Università degli Studi di Ferrara

DOTTORATO DI RICERCA IN
SCIENZE UMANE
"International Doctorate in Quaternary and Prehistory"

In Convenzione con
Universitat Rovira i Virgili
Museum national d'Histoire naturelle

CICLO XXXI

COORDINATRICE/COORDINATORE Prof. Trovato, Paolo

Functional Analysis of the Lithic Assemblages from the Middle and Upper Paleolithic sites of horramabad Valley (Western Iran), with special reference to Kaldar Cave

Settore Scientifico Disciplinare L-ANT /01

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Anni 2016/2019

UNIVERSITAT ROVIRA i VIRGILI

IDQP

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LAXMI TUMUNG

DOCTORAL THESIS

2019

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Supervised by Dr. Andreu Ollé and Pr. Hubert Forestier

Co-supervised by Dr. Antony Borel

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DOCTORAL THESIS

April 2019

We ATTEST that the present study, entitled “Functional Analysis of the Lithic Assemblages from the Middle and Upper Paleolithic sites of Khorramabad Valley (Western Iran), with special reference to Kaldar Cave” presented by Laxmi Tumung to achieve a doctoral degree, has been supervised by us in the Institut Català de Paleoecologia Humana i Evolució Social (IPHES) and Department of History and History of Art of the University of Rovira i Virgili (URV), and in the Muséum National d’Histoire Naturelle.

Tarragona, March 13, 2019

Thesis Supervisor 1	Thesis Supervisor 2	Thesis co-supervisor
Dr. Andreu Ollé Cañellas	Pr. Hubert Forestier	Dr. Antony Borel

The scientific man does not aim at an immediate result. He does not expect that his ideas will be readily taken up. His work is like that of a planter for the future. His duty is to lay foundation of those who are to come and point the way.

Nikola Tesla

I am dedicating this thesis to my lovely daughter VIDA who silently/unknowingly has gone through all the hard times of separation and difficult situations with me to pursue this PhD. She showed me the true meaning of motherhood, unconditional love, patience, courage, and how to be a role model for her with examples.

Thank you, my princess!!!

Acknowledgements

First of all, I am indebted to the Erasmus Mundus community which provided me with the two valuable scholarships opportunities of my life (first for my Masters, 2008 and second for this PhD, 2016). For me, this scholarship not only helped me to acquire knowledge in my field of interest but also opened up many opportunities for life. I am very grateful to all the co-coordinators of Erasmus Mundus community, especially Marta Arzarello, Robert Sala, Carlos Lorenzo and Chafika Falguères for helping me out with my official works during my stay in Spain and France.

I am highly indebted to my supervisor Dr Andreu Ollé who continuously showed me his trust in my work, gave his support and valuable guidance during my master's thesis as well as for this PhD research. All these years of working together, now he is not only as my supervisor he becomes more like my friend, colleague and family. I am also very grateful to my other two supervisor's Prof. Hubert Forestier and Dr Antony Borel, without whom this research would not have been fulfilled. Their constructive suggestions, discussions and guidance helped me to overcome many of my research problems.

I want to extend my heartiest thanks to all the Professors and researchers of Universitat Rovira i Virgili (URV), Institut Català de Paleoecologia Humana i Evolució Social (IPHES), Muséum National d'Histoire Naturelle (MNHN) and University of Ferrara for their knowledge and guidance during my 11 years of stay in Europe. I also like to thank URV, IPHES, MNHN, and MDH (Musée de l'Homme), for providing me with all the necessary access to the labs and microscopes to perform the functional analysis. I am indebted to Dr Fransesc for performing micro X-Ray diffraction; Dr Araujo-Andrade, Dr Marro, Dr Loza-Álvarez from ICFO (Institut de Ciències Fotòniques, Barcelona) for performing FTIR and Raman spectroscopy analysis.

Prof. Eudald Carbonell and Prof. Marcel Otte were the two significant people, who from the beginning believed in the potential of Khorramabad Project and funded for the excavations. Their constructive suggestions and guidance led us to significant achievements for our project. I also would like to thank Veerle Rots, with whom I meet on several occasions and discussed various issues related to hafting and prehension.

Dr Ignasi Pastó and Bernat Sentís have played an important role in plans and strategy of Khorramabad project, for which I am indebted to both of them. Following people helped and supported me in many aspects of administrative works: Vanessa Altès Batalla, Anna March Farré, Òscar Moreno Moliner, Laura Pérez Llort and Fèlix Torreblanca Hernández.

I am thankful to Dr Mahmoud Mir Eskandari (former director of ICAR) for issuing the permission for the first season excavation in 2010 and also to Mr. Seyed Mohammad Beheshti and Dr. Hamide Choubak directors of RICHT and ICAR for issuing second season excavation for Kaldar Cave in 2014-15 and even for giving permission for the excavation material.

I am indebted to Dr Behrouz Bazgir (director of the Khorrambad project) first of all, for giving me the opportunity to be the part of the Khorramabad project team. Secondly for trusting on me and giving me access to archaeological material to build up my PhD research. I take the opportunity to extend my gratitude to all the excavation team members without their hard work we could not have achieved this success of our project. They are Dr. Sushama Ganesh Deo, Dr. Pramod Joglekar, Davoud Davoudi, Ata Hassanpour, Hassan Dehghani Fard, Ali Bazogh, Mahtab Gholamdoust, Kazem Omidi, Mehdi Shahkarami, Reza Koshki, Shahab Yousofvand, Saeed Seifi, Saeed Derikvand, Rohoullah Norollahi, Kazem Omidi, Amir Baharvand, M. Jayez, N. Hashemi, I. Beheshti, S. Azadbakht, S. Horshid, M. Hashemi, F. Bakhtiari, Z. Feiz, and R. Khazaeli who participated for a period or a full season of the excavation.

The great efforts by the logistics team: Siros Bazgir, Hojat Moradi, Mostafa Derikvand, Iraj Moradi, Ali Rahmati, Mohammad Momeni, Hadi Jahangiri and Reza Beiranvand in organising the excavations and for providing further logistic services are highly appreciated. We much appreciate the support and logistic help provided by the guards of the wildlife sanctuary while excavating Kaldar Cave.

I am grateful to all the co-authors with whom I worked on different aspects of our Khorramabad Project, as well as with whom I published various articles in high impact factor journals and collaborating for the ongoing projects. They are Jan van der Made, Thomas Hingham, Katherina Douka and Lorena Beccara, Ethel Allué and Isabel Expósito Barea, Palmira Saladié, Juan Manuel López García, Hugues-Alexandre Blain, Mónica Fernández García and Iván Rey Rodríguez, Andrea Picin, Antonella Pedergnana, Lena Asryan, Juan Ignacio Martín-Viveros, Juan Luis Fernández-Marchena.

During my 11 years of stay in Tarragona, from my Master in 2008 until the submission of my PhD thesis, I have gone through many life challenges to reach where I am right now. The journey was rough and full of roller coaster rides, but it becomes all easier to face those challenges with the support of many amazing people in my life. This PhD thesis was not only a challenge to fulfil my research goals but also to succeed in my different aspect of life where I needed to play different roles as a daughter, sister, wife, sister-in-law, daughter-in-law, friend/colleague and most importantly as a single MOTHER. Therefore, I would like to take this opportunity to extend my heartiest gratitude to all those people in my life who contributed in shaping my life as a beautiful experience.

I am grateful for the friendship of Dr Deborah Barsky who always gave me significant support like a friend and mentor during my difficult times in finishing my PhD. I want to take this opportunity to thank Dr Lucia López-Polin Dolhaberriague, who helped and supported me during the time my daughter "Vida" was born in 2014. I also thankful to Venessa Altès Batalla, Gala Gómez Merino and Magda Gómez Puche for their emotional support as well as for helping me with the bureaucratic works for Vida's school. Special thanks to Maiyam, Antony, Ana Ines for making my life so much easier by occasionally taking care of Vida in the last moments of finishing my thesis. I also want to thank all the parents of Vida's classmate and her teachers who made us felt like family by giving their love and support during our difficult times.

I also want to thank all my great friends whom I met during my stay in Tarragona and Paris and shared unforgettable moments together. They are Shikha, Nilam, Souhila, Lebo, Karina, Elodie, Giulia, Madhavi, Fatima Zohra, Fatima Anna, Pinkie, Padmaja, Vijaylakshmi, Monica, Andrea Cosalan, Mehkahmeh, Lea, Nina, Nasibeh, Sadaf, Ximena, Eliana, Nuria, Kary, Alba, Marta, Razika, Omar, Marcos, Archi, Arya, Pezman, Sari, Laith, Momoka, Dominica, Yasmine, Victoria, Felix, Tsegai, Sofian, Moncef, Alex, Sachin, Guillem. Out of these friends, once Razika once jokingly said: "*Laxmi, you are not doing one PhD but doing three Phd's 1) your PhD, 2) PhD about bureaucracy and 3) how to manage a child and your PhD*".

Without the blessings of parents, life is meaningless. Hence, I want to extend my heartfelt gratitude to my parents (both from India and Iran). My father Late Jagat Chandra Tumung, whose great wisdom and encouraging words "*never feel scared of failure*" always pushed me to achieve my goals and never give up. I hope today he is

smiling proudly in heaven by seeing my achievements. I am grateful to my mother (my role model) Babuli Tumung, who showed me with examples, how to be a strong woman of substance.

In-laws are like second parents who accept you as their children. I am very grateful to God for blessing me with these beautiful people in my life who made me felt like home away from home. My father-in-law Mr Baksh Ali Bazgir (who suffers from severe cancer) has proved that with strong will power you can defeat any difficulty of life. My mother-in-law Khadijah Niazi, whose constant prayers and emotional support has helped me to find peace in the most challenging situations. I am very appreciative of the unconditional love and support I receieved from my other family members. My sisters (Kalpana Tumung, Shaila Tumung), my anuts (Nalani Mahi, Basanti Mahi, Banohi Mahi), my sister-in-laws (Shokat, Maryam, Seema, and Nastaran); my bother-in-laws (Siros and Sasan) and other relatives (Modar, Ame, Amo, Doi and Khale). My dear friend Ajana (for her moral support) and last but not the least, my lovely nephews and nieces Shadi, Kiarish, Raha, Kapil, Pari, Ava and Nikki.

ABSTRACT

The PhD research derive from the need to check the feasibility of the functional studies (use-wear and residues) on the Middle and Upper Paleolithic lithic assemblages of the Khorramabad Valley sites of western Iran. This research is a part of the “Khorramabad Project” started in 2009, which was a goal–oriented multi-disciplinary research towards the understanding of the Middle to Upper Paleolithic Transition in the Zagros Mountains and its implication in global debate on this regard. In 2011-12, four sites (Kaldar Cave, Gilvaran Cave, Ghamari Cave, Gar Arjeneh rock shelter) of Khorramabad Valley was test excavated to check the potential of the sites to answer the above mentioned aim. Later in 2014-15, Kaldar Cave was excavated in larger scale which led to the discovery of cultural remains associated to the Anatomical Modern Human (AMH) with the oldest C14 date of 54,600-36,000 cal BP in western Asia, as well as the Neanderthal made industry in the basal layer.

For this research, I used the Kaldar Cave lithic assemblage as the main case study for functional studies with comparison to other sites. The research is developed in two main parts: 1) Methodology and 2) archaeological application.

For the methodology part of the research, an excavation protocol was adapted which was functional study friendly to minimise the modern contaminations in the site and the results was compared between the lithic artefacts recovered from two seasons of excavation in the Kaldar Cave. For this research, I applied a non-invasive multi-analytic approach to identify the use-wear and residues. For the functional analysis, Optical Light Microscope (OLM), 3D digital microscope (3D DM) and Scanning Electron Microscope (SEM) was used to identify the traces. Here, for first time I assess the potential of the 3D digital microscope for functional studies on stone and shell tools, and its complementary aspect with the other two microscopes. For the residue analysis, SEM with microprobe EDX, FTIR and μXRD was applied to test which method is best suited for the identification of the archaeological residues. By using these multi-techniques, two type of reference collection of modern day residue (bone and adhesive material) was built to identify the archaeological residues (mainly, bone and black residue).

This thesis embodies seven articles which are the back bone of this research. Four articles published in high impact journals and discuss mainly about the two seasons of excavation in the Khorramabad Valley sites; lithic technology to understand the Middle and Upper Palaeolithic transition; dating problem for the Middle and Upper

Palaeolithic sites in the Zagros Mountains, flora and earliest evidence of *Prunus* sp. in the sites of Kaldar and Gilvaran. Another article is an accepted manuscript for a monograph which deals with the preliminary functional analysis result of the Upper Palaeolithic lithic assemblage of Kaldar Cave. Other two are prepared manuscripts based on the multi-analytic approach for the functional analysis results to identify the archaeological use-wear and residues.

RESUMEN

Esta tesis se centra en el estudio funcional de conjuntos del Paleolítico medio y superior del Valle de Khorramabad (Irán Occidental), con especial atención a la Cueva de Kaldar. Se nemarca en un proyecto de investigación multidisciplinar centrado en la transición del Paleolítico medio al superior en las montañas del Zagros.

Metodológicamente, se adopta una doble perspectiva, que incluye el análisis del microdesgaste y el de los residuos, siempre desde una perspectiva no invasiva y multi-técnica. A la microscopía óptica y electrónica de barrido (OM i SEM) comúnmente utilizadas, se ha añadido la microscopía 3D digital (3D DM). Para caracterización química de los residuos, hemos utilizado el SEM con microanálisis EDX, FTIR i μXRD. Todas estas técnicas se han aplicado tanto a muestras experimentales como arqueológicas.

La tesis incluye siete publicaciones. Cuatro de ellas son artículos publicados en revistas SCI, y están dedicados a presentar el contexto arqueológico, cronológico y paleoambiental de los conjuntos estudiados. Otra es un manuscrito aceptado parar una monografía, que incluye los resultados funcionales preliminares del conjunto de Paleolítico superior de la Cueva de Kaldar. Finalmente, incluimos el borrador de dos manuscritos centrados en la propuesta multi-analítica del análisis funcional para la identificación de huelals de uso y residuos arqueológicos.

RESUM

Aquesta tesi se centra en l'estudi funcional de conjunts de Paleolític mitjà i superior de la Vall de Khorramabad (Iran occidental), amb especial atenció a la cova de Kaldar. S'emmarca en un projecte de recerca multidisciplinària centrat en la transició del Paleolític mitjà al superior a les muntanyes del Zagros

Metodològicament, s'adopta una doble perspectiva, que inclou l'anàlisi de micro-desgast i la de residus, sempre des d'una perspectiva no invasiva i multi-tècnica.

A la microscòpia òptica i electrònica de rastreig (OM i SEM) comunament utilitzades, s'ha afegit la microscòpia 3D digital (3D DM). Per la caracterització química dels residus, hem utilitzat el SEM amb microanàlisi EDX, FTIR i µXRD. Totes aquestes tècniques s'han aplicat tant a mostres experimentals com arqueològiques.

La tesi inclou set publicacions. Quatre d'elles son articles publicats en revistes SCI, i estan dedicade a presentar el context arqueològic, cronològic i paleoambiental dels conjunts estudiats. Una és un manuscrit acceptat per una monografia, que inclou els resultats funcionals preliminars del conjunt de Paleolític superior de la cova de Kaldar. Finalment, incloem l'esborrany de dos manuscrits centrats en la proposta multi-analítica d'anàlisi funcional per la identificació de traces d'ús i residus arqueològics.

RÉSUMÉ

Cette thèse se concentre sur l'analyse fonctionnelle des assemblages lithiques du Paléolithique Moyen et Supérieur de la vallée de Khorramabad (Iran Occidental), notamment ceux de la grotte Kaldar. Cette analyse a été effectuée dans le cadre d'un projet multi-disciplinaire qui a pour objet la transition entre le Paléolithique Moyen et Supérieur dans les montagnes du Zagros.

En termes méthodologiques, nous avons utilisés deux méthodes, la tracéologie et les analyses de résidus, qui sont considérés comme non invasif et prépondérantes dans une perspective multi-technique. A l'approche traditionnelle optique et de la microscopie électronique à balayage (OM et SEM), nous avons complété celle-ci avec l'utilisation de données collectées au moyen d'un microscope digital en trois dimensions (3D DM). Concernant la reconnaissance chimique des résidus, nous avons utilisé la technique SEM en association avec un micropobe EDX, FTIR et µXRD. Toutes ces techniques ont été mises en applications sur des échantillons issus d'expérimentation, et archéologiques.

Cette thèse comprend sept publications. Quatre ont été publiés dans des revues SCI (pour Science Citation Index), et ont eu pour objectif de présenter le contexte archéologique, chronologique, et paléoenvironnemental des assemblages étudiés. Un cinquième article a été accepté pour publication dans une monographie portant sur les résultats préliminaires des études fonctionnelles des assemblages lithiques de la grotte de Kaldar. Enfin, nous avons inclus dans cette thèse deux articles en préparation qui se concentrent sur une approche multi-analytique portant sur les résultats d'analyses fonctionnelles, dans le but d'identifier les marques d'utilisations et de résidus.

PUBLICATION LIST

Publication 1: Becerra-Valdivia L., Douka K., Comeskey D., Bazgir B., Conard N J., Marean C.W., Ollé A., Otte M., **Tumung L.,** Zeidi M., Higham T.F.G. 2017. Chronometric investigations of the Middle to Upper Palaeolithic Transition in the Zagros Mountains using AMS radiocarbon dating and Bayesian age modelling, *Journal of Human Evolution* 109, 57-69.

Publication 2: Allué E., Expósito I., **Tumung L.**, Ollé A., Bazgir B. 2018. Early evidence of *Prunus* and *Prunus* cf. *amygdalus* from Palaeolithic sites in the Khorramabad Valley, Western. *CR Palevol* 17 (6), pp. 335-345. https://doi.org/10.1016/j.crpv.2018.01.001

Publication 3: Bazgir, B., Otte M., **Tumung L.,** Ollé A., Deo S. G., Joglekar P., Manuel López-García J., Picin A., Dadoudi D., Van der Made J., 2014. Test excavations and initial results at the Middle and Upper Paleolithic sites of Gilvaran, Kaldar, Ghamari caves and Gar ArjeneRockshelter, Khorramabad Valley, western Iran. *CR Palevol*. 13, 511–525.

Publication 4: Bazgir, B., Ollé A., **Tumung L.,** Becerra-Valdivia L, Douka K., Higham T, Van der Made J, Picin A., Saladié P, Manuel López-García J, Blain H, Allué E, Fernández-García M., Rey-Rodríguez I, Arceredillo D., Bahrololoumi F., Azimi M., Otte M. and Carbonell E. 2017. Understanding the emergence of modern humans and the disappearance of Neanderthals: Insights from Kaldar Cave (Khorramabad Valley, Western Iran). *Scientific Reports* 7, 43460.

ACCEPTED ARTICLE

Article 6: Laxmi Tumug, Behrouz Bazgir and Andreu Ollé. (Accepted). Functional analysis on the lithic industry from the Upper Paleolithic sequence (Layer 4) of Kaldar cave, Khorrambad Valley, western Iran: A preliminary Report. (Gibaja, J.,Marreiros, J., Clemente, I. & Mazzucco, N. Eds). Hunter-Gatherers tool kit: A functional perspective

ARTICLE UNDER PREPARATION

Article 5 (pre-draft): Laxmi Tumung, Antony Borel and Andreu Ollé; *Assessing the application of Digital 3D microscope for functional analysis on stone and shell tools: A complementary approach*

Article 7(pre-draft): Laxmi Tumug. *Understanding the bone and black bituminous residue from M –UP sites of Khorramabad Valley, western Iran*

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CHAPTER 1

INTRODUCTION

If you ask me, forget about the stone tools. They can tell you nothing, zero. At most, they can say something about how they were preparing food. But is what you do in the kitchen all of your life?

Ofer Bar-Yosef, Quoted in Shreeve 1995:193

CHAPTER 1

INTRODUCTION

In human prehistory, the time period around 50,000 to 30,000 BP is marked by the replacement of Neanderthal by Anatomical Modern Human (Cro-Magnon) in Eurasia and emergence of new modern technologies to cope with the drastic climatic changes. Many archeologists consider these events as a major revolutionary period in prehistory named as "Upper Paleolithic Revolution" (White 1982, 1997; Mellars 1989, 1996a, 2000; Klein 1995, 1999; Straus, 1996; Gibson, 1996; Clark1997a, b; Bar-Yosef 1998, 2002; Zilhao and D'Errico 1999; Hublin 2000; McBrearty & Brooks 2000; Churchill & Smith 2000; Wadley 2001). For decades several questions related to this event had kept the archaeologists busy to put together all the pieces of the puzzle to understand the phenomenon. The questions which made the pioneer archaeologists curious, still puzzle the young archaeologists due to few scattered evidence. The questions related to this event are (after Bricker 1976; Bar Yosef 2002),

(i) When and how the Neanderthals get extinct from Eurasia? Is the arrival of Anatomical modern human in Europe responsible for their extinction?
(ii) When did the precise transition from Middle to Upper Paleolithic happened? Was it a global dimension or a gradual transition ?
(iii) Were the climatic conditions or human migrations responsible for these bio-cultural and technological changes ?
(iv) Who were the bearer of these prehistoric cultures such as Chatelperronian, Aurignacian, Gravettian and others ?
(v) Were the Anatomical Modern Human's (AMHs) exclusively responsible for the Upper Paleolithic traditions ?
(vi) Is there any "core area" to explain this transition and modern cultural behaviours ?

These curiosities lead the archaeologists to explore different parts of the world to look for the answers. Hence, a few ended up field surveying in the Zagros Mountains which stretches from Strait of Hurmuz in Southwest of Iran to the southeast of Turkey providing a perfect corridor by connecting Africa to Levant and Eurasia for human migration (Lindly 2005).

Jacques de Morgan started the initial field surveys in the Zagros Mountains during 1920's-1930 around the Iraqi Zagros, followed by Henry Field (Smith 1986). Later Garrod (1930) test excavation in Hazer Mard in 1930 and she quoted that "*If the theory of an Eastern origin for the Aurignacian of Palestine is correct, we should expect ultimately to find that culture in the Zagros, most probably in immediate succession to the Levalloiso-Mousterian"* (Garrod 1937: 37). Since then, Zagros Mountains become a crucial study area for the researchers to test Garrod hypothesis to understand the Aurignacian culture, the transition from Middle Paleolithic (MP) to Upper Paleolithic (UP) as well as the human migration (pointing both to east and west).

The archaeological records from the Zagros Mountains are very scattered, and till now very few absolute dating has been published (e.g., Solecki 1963; Conard and Ghasidian, 2011; Otte *et al*., 2011; Zwyn *et. al.*, 2012; Bazgir *et al*., 2017; Becerra-Valdivia, 2017; Heydari-Guran and Ghasidian, 2017). The reason behind the few dates available is due to the poor preservation of the organic materials (bone collagen in particular) and the geopolitical instability within the region for 20 years for conducting field expeditions. However, the two zones which attracted the most attention by the prehistorians are Iraqi Zagros and Iranian Zagros, but the latter zone was most focused for archaeological studies.

Iranian Zagros is a series of parallel ridges interspersed with plains that bisect the country from northwest to southeast (Vahdati Nassab, 2010) and the two regions which were mainly focused are i) Kermanshah region and ii) Khorramabad Valley. There are also a few scattered studies in the central and Fars region of Iran. During 1920´s some scattered Paleolithic field survey's were undertaken in the Mazandaran province (de Morgan, 1907) and Fars Province (Field 1939a); and a small test pit was dug in the Kunji cave, Khorramabad Valley (Field 1939b). Since the beginning of the Paleolithic studies in Iran, Kermanshah and Khorramabad Valley have attracted the most attention by the archaeologists (both foreign and native) and since, 1950's major field survey's for Paleolithic sites were conducted and excavated in these two zones.

The important sites of Kermanshah region belonging to Lower Paleolithic are Gakia, Pal Barik and Amar Merdeg (Braidwood 1960; Singer and Wymer 1978; Biglari and Shidrang 2006) but none of these sites were excavated, and the interpretation of the chronology of these sites are based on the surface findings. The Middle and Upper Paleolithic sites of this zone include Warwasi, Eshkaft-e Gavi, Kobeh, Bisitun, Ghar-e Khar and Mar Tarik (Coon, 1951; Braidwood and Howe, 1960; Braidwood et. al.1961; Young and Smith, 1966; Holdaway, 1989; Dibble and Holdaway, 1993; Olszewski, 1993a, b, 2001, 2007a, b;

Olszewski and Dibble, 1994; Biglari and Heydari, 2001; Jaubert et al., 2009; Shidrang et.al. 2016).

After the field surveys and excavations by Hole and Flannery in 1963 around the Khorramabad Valley, this area gained a considerable interest among the archaeologists (foreign and native) to excavate and study the excavated material. Till date no Lower Paleolithic sites have been documented in this area, but the nearby Ilam province provides a few sites such as Shiwatoo and Mar Gwergalan Cave which shows the evidence of Lower Paleolithic assemblage (Mortensen 1974b, 1975, 1993; Jaubert et al. 2004, 2006, Biglari and Shidrang 2006; Davoudi et al. 2015). The important Middle and Upper Paleolithic sites of Khorramabad Valley are Kunji, Ghamari, Yafteh, Pa Sangar, Gilvaran, Kaldar and the Gar Arjeneh rock shelter(Field, 1939a 1939b, 1951a, 1951b; Hole and Flannery, 1967; Speth,1971; Baumler and Speth, 1993; Roustaei, 2010; Roustaei et.al., 2002, 2004; Otte and Kozlowski, 2007; Shidrang, 2007; Otte et.al., 2007, 2011; Tsanova, 2013; Bazgir et.al. 2013, 2014, 2017; as well as a reassessment paper on the Hole and Flannery report: Vahdati Nasab, 2010). All the important sites from both regions have been explained and discussed in detail in chapter 2.

1.1 Statement of the problem

Looking at the previous published Paleolithic literature, one can observe that all the earlier studies in Iran were focused more on lithic technology. They were mainly done to find the similarities or differences in the lithic technology characters for understanding the origin of Aurignacian and the local development of tool technologies such as the Baradostain, Rostamian and Zarzian (Dibble 1984; Olszewski 1993a, 1993b; Olszewski and Dibble 1994; Otte and Kozlowski, 2004; Olszewski 2009; Otte et al. 2007, 2012; Shidrang 2007, 2018; Ghasidian 2014; Conard and Ghasidian 2011; Bordes and Shidrang 2012; Tsanova 2013; Jayez et al. 2018; Abolfathi et al. 2018). Other works focused on describing the field survey's and excavation reports (Braidwood et al. 1961; Hole 1962; Hole and Flannery, 1967; Baumler and Smith 1993; Abdi et al. 2002; Jaubert et al. 2004, 2006; Biglari and Shidrang, 2006; Otte et al 2007; Biglari et al. 2009; Bazgir et al. 2014, 2017); understanding the MP-UP transition in the excavated sites (Shidrang 2018; Shidrang et al. 2016,; Bazgir et al. 2017); dating of the sites as well as the problems related to dating (Otte et al. 2011, Becerra-Valdivia, 2017); reconstructing the paleo-environment by studying faunal and floral remains (Maskour et al. 2008, 2009, 2012; Djamali et al. 2011; Allué et al. 2018). While some studied the human remains found in a few Paleolithic sites such as Warwasi, Bisitun, Eshkaft-e-Gavi and Wezmeh to understand their affinities to Neanderthal or AMH (Coon 1951; Trinkaus and Biglari, 2006; trinkaus et al. 2007; Scott and Marean 2009); a few focused on the geological formation of these caves (Heydari, 2007) and raw material sources (Ghasidian and Heydari-Guran 2018).

Till date in Iranian Paleolithic, a few functional analyses have been performed on the Iranian Middle and Upper Paleolithic sites, unlike the western world sites. Recently, native Iranian archaeologists have started collaborating with the foreign universities and institutes for the traceological studies to check its feasibility for functional studies for Iranian Palaeolithic sites (Claud et al. 2012; Bazgir and Tumung 2013).

The reasons behind the limited studies related to functional analysis in the Iranian Paleolithic are:

1. It was only after the 1930's, Iran Paleolithic studies just started to boom, and on the other hand, the use-wear analysis was also taking baby steps to emerge as a science in the western world.
2. Less enthusiasm showed by the previous archaeologists for this kind of studies.
3. Until 2012, this field was an unknown field in the Iran Paleolithic studies.

Despite all previous research efforts, a review of the literature on Paleolithic of this region shows a lack of publications, reliable dating and in-depth interpretation of the industry of the earlier and current excavations (Olszewski and Dibble, 2006) and this along with limited or no functional analysis studies made the complete knowledge of the past human activities in the area ~~is~~ less understood.

1.2 Objectives of the research study

This research is a fragment of the leading research project in Khorramabad Valley named as "Khorramabad Project". The project aims for a multi and interdisciplinary approach to provide more information that might challenge the classical views concerning the technological, behavioural, subsistence differences and changes between the Middle and Upper Paleolithic assemblages of the area. Since the very beginning of the 2011-12 excavation, I was a team member and actively participated in all the excavation seasons. As part of this project, my research focus was the study of the lithic assemblages using functional analysis with the addition to techno-typological analysis (as supplementary information supporting the functional results).

In our preliminary study of the 2011-12 excavation lithic material (especially points), we observed that the Khorramabad stone tools are well preserved and not only they have good evidence of use wear traces but also have well preserved residues (archeological and modern contamination), specifically black residue (possibly hafting adhesive) on most of them. This made us careful in the following excavations, especially on how to control these issues and how to better interpret these traces by applying different methods and techniques. Based on this, we developed our aims and objectives, which also got modified during the course of my research, depending on the type of issues we faced, let it be related to the methodological aspect or archeological interpretation of the functional traces. The main aims and objectives of the research are separated into two main parts, and they are mentioned below:

A. Methodology

1. Control measures during excavation and in the laboratory. How can we prevent post excavation contaminations and increase the effectiveness of the use-wear analysis?
2. Assessment of the feasibility of Digital 3D Microscopy (3D DM) for functional studies and its complementary aspect with Light Microscopy and Scanning Electron Microscopy (SEM). Is 3D DM ~~is~~ a good microscope as a complementary technique with Optical Microscope and SEM? How much it helps to interpret the traces (use-wear and residues) on stone and shell tools?
3. Chemical characterisation of residues. Which non-destructive method (ESEM with EDX, FTIR, and μXRD) is best and how much does their complementary aspect helps for the better interpretation of the residues?
4. Creation of a reference collection, including both a series of experimentally reconstructed actions on different worked materials, as well as of present day adhesive substances from Khorramabad Valley.

B. Archaeological applications

5. Is the functional analysis ~~is~~ feasible for the Khorramabad excavated sites?
6. Can we reconstruct the activities that took place in these sites during Paleolithic time?
7. What information can be retrieved from the residues about the use and exploitation of the local resources and the environment of the people who stayed in these caves and rock-shelters?

1.3 Chapterisation

Chapter 1 deals with the introduction to the basic idea of this research and discusses its aims very briefly. It also provides a brief review of the Upper Paleolithic Revolution and the questions related to it (MP-UP transition, replacement of Neanderthals by AMHs in Eurasia, modernity and human migration) - How and when the Zagros Mountains came into the picture to be able to answer all the above-mentioned questions. Here, the statement of the problem providing the reasons for the lack of functional studies in the Iranian Zagros sites is also explained. We set a few aims and objectives to attain the full understanding of the subsistence of the three sites (Gilvaran, and Kaldar). Later, a brief review of the emergence and development of the functional analysis has been discussed.

Chapter 2 discusses about the importance of the Zagros Mountains as a~~n~~ crucial place for understanding modern behavior by the Neanderthal and their replacement by AMHs, AMHs arrival in Eurasia, the transition from MP-UP and also the debate surrounding the technological aspects related to the origin of Aurignacian and its prototypes (Baradostian, Zarzian and Rostamian). This chapter, also briefly discusses the exciting find of human fossil remains, issues related to absolute dating results (provided with the article published on these issues) as well as fauna and flora of the Zagros region. It also includes discussion of the important sites present in Zagros divided~~ing~~ into two significant areas such as Iraqi Zagros and Iranian Zagros. Later further sub-dividing the Iranian Zagros into two major areas for Paleolithic studies (Kermanshah and Khorramabad Valley) and their important sites of these two regions have been described and discussed. Finally, a brief summary of the recent functional studies performed on the Zagros Mountain Paleolithic lithic assemblages. This chapter also embodies four major articles published; one before the PhD, three during the course of this PhD

Article 1: Becerra-Valdivia et al. (2017). This article published in the Journal of Human Evolution, deals with the radiocarbon dating issue in the Zagros mountains and setting a date for the onset of Upper Paleolithic in Zagros around 45,000-40,250 cal BP (68.2% probability).

Article 2: Allué et al. (2018). This article was published in the *CR Palevol*, where we discussed the earliest evidence of *Prunus* spp in the Kaldar and Gilvaran Cave, Khorramabad Valley, western Iran.

Article 3: Bazgir, et al. (2014) this article got published in the *CR Palevol*. 13 and discusses about the 2011-12 test excavation in the site of Gilvaran, Kaldar, Ghamari caves and Gar Arjeneh rock shelter.

Article 4: Bazgir et al. (2017) this article got published in the *Scientific Reports*. It discusses the 2014-15 Kaldar excavation assemblage to understand the MP-UP Transition in the Zagros regions and present the new radiocarbon date for the Upper Palaeolithic level of Kaldar Cave between 54,600- 36,750 cal BP .

Chapter 3 forms the framework of the research and discusses the methodology applied in the course of the research to fulfil the methodological aims and objectives. Here, the kind of the control measures applied during excavation and in lab are discussed; For the experimental protocol, what kind of dependent and independent variables were used?; How the reference collection for modern day adhesive and bone residue was created; What types of microscopes and techniques were employed to interpret the use wear and residue traces (archeological and experimental)? This chapter embodies one of the articles and discusses about the application of digital 3D microscope for the functional studies on stone and shell tools and its complementary aspects with the Optical Light Microscope and Scanning Electron Microscope.

Article 5 (pre-draft): Tumung L. Martin-Viveros, Borel A. and Olle A. Assessing the application of Digital 3D microscope for functional analysis on stone and shell tools

Chapter 4 deals with the outline of results of the experiments designed to test on a systematic basis, a range of contact materials and use actions; also discusses the trends in micro-wear traces on the edges. Trends related to the interpretation of particular use-actions and use-motions were also noticed. The observations have been described verbally and supplemented by photo documentation.

Chapter 5 constitutes the main body of this thesis. It outlines the results of the use-wear and residue analysis on the archaeological lithic material. The obtained results had been compared with the experimental as well as the previous works on flints to conclude the function of the lithics as well as to reconstruct the subsistence pattern of the sites of Khorramabad Valley. This chapter also includes two articles, 1) an accepted monograph, and 2) a predraft (where the bone and black or bituminous substance on the archaeological stone tools is discussed)

Article 6: Tumung et al. (accepted) Here, we presented the preliminary result for the 2014-15 excavation lithic assemblage belong to the Upper Palaeolithic level of Kaldar cave

Article 7 (pre-draft): Tumung L. This article discusses about the types of residues (modern-day contamination, bone and black bituminous residue) observed on the Gilvaran and Kaldar Cave lithic artefacts by applying non-invasive methods and techniques.

Chapter 6 includes a summary of the research, the discussion and conclusion with the addition to the suggested directions for future research.

1.4 Brief history of emergence and development of Functional analysis

1.4.1. The beginning

Functional analysis is the study of wear traces on edge and/or surface of objects caused by use (Odell 2004; Fullagar and Matherson 2013; Marreiros et al. 2015); also referred as micro-wear analysis, use-wear analysis, traceology or traceological studies. The use-wear analysis is born out of curiosity to learn how and for what tasks prehistoric man used his stone artefacts. As in any prehistoric sites, stone tools are the most abundant and evident (in some cases the only evidence remains which found) shows the presence of prehistoric man settlement. They embody a wealth of technological, functional and ideological information and therefore, much attention has been paid to the study of these artefacts in reconstructing early hominin behaviour (Agarwal 2008).

Although S. Semenov is considered as the father of functional studies, he was not the first to develop this curiosity to understand the functionality of the stone artefacts made by prehistoric man. They interpreted the tools by speculated functions such as knives, scrapers and borers (Nilsson 1838-1843; Lubbock 1872); or compared them with ethnographic analogies, for example, end scrapers from Paleolithic sites in Western Europe were compared to Eskimo skin scrapers (Hayden and Kamminga, 1979); and with metal tools of indigenous groups (Olausson 1980; Vaughan 1981, 1985; Grace 1989). During this time the use-wear traces were noticed with the help of magnifying lenses (e.g., see Olausson 1980, p 49, Vaughan 1981, p 14, Vaughan 1985, p 4, Juel Jensen 1988, Quente 1914). Others like Curwen (1930, 1935) and then Spurrell (1982) performed some of the first experiments concerning sickle polish. At the end of the 19th century, it was acknowledged Spurrell (1982) that there is a diagnostic relation between tool use and edge use and edge damage. Thus, the field of use wear analysis was born.

1.4.2. Use-wear revolution

At the beginning of the 20th century, use-wear analysis became well-known and widely used after Semenov published his Russian monograph "*Pervobitaya Teknika*" (Semenov 1957) in English "*Prehistoric Technology"* (Semenov 1964). Semenov's study introduced the systematic use of a microscope for analysing use-wear traces on stone tools and utilised systematic experimentation on stone tool use. He focused on the location of polish and striations to understand the "kinematics" in various tasks performed by stone tools. He emphasised on the importance of the lighting, surface treatment, photography and identification of the wears under the microscope. Since then, the use-wear analysis was seen as one of the essential proxy/keys to interpret the archaeological records (as a clear indicator of human behaviour) and to reconstruct their social-cultural human behaviour and organisation (Streud 1978; Redman 1973). Semenov's work was later continued and expanded upon by many researchers, especially by European and North American archaeologists (Tringham *et al.*, 1974; Kamminga, 1979; Keeley, 1974, 1980; Odell 1981).

After Semenov, the period of the 1970's to 1980's can be considered as the revolutionary period for functional studies. During this time, much of the works was to modify the experimental methodology and the application of microscope developed by Semenov (1964). Hence, archaeologists emphasised on experimentation, replication of the tasks and applied different microscopic approaches to understand different tool functions. These comprehensive experimental works developed to define edge chipping, striations, edge rounding, and polish/abrasion to determine the use-motion or actions and contact materials. The most significant works are by Tringham (et al.1974) along with her two PhD students Odell (1977, 1979, 1981) and Keeley (1980) as well as by Kamminga (1982), a doctoral candidate at the University of Sydney. They are the pioneers of the main two approaches (Low Power Approach and High Power Approach) vastly used to understand different aspects of use-wear analysis but mainly focused on edge fractures and polish.

1.4.3. Microscopic approaches

The **"Low Power Approach" (LPA)** mostly focus on the classification of fractures (Trigham et al. 1974; Odell 1981; Kamminga 1982) and this classification also is known as "Ho Ho classification" (Kamminga et al. 1979). For this approach, a stereoscopic binocular microscope with a magnification of less than 100x and incident lighting is used to examine the micro-fractures of the edge and striations related to the use action, worked material, edge angle and grip (Trigham *et al.*, 1974; Odell, 1981). Using this approach Kamminga (1982) classified the microfractures into six types and associated them with hardness of the material, the direction of use and the raw material of the tools (flint, quartzite, etc.). Others identified edge rounding and abrasion (Frison, 1968; Levi Sala, 1996), striations and well-developed polishes. A few argued that these polishes could appear on tool due to both additive (Keeley, 1980) and abrasion (Kamminga, 1979; Levi-Sala, 1996; Kay, 1996). However, some scholars recognised that this approach lacks the efficiency to determine the longitudinal and transverse motions on specific materials (Keeley, 1980; Odell and Odell-Vereecken, 1980). By applying this approach, first residue traces (specifically plant remains) were observed trapped on the tool surfaces (Briuer, 1976; Shafer and Holloway, 1979).

On the other hand **"High Power Approach" (HPA)**, mostly focused on the identification and interpretation of use related polishes. This approach mainly used non-stereoscopic optical or metallographic microscopes with magnifications ranging from 100x to 500x. Although Semenov was the pioneer of this approach, Keeley (1980) developed the methods to analyse polish related to specific worked material (Keeley, 1974; 1980; Keeley and Newcomer, 1977). This method provided better interpretation of worked material based on the observation of micro-traces, polishes, striations, micro-abrasions, and micro-rounding (Keeley, 1980; Vaughan, 1981, 1985; Levi-Sala, 1996). Among other HPA practitioners are Moss, 1983, Beyries, 1988, Juel Jensen, 1988, and Unger-Hamilton, 1988.

1.4.4. Blind tests

Initial blind test experiments were based on low and high power microscopic analysis to verify their reliability to determine the accuracy of micro-wear interpretation (Keeley and Newcomer, 1977; Odell and Odell-Vereecken, 1980; Evans, 2014; Shea, 1987, 1991; Shea and Klenck, 1993). Blind tests for both the approaches showed effective results in identifying the used part of a tool and determining how a tool was used, but was less accurate in identifying on which contact material the tool was used. As blind tests did not always give positive results (Newcomer *et al*., 1986, Unrath *et al*., 1984–1986, Yerkes and Kardulias, 1993, Evans, 2014), some scholars (Moss, 1987, Bamforth, 1988, Hurcombe, 1988, Newcomer *et al.*, 1988) criticise the use for this technique as reliable method. Blind-testing continued into the 1990's (Bamforth et al. 1990, Shea 1991, Yamei 1992, Shea and Klenck 1993, Van den Dries 1998) with results being somewhat better than those reported in earlier studies. From 2000 onwards, the importance of blind test was emphasized (Evans et al. 2014), and various blind tests were performed on the micro-residues (Downs & Lowenstein 1995; Wadley and Lombard, 2007; Wadley et al. 2004; Lombard and Waldey 2007; Monnier et al. 2012, 2013); prehension and hafting (Rots et al. 2006); groundstone (Hamon and Plisson 2008) and post-depositional and edge damage on the tool (Keeley and newcomer 1977; Plisson 1984–1986, Plisson and Mauger 1988; Lévi-Sala 1986, 1993; Grace 1996; Burroni et al 2002, Grosman et al 2011, Asryan et al 2014, Schoville 2014). These blind tests were mostly performed on stone tools; it showed a lack of interest for bone and shell tools.

During 1970's and 1990's two important conferences were held to discuss the major issues related to micro-wear. First conference was held in Vancouver in 1977 by Hayden (1979), where three significant issues were given focus: (1) the mechanisms responsible for wear; (2) the effects of post-depositional modification of stone tools; and (3) the reliability and reproducibility of lithic micro-wear analysis, based primarily on the results of blind-testing. Another one was in 1989 Uppsala conference, where Low Power and High Power Approach was the centre of discussion. For some time these two approaches were considered as separate approaches and strongly supported by their respective pioneers by providing their advantages and disadvantages (Yerkes and Kardulias, 1993). But in this conference, researchers agreed that both these approaches are complementary to each other and provides better solutions when combined rather than alone (Unger-Hamilton, 1989; Olausson, 1993; Grace, 1996).

1.4.5. Implications of microscopes

Among the microscopes used, 1970's onwards the use of SEM become very popular among the researchers as it provided greater depth of field, better images at high magnification and enabled the better identification of worked material (Brothwell 1969; Hay 1977; Keeley 1977; Anderson, 1980; Anderson-Gerfaud, 1981; Mansur-Franchomme, 1983; Unger-Hamilton, 1983; Shea 1992; Levi-Sala *et al.*, 1998). With SEM, the first residues (specifically, plant remains) were observed trapped on the tool surfaces, (Anderson, 1980; Meeks et al. 1982; Unger-Hamilton, 1984; Hall et al. 1989).

A notable change in micro-wear analysis in the 2000's is the increased combination of methods; either low and high-power microscopy (Stemp 2001, Stemp et al 2010), for example OLM and SEM (Jahren et al. 1997; Peretto et al., 1998; Márquez et al., 2001; Dubreuil and Grosman 2009, Pawlik and Thissen 2011; Hardy and Moncel, 2011; Monnier et al. 2012, 2013; Borel et al 2014; Pedergnana et.al 2016; Pedergnana and Ollé 2014, 2017a, 2017b**;** Ollé et al. 2016).

A few new microscopes made their debut for the use-wear analysis, such as (LSCM) Laser scanning confocal microscope (Evans and Macdonald 2011; Stemp et al 2011, 2013, 2015; Ibáñez et al 2014; Stevens et al 2010); (FVM) Variable Focus Microscopy (Dubreuil 2004; Evans and Macdonald 2011; Macdonald 2014); (3D DM) Digital 3D microscope (Revendi et.al. 2015; Ronchitelli et.al. 2015; Arrighi et. al. 2016; Bowosachoti 2016; Martín-Vivero 2016a, 2016b; Luengo Cortés, 2017; Marciani et al. 2018) and started to gain immense popularity among the traceologists. Details about the 3D DM used in this study are discussed in Chapter 3.

1.4.6. Use-wear in relation to raw material

With the microscopic approaches improved, many started to test variability of wear patterns in relation to raw material (e.g. Greiser and Sheets 1979; Beyries 1982). Among the traceologists since 1970's micro-wear studies were more focused on the fine-grained raw material such as flint or chert (Tringham *et al.*, 1974; Odell, 1977; Anderson, 1980; Keeley, 1980; White, 1982; Moss, 1983; Unger-Hamilton, 1983; 1984; 1985; Vaughan, 1985; van Gijn 1990, Levi-Sala 1996); obsidian (Hurcombe 1992; Hay, 1977; Fedje, 1979; Flenniken and Haggarty, 1979; Greiser and Sheets, 1979; Lewenstein, 1981; Vaughan, 1981) and a few observations on Chalcedony (Kamminga, 1978; Greiser and Sheets, 1979) using low power microscopes. Other stone types which gained little attention by traceologists observed using high power microscope are the coarse-grained lithic materials. Among the coarse-grained raw material, basalt (Price-Beggerly, 1976; Kamminga, 1978; Odell and Odell-Vereecken, 1980; Richard, 1988) was mostly analyzed, followed by quartz and quartzite (e.g. Broadbent and Knutsson 1975; Knutsson, 1988; Pedergnana et.al 2016, Pedergnana 2017; Pedergnana and Ollé 2014, 2017a, 2017b**;** Ollé et.al 2016), shale (Akoshima 1979; Kajiwara and Akoshima 1981), ground stone (e.g. Adams 1988, 1989; 2002; Dubreuil 2004; Dubreuil and Grosman 2009) and granite (Agarwal 2008). Other than stone tools, during 1980's use-wear analysis on bone tools (Olsen 1979, 1980, 1984, 1989; Campana 1989; Runnings et.al. 1989) and shell tools (Cleghorn 1977; Eaton 1974; Keegan 1984; Masson 1988; Toth and Woods 1989; Kamminga 1982; Fullagar 1986) also emerged. But unlike stone and bone tool, shell tools got the most attention from 2000 onwards (Schmidt et.al. 2001; Lucero 2004a, 2004b, Lucero and Jackson 2005; Choi and Driwantoro 2007; ; Joorden et.al 2009; Douka 2011; Cuenca-Solana 2010, 2015; Cuenca-Solana et.al., 2011, 2013, 2014, 2017; Tumung et.al. 2013; 2015Manca 2016, 2018; Mărgărit et.al. 2017 ; Manca et al. 2018).

