some invasively-retouched tools were removed from the population due to the fact that they are not good representatives of the original flake blanks' morphology. Based on the criteria defined for selecting the statistical population, at first 130 typologically-defined lithic tools were selected in the database. Then, 76 of which were selected out randomly; within which 31 specimens belong to the layer 2 and 45 specimens are from the layer 3 (Supplement Table 1). The reason behind choosing the tools and not the flake blanks are that the tools are more likely to be the objective pieces, involving in the daily activities, but the flake blanks could be the byproducts of flintknapping (whether to be the core preparatory or rejuvenation elements); in other words, lithic tools are more probable to be the ones involving in the subsistence activities. Due to the predominance of flake production at Mirak (esp. at layer 3) and using only typologically-defined tools with a higher probability of being used than the blank products, and in addition, using random techniques in selecting out the statistical population, it seems the two groups could be good representatives of the tool-kit of the population inhabiting Mirak and/or the morphologies they created or preferred. Among the other reasons for the use of the above-mentioned types of lithic tools is their ubiquity in the Middle Paleolithic assemblages (see e.g. Bordes 1961a,b; Debénath and Dibble 1994). In addition, various types of points have been frequently subjected to the functionalist and evolutionary discussions in Paleolithic archaeology (see e.g., O'Brien et al. 1999; Shea 2006).

Techno-typologically, the layer 3 of Mirak is fully representative of a predominantly flake-based Middle Paleolithic industry, with some elongated flake morphologies, as is the case for late Middle Palolithic of the Levant (see e.g., Bourguignon 1996; Richter et al. 2001). In this layer, some of the Mousterian industry artifact types, including Mousterian points (Fig. 2: 6–7), Levallois points (Fig. 2: 9), various scrapers (Fig. 2: 8, 10), déjeté points (Fig. 2: 5), and Levallois flake cores with radial/centripetal preparation (Fig. 2: 11) are recorded. Thus, as a whole, the layer 3 features Middle Paleolithic affinities (Vahdati Nasab et al. 2019). But, the layer 2 is of a mixed nature, meaning that both Middle and Upper Paleolithic technocomplexes are found there. For instance, both the levallois-Mousterian flake- and blade-based type-lists and blade/lets made via prismatic technique are recorded from this layer (Fig. 2, right); whereas, in the topmost layer (1), despite severe erosion (deflation), the lithic artifacts are reminiscent of Upper Paleolithic industry of the Iranian plateau, which is comparable to Baradostian or Zagros Aurignacian in many respects (Vahdati Nasab et al. 2019). Therefore, as it turns out, the layer 2 of Mirak is of great importance in examining the transition from Middle to Upper Paleolithic Period in the northern part of the ICP. The mechanism of this transition is not known in the region; thus, it may be possible to identify some trends over time by examining the morphological changes of the stone tools of the two layers (3 and 2).

Despite the fact that the layer 2 of Mirak consists of Middle and Upper Paleolithic cultural materials in which some new types of reduction such as prismatic technique was used to detach blade/lets, other traditions such as levallois-Mousterian type-lists were still common (Fig. 2: 1, 6) and in fact, a sizebale percentage of the tools were still made on flakes (Vahdati Nasab et al. 2019: 472; 85% of the tools in this layer are made on flakes). Additionally, just a few number of laminar blanks were retouched in such a way to make a formal tool (such as Fig. 2: 1; 16 pieces or 13% of the tools in this layer are blade tools, of which, 8 pieces are "discontinuously-retouched blades" which are not really considered as formal tools; Vahdati Nasab et al. 2019: table 4). By the way, as far as the diachronic study goes, comparability of the groups is needed to be as good as possible; thus, only the comparable flake-based tools (of the known type-lists of Middle Paleolithic Period) were selected out from the layer 2. Such action does not affect the results dramatically, since the blade tools are also recorded from layer 3, similar to the later layer 2 (17 blade tools are recorded from layer 3. They constitute 7.5% of the tools in this layer: Vahdati Nasab et al. 2019: table 4).

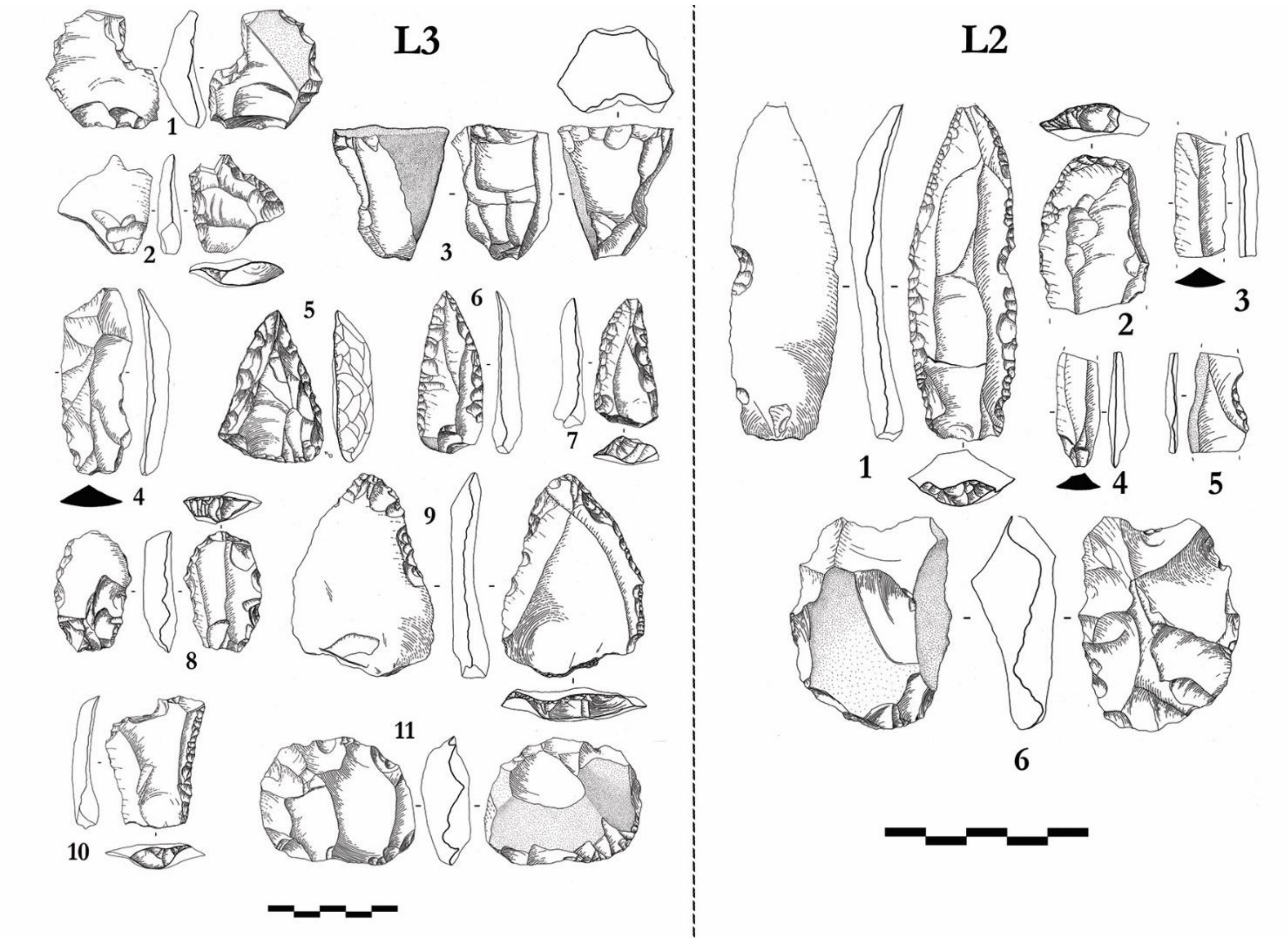

Figure 2. Selected lithic artifacts from Mirak; Right, Level 2: 1. Mousterian point on a blade; 2. End scraper; 3–4. Bladelet fragments; 5. Notched blade fragment; 6. Flake core with centripetal preparation and recurrent removal. Left, Level 3: 1. Notch-denticulated; 2. Convergent scraper; 3. Prismatic core (L2–L3); 4. Levallois blade; 5. Déjeté point; 6–7. Mousterian point on elongated flake; 8. End scraper with basal trimming on the ventral face; 9. Retouched Levallois point; 10. Side scraper and notched; 11. Levallois flake core (Vahdati Nasab et al. 2019: figs. 7–8; drawings by M. Jayez).

It should additionally be noted that part of the reason for smaller number of statistical population in the layer 2 is attributed to the more intensive toolmaking in layer 3 in relation to layer 2 (in L3: 36.5% and in L2: 19.1% of the blanks, whether flake or blade, were modified to become typologically-defined tools). The density of all types of lithic artifacts is also more than double in layer 3 in relation to layer 2 (238>102 pieces/m^3). Finally, all of the tools included in statistical population are made on high quality chert with colors ranging from green, greyish geen, to light-dark grey and black. Most of these colors are present simultaneously on some of the large chunks of lithic raw material scattered across the landscape (see the "Discussion" here); thus, the different colors of chert do not necessarily mean that they belong to various chert outcrops across the landscape.

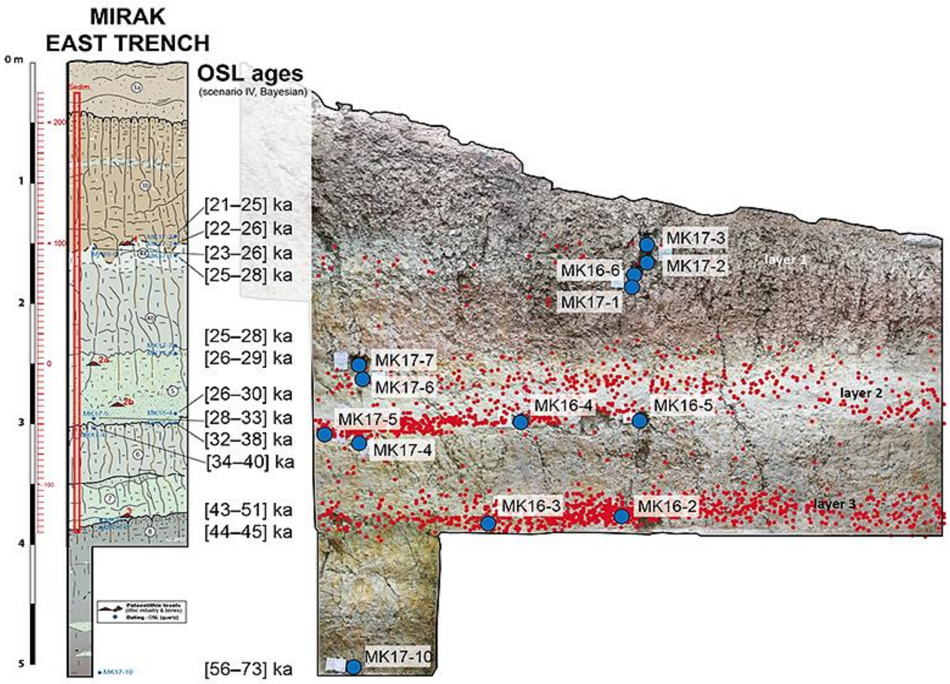

Figure 3. Right: the three cultural layers of Mirak with the red points representing the recovered cultural material, plus the location of the OSL chronological samples; left: the sedimentological column of the eastern trench of Mirak with OSL age-ranges (Heydari et al. 2020: fig. 3).

2-2 The Method

Here, the trend of possible diachronic changes in the lithic tools is investigated using 3-d GM and then, their significance is tested via multivariate statistics. 3-d scanning of the tools was conducted with the help of Shining 3D optical scanner[۶] (desktop version, fixed on a tripod). In addition, softwares such as Meshlab and Geomagic Studio were used to reconstruct and prepare the meshes from the point clouds (Fig. 4). Then, all formal analyses were performed using the 3rd version of AGMT 3-D software[۷] (Herzlinger and Grosman 2018) and the descriptive and multivariate statistical analyses were conducted using AGMT 3-D, XLSTAT, Excel, and SPSS softwares. The 3-d GM method was chosen since it allows the selection of countless points on the surface and edges of the tools at the same time. In order to precisely grasp the morphology of the tools, a total of 1800 landmarks were selected on the two faces of each of the tools in the statistical population (900 points on the dorsal face and 900 on the ventral) using AGMT 3-D (*ibid*). These landmarks are the basis of all further analysis in the present paper.