1.4.7. Projectiles and hafting

Many significant works related to projectiles and hafting with evidence of adhesive residues were published (Clark 1954; Keeley 1982; Fischer et al. 1984; Shea 1988, 1990; Lombard 2005). However, Rot's works are the most significant in the major developments related to prehension, and on how these projectiles were hafted (adhesives and hafting method), what kind of use-wear was produced by hafting (Rots 2002a, 2002b, 2003, 2008, 2010; Rots and Williamson, 2004; Rots et al. 2006, 2011).

Archaeologically, various types of hafting residue (adhesive) evidence have been reported from different parts of the world such as birch tar, plant resin, ocher, bitumen. There is evidence for the use of birch bark pitch as an hafting adhesive, mainly from several Middle Palaeolithic sites of Europe including Campitello in Italy (Mazza et al., 2006), Inden-Altdorf and Königsaue in Germany (Pawlik & Thissen, 2011; Koller et al., 2001; Grünberg, 2002), and some Upper Palaeolithic sites as Les Vachons, in France (Dinnis et al., 2009). Plant resins have been reported in the South African Middle Stone Age (MSA) and Late Stone Age (LSA) sites including Dieplkloof Rock Shelter and Border Cave (Charrié-Dunhaut et al., 2013; Villa et al., 2012) as well as more recent sites from the Yukon and Selwyn mountains, Canada (Helwig et al., 2014). In the South African sites, ochre was found mixed with the hafting material for the better binding of the haft (Lombard 2005; Wadley 2005; Wadley et.al 2004; Rots et.al 2011). The earliest evidence of the bitumen as hafting material is reported from the Near East Middle Paleolithic sites, including Umm el Tlel and Hummal in Syria (Boëda et al., 1996, 1998, 2007; Connan 1999; Hauck et al., 2013; Monnier et al., 2013). Bitumen has also been identified at the Paleolithic site of Gura cheii-Râsnov Cave, in Romania (Cârciumaru et al., 2012).

In the Near East and European Middle Paleolithic sites evidence of resin (Mazza et.al 2006; Mania and Toepfer 1973; Hedges et.al 1998; Bosinski 1985), birch tar (Clark 1954; Regert et.al 1998; Koller et al., 2001; Grünberg, 2002; Van Gijn and Boon 2006; Dinnis et al., 2009; Pawlik & Thissen, 2011), ochre (Lombard 2005), bitumen (Bar-Yosef 1985; Boëda et.al 1996, 1998, 2008; Cârciumaru et.al. 2012; Monnier et.al 2013) have been found. These hafting adhesives can be used alone and sometimes with some additives such as sand or earth to make stronger haft (Lombard 2005).

1.4.8. Residue analysis and multi analytic approaches

As use-wear analysis improved with its methodology and techniques, during 1970´s residue analysis took its first baby steps and began to be treated as a separate field. After years of research traceologists realized that both use-wear and residue analysis are complementary to each other for the better interpretation of the tool function. Initially, residue analysis was mostly focused on plant residues, but later animal remains were also observed and tested using different microscopes and techniques. The first attempt to analyse plant residues under a low power microscope using chemical reagents was by Briuer (1976). Later different plant residues such as plant fibers (Shafer and Holloway 1979), phytoliths (Shafer and Holloway 1979; Anderson 1980; Ollendorf 1987; Kealhofer et al. 1999), and starch grains (Shafer and Holloway 1979; Hall et.al. 1989; Loy et.al. 1992; Fullagar 2006b; Barton 2007) were identified. Archaeological adhesives (Boëda et al.1996, 1998, 1999, 2007; Rots 2011,), as well as experimental resins (Croft 2016; Cnuts et al.2017a, 2017b), were identified and tested on stone tools.

Animal residue methods to detect blood and different techniques to extract also interested many (Loy 1983; Custer et al. 1988; Gurfinkel and Franklin 1988; Loy and Wood 1989; Hyland et.al. 1990; Kooyman et.al.1992; Manning 1994; Eisele et al.1995; Fiedel 1996; Leach and Mauldin 1995; Loy and Dixon 1998). Other animal residues such as hair, feather, flesh, skin, bone collagen residue (both archeological and experiemental) were identified (Jahren et al. 1997; Lombard 2005; Pedergnana and Blasco 2016; Pedergnana and Ollé 2018; Martín-Viveros 2016; Zupancich et al. 2017). A few traceologists believed that extraction of the residue was very important (Cnuts and Rots 2017). This introduced surface treatment of the stone tools with different chemical reagents for better visibility of the traces under the microscope (Keeley 1980.), residue extraction using other biochemical methods, haemoglobin-specific chemical reagent test strip (Hb-CRTS) analysis (Matheson and Veall 2014) or crossover immunoelectrophoresis (CIEP) (Newman and Julig 1989).

Besides the archeological and experimental residues, a few traceologists focused on the modern-day contaminations which can occur in the lab and which can lead to misinterpretation of the artefact function (Wadley et al. 2004; Wadley and Lombard 2007; Monnier et al. 2012, 2013; Xhauflair et al. 2016; Pedergnana et al., 2016; Cnuts and Rots 2017).

Since the 1990's, residue analysis started to embrace different types of new technological techniques, microscopes and software were included to investigate the residues (e.g. Christensen et al.1992; Fullagar 1993). The widely used microscope for the residue analysis are Optical microscope (e.g. Fullagar and David 1997; Lombard 2007; Rots et al. 2011; Clarkson et al. 2015, 2017; Borel et al. 2014) and SEM (e.g.Andreson 1980; Levi-Sala 1996; Ollé and Verges 2008; Borel et al. 2014) but recently a few archeologists started to use 3D DM as well (e.g.Ronchitelli et.al. 2015; Martín-Vivero 2016a, 2016b).

Some of the organic residues, during the burial process lose its morphological characteristic feature and become difficult to identify (e..g. Lombard 2005; Monnier et al. 2012; Croft et al. 2016). Traceologists introduced different techniques for the residue analysis to understand the chemical composition of the residue for better identification of the residue, such as SEM with EDX (e.g. Borel et al. 2014; Pedergnana and Blasco 2016; Pedergnana and Ollé 2014, 2017, 2018; Pedergnana et al. 2016); Raman Spectroscopy (e.g. Schmidt et al. 2017); Gas Chromatographic mass spectrometry (GC-MS) (e.g. Boëda et al. 1996, 1998, 2008; Koller et al. 2001; d'Errico et al. 2012; Villa et al. 2012; Hauck et al. 2013; Charrié-Duhaut et al. 2013); Fourier Transmitted Infrared Spectroscopy (FTIR) (e.g. Monnier et al. 2013, 2017, 2018; Prinsloo et al. 2014; Solodenko et al. 2015; Zupancich et al. 2016) and X-Ray Diffraction (XRD) (e.g. Monnier et al. 2013). In the recent years, many tried to combine the techniques to better understand the residues (e.g.Cârciumaru et al. 2012; Monnier et al. 2013; Bradtmöller et al. 2016). The results obtained from such studies indicate that all the techniques are complimentary to each other and strengthen our understanding of the past human activities.

Finally, we can summarize that, since the time of Semenov till present, functional analysis by integrating different fields of investigation, microscopic approaches, methods and techniques have evolved as an independent science.

CHAPTER 2

ZAGROS MOUNTAINS AND ITS PALAEOLITHIC SITES: SPECIAL REFERENCE TO IRANIAN ZAGROS

"If the theory of an Eastern origin for the Aurignacian of Palestine is correct, we should expect ultimately to find that culture in the Zagros, most probably in immediate succession to the Levalloiso-Mousterian."
(Garrod 1937: 37)

CHAPTER 2

ZAGROS MOUNTAINS AND ITS PALAEOLITHIC SITES: SPECIAL REFERENCE TO IRANIAN ZAGROS

2.1 Zagros Mountains

Geographically, Zagros Mountains extend in the parallel ridge with a total length of 1500 km covering Iran, Iraq and Turkey. It covers Iran from northwest to southwest, reaching the northeast of Iraq and southeast of Turkey (Fig. 2.1). Hence, this area makes a perfect crossroads between the Levant (and therefore Africa), Europe and Asia (Lindly, 2005) for human migration. Topographically, the mountains chains consist of long, parallel limestone anticlinal ridge rising to 4000 m above sea level and divided by intermontane valleys etched out of younger shales, sandstones, and gravels at an elevation of 600 m to 1200 m above sea level (Wright and Herbert 1952:12-13).

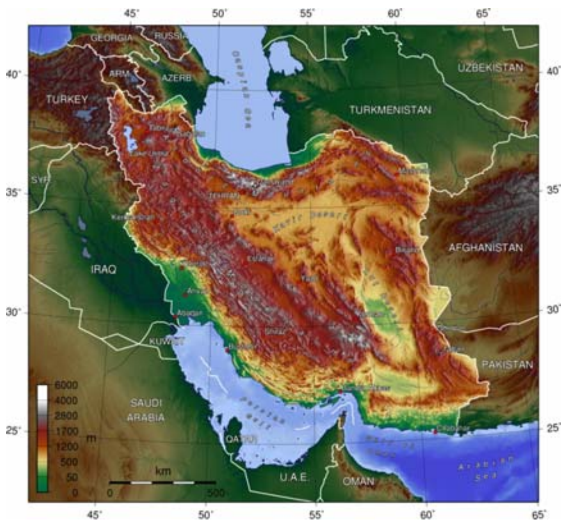

Figure 2.1: Map showing extend of the Zagros Mountains

Initial Paleolithic research around Zagros Mountain was started during the 1920s and 1930s. Jacques de Morgan was the first who initiated field surveys in Iraq, followed by Henry Field (Smith 1986). Their surface finding showed the flint tool typology is similar to Middle and Upper Paleolithic. Even though they were the pioneer of field survey in the area, Garrod (1930) was the first one to excavate in the Paleolithic site of Hazer Mard in Iraq which become the "benchmark" for all the future excavations. She was the first who claimed the theory of an *Eastern origin for the Aurignacian* which increased the curiosity among many researchers, hence followed with numerous other field expeditions mostly focused on two crucial zones i) Iraqi Zagros and ii) Iranian Zagros. The research works were mainly focused on identifying the Zagros Aurignacian culture, the possible transition from Middle to Upper Paleolithic and migration of AMH from the Middle East through the Zagros Mountains into Europe. All the important Paleolithic sites excavated in the Iranian Zagros Mountains have been shown in the map, represented in the (Table 2.2) with details and discussed below later in this chapter. In this chapter, I have tried to address in general about the chronology of the Zagros Mountains, followed by flora and fauna, lithic technology.

2.2. Zagros Mountains Paleolithic Chronology

Chronological, Zagros Mountains is having very few absolute dates available, which can clearly explain the M-UP transition in the area (e.g., Solecki, 1963; Conard and Ghasidian, 2011; Otte et al., 2011; Bazgir et al., 2017; Heydari-Guran and Ghasidian, 2017). The reasons behind the fewer dates in the area are:

(i) most of the sites were excavated prior to the modern dating techniques evolved such as Thermoluminescence (TL), Electron-spin-resonance (ESR) and Uranium series decay (Lindly 2005),

(ii) due to geo-political circumstances within the region which hampered the possibility to excavate as well as to access to the archeological material for studies (Vahdati Nassab 2011)

(iii) The poor preservation of organic material (bone collagen, in particular) to extract from archaeological sites for C14 dating (Bazgir et.al 2014; Becerra Valdivia et.al. 2017).

However, with few reliable dating available, we were able to set a date for the onset of Zagros Upper Paleolithic. Our article published in 2017 discussed this issue.

2.2.1. Publication 1: Becerra-Valdivia L., Douka K., Comeskey D., Bazgir B., Conard N J., Marean C.W., Ollé A., Otte M., **Tumung L.,** Zeidi M., Higham T.F.G. 2017. Chronometric investigations of the Middle to Upper Palaeolithic Transition in the Zagros Mountains using AMS radiocarbon dating and Bayesian age modelling, *Journal of Human Evolution* 109, 57-69.

This article explains about the problem related to dating methods in the Zagros region to help establish a reliable chronology for M-UP transition in the Zagros Mountains. We discuss the data extraction method for the high resolution AMS dates from Kobeh, Kaldar and Ghar-e-Boof. Later, statistically modelling them with the previously published dates from Shanidar (Iraqi Kurdistan) and Yafteh Cave (Iran) to improve their chronological resolution as well as compare with the new dates available. Brief descriptions of the sites with their stratigraphy and the radiocarbon dates obtained have been discussed. Finally, our Bayesian modelling results show the start of the Upper Paleolithic in the Zagros Mountains dates to (40,000-45,250 cal BP at 68.2% confidence). Further chronometric dates still required to improve the precision of this age range.

Journal of Human Evolution 109 (2017) 57–69

Contents lists available at ScienceDirect

Journal of Human Evolution

journal homepage: www.elsevier.com/locate/jhevol

Chronometric investigations of the Middle to Upper Paleolithic transition in the Zagros Mountains using AMS radiocarbon dating and Bayesian age modelling

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ARTICLE INFO

Article history:
Received 6 March 2017
Accepted 31 May 2017

Keywords:
AMS radiocarbon dating
Bayesian age modelling
Zagros Mountains
Upper Paleolithic
Middle Paleolithic

ABSTRACT

The Middle to Upper Paleolithic transition is often linked with a bio-cultural shift involving the dispersal of modern humans outside of Africa, the concomitant replacement of Neanderthals across Eurasia, and the emergence of new technological traditions. The Zagros Mountains region assumes importance in discussions concerning this period as its geographic location is central to all pertinent hominin migration areas, pointing to both east and west. As such, establishing a reliable chronology in the Zagros Mountains is crucial to our understanding of these biological and cultural developments. Political circumstance, coupled with the poor preservation of organic material, has meant that a clear chronological definition of the Middle to Upper Paleolithic transition for the Zagros Mountains region has not yet been achieved. To improve this situation, we have obtained new archaeological samples for AMS radiocarbon dating from three sites: Kobeh Cave, Kaldar Cave, and Ghār-e Boof (Iran). In addition, we have statistically modelled previously published radiocarbon determinations for Yafteh Cave (Iran) and Shanidar Cave (Iraqi Kurdistan), to improve their chronological resolution and enable us to compare the results with the new dataset. Bayesian modelling results suggest that the onset of the Upper Paleolithic in the Zagros Mountains dates to 45,000–40,250 cal BP (68.2% probability). Further chronometric data are required to improve the precision of this age range.

1. Introduction

The Middle to Upper Paleolithic (M–UP) transition, dating to between 50,000 and 30,000 years Before Present (BP), marks a pivotal point in late human evolution. It involves the dispersal of anatomically modern humans (AMHs) outside of Africa, the concomitant replacement of Neanderthal populations across the Eurasian record, and the emergence of what is widely termed the 'Early Upper Paleolithic' (EUP)—a period often associated with novel symbolic and behaviorally mediated artefacts thought to represent an important change in the cognitive processes of modern humans (see White et al., 1982; Mellars, 1991; Klein, 1995; Bar-Yosef, 2002). It is axiomatic that a reliable chronology is required to compare archaeological sites and material culture across space and place the biological and cultural developments occurring at this

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http://dx.doi.org/10.1016/j.jhevol.2017.05.011

time in a proper context. So far, however, the vast majority of Paleolithic archaeological sites that have been investigated chronometrically in any great detail are in Europe. Elsewhere, as is the case with the Zagros Mountains, the archaeological record is not only less abundant, but chronometric data are often absent. Considering that this geographic region acts as a corridor linking Africa to the Levant and Eurasia, establishing a spatio-temporal sequence for the Zagros is crucial. Due to political circumstances within the region and the poor preservation of organic material (bone collagen, in particular) extracted from archaeological sites, however, a clear chronological definition for the M–UP transition has not yet been achieved—very few absolute dates have been published (e.g., Solecki, 1963; Conard and Ghasidian, 2011; Otte et al., 2011; Bazgir et al., 2017; Heydari-Guran and Ghasidian, 2017). In this article, we present new accelerator mass spectrometry (AMS) radiocarbon results from three archaeological sites in the Zagros Mountains and model chronometric data using Bayesian statistics.

2. Background

2.1. Neanderthals and AMHs

Neanderthals and AMHs are hominin groups that are morphologically and genetically distinct from each other. Modern humans evolved in Africa around 200,000 years ago, exited the continent about 60,000–50,000 years ago (or earlier), and reached Eurasia and Australia by about 50,000–45,000 years ago (see Groucutt et al., 2015 for a recent review). Regions adjacent to East Africa—Arabia, Sinai, the Levant, and the Iranian Plateau—record the first modern humans migrating out of this continent and, as 'first contact' areas, hold great paleo-anthropological and archaeological potential. The weight of archaeological and fossil evidence suggests that Neanderthals evolved outside Africa, inhabiting Europe, western Asia, and the Middle East starting from, roughly, 250,000–300,000 years ago (see Hublin, 2009 for a review). Neanderthal occupation ended in Europe at around 41,000–39,000 (95.4% probability) calibrated (cal) BP, strongly suggesting an overlap with AMHs for several thousand years in the region (Higham et al., 2014). Numerous hypotheses have attempted to explain the disappearance of Neanderthals from the archaeological record. These often involve the role of climate (e.g., Finlayson and Carrion, 2007; Jiménez-Espejo et al., 2007) and the perceived superiority of AMHs over Neanderthals in terms of technology, diet, and cognition (e.g., Binford, 1985; Mellars, 1989; Richards and Trinkaus, 2009). Recent ancient genetic research suggests that Neanderthals and AMHs interbred outside of Africa (e.g., Green et al., 2010; Prüfer et al., 2014), resulting in the intrusion of Neanderthal-derived DNA at a proportion of 1.5–2.1% in all non-African modern humans (Prüfer et al., 2014).

2.2. The Zagros Mountains

The Zagros Mountains are a series of parallel mountain ridges interspersed with plains that cross Iran from northwest to southeast, reaching the northeast of Iraq and the southeast of Turkey. The geomorphological setting of the Zagros, a karstic system reaching over 4,000 m above sea level (m.a.s.l.), lends itself to the formation of caves that offer ample opportunities for both paleoenvironmental and archaeological research. Given the physical geography of Iran, bounded in the north and south by mountains, the region has long been considered a potential dispersal corridor for hominins emerging out of Africa. Indeed, Vahdati Nasab et al. (2013) have posited a number of distinct migration routes according to the naturally occurring boundaries in the landscape, including a passageway south of the Zagros Mountains.

2.3. Previous research within the Zagros

Early archaeological research in the Middle East began in the 1920s with researchers such as D.A.E. Garrod, who analysed local lithic assemblages in direct reference to European Paleolithic traditions, i.e., the Mousterian (assigned to Neanderthals and the MP) and the Aurignacian (attributed to AMHs and the UP), according to their typological features (see Garrod, 1928, 1951; Garrod and Bate, 1942). In the 1950s, R. and R. Solecki excavated Shanidar Cave in Iraqi Kurdistan, where a number of Neanderthal individuals were found buried within the MP deposit and the UP material culture was named 'Baradostian' (see Solecki, 1955, 1957, 1960, 1963; Solecki and Solecki, 1993). In addition to this work, C.S. Coon excavated the sites of Bisitun, Tamtama, and Khunik (Coon, 1951); R. Braidwood worked at Warwasi (Braidwood et al., 1961); F. Hole and K. Flannery excavated Kunji, Gar Arjeneh, Pa Sangar, Ghamari, and Yafteh Cave (Hole and Flannery, 1968); and M. Rosenberg investigated Eshkaft-e Gavi (Rosenberg, 1985; Scott and Marean, 2009). In the early 1980s, field investigations in Iran decreased in frequency due to political factors and, as Vahdati Nasab (2011) suggests, the lack of enthusiasm shown by local archaeologists. During this time, workers re-evaluated archaeological collections stored outside of the Zagros. Dibble (1984), for instance, re-studied artefacts from Bisitun, and posited that, in contrast to previous claims concerning the lack of Levallois attributes in Mousterian industries from the Zagros, the assemblage showed a relatively high frequency of the technique. A decade later, through the re-analysis of the Warwasi assemblage, Olszewski and Dibble (1994) proposed the renaming of the Baradostian tradition to 'Zagros Aurignacian', given the perceived similarities with Aurignacian material, and suggested the possibility of an in situ origin for the Aurignacian industry. Beginning in the early 2000s and into the present, joint Iranian-European teams have surveyed, excavated, and reported results from multiple Paleolithic sites across the Zagros Mountains (e.g., Conard et al., 2006; Jaubert et al., 2006; Otte et al., 2007; Conard and Ghasidian, 2011; Bazgir et al., 2014, 2017; Heydari-Guran and Ghasidian, 2017). This new field research may shed light on some of the major questions of interest to prehistorians in this region, including the issue of the origin of the Aurignacian and the Zagros Mountains, as well as the potential presence of mutually distinct and coeval lithic industries within the region during the UP (see Ghasidian et al., 2017).

3. Archaeological sites

We have obtained new chronometric results for Kaldar Cave, Ghār-e Boof, and Kobeh Cave, and analysed previously published radiocarbon dates for the sites of Yafteh and Shanidar Cave (Fig. 1)—all within the Zagros Mountains region. These archaeological sites are briefly described in the following sections.

3.1. Yafteh Cave

Yafteh Cave is located in the Khorramabad region of Lorestan province, western Iran (at 1278 m.a.s.l.; 33°30′30″N, 48°12′41″E), and was excavated in 1965 by Hole and Flannery (1968). The lithic technology at the site has assumed importance in discussions concerning the origin of the Aurignacian tradition due to its morphology and, as reported, similarity to European material (see Otte and Kozłowski, 2004). For this reason, a group from the University of Liège recommenced excavations at the site in 2005 and 2008. Following an analysis of the lithic assemblage, workers

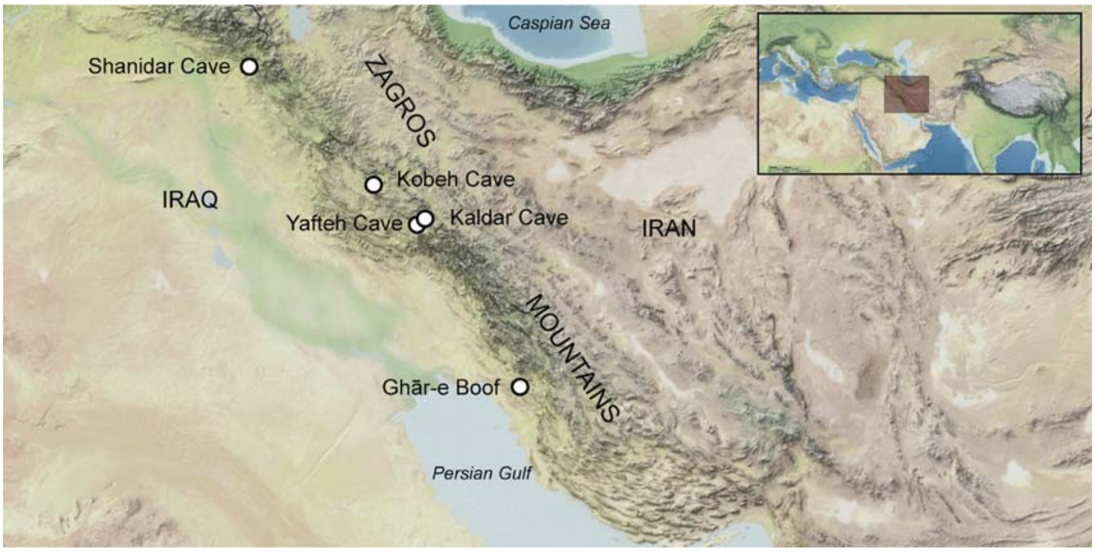

Figure 1. Location of archaeological sites investigated.

proposed an in situ development of the Aurignacian industry in the Zagros Mountains (Otte et al., 2007, 2011).

The stratigraphic sequence in Yafteh Cave contains 19 geological layers distinguished on the basis of soil coloration and texture (Fig. 2). Bedrock was reached during the 2008 season at approximately 3 m in depth. Strata 1–4 correspond to historic and Islamic periods, while evidence for an UP tradition begins near the top of stratum 5 and continues until the bottom of the deposit.

In the 1960s, Hole and Flannery (1968) submitted a series of charcoal samples for radiocarbon dating. The sequence obtained showed age-depth incongruences and wide error margins. Additional charcoal samples were radiocarbon dated following the re-excavation of the site in the 2000s. Based on the new chronometric information, Otte et al. (2011) assigned a date of 33,400 ± 840 BP (Beta-206712) to the beginning of the UP sequence, and 35,450 ± 600 BP (Beta-205844) to the bottom (Fig. 2). All radiocarbon determinations were combined and ordered by Otte et al. (2011) according to depth (Table 1). There is little correspondence between early (1960s) and later (2000s) excavations, however, as Hole and Flannery (1968) did not publish the exact location of their radiocarbon samples within the stratigraphy and the material obtained by Otte et al. (2007) was collected from a different area within the cave.

3.2. Shanidar Cave

Shanidar Cave is situated on Baradost Mountain, Iraqi Kurdistan (44°13′E, 36°′50′N; Solecki, 1957, 1963). The cave is at 731.5 m.a.s.l. or 365.8 m above the Greater Zab River (Solecki, 1955). It has a length of 40 m, a maximum width of 53.34 m, and a total surface area of 1200 m^2 (Solecki, 1955, 1957, 1963). Shanidar Cave was originally excavated by R. Solecki from 1951 to 1960, in four separate seasons (years 1951, 1953, 1956–1957 and 1960; Solecki, 1955, 1957, 1960, 1963). After a long hiatus, excavations recommenced in recent years under G. Barker, University of Cambridge.

In 1951, Solecki began excavations with a sounding of 4.47 by 6.10 m, reaching 7.62 m in the deepest section. This was enlarged in 1953 to an area of 6.10 by 12.9 m, where bedrock was reached at a maximum depth of 13.41 m in the western portion of the sounding, and to 20 by 7.75 m in the 1957 season. Solecki divided the excavation area into 44 vertical levels (Solecki and Solecki, 1993) and identified four distinct archaeological layers—A, B, C, and D (Solecki, 1957). Layer A extends from modern times to the Neolithic, while Layer B contains no evidence of agriculture, animal domestication, or pottery making. Following Layer B, Solecki noted a gap in the stratigraphic sequence of a suggested span of 17,000 years, a period during which the cave was apparently left unoccupied. The sequence continues with Layer C, which marks an UP occupation. Layer D, sealed from the above deposit by rockfall within levels 14 and 15 (4.27–4.52 m from the surface), corresponds to the MP and a Neanderthal occupation (Solecki, 1957; Solecki and Solecki, 1993). Within this layer, the remains of 10 Neanderthal individuals were found (see Solecki, 1957, 1963, 1975; Trinkaus, 1978; Trinkaus and Zimmerman, 1982; Solecki and Solecki, 1993; Cowgill et al., 2007) (Fig. 3).

The chronology of Shanidar Cave, in Solecki's time, was fixed by radiocarbon dates provided by four different laboratories (Table 2; Solecki, 1963). Apart from presenting some of these dates in publications, no further details concerning the materials or methods used in the dating process have been provided. Based on samples W-667 and W-179, Layer B1 was dated to 10,300 ± 300 BP and B2 to 12,000 ± 400 BP (Solecki, 1963). The top portion of Layer C was dated to 28,700 ± 700 BP (sample W-654) and the bottom to 35,080 ± 500 BP (GrN-2549), while material taken from 5.1 m below the surface yielded a determination of 46,000 ± 1500 BP (GnN-2527) for Layer D (Solecki, 1963). Additionally, several obsidian samples from Layers B and C were analysed using the obsidian hydration method (Evans and Meggers, 1960; Solecki, 1963). These determinations do not show a congruent age-depth pattern.

3.3. Kaldar Cave

Kaldar Cave is located in the Khorramabad Valley, Lorestan Province, western Iran (48°17′35″E, 33°33′25″N). The cave sits at 1290 m.a.s.l., has a length of 16 m, a width of 17 m, and is 7 m high. An international team initially investigated Kaldar Cave during 2012, along with three other archaeological sites (Bazgir et al., 2014). This initial effort consisted of the opening of a 1 m^2 test pit at the very centre of the cave, which revealed a 1.5 m

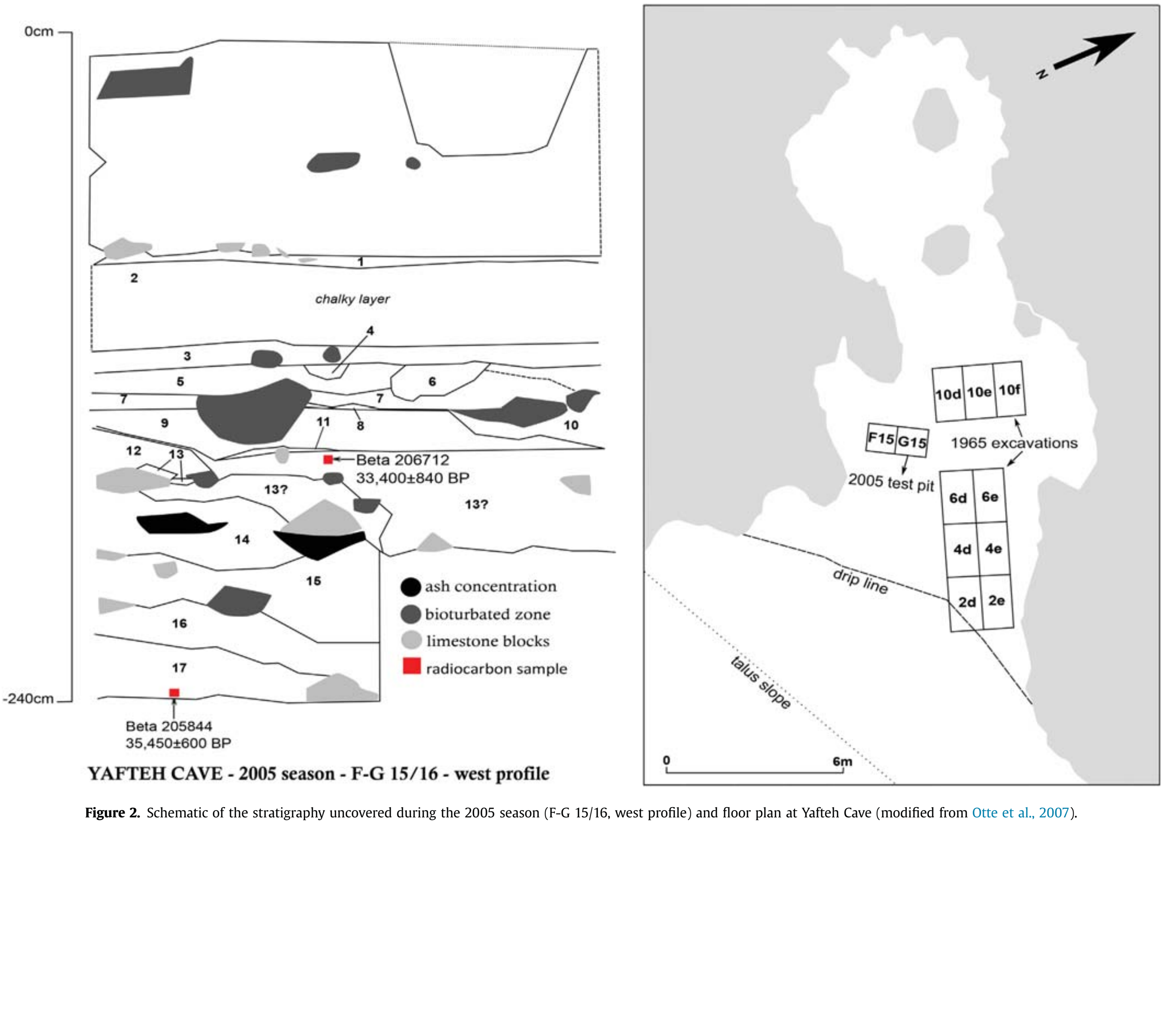

Figure 2. Schematic of the stratigraphy uncovered during the 2005 season (F-G 15/16, west profile) and floor plan at Yafteh Cave (modified from Otte et al., 2007).

Table 1
Published radiocarbon determinations for Yafteh Cave ordered by depth after Otte et al. (2011).

Laboratory number	Collected (year)	Depth (below datum; cm)	Radiocarbon date (BP)
Beta-206711	2005	125	24,470 ± 280
Beta-206712	2005	150	33,400 ± 840
GX-711	1965	200	34,800 + 2900/−4500
GX-710	1965	201	32,500 + 2400/−3400
SI-332	1965	201	29,410 ± 1150
Beta-245910	2008	210.5	33,800 ± 330
SI-333	1965	212	30,860 ± 3000
Beta-251058	2008	213	32,190 ± 290
Beta-251062	2008	213.5	33,160 ± 240
Beta-251059	2008	226.5	32,900 ± 290
Beta-251060	2008	234	33,260 ± 300
Beta-245908	2008	236	22,430 ± 310
Beta-205844	2005	240	35,450 ± 600
Beta-245909	2008	245	33,330 ± 310
SI-336	1965	250	21,000 ± 800
Beta-251061	2008	251	31,120 ± 240
Beta-245913	2008	258.5	34,360 ± 340
Beta-245907	2008	260	32,770 ± 290
GX-709	1965	260	38,000 + 3400/−7500
Beta-245911	2008	266.5	33,520 ± 330
Beta-24912	2008	273	34,160 ± 360
SI-334	1965	278	31,760 ± 3000
GX-708	1965	280	>36,000
GX-707	1965	280	34,300 + 2100/−3500
SI-335	1965	285	>40,000
GX-706	1965	290	>35,600

stratigraphic sequence containing multiple cultural levels. Following field observations, excavators realised that Kaldar Cave contained a better stratigraphic sequence than the other sites excavated. As such, a second excavation designed to obtain samples for dating and gain a better understanding of stratigraphic associations commenced in 2014. During this season, excavators opened a 3 × 3 m trench near the cave entrance and location of previous test pits (squares E5, E6, E7, F5, F6, F7, G5, G6 and G7) using 5 cm spits and recorded all findings within a three-dimensional (3-D) grid. The trench exposed an approximately 2 m section of sedimentary deposit characterised by five main cultural layers (see Fig. 4). Layers 1 to 3 (including sub-layers 4 and 4II) contain multiple phases dating to the Holocene; Layer 4 (including sub-layers 5, 5II, 6 and 6II), with its associated lithic technology, e.g., points, blades, and twisted bladelets, corresponds to the UP; and Layer 5 (including sub-layers 7 and 7II) contains a characteristic MP lithic assemblage with Levallois elements (Bazgir et al., 2014). So far, no chronometric data are available for Layer 5 (Bazgir et al., 2017).

3.4. Ghār-e Boof

Ghār-e Boof, a small cave with a total surface area of 100 m^2, is situated in the Dasht-e Rostam region of Fars Province, southern Iran, at 905 m.a.s.l. (Conrad and Ghasidian, 2011). The site was excavated by the Tübingen Iranian Stone Age Research Project in 2006, 2007, and 2015. The predominant lithic component in the UP are bladelets belonging to a technocomplex termed ‘Rostamian’ by the excavators (Conrad and Ghasidian, 2011; Ghasidian, 2014). A survey of 90 other caves and rockshelters of the Dasht-e Rostam yielded Rostamian assemblages but, so far, excavations have only been conducted at Ghār-e Boof. The Rostamian tradition consists of a specialised mode of lithic reduction that appears to be absent from contemporary sites along the Zagros Mountains, bearing no techno-typological resemblance to Aurignacian or Baradostian industries. As such, it is hypothesised that the Rostamian technocomplex evolved locally in the southern Zagros. This documents a high degree of cultural diversity in the region during the UP (Conrad and Ghasidian, 2011; Ghasidian, 2014; Ghasidian et al., 2017).

The excavation area (2 × 9 m) at Ghār-e Boof extends from the drip line to the back of the cave on a north–south axis. An elevation datum was assigned to the z-axis at an elevation of 8 m, and bedrock was reached at a depth of 5.5 m in the rear. Archaeological horizons (AH) were identified as such by material culture, soil coloration, and other distinctive features (Fig. 6). At the top of the sequence, AH I and II correspond to Holocene silts and ash deposits. AH III corresponds to the UP as identified through a lithic assemblage dominated by bladelets and bladelet cores. The stratigraphic sequence ends in unit 6/2 with Geological Horizon (GH) 4, containing AH IV, IVa, and IVb, also corresponding to the UP. The most recent excavation season, in 2015, reached MP deposits in the central part of the cave, but more fieldwork is required to obtain statistically significant artefact assemblages from these basal layers.

Radiocarbon dating of two seed samples (OxA-25783 and OxA-25785) was previously undertaken at the Oxford Radiocarbon Accelerator Unit (ORAU), using a pre-treatment method designed to minimise the destruction of material. These samples—legume remains found within AH IIIb at depths of 4.90 and 4.82 m, respectively—yielded dates of 33,850 ± 360 and 34,900 ± 650 BP. Additional material was submitted for radiocarbon dating at the Leibnitz-Labor Laboratory, University of Kiel (Conrad and Ghasidian, 2011; Ghasidian, 2014). Results obtained from two vetches (*Vicia ervilia*) from AH IV, the oldest stratum, were measured at 33,060 ± 270 BP and 36,030 ± 390 BP (see Fig. 5).

3.5. Kobeh Cave

Kobeh is a small cave (7 × 12 m) located near the capital of Kermanshah province, western Iran, in the west-central section of Zagros Mountains (47°10′8.25″E, 34°25′47.96″N; Marean and Kim, 1998). It is situated at an altitude of 1300 m.a.s.l. near the Tang-i-Knisht Valley. Fieldwork led by B. Howe began at the site in 1959, with a 2 × 2.5 m test pit (Marean and Kim, 1998). From the surface, the entire excavated sequence extends to a depth of 3.2 m, where a rockfall event overlies a separate, seemingly sterile horizon. Prior to a depth of 1.6 m, the presence of sporadic ceramic fragments and faunal remains was reported (Marean and Kim, 1998). Below this depth, layers P, Q, and R correspond to the terminal MP and include lithic and faunal material—the latter showing bone surface modification (Marean and Kim, 1998).

4. Materials and methods

Bone samples from Kobeh Cave ($n = 14$) and Ghār-e Boof ($n = 42$) were pre-screened for collagen preservation prior to sampling for radiocarbon dating (after Brock et al., 2010a). This step involved measuring the percent nitrogen (%N) in ~5 mg of whole bone powder (drilled and placed into a tin capsule) in a continuous flow isotope ratio mass spectrometer (Sercon 20/20), consisting of a CHN elemental analyser (Carlo-Erba NA, 2000) coupled to a gas source IRMS. Samples which show values lower than ~0.75 %N are not usually passed on to AMS radiocarbon dating, as they are not likely to contain sufficient collagen (<1% weight). All other materials—three seed samples from Ghār-e Boof, seven charcoal samples from Kaldar Cave, and one riverine snail from Ghār-e Boof—underwent the appropriate chemical pre-treatment method designed to remove exogenous carbon. These included phosphoric acid dissolution, acid-base-wet oxidation/stepped combustion (ABOx-SC), and modified versions of ABOx-SC employed to avoid

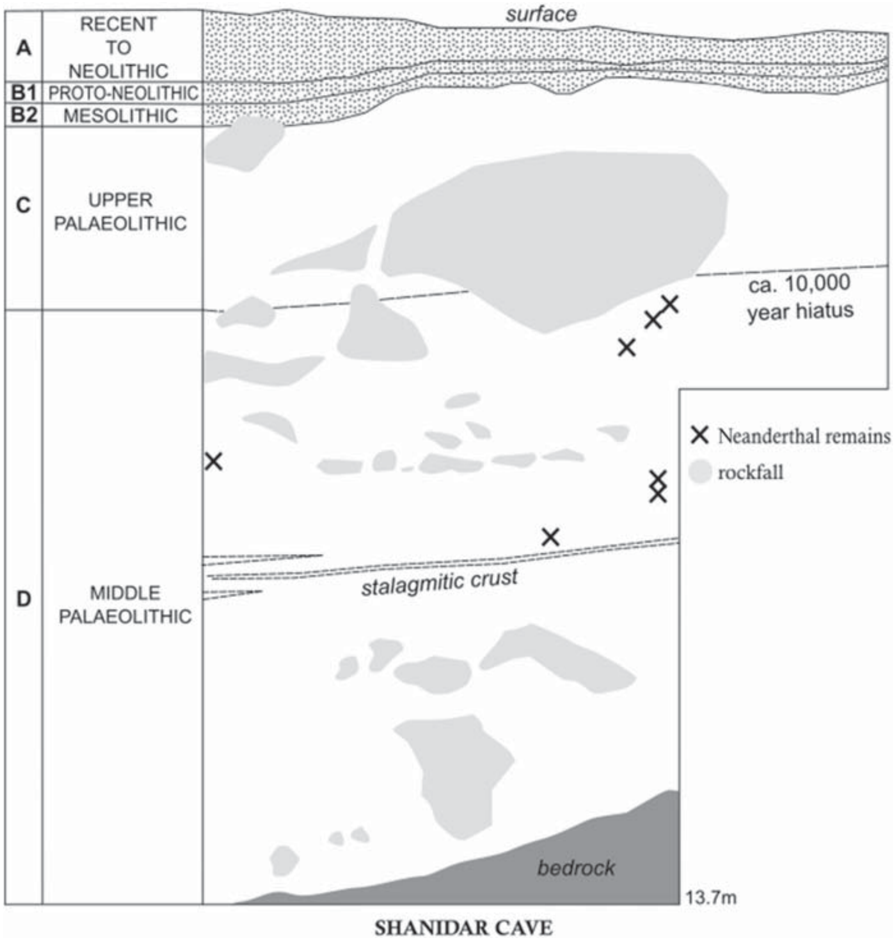

Figure 3. Schematic of the stratigraphy at Shanidar Cave (redrawn from Solecki, 1963).

Table 2
Published radiocarbon determinations for Shanidar Cave. This list reflects available information from the published sources reviewed.

Laboratory number	Archaeological context	Date (BP)	Published source
W-667	Layer B1	10,600 ± 300	Solecki, 1963
W-179	Layer B2	12,000 ± 400	Solecki, 1963; Hole and Flannery, 1968
W-654	Layer C	28,700 ± 700	Solecki, 1963; Hole and Flannery, 1968
W-178	Layer C (top); square S3W1; 3.05 m deep	29,500 ± 1500	Solecki, 1955; Hole and Flannery, 1968
W-180	Layer C	>34,000	Hole and Flannery, 1968
W-650	Layer C	33,300 ± 1000	Hole and Flannery, 1968
GrN-1830	Layer C	33,900 ± 900	Hole and Flannery, 1968
GrN-1494	Layer C	34,400 ± 420	Hole and Flannery, 1968
GrN-2016	Layer C	35,400 ± 600	Hole and Flannery, 1968
GrN-2015	Layer C	35,540 ± 500	Hole and Flannery, 1968
GrN-2549	Layer C	35,080 ± 500	Solecki, 1963
GrN-2527	Layer D	46,900 ± 1500	Solecki, 1963; Hole and Flannery, 1968
GrN-1495	Layer D	50,600 ± 3000	Hole and Flannery, 1968

sample failure (see Brock et al., 2010b, for a detailed description of routine pre-treatment protocols used). ABOx-SC was chosen over the routine acid-base-acid (ABA) method, as it has been shown to remove contaminants more efficiently from Paleolithic-aged charcoal samples, often yielding significantly older dates (e.g., Bird et al., 2003; Brock and Higham, 2009; Higham et al., 2009a, 2009b; Douka et al., 2010; Wood et al., 2012).

Following pre-treatment, dried samples were weighed and approximately 3–3.5 mg of material was combusted in the same CF-IRMS system employed for bone collagen pre-screening. Gaseous CO_2 produced during acid dissolution was inserted directly. After the measurement of carbon stable isotopes, the CO_2 was collected and transferred to pre-conditioned rigs containing a 2.0–2.5 mg iron catalyst and H_2 added at a ratio of $2.2H_2:CO_2$. These were heated at 560 °C for 6 h (Dee and Ramsey, 2000). Graphite targets were made with approximately 0.8 mg–1.8 mg of carbon, depending on the yield of each sample. Radiocarbon measurement was undertaken in a High Voltage Engineering Europa (HVEE) 2.5 MeV accelerator mass spectrometer. Radiocarbon determinations were calculated according to the conventions outlined in Stuiver and Polach (1977).

The calibration and Bayesian modelling of radiocarbon determinations was undertaken using the OxCal 4.3 platform (Bronk Ramsey, 2009a, 2009b) and the IntCal13 calibration curve (Reimer et al., 2013). Radiocarbon dates in a Bayesian model are expressed in terms of a probability density function (PDF) through use of Markhov Chain Monte Carlo simulation approaches, which finds the highest probability distribution for these as weighed towards known archaeological information for each site. The statistical

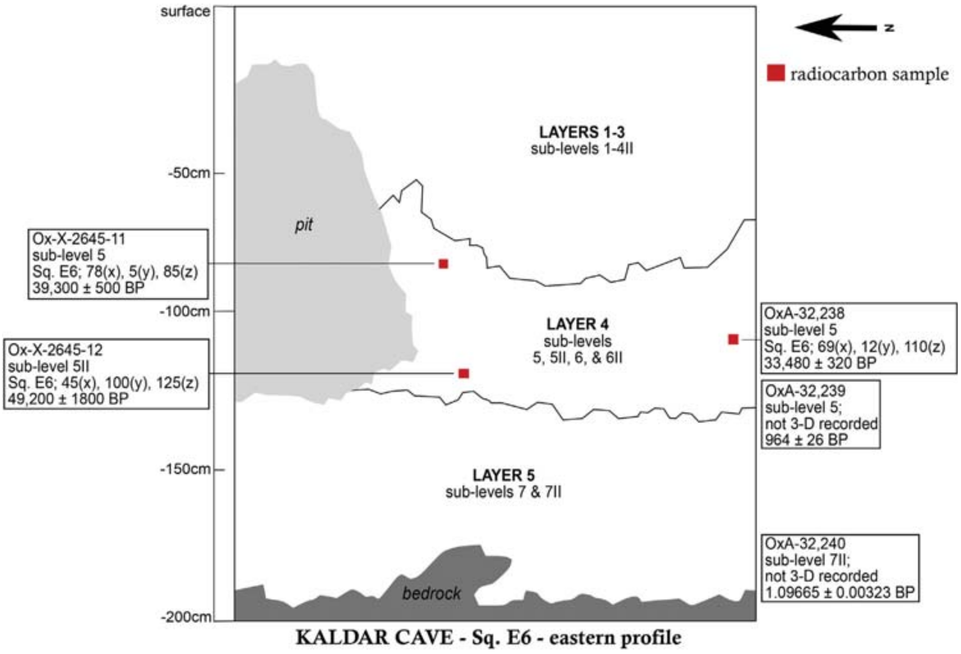

Figure 4. Schematic of the stratigraphic sequence at Kaldar Cave (SQ E6, eastern profile), showing the location of samples that were AMS radiocarbon dated.

analysis is based on the assumption that a given chronological sequence is divided into separate units of time, called 'Phases', which contain radiocarbon dates. Phases are constrained by 'boundaries' which serve as mathematical functions and produce PDFs estimating the start and end of each Phase. By assigning each likelihood a prior probability of being an outlier, its influence on a given model is down-weighted, allowing for flexibility. As such, all dates modelled here were ascribed a 5% prior probability of being an outlier within the General t-type Outlier Model (Bronk Ramsey, 2009b).

5. Results

None of the faunal bone samples tested for %N reached the threshold of 0.75 (Table 3). These results suggested that no samples contained enough collagen for AMS radiocarbon dating, thus none was passed on for further pre-treatment.

Of seven charcoal samples processed, only five from Kaldar Cave passed chemical pre-treatment and were AMS dated (Tables 4 and 5; these results are also noted in Bazgir et al., 2017). Of these, two yielded modern dates incongruent with their position in the stratigraphy. This is likely because the two charcoal samples were general finds and their exact location within the stratigraphy is not known (see Table 4; Fig. 4). Considering that only three reliable dates were obtained for Kaldar Cave, no modelling was undertaken. From Ghār-e Boof, two out of four samples analysed (three seeds and one riverine snail) passed pre-treatment and were AMS dated (Tables 4 and 5; Fig. 6). The snail sample (OxA-32390), collected from AH IV, yielded a comparatively younger date than the seed taken from AH III (OxA-X-2633-54) and was duly identified as an outlier in the resulting model (at 91% probability; Fig. 5). This age-depth discrepancy has a number of potential explanations. The two most parsimonious are i. post-depositional mixing within the sequence, e.g., bioturbation, or ii. modern carbon contamination resulting in an underestimation of the true age. The first explanation cannot be ruled out. The second applies to the carbonate if the presence of recrystallized calcite is detected or other sources of modern carbon are somehow introduced during laboratory procedures. In this case, both are unlikely as the snail shell was tested using geological staining techniques (Friedman, 1959) prior to acid dissolution and found to be aragonitic, while the procedural blank that accompanied it during dating procedures showed no significant levels of modern carbon contamination ($fM = 0.00001 \pm 0.00023$).

The Bayesian model created for this site incorporates previously published radiocarbon determinations (Ghasidian, 2014) and the two AMS dates obtained, yielding a start boundary for the UP at 41,950–39,850 cal BP (68.2% probability; Fig. 5). The model identified two outliers (KIA-32763 and OxA-32390) and resulted in bimodal distributions, especially for the end of AH III.

For Yafteh Cave, a Bayesian model incorporating radiocarbon determinations published by Otte et al. (2011) and their respective depths in a sequence yields a date boundary for the beginning of the UP at 38,850–38,000 cal BP (68.3% probability; Fig. 7). Beta-251061, Beta-205844, and Beta-206711 are identified as outliers at likelihoods of 100%, 90%, and 100%, respectively. The radiocarbon determinations obtained by Hole and Flannery (1968) were not included in this model as they show wide error margins and, as discussed, their stratigraphic relationship with the samples obtained in the 2000s is unknown.

For Shanidar cave, modelling the radiocarbon determinations obtained in the 1960s (Solecki, 1963; Hole and Flannery, 1968) for Layers B1, B2, C, and D, results in a PDF for the M–UP transition at 43,200–39,600 cal BP (68.2% probability) with no outliers (Fig. 8).

The incorporation of PDFs generated for the onset of the UP for Yafteh Cave, Ghār-e Boof, and Shanidar Cave into a single Bayesian model, results in a start boundary for the UP in the Zagros Mountains dating to 45,100–40,350 (68.2% probability) cal BP (Fig. 9).

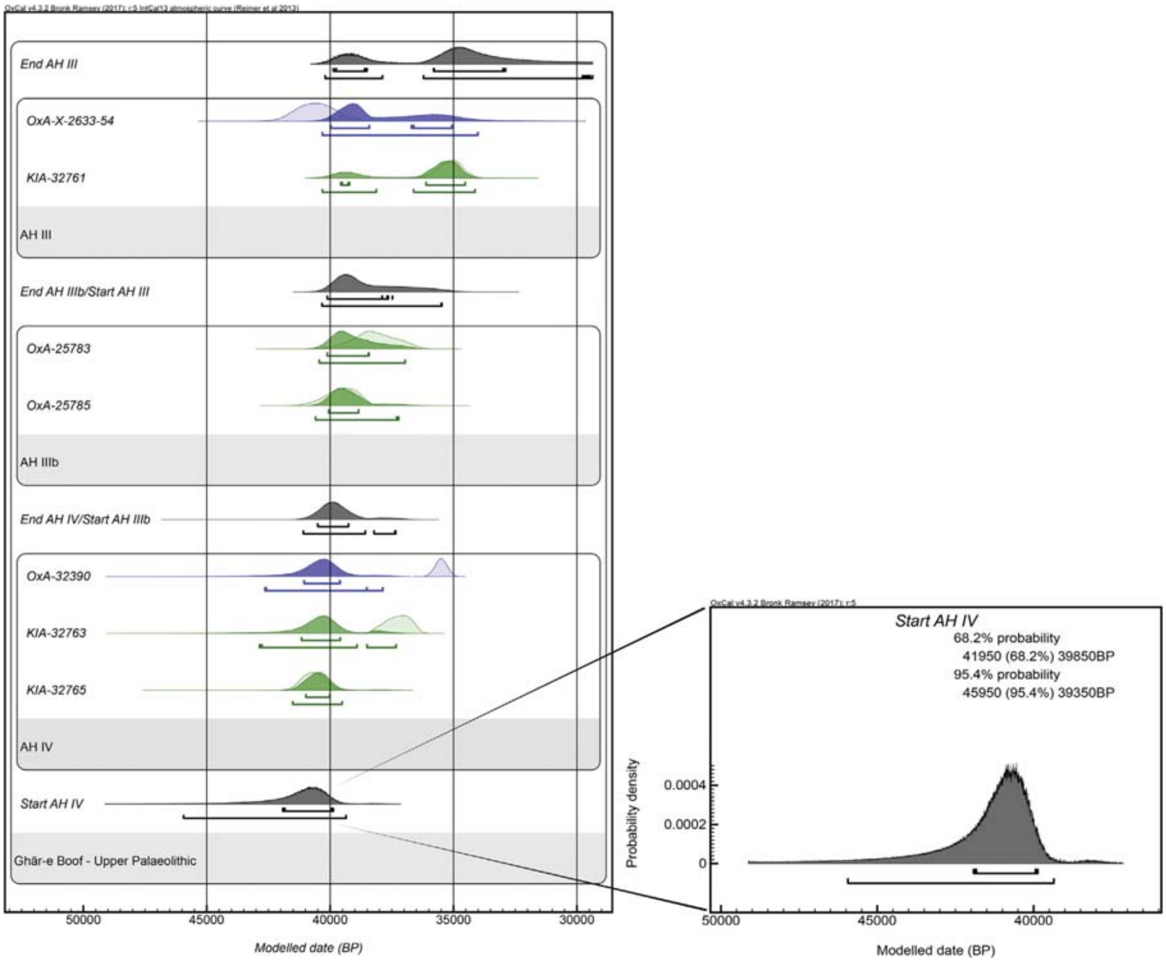

Figure 5. Bayesian model of radiocarbon dates for the Upper Paleolithic sequence at Ghār-e Boof, including those published by Ghasidian (2014; in green), and the two OxA dates obtained (in blue). This model has three separate phases corresponding to AHs IV, IIIb, and III. The boundary for the start of AH IV corresponds to the onset of the Upper Paleolithic at the site. OxCal CQL code is provided in Supplementary Online Material (SOM). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

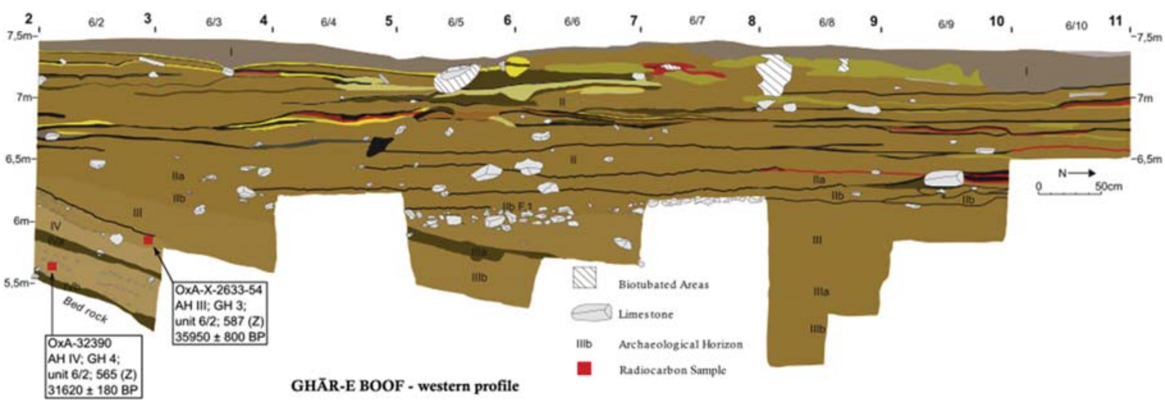

Figure 6. Schematic of the stratigraphic sequence at Ghār-e Boof (western profile), showing the location of samples which were AMS radiocarbon dated through this investigation. After Conard and Ghasidian, 2011, Figure 7.

Table 3
Pre-screening results (%N) of faunal bone samples from Kobeh Cave (KoC) and Ghār-e Boof (GB). Sample references followed by either 'A' or 'B' refer to sub-samples within the same bone fragment. The results suggest a uniformly low level of remaining collagen in the bones.

Site	Sample reference	Combusted (wt; mg)	N (μg)	%N (wt)
KoC	675	4.97	5.02949	0.101
KoC	684	5.14	6.27834	0.122
KoC	690A	4.99	5.37038	0.108
KoC	690B	5.13	4.92662	0.096
KoC	702	4.95	4.69297	0.095
KoC	1988	5.06	6.00349	0.119
KoC	8096	5.7	8.04789	0.141
KoC	8217	4.97	5.84302	0.118
KoC	8642	5.08	6.00941	0.118
KoC	8968	5.08	15.11011	0.297
KoC	3672	5.11	3.69197	0.072
KoC	3680A	5.07	17.27945	0.341
KoC	3680B	4.93	13.16061	0.267
KoC	3695	4.9	7.55116	0.154
KoC	3818	4.81	4.92294	0.102
KoC	3827	4.8	5.90319	0.123
GB	1A	2.61	5.59388	0.21
GB	1B	2.79	5.99152	0.21
GB	2A	2.46	5.05467	0.21
GB	2B	2.48	5.36492	0.22
GB	3A	2.73	4.61503	0.17
GB	3B	2.58	3.67806	0.14
GB	4A	2.5	6.13677	0.25
GB	4B	2.67	7.37776	0.28
GB	5A	2.99	5.58735	0.19
GB	5B	2.84	5.69284	0.2
GB	6A	3	6.07218	0.2
GB	6B	2.78	7.05446	0.25
GB	7A	2.35	4.9019	0.21
GB	7B	2.46	5.50677	0.22
GB	8	2.79	7.28358	0.26
GB	9	2.93	5.30434	0.18
GB	10A	2.82	6.60423	0.23
GB	10B	2.8	6.23539	0.22
GB	11A	2.69	8.31874	0.31
GB	11B	2.76	7.28077	0.26
GB	12A	3.03	7.33149	0.24
GB	12B	2.45	3.35461	0.14
GB	13	2.28	5.73843	0.25
GB	14	2.82	5.1007	0.18
GB	15	2.98	5.79644	0.19
GB	16	2.8	3.96831	0.14
GB	17	2.71	7.74739	0.29
GB	18	2.78	6.59087	0.24
GB	19	2.38	6.11892	0.26
GB	20	3.22	5.60614	0.17
GB	21	2.94	5.1426	0.17
GB	22	2.67	5.21032	0.2
GB	23	2.98	7.22746	0.24
GB	24	3.17	7.2795	0.23
GB	25	2.72	4.82615	0.18
GB	26	2.96	6.71204	0.23
GB	27	2.26	3.94588	0.17
GB	28	2.5	5.27486	0.21
GB	29	2.99	5.20558	0.17
GB	30	2.36	4.57249	0.19
GB	31	3.2	2.65732	0.08
GB	32	2.71	6.20176	0.23
GB	33	2.63	3.19625	0.12
GB	34	3.14	4.09168	0.13
GB	35	2.96	4.26613	0.14
GB	36	3.19	4.00298	0.13
GB	37	3.22	5.21662	0.16
GB	38	2.91	3.52456	0.12
GB	39	2.97	4.72232	0.16
GB	40	3.2	3.30962	0.1
GB	41	2.72	5.75578	0.21
GB	42A	3.17	2.26344	0.07
GB	42B	2.59	1.5701	0.06

6. Discussion

Based on the small number of new determinations which we were able to obtain, it is clear that further work is required if we are to obtain robust site chronologies and increase the temporal resolution of the M–UP transition in the Zagros Mountains. We encountered severe difficulties with the radiocarbon dating of bone from the region, and our pre-screening efforts showed that bones containing collagen are rare. Collagen is affected by the combined influences of post-depositional temperature, moisture content, bacterial presence and site pH, which together cause the loss of collagen through diagenetic processes (see Collins et al., 2002; Hedges, 2002). Under certain circumstances, this reduces the number of bones from a given site which are suitable for dating, restricting the potential to reliably date an archaeological sequence. Attempting to date material from archaeological sites known to yield poorly preserved bones with low collagen content is, therefore, an inefficient use of time and resources. Unfortunately, %N results for Kobeh Cave and Ghār-e Boof suggest that this might very well be the case for the Zagros Mountains—no pre-screened samples passed 0.4 %N, showing that collagen preservation was exceptionally poor. The data are not without value, however, as they do suggest that chronometric investigations in the region ought to focus on other types of organic material. The radiocarbon dating of charcoal, for example, will most likely produce a higher number of AMS radiocarbon dates. It is important to emphasise, however, that in the dating of Paleolithic-aged charcoal, rigorous pre-treatment methods should be employed in order to obtain robust results. The routinely used ABA protocol has been shown to consistently underestimate the age of 'old' charcoal when compared to ABOx-SC. The younger date range obtained for the UP start boundary at Yafteh Cave, in comparison to the other sites investigated, is likely to be an underestimate based on the use of ABA techniques in the preparation of previously obtained dates. If additional material was secured in the future, the use of more rigorous pre-treatment protocols would likely provide a more reliable, probably older, chronology for the site.

It is important that we continue our efforts to improve the chronology of Zagros sites due to the archaeological importance of the region and the likely elucidation of spatio-temporal dynamics in hominin dispersal. Future chronometric investigations focused on terminal MP sequences within the region, for instance, will help to determine the nature of the transition and whether it involved a direct replacement of Neanderthals by modern humans or not. Therein lies the importance of archaeological and chronometric research in sites like Kaldar, Ghār-e Boof, and Shanidar Cave, which contain both Middle and Upper Paleolithic sequences.

7. Conclusion

High-precision AMS radiocarbon dates were obtained for the Upper Paleolithic layers of Kaldar Cave and Ghār-e Boof—key archaeological sites within the Zagros Mountains. These, along with the statistical analysis of previously published radiocarbon determinations for the sites of Yafteh Cave (Iran) and Shanidar Cave (Iraqi Kurdistan), allowed us to build preliminary age models using Bayesian modelling methods with OxCal 4.3. The date boundary obtained for the start of the UP in the Zagros Mountains (40,000–45,250 cal BP at 68.2% confidence) is similar to estimates for the start of the UP in other parts of Eurasia, including the Levant (e.g., Douka, 2013) and Europe (e.g., Wood et al., 2014), but does not significantly predate them. Pre-screening efforts focused on faunal bone remains demonstrated that for Kobeh Cave and Ghār-e Boof,

Table 4
Details of samples from Kaldar Cave (KaC) and Ghār-e Boof (GB) which passed chemical pre-treatment and were AMS radiocarbon dated.

Site	Sample reference	Material	Species	Archaeological context
KaC	723	charcoal	*Prunus* cf. *amygdalus*	Trench (T) 1; Level 4, sub-level 5; SQ E6; 69 (X), 12 (Y), 110 (Z)
KaC	non-provided; 'A'	charcoal	*Quercus* sp. deciduous	T1; Level 4, sub-level 5; SQ G6
KaC	non-provided; 'B'	charcoal	*Quercus* sp. deciduous	T1; Level 5, sub-level 7II; SQ F7
KaC	274	charcoal	*Prunus* cf. *amygdalus*	T 1; Level 4, sub- level 5; SQ E7; 78 (X), 5 (Y), 85 (Z)
KaC	869	charcoal	*Prunus* cf. *amygdalus*	T1; Level 4, sub-level 5II; SQ E6; 45 (X), 100 (Y), 125 (Z)
GB	find no. 206	seed	*Lathyrus* sp.	AH III; GH 3; unit 6/2; 587 (Z)
GB	find no. 236	snail	*Theodoxus* sp.	AH IV; GH 4; unit 6/2; 565 (Z)

Table 5
AMS radiocarbon dates for the sites of Kaldar Cave (KaC) and Ghār-e Boof (GB).

Site	Sample reference	ORAU Lab code	$\delta^{13}C$ (‰)	Radiocarbon date (BP)	Calibrated date (95.4% probability)
KaC	723	OxA-32238	−23	33,480 ± 320	38,650–36,750 cal BP
KaC	'A'	OxA-32239	−23.1	964 ± 26	1000–1200 AD
KaC	'B'	OxA-32240	−27.1	1.09665 ± 0.00323	1850–1950 AD
KaC	274	OxA-X-2645-11	−23.4	39,300 ± 550	44,200–42,350 cal BP
KaC	869	OxA-X-2645-12	−24.5	49,200 ± 1800	54,400–46,050 cal BP
GB	find no. 206	OxA-X-2633-54	−21.3	35,950 ± 800	42,050–38,950 cal BP
GB	find no. 236	OxA-32390	−6.7	31,620 ± 180	36,000–35,000 cal BP

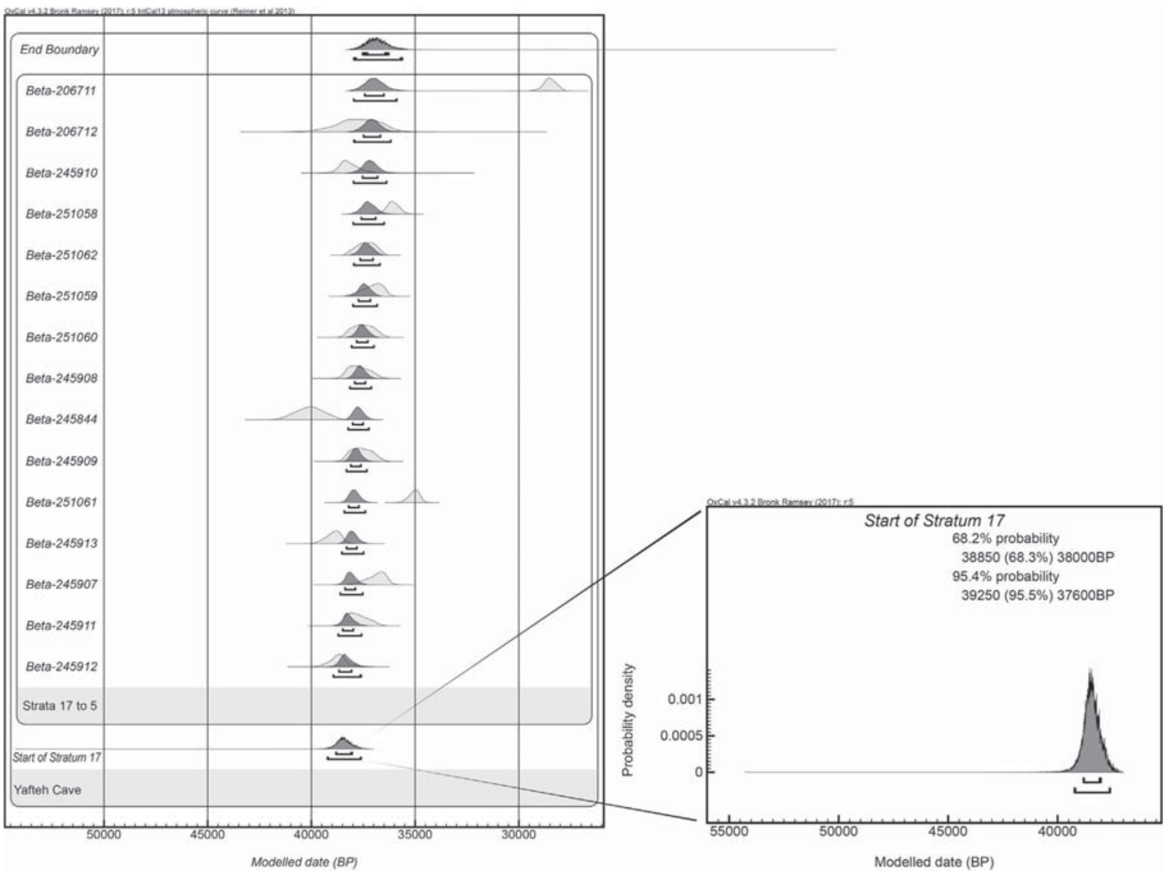

Figure 7. Bayesian model of radiocarbon dates for the Upper Paleolithic sequence at Yafteh Cave, including those obtained in the 2000s as published by Otte et al. (2011). The boundary for the start of stratum 17 corresponds to the onset of the Upper Paleolithic at the site. OxCal CQL code in SOM.

collagen preservation is low and yields are insufficient for radiocarbon dating. These results suggest that chronometric efforts for the Zagros region might do best to focus on dating other organic remains, such as charcoal, using rigorous pre-treatment methods that sufficiently decontaminate Paleolithic-aged material. Our results provide a starting point for further work in developing high precision data for understanding the Middle to Upper Paleolithic transition in this region.

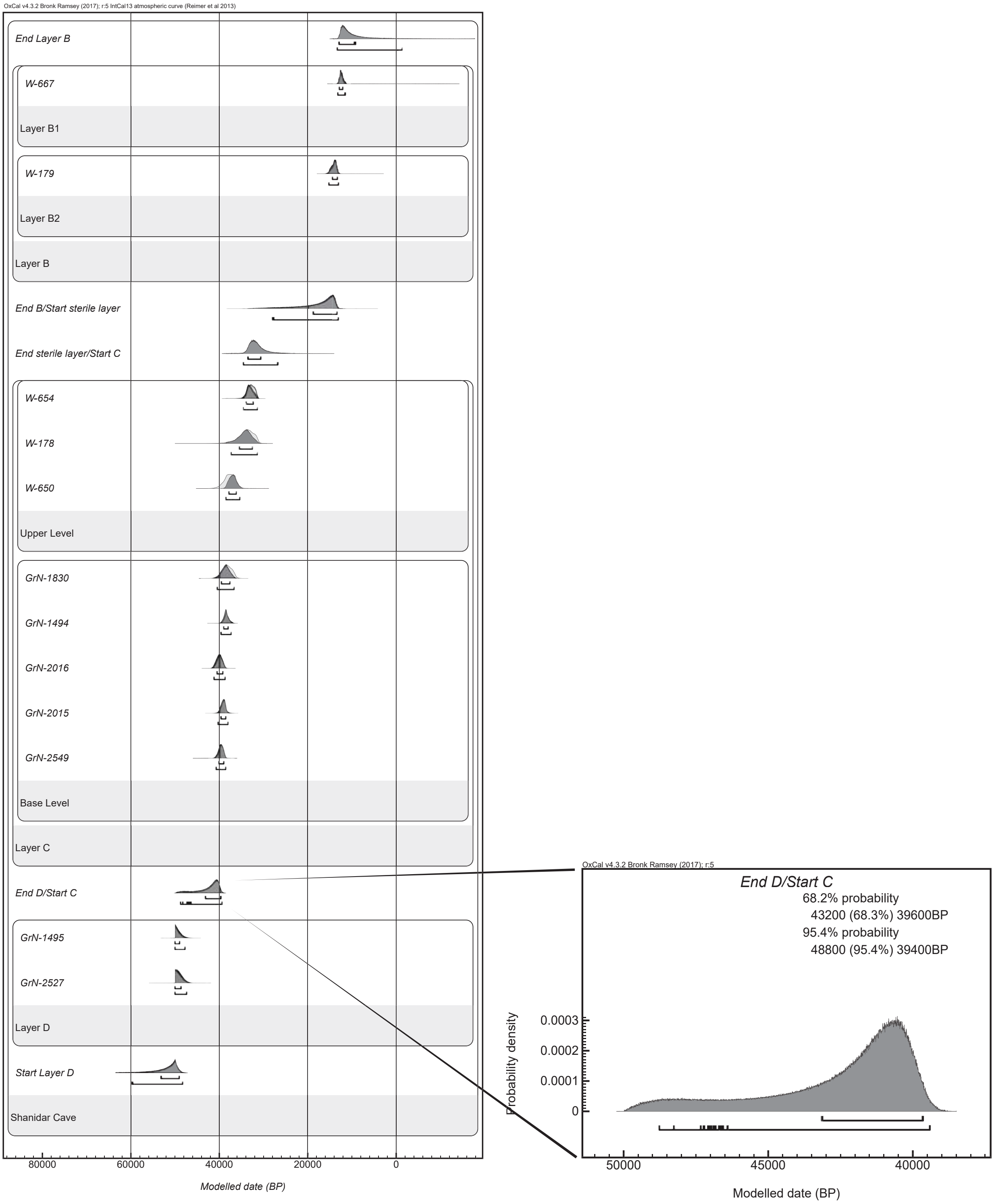

Figure 8. Bayesian model of radiocarbon dates for the Paleolithic sequence at Shanidar Cave, including those published by Hole and Flannery (1968), and Solecki (1963). This model has three separate phases corresponding to Layers D, C, and B. The boundary for the end of Layer D/start of Layer C corresponds to the Middle to Upper Paleolithic transition at the site. OxCal CQL code is shown in the SOM.

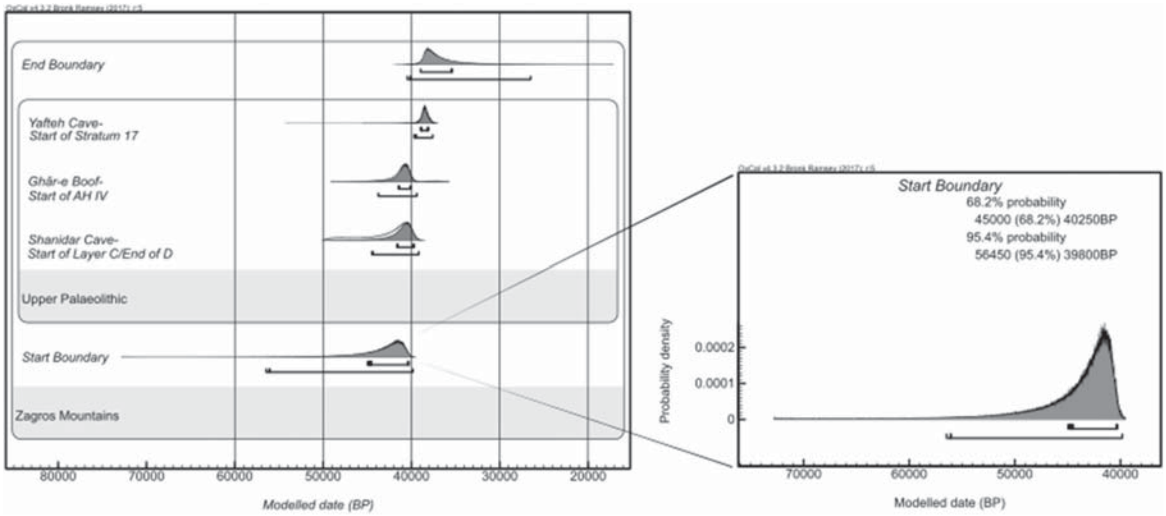

Figure 9. Bayesian model for the onset of the Upper Paleolithic in the Zagros Mountains, using modelled chronometric data for Yafteh Cave, Ghār-e Boof, and Shanidar Cave.

Acknowledgments

The research leading to these results has received funding from the European Research Council under the European Union's Seventh Framework Programme (FP7/2007-2013); ERC grant 324139 "PalaeoChron" awarded to Professor Tom Higham. We thank all members of the project; the staff of the Oxford Radiocarbon Accelerator Unit, University of Oxford; and Mariana Sontag González for her review of the manuscript. Work at Kaldar Cave was supported by the MINECO-FEDER (project CGL2015-65387-C3-1-P), AGAUR (project SGR 2014-899), and the URV (projects 2014/2015/2016PFR-URV-B2-17). B. Bazgir is a beneficiary of the Fundación Atapuerca pre-doctoral grant, and L. Tumung holds a IDQP pre-doctoral scholarship at URV. Research at IPHES is framed under the CERCA Programme/Generalitat de Catalunya. Investigations at Khorramabad region are part of an agreement between IPHES and RICHT, supported by ICAR. We are especially thankful to both directors (Seyed Mohammad Beheshti and Hamide Chubak). Excavations at Ghār-e Boof have been funded by a grant to NJC from the Deutsche Forschungsgemeinschaft.

Supplementary Online Material

Supplementary online material related to this article can be found at http://dx.doi.org/10.1016/j.jhevol.2017.05.011.

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2.3 Zagros Lithic technology:

Regarding the study of the lithic technology on the Zagros Palaeolithic sites, are mostly concentrated on the MP and UP sites compared to the Lower Palaeolithic sites. The reason behind this is, in the decades of Palaeolithic studies in the region there is the most number of MP and UP sites excavated; therefore, lithic assemblages were available to study. The identification of the LP sites and their chronology is mainly based on the surface collections. The concentration of the discovered and excavated sites is on the north-western part of the Zagros Mountains, Alborz Mountains and in the Kaushaf Basin of Iran (Biglari and Shidrang 2006). The Lower Paleolithic lithic artefacts show a variety of raw material used such as chert, quartz, sandstone, basalt and limestone. On the other hand, MP and UP lithic artefacts are dominated by chert and few examples of obsidian (Heydari 2004; Biglari 2004; Otte et al. 2007, Bazgir et al. 2014).

For the MP lithic studies, Lindly (2005) did the complete assessment of the Zagros Mousterian sites and concluded that the Zagros Mousterian due to its intensive core reduction, tool retouches and high frequencies of pointed tools, it can be grouped as a specialized variant of Eurasian Mousterian.

For the Paleolithic studies, Zagros Mountain always stands on the pedestal of debate regarding the origin of Aurignacian. Although, Aurignacian tool types first were found in Western Europe associated with Cro-Magnons, but chronologically it indicates that they were originated somewhere in the Levant or Middle East (Henry 1995, Bar-Yosef 2000, Bar-Yosef et al. 1996, Goring-Morris & Belfer-Cohen 2002). Aurignacian (ambiguous in nature) has gained a wide interest among archaeologists; initially to locate its origin place and to understand its technological variations (Ahmarian) in the Levant and (Baradostain, Rostamian and Zarian) in the Zagros.

For the Zagros UP technology, Garrod initially suggested they are very similar to Aurignacian culture (Lumper approach), which she holds firm till the 1950s, but by late 1950´s she recognised that Zagros Upper Paleolithic assemblages are having its distinct lithic typology (Splitter approach) (Olszewski, 1999). In the 1950s, Baradostain and Zarizian culture were first identified in Iraqi Zagros, whereas, Rostamian culture was identified in Iranian Zagros in 2010.

The Aurignacian of Zagros Mountains is characterized by the Baradostain and Rostamian cultures (representing early phase of Upper Paleolithic) and Zarian culture (representing later phase of Upper Paleolithic) (Garrod 1953, 1957; Solecki 1958; Braidwood

and Howe 1960, Braidwood *et al.* 1961; Hole and Flannery 1967; Olszewski 1993a, 1993b; Smith 1986; Wahida 1981; Conard and Ghasidian, 2011; Ghasidian 2010; Jayez et.al. 2018).
The Early phase of Upper Paleolithic of Zagros Mountains (Baradostian and Rostamian) comes from the two type sites Shanidar (Northern Zagros, Iraq) and Ghar- e- Boof (Southern Zagros, Iran) which represented distinct tool types. The term Baradostian was derived from the Baradost Mountains (Northern Iraqi Kurdistan), where the famous site of Shanidar is located. Following the suggestion of D. Garrod, Solecki first used the term Baradostian after recognising strong regional characteristics of the blade and burin-based lithic industry from UP layer C of Shanidar Cave in the Northern Zagros (Olszewski and Dibble, 1994). The similar industry is also present in various sites of Iran such as Warwasi Rock shelter, Yafteh and Kaldar Cave (Olszewski and Dibble, 1994, 2006; Otte et al. 2007; Bazgir et al. 2014, 2017). The Baradostian tools are mostly dominated by scrapers and various burins, notch/denticulates, points (mostly Mousterian points), carinated scrapers, and Aurignacian blades (Solecki 1963). The characteristics of this tool typology, they are made on short blades with many "chisels", often faired, and slats with fine marginal retouching (Otte and Kozlowski 2004). Another important tool type is the "Arjeneh point" (a term derived from Gar Arjeneh Cave, Khorramabad Valley, Iran), they are assigning to the tools, which are having appointed lamellae obtained by two retouched edges convergent towards the apical end (Hole and Flannery, 1967).

Northern Zagros the Baradostain tools are mostly dominated by scrapers and various burin, notch/denticulates points (mostly Mousterian points), carinated scraper and Aurignacian blades. West Central Zagros Mountains consists of two Early and Late Baradostian/Zagros Aurignacian phases. The Early Baradostian lithics are flake-based, and tools include mostly burins, scrapers on flakes, carinated scrapers, and end scrapers (Tsanova 2013). Late Baradostian is characterized by bladelet production, also among tool blanks in the form of Dufour bladelets (Olsweski and Dibble 1994).

On the other hand, Rostamian tools are basically a bladelet industry. Early UP Rostamian techno-complex based on chipped stone assemblages from Dasht-e Rostam in Southern Zagros, the type site of which is the cave site of Boof. Although it has similarities to the Baradostian/Zagros Aurignacian, some experts believe that many different characteristics define it as a local group in Southern Zagros (see Conard and Ghasidian, 2011; Ghasidian et al., 2017). Rostamian techno-complex is characterized by unidirectional single platform bladelet cores and many bladelets, some of which are retouched or/and twisted in morphology, entitled “Rostamian bladelets”; there are also end scrapers in this group, but Arjeneh (Font-Yves) points are rare and small (Conard and Ghasidian, 2011). The Rostamian lithics are characterized by a strong emphasis on the production of bladelets from single platform cores dated to Early UP. Throughout the sequence, bladelets are the main tool blanks, and represent different variants of retouch including “Rostam bladelets”.

Although these terms are frequently used by many archaeologists to attribute to Zagros Upper Paleolithic, still some (such as Olszewsky and Dibble 2006; Olszewsky 2009; Otte and Kozlowski, 2004) refer to them as *Zagros Aurignacian* due to their distinct characteristics with certain similarities to European Aurignacian (Bazgir et al. 2017).

Zarzian was defined based on the assemblage from the type site of Zarzi in Iraqi Kurdistan (Garrod, 1930; Wahida, 1981, 1999). This techno-complex better understood after the study on the lithic assemblage of Warwasi, Kermanshah province (Iran) (Olszewsky 1993). The lithic industry is characterized as having non-geometric microliths, mainly Dufour bladelets, and thumbnail scrapers in the earliest phases and introduction and increase in geometric microliths (i.e. scalene triangles and lunates) in the course of later phases (Olszewski, 2012: 18). Other notable sites showing the presence of Zarzian assemblages are Zarzi cave in Iraq (Garrod, 1930; Wahida, 1981), Shanidar (Solecki, 1963), Warwasi (Olszewski, 1993a,b) and a small assemblage form Ghar-e Khar (Shidrang et al., 2016). The most concentration of the Zarzian sites on the Zagros Mountains are distributed in the northern part with some scattered sites in southern Zagros and Alborz region of Iran (Jayez et al. 2018).

2.4 Human remains

Although, rich with the variety of technological lithic assemblages; the Zagros Mountains shows lack of human remains in the excavated sites. Till date, Shanidar Cave (Iraqi Zagros) is the soul site, where ten partial Neanderthal remains were uncovered from the Layer D which was excavated between 1953 and 1960 by R.S. Solecki (Solecki, 1963; Trinkaus, 1978; Cowgill et al., 2007). After a halt of many years, new excavation commenced in Shanidar and exposed a few more Neanderthal remains (Pomeroy et al. 2017). Most of Solecki’s publications centred on the spectacular finds of the skeletal remains of Neanderthals and the associated behavioural evidence for burial, care of the elderly and possible burials with flowers (Leroi-Gourhan, 1975; Solecki, 1975).

In Iranian Zagros only few sites have reported of remains but with no reliable dating of the sites. These are Bisitun 1 (Coon 1951; Trinkaus and Briglari 2006), Mar Tarik (Jaubert et al.

2009), Wezmeh (Trinkaus et al. 2007) and Eshgaft-e Gavi (Scott and Marean 2009). Besides these sites, at the site of Gar Arjeneh Rockshelter, Hole and Flannery (1967) found some fragments of earlier Upper Paleolithic humans but are remain undescribed.

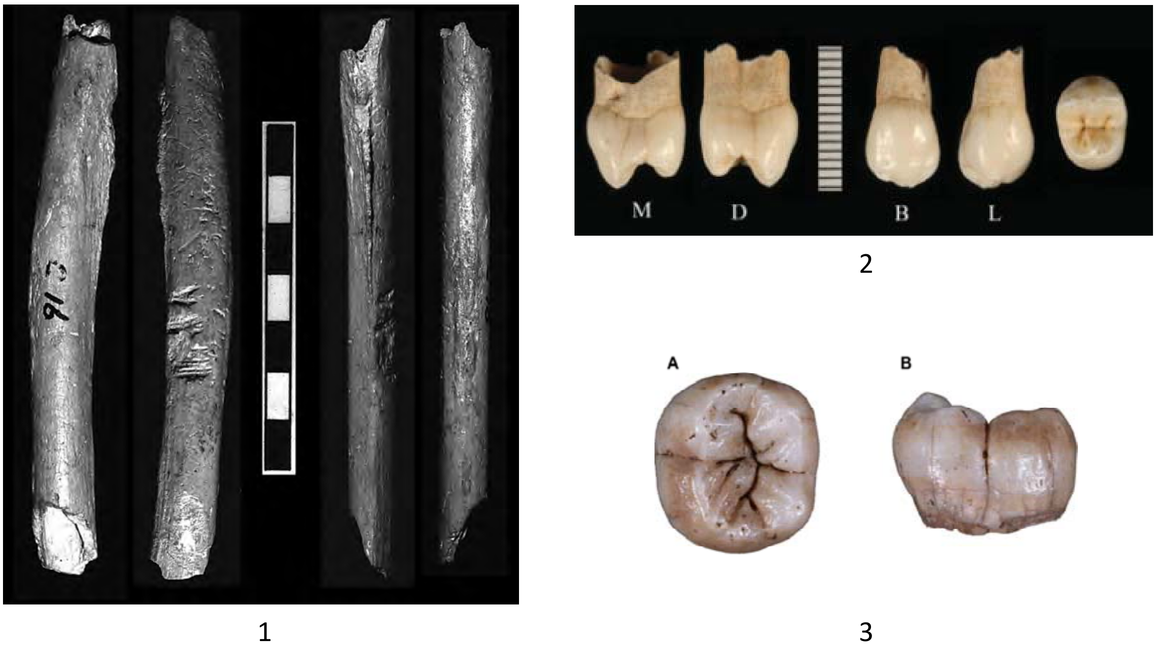

Figure 2.2: Human remains from Iranian Zagros: 1) Bisitun1 Human Radius (Courtesy of Trinkaus and Biglari et.al. 2006), 2) Premolar of Mar Tarik human fossil (Courtesy of Trinkaus et.al. 2007) and 3) Left mandibular molar Eshgafte-gavi human fossil (courtesy of Scott and Marean 2009)

The first human remains reported from Iranian Zagros come from Bisitun Cave, Kermanshah Province. Coon (1951) in his 1949 excavation at the Bisitun and Tamtama Caves (Iran) discovered few fragments of human remains, which he described as human incisors and radius. These fossil remains were reanalyzed by E. Trinkaus, and he explained that only one radius is human, whereas the incisor belongs to a bovid (Trinkaus and Bigliari 2006). Trinkaus (et al 2007) also analysed an isolated human immature P3 (or P4) from Wezmeh Cave, chronologically belonging to OIS2 Upper Palaeolithic period and was analyzed by non-destructive gamma spectrometry and gave a date of ca. 25000 years ago. He described it as large, but otherwise morphologically unexceptional, tooth. As Wezmeh Cave is also known as the carnivore den due to large number of carnivore faunal reamins; It is hypothesised that the juvenile individual may have been the prey of those carnivores or had its remains scavenged after death (Trinkaus et al. 2007).

Although, the other Iranian sites showed human remains, but the human fossil remains of Eshgaft-e-gavi remained unique. This site was excavated in 1970s and revealed ten hominin specimens (the bones derive from a minimum of four individuals, including two juveniles) out of which four specimens displayed evidence of intentional defleshing with stone tools, indicating possible evidence of cannibalism. The condition of the faunal remains is very fragmentary, but those that preserve diagnostic morphology indicate that they represent modern humans. The molar is taxonomically diagnostic, thus confirming the association of the Aurignacian-like Baradostian Industry with modern humans. Chronologically, they could be Epi-Paleolithic in age, except for one mandibular molar (which occured at the base of the cave's Upper Palaeolithic sequence) Scott and Marean (2009).

2.5 Flora and Fauna

Through the recently published works on the fauna and flora remains from the Zagros Mountains sites we can have some idea about the paleoenvironment. Most of the excavations in the Zagros region for the large mammals shows the most dominance of *Capra*, *Cervus* and *Equus* species (Table 2.1). Besides these, there is also the presence of species of *Sus*, *Bos*, Gazelle and carnivores. Some of the rare species which showed the first time presence in the Zagros are the presence of Rhino in the site of Barda Balba (Iraq), Ke-Aram I (northern Iran) and Gilvaran (Western Iran) (Lindly 2005; Bazgir et al. 2014).

For the marine fauna, there is evidence of carb, fishes and shells (Otte et al. 2007 and Bazgir et al. 2014). The presence of carb in the Kaldar cave is unique as they are perfectly cut claws (Bazgir et al. 2014). In Yafteh and Kaldar there is evidence of fish bone, Mashkour (et al. 2009) described about the fish spp., whereas for Kaldar right now they are under study. Yafteh Cave provided the evidence of shell pendant which shows the distant relationships, as the nearby Caspian Sea is 350 kms away from the site (Otte et al. 2007). Micro-mammals studies have been performed in the Khorramabad sites, Yafteh (Maskour et.al. 2009), Gilvaran and Kaldar (Bazgir et.al. 2014, 2017). The detail study of the micro/mammal from Kaldar cave is under process and a PhD study is developing by our colleague Ivan Rey Rodríguez.

Site	Equus	Cervus	Ovis/Capra	Sus	Bos	Bovini	Gazella	Carnivores	Rhinoceros	Fish	Turtle
Shanidar Cave (Flower men´s cave)	-	+	++	+	+	-	+	+	+		+
Bisitun Cave (Hunter´s cave)	+	++	+	+	+	-	+	+	-		
Warwasi Rockshelter	++	+	++	-	+	-	-	+	-		
Kobeh Cave	+	+	++	+	+	-	+	+	-		
Gare Khar	+	+	++	-	-	-	+	-	-		
Wezmeh Cave	+	+	+	+	+	-	+	++	+	-	
Eshkaft-e Gavi Cave											
Mar Tarik	+	-	++	-	-	-	+	+	-	+	+
Gar-e Boof Cave		++	+	+	+		+	+			+
Kunji Cave	+	++	++	+	+	-	+	+	-	-	-
Pa sangar Rockshelter	+	-	++	-	-	-	+	-	-	-	-
Yafteh Cave	-	+	++	+	+	-	+	+	-	++	
Qaleh Bozi Rockshelter	++	-	+	-	-	-	+	-	+	-	-
Gar Arjeneh Cave	+	+	-	-	+	-	-	-	-	-	-
Ghamari Cave	-	-	+	-	-	+	-	-	-	-	-
Gilvaran Cave	-	+	+	-	-	+	-	-	+	-	-
Kaldar Cave	+	+	+	+		+				++	
Eshkaft-e Gadhi burmishur Cave											
Houmian1	+	+	++	+	-		+	+	-	-	

Table 2.1: Showing the distribution of faunal remains in the Zagros Sites (Modified after Lindly 2005).