As mentioned above, after scanning all the tools of the statistical population (76 pieces) with the 3-d scanner and creating point clouds, preparing the mesh and the 3-d models and initial corrections were done using Meshlab and Geomagic Studio. Then, the methodologies explained in the Herzlinger and Grosmans' work (2018) was adopted. Afterwards, with the help of the geometric algorithms designed in AGMT 3-D software (*ibid*), landmarks were defined on the two surfaces and edges of the tools. Totally, 1800 landmarks were defined on each specimen, each faces of which benefited from 900 points (two faces=900×2; Fig. 5). It is only after this step that performing various statistical analyses will be possible in the software. Prior to conduct any analysis, it is necessary to perform a generalized procrustes analysis (GPA) to remove the variabilities unrelated to morphology, such as size and direction. Doing so, the variabilities in landmarks would be dependent only to the morphology (*ibid*). Afterwards, it is necessary to benefit from some dimensionality reduction methods that are common in the statistical shape analysis. One of the most common of these methods, especially in archaeology, is principal component analysis in which the landmarks in 3-d or higher dimension spaces are taken to a new coordinate system. In that coordinate system, in the simplest state, the horizontal axis represents the axis in which there is the greatest variance of the data (PC1) and the vertical axis (PC2) is secondary in this aspect (Abdi and Williams 2010: 434). In other words, the greatest variability of the data is explained by these two components. The principal components of the statistical population were measured using AGMT 3-d software (Herzlinger and Grosman 2018). Nowadays, the use of this dimensionality reduction method is very common in archaeology of stone artifacts (see e.g., Borel et al. 2017; Scerri et al. 2016). The raw results of the PC scores (up to PC7=definition of about 75% of the morphological variations) are shown in Table 2 of the supplementary file. The probability of the relationship between shape and size of the lithic tools was investigated using PC1 and PC2, as well as the isometric size of each specimen. The results indicate that there is no significant relationship between shape and dimensions in the tools of the two layers (MANOVA: DF=Hypothesis 3 and Error 72; Pillai=0.014; F=0.352; p-value = 0.788). This implies that despite the differences in dimensions, all the tools are comparable in morphology, and as a result, no further correction is needed for making the meshes comparable. Isometric size was obtained by adding the natural logarithm of the maximum length, width, and thickness, divided by 3 (see Borel et al. 2017).

Table 1. descriptive statistics of the dimensions of the selected lithic tools (automatic measurements by AGMT 3-D software: Herzlinger and Grosman 2018). L, W, and T are length, width, and thickness, respectively.

	layer	no.	max. L	max. w.	max. t.	w. at lower 1/5	w. at 1/2	w. at upper 1/5	T. at lower 1/5	T. at ½	T. at upper 1/5
mean	2	31	49.43	34.16	12.88	26.19	30.08	23.35	9.40	9.69	7.85
STD.	2	31	17.56	11.87	5.33	9.38	9.08	10.79	3.77	4.09	4.53
mean	3	45	45.93	33.40	12.94	25.66	30.42	23.44	10.54	10.02	7.57
STD.	3	45	12.36	7.18	4.28	7.27	8.36	7.71	3.81	3.67	2.80

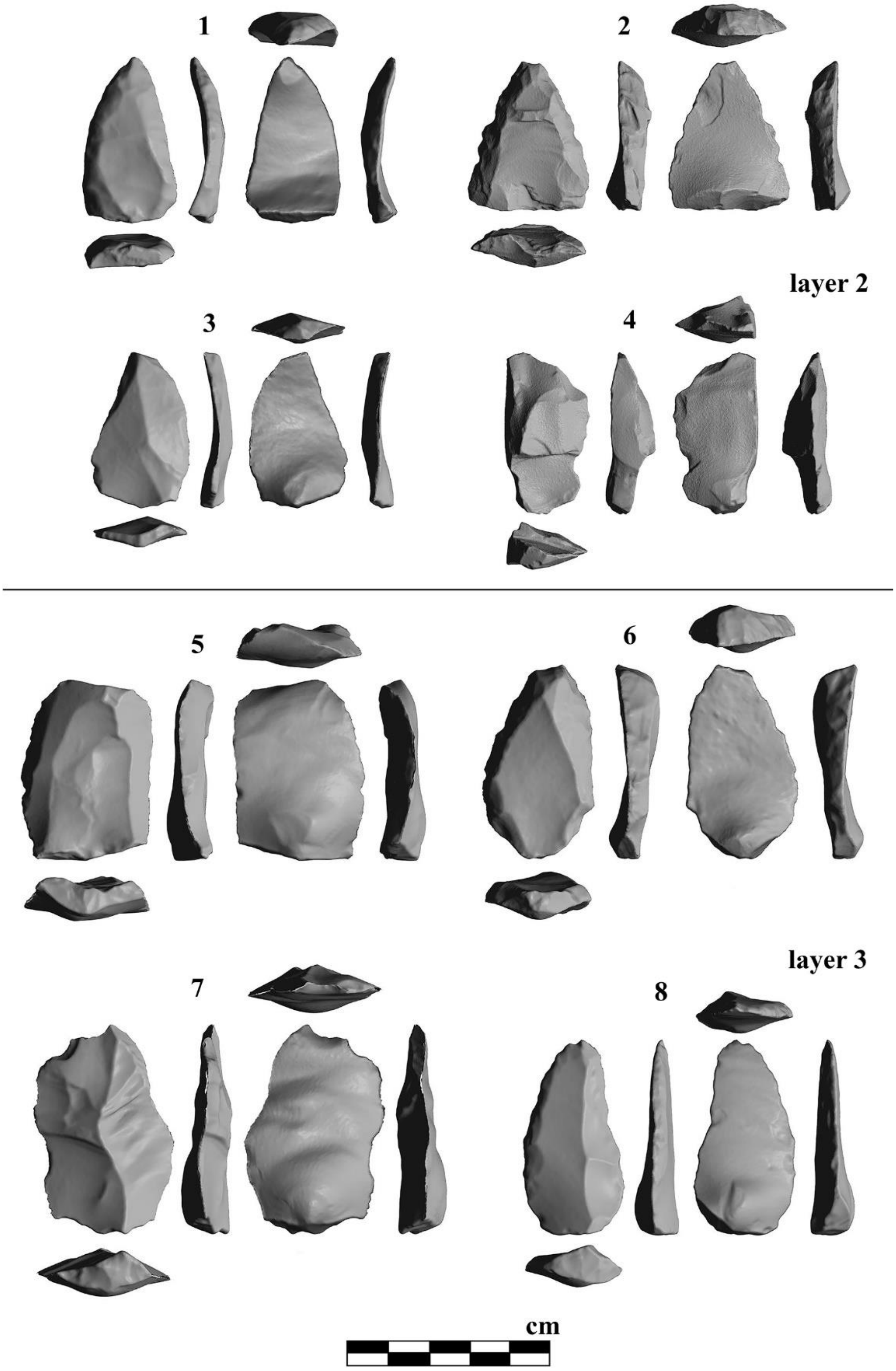

Figure 4. The selected flake-based lithic tools of Mirak from the layers 2 and 3. Layer 2: 1. Retouched point; 2. Convergent scraper; 3. Mousterian point; 4. Retouched piece; layer 3: 5. Retouched piece; 6. Convergent scraper; 7. Denticulate; 8. Convergent scraper (AGMT 3-D software was used for this presentation).

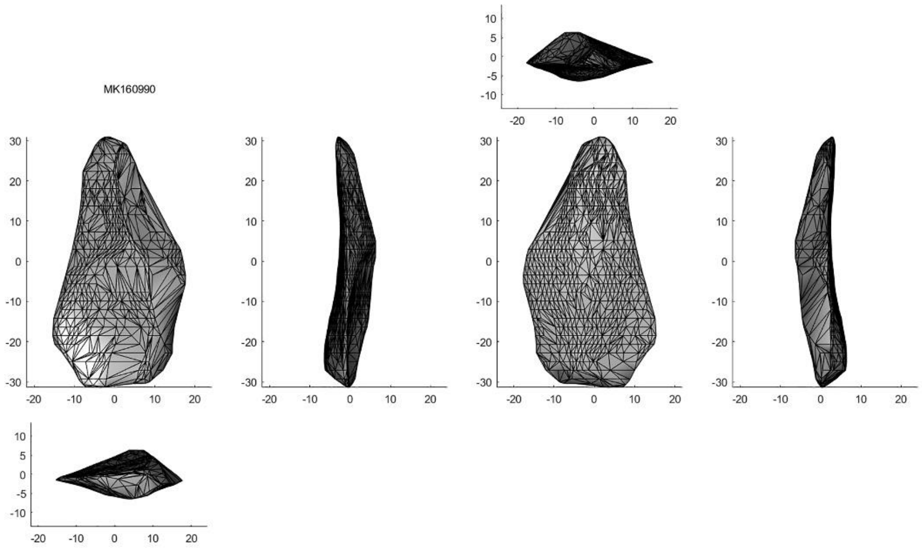

Figure 5. The landmark configuration in one specimen of the statistical population (using AGMT 3-D software: Herzlinger and Grosman 2018).

3 RESULTS

Figure 6 shows the scatterplot based on PC1 and PC2. The lithic tools of layer 2 are in blue and layer 3 in red. As is depicted, PC1 defines about 35.15% of the morphological variabilities, while PC2 defines about 13.92% (total: 49.07%). The two crosses (+), blue and red are representatives of the centroids of the layers 2 and 3, respectively. In addition to that, the morphological trends of the tools are indicated as color-coded shapes along each axis, assuming all other PCs, except that axis as 0 (Herzlinger and Grosman 2018).

Based on figure 6, the two sets of tools are not significantly different in morphology. In addition to the fact that the positions of the two centroids are close to each other, the ranges of PC scores are also comparable in the two groups; hence, the 90% confidence ellipses are analogous. The trend of morphological change along PC1 axis (assuming a score of 0 for all other PCs) is as follows: as the positive value of PC1 increases from zero, the tool length gradually decreases and the maximum width gradually increases; So that the hypothetical sample with a score of PC1=15 has the shortest length and the highest maximum width (Fig. 6: 3). Furthermore, by moving in the positive direction of PC1, the elliptical form of the edges is reduced and the movement towards being similar to an inverted triangle is observable (decrease in symmetry). The lateral sections do change as well; by moving on the positive horizontal axis, in addition to increasing the thickness of the tools (especially in the proximal half), the convexity of the dorsal face is reduced and the concavity of the ventral face is increased. On the other hand, the sections of the two ends gradually take a plano-convex shape (Fig. 6: 3). There are also significant changes in moving in the negative direction of PC1. In this direction, the length of the tools is increased and their thickness and width are reduced; the change in length and width is relatively remarkable. The reduction in width occurs mostly in the distal half of the hypothetical shape and is reminiscent of the shapes similar to points (Fig. 6: 5). It should be noted that the convexity of the dorsal face is also reduced in this direction comparing to PC1=0.

In Moving on the PC2 axis and in positive direction, the bilateral symmetry is significantly reduced; in a way that the convexity of the left edge is increased, while the right edge will be less convex. This is such that the hypothetical shape with PC2=6 will have a completely out of shape convex left edge (shouldered tool?) and a straight right edge, and therefore, the bilateral symmetry in this area of the diagram disappears completely (Fig. 6: 6). It should be mentioned that the length remains almost constant and the average thickness also does not change significantly in this direction. Moreover, the sections' symmetry is reduced in this direction and the shapes will have localized changes, as in the face's view. In the negative direction of PC2, the bilateral symmetry gradually decreases, as well; most changes occur in the lateral edges and not in the sections. As shown in Figure 6: 8, the convexity of the left edge gradually decreases until in the area PC2=-4 this edge takes the form of a straight line and then, concavity will increase (Fig. 6: 9). The right edge becomes more convex in this direction. In sum, PC1 is mostly responsible for variations in the lateral edges of the tools (especially in the distal half), and PC2 defines mostly the variations at both ends of the tools (especially, the distal end).