2.5.1. Publication 2: Ethel Allué, Isabel Expósito, **Laxmi Tumung**, Andreu Ollé, Behrouz Bazgir. 2018. Early evidence of *Prunus* and *Prunus* cf. *amygdalus* from Palaeolithic sites in the Khorramabad Valley, Western. *CR Palevol* 17 (6), pp. 335-345. https://doi.org/10.1016/j.crpv.2018.01.001

In this article, we have discussed about the identification of *Prunus* spp. through charcoal analysis in the sites of Gilvaran and Kaldar Cave, Khorramabad Valley (Iran). The charcoal samples correspond to Middle and Upper Paleolithic, which are the earliest finds attesting to the presence of this taxa in the area. Our anatomical observation of the samples revealed the presence of *Prunus* spp. (plums) and *Prunus* cf. *amygdalus* (cf. almond). This also reflects specific plant communities in the area, characteristic of open forest growing in cool, dry conditions. These results provide new insights into the Late Glacial arboreal cover in this area.
Furthermore, anthracological evidence together with other contextual materials provides a great opportunity to assess how Neanderthals and early modern humans adapted to their surroundings landscape, and their relationship with their environment in this region and beyond.

C. R. Palevol 17 (2018) 335–345

Contents lists available at ScienceDirect

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General Palaeontology, Systematics and Evolution

Early evidence of *Prunus* and *Prunus* cf. *amygdalus* from Palaeolithic sites in the Khorramabad Valley, western Iran

Évidences anciennes de Prunus *et* Prunus *cf.* amygdalus *dans des sites paléolithiques de la vallée de Khorramabad, dans l'Ouest de l'Iran*

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ARTICLE INFO

Article history:
Received 17 August 2017
Received in revised form
21 December 2017
Accepted after revision 9 January 2018
Available online 22 February 2018

Presented by Evelyn Kustatscher

Keywords:
Anthracology
Iran
Prunus spp.
Palaeoecology
Arboreal vegetation
Fuel

Mots clés :
Anthracologie
Iran
Prunus spp.
Paléoécologie
Végétation arborée
Combustible

ABSTRACT

Along with the early age obtained for the cultural remains attributed to anatomically modern humans from Kaldar Cave, the archaeological assemblages recovered from both Kaldar and Gilvaran Cave located in the Khorramabad Valley (Iran), have yielded charcoal remains that allow the identification of *Prunus* spp. These remains correspond to the Middle and Upper Palaeolithic, which are the earliest finds attesting to the presence of this taxa in the area. Our anatomical observation of the samples revealed the presence of *Prunus* spp. (plums) and *Prunus* cf. *amygdalus* (cf. almond). This also reflects specific plant communities in the area, characteristic of open forest growing in cool, dry conditions. These results provide new insights into the arboreal cover in this area during an Upper Pleistocene period. Furthermore, anthracological evidence together with other contextual materials provides new clues to assess how Neanderthals and early modern humans adapted to their surrounding landscape, and their relationship with their environment in this region and beyond.

RÉSUMÉ

En même temps que l'âge précoce obtenu pour les restes culturels attribués aux humains anatomiquement modernes de la grotte de Kaldar, les assemblages archéologiques récupérés à la fois dans les grottes de Kaldar et de Gilvaran, situées dans la vallée de Khorramabad (Iran) ont donné des restes de charbon qui permettent l'identification de *Prunus* spp. Ces restes correspondent au Paléolithique moyen et supérieur et sont les premières découvertes attestant la présence de ces taxons dans la région. Notre observation anatomique des échantillons a révélé la présence de *Prunus* spp. (Prunes) et *Prunus* cf. *amygdalus* (cf. l'amande). Ceci reflète également la présence, dans la région, de communautés végétales spécifiques, caractéristiques des forêts ouvertes se développant dans des

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https://doi.org/10.1016/j.crpv.2018.01.001
1631-0683/

conditions fraîches et sèches. Ces résultats apportent un nouveau regard sur la couverture arborescente présente dans cette zone au Pléistocène supérieur. En outre, les résultats anthracologiques ainsi que d'autres obtenus sur d'autres matériaux contextuels fournissent de nouvelles indications permettant d'évaluer comment les Néandertaliens et les premiers humains modernes se sont adaptés à leur environnement, et quelles ont été leurs relations avec leur environnement dans cette région et au-delà.

1. Introduction

The genus *Prunus* includes a large number of species that are distributed throughout the northern hemisphere (Kurtto, 2009). This genus is part of the Rosaceae family and the Amygdaloideae subfamily. *Prunus* spp. is referred to several synonyms including *Prunus*, *Amygdalus* and *Cerasus*. In this work, to avoid confusion between the different accepted nomenclatures, we use *Prunus* spp., which includes all three-mentioned genus names accepted in the Flora europaea (Kurtto, 2009). *Prunus* spp. is an entomophilous flowering tree or shrub with edible fruit (e.g., plums) or edible seeds (e.g., almonds). This genus includes 200 species of plums, almonds, peaches, apricots and cherries. Iran is the centre of origin of some of these species and a global center of nowadays world production (Gharaghani et al., 2017; Vafadar et al., 2010). Iran's geographical characteristics allow these species to spread in various tree communities under semi-arid conditions, such as Pistachio-almond communities, edges of the oak forests, open steppe forests, and steppe-like communities (Heshmati, 2007; Kashki and Amirabadizadeh, 2011; Pourmoghadam et al., 2013).

Past evidence of *Prunus* includes palaeobotanical records, which involve pollen, travertine imprints, charcoal, and seeds. Palynological records only permit identification to family level, i.e. Rosaceae, and pollen is usually absent or underrepresented due to the entomophilous character of this family (Djamali et al., 2008). According to Vafadar et al. (2010) *Amygdalus* L. (syn. *Prunus*) pollen grains from Iranian species are tricolporate and symmetric isopolar monads with a predominantly striated exine. According to these authors, the shape of the pollen grains allows different subgenera to be distinguished, whereas other features such as the exine show no differences. However, when the pollen is preserved in the archaeological record, it can only be identified as cf. *Prunus* (cf. *Amygdalus*) (Djamali et al., 2008; Vafadar et al., 2010). In Iran, there are several palynological sequences providing palaeoecological evidence from the upper Pleistocene to the Holocene (Bottema, 1986; Djamali et al., 2008, 2009a, 2009b, 2012; El-Moslimany, 1987; Miller et al., 2013; van Zeist, 1967). These sequences have yielded information on the arboreal cover in which Rosaceae is rarely present. Leaf imprints have preserved evidence of *Prunus*, but there have been very few records identified in natural environments in a diatomite deposit, suggesting that they were present from 1.2 Ma (Ollivier et al., 2010). Charcoal and seeds in archaeological contexts are the most abundant evidence of this genus. *Prunus* stones from several species have been identified from the Upper Palaeolithic, usually burnt and related to wild fruit gathering (Martinoli and Jacomet, 2004; Zohary and Hopf, 1993). There are 26 species of almond that include two eco-geographical groups: one is adapted to Mediterranean environments and the other occupies steppe forests or steppe-like environments (Zohary and Hopf, 1993). Archaeological evidence of this plant has been identified in Mesolithic and Neolithic layers in the Levant (Martinoli and Jacomet, 2004; Zohary and Hopf, 1993). The earliest evidence from Iran is from the Late Neolithic Tepe Musyan (Zohary and Hopf, 1993). Plums and cherries grow in temperate parts of Europe and Turkey, in woods and on cleared hills, and have been identified from the Neolithic. Some differences in the stones allow certain species to be distinguished, such as *Prunus spinosa*, and some types of almond have been recorded from Upper Palaeolithic deposits (Allué et al., 2010; Martinoli and Jacomet, 2004; Mason and Hather, 2002).

Until now charcoal macro-remains have provided the largest dataset of *Prunus* evidence, most of this from archaeological sites in various contexts. As charcoal is related to the use of wood for combustion, most records are from the upper Pleistocene to Holocene, whereas earlier evidence, where there is scarce evidence of fire, is rare. Charcoal analysis (or anthracology) is based on the taxonomic identification of charred wood remains recovered from archaeological sites. Anthracology is aimed at recognising past vegetation and its evolution through time, as well as understanding human behaviour in relation to the use of vegetal resources, particularly as fuel (Chabal et al., 1999). The significance of charcoal analysis as a tool for palaeoecological reconstruction has been demonstrated and its interpretation is based on the ecological characterisation of the species depending on the climatic conditions and their diachronic evolution. Also charcoal remains from domestic fires allow us to understand the uses of wood as a raw material for fuel, manufacturing objects, and as a building material (Chabal et al., 1999).

In the Near East, studies of archaeobotanical remains (fruits, seeds and charcoal) have been focused on tracing evidence of early agriculture, yielding excellent evidence for the study of past vegetation and plant uses (e.g., Asouti, 2003, 2013; Asouti and Kabukcu, 2014; Asouti and Fuller, 2013; Emery-Barbier and Thiébault, 2005; Mashkour and Tengberg, 2013; Miller, 1985, 2003; Miller and Marston, 2012; Miller et al., 2011; Willcox, 1999, 2002; Zohary and Hopf, 1993). In Iran, these studies mainly focus on seeds and charcoal remains from Neolithic and Bronze Age archaeological sites (Mashkour and Tengberg, 2013; Miller, 1985, 2003; Miller et al., 2011; Riehl et al., 2012; Tengberg, 2012; Willcox, 1990). In contrast, Palaeolithic records within the country are very scarce, with the exception of the Middle Palaeolithic site of Qaleh Bozi in central Iran, where charcoal analysis was carried out (Biglari et al., 2009). Preservation problems and lack of adequate sampling and excavation could be the main reason for the absence of charcoal remains from Iranian Palaeolithic sites. The importance of this region is focused on its important role for deciphering the Middle to Upper Palaeolithic transition related to the dispersal of Anatomically Modern Humans in terms of chronology and archaeological evidences (Bazgir et al., 2017; Becerra-Valdivia et al., 2017).

The aim of this work is to report the evidence of *Prunus* and *Prunus* cf. *amygdalus* yielded from the Palaeolithic sites of Gilvaran and Kaldar Caves. This evidence allows us to discuss palaeoenvironmental issues with regard to the presence of arboreal cover in the area during periods in which the region was occupied by culturally different human populations. These results are particularly important due to the scarcity of data from this period in the area, more specifically for providing new valuable evidence for the study of the Iranian Palaeolithic.

2. Site description

As a goal-oriented study with a regional and wide-ranging perspective, the Khorramabad research programme began in 2009. After a comprehensive field survey, in 2011–2012 we carried out an extensive excavation programme at the Palaeolithic localities including Gilvaran and Kaldar Caves (Fig. 1).

2.1. Gilvaran Cave

Gilvaran Cave is situated in the north-western part of the Khorramabad valley and located at 48° 18′ 56″ E longitude, 32° 28′ 12″ N latitude, at about 1225 m a.s.l. (Fig. 1). Excavation in Gilvaran involved two 2 × 2 m trenches, one near the cave dripline (trench A8) and the other about 20 m outside the cave entrance. Test pit AY1 exposed 4.8 m section of sedimentary deposit and is characterised by 5 main levels (Fig. 2). Level 1 consists of ashy blackish-green sediment with angular stones. It varies in thickness from 5 to 20 cm. This is the most recent level and contains an assemblage of Islamic materials. Level 2 consists of fine, light grey sediment with few angular stones. It varies in thickness from 28 to 84 cm and includes a Historical and Bronze Age record. Level 3 consists of grey, coarse sandy sediment that varies from 60 to 110 cm in thickness and which contains mixed evidence of Chalcolithic and Neolithic potsherds and lithic industries. Level 4 varies in thickness from 39 to 62 cm and consists of dark grey sediment with a large number of limestone blocks of different sizes. It contains an Upper Palaeolithic assemblage. Level 5 is a reddish brown deposit with many large limestone blocks. It increases in depth from the northern section towards the south, varying from 2.45 to 2.85 m in thickness. It includes two sub-levels that do not vary in colour. Evidence of Middle Palaeolithic industry is found in level 5, with mixed Middle and early Upper Palaeolithic/Baradostian industries in its sub-level 2 (Bazgir, 2013; Bazgir et al., 2014).

2.2. Kaldar Cave

Kaldar Cave is situated in the northern part of Khorramabad Valley at 48° 17′ 35″ E longitude, 33° 33′ 25″ N latitude, and an elevation of 1290 m a.s.l. It is 16 m long, 17 m wide, and 7 m high (Fig. 1). Its great potential was realised during our 2011–2012 test excavation. During the 2014–2015 excavation season at Kaldar, we enlarged the excavation area, focusing on gaining a better understanding of the stratigraphy and obtaining samples for dating. We dug a 3 × 3-m trench near the entrance and kept a 50-cm bulk sample from the previous test pit (squares E5, E6, E7, F5, F6, F7, G5, G6 and G7) (Fig. 3). The excavation was conducted using 5 cm spits within each archaeostratigraphic unit, as well as 3D recordings of all findings. The excavated trench exposed an approximately 2 m (195 cm) section of sedimentary deposit, which is characterised by five main layers. Layers 1 to 3 (including sub-layers 4 and 4II) consist of blackish-green ashy sediment containing both thick and thin angular limestone clasts. These layers vary in thickness from 60 to 90 cm and contain many phases dated as Holocene, i.e. the Islamic and Historical eras, Iron Age, Bronze Age, Chalcolithic, and Neolithic. However, due to the presence of some bioturbation in these layers, the phases were recognised only by a preliminary study of the potsherds, metal artefacts, and some diagnostic lithic artefacts from the lower layers. Layer 4 (including sub-layers 5, 5II, 6 and 6II) consists of a silty but compact dark-brown sediment with cultural remains from the Upper and Early Upper Palaeolithic. In the uppermost parts of this layer, two fireplaces made of clay were recovered and dated through thermoluminescence as 23,100 ± 3300 BP and 29,400 ± 2300 BP (Bazgir et al., 2017). The dates obtained show that these fireplaces were made or re-used from existing older sediment from the upper part of this layer in the later stages of the Upper Palaeolithic. AMS radiocarbon dates of 38,650–36,750 cal BP, 44,200–42,350 cal BP, and 54,400–46,050 cal BP have been obtained from charcoal material located below this layer (Bazgir et al., 2017; Becerra-Valdivia et al., 2017). Layer 5 (including sub-layers 7 and 7II) consists of an extremely well-cemented, reddish-brown sediment with some small angular limestone blocks and Middle Palaeolithic artefacts (Fig. 3). To date, no radiometric data are available for this layer (Bazgir et al., 2017). Charcoal remains included in this study belong to layers 4 and 5.

3. Materials and methods

The charcoal study is based on materials recovered from the 2011–2014 field seasons at Gilvaran and Kaldar Caves (Bazgir, 2013; Bazgir et al., 2014). Charcoal remains were handpicked and the sediments when possible were water sieved on the spot. At Gilvaran Cave, charcoals were recovered from Level 4, yielding positive results. The charcoal samples recovered from Level 4 are attributed to the Upper Palaeolithic, showing a clear association with other archaeological material (lithic remains and bones). The remains from Kaldar Cave came from two layers, Layer 4 belonging to the Upper Palaeolithic and Layer 5 belonging to the Middle Palaeolithic (Bazgir et al., 2017).

Fig. 1. Map of the area showing the location of the sites. The geographic position of the Khorramabad Valley and the position of the localities excavated in 2011–2012 field season indicated on an aerial photograph (Source of the original map: https://commons.wikimedia.org/wiki/File:Iran_relief_location_map.jpg (under the license of Creative Commons Attribution-Share Alike 3.0 Unporte). Modified by E. Allué. Original license pages: https://en.wikiedia.org/wiki/Creative Commons – https://creativecommons.org/licenses/by-sa/3.0/deed.en).
Fig. 1. Carte de la région, montrant la situation des sites. Position géographique de la vallée de Khorramabad et position des endroits creusés pendant la campagne 2011–2012 et indiqués sur la photo aérienne (Source : voir légende en anglais).

Fig. 2. Left, general view of Gilvaran Cave; middle, stratigraphic profile of Gilvaran cave; right, detail of the stratigraphy.
Fig. 2. À gauche, vue générale de la grotte de Gilvaran ; au milieu, profil stratigraphique de la grotte de Gilvaran ; à droite, détail de la stratigraphie.

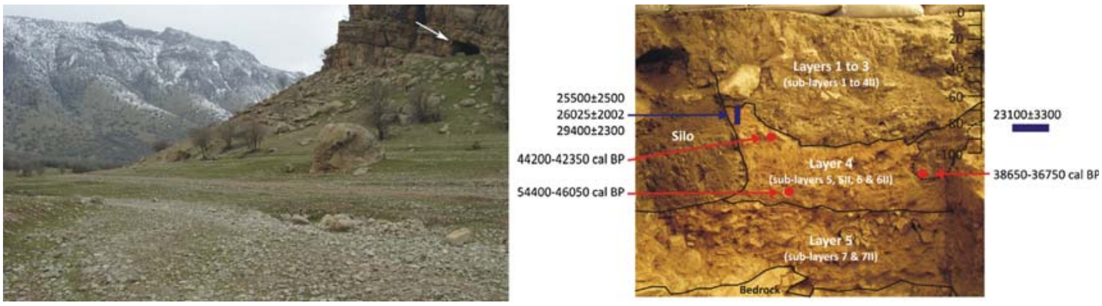

Fig. 3. Left, general view of Kaldar Cave; right, stratigraphy (eastern section) of Kaldar with location and results of the dated samples (created by A. Ollé and B. Bazgir. Modified from Bazgir et al., 2017).
Fig. 3. À gauche, vue générale de la grotte de Kaldar ; à droite, stratigraphie (coupe orientale) de Kaldar avec la localisation et les résultats des échantillons datés (créé par A. Ollé et B. Bazgir. Modifié d'après Bazgir et al., 2017).

For charcoal identification, the remains were fragmented by hand in order to obtain the three wood anatomy sections. This permitted a description of the cell structure. The charcoal fragments were observed using a metallographic reflected light microscope with dark and light fields, at ×50, ×100, ×200, and ×500 magnifications (Olympus BX41). The identification was supported with various wood anatomy atlases (Fahn et al., 1986; Parsapajouh et al., 1987; Schweingruber and Landolt, 2005). Charcoal analysis does not always permit a species-level identification due to factors such as size of the charcoal piece, anatomy defects produced by combustion or post-depositional processes, low degree of anatomical variability among species, or the absence within the fragment of all the characteristics needed to define a species. The identification categories used in charcoal analysis are genus, family, type, and occasionally species. Quantification of charcoal assemblages is usually based on the number of fragments or the presence/absence of the different taxa. Furthermore, depending on the number of fragments a statistical approach can be taken. Usually a minimum number of fragments should be studied in order to obtain a valid data set. A commonly agreed-upon and widely accepted standard among authors is that between 250 and 500 fragments per level are required to validate a sample (Chabal et al., 1999). At Gilvaran and Kaldar Caves, the number of remains is small; we will, therefore, take into account the presence of taxa to explain our results.

The palynological analysis was based on 12 samples 6 from Gilvaran Cave and 6 from Kaldar Cave. Samples were treated following a modified Goeury and de Beaulieu (1979) methodology by Burjachs et al. (2003), including hydrochloric acid (HCl), followed by KOH digestion, concentration using Thoulet heavy liquid, and finally silicate removal with hydrofluoric acid (HF). Fossil pollen was identified using published keys and a modern pollen reference collection (Moore et al., 1991; Reille, 1992, 1992).

4. Results

Gilvaran Cave Level 4 (Upper Palaeolithic) yielded 30 charcoal fragments belonging to *Prunus* sp. Kaldar Cave yielded 30 charcoal fragments from two archaeological layers. Layer 5 yielded 17 fragments including *Prunus*, *Prunus* cf. *amygdalus*, *Salix* and a few undetermined fragments. The Middle Palaeolithic Layer 4 yielded 13 fragments showing the presence of *Prunus* and *Prunus* cf. *amygdalus*, as well as a few undetermined fragments (Table 1).

Table 1
Number of charcoal fragments from Kaldar and Gilvaran Caves.
Tableau 1
Nombre de fragments de charbon extraits des grottes de Kaldar et de Gilvaran.

	Kaldar		Gilvaran
Taxa	Layer 4	Layer 5	Level 4
Prunus	2	5	30
Prunus cf. *amygdalus*	5	1	
cf. *Prunus*		2	
Salix		2	
Angiosperm	3	2	
Undetermined	2	8	
Total	**13**	**17**	**30**

Prunus is the only recurring taxa in the results from the 60 remains from Kaldar and Gilvaran Caves. This genus includes different subgenera among which *Prunus* (e.g., *P. divaricata*, *P. spinosa*), *Amygdalus* (e.g., *A. fenzliana*, *A. communis*, *A. scoparia*), and *Cerasus* (e.g., *C. incana*, *C. mahaleb*) are the most common species in Iran. *Prunus* wood anatomy commonly shows a diffuse to semi-ring distribution of the pores in the transversal wood section (Schweingruber and Landolt, 2005). *Amygdalus* show a ring-porous distribution of vessels, whereas the wood of other types, such as *Cerasus* and *P. spinosa*, has diffuse porosity. Ray cells are uniseriate to 3- and 7-seriate depending on the species. Vessels show spiral thickenings with simple perforation plates. Three different types of *Prunus* can be regrouped according to the wood anatomy (Allué, 2016; Heinz and Barbaza, 1998; Ntinou, 2002). *Prunus* type 1 rays does not have more than 2 cells; *Prunus* type 2 contain between 3 and 4 cells per ray; and *Prunus* type 3 has more than 5 cells. Each type corresponds to different groups, for example type 1 includes *Prunus avium/padus* (cherry/European bird cherry), type 2 is *Prunus spinosa/mahaleb* (blackthorn/mahaleb cherry), and type 3 is *Prunus spinosa/amygdalus* (blackthorn/almond tree). Ntinou (2002) also uses three groupings according to the species currently present in Greece. Group I includes *P. armeriaca*, *P. dulcis*, *P. persica*, and *P. webbii*. When the

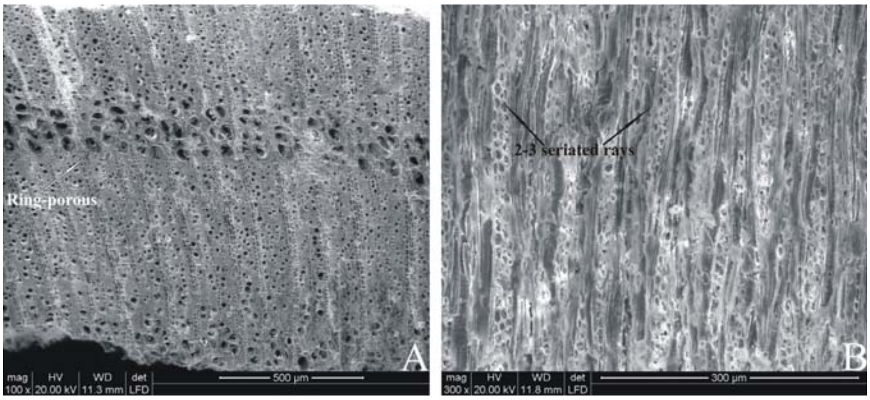

Fig. 4. A. Transversal section of *Prunus* cf. *amygdalus* from Kaldar showing a ring-porous Distribution. B. Tangential section of *Prunus* sp. showing 2 to 3 seriated ray cells.

Fig. 4. A. Section transversale de *Prunus* cf. *amygdalus* de Kaldar montrant une répartition annulaire poreuse. B. Section tangentielle de *Prunus* sp. montrant deux à trois cellules en rayon sérié.

rays were 7- or 8-seriated with ring-porous wood they were identified as *Prunus* cf. *amygdalus*. Group II with diffuse-porous wood and 2 to 7 cell rays (an average of 5) includes *P. domestica*, *P. padus*, *P. mahaleb*, *P. spinosa* and *P. cerasifera*. Group III with semi ring-porous wood to diffuse-porous wood and with 2 to 4 ray cells includes *P. avium* and *P. cerasus*.

The samples from Gilvaran are woods with a diffuse porosity distribution; 5 to 7 cells in rays, ruling out a possible identification as *Amygdalus* type. In contrast, some of the samples from Kaldar Cave have the anatomical characters of *P.* cf. *amygdalus*, showing ring porous wood (Fig. 4).

5. Discussion

The study of the charcoal remains from Kaldar and Gilvaran Caves shows the presence of *Prunus* and *Prunus* cf. *amygdalus* during the Middle and Upper Palaeolithic. This evidence, together with other palaeoenvironmental proxies (microvetebrates and macromammals) at Kaldar Cave, suggests temperate "interglacial" environmental conditions (Bazgir et al., 2017). The presence of *Salix* in both the anthracological and palynological records indicates that there were active water sources or flows, and steppe-like or open forests areas in which *Prunus* spp. could grow. Other data records from Kaldar Cave show the presence of herpetofauna, as well as macro and micromammals, suggesting open wooded areas and dry steppe areas indicating mild conditions. The poor palynological record from here shows, however, the presence of temperate taxa as *Corylus* or evergreen *Quercus*.

Species belonging to the genus *Prunus* are distributed among different plant communities in the Iranian region. They form the undergrowth of oak forests, the Pistachio-almond steppe, or stands in open areas (Heshmati, 2007). The Pistachio-almond steppe is present throughout the area and is characterised by dominance of *Pistacia* and *Amygdalus* cf. *scoparia*. This type of vegetation has been interpreted at the Qaleh Bozi Palaeolithic site as well, where two taxa were identified, *Salix/Populus* and *Pistacia*, underlining the presence of open steppe-forests and riverside formations (Biglari et al., 2009). Evidence from the early Holocene/early Neolithic suggests that Pistachio-almond vegetation was spread throughout Iran, Turkey and other neighbouring regions (Asouti, 2003; Miller, 2011). The evidence obtained from Gilvaran and Kaldar Caves shows the presence of two different taxa: *Prunus* cf. *amygdalus* and *Prunus* spp. According to the archaeological context, the charcoal remains belong to the anthropic assemblage that includes lithic and faunal remains. Despite of the lack of structured hearths, the scattered charcoal are probably related to the use of wood as fuel.

Evidence of *Prunus* in an archaeological context has been identified at a number of sites showing significant values during the Late Glacial (ca. 13–11 kyr BP) (Allué et al., 2010, 2012a; Bazile-Robert, 1980; Henry et al., 2013) (Fig. 5, Table 2). In earlier periods, the *Prunus* spp. communities were probably more important than assumed. The Azokh Cave layer II charcoal record, dated back to ca. 100 ka, shows high values (80%) of *Prunus*, mostly *P. spinosa*, and *P. mahaleb* types (Allué, 2016), and is interpreted as a pioneer vegetation succession or pre-forest formation in an open woodland. Several sites in Greece show the presence of *Prunus* (*Prunus* type *spinosa* group and *Prunus* cf. *amydalus*) and there were particularly high numbers of remains in Theopetra Cave from MIS 6 to MIS 3 (Ntinou and Kyparissi-Apostolika, 2016). The *Prunus* identified in that sequence belonged to the *P. spinosa*, *P. mahaleb* and *P. prostrata* types and the authors relate the dominance of *Prunus* and *Juniperus* to unstable climatic conditions in an open steppe-like environment (Ntinou and Kyparissi-Apostolika, 2016). In both sequences at Azokh and Theopetra, *Prunus* is interpreted as part of the pioneer vegetation in the glacial and interglacial vegetation cycles (Allué, 2016; Ntinou and Kyparissi-Apostolika, 2016).

Throughout MIS 3 and MIS 2, several western European records from Iberia, SE France, Italy and Greece show evidence of *Prunus* (Allué et al., 2007, 2012a, 2012b, 2017; Bazile-Robert, 1979; Bazile-Robert, 1980; Fiorentino and Parra, 2015; Maspero, 2004; Ntinou, 2002, 2010, 2016; Ros, 1987). According to these charcoal studies, *Prunus* was

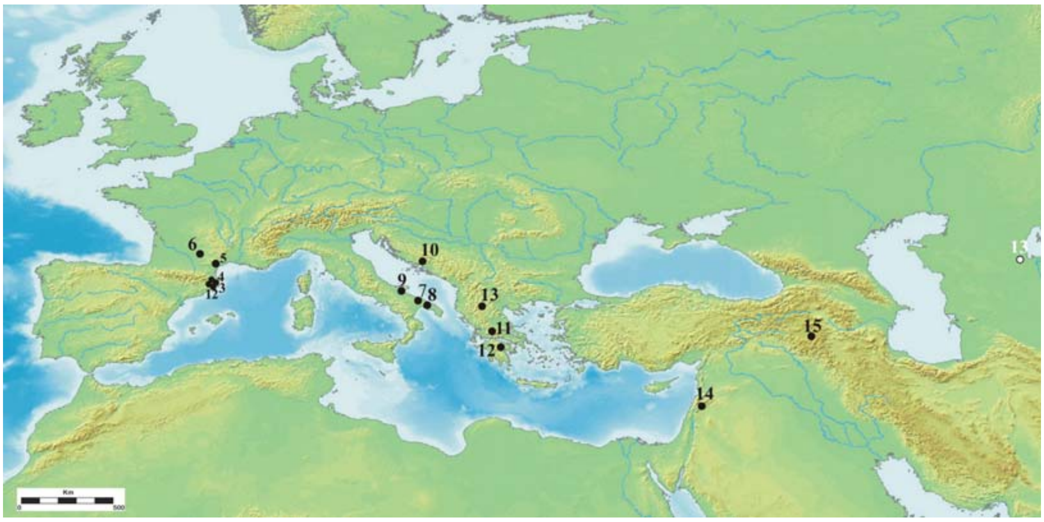

Fig. 5. Distribution of sites and areas mentioned in the discussion refering to *Prunus* anthracological evidences. (1) Balma del Gai; (2) Molí del Salt; (3) Arbreda; (4) Abric Romaní; (5) Salpetriere; (6) Coudoulous II; (7) Grotta delle Mura; (8) Grotta S. Maria D'Agnano; (9) Grotta Paglicci; (10) Konispol; (11) Klissoura; (12) Lakonis; (13) Theropestra Cave; (14) Manot Cave; (15) Azokh Cave. https://commons.wikimedia.org/wiki/Category:Maps_of_Eurasia#/media/File:Eurasian_mass.jpg User:Koba-chan, compiled by PHGCOM–Commons topographical maps File:Topographic30deg N0E60.png modified by E. Allué. Original license pages: https://en.wikiedia.org/wiki/Creative Commons.

Fig. 5. Distribution des sites et zones mentionnés dans la discussion se référant aux preuves anthracologiques de *Prunus*. (1) Balma del Gai ; (2) Moli del Salt ; (3) Arbreda ; (4) Abric Romani ; (5) Salêtriere ; (6) Coudoulous II ; (7) Grotta delle Mura ; (8) Grotta S. Maria D'Agnano ; (9) Grotta Paglicci ; (10) Konispol ; (11) Klissoura ; (12) Lakonis ; (13) grotte de Theropsetra ; (14) grotte de Manot ; (15) grotte d'Azokh. Source : voir légende en anglais.

present throughout MIS 3 and MIS 2 in Western Europe, but montane pine forests were the dominant arboreal cover. *Prunus* was increasingly represented in the woodlands during the Late Glacial and in general at the beginning of the Holocene, related to climatic improvement (Allué et al., 2012a, 2012b) (Fig. 5). Its increase is usually related to the development of pre-forest communities growing under milder climatic conditions. The good adaptation of the different *Prunus* species enabled them to resist cold and dry conditions, and they were pioneer plants during the Pleistocene glacial and interglacial cycles overall from Greece to western Asia. There was an important spread of this taxa during the Late Glacial and its archaeological remains are related to its use as fuel, as well as fruit gathering as food (Allué et al., 2012a; Filipović et al., 2010; Heinz and Barbaza, 1998; Henry et al., 2013). The presence of *Prunus* in the eastern Mediterranean and western Asia (Central Asia) might be also related to the development of open forests more adapted to cold and dry climates, lacking montane pine components. This fact might be linked to general biogeographical (e.g., Mediterranean peninsulas, mean altitudes of mountain ranges) and climatic conditions (higher precipitation rates in western Asia than in the Mediterranean peninsulas) in these different areas since the Pliocene, as part of the disjointed distribution of species between the different areas (Ribera and Blasco-Zumeta, 1998; Willis, 1996).

As mentioned earlier, the absence of *Prunus* in palynological sequences due to its entomophilous dispersal means it is difficult to obtain comparable records from continuous natural deposits. Palynological deposits from Iran show that during the last Pleniglacial and Late Glacial the dominant vegetation was characterised by steppe-forest with predominant herbaceous components including *Artemisia* and Chenopodiaceae (syn. Amaranthaceae) (Djamali et al., 2012). This vegetation is typical of open, dry steppe landscape with little arboreal cover. *Hippophae rhamnoides* spread throughout MIS 3, being the most significant arboreal cover along with riverside species (Djamali et al., 2012). In the case of Gilvaran Cave, all the samples analysed from Pleistocene levels were sterile.

The results of Kaldar Cave samples are slightly more decisive but insufficient to carry out a palaeoenvironmental reconstruction except in the samples related to the Holocene levels. Even so, in Level 4 there has been identified the presence of evergreen *Quercus*, *Corylus* and *Salix* in relation to the arboreal vegetation. The rest of the identified pollen spectrum corresponds to herbaceous plants among which there are wild grasses (Poaceae), Asteraceae, Apiaceae, Centaureae and hygrophytes Cyperaceae. At Level 5 only evergreen *Quercus* has been identified as representative of the arboreal stratum and the herbaceous plants identified are Poaceae, Asteraceae, and Apiaceae.

The palynological record from Kaldar, although very poor, suggests, however, that in these environments with mesic, thermophilous and riparian taxa; the presence of *Prunus* is consistent with this. Furthermore, according to Rajaei et al. (2013) the presence of *Gnofarmia*, a species of insect, during the Late Glacial Maximum indicates the presence of the host plants: *Prunus scoparia* and *Prunus felziliana*. Rajaei et al. (2013) also suggest that the presence of these host plants could indicate that the area acted

Table 2
Synthetical table of Lower to Upper Pleistocene sites with *Prunus* remains.
Tableau 2
Tableau synthétique des sites du Pléistocène inférieur à supérieur contenant des restes de *Prunus*.

MIS	Chronoculture	Name of the site	Location	Layer	Taxa	Values	Reference
MIS 2	Upper Paleolithic	Konispol	Albania	42–36	*Prunus* cf. *amygdalus*	80–100%	Ntinou and Kyparissi-Apostolika, 2016; Hansen, 2001; Ntinou and Kyparissi-Apostolika 2016; Hansen, 2001
		Theropestra cave	Greece		*Prunus* cf. *spinosa*	0–10%	
		Grotta Paglicci	Italy		*Prunus* cf. *amygdalus*	20–40%	Maspero, 2004
		Balma del Gai	Spain	I (140–150)	*Prunus*	10–30%	Allué, 2007
		Molí del Salt		Asup	*Prunus*	40–50%	Allué et al., 2010
				B1		10–30%	
				B2		10–30%	
		Salpetrière	France	107	*Prunus* cf. *amygdalus*, *Prunus*	< 1%	Bazile-Robert, 1980
MIS 3	Early Upper Paleolithic	Klissoura	Greece	IV	*Prunus* cf. *amygdalus*/*Prunus* cf. *spinosa*	50%	Ntinou, 2010
		Manot Cave	Israel	Areas A–G	*Prunus* cf. *amygdalus*	Presence	Barzilai et al., 2016
		Grotta Paglicci	Italy		*Prunus* cf. *amygdalus*	30%	Maspero, 2004
		Grotta S. Maria D'Agnano			*Prunoideae*	10–30%	Fiorentino and Parra, 2015
		Grotta delle Mura			*Prunus* cf. *spinosa*, *cf.maheleb*	20–40%	
		Arbreda	Spain	H I	*Prunus*	10–30%	Maroto, 1994
	Middle Paleolithic	Abric Romaní	Spain	M & O	*Prunus* sp.	< 1%	Allué et al., 2017
		Lakonis	Greece		*Prunus* sp.	Presence	Ntinou and Kyparissi-Apostolika, 2016; Panagopoulos, 2004; Ntinou and Kyparissi-Apostolika 2016
		Theropestra cave			*Prunus* cf. *spinosa*	60%	
MIS 4	Lower Paleolithic	Azokh	Nagorno-Karabagh	II	*Prunus*	80%	Allué, 2016
MIS 5		Coudoulous II	France	7a1, 7a2	*Prunus spinosa*	3–14%	Thery-Parisot et al., 2008
		Theropestra cave	Greece		*Prunus* cf. *spinosa*	0–5%	Ntinou and Kyparissi-Apostolika, 2016; Ntinou and Kyparissi-Apostolika 2016
MIS 5e						10–50%	
MIS 6-5	Lower Paleolithic					50–70%	

as a refuge during cold periods. Based on the data from Gilvaran and Kaldar Caves, the presence of *Prunus* could be tracked to earlier periods and confirm the presence of these taxa during the Pleistocene. The precise dating at Kaldar cave was carried out using *Prunus* and *Prunus* cf. *amygdalus* fragments, demonstrating their presence in MIS 3.

The most complete palynological sequence from Lake Urmia indicates that in the north-western part of Iran, the last glacial landscape was dominated by *Artemisa*, Chenopodiaceae (syn. Amaranthaceae), and other steppe grasses. There was more arboreal cover than in previous glacial periods and this was characterised by higher numbers of *Hippophae rhamnoides* (Djamali et al., 2008). According to these authors, winter temperatures were lower than today and there was very little arboreal cover (Djamali et al., 2008; van Zeist, 1967). Data obtained from the Damavand volcano (northern Iran) also suggests steppe-like vegetation in the Late Glacial; however, the increase of tree taxa in several samples suggests the occurrence of some wetter periods (Sharma et al., 2014). The presence of at least two species from the genus *Prunus* and the presence of *Salix* in Kaldar and Gilvaran Caves suggest that there was arboreal tree cover during the interstadial periods in the Late Glacial. Additionally, the palaeoecological evidence from palynological record, including the presence of *Corylus*, evergreen *Quercus*, *Salix* and Cyperaceae, among other taxa, and from micromammals (*Microtus* gr. *socialis*, *Ellobius* cf. *lutescens*, *Ellobius* sp., *Meriones* spp., *Apodemus* cf. *flavicollis* among others) and macro-mammals (*Sus scrofa*, *Capreolus*, *Cervus elaphus* among others) from Kaldar Cave, supports this interpretation of interstadial conditions (Bazgir et al., 2017).

Taking into account the older dates obtained for the modern human occupation at Kaldar Cave and adding the charcoal evidence to the other cultural remains recovered from this locality, we are able to assess an important climatic moment that provides information for reconstructing the relationship between the environment and human occupation in this region. The dates obtained from the lower part of the Upper Palaeolithic sequence at Kaldar Cave are among the oldest attributed to a lithic industry that traditionally has been associated with anatomically modern humans (AMHs) in western Asia (Goring-Morris and Belfer-Cohen, 2003; Otte et al., 2012; Mellars, 2006). From an archaeological and anthropological point of view, the timing of modern human emergence and demise of the Neanderthals has been always a pivotal issue. Moreover, data on the climatic conditions during this crucial moment necessary data to the understanding the role of humans and their relationship with the surrounding environment. Therefore, enlarging the datasets, along with the high potential of the Palaeolithic deposits in the region, would certainly provide a great opportunity to better understand human occupation and adaptation in this region and beyond.

6. Conclusions

The identification of charcoal remains of *Prunus* from Kaldar and Gilvaran Caves shows that these trees and shrubs were probably important in the environment even during climatically cold periods. The wooded vegetation was probably characteristic of an open steppe. These results and the results obtained using other proxies from the sites excavated in the Khorramabad Valley, allow us to identify this area as a suitable region where resources were available and in which humans were probably well adapted. Charcoal evidence from Palaeolithic sites is generally scarce; hence, new evidence is always important to enlarge the datasets for the study of past vegetation and plant use. Therein lies the importance of the well-dated Kaldar Cave–a key archaeological site–in the region where there are large number of caves and rock shelters that could strength these datasets for understanding more about Neanderthals and early modern human occupation in respect to their adaptation with climatic condition from further studies.

Acknowledgments

We would like to thank director of RICHT and former director of ICAR (Seyed Mohamad Behesti and Hamide Choubak for their support and issuing us the necessary permission for conducting excavation. We also thank the current director of ICAR (Dr. Behrooz Omrani) for extending the permission of recovered material from the excavation at Khorramabad sites to continue our remaining analysis. We appreciate all the efforts by the head of International Ties and Collaboration of RICHT (Ms. Monir Kholghi) for organizing the related International issues. This research is conducted in the framework of a signed scientific agreement between RICHT and IPHES. This research was developed within the framework of various projects from the Spanish Government MINECO/FEDER (CGL2015-65387-C3-1-P) MINECO (HAR2016-76760-C3-1-P), Generalitat de Catalunya (SGR2017-836, SGR2017-1040 and CERCA Programme), and URV (2014/2015/2016PFR-URV-B2-17). B. Bazgir is the beneficiary of a Fundación Atapuerca doctoral fellowship. L. Tumung is the beneficiary of a PhD scholarship founded under the Erasmus Mundus Programme–International Doctorate in Quaternary and Prehistory.

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2.6. The Iranian Zagros Mountains and its Paleolithic sites

The Iranian Zagros Mountains stretches from northwest to Strait of Hormuz, forming a continuous range with numerous peaks over 3000 and 4000 m above sea level. The crust is essentially made up of non-volcanic sedimentary rocks. The Zagros Mountains consist of two parallel geological zones: the highland and the folded zones (see Heydari 2007). The Paleolithic investigation in the Iranian Zagros regions started during the 1920s, when some scattered Paleolithic field survey happened in Mazandaran province (de Morgan, 1907) and Fars Province (Field 1939); as well a small test pit in Kunji cave, Khorramabad Valley (Field 1939). In 1949, the first actual excavation was done by S. Coon followed by Braidwood in the Iranian Zagros Mountains. The Lower Palaeolithic sites of Iran are mostly concentrated in the northwestern part of Iran (Gilan and Lorestan province), and most of the assemblages interpretations are made on the basis of field survey. On the contrary, the Middle and Upper Palaeolithic sites are widely excavated by the Iranian and foreign researchers to understand the MP-UP transition as well as the technological similarities and differences of Aurignacian culture in Iran. The two important regions in Iranian Zagros for some of the famous Middle and Upper Paleolithic sites are: i) Kermanshah Region and ii) Khorramabad Valley. There are also few scattered studies in the central and Fars region of Iran. All the important Paleolithic sites of the Iranian Zagros has been described below except for the ones which are already have been explained in our 2017 article (Publication 4: Becerra-Valdivia 2017 and publication 5: Bazgir et al. 2014, 2017).

Chronoculture	Location	Name of the sites	Discovered by Researcher's	Field survey	Excavation	Chronology	Dating method	Human Remains	Tool typology	Functional analysis	Refernces
Lower Palaeolithic	Khorasan	Kashaf roud Basin	Ariai, Thibault	1974-75	No	<800,000		NO	Oldowan	NO	Ariai, Thibault 1975; Biglari and Shidrang 2006
	Western Albroz	Ganj par	Biglari and Heydari	2002	No	No radiometric dates		NO	Caucaus Achuelian	NO	Biglari, Heydari, and Shidrang 2004; Biglari and Shidrang 2006
		Darband cave	Jahani	2005	No	Late middle pleistocene	U series dating	NO	Achuelian	NO	Biglari and Shidrang 2006; Baiglari et.al. 2007; Biglari and Jahani 2012
	Ilam provence	Shiwatoo	S. Alipour	2004	NO	No radiometric dates		NO	Achuelian	NO	Jaubert et al. 2004, 2006; Biglari and Shidrang 2006
		Mar Gwergalan cave	Mortensen	1974		No radiometric dates		NO	Achuelian	No	Mortensen 1974b, 1993, 1975; Dovoudi et al 2015
	Kermenshah Province	Gakiah cave	Braidwood	1959-60	NO	No radiometric dates			Achuelian	No	Braidwood 1960; Singer and Wymer 1978; Biglari and Shidrang 2006
		Pal Barik	Mortensen	1974		No radiometric dates		No	Achuelian	No	Mortensen 1993; Biglari and Shidrang 2006
		Amar Merdeg	Biglari, Nokandeh, and Heydari	1999	No	No radiometric dates		No	Achuelian	No	Biglari, Nokandeh, and Heydari (2000)
Middle Palaeolithic		Bisitun Cave (Hunter´s cave)+B3:K14	Carleton S. Coon	1949	1949	No radiometric dates		1 radius	Zagros Mousterian	NO	Coon 1951; Dibble 1984; Lindly 2005; trinkaus and Biglari 2006
		Warwasi Rockshelter	Bruce Howe,	1969, 1978,	1960	No radiometric dates		NO	Mousterian, Baradostain, Zarzian	NO	Braidwood 1960; Braidwood and Howe, 1960; Braidwood et. al.1961; Olszewski, 1993a, b, 2001, 2007a, b; Olszewski and Dibble, 1994; Olszewski; Tsanova 2013
		Kobeh Cave	Bruce Howe,	1959	1959	No radiometric dates		NO	Zagros Mousterian	NO	Marean 1998; Marean and Kim, 1998; Becerra-Valdavia, 2017
		Eshkaft-e Gavi Cave	Rosenberg,	Sumner 1969	1978	18,000 to >28,000 years BP		4 individual (10 craniodental and postcranial specimens) Possibly AHM, Possible canabilism evidences.	Mousterian, Baradostain	NO	Scott and Marean 2009; Rosenberg 1985
		Mar Tarik	Bigalri	2000	2004	U7Th 123,6 [+3,4/-3,2] kyr BP	TH/U Dating	9 teeth, 7 cranial fragments and 7 infra-cranial skeleton. Neandertahl or AMH ??	Mousterian	NO	Biglari 2000; Jaubert et al., 2005
	Khorra mabad	Kunji Cave	Henry Field; Hole and Flannery; John D. Speth	1939	1951; 1963; 1969	40,000 years BP		NO	Zagros Mousterian	NO	Field, 1939; Hole and Flannery 1967; Speth,1971; Baumler and Speth, 1993

		Gar Arjeneh Cave	Hole and Flannery; Bazgir	1963, 2009	1963; 2011-12	No radiometric dates		NO	Mousterian, Baradostain, Zarzian	YES	Hole and Flannery 1967; Bazgir et.al 2014
		Ghamari Cave	Hole and Flannery; Bazgir	2009	1963; 2011-12	No radiometric dates		NO	Levallios, Mousterian Baradostain	YES	Hole and Flannery 1967; Vadhati Nassab 2011; Bazgir et.al 2014
		Gilvaran Cave	Hole and Flannery; Bazgir	2002, 2004, 2009	2011-12	No radiometric dates		NO	Levallios, Mousterian Baradostain	YES	Vadhati Nassab 2011; Bazgir et.al 2014
		Kaldar Cave	Bazgir	2007, 2009	Bazgir 2011-12 and 2014-15	54,400 years BP	C14 dating	NO	Levallios, Mousterian Baradostain	YES	Bazgir et.al.2014, 2017; Becerra-Valdivia, 2017; Allué et.al 2017; Tumung et.al. 2018
		Houmian1	McBurney	1979	1979	Th/U 148000 ± 35000 BP	Th/U dating	NO	Zagros Mousterian	NO	McBurney 1969, 1970; Bewley 1980, 1984; Mercier and Valladas 1994; VahdatiNasab 2013
	Isfahan, Iran	Qaleh Bozi Rockshelter	Yazdi; Biglari	2004	2004, 2005, 2008	No radiometric dates		NO	Levallios, Zagros Mousterian	YES	Elhami *et al.* 2004; Javeri *et al.* 2004; Biglari et.al. Claud et.al 2012
	fars Province, Iram	Eshkaft-e Gavi burmishur Cave	Rosenberg	Sumner 1969	1978	18-3000 BP	C14 dating	NO	Mousterian	NO	Vadhati Nassab 2011
Upper Palaeolithic	Khorramabad	Pa sangar Rockshelter	Hole and Flannery	1963	1963	No radiometric dates		NO	Baradostain, Zarzian	NO	Hole and Flannery 1963 personnal notes; Shidrang 2007a
		Yafteh Cave	Hole and Flannery; Otte and shidrang	1963	1963; 2005-2007	35,000 years BP	C14 dating	NO	Baradostain, Zarzian	NO	Hole and Flannery 1968; Otte and Kozłowski, 2004, 2009; Otte et al., 2007, 2011, 2012; Shidrang, 2007a and 2007b; Mashkour et.al 2009; Bordes and Shidrang 2009, 2012 Zwyn et.al 2012; Becerra-Valdavia, 2017
	Kermanshah	Wezmeh Cave	K. Abdi	1999	2001	20-25 k BP	Gamma Spectroscopy dating	Premolar		NO	Abdi et.al 2002; Mazkour et.al. 2008; Trinkaus et.al 2008; Djamali 2011; Vahdatinassab 2011
	Dasht-e rostam-Basht, Iran	Gar-e Boof Cave	Conard	2004	2006-07	40,000 cal BP	C14 dating	NO	Rostamian	NO	Ghasidian 2010; Conard and Ghasidian 2011, 2014; Conard et.al 2013; Heydari

Table 2.2: Showing the details of the important sites in the Zagros Mountains

2.6.1. Kermanshah Region

Kermanshah is situated in (76°34.31 N, 47.08.69°E) is located 525 kilometres (326 miles) from Tehran in the western part of Iran. In 1949, did the first field expedition around and excavated Bisitun, Tam Tama sites belonging to (Coon 1951). The sites of this region have shown few humans remained identified (Trinkaus and Biglari 2006; Trinkaus et al. 2007; Scott and Marean 2011). All the important sites are shown in the (fig. 2.3 and 2.4).

2.6.1.1. Lower Palaeolithic

2.6.1.1.1. Gakia Cave

Gakia is located 10 km East-southeast of Kermanshah at 1260 a.s.l. Near Qara Su River. Braidwood and his team first discovered the site during their field survey in 1959-60. A biface was found with numerous flakes and cores which were assigned to later periods based on their techno-typological characteristics (Singer and Wymer 1978). In 1997 field survey Biglari and Heydari, they reported of various Middle Paleolithic lithic artefacts. In 2006, Biglari found the chert outcrop of the Gakia is 25 km and also found two bifaces along with other Middle Paleolithic artefacts such as Levallois cores and debitage.

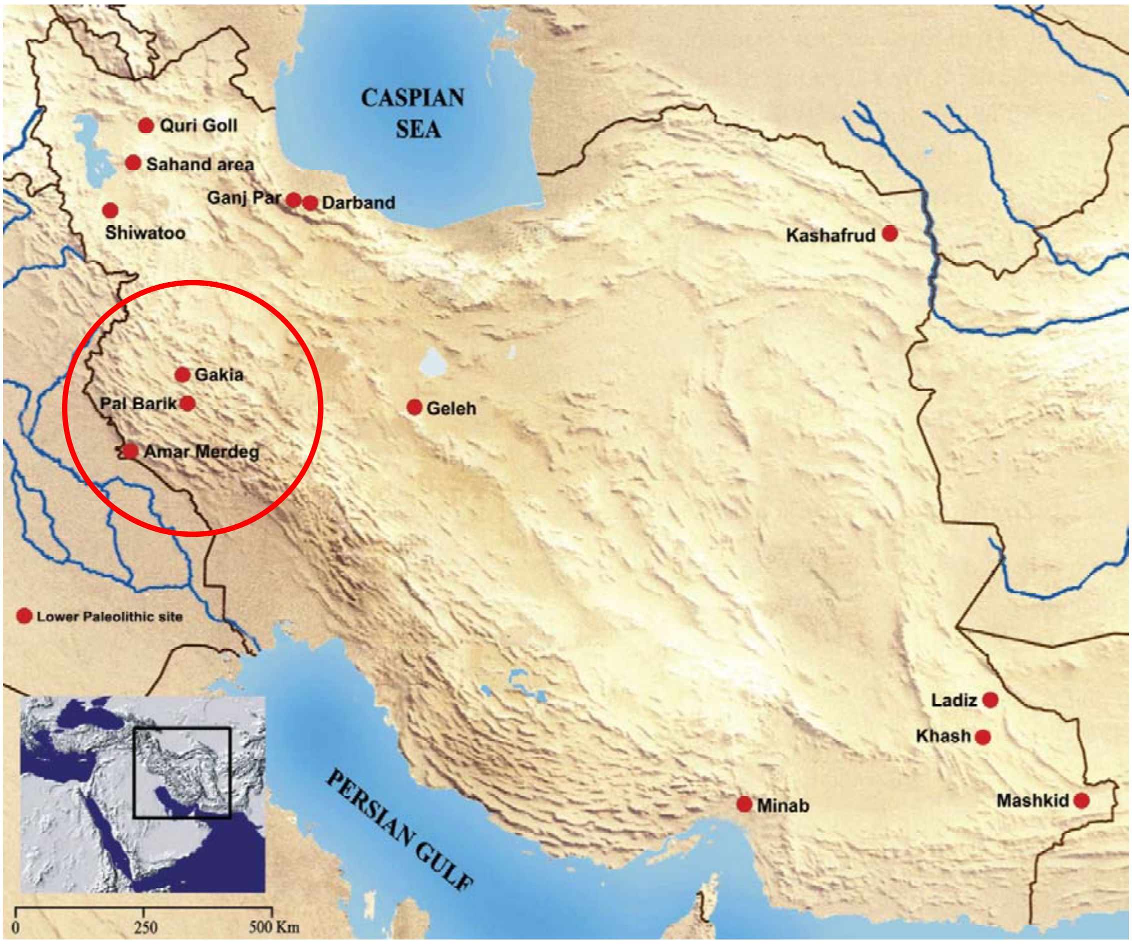

Figure 2.3: Map indicates the distribution of known Lower Paleolithic localities (indicated in red circle) in Kermanshah province, Iran. (Courtesy of Biglari and Shidrang 2006) (Blank topographic map of Iran after Deutschen Bergbau-Museums Bochum 2004, with some modifications.)

2.6.1.1.2. Amar Merdeg

This site is located 150 km southwest of Gakia Cave at 200-300 asl. In 1999 Biglari and his team discovered this site. These assemblages consisted of only core-choppers, flake tools, and large numbers of tested cobbles, cores, and cortical debitage. Additional fieldwork in 2001 and 2004 resulted in the discovery of four bifaces and partial bifaces, some Levallois cores and debitage, and more core-choppers. Chert, sandstone, and quartzite cobbles were the most commonly used raw materials (Biglari et al. 2000). Handaxe of Amar Merdeg resembles most closely the illustrated handaxe from Barda Balka in Iraqi Kurdistan at the western foothills of the Zagros (Wright and Howe 1951).

2.6.1.1.3. Pal barik

The site is situated in Halailan Valley on a flat hilltop overlooking the Saimareh River valley, at an altitude of about 975 meters above sea level. It was discovered by Mortensen in an area of approximately 50 × 80 meters, he collected a total of eighty-nine heavily patinated artifacts. The assemblage consisted of a relatively small subtriangular biface; large numbers of core choppers; unipolar, discoid, multiple and irregular cores; retouched tools such as side and end scrapers; notched, denticulated, and other debitages (Mortensen 1993). An additional small biface was found about one kilometer to the southwest of Pal Barik. This core-like biface is biconvex in cross-section and has a twisted profile.

According to Brookes, who studied the geomorphology of the Holailan valley, these pediments probably predate the last interglacial (Mortensen 1993). Thus, the site may date back to the last interglacial, or somewhat later. As for the Minab and probably the Sarhad localities, the age proposed by Mortensen for Pal Barik is within the early Middle Paleolithic time range.

2.6.1.2 Middle and Upper Palaeolithic

a b

Figure 2.4: a) Kermanshah province (shown in red) b) Map of Kermanshah province showing the Middle and Upper Palaeolothic sites (Courtesy of Shidrang 2016)

2.6.1.2.1. Bisitun Cave

Bisitun Cave (also called "Hunter's Cave") is located near the small town of Bisitun (34° 23' 25" N, 47° 26' 13" E) at an altitude of *ca* 1,300 m. It is about 30 km east-north-east of the city of Kermanshah in the Kermanshah province of central western Iran. It is a small cave within the large and prominent rock on which the Darius I inscription is to be found. In

1949 Coon (1951) excavated this site and he recognized a surface (mixed historic) level, a thin post-Pleistocene level with ceramics and other remains pressed into the underlying deposits, and then a continuous but varying through its depth Late Pleistocene deposit (Trinkaus and Biglari, 2006). In this excavation, he also discovered human remains (1 incisor and 1 radius) (Coon 1951, 1953, 1957, 1962, 1975) which, later analysed by Trinkaus (Trinkaus and Biglari, 2006).

2.6.1.2.2. Ghar-e-Khar

Ghar-e-Khar Cave is situated in the southeastern ridge of Bisotun Mountain (34° 24′00.52″ N, 47°26′27.41″ E) Central Zagros in Kermanshah Province. It is located at an elevation of 1420 m a.s.l., opens southwards, and faces the green corridor of the Gamasiab river valley. The Cave is long and relatively narrow, about 27 m in length and with an average width of 6 m. This cave was first discovered by Carleton S. Coon in 1949, followed by a later prehistoric survey by Philip E.L. Smith and T. Cuyler Young between 1964 and 1965.

In 1965, they excavated a 1 × 2 m test-trench near the entrance of Khar Cave, which proceeded in 10-to-30-cm arbitrary levels, and reached a depth of 5 m below the current surface of the cave. This trial-trench did not reach bedrock but revealed the promising potential of the site by uncovering a sequence beginning from the Late Middle Paleolithic and through the Epipaleolithic and later periods (Smith, 1986; Young and Smith; 1966). The lithic assemblage was studied for techno typology by Shidrang (et al. 2016), and they concluded that the study material is insufficient to fully confirm or deny the hypothesis of M-UP transition in Zagros (Shidrand et al. 2016).

2.6.1.2.3. Mar Tarik

This cave is located in Kermanshah, in between the two caves of Bisotun massif already known in the past (Hunter’s Cave and Ghar-e Khar: Coon 1951, Young and Smith 1966). This was discovered in 1986 (Biglari 2000) and later excavated by the French-Iranian team in 2004 (Jaubert *et al*., 2009). U/TH dating method was applied for this site which gave the date of 123,6 [+3,4/-3,2] Kyr BP. In the excavation, along with the lithic and faunal remains, they also discovered human remains and a limestone slab with engravings. This limestone engraved slab was discovered in the mixed sediments of Mar Tarik, but they believe it to belonging to the Middle Palaeolithic occupation. Human remains of this site is discussed above in 2.4 section.

2.6.1.2.4. Warwasi Rock shelter

It is situated above the Tang-i-knisht Valley in the Zagros Mountains, about 11 km from Baktaran in Iran. In the 1950s and 1960s, Warwasi was excavated as part of Robert Braidwood's extensive archaeological research in the eastern end of the Fertile Crescent (Braidwood and Howe 1960; Braidwood et al. 1960). Its Upper Paleolithic deposits comprise approximately 2.2 m of the 5.6 m deep trench. The site contains a rich archaeological sequence from Middle Paleolithic to late Epipaleolithic. They are overlain by Epipaleolithic (Zarzian) occupations and underlain by Middle Paleolithic (Zagros Mousterian) deposits is a Paleolithic rock shelter site located at north of Kermanshah in western Iran. The Upper Paleolithic assemblage studies shows the close affinity to Aurignacian tool type (Olsweski and Dibble 1994, 2006)

2.6.1.2.5. Kobeh Cave

Details of the site are mentioned in Publication 1 (Becerra et al. 2018)

2.6.1.2.6. Wezmeh Cave

Wezmeh Cave is located at 34º03'20''N and 46º38'52'' E, about 12 km southeast of the town of Islamabad-e Gharb and 3.5 km northeast of the village of Tajar-e Akbar. The cave is 27 m long, 2 m wide and 1.2 m high and has about 45 m2 of floor area at an elevation of 1430 m a.s.l, Wezmeh Cave is almost horizontal, formed between geological layers of karstic limestone.

The cave was discovered in 1999, during an archaeological survey of the Islamabad Plain when it was realised that part of the cave's contents at the rear chamber had been displaced onto the slope in 1995 by local people looking for artefacts (Abdi et al., 2002). The survey discovered Early and Middle Chalcolithic material mixed with a large mammal fauna and some human remains. In light of these findings, in 2001 a short field season was undertaken, during which faunal remains out of context were collected from the exterior slope, a 3 x 3 m2 trench was excavated to bedrock on the terrace immediately outside of the cave entrance, and six test pits at 2-m intervals were dug to bedrock within the cave (Trinkaus et al. 2007). The excavated trench and other small test pits yielded Chalcolithic material consisting of sherds, two flint blades, beads, bone tools, and some faunal remains.

The faunal remains of the site is particularly rich in carnivore remains, hence also known as carnivore den (Mashkour et al. 2009a).

2.6.2. Khorrambad Valley

Khorramabad Valley is situated in the central heights of Lorestan Province in western Iran and stretches from northern highlands to the southern lowlands of Khuzistan which also constitutes one of the crucial passage-ways for both humans and animals to cross the Zagros Mountain range (Bazgir et al. 2014). It also comes within the border of the Palearctic and Saharan-Arabian biogeographic realms and not very far away from the Oriental realm (Holt et al., 2013).

The presence of abundant of the water reservoir, plants animals and numerous caves and rock shelters around the valley makes it a very favourable place to live. The palaeoenvironment study of the area shows that the area was very suitable for humans and must have played a significant role in the dispersal of the humans during Quaternary (Bazgir et al. 2014, 2017 and Mashkour et al. 2009a, 2009b). The palaeo-environmental study through zooarchaeological evidence in the archaeological site of Kaldar Cave proves that the early AMHs of the area not only lived with the large Palearctic mammals but also knew how to exploit them as resources (Bazgir et al. 2017: p 4-7). For this reason, the valley comes under the UNESCO World Heritage Convention Concerning the Protection of the World Cultural and Natural Heritage.

Since the 1930´s till now, Khorramabad Valley has gained a lot of interest initially by the foreign archaeologists later by the joint Iranian and international archaeologists. In the valley number of Palaeolithic sites has been reported in the form of caves and rock shelters. Among the caves, the most important are Kunji, Ghamari, Yafteh, Pa Sangar, Gilvaran, Kaldar and the only one Rock Shelter studied up to date is Gar Arjeneh. Henry Field (1939) was the first to excavate in the valley by excavating a small test pit in Kunji Cave. Later during the 1960's, Kunji Cave was again re-excavated by Hole and Flannery (1967) and Speth (1969). In 1964-65, Hole and Flannery (1967) along with Kunji also excavated three more cave sites (Ghamari, Pa Sangar, Yafteh) and Gar Arjeneh Rock shelter. After a long gap, Yafteh Cave was again re-excavated by Iran-Belgium team in 2005-2008 (Otte et al. 2007; Shidrang 2007). In 2012, Indo-Iranian team test-excavated Ghamari, Gilvaran, Kaldar Cave and Gar Arjeneh Rock Shelter (Bazgir et al. 2014). Most of these sites are located on the east, west, and south part of the valley except for Kaldar Cave which was excavated in larger scale by Iranian-Spanish team in 2014 to re-evaluate the Palaeolithic cultural materials to trace the transition from Middle to Upper Palaeolithic and also to obtain reliable dating (Bazgir et.al.2017).

Few important studies about these Palaeolithic sites related to their field survey (Field 1939, 1951a, 1951b; Jaubert et.al. 2005; Roustaei, 2002, 2004; VahdatiNasab 2004, 2010), excavation reports (Bazgir et.al. 2014, 2017, Hole and Flannery, 1967; Speth,1971; Otte et al. 2007), faunal and floral remains (Allué et.al 2017; Mashkour et.al 2009a, 2009b), dating problems (Becerra-Valdivia et.al. 2017, Otte et. al. 2011) and lithic techno-typology studies (Baumler and Speth, 1993; Bordes and Shidrang, 2012; Otte and Kozlowski, 2007; Otte et.al., 2007; Shidrang, 2007; Tsanova, 2013) have been published. Most of these works were mainly focused on understanding the Middle and Upper Palaeolithic transition, the Aurignacian culture of Zagros Mountains, the Baradostain culture of Iranian Zagros, the chronology of the region and the modern human dispersal from western Asia into Europe.

Khorramabad Valley, situated in the heart of Lorestan at an elevation between 1210 and 1280 m (4000-4200), the well-watered Khorramabad Valley is somewhat T-shaped with its longest dimension oriented NW-SE. The long axis is about 28 km and averages about 8 km wide. Entering from North and exiting through the west is the Khorramabad which receives most of its water from the large freshwater spring that issue from the Sefid Kuh mountain on the west side of the valley. Another river, flowing intermittently over a wide gravel bed, runs east-west joining the Ab-i-Khorramabad roughly in the centre of the valley. Frank Hole and Flannery did his survey during 1963-65 and found 14 village sites and at least 15 caves or rock shelters.

2.6.2.1. Middle Palaeolithic and Upper Palaeolithic

2.6.2.1.1 Kunji Cave

It is situated 1300 m above sea level with the entrance facing the west and is 18 m wide, 4 m high. This site was the first site discovered by Henry Field in 1939 and dug a small test pit (in Iran Paleolithic it was the first site to be test excavated as well as in Lorestan province). Later in 1963, Hole and Flannery's test excavated this site along with four other sites which later got published in 1967 report. The test excavation revealed the potential of the site with the radio carbon dates of 40,000 BP. During 1969, a large excavation was conducted by John D. Speth for his doctoral thesis dissertation. Speth in his excavation encountered a very disturbed stratigraphy due to the rodents and porcupine intrusions. The lithic assemblage shows the presence of Mousterian stone tools. In the present day, the site is not suitable for excavation as locals use it as sheep pen.

2.6.2.1.2 Gilvaran Cave

Details of the site mentioned in Publications 2 and 3 (Allué et al. 2018; Bazgir et.al. 2014).

2.6.2.1.3 Ghamari Cave

Details of the site mentioned in Publication 3 (Bazgir et.al. 2014).

2.6.2.1.4 GarArjeneh Rock shelter

Details of the site mentioned in Publication 3 (Bazgir et.al. 2014).

2.6.2.1.5 Kaldar Cave

Details of the site mentioned in Publication 1, 2, 3 and 4 (Becerra et.al. 2017; Allué et al. 2018, Bazgir et.al. 2014, 2017).

2.6.2.1.6. Yafteh Cave

Details of the site mentioned in Publication 1 (Becerra et al. 2017).

2.6.2.1.7. Pa Sangar Rock Shelter

Hole and Flannery discovered this rock shelter in 1961 field survey and test excavated in 1963 along with four other sites. The cave is located in the west side of the Valley next to the Ghamari Cave on the Sefid Kuh mountain ridge. The cave overlooked an east-west running enclave of the valley and was cut by a tributary to the mainstream, the Ab-i-Khorramabad which runs roughly north-south at this point. The shelter is formed by the abrupt turning of this portion of the ridge from east-west to north-south. The west end is about 6 meters long, after which the ridge again turns east-west. Three adjacent rectangles trenches of 2x3 m area were excavated in the west, a central and eastern portion of the rock shelter and considered as three separate excavations. Hole found that stratigraphy of the site is very monotonous the upper layer very dry and lower layer very moist. The Upper Palaeolithic level is with no stratigraphy or chronology gap. Perhaps the chronology of the lithics showed that the two levels are Borodostain and later is Zarzian**.** Hole concluded in his 1963 draft, that "*the site was not good for the shelter when first occupied as the rock forms were very irregular and had little room to sit*". In 2010, Bazgir in his field survey visited the site and concluded that the site is not in an excellent condition to excavate and not having that much of potential as the other sites of the Khorramabad Valley.

2.6.2.1.8. Publication 3: Bazgir, B., Otte M., **Tumung L.,** Ollé A., Deo S. G., Joglekar P., Manuel López-García J., Picin A., Dadoudi D., Van der Made J., 2014. Test excavations and initial results at the Middle and Upper Paleolithic sites of Gilvaran, Kaldar, Ghamari caves and Gar ArjeneRockshelter, Khorramabad Valley, western Iran. *CR Palevol*. 13, 511–525.

This article explains about the sites history and 2011-12 test excavation results. Here we discuss excavation methods, sites stratigraphies, multidisciplinary approach (lithic technology, taphonomy, palaeontology, anthropology, micromammals as well as various dating method employed) to understand the site assemblage.

C. R. Palevol 13 (2014) 511–525

Contents lists available at ScienceDirect

Comptes Rendus Palevol

www.sciencedirect.com

Human palaeontology and prehistory

Test excavations and initial results at the Middle and Upper Paleolithic sites of Gilvaran, Kaldar, Ghamari caves and Gar Arjene Rockshelter, Khorramabad Valley, western Iran

Sondages et premiers résultats acquis sur les sites paléolithiques de la vallée de Khorramabad, Iran occidental : Gilvaran, Kaldar, Ghamari, Gar Arjeneh

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ARTICLE INFO

Article history:
Received 12 July 2013
Accepted after revision 28 January 2014
Available online 17 April 2014

Handled by Michel Laurin

Keywords:
Middle and Upper Paleolithic
Gilvaran Cave
Kaldar Cave
Ghamari Cave
Gar Arjeneh Rockshelter
Khorramabad Valley
Western Iran

ABSTRACT

This paper introduces the excavations in several Paleolithic sites in the Khorramabad Valley, Western Iran. Apart from the two well-known sites of Ghamari Cave and Gar Arjene rock shelter, first excavated by Frank Hole and Kent Flannery in the 1960s, the Gilvaran and Kaldar caves were excavated for the first time. Here we present the stratigraphy of these sites, general data from the lithic assemblages, and the identifications of a small part of the faunal remains. Preliminary results are showing that all of the sites were occupied from the Middle and Upper Paleolithic onward, and therefore provide great potential for the study of the transition between these cultural periods. Our preliminary techno-typological observations show that the lower levels of the Gilvaran and Ghamari sequences may represent an early phase of the Middle Paleolithic.

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http://dx.doi.org/10.1016/j.crpv.2014.01.005
1631-0683/

R É S U M É

Ce texte résume les résultats de fouilles paléolithiques menées par une équipe internationale dans différents sites de la vallée de Khorramabad, en Iran occidental. Les sites de Ghamari et Arjeneh ont, à l'origine, été fouillés par Frank Hole et Kent Flannery dans les années 1960. Ceux de Gilvaran et Kaldar ont été explorés pour la première fois par notre équipe. Nous présentons la stratigraphie ainsi que des données générales et les résultats quantitatifs obtenus pour l'essentiel des composantes lithiques ; l'identification préliminaire de la faune est aussi fournie. Ces résultats provisoires montrent que tous ces sites ont été occupés durant le Paléolithique moyen et supérieur. Ils fournissent ainsi un puissant potentiel pour l'analyse des processus de transition entre ces phases culturelles. Des échantillons ont été prélevés aux différents sites, afin d'y établir une séquence chronologique. Les études techniques et typologiques montrent que les phases anciennes de Gilvaran et de Ghamari appartiennent au Paléolithique moyen.

Mots clés :
Paléolithique moyen
Paléolithique supérieur
Grottes de Gilvaran
Kaldar et Ghamari
Abri d'Arjeneh
Vallée de Khorramabad
Iran occidental

1. Introduction

Recent research in paleoanthropology underscores the importance of Southwest Asia for the evolution of hominins and their dispersal to other regions (Hughes et al., 2007; Martinón-Torres et al., 2007). Its geographic position as a crossroad between Africa, Europe and eastern Asia plays a strategic role in the understanding of the biological developments of different human lineages and of the spread of different knapping technologies (Bermúdez de Castro and Martinón-Torres, 2013). Consequently, SW Asia, including Iran, certainly played an important role in Paleolithic cultural development. However, the patchy distribution of archaeological evidence and the diverse local research traditions entail some differences within these territories. The Zagros Mountains are a key area to disentangle the events that mostly marked the archaeological record of the Late Pleistocene.

The spread of techno-complexes of blades/bladelets associated with Anatomically Modern Humans across Eurasia is documented at 45–40 kyr before present (Goring-Morris and Belfer-Cohen, 2003; Mellars, 2006). This technological innovation was accompanied by other cultural novelties such as portable art, graphic representations, musical instruments and bone projectiles (Bar-Yosef and Zilhão, 2006; Conard, 2003; Conard et al., 2009). In the same chronological interval, Neanderthals, who lived in an area that extended from the Iberian Peninsula to Siberia, suddenly disappeared. Several hypotheses have been advanced but the causes that led to the Neanderthal extinction are still debated (Lowe et al., 2012; Tzedakis et al., 2007; Valet and Valladas, 2010; Wolff and Greenwood, 2010). In this scenario, tracing where these blade/bladelets industries developed is crucial to figure out the patterns of dispersal of Anatomically Modern Humans, the possible interaction with Neanderthals and the causes of their disappearance.

In the central Zagros, several sites document the presence of blade/bladelet assemblages, the oldest one named Baradostian (Garrod, 1937) and a younger one indicated as Zagros Aurignacian (Olszewski and Dibble, 1994, 2006). Some stone tools (Gar Arjeneh points, rectilinear and curved bladelets with inverse retouch) were found in these lithic assemblages, that resemble elements of the typical toolkits of the European Proto-Aurignacian and Aurignacian such as Font-Yves and Krems points, and Dufour bladelets (Tsanova, 2013). Few dates are available for these sites but the recent radiocarbon dating of charcoals from Yafte Cave (Iran) reveals that the Baradostian levels predate the chronological range of the Levantine Aurignacian, predate and overlap with some Early Ahmarian dates, and are contemporaneous with assemblages of the northern Caucasus (Otte et al., 2011). These results place the Iranian Late Paleolithic in an intermediate chronological position between the Levant Ahmarian and the Kozarnikien (Tsanova et al., 2012), suggesting its possible role as a source for the development of the Aurignacian culture (Otte and Kozłowski, 2004; Otte et al., 2012).

The Khorammabad Valley is a narrow passage connecting the northern highlands with the southern lowlands of Khuzistan and constitutes one of the important passageways for both humans and animals to cross the Zagros mountain range. The presence of numerous caves and rock shelters, springs and rivers and the Pleistocene paleoenvironment seem to have been favorable for human settlement in the area. As a consequence, the Khorramabad Valley likely played a significant role in human adaptation and dispersal during the Quaternary. However, there are only a few studies that deal with the sites in this area (Baumler and Speth, 1993; Field, 1951a, 1951b; Hole and Flannery, 1967; Otte and Kozlowski, 2007; Otte et al., 2007, 2011; Roustaei et al., 2002, 2004; Shidrang, 2007; Speth, 1971; Tsanova, 2013; as well as a reassessment paper on the Hole and Flannery report: Vahdati Nasab, 2010).

In this paper we are presenting preliminary results of the archaeological excavations at four Paleolithic sites in the Khorramabad Valley (Western Iran) (Fig. 1) of which the well-known sites of Ghamari cave and Gar Arjeneh rock shelter were excavated after Hole and Flannery's excavation in 1960s, while the Gilvaran and Kaldar caves were excavated for the first time. In all these sites, Middle and Upper Paleolithic human occupations were documented, adding new data to this important period of human evolution.

A general summary of the findings in the 4 excavated sites (Table 1), and detailed quantification results of the

Table 1
Summary of the archaeological materials recovered in the 2011–2012 seasons at the Khorramabad Valley sites.
Tableau 1
Résumé du matériel archéologique découvert en 2011–2012.

Site	Lithic remains	Faunal remains
Gilvaran (GLV-AY1)	5391	2740
Gilvaran (GLV-A8)	1818	871
Kaldar (KLD)	1394	1296
Ghamari (GHM)	1106	1475
Gar Arjeneh (GRA)	566	698
Total	**10,275**	**7080**

levels attributed to Middle and Upper Paleolithic in 3 of these localities are shown in the Tables 2 and 3. The results comprise two sections. The first section presents the four sites, making special reference to the main stratigraphic issues and to the lithic assemblages. The second is dedicated to the paleontology: it gives detailed descriptions in the Supplementary Online Materials (SOM), gives the faunal lists and briefly discusses some biogeographic aspects.

2. The archaeological sites

2.1. Gilvaran Cave

The cave is situated in the northwestern part of the Khorramabad Valley and located in 48°:18′:56″E longitude, 32°:28′:12″N latitude, and about 1225 m a.s.l (SOM Fig. 1A and E). It is 16 m long, 17 m wide and 7 m high. In 2002, the cave was officially included with record number 5971 into the Lorestan Cultural Heritage, Handicraft and Tourism Organization (LCHTO) archive as an Upper Paleolithic site by A. Parviz. The site has been visited twice; by an Iranian team in 2002 and by international team in 2004, both lead by K. Roustaei. They have systematically carried out surface collection on this locality. "Twenty-one collections ranging in size from a single artifact (Dozaleh II rock shelter, region 3) to 357 pieces (Gilvaran I, region 1) were recovered" (Roustaei et al., 2004, p. 7).

We explored the sediment fill of this cave with two test-pits of 2 × 2 m named AY1 and A8. AY1 is situated at the southern side of the cave opening at about 20 m

Table 2
Quantification results of the lithics attributed to Middle Paleolithic levels of the three excavated sites in the 2011–2012 seasons at the Khorramabad Valley.
Tableau 2
Résultats de la quantification des industries lithiques des trois sites fouillés au cours des années 2011–2012 dans la vallée de Khorramabad, attribués aux niveaux du Paléolithique moyen.

	GLV-AY1-Level 5		GLV-A8-Level 3		KLD-Level 5		GHM-Level 5	
	n	%	*n*	%	*n*	%	*n*	%
Cortical piece	101	*4.0*	162	*11.3*	6	*5*	27	*12.1*
Levallois flake	66	*2.6*	66	*4.6*	8	*6.6*	28	*12.5*
Levallois blade	11	*0.4*	12	*0.8*	4	*3.3*	4	*1.8*
Levallois point	48	*1.9*	15	*1.1*	9	*7.4*	16	*7.1*
Levallois core	7	*0.3*	7	*0.5*	1	*0.8*	–	–
Other types of core	4	*0.2*	1	*0.0*	3	*2.5*	–	–
Retouched tool	227	*9*	119	*8.3*	42	*34.7*	68	*30.4*
Flake byproducts	1894	*75.1*	N/A	*N/A*	16	*13.2*	63	*28.1*
Debris	149	*5.9*	211	*14.7*	31	*25.7*	18	*8*
Hammerstone	14	*0.6*	9	*0.6*	1	*0.8*	–	–
Total	2521	*100*	1428	*N/A*	121	*100*	224	*100*

Due to the hybridity caused by fallen rocks in level 3 of A8 trench of Gilvaran, distinguishing Levallois and blade byproducts was not possible, therefore in this case and in this trench, we presented exceptionally the same total numbers for the GLV-A8-Level 3 in the Tables 2 and 3. The sign "N/A" here means "data not applicable".
The total numbers given for "Retouched tool" in the Tables 2 and 3 for all the sites excluded other retouched tools such as retouched Levallois points, Levallois flakes, etc.

Table 3
Quantification results of the lithics attributed to Upper Paleolithic levels of three of the excavated sites in the 2011–2012 seasons at the Khorramabad Valley.
Tableau 3
Résultats de la quantification des industries lithiques des trois sites fouillés au cours des années 2011–2012 dans la vallée de Khorramabad, attribués aux niveaux du Paléolithique supérieur.

	GLV-AY1-Level 4		GLV-A8-Level 3		KLD-Level 4		GHM-Level 4	
	n	%	*n*	%	*n*	%	*n*	%
Cortical piece	43	*3.8*	–	–	2	*0.3*	6	*4.2*
Blade	196	*17.5*	88	*6.2*	92	*16.4*	27	*18.9*
Bladelet	180	*16.0*	73	*5.1*	89	*15.8*	17	*11.9*
Blade core	7	*0.6*	3	*0.2*	1	*0.2*	–	–
Bladelet core	3	*0.3*	1	*0.1*	1	*0.2*	–	–
Retouched tools	146	*13*	–	–	11	*1.9*	33	*23.1*
Other type of core	2	*0.2*	–	–	1	*0.2*	–	–
Blade byproducts	365	*32.6*	N/A	*N/A*	312	*55.6*	46	*32.1*
Debris	179	*16.0*	–	–	53	*9.4*	14	*9.8*
Hammerstone	–	–	–	–	–	–	–	–
Total	1121	*100*	1428	*N/A*	562	*100*	143	*100*

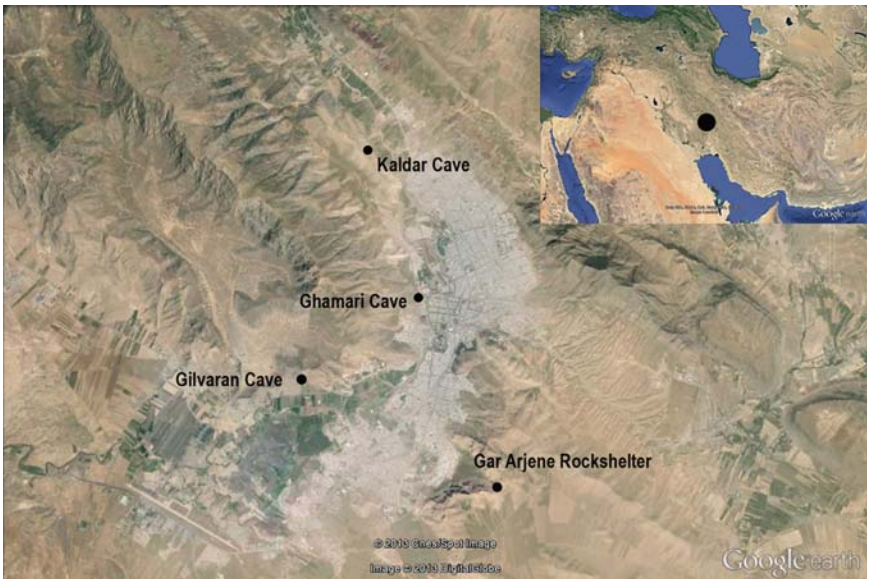


Fig. 1. (Color online). The geographic position of the Khorramabad Valley and the position of the localities indicated on an aerial photograph.
Fig. 1. (Couleur en ligne). Position géographique de la vallée de Khorramabad et localités indiquées sur la photo aérienne.

from the drip line (SOM Fig. 1 D). A8 was dug again at the southern side of the cave opening at about 4 m from the drip line (SOM Fig. 1B). Samples for contextual studies, including sedimentology paleontology paleoenvironment (pollen, charcoal, seeds, and land snails) and dating (OSL tubes and charcoal) were systematically collected (Fig. 2).

Test-pit AY1 exposed a 4.8 m section of the sedimentary deposit and is characterized by 5 main levels (Fig. 3B). Level 1 consists of ashy sediment with a blackish green color with angular stones. It has a thickness that varies from 5 to 20 cm. This is the most recent level and it contains an assemblage of Islamic materials. Level 2 consists of sediment with a fine light gray color and with few angular stones. It varies in thickness from 28 to 84 cm and it includes a Historical and Bronze Age record. Level 3 consists of grey coarse sandy sediment, that varies from 60 to 110 cm in thickness and which has mixed Chalcolithic and Neolithic potsherds and lithic industries. Level 4 consists of dark gray sediment with a large number of limestone blocks of different sizes and varies from 39 to 62 cm in thickness. It contains an Upper Paleolithic assemblage. Level 5 is a reddish brown deposit with many large limestone blocks. It increases in depth from the northern towards the southern section, varying from 2.45 to 2.85 m in thickness. It includes two sub-levels that have no difference in color. Middle Paleolithic industry is found in sub-level 1, and mixed Middle and early Upper Paleolithic/Baradostian industries in sub-level 2 (Fig. 4A1 and A2 and SOM Fig. A1 and A2).

Test-pit A8 showed a sequence of 1.5 m of sedimentary deposit, in which three levels could be recognized, (Fig. 3A) and overlying a layer of heavy rocks, deposited due to the collapse of the entry of the cave (SOM Fig. 1C). Level 1 consists of ashy blackish green sediments with a

Fig. 2. (Color online). Collection of sediment samples at Gilvaran Cave.
Fig. 2. (Couleur en ligne). Récoltes d'échantillons sédimentaires à Gilvaran.

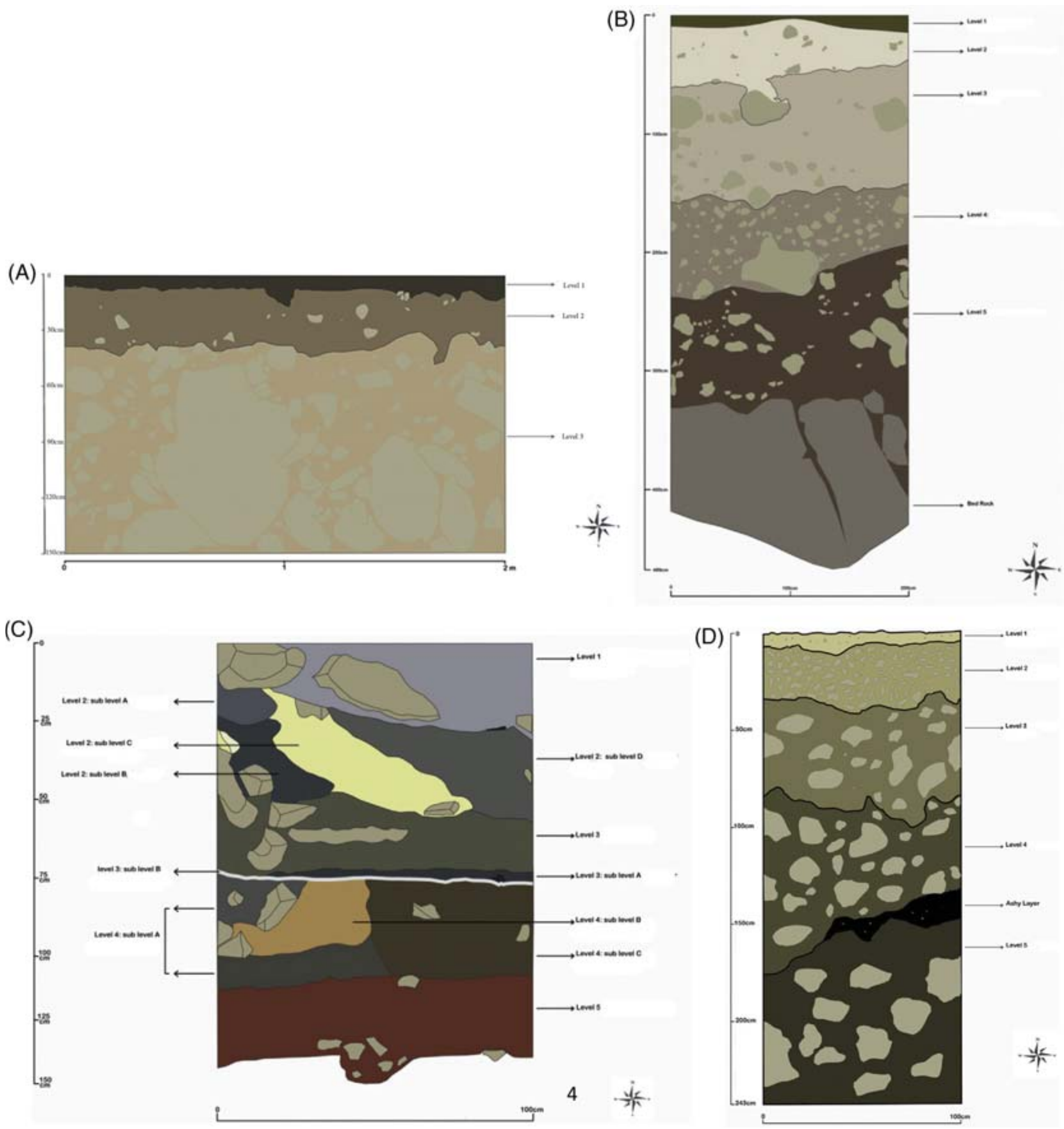


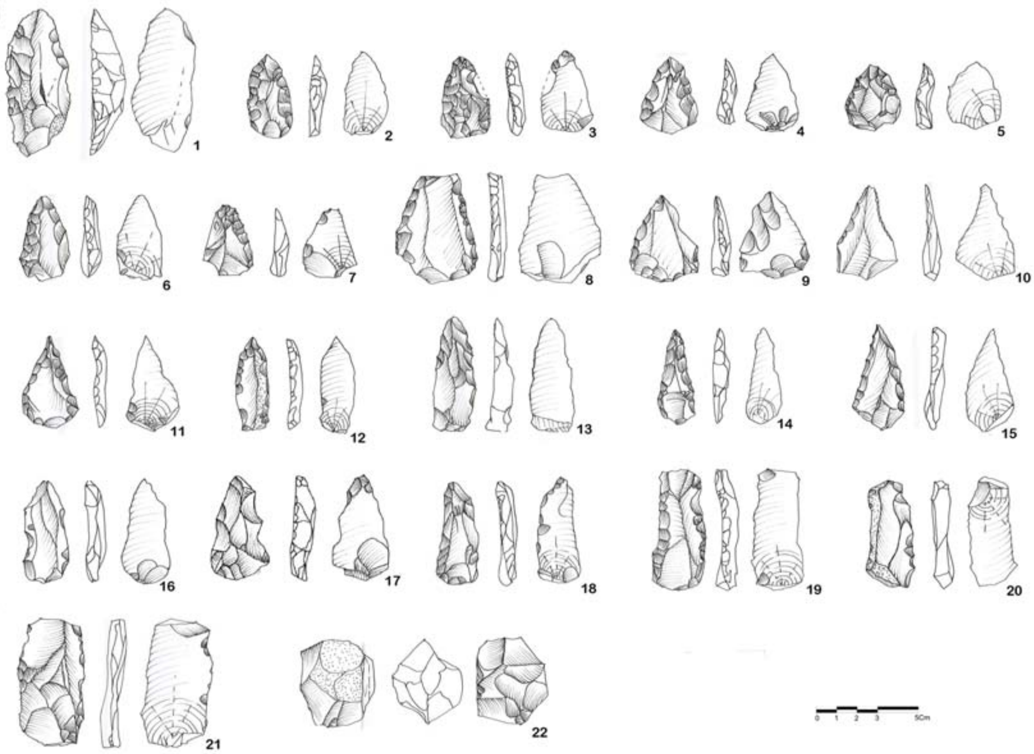
Fig. 3. (Color online). A. Gilvaran = Stratigraphy of the northern section of trench A8. B. Stratigraphy of the northern section of trench AY1. C. Kaldar = northern section of the D4 test-pit and detailed stratigraphy. D. Ghamari = the F2 (detailed stratigraphy).
Fig. 3. (Couleur en ligne). A. Gilvaran = Stratigraphie du côté nord de la tranchée A8. B. Stratigraphie du côté nord de la tranchée AY1. C. Kaldar = section nord du sondage D4 et stratigraphie détaillée. D. Ghamari = sondage F2, stratigraphie détaillée.

thickness varying from 5 to 10 cm and includes a superficial layer with Historical and Islamic materials. Level 2 consists of dark gray sediment with a few limestone blocks and has a thickness from 19 to 30 cm. It includes a unit of mixed Neolithic, Chalcolithic and Bronze Age. Level 3 consists of light gray sediment with a large number of angular limestone blocks and has a thickness from 31 to 150 cm. It contains a unit of mixed Middle and Upper Paleolithic (SOM Fig. 6A1 and A2).

The important assemblage of Mousterian industry from level 5 stands out in this sequence. In the lower part of sub-level 1 in level 5, a variety of Mousterian points and flakes, made with Levallois technique is present in large numbers. By contrast, in sub-level 2, we have observed both the Middle and Early Upper Paleolithic/Baradostian industry that seems to be mixed due to the variation in the depths. The most common retouched tool types in this level are different kind of points, side-scrapers, déjeté

(A1)

(A2)



scrapers, double-scrapers and other tools that do not fit to any known standard (some of them fractured).

Among the points, a wide variety of types has been identified, including Levallois points, Mousterian, limaces and Tayac points, unmodified and asymmetrical pointed flakes, resulting from unidirectional reduction, with different kinds of platform preparations (retouched, flat, dihedral, faceted, cortical). This variety makes Gilvaran somewhat different from the other localities in the Khorramabad Valley. The side-scrapers are mostly produced on core-edge flakes.

In the AY1 and A8 trenches, we recovered a total of 23 hammer stones showing discrete patches of pitting and crushing, reflecting that hard hammer percussion took place on the site (SOM Fig. 7). The principal knapping methods identified are Levallois recurrent centripetal and discoid as described by (Boëda, 1993, 1994). Retouched artifacts in the Upper Paleolithic industry in both AY1 (level 4) and A8 (level 3) are dominated by different types of flakes, blades and bladelets.

At the bottom of the Upper Paleolithic levels of both the trenches, tools are found that show some general characteristics of early Upper Paleolithic/Baradostian industry, such as long blades and bladelets, side-scrapers, end-scrapers (mostly fractured) and composite/multifunctional tools with step retouches, different types of pointed flakes along with bladelet cores. Unfortunately, in this level most of the cores are covered with heavy concretion.