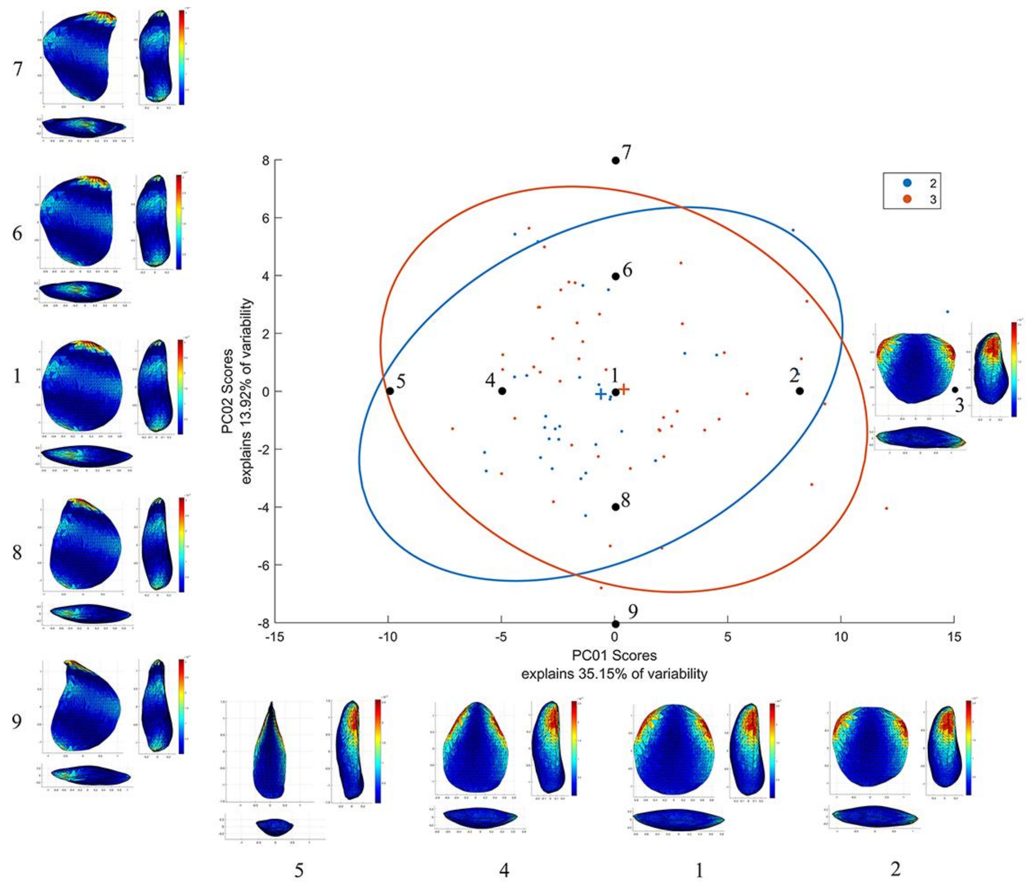

Figure 6. The scatterplot based on PC1 and 2 with 90% confidence ellipses. Each blue dot represents the lithic tools of layer 2 and each red dot belongs to one of the layer 3 lithic tools. The precise location of the colored shapes is numbered inside the diagram using black font (AGMT 3-D software, Herzlinger and Grosman 2018, with the authors' modifications).

Figure 7 depicts the mean shape of the tools recovered from the layers 2 and 3 of Mirak. As it turns out, the two have a lot in common in morphology; but, while the average maximum length is higher in the tools of the layer 2, the average maximum width is lower in this layer (Table 1). This means that, on average, the flake tools of layer 2 are more elongated relative to the layer 3. This is not unusual regarding the fact of the entry into Upper Paleolithic

Period in the layer 2. In addition to what has been said, in the lateral section of the layer 2 mean shape (Fig. 7: 2), more convexity is evident on the dorsal face and less thickness at the proximal end. The greater thickness of the mean shape of the layer 3 lithic tools in proximal half could probably be due to bulbar eminence as a result of hard hammer percussion, more intense blows, or the blows with different angles than what is the case for the layer 2. The mean maximum thickness in the layer 3 lithic tools is also larger, as shown in table 1; although all other mean dimensiones in the tools from the layer 2 are larger than 3 (table 1).

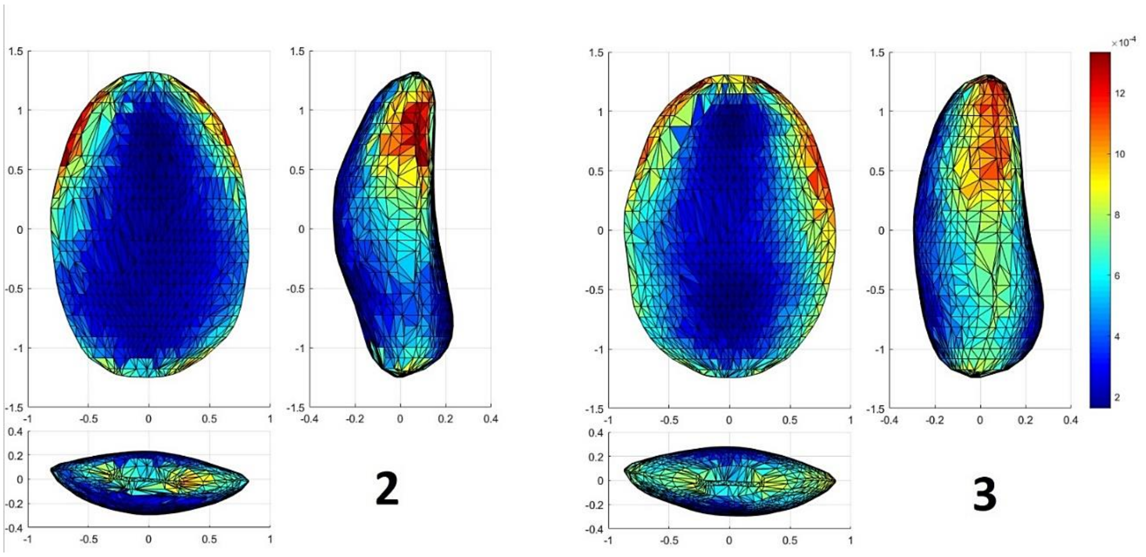

Figure 7. The mean shapes of the flake tools of each layer (AGMT 3-D software, Herzlinger and Grosman 2018).

Table 2 contains information on the intra-group variabilities between the two sets of Mirak tools. The shape diversity index is obtained from a combination of different factors, such as variation in length, width, thickness, and symmetry, and is measured as the average Euclidean distance (in multidimensional space) of each sample relative to the centroid of the same group. The size of each item's centroid is also measured as the square root of the sum of the Euclidean distances of all landmarks to the item's centroid (Herzlinger and Grosman 2018). As can be seen in table 2, the value of the variability index is not much different in the two sets (the difference=0.5). Table 2 also indicates that the main variable responsible for morphological variabilities in the lithic tools is their width. The interesting thing is that in both groups, the thickness of the tools varies more than their length. This could indicate different angles of blows at the time of flintknapping, variations in the hammerstones used, and different blow strengths on the cores. Symmetry is another factor in defining inter-group differences. This factor is divided into two groups of bilateral and bifacial symmetry. While the bilateral symmetry index is almost the same in both layers, the deviation from bifacial symmetry is slightly greater in layer 2. In addition to what mentioned, the curvature index is a bit greater in the layer 3 than 2; but of course, not that much significant. The less bilateral curvature of the tools in the layer 2 and their slight higher elongation as mentioned, may imply the movement towards detaching more elongated flake blanks in Upper Paleolithic Period. Such blanks were also produced during Middle Paleolithic Period in Southwest Asia and became common in the ensuing period (see e.g., Olszewski 2001: 80; 2009: 324).

Table 2. Information on intra-group shape variations of the two sets of lithic tools recovered from Mirak. Guide: X%: X-axis (width) participation percentage in shape variabilities. Y% (length) represents the percentage of diversity defined by the Y axis, and Z% (thickness): the percentage of Z-axis participation in morphological variability (AGMT 3-D software).

Layer	No.	Shape variability index	X%	Y%	Z%	Dev. from bilat. symm.	Dev. from bifac. symm.	Left edge curv.	Right edge curv.
2	31	6.65	65.55	12.80	21.66	3.61	2.82	1.94	2.09
3	45	7.06	65.91	9.82	24.27	3.67	2.46	2.26	2.39

4 DISCUSSION

The results of the present study indicate that there is no significant difference between the mean shapes of the two groups (the Wilcoxon rank-sum test on the inter-point distances between the groups' means; 95% Confidence interval; ranksum=5557, pValue=0.34). It is worth mentioning that the inter-group shape difference is calculated as the Euclidean distance between the landmarks (in multidimensional space) in the two mean shapes (Herzlinger and Grosman 2018). Also, there are no significant differences between the points on the tools of each layer with the corresponding points on the mean shape of the same layer (Wilcoxon rank-sum test on within-group inter-point distances: 95% confidence interval; ranksum=1062, p=0.16). Therefore, there is no significant difference between the mean shape of the tools from the two layers and among the tools within each layer. The similarity of the morphology of flake blanks implies that although a relatively high percentage of Mirak flake tools fall into the category of informal tools (Andrefsky 1994), flake detachment was relatively standardized or the ranges of the techniques used for flake detachment were comparable.

In addition to what mentioned, the descriptive statistics of bilateral and bifacial symmetry imply that while the average deviation score from bilateral symmetry in the two layers is similar, the average deviation score from bifacial symmetry in layer 2 is a bit larger than layer 3 (table 3). In other words, the symmetry of the tools from layer 2 is less than the layer 3 in the longitudinal section and considering the longitudinal axis, despite the fact that the thicknesses are more variable in the layer 3 that 2 (table 2: Z%). This may indicate the impact of length variability and more localized changes of thickness in the longitudinal axis in the layer 2 in relation to 3 (Fig. 7). Nevertheless, the standard deviation, range, median, and mean of the deviation from bilateral symmetry in both layers are higher than the same variables in the deviation from bifacial symmetry. This indicates the greater variability of the lateral outlines and their less symmetry with respect to the sections, which of course is not an unusual thing; since the range of changes at the edges is usually greater than the variability in thickness. Figure 7 also shows the greater importance of the lateral edge changes in defining the shape variations of the Mirak lithic tools (warmer colors near the lateral edges), as PC1 is mostly responsible for variations in the lateral edges of the tools (35.15% of the variability: Fig. 6).