As a consequence, in level 5 of Gilvaran cave, two distinct sub-levels have been recognized. The lower one contains many elongated flakes, produced by hard hammer on facetted platform, which subsequently were retouched or pointed. The upper sub-level contains elongated blades obtained with soft hammer, very clearly made with an Upper Paleolithic technology. These blades have been transformed into burins, scrapers with bilateral retouches. Some points made on bladelets are the so-called "Arjeneh" type. Also one carenated scraper was recovered. The upper part of the level 5 belongs to the Zagros Aurignacian, as it has been found in Yafteh and in many other sites in Iran (Otte and Kozlowski, 2007).

Hence, Gilvaran Cave is a promising site located in a suitable part of Khorramabad Valley, in particular for the study of technological variability and its potentiality for Middle to the early Upper Paleolithic transition.

2.2. *Kaldar Cave*

This cave is situated north of Khorramabad valley at 48°:17′:35″E longitude, 33°:33°:25N latitude and 1290 meters a.s.l (SOM Fig. 2 A, B and C). It is 16 m long, 17 m wide and 7 m high. In 2007, Z. Bakhtiari realized the archaeological importance of this cave. He recorded it with the file number 18796 in the LCHTO archive as an Epipaleolithic site. This site is located in the "Wild Life Century" zone, where it is protected from illegal excavation, which is a common problem in almost all Khorramabad localities. However, the cultural deposit in this case is very well preserved.

The fill of the cave was investigated with a test-pit of $1 \times 1\,m^2$ at the center inside the cave very close to the drip and reveals in 1.5 m a stratigraphic succession of five levels and six sub-levels (Fig. 3C). Level 1 consists of fine light gray sediment with large angular limestone blocks. This level has a thickness varying from 12 to 28 cm and it contains mixed Islamic, Historical and Chalcolithic materials. Level 2 consists of 4 sub-levels varying from colors (white, gray, bluish gray and dark bluish gray) with several angular blocks and a thickness from 37 to 42 cm. The cultural remains in this level includes: Sub-level A and B ashy layer, sub-level C Neolithic with typical potteries, sub-level D Pre-pottery Neolithic. Level 3: Contain three sub-levels resulting from fire activities with some flat and irregular limestone blocks with a thick ashy color and very thin bluish gray and lime color and soft sediment varying in a thickness from 19 to 24 cm with presence of different fractured flints showing Epipaleolithic characteristics.

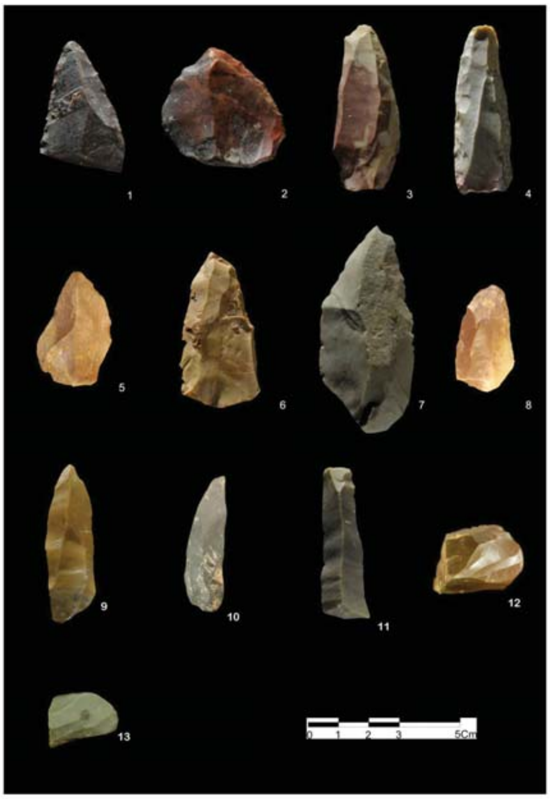
Level 4 consists of 3 sub-levels in dark brown, cream and bluish gray tense sediments, angular blocks. Its thickness varies from 30 to 35 cm. Its archaeological content shows Upper Paleolithic features. Level 5 consists of hard sandy reddish brown sediment with few small irregular blocks and has a thickness that varies from 30 to 35 cm. It contains a Middle Paleolithic assemblage, but at the top some blade technology appears, which might correspond to an early Upper Paleolithic phase.

Fig. 4. (Color on line). A1 and A2. Selected artifacts from Gilvaran GLV-AY1 trench, level 5 and 4: (same as picture above). 1: Limace, 2: Mousterian point with retouched platform, 3: Mousterian point with retouched platform and a fracture on its distal portion, 4: Mousterian point on Levallois flake with two convergent negatives and faceted platform, 5: déjeté scraper or Mousterian point, 6: Mousterian point with dihedral platform, 7: fragmented Mousterian point on Levallois flake, 8: point with direct flat retouches on the left side and three inverse notches on the right side, 9: Levallois point, concretion covers the platform, 10: déjeté scraper, 11: elongated Mousterian point with cortical platform, 12: elongated Mousterian point with flat platform, 13: elongated Mousterian point with dihedral platform, 14: déjeté scraper, 15: Mousterian point with retouched platform, 16 and 17: Tayac points, 18: double scraper on Levallois recurrent unidirectional blank, 19: déjeté scraper, 20: side-scraper with cortical platform on semi-cortical natural core-edge flake, 21: Levallois recurrent unidirectional blade with flat platform and pseudo-retouches on both sides, 22: polyhedral core.

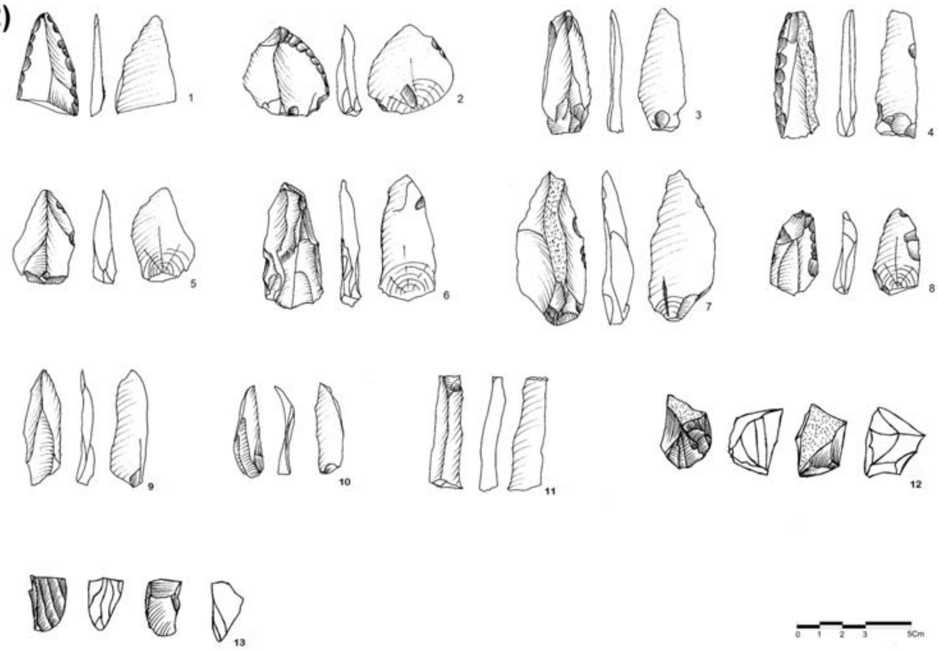
Fig. 4. (Couleur en ligne). A1 et A2. Artefacts sélectionnés de la tranchée de Gilvaran GLV-AY1, niveau 5 et 4 (les mêmes que sur la planche précédente). 1 : « Limace », 2 : pointe moustérienne avec talon retouché, 3 : pointe moustérienne avec talon retouché et partie distale fracturée, 4 : pointe moustérienne sur éclat Levallois avec deux négatifs convergents et talon facetté, 5 : racloir déjeté ou pointe moustérienne, 6 : pointe moustérienne avec talon dièdre, 7 : fragment de pointe moustérienne sur éclat Levallois, 8 : pointe avec retouches plates directes latérales et reprise inverse, 9 : pointe Levallois, talon concrétionné, 10 : racloir déjeté, 11 : pointe moustérienne allongée avec talon cortical, 12 : pointe moustérienne allongée avec talon lisse, 13 : pointe moustérienne allongée avec talon dièdre, 14 : racloir déjeté, 15 : pointe moustérienne avec plateforme retouchée, 16 et 17 : pointes de Tayac, 18 : racloir double sur éclat Levallois, 19: déjeté *scraper*, 20 : racloir latéral avec talon cortical, 21 : lame Levallois à talon lisse et pseudo-retouches sur les deux bords, 22 : nucléus polyédrique.

Drawings by Laxmi Tumung.

(A1)



(A2)



As in Gilvaran Cave, tools were made from different kinds of pebbles, easily available from the Robat River, which is very close to the site. In level 5, there are different types of points (mostly Mousterian and Levallois) along with pointed blades (with early Upper Paleolithic characteristics) and pointed flakes are the dominant tools, followed by side-scrapers. In level 4, flakes, blades and bladelets, polyhedral and bladelet cores along with twisted bladelets are present. As mentioned above, it was believed that the site was occupied only during the Epipaleolithic. However, the recovery in our excavation in levels 4 and 5 of many Mousterian and Upper Paleolithic tools such as points (Fig. 5A1 and A2), side- scrapers and many retouched flakes, indicates that the site was also occupied in Upper and Middle Paleolithic times.

Like Gilvaran, Kaldar Cave also is a promising site for studying the possible transition from the Middle to the early Upper Paleolithic.

2.3. Ghamari Cave

This site is located in 48°:20′:56″E longitude, 33°:29°:31N latitude and 1305 m a.s.l (SOM Fig. 3A to 3C). The fill of the cave was explored with a test-pit $1 \times 1\,m^2$ and five levels were recognized in the 2.45 m of sedimentary sequence (Fig. 3D). Level 1 consists of superficial fine cream-colored sediment with a few Islamic potsherds and a thickness varying from 4 to 9 cm. Level 2 consists of yellowish grey sediment, containing a large number of historical and Bronze Age potsherds and has a thickness varying from 25 to 40 cm. Level 3 consists of a soft and light grey color sediment with limestone blocks of different sizes varying from 45 to 70 cm and a mixed Chalcolithic and Neolithic assemblage with a few flint remains. Level 4 consists of sandy sediment with mixed grey ashy and lime color in the upper part and a black color in the lower part, which clearly results from fire activities. This level contains several limestone blocks of different sizes and is covered by concretions with a kind of heavy lime color. It contains Upper Paleolithic industry, and has a thickness from 50 to 85 cm. Level 5 consists of dark grey sediment with several large and heavy limestone blocks. It has a thickness varying from 60 to 94 cm and contains a Middle Paleolithic assemblage.

The excavation did not reach to the bedrock due to difficulties of the lighting system and high elevation. The real extent of the sedimentary sequence will be investigated in the next field work. A large number of faunal remains and some lithics were recovered from the test-pit. As a consequence, we recovered only a small number of lithics. These have the general characteristics of Upper Paleolithic industry. The Middle Paleolithic industry from level 5 stands out notably in this sequence, especially for the presence of Levallois byproducts, *limace* points and side-scrapers (Fig. 6A1 and A2). The low number of cores in Ghamari Cave could be related to the position of the test-pit further inside the cave or due to the small part investigated. In level 4, fractured retouched and not modified blades, pointed flakes, and side-scrapers are present, as well as byproducts of flaking sequences.

2.4. Gar Arjeneh Rock Shelter

It is located in 48°:20′:21″E longitude, 33°:26′:30N latitude and 1205 m a.s.l (SOM Fig. 4 A, B and C). The locality was excavated by Hole and Flannery in 1967 with some problems for tracking the stratigraphy because the deposit was too disturbed. Their notes indicate that the deposit had been badly disturbed by intrusive porcupine burrows and tools were cataloged by type and not by stratigraphic level (Petraglia and Potts, 2004). Although two 1 × 1 m test-pits were opened in different parts of the site, the deposit shows stratigraphic problems and no clear evidences for cultural interpretations.

Despite these problems, the analysis of the lithic assemblage documented high percentages of side-scrapers and retouched bladelets (Fig. 7A1 and A2), rather than the known Arjeneh points which certainly reflect the high degradation of the deposit. Further fieldwork is needed to give more information about the cultural sequences and the stratigraphy.

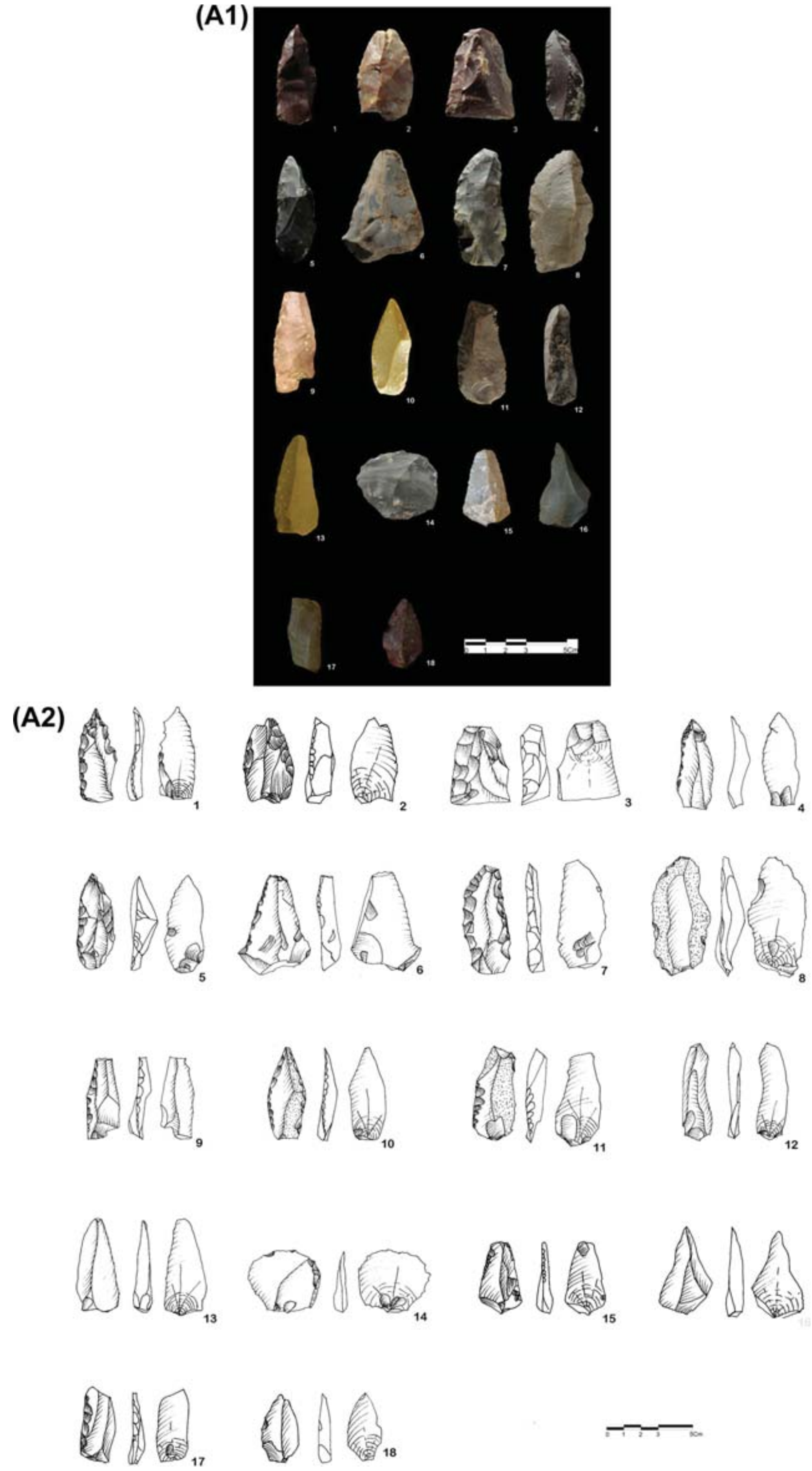
3. Paleontology

A small collection of the fossils from the excavations in the Khorramabad Valley was taken to Tarragona and has been studied in detail. Some of these specimens are illustrated in Fig. 8. Detailed descriptions, comparisons and taxonomic discussions are given as Supplementary Online Materials. The list of identified animal species is given below:

Crustacea indet.: Kaldar Cave
Erinaceidae indet.: Ghamari Cave
Chiroptera indet.: Ghamari Cave
Leporidae? indet.: Kaldar Cave

Fig. 5. (Color on line). A1 and A2. Selected artifacts from Kaldar KLD level 5 and 4. 1: Distal portion of a fragmented Mousterian point on a Levallois blank, 2: point on a Levallois flake with dihedral platform, 3: Levallois point with flat platform, recurrent unidirectional convergent, 4: side-scraper on cortical blade with faceted platform and unidirectional convergent negatives, 5: predetermining Levallois flake with four convergent negatives, flat platform, 6: Levallois point on core-edge flake with flat platform, 7: semi-cortical flake with flat platform and presence of unidirectional negatives, 8: Levallois point with dihedral platform obtained by the recurrent unidirectional modality, 9: pointed flake on Levallois core, 10: twisted bladelet with flat platform, 11: flake of re-shaping the knapping surface, 12: bladelet core, 13: fragmented bladelet core with four negatives.

Fig. 5. (Couleur en ligne). A1 et A2. Sélection d'artefacts de la grotte KLD, niveau 5 et 4. 1 : partie distale d'une pointe moustérienne sur éclat Levallois, 2 : pointe sur éclat Levallois à talon dièdre, 3 : pointe Levallois à talon lisse, récurrent unidirectionnel convergent, 4 : racloir sur lame corticale avec talon facetté et négatifs unidirectionnels convergents, 5 : éclat Levallois prédéterminé avec quatre négatifs convergents, talon lisse, 6 : pointe Levallois sur éclat débordant avec talon lisse, 7 : éclat semi-cortical avec talon lisse et négatifs unidirectionnels, 8 : pointe Levallois à talon dièdre obtenu par la modalité récurrente unidirectionnelle, 9 : pointe Levallois, 10 : lamelle torse avec talon lisse, 11 : éclat de réaménagement, 12 : nucléus à lamelles, 13 : nucléus à lamelles fragmenté, avec quatre négatifs.


(A1)
(A2)

(A1)

(A2)

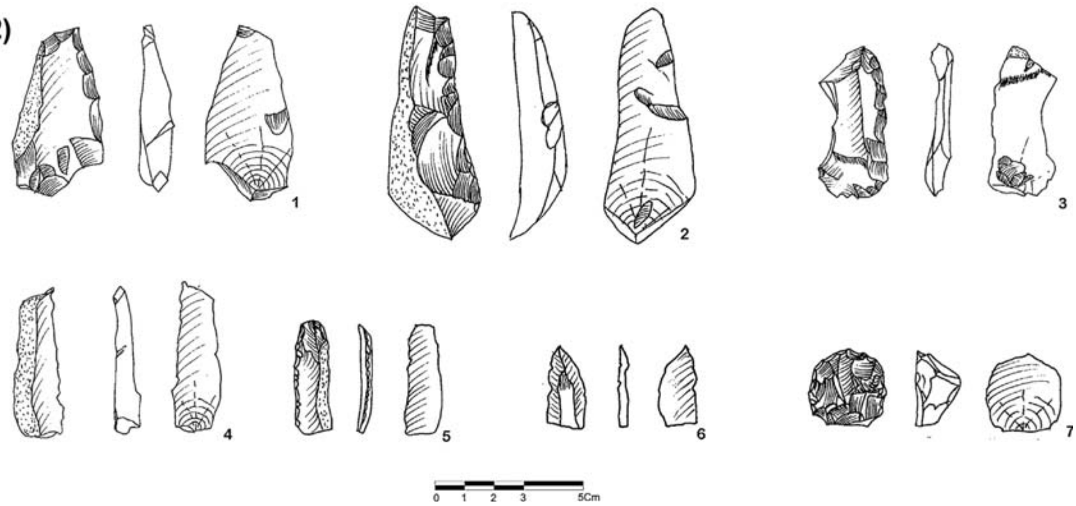


Fig. 7. (Color online). A1 and A2. Selected artifacts from Gar Arjeneh Rock Shelter. 1 and 2: Side-scraper on cortical flake with flat platform, 3: Fractured side-scraper with dihedral platform, 4: cortical blade, 5: fractured retouched bladelet, 6: pointed fractured bladelet, 7: discoid core.
Fig. 7. (Couleur en ligne). A1 et A2. Sélection d'artefacts de l'abri Gar Arjeneh. 1 et 2 : racloir cortical avec talon lisse, 3 : racloir fragmenté avec talon dièdre, 4 : lame corticale, 5 : lamelle retouchée fragmentée, 6 : lamelle appointée, 7 : nucléus discoïde.

Fig. 6. (Color online). A1 and A2. Selected artifacts from Ghamari Cave level 5 and 4: 1: Mousterian point on a Levallois flake with faceted platform, 2: Mousterian point with a flat platform and distal fracture, 3: Mousterian point on a Levallois unidirectional convergent flake, 4: Mousterian point with flat platform and distal fracture, 5: limace, 6: side-scraper on core-edge flake, 7: side-scraper with flat platform, 8: semi- cortical flake with flat platform, pseudo retouch on both sides, three unidirectional negatives, 9: fragmented side-scraper with flat platform, 10: side-scraper on cortical flake with flat platform, one parallel unidirectional extraction and open internal flaking angle, 11: side-scraper on cortical flake with flat platform, 12 and 13: Levallois point with dihedral platform, 14: Levallois flake with faceted platform, 15: fractured pointed flake with dihedral platform and pseudo retouch on the left side, 16: fractured overshot pointed flake, 17: fractured side-scraper with flat platform, 18: fractured pointed flake.
Fig. 6. (Couleur en ligne). A1 et A2. Sélection d'artefacts de la grotte Ghamari, niveaux 5 et 4. 1 : pointe moustérienne à talon facetté, 2 : pointe moustérienne à talon lisse, fracturée, 3 : pointe moustérienne sur éclat Levallois unidirectionnel convergent, 4 : pointe moustérienne à talon lisse, fracturée, 5 : « limace », 6 : racloir sur éclat débordant, 7 : racloir à talon lisse, 8 : éclat cortical à talon lisse avec pseudo-retouches et trois négatifs unidirectionnels, 9 : racloir fragmenté avec talon lisse, 10 : racloir cortical, avec un négatif parallèle unidirectionnel, 11 : racloir cortical à talon lisse, 12 et 13 : pointes Levallois à talon dièdre, 14 : éclat Levallois à talon facetté, 15 : éclat appointé fragmenté à talon dièdre et pseudo-retouches sur le côté gauche, 16 : éclat appointé fragmenté, 17 : racloir fragmenté avec talon lisse, 18 : éclat appointé fragmenté.

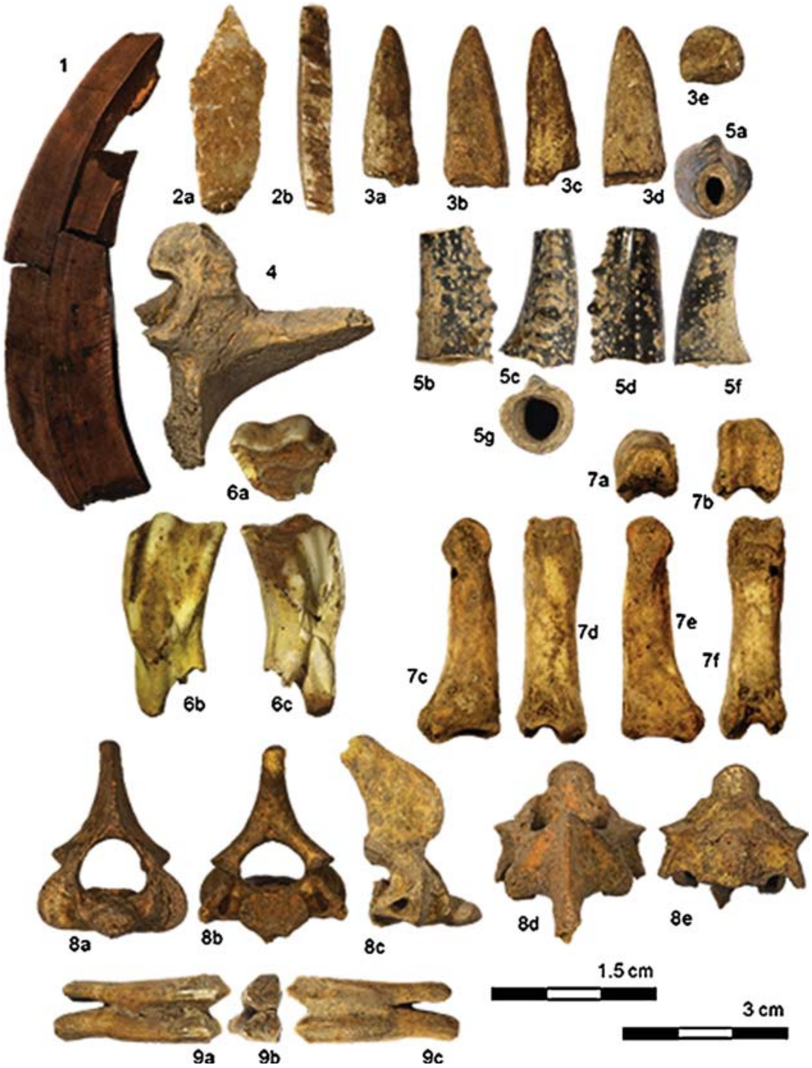


Fig. 8. (Color online). 1: KLD-DS-5 + KLD-1—right lower canine of a male *Sus scrofa* from Kaldar Cave; lingual view; 2: GLV-A1-17-enamel fragment of a cheek tooth of a rhinoceros (?) from Gilvaran Cave; (a) buccal view, and (b) section; 3: KLD-11 – tip of the tine of an antler of Cervidae indet. cf. *Cervus elaphus*; (a) anterior/posterior, (b) lateral/medial, (c) anterior/posterior, and (d) lateral/medial views, and (e) section; 4: GLV-A8-103—fragment of a lumbar vertebra of Cervidae indet. cf. *Cervus elaphus* from Gilvaran Cave; posterior view; 5: KLD-9—fragment of the pincer of a crab from Kaldar Cave; (a) distal section, (b) mesial view, (c) occlusal view, (d) lateral view, (e) inferior (?) view, and (f) proximal section; 6: GHM-F2-8—right P2 of Bovini indet. from Ghamari Cave; (a) occlusal, (b) buccal, and (c) lingual views; 7: KLD-14—first phalanx right of the axis of the hand (?) of *Capreolus* from Kaldar Cave; (a) distal, (b) proximal, (c) axial, (d) dorsal, (e) abaxial, and (f) plantar views. 8: GHM-F2-22 – axis of *Hystrix* from Ghamari; (a) anterior, (b) posterior, (c) right, (d) dorsal, and (e) ventral views; 9: KLD-10 – left M1/2 (M1?) of *Capra* from Kaldar Cave; (a) buccal, (b) occlusal, and (c) lingual views. The scale bars represent 1.5 cm for photographs 2 and 5 and represents 3 cm for the remaining photographs.

Fig. 8. (Couleur en ligne). 1 : KLD-DS-5 + KLD-1, niveau 4–canine inférieure droite d'un mâle *Sus scrofa* de la grotte Kaldar ; vue linguale ; 2 : GLV-AY1-17, niveau 4-fragment d'émail d'une dent de rhinocéros (?) de la grotte Gilvaran ; (a) vue buccale, (b) vue en section ; 3 : KLD-11, niveau 5–point d'andouiller de Cervidae indét. cf. *Cervus elaphus* ; (a) vues antérieure, (b) médiale, (c) postérieure, (d) latérale, (e) section ; 4 : GLV-A8-103, niveau 2–fragment d'une vertèbre lombaire de Cervidae indet. cf. *Cervus elaphus* de la grotte Gilvaran ; vue postérieure ; 5 : KLD-9, niveau 5–fragment de pince de crabe de la grotte Kaldar ; (a) section distale, (b) vue mésiale, (c) vue occlusale, (d) vue latérale, (e) vue inférieure, (f) section proximale ; 6 : GHM-F2-8, niveau 4–P^2 droite de Bovini indet. de la grotte Ghamari ; vues (a) occlusale, (b) buccale, (c) linguale ; 7 : KLD-14–première phalange, droite de l'axis de la main (?) de *Capreolus* de la grotte Kaldar; vues (a) distale, (b) proximale, (c) axiale, (d) dorsale, (e) abaxiale, (f) plantire ; 8 : GHM-F2-22–axis d'*Hystrix* de la grotte Ghamari ; vues (a) antérieure, (b) postérieure, (c) droite, (d) dorsale, (e) ventrale ; 9 : KLD-10–M1/2 (M1?) gauche de *Capra* de la grotte Kaldar ; vues (a) buccale, (b) occlusale, (c) linguale. L'échelle est de 1,5 cm sur les clichés 2 et 5, et 3 cm pour les autres clichés.

Hystrix sp. cf. *Hystrix indica*: Ghamari Cave
Gliridae indet.: Ghamari Cave
Mustelidae indet.: Kaldar Cave
Rhinocerotidae indet.?: Gilvaran Cave, level 4.
Sus scrofa: Kaldar Cave
Capreolus sp.: Kaldar Cave, Gilvaran Cave
Cervidae indet. cf. *Cervus elaphus* Kaldar Cave, Gilvaran Cave
Bovini indet.: Gilvaran and Ghamari Caves
Caprini indet. cf. *Capra aegagrus*: Gilvaran, Ghamari, Kaldar Caves

The presence of a crab in Kaldar Cave either suggests that water was very near to the cave at the time the deposits were formed, or that it was brought into the cave by a predator or humans.

In large parts of Europe, the fossil record is sufficiently known to allow fairly precise age estimation, often allowing in assigning fossil associations to a particular glacial cycle or oxygen isotope stage. At present this is not possible in Iran. However, the fossil association is interesting from a biogeographical point of view. The Khorramabad Valley is a passageway across the Zagros Mountains and is situated at the border of the Palearctic and Saharan-Arabian biogeographic realms and not very far away from the Oriental realm (Holt et al., 2013). Dealing here with Pleistocene fossils, we might expect species from these different realms. However, the taxa identified here, and those known from the literature (Marean, 1998; Mashkour et al., 2008, 2009, 2012; Trinkaus and Biglari, 2006; Trinkaus et al., 2008), suggest that, the humans in this area lived in a Palearctic and more precisely a West Eurasian biogeographic context. This must have had importance for their geographic distribution, contacts with other populations and gene flow, or for their opportunities of dispersal.

Against this biogeographical background it is interesting to note that the fossils of *Capreolus* are the southern-most records of the genus in western Eurasia. The same may be true of *Cervus*. The possible presence of a rhinoceros at Gilvaran Cave is intriguing. An indeterminate species of "*Dicerorhinus*" was cited from the Wezmeh Cave in Iran (Mashkour et al., 2008). That genus lives today in SE Asia, while the related *Rhinoceros* lives also in the Indian Subcontinent. Both have long records in East Asia and the Indian Subcontinent, respectively. However, these authors may have meant the genus *Stephanorhinus*, which previously was included in *Dicerorhinus*, a practice still followed by some. *Stephanorhinus* and the closely related woolly rhinoceros *Coelodonta* are fossil rhinoceroses from northern Eurasia. The latter was cited also from the Indian Subcontinent (Colbert, 1935), while *S. kirchbergensis* and *S. hemitoechus* are described from Azokh Cave in Nagorno Karabach (Van der Made et al., in press). Biogeographically it would be very interesting to know which of these species were present in Iran.

4. Discussion and conclusions

Thanks to the advances made by pioneering researchers, we were able to expand and test their initial results with modern techniques. Although some of our results confirm previous findings, others enable us to advance new data. For instance, Hole and Flannery reported that: "The technique of the Luristan Mousterian is non-Levallois, like that observed elsewhere in the Zagros" (e.g., Shanidar, Hazar Merd, Warwasi, Bisitun) (Hole and Flannery, 1967: 155; see also Vahdati Nasab, 2010). However, we recovered many Levallois points, pointed flakes, flakes and Levallois cores not only at Gilvaran and Kaldar, but also at Ghamari, where these had not previously been reported. Regardless of these differences, our results are in general agreement with Hole and Flannery's categorization of technologies from these sites.

Parviz recorded Gilvaran as an Upper Paleolithic locality. Roustaei et al. (2004) stated that: "The two large collections from Sorkh-e Lizeh and Gilvaran I exhibit some generic early Upper Paleolithic characteristics (e.g., many flakes, retouched pieces made on flakes, flake cores, denticulates and notches, side-scrapers), but they occur along with lamellar elements and even bullet cores" (Roustaei et al., 2004: 8). However, we recovered a large number of Middle Paleolithic tools in the A8 and AY1 trenches from this site (several types of typical Mousterian, Levallois, *limace*, Tayac and déjeté points, side-scrapers and blades from Levallois cores. According to their report: "Hammer stones and grinding stones were reported by Hole and Flannery (1967) from their tests at Gar Arjeneh and also show up at Gilvaran I but are of uncertain chronological or diagnostic significance" (Roustaei et al., 2004: 9). From this, it is clear that a surface collection does not allow assessment for a reliable chronology and that the recent excavations in the Khorammabad Valley provide new data necessary to fully understand these lithic assemblages.

Apart from documenting two more Middle Paleolithic localities in the Khorramabad Valley, the recognition in our excavations of two distinct but continues levels in level 5 of Gilvaran cave is of vital importance, because it might help in understanding some of the dark angles of the possible interaction between *Homo sapiens* and the Neanderthals and the causes of the extinction of the latter.

Another important issue, which is one of the main objectives of this research, is the beginning of the Middle Paleolithic period in this area. "The true age of the Mousterian in the Zagros is not known, although carbon from Kunji Cave gave a radiocarbon date of greater than 40,000 years" (Hole and Flannery, 1967). However, relying on 1970s dating, we may know, more or less, the end of Middle Paleolithic age of Khorramabad Valley. "An important point is that in case of absolute dating; most of the Paleolithic sites in Iran suffer from the lack of reliable dating techniques (e.g., some of the dates obtained by ^{14}C techniques prior to the 1970 could be drastically changed because of absence of reliable calibration at the time)" (Vahdati Nasab, 2011).

Although new radiometric dating is still in progress, the techno-typological similarities between the sites investigated and the nearby Yafteh Cave permit to associate the radiocarbon dates of the latter (Otte et al., 2011) for timing the appearance of the Upper Paleolithic in the Khorramabad Valley. The Mousterian tradition instead might be older than expected. The preliminary paleontological study confirms that faunal affinities are predominantly European and adds a new taxon which has its southern-most distribution in the area. When more extensive collections are studied in detail, biostratigraphy has the potential to contribute to dating the different levels and making paleoecological interpretations.

Our preliminary study also shows that modern and systematic excavations may provide information that challenges the classical views on the technology of the stone tools of this area. A brief study of the lithic assemblages of all the sites shows that the raw materials used are mostly pebbles from the Khorramabad River. Field observations indicate that the majority of the caves and rock shelters in the region are close to water sources, mainly the Khorramabad River. The assemblages are dominated by relatively high-quality raw materials procured as pebbles from local gravels.

In the fluvial deposits in the valley, there are pebbles and cobbles of many different colors and quality (dominated by chert stone) easily available. Flint is easy to find and it therefore seems a convenient source for the Paleolithic hunters and gatherers inhabiting this area. As a result, it is not unreasonable to think that the majority of the knapped materials in the sites are of local origin.

Except a single obsidian microlith blade in the AY1 trench in the Gilvaran, chert is the predominant raw material in all the sites (SOM Fig. 8). As far as we know, the nearest obsidian sources are in the Caucasus and Turkey. "The most important sources of obsidian in the Near East are located in Anatolia and Caucasus. There are also smaller sources in southern Yemen, possibly in southwest Arabia and the Red Sea islands (Francaviglia, 1990; Zarins, 1989), and perhaps some localities in Iran, yet to be explored" (Abdi, 2004).

The preliminary technological analyses of the lithic assemblages indicate in the Mousterian the exclusive use of the Levallois recurrent unidirectional methods with the shift to the centripetal modality at the end of the flaking sequence. The dimension of the raw material plays also an important role in the choice of the knapping method, as is the case in small discoid cores. The retouched artifacts are dominated by Mousterian and elongated points, side-scrapers, déjetés and convergent scrapers. These features are common in the other sites of the Zagros regions during the late Middle Paleolithic indicating a certain technological stability. In the lithic assemblages of the Upper Paleolithic instead is documented a technological change towards the production of blades and retouched bladelets. Within the retouched tools it is worth noting the production of Arjeneh points that are exclusive of these territories, suggesting an in situ development of these artifacts in the Baradostian tradition. Recent examinations of the Upper Paleolithic assemblages of Warsawi and Yafteh Caves highlighted the independence of these technological innovations that are not rooted in the Mousterian tradition as was traditionally stated. It is one of the aims of our future research to know more about environmental conditions and constraints in order to better understand technological and behavioral evolution. For this end, we intend to study the lithics by means of microwear and residue analysis to understand the function of the tools and the features of the behavioral changes and transition. We are also studying the fossils remains to better assess the faunal changes between those periods. To obtain all of this knowledge, a wide comparison analysis of assemblages in the area is of vital importance.

Acknowledgments

We would like to thank Mr. M. Rahmdel, Dr. Bazergar and Dr. M. Mireskandari former Directors of (LCHHTO), (RCICHHTO) and (ICAR) for permission and funding to conduct research in the area. Our heartiest thanks go to Prof. F. Hole for visiting Gilvaran and advices on the excavation method, Dr. T. Tsanova for providing us Frank Hole's drafts on Khorramabad Valley and her constructive suggestions. B. Bazgir is a beneficiary of Fundación Atapuerca doctoral fellowship; J.-M. López-García is a beneficiary of a Beatriu de Pinós postdoctoral fellowship (2011BP-A00272) from Generalitat de Catalunya, a grant cofounded by the European Union through the Marie Curie Actions of the 7th Framework Program for R + D; and A. Picin is a beneficiary of the Fuhlrott-Research Fellowship of the Neanderthal Museum Foundation. The following persons gave access to fossils or osteological material that was used for comparison: S.D. Aliev, J. Bareiro, G. Bossinski, E. Crégut-Bonnoure, M. Esteban, Y. Fernández-Jalvo, J.H. Grünberg, O. Hampe, R.D. Kahlke, D. Lordkipanidze, H. Meller, S. van der Mije, J. Morales, P. Pérez de Díos, E. Pons, K. Rauscher, B. Sánchez Chillón, C. Smeenk, late E. Tchernov, E. Tsoukala, and E. Turner. This work has been developed within the framework of the projects CGL2009-12703-C03-01, CGL2008-03881 and CGL2012-38434-C03-03 of the Spanish Ministerio de Ciencia e Innovación, and the 2009SGR-188 project from the Catalan AGAUR.

Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.crpv.2014.01.005.

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Supplementary On-line Material

Palaeontology

Material and Methods

A small collection of the fossils from the excavations in the Khorramabad Valley was taken to Tarragona and has been studied in detail. Those specimens are presently (and temporarily) kept in the IPHES and were compared to fossil and recent animals. Most of the comparisons are with recent mammals from the IPHES collections. Where comparative data are explicitly cited, the acronym of the institution where the material was studied, or where it is presently kept, is given: ASM = Artsakh State Museum, Stepanakert; AUT = Aristotle University of Thessaloniki; FASMN = Römisch-Germanisisches Zentralmuseum, Forschungsinstitut für Vor- und Frühgeschichte, Forschungsbereich Altsteinzeit Schloss Monrepos, Neuwied; CIAG = Centre d'Investigacions Arquelògics de Girona; GSM = Georgian State Museum, Tbilisi; HUJ = Hebrew University, Jerusalem; IPHES = Institut Català de Paleoecologia Humana i Evolució Social, Tarragona; IPUW = Institut für Paläontologie der Universität, Wien; IQW = Institut für Quartärpaläontologie, Weimar. (at present: Senckenberg Forschungsinstitut und Naturmuseum, Forschungsstation für Quartärpaläontologie, Weimar); LVH = Landesmuseum für Vorgeschichte, Halle; MNCN = Museo Nacional de Ciencias Naturales, Madrid; MRA = Museum Requien, Avignon; MUB = Medical University, Baku; MNB = Museum für Naturkunde der Humboldt-Universität, Berlin; NNML = Nationaal Natuurhistorisch Museum, Leiden; NMP = National Museum, Prague.

Measurements were taken according to Van der Made (1996) and Van der Made & Tong (2008). The measurements are given in mm and are indicated with the following acronyms: DAP = antero-posterior diameter (maximum or at the occlusal surface of a tooth); DAPd = DAP of the distal part of a bone; DAPp = DAP of the proximal part of a bone or DAP of the posterior lobe of a tooth; DAPb = DAP at the base of the crown of a tooth; DLL = labio-lingual diameter of an incisor; DMD = mesio-distal diameter of an incisor; DT = transverse diameter; DTa = DT of the anterior lobe of a tooth; DTd = DT of the distal end of a bone; DTp = DT of the proximal end of a bone or of the posterior lobe of a tooth; Ha = height of the crown of a molar measured at the lingual (lower) or buccal (upper) side of the anterior lobe; Hli = height of the crown of an incisor measured at the lingual side; L = length; Li = width of the lingual side of the male lower canine in suids.

Systematic description, comparison and discussion.

The most indicative specimens of the small collection that was taken to the IPHES are described below.

Crustacea indet. A pincer of a crab was recovered from Kaldar Cave (Figure 8-5). The fragment has a length of 12.8, greatest width of 7.4 and height of 6.9 mm.

Rhinocerotidae indet.? An enamel fragment from Gilvaran Cave, level 4 (Figure 8-2) has a length of over 19, a width of over 7, and a thickness of about 2.7 mm. The surface is flat and very smooth. The fragment must have belonged to a large tooth with an extensive flat surface. It may have formed part of the buccal surface of an upper tooth of a rhinoceros. Species like *Stephanorhinus hemitoechus* and *Coelodonta antiquitatis* have enamel that is more crenelated. Species with relatively smooth enamel include *Stephanorhinus kirchbergensis* and *Rhinoceros unicornis*. In any case, the presence of a rhinoceros should be considered to be tentative.

An unidentified species of "*Dicerorhinus*" was cited from the Wezmeh Cave in Iran (Mashkour et al., 2008). *Dicerorhinus sumatrensis* is a species that lives in SE Asia, while *Rhinoceros unicornis* is the living Indian species (Duff & Lawson, 2004). Both genera have long fossil records in in East Asia and the Indian Subcontinent, respectively (Colbert, 1935; Xue & Zhang, 1991). However, it was custom to assign the European and North Asian rhinoceroses to *Dicerorhinus*, that are now placed in *Stephanorhinus* and this may have been meant in the case of the material from Wezmeh Cave. *Stephanorhinus kirchbergensis, S. hemitoechus and Coelodonta antiquitatis* are the typical West Eurasian species for the late Middle and Late Pleistocene of western Eurasia (Guérin, 1980; Van der Made, 2010; Van der Made & Grube, 2010). The first two species have been described from Azokh, in Nagorno Karabach (Van der Made et al. in press). *Coelodonta* was cited from the Indian Subcontinent (Colbert, 1935). From this review it is obvious that it would be very interesting if rhinoceros species could be identified from the Pleistocene of Iran. At present the identification is not possible for the fossil from Gilvaran Cave.

Sus scrofa. A canine from Kaldar Cave (Figure 8-1) has the characteristics of the lower canine of a male suid: it is very high crowned (hypselodont) and has a triangular section with the posterior side lacking enamel and a large facet near the tip. The section is "scrofic", meaning that the posterior side (which lacks enamel) is wider than the labial side, as opposed to a “verrucose” section with the posterior side narrower than labial side. The specimen is large (Li >20.6).

Sus scrofa and the very small *Sus salvanius* are the only species of *Sus* that are known to have canines with “scrofic” sections, while the remaining species of *Sus* have “verrucose” sections. The size of the specimen from Kaldar is far superior to that of the canines of *Sus salvanius*. *Sus scrofa* is also present in Gilvaran Cave and has been cited or described from Wezmeh, Bisitun and Yafteh Caves in Iran (Trinkaus & Biglari, 2006; Mashkour et al., 2008; Maskour et al. 2012), as well as from Azokh Cave in Nagorno Karabach (Van der Made et al. in press) and Shanidar in Iraq (Evins, 1982), which are not very far away from the Khorramabad Valley.

The wild boar *Sus scrofa* appeared not later than some 800 ka ago in Western Europe (Van der Made, 1999; Franzen et al., 2000). It must have come from Asia, but at present older records have not been documented there. At present it lives in an area that extends from western Europe and Morocco to Japan and Indonesia, including Iran. In most of this area it is the only suid species since the beginning of the Middle Pleistocene onwards, but in Nepal and surrounding areas it is sympatric with the very small *Sus salvanius* and in SE Asia it is sympatric with *Sus barbatus* and *Sus verrucosus* (Duff & Lawson, 2004).

***Capreolus* sp.** A first (or “proximal”) phalanx (Figure 8-7) from Kaldar Cave has a morphology as occurs in artiodactyls. It is narrower than in the Suidae. The proximal side is wide and its dorsal edge is flat, but this is at least partially due to the fact that the proximo-dorsal area is slightly damaged there. The articular surface axial of the dorso-plantar grove is narrow, but is wider in a specimen from Gar Arjeneh rock shelter (Figure 9-2). In both specimens, the facets for the sesamoids are small. The measurements of the first specimen are: DAPp >15.2, DAPpf >12.9, DTp = 10.9, L = 41.7, DAPd = 8.4, DTd = 10.7. Those of the second are: DAPp = 15.6, DAPpf = 15.6, DTp = 13.0. Metrically the complete phalanx is narrower than in typical Caprini, such as *Capra, Hemitragus* and even *Ovis*, but somewhat wider than in recent *Gazella* and *Axis* (SOM Figure 9, DTp-L diagram). Despite its proximo-dorsal damage, the phalanx is proximally relatively narrower than in *Saiga* or slender caprines like *Rupicapra* (SOM Figure 9, DTp-DAPp diagram). The distal articulation is wider than in *Antilope*, *Saiga* and *Gazella* (SOM Figure 9, DTd-DAPd diagram). In one or another bivariate diagram the specimen from Kaldar Cave is separate from each of the taxa with which it was compared, save for *Capreolus.* (Surprisingly, this result could not be obtained in a single diagram of the principal components.) The two specimens tend to be large or larger than their homologues in *Capreolus capreolus*.

Being small and simple bones, sesamoids are generally not studied. However, it is possible to assign them to taxa and even they may help to determine a taxon. Artiodactyls have in each finger or toe two sesamoids at the plantar side proximal to the first phalanx and a third one proximal to the third phalanx. The latter is wide and low and the former two are long and narrow. Of these the axial one is “low” (with a short dorso-plantar diameter) and the abaxial one is “high”. A sesamoid from Gilvaran Cave (SOM figure 10-1) had the morphology of an axial sesamoid of an artiodactyl. It has a plantar surface with rounded edges (SOM Figures 10-1a & f), like in cervids (SOM Figures 10-2a & f, 10-3a & f), whereas in bovids (or at least caprines) this surface tends to be flatter (in transverse direction) and tends to form more clearly defined angles with the axial and abaxial sides of the bone, particularly making a sharp angle with the abaxial side (SOM Figures 10-4a & f; 10-5a & f). In suids this angle is even much sharper. The specimen from Gilvaran has the size (DPD = 11.0, DT = 5.6, DDPmax ≥6.0, DDPmini = 5.9) of the axial sesamoid behind the first phalanx of a *Capreolus*. In the diagram in SOM Figure 10 the *Capreolus* sesamoids form two clusters for the manus and pes, respectively, whereas the sesamoids of manus and pes of the same individuals of Caprini are closer together.

A patella from Gilvaran Cave has a wide facet for the femur. There is a clear angle in the facet, while in the Caprini it is more rounded. The bone is wide (transverse diameter DT = 19.0) and thick (antero-posterior diameter 14.5; its height was superior to 18.9 mm). *Lynx* has a wide and flat patella, while *Canis lupus* has a narrow and thick patella. The patella of *Gazella* is flat with a not so clear angle in the facet. The latter is also the case in *Capra*. *Capreolus* has a relatively thick and wide patella with a clear angle in the middle of the facet. The specimen from Gilvaran is somewhat larger than the specimens from recent *Capreolus capreolus* from Spain we used for comparison (IPHES).

Capreolus capreolus lives from Europe to the area south of the Caspian Sea in northern Iran, while *Capreolus pygargus,* which is larger with larger antlers, lives in an area from north of the Caucasus extending eastward into Asia (Duff & Lawson, 2004; Aulagnier et al., 2009). In Western Europe, the size of *Capreolus* decreased markedly during the Late Pleistocene, while a fossil *Capreolus* from Azokh Cave in Nagorno Karabach is very large (Van der Made et al., in press). Evins (1982) noted that *Capreolus* is a rare element in SW Asia and indicated its presence in Jarmo and “Mousterian levels” of Shanidar Cave in Iraq, but not in Iran. The material was assigned to *Capreolus capreolus*, but there does not seem to be much more than a carpal from the former and a P^2 from the latter locality. This P^2 is indeed not very large and is in the metrical ranges of recent *Capreolus capreolus*. The remains from the Khorramabad valley are relatively large and are in the metrical ranges of, what in Western Europe would be called, *Capreolus priscus* or *C. capreolus priscus*, but could also to belong to *C. pygargus*. While *Capreolus pygargus* ranges far south into China, this is possibly the southernmost record of the genus in western Eurasia.

Cervidae indet. cf. *Cervus elaphus.* The tip of an antler (Figure 8-3) from Kaldar Cave has a length of 3 cm. At one side there is probably some rodent gnawing and apart from this the section is round and has a diameter of about 11 mm. Such tips may occur in *Cervus elaphus*, *Cervus unicolor*, *Cervus duvauceli, Cervus eldi* and *Axis*, as well as in the lower tines in the different species of *Dama*. The fragment is too robust for *Capreolus*.

A fragment of a lumbar vertebra from Gilvaran Cave (Figure 8-4) preserves the right side of the vertebral arch, the cranial articular process, and the base of the transverse process. The transverse process is wing-like as is typical of lumbar vertebras, and is directed outward and slightly forward. The cranial articular process has an S-shaped articular surface, as in cervids, but unlike in bovids, equids and carnivores. The curvature of what is left of the wall of the vertebral foramen indicates that this foramen was relatively high, higher than in *Sus scrofa*. The vertebra seems to belong to a cervid. The S-shaped facet is about the only thing that can be measured in this specimen; its length is 18.6 mm. The general size of the specimen is slightly larger than that of a recent *Cervus elaphus* from Spain, which is a small sized subspecies.

Today the large *Cervus elaphus maral* lives in an area that includes the north of Iran, while *C. e. bactrianus* (Turkmenistan, Afghanistan) and *C. e. hanglu* (Norhern India) are also large, as well as *Cervus duvauceli* and *Cervus unicolor* (both living in India) (Whitehead, 1993; Gurung & Singh, 1996). *Cervus elaphus* has been cited or described from Nagorno Karabach (Lioubine 2002; Rivals 2004; Van der Made et al. in press), NE Irak (Evins, 1982) and from Iran (Trinkaus & Biglari, 2006; Mashkour et al., 2008). In some of these cases, it is not clear on which features the determination is based. It seems likely that the material from Kaldar and Gilvaran Caves belongs to *Cervus elaphus*, but we have to await more material to be able to make a determination based on morphology. If confirmed, these finds represent the southern most record of *Cervus elaphus* en the western part of Eurasia.

Caprini indet. cf. *Capra aegagrus.* Some lower molars (Figure 8-9; SOM Figures, 11-5, 11-6) have high crowns, smooth lingual surfaces, lack an interlobular column at the buccal side and have a caprine fold. Some upper molars (SOM figure 11-1) have buccal walls with three pronounced styles, but no buccal crests departing from the para- and metacone (paraexostyle and metaexostyle; nomenclature Van der Made, 1996) and lack a lingual interlobular column. Such a morphology fits Caprinae, such as *Capra*, *Hemitragus*, *Rupicapra*, and *Ovis*, but also antelopes such as *Saiga* and *Pantholops*. The two lower molars measure DAP=12.9, DAPb=11.6, DTa=7.6, DTp=8.5 (KLD-10) and DAP=18.3, DAPb=15.9, DTa≥8.6, DTp≥8.3, Ha>28.4. The upper molar measures DAP=19.2, DAPb=18.2, DTa≈15.2, DTp≈16.1. The size of these molars is large for *Rupicapra*, *Saiga* and *Pantholops*.

Some lower incisors (SOM Figures 11-2, 11-4) are very high crowned as in Caprinae and *Saiga*. The larger one is possibly a I_2 and has the following measurements: DT = 6.6, DLL = 5.2, DMD = 5.7. The smaller one seems to have a distal facet, so cannot be a canine and should be the I_3. Its measurements are: DT = 4.8, DMD = 4.1, DLL = 4.7. In *Saiga*, the size of the incisiform teeth decreases rapidly from I_1 to the canine, while in the caprines, this cline is not so strong. The I_3 is larger than what is expected in *Saiga*, but would fit *Capra*.

The distal part of a first (or "proximal") phalanx from sublevel B at Ghamari Cave has the typical morphology of a ruminant (SOM figure 11-3). The morphology of the distal articulation recalls cervids, but is damaged and it is not possible to rule out small bovids. It is smaller (DAPd=12.3, DTd=16.2) than its homologue in *Cervus elaphus*, close in size to that of *Dama dama* and larger than that of *Axis* (Bivariate diagram Figure 11). Peculiar is its small anteroposterior diameter, which might be due to some minor damage of the planto-axial area, but possibly it is real and is a resemblance to phalanges of *Capra* and a difference with *Dama*.

Each of these elements could be assigned to more than one taxon, but all of them could belong to a species of *Capra* or *Hemitragus*, more or less of the size of *Capra caucasica*. Today *Capra caucasica* and *C. cylindircornis* live in the Caucasus, while *Capra nubiana* (or *C. ibex nubiana*) lives in the Arabian Peninsula, *Capra falconeri* and *C. siberica* live in areas that include parts of Afghanistan and Pakistan, *C. aegagrus* lives in southern Iran and *Hemitragus jemlahicus* lives in the Himalaya as far west as the north of India and two other species or subspecies in Oman and Unites Arab Emirates and in the south of India (Duff & Lawson, 2004; Gurung & Singh, 1996; Aulagnier et al., 2009). Relatively little is known of the fossil record of all these species. *Hemitragus* had a wide geographic distribution and *H. bonali* was common in the late Early and most of the Middle Pleistocene of Europe and if not the direct ancestor of the living species, must have been close to their common ancestor. Fossil material from the Caucasus was assigned to *C. aegagrus* and *C. caucasica* (Lioubine 2002; Touchabramichvili 2003; Rivals 2004; Van der Made et al. in press). *Capra aegagrus* was cited from Shanidar in NE Irak (Evins, 1982). Fossil material from Iran was assigned to *Capra aegagrus* (Marean, 1998; Mashkour et al., 2008) or/and indefinite species (Mashkour et al., 2009). It is generally not clear on which features the specific assignation is based. Whereas the different species can be recognized by their external morphology, it is more difficult to recognize their bones or teeth. Important differences exist in horn core morphology, and there are minor differences in size. It is likely that the material from the Khorramabad Valley belongs to *Capra aegagrus*, but more material is needed to confirm such an assignation with morphology or biometrics.

Bovini indet. The presence of a bovine in Ghamari Cave is indicated by a second upper premolar (Figure 8-6). It is a large (DAP≥19.3, DAPb≥18.2, DT ≥15.3) and high crowned tooth. Numerous fragmentary fossils indicate the presence of a bovine in Gilvaran and Ghamari Caves. Some of the remains belonged to individuals of very large size. *Bos*, *Bison* and *Bubalus* all occured in the Middle to Late Pleistocene of both Europe and the Indian Subcontinent. Indian *Bubalus* reached very large sizes. *Bison* was cited or described from Azokh Cave in Nagorno Karabach (Lioubine 2002; Rivals 2004; Van der Made et al. in press), which is not so far away from Khorramabad. Fossil auerochs *Bos primigenius* or an unidentfied species of *Bos* have been cited from Iran (Mashkour et al, 2008; Trikaus & Biglari, 2006; Mashkour et al., 2012) and the auerochs has been cited tentatively from Shanidar in northern Irak (Evins, 1982). The studied remains from Ghamari Cave do not allow a precise assignation.

Hystrix* sp. cf. *Hystrix indica. An axis from Ghamari (Figure 8-8; SOM figure 12-2) has a dorsal spine that is posteriorly high (17.3 mm from the vertebral foramen to the tip). In Carnivora it is low. The “tooth” is flattened with a relatively flat ventral facet, which is not confluent with the obliquely oriented antero-lateral facets. This is unlike in ruminants. In Proboscidea and Perissodactyla the bone is much larger and in Lagomorpha and even the largest Insectivora (eg. *Erinceus*) it is much smaller. In primates and a large rodent, like *Castor*, the bone is much shorter. The bone has many resemblances to its homologue in *Hystix cristata* (SOM figure 12-1), but also many minor points of difference: the shape of the “tooth” and the circumference of the posterior articulation (the fossil is of a juvenile and the articular surface is not fused) and it is more robust. The minimal width in the middle is 22.4, the width at the anterior facets is 27.2 and at the posterior facets 22.1 mm. The length at the lower side of the specimen is 22.0 mm. The total height is 37.9. mm. Several other vertebra seem to belong to the same species and probably even the same individual.

Hystrix cristata is the largest living species of the genus and is larger than the European fossil forms, but the living species *Hystrix indica* is nearly as large. The latter species occurs today in Iran (Aulagnier et al., 2009) and has been cited from the Iranian Late Pleistocene (Mashkour et al., 2009). It is possible that the material from Ghamari Cave belongs to that species, but this needs to be confirmed.

Micromammals. The small mammals have been identified by comparing with the fossil collections which are housed at IPHES. SOM Table 1 shows the list of most indicative specimens that we have identified.

Taxa	**Anatomic part**	**Level**	**Site**
Gliridae	femur	level 5	GHAMARI
Mustelidae	fragmented femur	level 5	KALDAR
Mustelidae	fragmented femur	level 5	KALDAR
Leporidae?	distal epiphysis femur	level 5	KALDAR
Erinaceidae	fragmented humerus	level 5	GHAMARI
Gliridae	humerus	level 4	KALDAR
Chiroptera indet.	proximal epihysis femur	level 4	GHAMARI
Rodentia indet.	distal epiphisis humerus	level 4	GHAMARI

SOM Table 1.List of identified micromammals from the Khorramabad sites.

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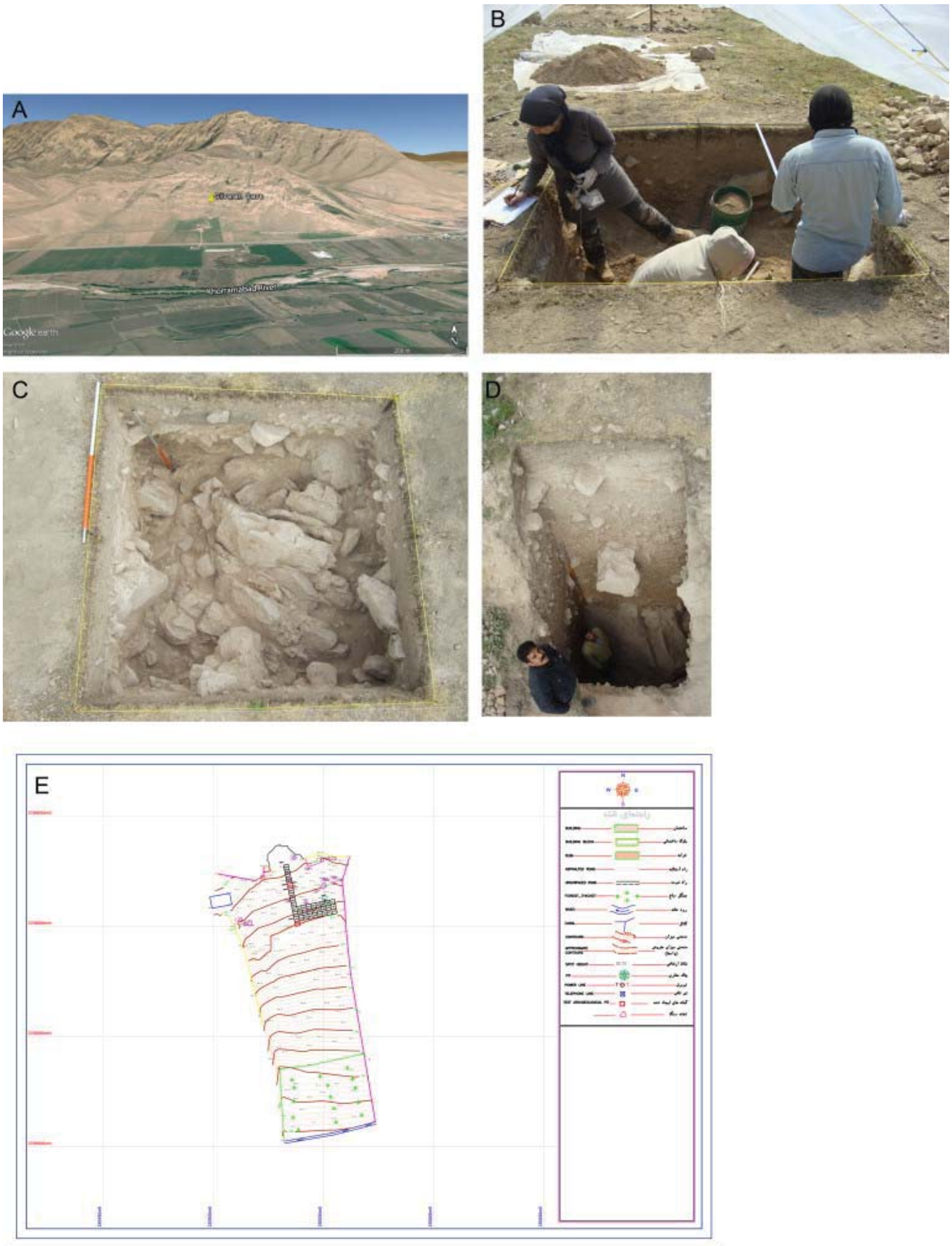
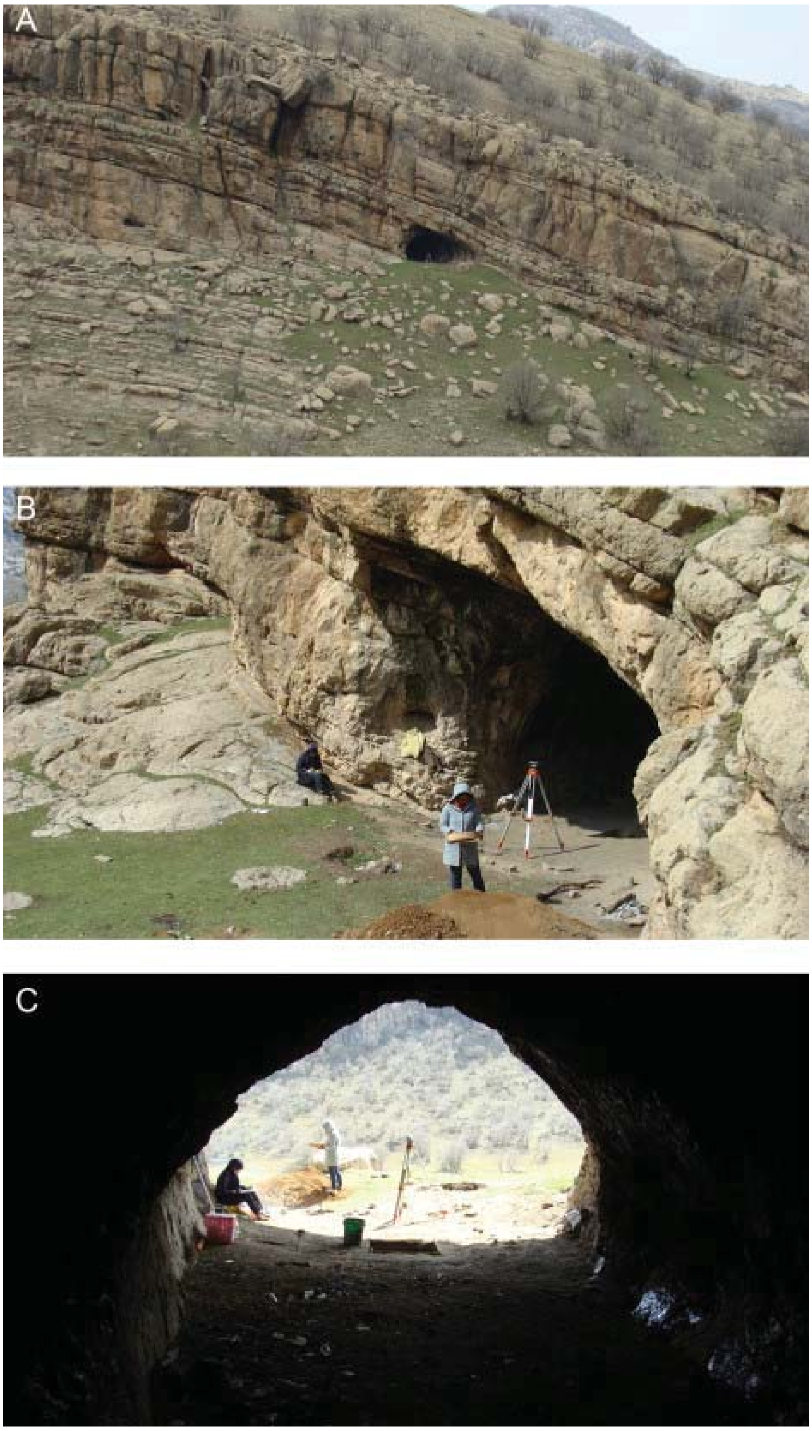


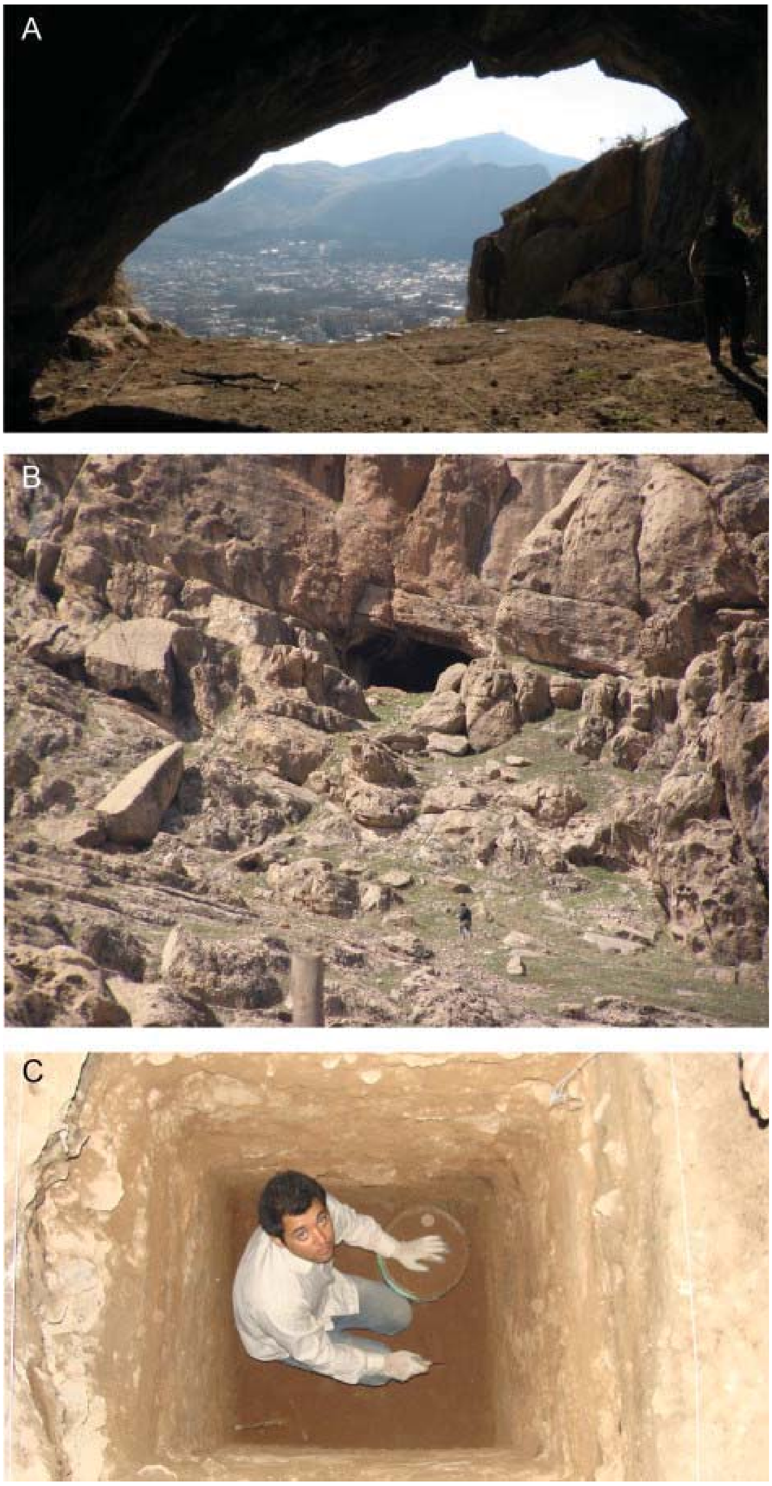
SOM Figure 1. Gilvaran Cave: A) Aerial view and present position relative to the Khorramabad River, general view,B) Excavation of the A8 trench C) A8 trench, exposed huge collapsed rocks D) Position of AY1 trench E) Detailed topography of the cave and surroundings.

SOM Figure 1. Grotte de Gilvaran : A) Vue aérienne et position relative de la Riviére Khorramabad, B) fouilles de la tranchée A8, C) Tranchée A8, énormes rochers effondrés; D) Position de la tranchée AY1 E) Topographie détaillée de la grotte et ses environs.



SOM Figure 2. Kaldar Cave: A) General view, B), Cave entrance C) View from inside the cave and position of the test pit.

SOM Figure 2. Grotte de Kaldar : A) Vue générale, B) Entrée de la grotte, C) Vue de l'intérieure de la grotte et position du sondage.

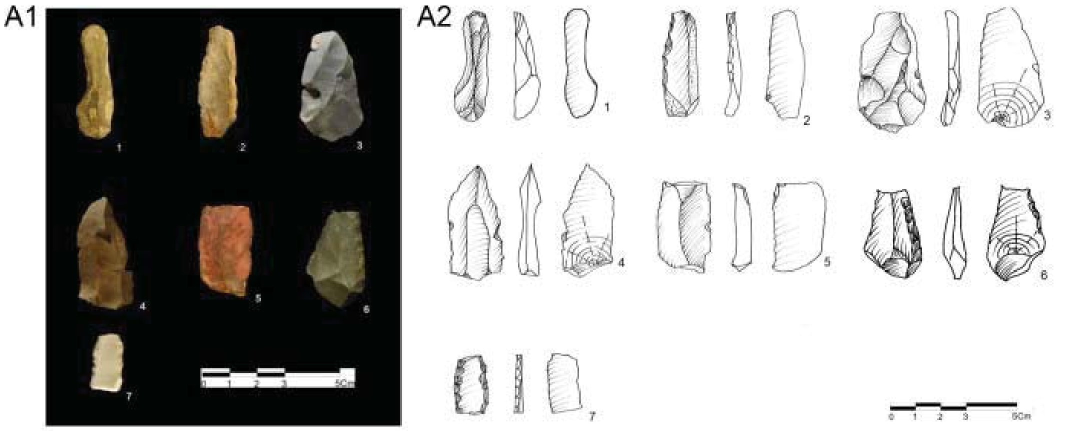


SOM Figure 3. Ghamari Cave: A) Plotting inside the cave B) General view, C) The F2 test pit excavation.

SOM Figure 3. Grotte de Gilvaran : A) disposition intérieure, B) Vue générale, C) Sondage F2.

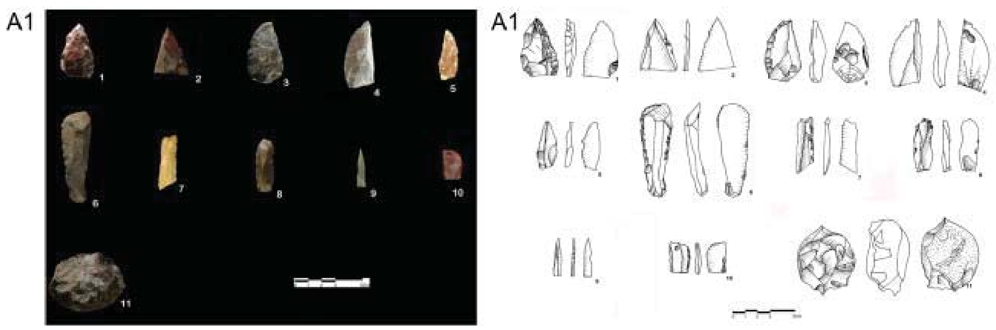
SOM Figure 4. Gar Arjene Rock Shelter: A) General view, B) The H1 test pit excavation, C) The E-4 test pit excavation.

SOM Figure 4. Abri de Gar Arjene : A) Vue générale, B) Sondage H1, C) Sondage E4.



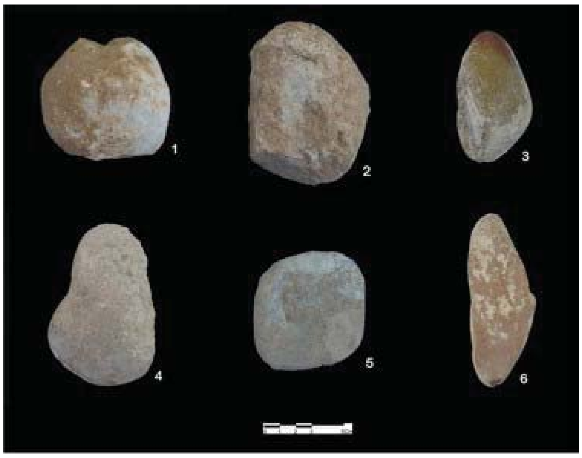
SOM Figure 5. (A1&A2). Selected artifacts from Gilvaran Cave-AY1, level 5&4: 1) Endscraper 2) Sidescraper on natural core- edge blade 3) Pointed flake with dihedral platform 4) Pointed flake with flat platform and pseudo retouch 5) Burnt blade fragment with pseudo retouch 6) Fragment of pointed flake with stepped retouch on the right side 7) Retouched bladelet fragment.

SOM Figure 5. (A1&A2).Sélection d'artefacts de la Grotte Gilvaran-AY1, niveau 5et 4. 1) Grattoir, 2) Racloir sur lame, 3) Éclat appointé à talon dièdre, 4) Éclat appointé avec talon lisse et pseudo-retouch, 5) Lame brulée, 6) Éclat appointé avec retouches scalariformes et pseudo-retouches, 7) Fragment de lame retouchée.



SOM Figure 6. (A1&A2).Selected artifacts from GLV-A8 trench, level 3: 1) Mousterian point, platform is absent, 2) Distal portion of fragmented pointed flake, probably on Levallois blank with pseudo retouch on the right side 3) Sidescraper on core-edge flake with flat platform, the blank could be Levallois recurrent centripetal, 4) Flake produced by Levallois recurrent unidirectional convergent technology, the concretion covers the right side and the platform, 5) Pointed flake, 6), Bilateral retouched bladelet, 7) Fractured blade with retouches on the right side 8) Endscraper, 9) Distal fragment of backed bladelet / Arjeneh point, 10) Burned blade fragment with retouch on the right side, 11) Levallois recurrent unidirectional core.

SOM Figure 6. **(A1&A2).**Sélection d'outils de la tranchée GLV-A8, niveau 3 : 1) Pointe Moustérienne ; 2) Fragment distal d'un éclat appointé sur un support Levallois, 3) Racloir sur éclat latéral à talon lisse, le support peut être Levallois ou récurrent, 4) Éclat produit par Levallois unidirectionnel et convergent, 5) Éclat appointé, 6) Retouches bilatérales sur lamelle, 7) Lame fracturée avec retouches latérales, 8) Grattoir, 9) Fragment distal de lamelle â dos (pointe de Arjeneh), 10) Lame brulée retouchée, 11) Nucleus Levallois.

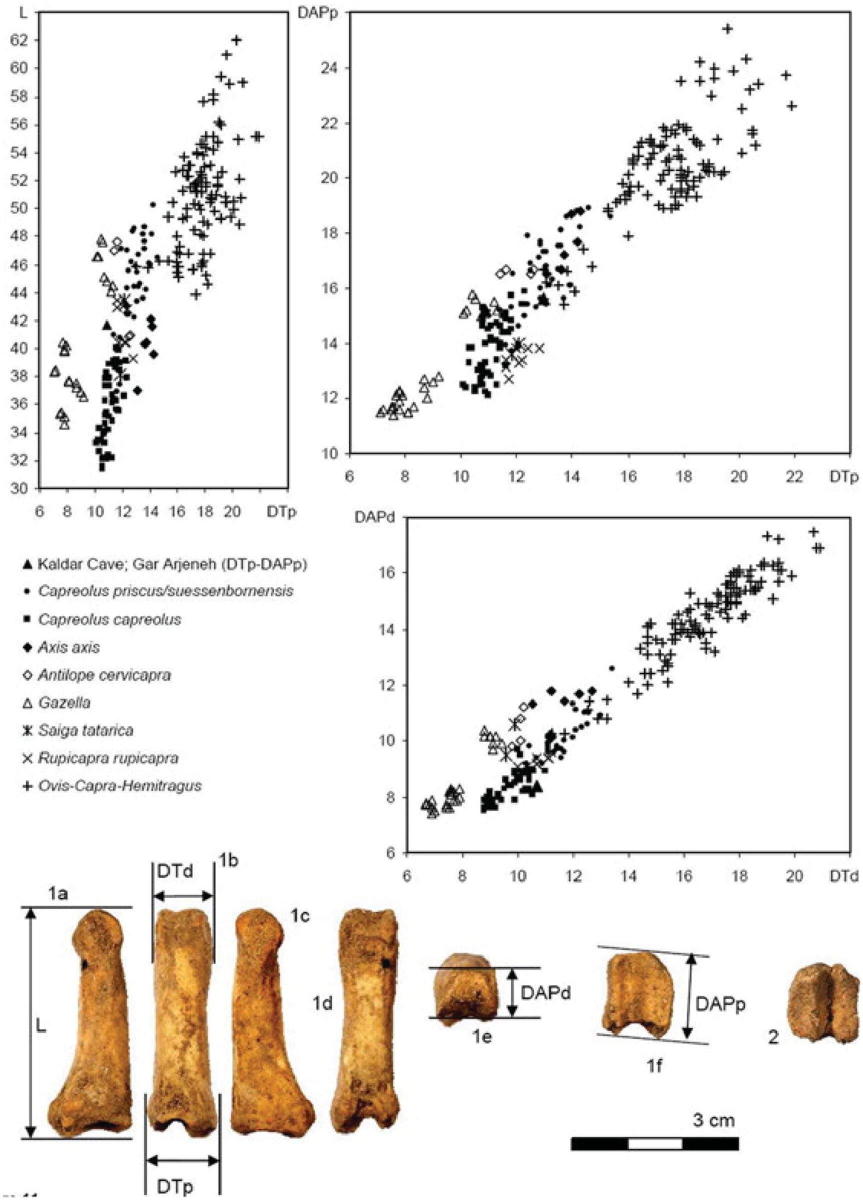


SOM Figure 7. Hammer stones from GLV AY1 & A8 trenches. (1, 2 & 3 AY1 – 4 ,5 & 6 A8).

SOM Figure 7. Percuteur en pierre de GLV AY1 et tranchée 8 (1, 2 & 3 AY1 – 4, 5 & 6 A8).

SOM Figure 8. General and closer view of a Pleistocene deposit of high quality of raw materials in the banks of the Khorramabad River.

SOM Figure 8. Vue générale et détaille d'un dépôt Pléistocène avec des matières premières de bonne qualité sur les rives de la rivière Khorramabad.

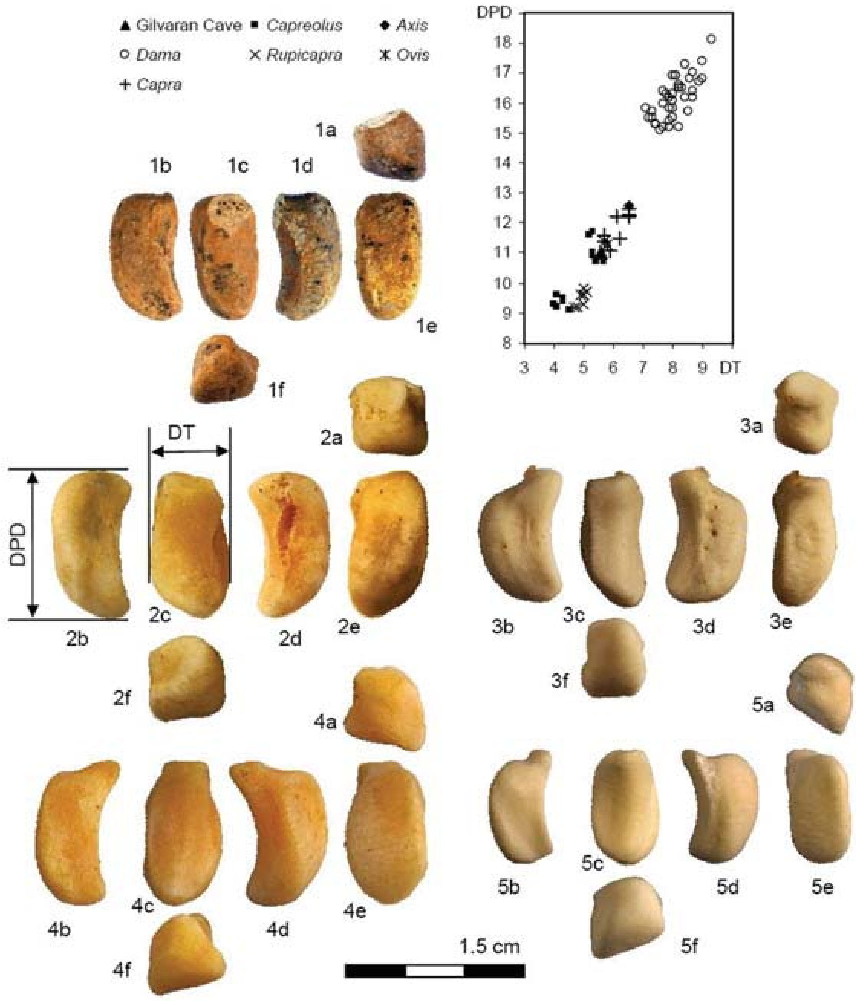


SOM Figure 9: Bivariate diagrams of the first (or proximal) phalanx of: *Capreolus* from Kaldar Cave, level 4 and Gar Arjeneh Rock Shelter (only DTp-DAPp diagram); *Capreolus priscus / suessenbornensis* from Voigtstedt (IQW), Süssenborn (IQW), Koneprusy (NMP), Miesenheim I (FASMN), Azokh V (MUB), Grotte des Cèdres (MRA), Ehringsdorf (IQW); *Capreolus capreolus* from Can Rubau (CIAG), Cueva Morín (MNCN) and recent from Spain (IPHES); recent *Axis axis* (MNCN); recent *Antilope cervicapra* (MNCN); recent *Gazella cuvieri* (MNCN) and recent *Gazella dorcas?* (IPHES, MNCN); recent *Saiga tatarica* (NNML); recent *Rupicapra pyrenaica* (MNCN, all first phalanges of individual no. 14259); and, all together *Capra ibex* from Petralona (AUT); recent *Capra pyrenaica* (IPHES); *Capra caucasica?*from Azykh V (MUB), Ortvala (GSM) and Sakazia (GSM); *Hemitragus bonali* from Hundsheim (IPUW) and feral *Ovis* from Spain (MNCN).

Photographs: 1) KLD-14, level 4 - first phalanx right of the axis of the foot/hand of *Capreolus* from Kaldar Cave; a) axial, b) dorsal, c) abaxial, d) plantar, e) distal, and f) proximal views 2) GRA-5 - proximal epiphysis of first phalanx, left of the axis of the foot from the Gar Arjeneh rock shelter; juvenile, not fused to the diaphysis; proximal view.

SOM Figure 9: Diagramme à deux entrées de la première phalange d'une *Capreolus* de la Grotte Kaldar, niveau 4 et de l'Abri Gar Arjeneh (seulement sur le diagramme DTp-DAPp); *Capreolus priscus / suessenbornensis* de Voigtstedt (IQW), Süssenborn (IQW), Koneprusy (NMP), Miesenheim (FASMN), Azokh V (MUB), Grotte des Cèdres (MRA), Ehringsdorf (IQW); *Capreolus capreolus* de Can Rubau (CIAG), Cueva Morín (MNCN) et récent d'Espagne (IPHES); récent *Axis axis* (MNCN); récent *Antilope cervicapra* (MNCN); récent *Gazella cuvieri* (MNCN) et récent *Gazella dorcas?* (IPHES, MNCN); récent *Saiga tatarica* (NNML); récent *Rupicapra pyrenaica* (MNCN, toutes les premières phalanges de l'individu no. 14259); et ensemble avec *Capra ibex* de Petralona (AUT); récent *Capra pyrenaica* (IPHES); *Capra caucasica?* de Azykh V (MUB), Ortvala (GSM) and Sakazia (GSM); *Hemitragus bonali* de Hundsheim (IPUW) et *Ovis* sauvage de l'Espagne (MNCN).

Photographie: 1) KLD-14, niveau 4 -première phalange droite de *Capreolus* de la Grotte Kaldar; vue a) axiale, b) dorsale, c) latérale, d) plantare, e) distal, et f) proximale. 2) GRA-5 - épiphyse proximale de la première phalange, de l'Abri Gar Arjeneh; jeune individu, diaphyse pas fusionnée; vue proximale.

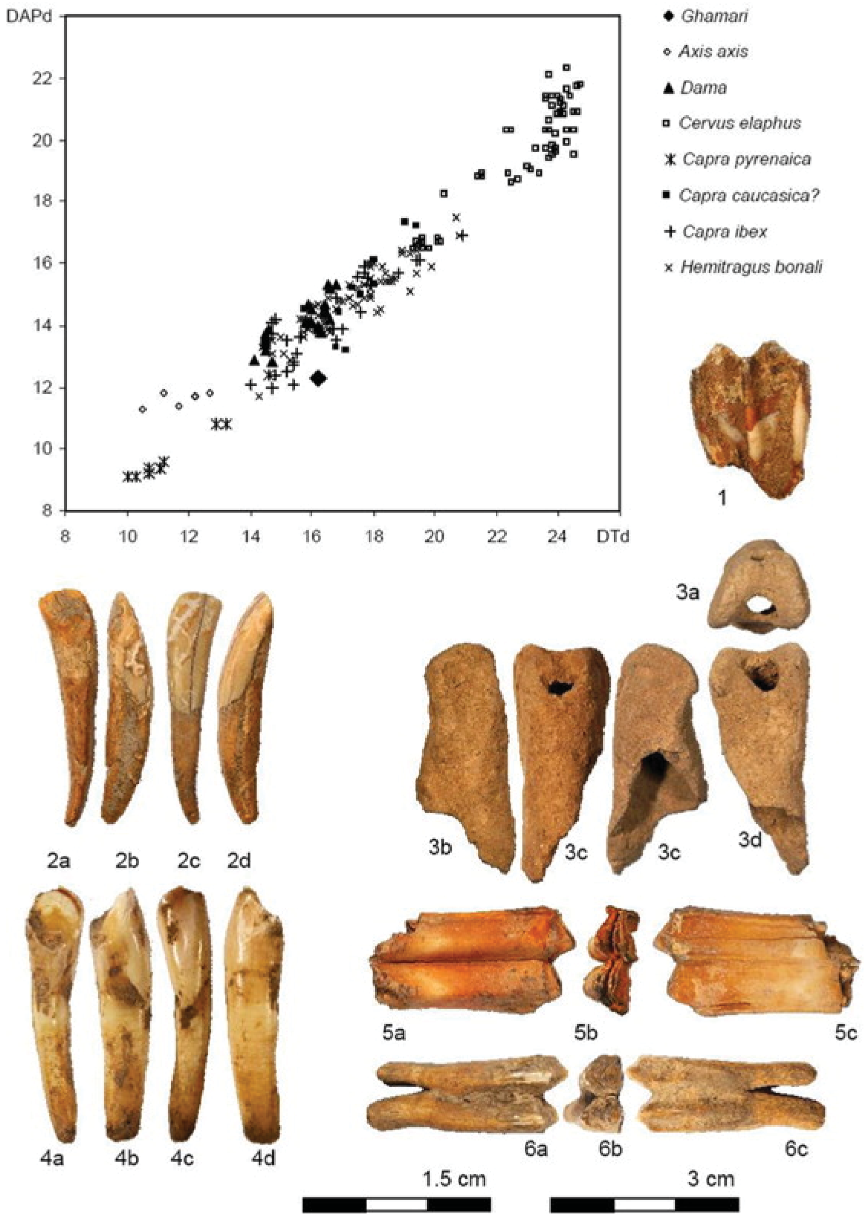


SOM Figure 10. Bivariate diagram of the axial sesamoid behind the first phalanx of: *Capreolus* from Gilvaran Cave, level 5; recent *Capreolus capreolus* from Spain (MNCN); recent *Axis axis* (MNCN); *Dama dama geiselana* from Neumark Nord (LVH); recent *Rupicapra rupicapra* from Spain (MNCN); feral *Ovis* from Spain (MNCN); *Capra pyrenaica* from the Sierra de Gredos (Spain; MNCN).

Photographs: All axial sesamoids from behind the first phalanx, right of the axis of the foot or figured in mirror image (figs 3-5), in each case: a) distal, b) abaxial, c) dorsal, d) axial, e) plantar, and f) proximal views. 1) GLV-AY1-35, level 5 - *Capreolus* from Gilvaran Cave 2) MNCN no number comparative collection Palaeobiology - sesamoid of the manus of *Axis axis* 3) MNCN 21437 - sesamoid of the pes of *Capreolus capreolus* from Otero del Valle (Spain) 4) MNCN 18247 - sesamoid of the manus of *Capra pyrenaica* from the Sierra de Gredos (Spain) 5) MNCN 14259 - sesamoid of the manus of *Rupicapra pyrenaica* from Asturias (Spain).

SOM Figure 10. Diagramme â double entrée de sésamoïde dernière la première phalange de: *Capreolus* de la Grotte Gilvaran, niveau 5; récent *Capreolus capreolus* d'Espagne (MNCN); récent *Axis axis* (MNCN); *Dama dama geiselana* de Neumark Nord (LVH); récent *Rupicapra rupicapra* d'Espagne (MNCN); *Ovis* sauvage de l'Espagne (MNCN); *Capra pyrenaica* de la Sierra de Gredos (Espagne; MNCN).

Photographie: sésamoïdes axiaux, à l'arrière de la première phalange, du côté droite de l'axe du pied (figs 3-5), dans chaque cas: vue a) distale, b) latérale, c) dorsale, d) axiale, e) plantaire, et f) proximale. 1) GLV-AY1-35, niveau 5 - *Capreolus* de la Grotte Gilvaran 2) MNCN exemplaire sans numeró de la collection du département de paleobiologie - sésamoïde du pied de *Axis axis* 3) MNCN 21437 - sésamoïde de le pied de *Capreolus capreolus* de Otero del Valle (Espagne) 4) MNCN 18247 - sésamoïde de le pied *Capra pyrenaica* de the Sierra de Gredos (Espagne) 5) MNCN 14259 – sésamoïde de le pied de *Rupicapra pyrenaica* de Asturias (Espagne).