Table 5. The descriptive statistics of the deviation from bifacial (grey rows) and bilateral (transparent rows) symmetry.

layer	Max.	Median	Min.	Range	Mean	STD.
2	6.51	2.54	0.82	5.69	2.82	1.45
3	5.70	2.09	0.71	4.99	2.46	1.39
2	9.27	3.16	1.08	8.19	3.61	1.68
3	7.97	3.25	1.63	6.34	3.67	1.53

Since there are no significant differences between the morphology of the tools from the two layers, the third scenario given in the "Objectives" section is examined. As stated in that section, if there are no morphological differences between the two sets of the lithic tools, there would be possible to talk about the information flow and the existence of regional metapopulation networks, plus, the comparable technological organization (as part of the adaptive strategies) in two different time periods in the site. Additionally, the role of the similar lithic raw material in shaping the morphology of the flake blanks would be investigated. One of the first impressions after observing similar morphologies in stone tools after almost 20000 years of gap is the question of the similarity of lithic raw material and its impact upon the shape of the cores and the resultant blanks. At present, there are various and sometimes regional perspectives for examining the relationship between lithic raw materials and the morphological diversity of the dependent stone artifacts. While the results of some studies have shown that the use of various lithic raw materials does not necessarily mean formal differences in the sets of stone artifacts (see e.g., Eren et al. 2014; Sharon 2008), others emphasize the importance of the quality and availability of lithic raw materials in the morphological diversity of lithic assemblages in a cultural landscape (see e.g., Polley et al. 2017). It should be noted that these studies are often performed on tools such as ancient or replica hand axes by keeping some variables constant, and such research on retouched tools is still very rare. In addition, since most of these studies have so far been regional with results that are not applicable to other parts of the world, the raw material factor was kept constant in the present paper and only the tools made on high quality chert were used in the analysis. The scatters of the chunks of chert is seen in the southern landscape of Mirak, beginning at a distance of 1 km to the south of the site, with unknown boundaries in the more southern landscapes. These chunks come in size-ranges such as 10–30 cm in the largest dimension in the southern landscape (Fig. 8), the origin or outcrops of which or the mechanism of their movement in the landscape have not yet been specified. In addition, the location of the initial core preparation and flake removal has not yet been found in Mirak's landscape; the cores and their associated preparatory and rejuvenation elements are also very few among the *in situ* excavation findings (1.8% of the *in situ* material from the layer 2 and 4.2% from the layer 3 belong to the cores and the associated pieces: Vahdati Nasab et al. 2019: table 2). Perhaps, due to the erosional processes, the location of the initial flake detachment has been completely destroyed. The only reason for the preservation of the archaeological deposits of Mirak is the formation of the late Holocene nebkha mounds across the landcape (including Mirak mound 8, the excavation site), while there are no intact Paleolithic deposits on the surface of the other parts of the landscape. Due to the mentioned characteristics, the morphology of Mirak flake cores and their reduction process is not well-known at present. Thus, the objective pieces (like flakes) may have implications for the shape of the cores; albeit this is not the subject of study here. It should be noted that due to the large size of the chunks of lithic raw material and significant size difference between the flake tools and the raw material in Mirak, as well as the absence of cortex on the surface of Mirak lithic tools, the impact of the raw material on the morphology of the tools could be considered low or very difficult to assess^; the size of the few lithic cores are also significantly smaller than the scattered chunks of the lithic raw material in the landscape. Given what has been said here, the summary of the properties of the lithic raw material is as follows: high quality and good accessibility. In such a case, it is expected that both types of formal and informal tools would be made, and in addition, the retouching intensity will not necessarily be an indication of utilization intensity (see Andrefsky 1994; Kuhn 1991). Albeit, one should also look for non-economic rationale such as toolmaking tradition from a cultural point of view and the history of technology (see e.g., Prentiss and Clarke 2008). Due to the proximity of high quality raw material to Mirak and also, their relatively large dimensions[9], these sources were the main focus for raw material procurement. However, from what has been said, the original form of the comparable lithic raw materials in the two layers cannot be the only answer to the morphological similarities of the flake tools in the layers 2 and 3 of Mirak, despite its probable effecs.

Figure 8. One of the weathered chunk of chert as potential lithic raw material used in Mirak. Note the scale in cm.

After discussing the characteristics of lithic raw materials over time, it is time to talk about the climatic fluctuations and environmental changes in Late Pleistocene period across the northern edges of the ICP. Human behavioral ecology predicts that as a result of changes in the distribution pattern of resources due to climatic fluctuations, mobility-related features, land use patterns, and technology will undergo modifications (See e.g., Morisaki et al. 2015; Wilkins et al. 2017); thus, some hypothetical changes in the morphology of the Mirak lithic assemblages may be related to changes in the subsistence strategies. However, despite the techno-typological modifications, the morphology of the flake-based tools in Mirak has not undergone significant changes (the results of the present study). Here, first the nature of environmental fluctuations in Mirak landscape will be reviewed in order to talk on the dynamism of resource distribution patterns.

As noted above, the layers 2 and 3 of Mirak were deposited during MIS 3 (60–25 kya: Siddall et al. 2008). This stage seems to have been an unstable one, especially in terms of precipitation in the arid and semi-arid regions of Asia (Dennell 2020: 50). Precipitation in the northern edges of the ICD was also likely to be more unpredictable and abrupt relative to the stages such as MIS 5, resulting in flash floods. Such unpredictability in precipitation had probably led to the spatio-temporal uneven distribution of resources (food and water) across the landscape of the ICD including Mirak. In general, the last glacial cycle, including MIS 3, is characterized by severe and short-term climatic fluctuations, especially at millennial and even centennial scales (see e.g., Latif et al. 2016; Lowe 2001). The most well-known of these fluctuations are the short periods with rapid temperature improvement (higher average temperatures) called Dansgaard-Oeschger which was first identified in Greenland ice cores (D-O; Dansgaard et al. 1993; Johnsen et al. 1992) as well as, more gradual cold Heinrich events (Heinrich 1988; Lowe 2001), identified again in Greenland cores. Evidence correlated with these events is reported from many parts of Asia, including the Chinese Loess Plateau (Liu and Ding 1998), east Central Asia (Li et al. 2018), the Arabian Sea (Schulz et al. 1998), Lake Van in Anatolia (Litt et al. 2014; Pickarski et al. 2015), eastern Mediterranean (Bartov et al. 2003), the northern Alborz loess sequences (Feizi et al. 2017; Vlaminck 2018), and the western part of the ICP (Mehterian et al. 2017). The effects of the events such as Heinrich are probably most pronounced in arid and semi-arid regions, which were vulnerable to declining annual rainfall (Dennell 2020: 51). In general, due to the prevalence of general and progressive drought in the various parts of Asia during the last glacial cycle (Dennell 2009, 2013, 2017), as well as the evidence from Lake Urmia (Djamali et al. 2008), the Loess Plateau of Iran (Lauer et al. 2017), loess-paleosol sequences of the northern Alborz (Vlaminck 2018), and Qaleh Kurd Cave speleothem research (in the west part of the ICP; Mehterian et al. 2017), the last glacial cycle in the ICP was most likely a relatively dry period. Moreover, correlations with varying degrees between global millennial-scale events and the environmental fluctuations in the northern edges of the ICD are expected during MIS 3. As a first step, and only on the basis of Mirak chronological evidence, the layer 3 was contemporary to the D-O events of 11–15, with the Heinrich event 5 occurrence in between the D-O events 14 and 13. In addition, D-O events 3–5 took place contemporary to Mirak Layer 2 with Heinrich event 3 in between the D-Os 5 and 4 (Fig. 9).

The sedimentological-micromorphological analysis in Mirak revealed that, in general, there are two general sequences (Akhavan Kharazian et al. 2018). The lower (first) sequence is of Late Pleistocene and the upper one, of Holocene. The lower one is an alluvial sequence containing foothill-originated flood-plain sediments formed in a colder and wetter condition than Holocene in the area, when the area was a floodplain (groundwater levels was dramatically higher here before 28 kya). Additionally, the influx of unpredictable hydrologically high energy currents was one of the features of the landscape that created the right conditions for the formation of small and large temporary ponds. In association with the currents were the sediments of the higher altitudes and latitudes deposited across the landscape of Mirak; afterwards, these alluvial deposits were exposed to varying degrees of soil formation processes. The sedimentological units of 7 and 5 indicate the high-energy alluvial mechanisms explained and they contain archaeological layers 3 and 2, respectively (Fig. 3). The texture of these two units is sandy loam (very fine-grained sand) with a prismatic structure in the unit 7 and a blocky structure in 5. In sum, unit 7 indicates a colder, wetter condition, and unit 5 represent a warmer, drier condition, relatively speaking. The archaeological cultural materials are mostly found in the lower parts of these two coarse-grained (compared to the other silty-clayey units in this sequence) units, and it seems that the same sediments are responsible for preserving the archaeological remains (Akhavan Kharazian et al. 2018; Jamet et al. 2018; Vahdati Nasab et al. 2019). According to what mentioned, in addition to the global millennial fluctuations and its possible effects on the Mirak's landscape, the trencd of gradual warming and drying is recorded from the alluvial sequence of Mirak (Akhavan Kharazian et al. 2018). Additionally, according to Figure 9, the layer 2 of Mirak was probably coincided with a drier and more unstable period than the layer 3. Regarding what mentioned above, the general climatic-environmental fluctuation in the first sequence of Mirak was as the following: the general trend from colder and wetter to warmer and drier condition, the general trend of decreasing groundwater level, fluctuations in the hydrological energy of the environment in the presence or absence of flash floods, and the growing unpredictability regarding precipitation and the resultant surface run off. Also, the expected characteristics presumed from the results of research in global scale are: short-term temperature and precipitation fluctuations in the both layers of Mirak and the more gradual nature of such changes in the layer 3 compared to 2 (Fig. 9). Therefore, based on what mentioned, it could be deduced that the landscape of Mirak was a dynamic one in terms of climatic and environmental change, and the pattern of the distribution and predictability of resources was probably different between the two layers; therefore, the stability of the overall morphology of the flake blanks cannot probably be due to environmental stability.

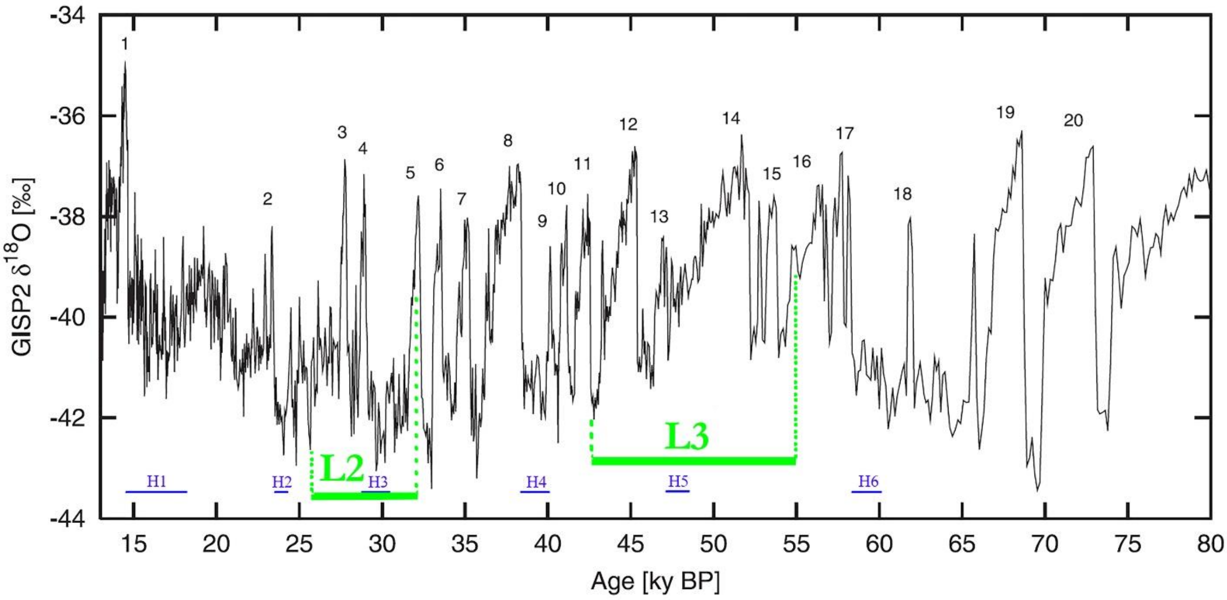

Figure 9. The fluctuations in $\delta^{18}O$ in GISP2 core from Greenland during the last glacial cycle with black numbers denoting the D-O events (raw diagram source: Schulz 2002: fig. 1). Blue H_n represents Heinrich events (their time-frame is based on Saha 2015; Schulz 2002). Green lines represent the age-ranges of the Mirak layers 2 and 3. The more frequent and intensive nature of fluctuations is evident in the age-ranges correspondent to the layer 2 compared to 3.

After examining the climatic fluctuations and knowing that the environment was most likely unstable in Mirak, and that there were probable differences between the two layers in terms of the environmental features, it could be assumed that the adaptive strategies of the hominid populations in the two layers were somewhat different. Because of such possibility of having correlation between environmental fluctuations and technological organization (see the seminal papers of Binford 1977, 1980 or the papers in Robinson and Sellet's edited volume, 2018), the fact of the comparability of the Mirak flake blanks in terms of general morphology indicates that at least some aspects of technological organization have remained unchanged, despite the environmental fluctuations in Mirak. Therefore, these environmental fluctuations cannot be the only factor determining the stability or change in technological organization here. Hence, another possibility will be raised and that is the presence of some inter-related population networks, and consequently, the flow of information and cultural transmission between such groups in the northern ICD, especially in its more western areas (see e.g., Vahdati Nasab et al. 2013). Human groups, especially modern humans tend to create interrelated networks of populations at various spatial scales, which are called metapopulations. This term refers to the spatially-structured populations that are composed of sub-groups (sub-populations), living in a large area in suitable patches (such as the margins of water resources) and are usually separated from each other in most periods due to physical barriers or unfavorable environmental conditions, but with the help of mobility-related mechanisms could make contact to each other from time to time. The formation of such populations is highly optimal, especially in fragmented landscapes; since it can improve the knowledge of the distribution patterns of resources within a region and enables information flow between various groups (Dennell 2020; Hanski and Ovaskainen 2003; Opdam 1991). The existence of such communication networks of human groups has long been suggested, especially in the Upper Paleolithic Period (see e.g., the classic paper of Jochim 1983). From ethnographic observations, it seems that during the more severe periods of the last glacial cycle, especially in the arid and semi-arid zones of Asia, the population density decreased and the groups' mobility increased (drought-scape strategy; see Gould 1991). In such situations, it becomes more difficult to create population networks; since the patches would become fragmented with increased distances to each other (see Dennell 2020, chapter 1). Thus, the chance of extinction or isolation of human groups would arise (fragmentation of living environments is one of the hypotheses associated with the extinction of Neanderthals; see e.g., d'Errico and Sánchez Goñi 2003). In addition, when the climate/environment becomes harsher, human groups tend to move collectively from their original habitats to areas, which are called "refiugia". Here, the candidates of refugis are the northern landscapes of Mirak about the same areas the modern city of Semnan is constructed, or the more western areas within the northern ICP. Due to the east-west climatic gradient in the ICP and more precipitation and available moisture in the form of air humidity and surface water resources in its western parts, the situation of these areas of the ICP was more favorable for sustaining human life. The high probability of the existence of such an east-west climatic gradient in the Iranian Plateau, especially in its northern half during Late Pleistocene Period is developed in some studies (see e.g., Vlaminck et al. 2016). One of the evidence of the east-west movements of human groups in the northern part of the ICP is maybe the existence of numerous Paleolithic sites in the region and the increase in their numbers with archaeological reconnaissance surveys (apart from Mirak, Paleolithic sites such as Chah-e Jam (Vahdati Nasab and Hashemi 2016), Delazian (Vahdati Nasab and Clark 2014a), Sufiabad (Vahdati Nasab and Feiz 2014), Moghanak and Ochunak (Berillon et al. 2007), and the newly-found Paleolithic landscape of Shur-e qazi (Nateqi et al. in press) are among the examples of the sites in the northern ICD).

Apart from what was mentioned, most likely, the landscape of Mirak was favorable only during some sub-stages of MIS 3, the evidence of which is including the discontinuous but frequent presence of human groups in the landscape (the most parsimonious interpretation of the gaps in the archaeological deposits of Mirak in the lack of the other evidence; see Vahdati Nasab et al. 2019), the numerous environmental fluctuations in the form of particle size changes (due to fluctuations in hydrological energy and perhaps, aeolian processes: Akhavan Kharazian et al. 2018), the gradual drying of the area in question, and also, the regional climatic fluctuations during the last glacial cycle (see e.g., Schulz et al. 1998). During more difficult sub-stages, the inhabitants of Mirak were probably moving out from the landscape in search of the more suitable patches; likely to the west (northwest). In such situations, the possibility of making contacts and exchanging information between the various human groups increases. Among the evidence of such information flow may be the yet-superficial evidence of having separate techno-typological clusters in the northern ICP in comparison with the Zagros (Initial steps for drawing such a cluster is seen in Hashemi et al. 2018). It should be noted that when climatic condition was becoming more favorable, human groups re-expanded their range, in which case, in addition to the possibility of the emergence of new features, the old traditions of reducing the cores was preserved (population networks could preserve the flow of information and prevent its destruction; as a result, the cultural traditions survive). Of course, it should be noted that in addition to ecological aspects of preserving cultural traditions (such as optimality and adaptation to the environment), evolutionary studies highlight the so-called history-related inertia or human resistance to change (see e.g., Prentiss and Clarke 2008) as another factor affecting the stability of technological organization, for instance, in methods of reduction. Thus, based on what mentioned, perhaps the lack of formal differences in the lithic tools from the two layers of Mirak in two discrete times is due to the existence of metapopulations in the region in question, the inter-group contacts and the resultant flow of information. Some researchers (e.g., Bretzke 2015) have developed the idea of the formation of metapopulations and the inter-group information flow in southwest Asia during MIS 5 due to the relatively favorable climatic conditions within the Arabian Peninsula during this time (see Parker 2009), and the evidence of which is the similarity of the lithic assemblages recovered from Yemen (Crassard 2009), southern and central Arabia (Crassard and Hilbert 2013; Crassard et al. 2013), and south Oman (Rose 2007), techno-typologically. Thus, the formation of such groups of inter-related populations is not far from the mind for the ICP, as well.

After examining the existence of population networks in the region under discussion, the mobility of these population should be examined, too. The question is, how and in what direction the mobility of the population was and how was the quality of the claimed inter-relationships? As noted above, the presence of human populations has been frequent but discontinuous in Mirak. Therefore, it seems that in some of the more difficult sub-stages of MIS 3 and 2, climatically speaking, living in the landscape was not possible for the populations.

Due to the existence of more suitable environments in terms of humidity at a distance of only ten or few tens of kilometers (for instance, 10–30 km) in the north, as well as more available moisture to the west, and the presence of large and small water reservoirs at different periods in these directions, human groups were probably preferred such parts of the region (more northern and western landscapes) to live and survive through the harsher periods. Living in the last glacial cycle may seem illogical in the more northern landscapes due to the cold, but it should be noted that, first of all, by north, we do not mean the harsh high altitudes of the Alborz, but close distances to Mirak with suitable altitudes (one of the evidence indicating the presence of human population in the more northern landscapes of the ICP is the Paleolithic landscape of Moghanak-Ochunak at an average altitude of 1850 m asl. in the Alborz: Berillon et al. 2007). Secondly, contrary to the classical view in which human groups are considered completely helpless against the harsher periods or higher altitudes during the last glacial cycle, the recent discoveries have helped to modify this view. For instance, we now know that the human populatuions in southern Siberia (Denisovans) used clothing to protect themselves from the cold; evidence of which is the recovery of sewing bone needles dating back to about 50 kya (Derevianko et al. 2016). It is also interesting to note that much older sewing needles are recovered from South Africa, dating back to about 61 kya (Backwell et al. 2008). Hence, humans were not that much vulnerable against environmental changes as previously thought. It is worth mentioining that the more western landscapes, as another candidate for being like a refiugium for the humans populating the landscape of Mirak are not accessible for conducting systematic surface suveys, due to the covering effects of the Holocene alluvial fans, agricultural fields, or the other modern rural and urban constructions. Yet, occasionally, some outcrops containing remains of the Paleolithic artifacts in this part of the plateau are observed due to the impacts of erosion or anthropogenic activity; for instance, the newly-found Paleolithic landscape of Shur-e qazi in the south of the modern towns of Eyvanekey and Sharifabad, Tehran Province, are among such sites (Nateqi et al. in press). It should be noted that the issue of the existence of some suitable patches in more western and northern areas in the study region requires the discovery of a large number of sites, some of them with absolute chronology, in order to provide a more reliable interpretation of the mobility of human populations; therefore, at present, only speculations could be made about the type and the direction of this mobility.

Another important issue needed to be addressed is the attribution of Mirak lithic assemblages to different human species (modern humans and Neanderthals) or to various modern human populations. Following what has been stated in the "Objectives" section about the relationship between Mousterian industry and Neanderthals, as well as the discovery of Neanderthal fossil remains alongside this industry and the use of the levallois technique from Central Asia (See e.g., Ranov and Davis 1979), and the Levant (see e.g., Meignen and Bar-Yosef eds., 2019), and the presence of the relatively open plains in Central Asia with no significant physical barrier with Iranian Plateau, plus the discovery of Neanderthal remains in the Zagros (Trinkaus 1983; Trinkaus and Biglari 2006; Zanolli et al. 2019) and the western part of the ICP (Vahdati Nasab et al., in press), the presence of Neanderthals in Mirak seems reasonable, especially in the layer 3. On the other hand, perhaps both modern humans and

Neanderthals lived in this landscape simultaneously or with intervals; similar to Central Asia in which both species were present during Late Pleistocene (see e.g., Glantz 2010). The proximity of the northern fringes of the ICD to Central Asia and the possibility of the dispersal of human population in east-west direction (from Central Asia to Iran in the opposite direction of the classic models. On the possibility and importance of the east-west routes of dispersal see e.g., Dennell and Roebroeks 2005. Genetic studies also indicate the return waves of human populations to Africa (see e.g., López et al. 2015)). This fact may imply that during the harsher sub-periods of the last glacial cycle, some parts of the Iranian plateau could be used as new habitats by Neanderthals. Also, due to the long history of the presence of modern humans in Southwest Asia about 180 kya (Hershkovitz et al. 2018) and also, the MIS 5 out-of-Africa model of modern human dispersal (Armitage et al. 2011; Petraglia et al. 2007, 2010; Rose et al. 2011; Scally and Durbin 2012), in stages such as MIS 3, modern humans were probably well-dispersed across Southwest Asia. Therefore, the probability of the presence of both groups of humans in the northern margin of the ICP is high and, for instance, the layer 2 of Mirak could be attributed to them. It is necessary to mention one point here, and that is the absence of what one could call Mousterian industry, as defined in Europe (see e.g., Bordes 1961a,b) for the northern ICP. Similar to the claims of some Levantine archaeologists on the absence of the European Neanderthal-related classic Mousterian assemblage in the Levant (see e.g., Shea 2014), the Middle Paleolithic industries of the northern ICD (at least, based on the Paleolithic sites of Semnan Province) cannot be considered classic Mousterian (see Hashemi 2018). As noted by Shea (2014), similar to Levant and contrary to the western Europe, using Levallois technique is common in the northern ICD, heavily-retouched scrapers are rare, points are made (whether levallois or the retouched varieties) commonly, and finally, no handaxe is yet recovered from any Middle Paleolithic sites of the northern ICD. Altogether, this means that despite being classified as Middle Paleolithic industry, the assemblage of Mirak are more reminiscnet of the Levantine than classic Mousterian in west Europe. Therefore, the possibility of the attribution of the Mirak layer 3 lithic tools by modern humans is not also far from the mind.

According to what mentioned above, due to the stability in morphology of the flake blanks in the two layers of Mirak that could perhaps be attributed to the two species of human, there is the possibility of making inter-specific contacts. Becasue of the evidence of the existence of such contacts in the Levant, Europe, Central Asia, and possibly in the Zagros, claiming such a connection for the ICP is not far from the truth. Thus, there is the possibility of inter-specific flow of technological information as an important part of the adaptive strategies. Therefore, this might be why, in addition to the use of new types of lithic tools and more innovative methods of core reduction in the layer 2 of Mirak, and then, the layer 1 (see Vahdati Nasab et al. 2019), the previous reduction methods on the same lithic raw material (common in the layer 3) are also preserved in Mirak. Unfortunately, due to the severe erosion in the layer 1, it is not possible to study the morphology of the flake-based tools at the moment. In Zagros, despite the observation of novel features in the Baradostian (Zagros Aurignacian) layers (Dennell 2020: 232; Ghasidian et al. 2019), the local/indigenous evolution of some features of the Upper Paleolithic tools from Mousterian is not a new claim; put in another way, the Mosuterian-related tools made on flakes were continued to be made and used during the early Upper Paleolithic Period of the Zagros (see e.g., Olszewski and Dibble 1993; Tsanova 2013), similar to the Mirak layer 2, both techno-typologically (Vahdati Nasab et al., 2019), and morphologically (the present paper). Therefore, given what has been discussed, two possibilities arise. First, the Mirak's flake tools are made by different human species (neanderthals and modern humans), and the flake blanks' morphological continuity can indicate inter-specific flow of information and thus, making contacts, especially during the periods with more unfavorable climates when the the ranges of human populations contracted and some movements occurred towards the possible refugia mentioned above. This could also imply some similarities in the adaptive strategies of neanderthals and modern humans in relatively similar and comparable landscapes; in other words, it may highlight the high capacity of neanderthals to adapt to the harsh environment.

In the second possibility, it could be assumed that the flake tools of the both layers are made by different groups of modern humans. This means that we need to assume an assemblage of Mosuterian lithic artifacts in the latitude of about 35° N were made by modern humans (if one can call it a Mousterian assemblage) and that the existence of large interconnected populations of modern humans has made it possible for information to flow and the same methods of flake removal from the cores have been continued by the other groups of modern human after about 20000 years of gap. Here, the need for the absolute chronology of the archaeological sites in the region, such as Chah-e Jam, Delazian, and Sufiabad seems more and more necessary; since without knowing the chronology of these Paleolithic sites, it would be very difficult, if not impossible, to reconstruct the mobility of the human populations and to examine the communication networks.

5 CONCLUSION

The aim of this study was to first examine the morphological change in shape of the Mirak flake tools over time, and then, to evaluate and interpret the preliminary findings and discuss some questions such as the relationship between morphological change and modifications in subsistence strategies, or the attribution of the technological assemblage to various populations (whether different species or not). In addition to what has been said, the use of three-dimensional methods may have implications for the role of lithi raw material in shaping the characteristics of the technological complex and land use patterns. After standardizing the statistical population and neutralizing the effects of size, the study indicated that the two groups of flake-based tools in Mirak (from the layers 1 and 2) are not significantly different from each other in terms of morphology. Part of this seems to be related to good access to the high quality lithic raw material (chert) in proximity to the central place (Mirak) of the hunter-gatherers present in the landscape. However, as mentioned, there is significant size difference between the chunks of the raw material scattered across the landscape and the flake blanks recovered from Mirak. On the other hand, only a very small number of lithic cores are recorded *in situ* which makes the size comparisons between the raw material chunks, the cores, and the flake blanks very difficult; this means that, the intermediate shapes such as lithic cores that allow us to make comparisons between the tools and the lithic raw materials are not currently available. Precisely for this reason, it is not possible to study the flake core reduction process and to check the flake scars on the surface of the cores from the findings of the *in situ* layers. If the flake cores of both layers were available, the researcher could compare the reduction processes and gain a better understanding of the reasons for the similarity in morphology. From what has been said, the morphology of the lithic raw materials is not the only factor explaining the morphological stability of the flake-based tools in Mirak. On the other hand, this stability cannot be attributed to the stability of environmental features and the distribution of resources in the landscape; since, as seen above, the probability of differences in environmental features and the spatio-temporal patterns of resource distribution during the the layers 2 and 3 of Mirak is high.

Here, the lack of change in the general morphology of Mirak lithic tools during two discrete time periods could also be attributed to the flow and survival of information and, consequently, the presence of metapopulations in the northern part of the ICP. Just as in biology, when the linkage and gene flow between the two subpopulations of a species survives continuously, the likelihood of speciation and divergent evolution decreases (except for sympatric speciation which is a matter of debate; see e.g., Coyne 2007), so does the possibility of information survival and cultural continuity if the inter-related population networks are established (see, e.g., Goodale and Andrefsky eds., 2015). It is in this situation that the possibility of the emergence of the stone artifacts with novel features decreases, at least in short periods of time. One of the evidence of information survival in Mirak is probably the diachronic stability in the morphology of the flake-based stone tools. This stability could be interpreted as the presence of similar and comparable methods of reduction in the periods with different environmental characteristics (adherence to the same principles of flake removal and the probable cultural transmission). In other words, inter-connected population networks probably existed in the northern fringes of the ICP which prevented the loss of information. Therefore, it seems that one of the most important factors causing stability in the morphology of the flake-based tools in Mirak was the flow of information and inter-group contacts; whether this connection was between the two different species (neanderthals and modern humans) or various populations of modern humans inhabiting the landscape of the northern ICP. Further research may help to shed light on this issue.

In the end, it should be stated that the present research is just a pilot one in Iran and has the potential capacity to be conducted on a much larger scale in the Iranian plateau and to achieve results with greater reliability. For instance, using the help of the GM methods, the lithic artifacts recovered from various Paleolithic sites could be compared to each other more objectively and the preliminary results could be combined with the results of the other archaeological analyses (such as geoarchaeology, zooarchaeology, archaeoethnobotany, and absolute chronology) to answer research questions. Statistical shape analysis of cultural materials is in its beginnings in Iranian archaeology and needs support.

6 ACKNOWLEDGEMENT

This research was conducted by the financial support of Tarbiat Modares University (TMU) in the framework of the post-doc scholarship for the first author. The budget for the three-seasons of excavations at Mirak Paleolithic site was provided by the General Directorate of Semnan Cultural Heritage and the French Ministry of Foreign Affairs; without their assistance, the excavation at the site would not have been possible. The authors would like to thank Dr. Yaghoub Fathollahi, vice chancellor for research, and Dr. Seyyed Mahdi Mousavi Kouhpar, vice chancellor for human resources management, at TMU for accepting the first author as a postdoctoral researcher. Dr. Hamidreza Nejati, the esteemed director of the Department of Rock Mechanics, TMU, and Mr. Sheikhani, the curator of the mentioned department's laboratories did their best to be of help for hardware part of the research. The authors are grateful for the preliminary guidance of Dr. Nasim Feizi before starting the research work. Finally, we would like to express our special thanks of gratitude to all the mentioned people and organizations, and to the the Mirak excavation and post-excavation analysis team, plus the anonymous reviewers of the journal; any possible error in this article is on the authors alone.

7 REFERENCES

Abdi, H., and L.J. Williams. 2010. Principal component analysis. *WIREs Computational Statistics* 2(4): 433–459.

Akhavan Kharazian, M., Jamet, G., Puaud, S., et al., 2018. Geoarcheological study of the Mirk Archaeological site (Semnan, Iran) using sedimentological and physico-chemical analyses. *The Quaternary Journal of Iran* 4(3): 273–290 (in Farsi).

Andrefsky, W., 1994. Raw-Material Availability and the Organization of Technology. *American Antiquity* 59(1): 21–34.

Andrefsky, W., 2008. An Introduction to Stone Tool Life History and Technological Organization. In: *Lithic Technology: Measures of production, use, and curation*, W. Andrefsky, Jr., (ed.), pp. 3–22. Cambridge University Press.

Archer, W., Gunz, P., van Niekerk, K.L., Henshilwood, C.S., and S.P. McPherron. 2015. Diachronic Change within the Still Bay at Blombos Cave, South Africa. *PLOS ONE* 10(7): e0132428.

Archer, W., Pop, C.M., Režek, Ž., et al., 2017. A geometric morphometric relationship predicts stone flake shape and size variability. *Archaeological and Anthropological Sciences* 10: 1991–2003.

Armitage, S.J., Jasim, S.A., et al., 2011. The southern route 'out of Africa': evidence for an early expansion of modern humans into Arabia. *Science* 331: 453–456.

Backwell, L., d'Errico, F., and L. Wadley. 2008. Middle Stone Age bone tools from the Howiesons Poort layers, Sibudu Cave, South Africa. *Journal of Archaeological Science* 35(6): 1566–1580.

Bartov, Y., Goldstein, S.L., Stein, M. and Y. Enzel. 2003. Catastrophic arid episodes in the eastern Mediterranean linked with the North Atlantic Heinrich Events. *Geology* 31: 439–442.

Baumler, M.F. and J.D. Speth. 1993. A Middle Paleolithic assemblage from Kunji Cave, Iran. In: *The Paleolithic prehistory of the Zagros-Taurus*, D.I. Olszewski and H.L. Dibble (eds.), pp. 1–73. Philadelphia: University of Pennsylvania, Museum of Archaeology and Anthropology.

Berillon, G., Asgari Khaneghah, A., Antoine, P., *et al.* 2007. Discovery of New Open-air Paleolithic Localities in Central Alborz, Northern Iran. *Journal of Human Evolution* 52: 380–387.

Binford, L.R., 1977. Forty-seven trips: A case study in the character of archaeological formation processes. In: *Stone tools as cultural markers: Change, evolution and complexity,* R.V.S. Wright (ed.), pp. 24–36. Canberra: Australian Institute of Aboriginal Studies.

Binford, L.R., 1980. Willow smoke and dog's tails: Hunter-gatherer settlement systems and archaeological site formation. *American Antiquity 45*(1): 4–20.

Bookstein, F.L., 1978. *The Measurement of Biological Shape and Shape Change*. Berlin: Springer-Verlag.

Bookstein, F.L., 1991. *Morphometric Tools for Landmark Data: Geometry and Biology*. Cambridge University Press, Cambridge.

Bookstein, F.L., Chernoff, B., Elder, R.L., Humphries, J., Smith, G.R., and R.E. Strauss. 1985. *Morphometrics in evolutionary biology: The geometry of size and shape change, with examples from fishes*. Philadelphia: Academy of Natural Sciences of Philadelphia.

Bordes, F., 1961a. Mousterian cultures in France. *Science* 134: 803–810.

Bordes, F., 1961b. *Typologie du Paléolithique ancien et moyen*. Bordeaux, Delmas.

Borel, A., Cornette, R., and M. Baylac. 2017. Stone Tool Forms and Functions: A Morphometric Analysis of Modern Humans' Stone Tools From Song Terus Cave (Java, Indonesia). *Archaeometry* 59(3): 455–471.

Bourguignon, L., 1996. Un Mousterien tardif sur le site d'Umm el Tlel (Bassin d'El Khowm, Syric). In: *The last Neanderthals, the first anatomically modern humans: A tale about human diversity, Cultural change and human evolution, the crisis at 40 ka BP*, E. Carbonell, and M. Vaquero (eds.), pp. 317-336. Tarragona: Universitat Rovira & Virgili.

Bretzke, K., 2015. Paleolithic assemblages from the central region of the Emirate of Sharjah (UAE) and implications for human settlement dynamics in southern Arabia. In: *Settlement dynamics of the Middle Paleolithic and Middle Stone Age*, vol. 4., N.J. Conard and A. Delagnes (eds.), pp. 105–125. Tübingen: Kerns.

Buchanan, B., and M. Collard. 2010. An Assessment of the Impact of Resharpening on Paleoindian Projectile Point Blade Shape Using Geometric Morphometric Techniques. In: *New Perspectives on Old Stones*, S.J. Lycett and P. Chauhan, (eds.), pp. 255–273. New York: Springer.

Cardillo, M., 2010. Some applications of Geometric Morphometrics to archaeology. In: *Morphometrics to Nonmorphometricians*, A.M.T. Elewa (ed.), pp. 325–341. Springer.

Chacón, M.G., Détroit, F., Coudenneau, A., and M.-H. Moncel. 2016. Morphometric Assessment of Convergent Tool Technology and Function during the Early Middle Palaeolithic: The Case of Payre, France. *PLOS ONE* 11(5): e0155316.

Coyne, J.A., 2007. Sympatric Speciation. *Current Biology* (Quick Guide) 17(18): 787–788.

Clarkson, C.J., 2002. An index of invasiveness for the measurement of unifacial and bifacial retouch: a theoretical, experimental and archaeological verification. *Journal of Archaeological Science* 29(1): 65–75.

Crassard, R., 2009. The Middle Paleolithic of Arabia: the view from the Hadramawt region, Yemen. In: *The evolution of human populations in Arabia: paleoenvironments, prehistory and genetics*, M.D. Petraglia and J.I. Rose (eds.), pp. 151–168. London: Springer.

Crassard, R., and Y.H. Hilbert. 2013. A Nubian complex site from Central Arabia: implications for Levallois taxonomy and human dispersals during the Upper Pleistocene. *PLOS ONE* 8: e69221.

Crassard, R., Petraglia, M.D., et al., 2013. Middle Palaeolithic and Neolithic occupations around Mundafan Palaeolake, Saudi Arabia: implications for climate change and human dispersals. *PLOS ONE* 8: e69665.

Cserkész-Nagy, A., and O. Sztanó. 2016. Millennial-scale climatic fluctuation in the fluvial record during MIS3: Very high-resolution seismic images from NE Hungary. *Geomorphology* 274: 116–128.

d'Errico, F., and M.F. Sánchez Goñi. 2003. Neandertal extinction and the millennial scale climatic variability of OIS 3. *Quaternary Science Reviews* 22: 769–788.

Dansgaard, W., Johnson, S.J., et al., 1993. Evidence for general instability of past climate from a 250-kyr ice core record. *Nature* 364: 218–20.

de Azevedo, S., Charlin, J., and R. González-José. 2014. Identifying design and reduction effects on lithic projectile point shapes. *Journal of Archaeological Science* 41: 297–307.

Debénath, A., and H.L. Dibble. 1994. *Handbook of Paleolithic Typology, Vol. 1: Lower and Middle Paleolithic of Europe*. Philadelphia: University of Pennsylvania Press.

Delson, E., and K. Harvati. 2006. Return of the last Neanderthal. *Nature* 443: 762–763.

Dennell, R.W., 2009. *The Paleolithic Settlement of Asia*. Cambridge University Press.

Dennell, R.W., 2013. Hominins, deserts, and the colonisation and settlement of continental Asia. *Quaternary International* 300: 13–21.

Dennell, R.W., 2017. Human Colonization of Asia in the Late Pleistocene: The History of an Invasive Species. *Current Anthropology* 58(S17): S383–S396.

Dennell, R.W., 2020. *From Arabia to the Pacific: How Our Species Colonised Asia*. London: Routledge.

Dennell, R.W., and W. Roebroeks. 2005. An Asian perspective on early human dispersal from Africa. *Nature* 438: 1099–1104.

Derevianko, A.P., Shunkov, M.V., Kozlikin, M.B., Fedorchenko, A.Y., Pavlenok, G.D., and N.E., Belousova. 2016. Early Upper Paleolithic bone needle from the main chamber of Denisova Cave (Based on data from the 2016 excavation). *Issues of Archaeology, Ethnography, Anthropology of Siberia and Nearby Territories* 22: 72–75 (in Russian).

Djamali, M., de Beaulieu, J.-L., Shah-hosseini, M., et al., 2008. A late Pleistocene long pollen record from Lake Urmia, NW Iran. *Quaternary Research* 69: 413–420.

Eren, M.I., Roos, C.I., Story, B.A., von Cramon-Taubadel, N., and S.J. Lycett. 2014. The role of raw material differences in stone tool shape variation: An experimental assessment. *Journal of Archaeological Science* 49: 472–487.

Ericson, J.E., 1984. Toward the analysis of lithic production systems. In: *Prehistoric Quarries and Lithic Production*, J.E. Ericson and B.A. Purdy (eds.), pp. 1–10. Cambridge University Press.

Feizi, N., Vahdati Nasab, H., and T. Wynn. 2018. Consider the third dimension: A new approach for measuring the symmetry of the middle Paleolithic points of the Mirak Site. *Comptes Rendus Palevol* 17(6): 388–398.

Feizi, N., Vahdati Nasab, H., and T. Wynn. 2020. New Approach to Analysis the Middle Paleolithic Points of the Iranian Plateau: Style vs. Environment. *Lithic Technology* 45(1): 19–37.

Feizi, V., Azizi, Q., Alimohammadian, H., and M. Mollashahi. 2017. Paleoclimate analysis of Nowdeh section (Golestan Province) using geochemical element analysis. *The Quaternary Journal of Iran* 3(9): 29–39 (in Farsi).

Ghasidian, E., Heydari-Guran, S., and M.M. Lahr. 2019. Upper Paleolithic cultural diversity in the Iranian Zagros Mountains and the expansion of modern humans into Eurasia. *Journal of Human Evolution* 132: 101–118.

Glantz, M.M., 2010. The History of Hominin Occupation of Central Asia in Review. In: *Asian Paleoanthropology from Africa to China and Beyond*, C.J. Norton and D.R. Braun (eds.), pp. 101–112. Springer.

Goodale, N., and W. Andrefsky, Jr., eds., 2015. *Lithic Technological Systems and Evolutionary Theory*. New York, NY: Cambridge University Press.

Gould, R.A., 1991. Arid-land foraging as seen from Australia: adaptive models and behavioural realities. *Oceania* 62: 12–33.

Groucutt, H., Grün, R., Zalmout, I.S.A., Drake, N.A., et al., 2018. Homo sapiens in Arabia by 85,000 years ago. *Nature Ecology and Evolution* 2: 800–809.

Gunz, P., and E. Bulygina. 2012. The Mousterian child from Teshik-Tash is a Neanderthal: a geometric morphometric study of the frontal bone. *American Journal of Physical Anthropology* 149(3): 365–379.

Hashemi, S.M., 2018. Reconstruction of Pleistocene Human Settlements at the Northern Fringes of the Iranian Central Desert: A Multidisciplinary Approach. PhD Dissertation in Archaeology, Tarbiat Modares University (unpublished; in Farsi).

Hashemi, S.M., Vahdati Nasab, H., Berillon, G., et al., 2018. The Late Pleistocene in the Northern fringes of Iranian Central Desert and the Formation of Archaeological Sites; Case Study: Mirak, Semnan. *The Quaternary Journal of Iran* 3(4): 405–430 (in Farsi).

Hanski, I., and O. Ovaskainen. 2003. Metapopulation theory for fragmented landscapes. *Theoretical Population Biology* 64: 119–127.

Heinrich, H., 1988. Origin and consequences of cyclic ice rafting in the northeast Atlantic Ocean during the past 130,000 years. *Quaternary Research* 29(2): 142–152.

Hershkovitz, I., Weber, G.W., Quam, R., et al., 2018. The earliest modern humans outside Africa. *Science* 359(6374): 456–459.

Herzlinger, G., and L. Grosman. 2018. AGMT3-D: A software for 3-D landmarks-based geometric morphometric shape analysis of archaeological artifacts. *PLOS ONE* 13(11): e0207890.

Hetherington, R., and R.G.B. Reid. 2010. *The climate connection: climate change and modern human evolution*. Cambridge University Press.

Heydari, M., Guérin, G., Kreutzer, S., Jamet, G., Akhavan Kharazian, M., Hashemi, M., Vahdati Nasab, H., and G. Berillon. 2020. Do Bayesian methods lead to more precise 1 chronologies? 'BayLum' and a first OSL-based chronology for the Palaeolithic open-air site of Mirak (Iran). *Quaternary Geochronology* 59: 101082.

Higham, T., Douka, K., Wood, R., Ramsey, C.B., et al., 2014. The timing and spatiotemporal patterning of Neanderthal disappearance. *Nature* 512(7514): 306–309.

Ishiwa, T., Yokoyama, Y., Okuno, J., et al., 2019. A sea-level plateau preceding the Marine Isotope Stage 2 minima revealed by Australian sediments. *Scientific Report* 9: 6449.

Jamet, G., Akhavan Kharrazian, M., Guerin, G., et al., 2018. Pedosedimentary Evolution and Site Formation Processes in Mirak Mound 8, South of Semnan. In: *Proceedings of the first International Conference of the Iranian Quaternary Association*, 2018, Tehran: Geological Survey and Mineral Explorations of Iran (GSI) (in Farsi).

Jochim, M.A., 1983. Paleolithic art in Ecological Perspective. In: *Hunter-Gatherer Economy in Prehistory: A European Perspective*, G. Bailey (ed.), pp. 212–219. Cambridge University Press.

Johnsen, S.B., Clausen, H.B., et al., 1992. Irregular glacial mterstadials recorded in a new Greenland ice core. *Nature* 359: 311-3.

Krause, J., Orlando, L., Serre, D., Viola, B., et al., 2007. Neanderthals in central Asia and Siberia. *Nature* 449(7164): 902–904.

Kuhn, S., 1991. Unpacking reduction: Lithic raw-material economy m the Mousterian of West-Central Italy. *Journal of Anthropological Archaeology* 10: 76–106.

Latif, M., Claussen, M., Schulz, M., and T. Brücher. 2016. Comprehensive Earth system models of the last glacial cycle. *Eos* 97.

Lauer, T., Vlaminck, S., et al., 2017. The Agh Band loess-palaeosol sequence: A terrestrial archive for climatic shifts during the lats and penultimate glacial-interglacial cycles in a semiarid region in northern Iran. *Quaternary International* 429(Part B): 13–30.

Li, Y., Song, Y., Fitzsimmons, K.E., et al., 2018. Eolian dust dispersal patterns since the last glacial period in eastern Central Asia: insights from a loess-paleosol sequence in the Ili Basin. *Climate of the Past* 14: 271–286.

Lindly, J.M., 1997. The Zagros Mousterian: A regional perspective. Ph.D. dissertation, Department of Anthropology, Arizona State University (Unpublished).

Litt, T., Pickarski, N., et al., 2014. A 600,000-year long continental pollen record from Lake Van, eastern Anatolia (Turkey). *Quaternary Science Reviews* 104: 30–41.

Liu, T.S., and Z.L. Ding. 1998. Chinese loess and the paleomonsoon. *Annual Review of Earth and Planetary Sciences* 26: 111-145.

López, S., van Dorp, L., and G. Hellenthal. 2015. Human dispersal out of Africa: A lasting debate. *Evolutionary Bioinformatics* 11(s2): 57–68.

Lowe, J.J., 2001. Climatic Oscillations during the Last Glacial Cycle: Nature, Causes and the Case for Synchronous Effects. *Biology and Environment: Proceedings of the Royal Irish Academy* 101B (1/2): 19–33.

Lycett, S.J., 2015. Cultural evolutionary approaches to artifact variation over time and space: basis, progress, and prospects. *Journal of Archaeological Science* 56: 21–31.

Lycett, S.J., and P.R. Chauhan. 2010. Analytical approaches to Palaeolithic technologies: an introduction. In: *New Perspectives on Old Stones*, S.J. Lycett and P. Chauhan, (eds.), pp. 1–22. New York: Springer.

Lycett, S.J., and N. von Cramon-Taubadel. 2013. A 3D morphometric analysis of surface geometry in Levallois cores: patterns of stability and variability across regions and their implications. *Journal of Archaeological Science* 40: 1508–1517.

Mehterian, S., Pourmand, A., et al., 2017. Speleothem records of glacial/interglacial climate from Iran forewarn of future Water Availability in the interior of the Middle East. *Quaternary Science Reviews* 164: 187–198.

Meignen, L., and O. Bar-Yosef, eds., 2019. *Kebara Cave, Mt Carmel, Israel: The Middle and Upper Paleolithic Archaeology, Part II*. Harvard University, Peabody Museum Press.

Monnier, G.F., and K.P. McNulty. 2010. Questioning the Link Between Stone Tool Standardization and Behavioral Modernity. In: *New Perspectives on Old Stones*, S.J. Lycett and P. Chauhan, (eds.), pp. 61–81. New York: Springer.

Morisaki, K., Izuho, M., Terry, K., and H. Sato. 2015. Lithics and climate: Technological responses to landscape change in Upper Palaeolithic northern Japan. *Antiquity* 89(345): 554–572.

Nateqi, A., Vahdati Nasab, H., and S.M. Hashemi. The Quaternary sediments and Paleolithic settlements along the Northern fringes of the Iranian Central Desert; introduction of the two newly-found Paleolithic sites of Shur Qazi and Sar Darreh. *The Quaternary Journal of Iran* X (in Farsi; In Press).

Needham, A.E., 1950. The form transformation of the abdomen of the female pea-crab Pinnotheres pisum Leach. *Proceedings of the Royal Society B: Biological Sciences* 137(886): 115–136.

O'Brien, M.J., and R.L. Lyman, eds., 2003. *Style, Function, Transmission: Evolutionary Archaeological Perspectives*. Salt Lake City: University of Utah Press.

O'Brien, M.J., Darwent, J., and R.L. Lyman. 1999. Cladistics is Useful for Reconstructing Archaeological Phylogenies: Palaeoindian Points from the Southeastern United States. *Journal of Archaeological Science* 28: 1115–36.

Okumura, M., and A.G.M. Araujo. 2019. Archaeology, biology, and borrowing: A critical examination of Geometric Morphometrics in Archaeology. *Journal of Archaeological Science* 101: 149–158.

Olszewski, D.I., 2001. Ruminations on the early Upper Paleolithic and a consideration of the Zagros Aurignacian. In: *Questioning the Answers: Resolving fundamental problems of the early Upper Paleolithic*, M. Hays and P. Thacker (eds.), pp.79–89. Oxford: BAR International Series 1005, Archaeopress.

Olszewski, D.I., 2009. Comparing Middle to Upper Paleolithic Transitions in the Middle East and Egypt. In: *Sourcebook of Paleolithic Transitions: Methods, Theories, and Interpretations*, M. Camps and P. Chauhan (eds.), pp. 315-332. Springer.

Olszewski, D. and H.L. Dibble. 1993. *The Paleolithic Prehistory of the Zagros-Tauros*. University of Pennsylvania: The University Museum.

Opdam, P., 1991. Metapopulation theory and habitat fragmentation: a review of Holarctic breeding bird studies. *Landscape Ecology* 5(2): 93–106.

Parker, A.G., 2009. Pleistocene Climate Change in Arabia: Developing a Framework for Hominin Dispersal over the Last 350 ka. In: The Evolution of Human Populations in Arabia: Paleoenvironments, Prehistory and Genetics, M.D. Petraglia and J.I. Rose (eds.), pp. 39–49. Springer.

Pecl, G.T., Araújo, M.B., Bell, J.D., et al., 2017. Biodiversity redistribution under climate change: Impacts on ecosystems and human well-being. *Science* 355(6332): eaai9214.

Petraglia, M.D., Korisettar, R., et al., 2007.Middle Paleolithic assemblages from the Indian subcontinent before and after the Toba super-eruption. *Science* 317: 114–116.

Petraglia, M.D., Haslam, M., Fuller, D.Q., Boivin, N., and C. Clarkson. 2010. Out of Africa: New hypotheses and evidence for the dispersal of Homo sapiens along the Indian Ocean rim. *Annals of Human Biology* 37: 288–311.

Pickarski, N., Kwiecien, O., Langgut, D., and T. Litt. 2015. Abrupt climate and vegetation variability of eastern Anatolia during the last glacial. *Climate of the Past* 11: 1491–1505.

Polley, K., Chandrar, S., Banerjee, A., and W.K. Bain. 2017. The Impact of Raw Material Properties on Lithic Debitage Assemblage Variation: An Experimental Assessment in Indian Context. *Man and Environment* XLII(1): 36–49.

Prentiss, A.M., and D.S. Clarke. 2008. Lithic Technological Organization in an Evolutionary Framework: Examples from North America's Pacific Northwest Region. In: *Lithic Technology: Measures of Production, Use, and Curation*, W. Andrefsky Jr. (ed.), pp. 257–285. Cambridge University Press.

Ranov, V.A., and R.S. Davis. 1979. Toward a New Outline of the Soviet Central Asian Paleolithic. *Current Anthropology* 20(2): 249–270.

Richter, D., Schroeder, H.B., Rink, W.J., Julig, P.J., and H.P. Schwarcz. 2001. The Middle to Upper Palaeolithic Transition in the Levant and New Thermoluminescence Dates for a Late Mousterian Assemblage from Jerf al-Ajla Cave (Syria). *Paléorient* 27(2): 29–46.

Richter, D., Grün, R., Joannes-Boyau, R. et al., 2017. The age of the hominin fossils from Jebel Irhoud, Morocco, and the origins of the Middle Stone Age. *Nature* 546: 293–296.

Robinson, E., and F. Sellet, eds., 2018. *Lithic Technological Organization and Paleoenvironmental Change: Global and Diachronic Perspectives*. Springer.

Rose, J.I., 2007. The Arabian corridor migration model: archaeological evidence for hominin dispersals into Oman during the Middle and Upper Pleistocene. *Proceedings of the Seminar for Arabian Studies* 37: 219–237.

Rose, J.I., Usik, V.A., et al. 2011. The Nubian complex of Dhofar, Oman: An African Middle Stone Age industry in southern Arabia. *PloS ONE* 6(11): e28239.

Saha, R., 2015. Millennial-scale oscillations between sea ice and convective deep water formation. *Paleoceanography* 30: 1540–1555.

Scally, A., and R. Durbin. 2012. Revising the human mutation rate: implications for understanding human evolution. *Nature Reviews Genetics* 13: 745–753.

Scerri, E.M.L., Gravina, B., Blinkhorn, J., and A. Delagnes. 2016. Can Lithic Attribute Analyses Identify Discrete Reduction Trajectories? A Quantitative Study Using Refitted Lithic Sets. *Journal of Archaeological Method and Theory* 23: 669–691.

Schulz, H., von Rad, U., and H. Erlenkeuser. 1998. Correlation between Arabian Sea and Greenland climate oscillations for the past 110000 years. *Nature* 393: 54–7.

Schulz, M., 2002. On the 1470-year pacing of Dansgaard-Oeschger warm events. *Paleoceanography* 17(2): 1014.

Sharon, G., 2008. The impact of raw material on Acheulian large flake production. *Journal of Archaeological Science* 35(5): 1329–1344.

Shea, J.J., 2003. Neandertals, competition, and the origin of modern human behavior in the Levant. *Evolutionary Anthropology* 12(4): 173–187.

Shea, J.J., 2006. The origins of lithic projectile point technology: evidence from Africa, the Levant, and Europe. *Journal of Archaeological Science* 33(6): 823–846.

Shea, J.J., 2014. Sink the Mousterian? Named stone tool industries (NASTIES) as obstacles to investigating hominin evolutionary relationships in the Later Middle Paleolithic Levant. *Quaternary International* 350: 169–179.

Shott, M., and B. Trail. 2010. Exploring new approaches to lithic analysis: Laser scanning and geometric morphometrics. *Lithic Technology, 35*(2): 195–220.

Siddall, M., Rohling, E.J., Thompson, W.G., and C. Waelbroeck. 2008. Marine isotope stage 3 sea level fluctuations: Data synthesis and new outlook. *Reviews of Geophysics* 46(4): RG4003.

Slice, D.E., 2007. Geometric morphometrics. *Annual Review of Anthropology* 36: 261–281.

Slimak, L., Svendsen, J.I., et al., 2011. Late Mousterian Persistence near the Arctic Circle. *Science*13: 841–845.

Trinkaus, E., 1983. *The Shanidar Neanderthals*. New York and London: Academic Press.

Trinkaus, E., and F. Biglari. 2006. Middle paleolithic human remains from Bisitun Cave, Iran. *Paléorient* 32(2): 105–111.

Tsanova, T., 2013. The beginning of the Upper Paleolithic in the Iranian Zagros: A taphonomic approach and techno-economic comparison of Early Baradostian assemblages from Warwasi and Yafteh (Iran). *Journal of Human Evolution* 65: 39–64.

Vahdati Nasab, H., and M. Vahidi. 2011. Re-evaluation of Scrapers Reduction Model Using Geometric Index of Reduction (Mar-Tarik Middle Paleolithic Assemblages). *Iranian Journal of Archaeological Studies* 1(1): 26–34.

Vahdati Nasab, H., and G. Clark. 2014a. The upper Paleolithic of the Iranian central desert: The delazian site, a case study. *AMIT* 46: 1–20.

Vahdati Nasab, H., and G. Clark. 2014b. Modern Human Origins: Midfacial Prognathism, 3D Approach. *International Journal of the Society of Iranian Archaeologists* 1(1): 33–46.

Vahdati, H., and Z. Feiz. 2014. Survey and identification of Paleolithic sites in the northern fringes of the Iranian Central Desert plain: between Semnan and Sorkheh. In: *Proceedings of the 12th Annual Archaeological Conference of Iran*, K. Roustaei (ed.), pp. 468–465. Tehran: Research Institute of Cultural Heritage and Tourism (in Farsi).

Vahdati Nasab, H., and M. Hashemi. 2016. Playas and Middle Paleolithic settlement of the Iranian Central Desert: The discovery of the Chah-e Jam Middle Paleolithic site. *Quaternary International* 408 (part B): 140–152.

Vahdati Nasab, H., Afshar, Z., and S.S. Arab. 2007. The introduction of geometric morphometric technique and the investigation on the skulls recovered from Gohar Tepe archaeological site. In: *Proceedings of the 9th Annual Conference on Iranian Archeology*, Vol. 3. Tehran: National Museum of Iran (in Farsi).

Vahdati Nasab, H., Clark, G.A., and S. Torkamandi. 2013. Late Pleistocene dispersal corridors across the Iranian Plateau: A case study from Mirak, a Middle Paleolithic site on the northern edge of the Iranian Central desert (Dasht-e Kavir). *Quaternary International* 300: 267–281.

Vahdati Nasab, H., Berillon, G., Jamet, G., Hashemi, M., et al. 2019. The Open-Air Paleolithic Site of Mirak, Northern Edge of the Iranian Central Desert (Semnan, IRAN): Evidence of repeated human occupations during the late Pleistocene. *Comptes Rendus Palevol* 18(4): 465–478.

Vahdati Nasab, H., Berillon, G., Hashemi, S.M., Jamet, G., et al., 2020. Qaleh Kurd Cave, a Middle Paleolithic Site with Evidence of Human Remains, Avaj, Qazvin. *Archaeology, Journal of the ICAR* (in Press; in Farsi).

Vandermeersch, B. (ed.), 1981. *Les Hommes fossiles de Qafzeh*. Paris: Cahiers de paléontologie Series, Editions du Centre national de la recherche scientifique.

Vlaminck, S., 2018. *Northeastern Iranian loess and its palaeoclimatic implications*. PhD dissertation, Faculty of Mathematics and Natural Sciences, University of Cologne.

Vlaminck, S., Kehl, M., et al., 2016. Loess-soil sequence at Toshan (Northern Iran): Insights into late Pleistocene climate change. *Quaternary International* 399: 122–135.

Webster, M., and D. Sheets. 2010. A Practical Introduction to Landmark-Based Geometric Morphometrics. *Paleontological Society Papers* 16 (Quantitative Methods in Paleobiology): 163–188.

Wilkins, J., Brown, K.S., Oestmo, S., Pereira, T., Ranhorn, K.L., Schoville, B.J., and C.W. Marean. 2017. Lithic technological responses to Late Pleistocene glacial cycling at Pinnacle Point Site 5–6, South Africa. *PLOS ONE* 12(3): e0174051.

Zanolli, C., Biglari, F., Mashkour, M., et al., 2019. A Neanderthal from the Central Western Zagros, Iran. Structural reassessment of the Wezmeh 1 maxillary premolar. *Journal of Human Evolution* 135: 102643.

8 Endnotes

۱. See, e.g., the statistical shape analysis of some Paleolithic lithic points recovered from the Iranian sites focusing on the subject of symmetry: Feizi et al. 2018, 2020. Besides, some anthropological GM studies have also been carried out in Iran so far, which their bibliographic information is as the following: Vahdati Nasab and Clark 2014b; Vahdati Nasab et al. 2007; Zanolli et al. 2019).

۲. The remains of another potential archaeological deposit were found during the third season of excavation in the bottom of a clandestine hole with a sandy-silty texture. This deposit is of about 38 kya, based on the OSL dating (Heydari et al. 2020). Future excavations is needed to specify the nature of this deposit and its relationship to other Mirak's known cultural deposits.

۳. Yet, it should be noted that the date of the beginning of MIS 2 is 29kya (see e.g., Ishiwa et al. 2019).

۴. Note that the ICD is a part of the larger ICP; thus, here we use the term ICD when referring specifically to the northern landscapes and Paleolithic sites in the northern modern Semnan or Tehran Provinces, such as the sites mentioned in the text, and the term ICP is used when talking generally about the region and the population networks.

۵. Fig. 2 depicts only the exceptional classic types recovered, with sometimes long and invasive retouches; but these specimens are not included within the present statistical population. A high percentage of Mirak lithic tools are just simply informally retouched pieces (Vahdati Nasab et al. 2019).

۶. Owned by the department of Rock mechanics, Tarbiat Modares University.

۷. Artifact GeoMorph toolbox 3-D (2020 version: https://sourceforge.net/projects/artifact-geomorph-toolbox-3d/)

۸. Compare this to some Paleolithic sites of the Zagros in which the impact of the lithic raw materials morphology is detectable; for instance, the river cobbles were the main raw material for the inhabitants of some Zagros sites such as Mar-Tarik Cave and the size and morphology of which dramatically impacted the morphology of the flake blanks: see Vahdati Nasab and Vahidi 2011. See also Baumler and Speth 1993; Lindly 1997 as examples for discussing the mentioned impact of riverine cobbles in some other Paleolithic sites within the Zagros.

۹. The large dimension may imply that the chunks had little movement in the landscape due to natural processes; thus, they were available at Late Pleistocene, as is the case today.