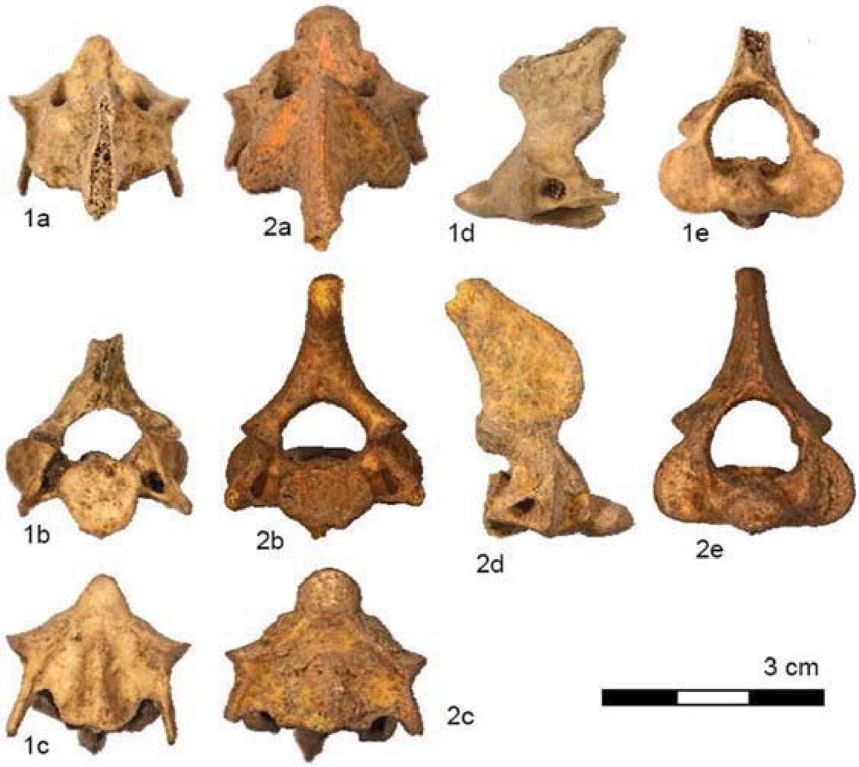
SOM Figure 11. Bivariate diagram of the first phalanx of: Ghamari Cave specimen GHM-17; recent *Axis axis* (MNCN, HUJ); *Dama dama geiselana* from Neumark Nord (LVH); *Cervus elaphus* from Neumark Nord (LVH) and Roter Berg (NMB); recent *Capra pyrenaica* (MNCN, IPHES); *Capra caucasica?*from Azykh V (MUB), Ortvala (GSM) and Sakazia (GSM); *Capra ibex* from Petralona (AUT); *Hemitragus bonali* from Hundsheim (IPUW).

Photographs: 1) KLD-12, level 5 - left $M^{1/2}$ of *Capra* from Kaldar Cave; buccal view 2) GLV-AY1-97, level 3 - left I_2 of *Capra* from Gilvaran Cave; a) lingual, b) mesial, c) labial, and d) distal views 3) GHM-17, level 4 - distal fragment of a first (or "proximal") phalanx from Ghamari Cave of cf. *Dama mesopotamica*; a) distal, b) axial, c) dorsal, d) abaxial, and e) abaxial views 4) KLD-20, level 4 - right I_3 of *Capra* from Kaldar

Cave; a) lingual, b) distal, c) labial, and d) mesial views 5) GHM-48, level 5 - left $M_{1/2}$ (M_2?) of *Capra* from Ghamari Cave; a) buccal, b) occlusal, and c) lingual views 6) KLD-10, level 5 - left $M_{1/2}$ (M_1?) of *Capra* from Kaldar Cave; a) buccal, b) occlusal, and c) lingual views. The scale bar represents 1.5 cm for figure 4 and 3 cm for the remaining figures.

SOM Figure 11. Diagramme â deux entrées de la première phalange de: Grotte Ghamari spécimen GHM-17; *Axis axis* récente (MNCN, HUJ); *Dama dama geiselana* de Neumark Nord (LVH); *Cervus elaphus* de Neumark Nord (LVH) et Roter Berg (NMB); *Capra pyrenaica* récente (MNCN, IPHES); *Capra caucasica?*de Azykh V (MUB), Ortvala (GSM) et Sakazia (GSM); *Capra ibex* de Petralona (AUT); *Hemitragus bonali* from Hundsheim (IPUW).

Photographie: 1) KLD-12, niveau 5 - $M^{1/2}$ gauche de *Capra* de Grotte Kaldar; vue buccale 2) GLV-AY1-97, niveau 3 - I_2 gauche de *Capra* de la Grotte Gilvaran; vue a) linguale, b) mesiale, c) labiale, et d) distale. 3) GHM-17, niveau 4 - fragment distal d'une phalange de la Grotte Ghamari de cf. *Dama mesopotamica*; vue a) distale, b) axiale, c) dorsale, d) latérale, et e) latérale. 4) KLD-20, niveau 4 - I_3 droite de *Capra* de la Grotte Kaldar; vue a) linguale, b) distale, c) labiale, et d) mesiale. 5) GHM-48, niveau 5 - $M_{1/2}$ (M_2?) gauche de *Capra* de la Grotte Ghamari; vue a) buccale, b) occlusale, et c) linguale. 6) KLD-10, niveau 5 - $M_{1/2}$ (M_1?) gauche de *Capra* de la Grotte Kaldar; vues a) buccale, b) occlusale, et c) linguale. L'échelle est de 1,5 cm à la figure 4 et 3cm pour les autres figures.



SOM Figure 12.

1) CENIEH O-75 - axis of *Hystrix cristata*; a) dorsal, b) posterior, c) ventral, d) left lateral, and e) anterior views. 2) GHM-F2-22, level 4 - axis of *Hystrix* from Ghamari; a) dorsal, b) posterior, c) ventral, d) right lateral, and e) anterior views.

SOM Figure 12.

1) CENIEH O-75 - axis de *Hystrix cristata*; vues a) dorsal, b) postérieure, c) ventrale, d) latéral gauche, et e) antérieure. 2) GHM-F2-22, niveau 4 - axis de *Hystrix* de Ghamari; vues a) dorsale, b) posterieure, c) ventrale, d) latérale droite, et e) antérieure.

2.6.2.1.9. Publication 4: Bazgir, B., Ollé A., **Tumung L.,** Becerra-Valdivia L, Douka K., Higham T, Van der Made J, Picin A., Saladié P, Manuel López-García J, Blain H, Allué E, Fernández-García M., Rey-Rodríguez I, Arceredillo D., Bahrololoumi F., Azimi M., Otte M. and Carbonell E. 2017. Understanding the emergence of modern humans and the disappearance of Neanderthals: Insights from Kaldar Cave (Khorramabad Valley, Western Iran). *Scientific Reports* 7, 43460.

This article represents the results from the full fledge excavation of the Kaldar site. The article tries to explain the Modern human dispersal from western Asia to Europe and also reveals the newfound TL and C14 dates for the Upper Paleolithic Level. Here we even try to reconstruct the paleoenvironment of the site by combining the study of zooarcheology, palaeontology, micro-mammals and charcoal analysis.

SCIENTIFIC REPORTS

OPEN

Received: 10 August 2016
Accepted: 25 January 2017
Published: 02 March 2017

Understanding the emergence of modern humans and the disappearance of Neanderthals: Insights from Kaldar Cave (Khorramabad Valley, Western Iran)

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Kaldar Cave is a key archaeological site that provides evidence of the Middle to Upper Palaeolithic transition in Iran. Excavations at the site in 2014–2015 led to the discovery of cultural remains generally associated with anatomically modern humans (AMHs) and evidence of a probable Neanderthal-made industry in the basal layers. Attempts have been made to establish a chronology for the site. These include four thermoluminescence (TL) dates for Layer 4, ranging from 23,100 ± 3300 to 29,400 ± 2300 BP, and three AMS radiocarbon dates from charcoal samples belonging to the lower part of the same layer, yielding ages of 38,650–36,750 cal BP, 44,200–42,350 cal BP, and 54,400–46,050 cal BP (all at the 95.4% confidence level). Kaldar Cave is the first well-stratified Late Palaeolithic locality to be excavated in the Zagros which is one of the earliest sites with cultural materials attributed to early AMHs in western Asia. It also offers an opportunity to study the technological differences between the Mousterian and the first Upper Palaeolithic lithic technologies as well as the human behaviour in the region. In this study, we present a detailed description of the newly excavated stratigraphy, quantified results from the lithic assemblages, preliminary faunal remains analyses, geochronologic data, taphonomic aspects, and an interpretation of the regional paleoenvironment.

Understanding the initial spread of anatomically modern humans (AMHs) out of Africa is a key goal for palaeo-anthropologists. AMHs originated in Africa and spread across the Middle East into Eurasia and towards Australia and the Americas. These AMHs were the first humans to occupy the latter two continents, but they replaced

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other populations in Eurasia. Because few well-dated human remains are available to study this dispersal process, the spread of AMHs is best documented by the appearance of the early phase of their culture, inferred to be the Aurignacian (but see ref. 1). In western Eurasia, this technocomplex replaced the Mousterian, associated in this region with Neanderthals. This transition may have occurred at approximately 50 to 40 ka (see refs 2–7).

One key area relevant to the dispersal process is Iran and Iraq, particularly the Zagros Mountains. Since the first survey of the Zagros by D. Garrod in 1930, Palaeolithic deposits and surface finds have been reported from a large number of caves, rockshelters, and open-air sites, but few of them have been fully excavated. Locally, the early phase of the technocomplex associated with early AMHs is known as the Baradostian. The early Upper Palaeolithic assemblages are also known as the Rostamian, which is defined as a bladelet-based technocomplex[8–11]. Although Conard et al. view the Rostamian as an industry distinct from the Baradostian[11], both terms refer to the early Upper Palaeolithic in the Zagros region.

Many of the researchers who study materials from the Zagros agree that the lithic assemblages from this region share some features with assemblages from central Europe and the Levant. These include typo-technological characteristics of the Aurignacian tradition as well as inter-assemblage variability[12–14]. Olszewski and Dibble[12], for example, proposed changing the name of the Baradostian to the 'Zagros Aurignacian' in light of the perceived similarities with Aurignacian material.

There is disagreement, however, regarding whether the Upper Palaeolithic evolved from earlier Mousterian industries in the region[15]. Some authors have proposed that the Baradostian might have developed locally from the Mousterian[5,12–14,16–32]. On the one hand, recent work on two stratified assemblages from Warwasi and Yafteh support an *in situ* evolution of the Upper Palaeolithic from the local Mousterian[15]. That study, however, focused on only two assemblages; thus, the conclusions might not be fully applicable to the entire Zagros region. On the other hand, Tsanova[15] raised doubts about whether the Iranian Zagros was the source of bladelet technology. However, the discovery of over 90 sites in the southern Zagros mostly associated with bladelet-based technologies—one of which dates to 40,000 cal. BP—suggests that the technology in the region featured a high degree of complexity[5,8–11].

Additionally, the Zagros is more than 2,000 km long from northwest to southeast and up to several hundred kilometres wide from east to west[27]. Due to the lack of extensive surveys and archaeological excavations in the region, many aspects remain poorly understood. The latest typo-technological analyses on the lithic assemblage from the site of Ghar-e-Khar, for example, indicate the presence of multiple sites containing both Middle and Upper Palaeolithic sequences in the Zagros region. These findings confirm the potential for continued research into the Middle to Upper Palaeolithic transition[33]. However, only a few excavated sites contain uninterrupted archaeological sequences that include both Middle and Upper Palaeolithic deposits[34]. Some well-excavated sites, e.g., Yafteh, do not have Middle Palaeolithic occupation levels. Besides the reported sites in the Gilvaran and Ghamari caves[35], Warwasi and Ghar-e-Khar are the only sites in the Iranian Zagros containing cultural remains belonging to both the Middle and Upper Palaeolithic (Fig. 1). To date, however, neither has been dated. Warwasi and Ghar-e-Khar were coarsely excavated (20 cm spits in Warwasi and 10–30 cm spits in Ghar-e-Khar). Chronometric control of the sites has been hampered by the poor preservation of organic material extracted from the archaeological sites and by political challenges and instability, which have made excavation work virtually impossible for more than 20 years. Here, we present the recently excavated and dated well-stratified sequence of Kaldar Cave, which documents the transition from the Middle to the Upper Palaeolithic.

Results

Site stratigraphy. Kaldar Cave is situated in the northern Khorramabad Valley at 48° 17′35″E longitude, 33°33′25″N latitude, and an elevation of 1,290 m above sea level. It is 16 m long, 17 m wide, and 7 m high. The potential of this site for excavation was first realized during a survey in 2010, when we started our regional study of the Khorramabad Valley as a goal-oriented research project. The first excavation[35] was conducted in 2011–12.

The 2014–15 excavation focused on gaining a better understanding of the stratigraphy and obtaining samples for dating. We opened a 3×3 m trench near the entrance and kept a 50 cm bulk sample from the previous test pit (squares E5, E6, E7, F5, F6, F7, G5, G6 and G7) (Supplementary Fig. S1). The excavation was conducted using spits of 5 cm within each archaeostratigraphic unit, as well as 3D recording of all findings.

The excavated trench exposed an approximately 2-m (195-cm) section of the sedimentary deposit, which is characterized by five main layers. During fieldwork, distinctions within the layers were made according to minor sedimentological differences. Ongoing microstratigraphic research will provide a proper characterization of the sub-layers.

Layers 1 to 3 (including sub-layers 4 and 4II) consist of ashy sediment with a blackish-green colour containing both thick and thin angular limestone clasts. These layers varied in thickness from 60 to 90 cm and contained many phases dating to the Holocene: the Islamic and historical eras, Iron Age, Bronze Age, Chalcolithic, and Neolithic. However, due to the presence of some bioturbation in these layers, the phases were recognized only by a preliminary study of the potsherds, metal artefacts and some diagnostic lithic artefacts from the lower layers.

Layer 4 (including sub-layers 5, 5II, 6 and 6II) consists a silty but compact dark-brown sediment with cultural remains from the Upper and early Upper Palaeolithic. In the uppermost parts of this layer, two fireplaces made of clay were recovered and dated through thermoluminescence, yielding ages that ranged from 23100 ± 3300 to 29400 ± 2300 BP (Table 1). The dates obtained show that these fireplaces were made or re-used from existing older sediment from the upper part of this layer in the later stages of the Upper Palaeolithic. AMS radiocarbon dates of 38650–36750 cal BP, 44200–42350 cal BP, and 54400–46050 cal BP have been obtained from charcoal material located below this layer (Table 2).

Layer 5 (including sub-layers 7 and 7II) consists of an extremely cemented reddish-brown sediment with some small angular limestone blocks and Middle Palaeolithic artefacts (Figs 2a,b and 3). To date, no radiometric data are available for this layer.

Figure 1. The excavated sites containing Middle Palaeolithic and early Upper Palaeolithic sequences in the Zagros. (Source of the original map: https://commons.wikimedia.org/wiki/File:Iran_relief_location_map.jpg (under the license of Creative Commons Attribution-Share Alike 3.0 Unporte). Modified by B. Bazgir. Original license pages: https://en.wikiedia.org/wiki/Creative Commons - https://creativecommons.org/licenses/by-sa/3.0/deed.en.

Sample	Specifications	Th	Ur	K2%	Equivalent Dose (ED)	Age
1	Layer 4: sub-layer 5, E6-7	1.76	3.95	0.81	73.64	26025 ± 2002
2	Layer 4: sub-layer 5, E6-7	2.94	1.86	0.97	51.97	29400 ± 2300
5	Layer 4: sub-layer 5, E6-7	2.46	5.54	1.29	178.79	25500 ± 2500
4	Layer 4: sub-layer 5, E5	1.51	3.30	1.19	64.85	23100 ± 3300

Table 1. List of thermoluminescence dating results from Kaldar Cave.

Sample	OxA-	Archaeological context	$\delta^{13}C$ (‰)	Conventionl radiocarbon age (BP)	Calibrated date (95.4% probability)
723	32238	Trench (T) 1; Layer 4, sub-layer 5; SQ E6; 69 (X), 12 (Y), 110 (Z)	−23.0	33,480 ± 320	38650–36750 cal BP
—	32239	T1; Layer 4, sub-layer 5; SQ G6	−23.1	964 ± 26	1000–1200 AD
—	32240	T1; Layer 5, sub-layer 7II; SQ F7	−27.1	1.09665 ± 0.00323**	1850–1950 AD
274	X-2645-11	T 1; Layer 4, sub- layer 5; SQ E7; 78 (X), 5 (Y), 85 (Z)	−23.4	39,300 ± 550	44200–42350 cal BP
869	X-2645-12	T1; Layer 4, sub-layer 5II; SQ E6; 45 (X), 100 (Y), 125 (Z)	−24.5	49,200 ± 1800	54400–46050 cal BP

Table 2. Radiocarbon results for charcoal samples from Kaldar Cave.

Bioturbation or disturbance was plotted, and sediment associated with the disturbance was removed without coordinating the finds, which were recorded as general finds with their approximate depths. Isolated evidence for intrusion below the Holocene layers was identified in a deep pit in square E7 in the upper part of the junction of sub-layers 5 and 5II. In the remainder of the site's sequence, these layers are extremely hard and contain no evidence of bioturbation or disturbance. Heavy hammers and chisels were necessary to excavate these deposits (Supplementary Fig. S2). Consequently, we reached bedrock only in squares E6, E7, F6 and F7 (Supplementary Fig. S3).

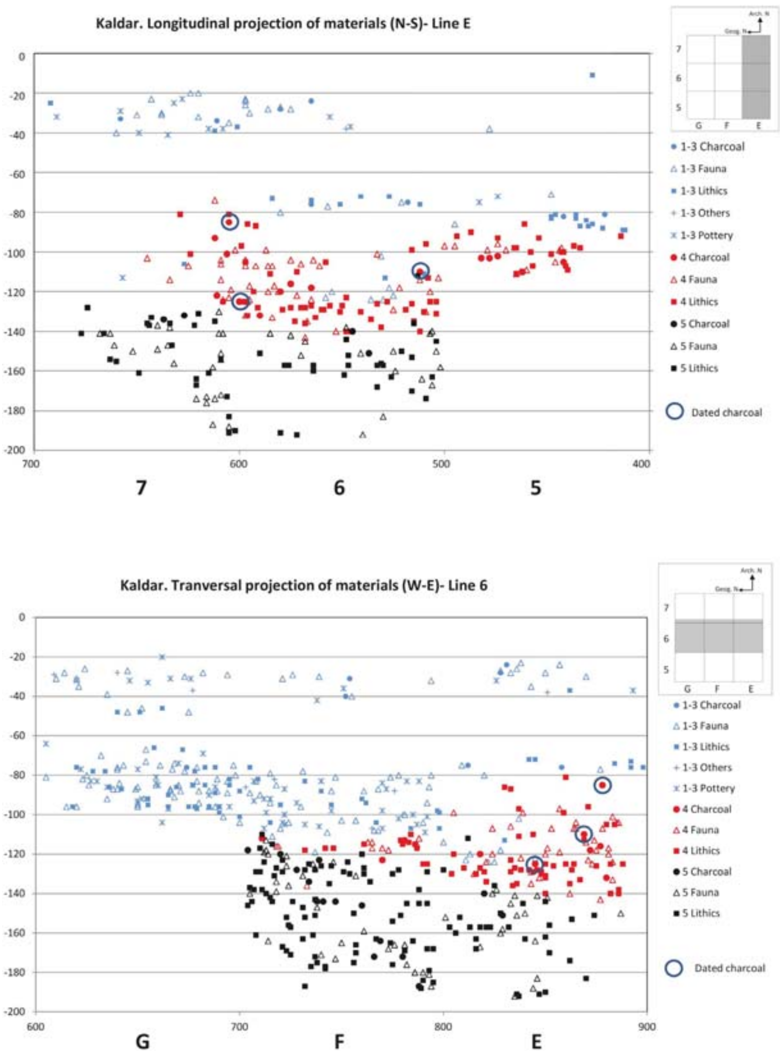

Figure 2. (**a**) North-south longitudinal projection of the materials from squares in line E. (**b**) West-east transversal projection of the materials from squares in line 6. Materials from Layers 1 to 3 have been projected together (blue). Projected separately are the materials from Layer 4 (red) and Layer 5 (black). Created by A. Ollé and B. Bazgir.

Faunal and floral remains. Bioarchaeological remains recovered to date allow us to make some initial environmental inferences and to correlate the faunal and the lithic records to reconstruct human subsistence activities.

A small portion of the faunal assemblage from Kaldar Cave was previously described[35], but the recent excavations have yielded new material—some of which is described in the supplemental information (Supplementary Information, Supplementary Fig. S11). The preliminary study of the small vertebrates from Kaldar Cave has identified 218 remains coming from Layer 4 (sub-layer 5II) and Layer 5 (sub-layer 7II), comprising rodents, squamate reptiles, and amphibians. The updated faunal list is given in Table 3. There is no indication of a faunal change coincident with the cultural change from Layer 5 to Layer 4.

Most of the amphibians and reptiles (Agamidae, *Eryx* and Elapidae) live in savannah, steppe and desert environments and feature lifestyles linked to warm arid areas in rocky or sandy environments. *Pseudopus* lives in dry and bushy environments, sometimes in open woodlands, but avoids dense forest areas. The two most abundant rodent species in both Layers 4 and 5 are *Microtus* gr. *socialis* and *Meriones* spp., indicating that the environment surrounding the cave was composed mainly of dry open areas, with some vegetation cover, as indicated by the presence of Gliridae and Murinae taxa in both layers. *Cervus elaphus*, *Sus scrofa* and *Capreolus* may have preferred the more closed and humid environments in the valley near the river, whereas *Equus* may have favoured more open environments somewhat farther away on the flood plain (which could not have been very wide).

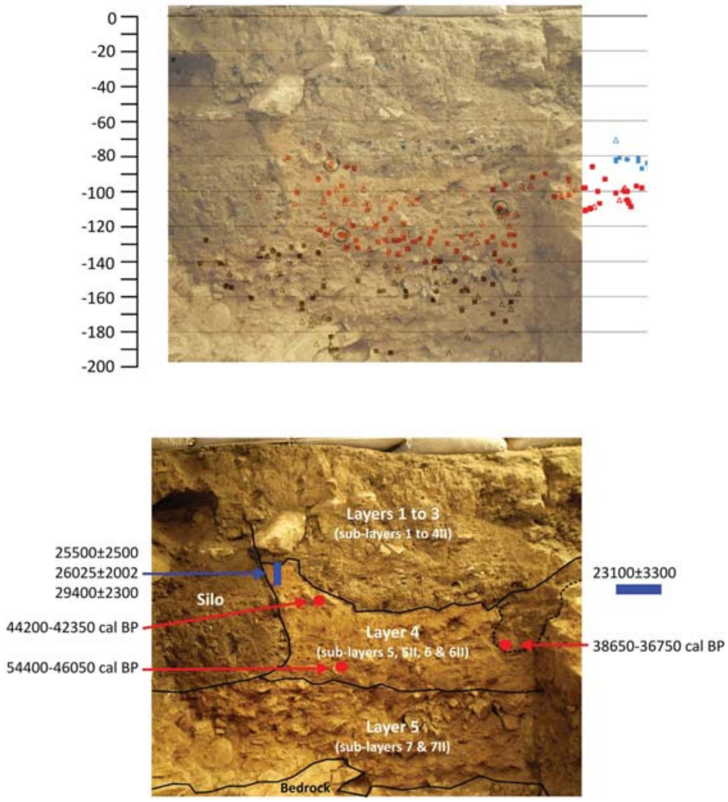

Figure 3. (Above) Stratigraphy (eastern section) along with transparent north-south longitudinal projection of the materials from squares in line E. (Below) Stratigraphy (eastern section) with location and results of the dated samples. Created by A. Ollé and B. Bazgir.

Additionally, *Capra* may have lived in the higher areas. The region surrounding the cave was likely relatively humid close to the river and drier farther away, i.e., more or less similar to the modern conditions.

The charcoal assemblage shows the presence of *Prunus* (Layers 4 and 5) and *Salix* (Layer 5). This would suggest the presence of tree cover composed of willows near the river and open woodland possibly composed of several species including plum trees farther away. The presence of these taxa support the interpretation of an open woodland under mild climatic conditions inferred from the other proxies.

The animal species present in Kaldar Cave originated long before the Late Pleistocene. Some of the species show changes during this period, but the material from Kaldar Cave is not yet sufficient to assess the evolutionary level of these species. Thus, from this perspective, the fauna has limited biochronological value at the scale needed here.

A preliminary taphonomic analysis of the small mammal assemblage has shown a high number of digested elements, suggesting predation activity. According to the different degrees of digestion observed in the remains (light, moderate and some heavy), a category 3 predator, such as the tawny owl (*Strix aluco*) or the Eurasian eagle owl (*Bubo bubo*[36]), might be responsible. Both species are compatible with the inferred habitat and are present in the area today[37]. Additionally, both have opportunistic hunting habits and are sedentary; therefore, their prey well represents the local ecosystem.

The large vertebrates in Layers 4 and 5 are represented by highly fractured bones and teeth. Only seven complete remains (8.2% in Layer 4 and 7.1% in Layer 5) were recovered (1 unciform of *Capra*, 1 coracoid of *Testudo*, 1 tarso-metatarso of Aves from Layer 4; 2 teeth, 1 sesamoid of *Capra* and 1 caudal vertebra of a small mammal from Layer 5). Remarkably, approximately half of both sets (44.7% and 50%, respectively) are shaft fragments. An analysis of the fracture edges (according to Villa and Mahieu[38]) shows that breakage of the bones occurred when they were fresh because most fracture delineations are curved or v-shaped (59.4%) and longitudinal (36.8%), with oblique angles (85.8%). Despite the high degree of fracturing of the large vertebrate bones and teeth in Layers 4 and 5, the assemblages on the whole appear to be well preserved. Post-depositional modifications were generally scarce in the Kaldar assemblage, except for black stains from manganese oxide deposits, which were found on 24.1% of the Layer 4 remains and on 30.9% of the Layer 5 remains, and the cemented sediment attached to surfaces, which were found on 18.2% of the Layer 5 remains. These modifications suggest alternating damp and dry

	Layer 4	Layer 5
Mammals		
Carnivora		
Mustelidae indet.		x
Perissodactyla		
Equus sp. (horse)	x	
Artiodactyla		
Sus scrofa (wild boar)	x	
Capreolus sp. (roe deer)		x
Cervus elaphus (red deer)	x	x
Capra cf. *aegagrus* (goat)	x	x
Rodents		
Microtus gr. *socialis* (social vole)	x	x
Chionomys cf. *nivalis* (European snow vole)	x	
Ellobius cf. *lutescens* (Transcaucasican mole vole)		x
Ellobius cf. *talpinus* (northern mole vole)	x	
Ellobius sp. (mole vole)	x	x
Cricetulus cf. *migratorius* (migratory hamster)	x	x
Mesocricetus cf. *brandti* (Turkish hamster)	x	x
Calomyscus sp. (mouse-like hamster)		x
Meriones spp. (two morphotypes of gerbil)	x	x
Cf. *Allactaga* sp. (toad jeroba)		x
Myominus sp. (mouse-tailed dormouse)		x
Dryomys cf. *nitedula* (forest dormouse)		x
Apodemus cf. *flavicollis* (yellow-necked mouse)	x	x
Mus cf. *musculus* (house mouse)	x	x
Birds		
Aves indet.	x	
Reptiles		
Agamidae indet. (agamid lizard)	x	x
Gekkonidae indet. (gecko)		x
Scincidae indet. (skink)		x
Lacertidae indet. (lacertid lizard)	x	x
Pseudopus sp. (glass lizard)		x
Eryx sp. (sand boa)	x	x
Colubrinae indet. (6 morphotypes)		x
Elapidae indet. (cobra)		x
Viperidae indet. (viper)	x	x
Testudo sp. (tortoise)	x	
Amphibians		
Bufo sp. (toad)		x
Anura indet.	x	
Crustaceans		
Crustacea indet. (crab)	x	

Table 3. Distribution of the faunal taxa identified in Kaldar Cave, Layers 4 and 5.

periods in the cave during the formation of Layer 5. Furthermore, sub-aerial weathering (stage 1 according to Behrensmeyer[39]) has been identified in just one specimen in each of the layers.

Evidence of anthropogenic activity appears in three ways: cut marks, bone fracturing, and cremations (Supplementary Fig. S4). Cut marks were observed on thirteen specimens: five from Layer 4 and eight from Layer 5. The remains from Layer 4 are long bones (humerus of Caprini, two tibia fragments and one femur of Cervidae and a long bone shaft of an indeterminate mammal). The cut marks appear in the form of slicing and scraping marks, and all instances are located on the shaft portions, indicating the defleshing of the carcasses. In Layer 5, the elements with cut marks comprise one radius and one tibia of *Capra*, one rib and one caudal vertebra of indeterminate taxa and four indeterminate long bone fragments. The incisions on the rib fragment were located on the neck of the bone and were associated with disarticulation activities. The incisions on the caudal vertebrae were located in the central part of the bone. The positions of the marks suggest that they are related to skinning tasks.

Other bones have cut marks in midshaft positions, indicating defleshing of the carcasses. The *Capra* radius with cut marks also had an impact point produced by the anthropogenic breakage of the bone.

Among the anthropogenic modifications of the bones in Kaldar Cave, the most important are the changes in coloration due to cremation, which is present in all layers. Fully 23.2% of the remains of the assemblage are burned (24.1% in Layer 4 and 21.8% in Layer 5). These remains include charred (black coloured, 34.4%) and rubefacted (brown and red coloured, 9.4%) bones. Bones with multiple colours are also common (53.2% of the burned bones). The most common combination is rubefacted (brown) and charred (black) colours (46.9%) on the same bone, although partially calcined (grey-blue-white colours) specimens are also present. The presence of multiple colours on the surface of the bones has been associated with meat cooking[40]. The distribution of the colours is homogeneous on the surface and affects the fracture edge and the cortical and medullar faces, suggesting that the bones were burned after they had been broken. According to several experimental studies[40–42], the presence of multiple colours indicates that the bones (regardless of the size) experienced cremation damage when they were fresh and unburied. The origin of this modification may be related to cooking but may also be related to their use as fuel for the maintenance of fires, cleaning of the living floor, or accidentally building a fire near the location where the bones had been deposited.

Little carnivore activity is recorded by the assemblage. Three bones in Layer 4 (1 tibia of Cervidae and 2 indeterminate long bones) showed carnivore tooth marks (Supplementary Fig. S4e). It is difficult to determine the size of the carnivore because only a few tooth marks are recorded. However, the low frequency of these modifications suggests carnivores played a limited role in the formation and/or modification of assemblage.

The zooarchaeological results suggest that not only were the early AMHs that occupied Kaldar Cave among the first to come into contact with large Palaearctic mammals but that they also quickly adapted to exploiting them as a resource.

Lithic industry. The technological analysis of the archaeological samples associated with the Mousterian assemblage from Kaldar Cave (Layer 5 - sub-layers 7 and 7II) indicates that by-products (fragments and flake fragments) are the most common elements (12%) followed by retouched tools (10.8%), Levallois flakes (8.5%), cortical pieces (5.8%), Levallois blades (4%), Levallois points (2.4%), Levallois cores (0.8), other types of cores (0.8%) and hammerstones (0.4%). A large amount of debris (54.5%) is also present in the assemblage. The flakes are dominated by Levallois and cortical pieces, mostly with elongated morphologies and predetermined pointed shapes. Among the 82 flakes counted, 24.4% are cortical pieces, 24.4% are retouched, 20.7% have pointed shapes, 15.8% are broken, and 15.8% show enough major characteristics to be defined as a Levallois flake. Among the blade group, 37.1% are pointed in shape, 25.9% do not fit within a standard category, 14.8% are cortical, 11.1% are broken, 7.4% are retouched, and just one core (3.7%) was found. The retouched artefacts are dominated by marginal and broken retouched flakes (37%), Mousterian points (26%), different types of scrapers (24.1%), retouched points (5.6%), retouched blades (3.7%), Tayac points (1.8%), and limace (1.8%). The points (including Mousterian, Levallois, retouched and Tayac), along with pointed flakes and blades, comprise 11.4% of the entire assemblage in this layer. Among the material other than debris, the points and pointed elements comprise 25.1% of the assemblage in this layer. Mousterian points, Levallois points and retouched points comprise 2.8%, 2.4% and 0.6% of the assemblage, respectively. Not counting the debris, the Mousterian points and Levallois points comprise 6.2% and 5.3% the assemblage, respectively (Table 4).

The low number of cores (all exhausted) among the Mousterian assemblage from Kaldar Cave could be meaningful. This observation is in agreement with the techno-typological results from the Mousterian assemblage of the nearby Kunji Cave[43]. Given the notable scarcity of cores, the absence of refittable pieces, the large differences between the size of the tools and the size of the cores and their negative scars, and the condition of the cores that are exhausted, the *chaîne opératoire* is incomplete. Therefore, many of the artefacts were likely carried in from elsewhere (Fig. 4 and Supplementary Figs SI, S5, S9A & B, S10A & B).

In the Upper Palaeolithic lithic assemblages of Layer 4 (sub-layers 5 & 5II), bladelets dominate (13%), followed by blades (12.5%), retouched tools (5.1%), cortical pieces (4.4%), by-products (3.5%), bladelet cores (1.6%), undetermined cores (1.4%; including a centripetal core), pointed flakes, blanks, and other types of tools (a borer and point; all less than 1%), a blade core (0.2%) and finally a considerable amount of debris (56.4%). Within the bladelet categories, there is a good representation of twisted bladelets (14.3%). Among the retouched tools, Arjeneh points are abundant, but pointed pieces (including Tanged, retouched points, pointed blades and bladelets and Arjeneh points) are more numerous (54.5%) compared to other types of retouched tools (Figs 5, 6 and 7, and Supplementary Figs S6, S7 and S8). Excluding the debris in this layer, the points and pointed elements comprise 11.2% of the entire assemblage. The next most abundant tools among the retouched pieces are the scrapers (including side-scraper, end scraper and nosed scraper), representing 18.2% of the tools. The number of flakes in this layer is very low (4.6% of the assemblage), and among the flakes, 3.7% are cortical flakes, 0.7% are pointed flakes and 0.2% are retouched flake (Table 5).

Despite the small size of the assemblage, a quick examination of the assemblage data from both Layer 5 (sub-layers 7 & 7II) and Layer 4 (sub-layers 5, 5II, 6 & 6II) shows a significant technological change from flake technology towards the production of blades and bladelets. However, to be more precise, a preliminary comparative analysis between the two layers was performed (Supplementary diagrams S1 to S5). In this analysis, we compared the weights and average values of metric measurements of various characteristics and attributes. The comparison of comparable categories was performed to provide meaningful results and to aid our interpretation of these two layers. Therefore, we compared Levallois cores vs. blade/bladelet cores, pointed blades vs. pointed blade/bladelets, and the retouched points, cortical pieces and cortical flakes (within the cortical pieces) from both the layers. Interestingly, our comparative analysis shows that significant differences are present among all the elements from the Middle and Upper Palaeolithic industries of Kaldar Cave. The weights and sizes of all

Layer 5 (sub-layers 7 and 7II)			N	%
Cortical piece	Cortical flake	20	29	**5.8**
	Cortical elongated point	1		
	Cortical blade	4		
	Pebble	1		
	Cortical scraper	3		
Levallois flake	Levallois flake	13	42	**8.5**
	Retouched flake	(20 counted in retouched tools)		
	Pointed flake	16		
	Broken flake	13		
Levallois blade	Pointed blade	10	20	**4**
	Cortical blade	(4 counted in cortical pieces)		
	Retouched blade	(2 counted in retouched tools)		
	Broken blade	3		
	Others	7		
Levallois point	—	12	12	**2.4**
Levallois core	—	4	4	**0.8**
Other types of core	Undetermined core	2	4	**0.8**
	Discoid core	1		
	Blade core	1		
Retouched tool	Mousterian point	14	54	**10.8**
	Marginal and broken retouched flake	20		
	Retouched point	3		
	Scraper	7		
	Nosed scraper	1		
	Side scraper	1		
	Retouched blade	2		
	Cortical scraper	4		
	Limace	1		
	Tayac point	1		
Byproduct	—	60	60	**12**
Debris	—	271	271	**54.5**
Hammerstone	—	2	2	**0.4**
Total	—	498	498	**100%**

Table 4. Quantified results of the lithics attributed to the Middle Palaeolithic Layer 5 of the 2014–2015 excavation season at Kaldar Cave.

the compared elements tend to be greater in Layer 5 than in Layer 4. The only exception was found within the retouched points. In this case, the average length and thickness are slightly greater for Layer 4 than for Layer 5.

Discussion

Considerable efforts have been made to address fundamental questions concerning the cultural remains associated with AMHs. These attempts have been based mainly on Upper Palaeolithic lithic assemblages and their potential places of origin.

Based on technological comparisons between the lithic assemblages found in Europe and those found in the Zagros, some authors report close typological similarities between the two and further propose the latter region as the most probable source of the technology, with an east-to-west diffusion into Europe. Consequently, the Upper Palaeolithic tradition of the Zagros has been termed the 'Zagros Aurignacian'[12–14,19–21,23–27,44]. Based on the techno-typological analysis of material from Warwasi, some also claim that the Baradostian (or Zagros Aurignacian) technology evolved from a local Mousterian foundation in the area.

In conflict with the statement by Tsanova[15] that the Iranian Zagros cannot be the source of bladelet technology and cultural modernity as the Warwasi rockshelter lacks both radiocarbon dates and evidence of antecedent blade technology, strong evidence indicates that the Zagros assemblages are not merely blade-based. Over 90 sites contain evidence of clear blade(let) production (defined as the Rostamian tradition), and these tools are all similar to and associated with those from the well-stratified Ghare-Boof locality[8–11].

Based on the detailed techno-typological analysis of the industries from Yafteh, some authors claim that the Baradostian technology of the Zagros is an Early Ahmarian-like technology[45,46] and conclude that, on the basis of the available data, continuity from the Zagros Mousterian to the Zagros Aurignacian cannot be confirmed. However, based on the gradual transition from the Middle Palaeolithic to the Upper Palaeolithic at Warwasi and the technological and chronological analogies between the lower Baradostian at Yafteh and the Early

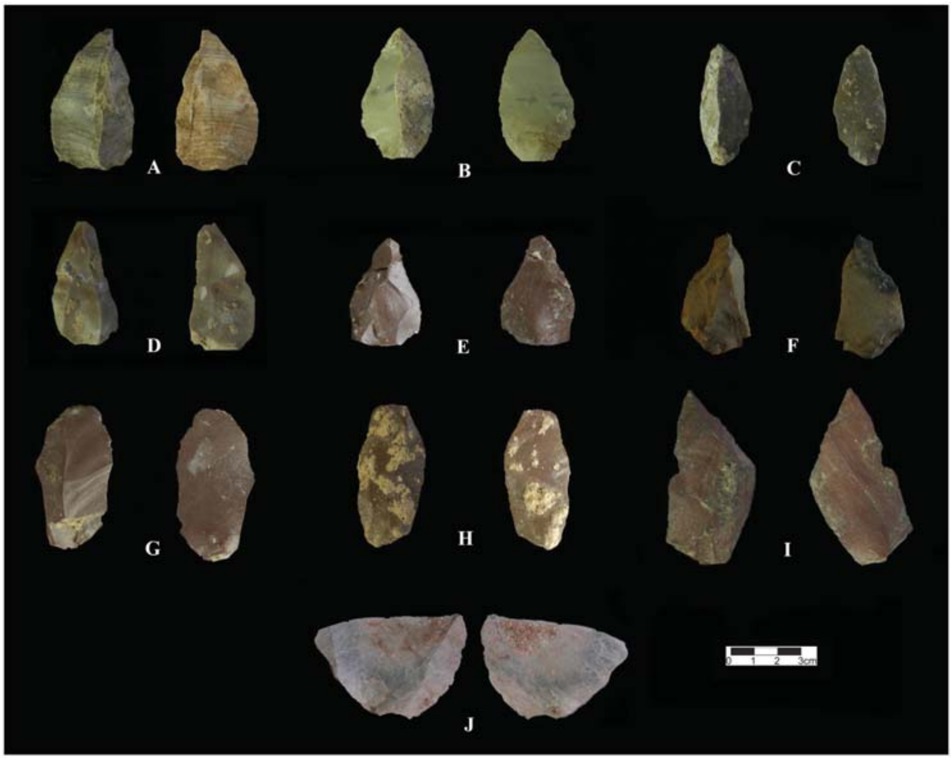

Figure 4. Selection of Middle Palaeolithic Levallois pieces from Kaldar Cave (Layer 5). (**A**) and (**B**); Point, (**C**); Elongated cortical point/Pointed flake with cortical butt, (**D**) to (**F**); Levallois point, (**G**) and (**H**); Elongated Levallois flake, (**I**); Levallois elongated pointed flake, (**J**); Levallois flake. Created by B. Bazgir.

Ahmarian, the Zagros region remains a potential candidate for the origin of the Aurignacian[5,32]. In a very recent typo-technological study on the Ghar-e-Khar lithic assemblages[33], the authors estimated the potential of the area for future research. Nevertheless, in addition to the small sizes of the studied assemblages, methodological problems (e.g., using 10- to 30-cm arbitrary levels) during the excavation and the lack of absolute chronometric data might raise concerns similar to those for the material from Warwasi and cast doubt on the results from Ghar-e-Khar, which are not compelling. Thus, the hypothesis of Middle-to-Upper Palaeolithic continuity in Zagros and the possibility of a gradual transition are hard to assess due to the current state of the technological data[33].

Similar to Yafteh, the Üçağizli sequence in Turkey provides some evidence of evolution from the Initial Upper Palaeolithic (IUP) into the early Upper Palaeolithic "Early Ahmarian". Given the absence of Middle Palaeolithic underlying the IUP layers in Üçağizli, however, the site offers little to the discussion of the appearance of the IUP in the region[47] (see also Shidrang[32]). Additionally, an IUP assemblage has also been discovered in Manot Cave, to the north of Mount Carmel[48]. The presence of both Mousterian and Baradostian cultural remains in Kaldar Cave and the recent chronometric data can be used to address many of the stated uncertainties associated with the transition process.

In regard to the terms "IUP", "Aurignacian", "Baradostian" and "Zagros Aurignacian", our data from Kaldar Cave and other excavated localities[35] support the arguments advanced by Kuhn and Zwyns[49] with respect to the technological diversity within the assemblages and the long duration of the Upper Palaeolithic in Kaldar. We therefore avoid using the term "IUP" for this assemblage. On the other hand, we cannot simply assign the term "Aurignacian" to the assemblage based on certain similarities with assemblages from European sites. However, our observations and technological analysis of the Kaldar assemblage are in agreement with that of Olszewski[12–14,19–24,44]: certain similarities do exist, yet the Zagros industry differs from the purely European Aurignacian. Therefore, to us, the terms "Baradostian" or "Zagros Aurignacian" are more appropriate.

Notably, based on our earlier technological work[35], the recent TL dates are older than we anticipated for the lithic assemblages of the uppermost part of Layer 4. These dates have led us to abandon the Epipalaeolithic designation we previously applied to these bladelet assemblages.

The AMHs in Kaldar Cave may have been among the first of their kind to interact with Palaearctic fauna. Thus, many of the species were new to them. In this part of Eurasia, the Palaearctic had an east-west-oriented southern border with the newly defined Saharan-Arabian biogeographic realm. The Zagros Mountains acted as an extension of the Palaearctic into the more southern realm[50]. However, it is not known whether the boundary between these realms occupied the same location during the Late Pleistocene. The presence of large mammals is

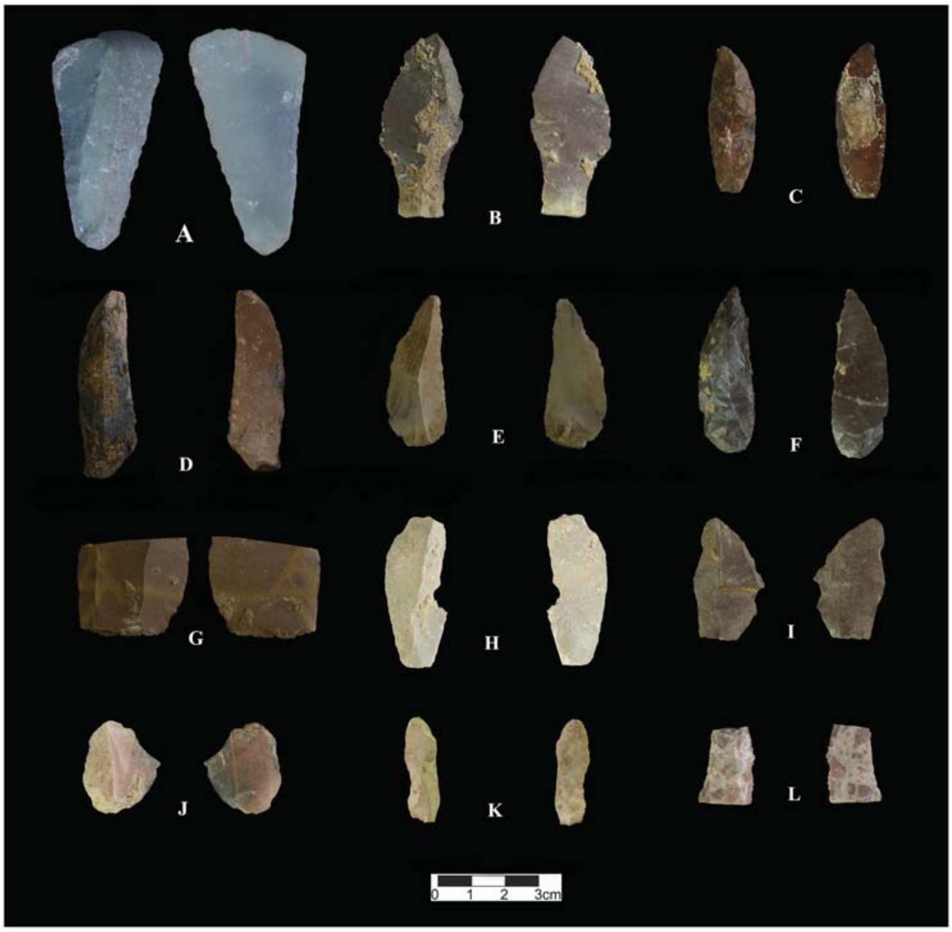

Figure 5. Selection of Upper Palaeolithic retouched pieces from Kaldar Cave (Layer 4). (**A**); Cortical retouched double scraper, (**B**); Tanged point, (**C**) to (**F**); Arjeneh points, (**G**); Retouched blade, (**H**); Elongated retouched blade, (**I**); Point on blade with retouches on its distal portion of ventral face, (**J**); Retouched end scraper, (**K**); Retouched nosed scraper, (**L**); Mesial portion of a retouched bladelet point. Created by B. Bazgir.

indicative of the seasonality of the Palaearctic, but most of the reptiles have Saharan-Arabian affinities, and the rodents yield a mixed signal.

The fauna present in the mid-latitude Palearctic represent "interglacial" fauna, and similar faunas (albeit generally richer in species) occupied the area during previous interglacials. During glacial periods, these species survived in southern refugia, while cold-adapted species occupied the mid-latitudes. Iran may have acted as one of these refugia. Up to now, no typically glacial species has been recorded in Iran or other areas at similar latitudes. The Palaearctic mammal species recorded in Iran, and in particular in Kaldar Cave, are "interglacial", suggesting the presence of at least temperate conditions. In contrast, the herpetofauna clearly indicates warm conditions. This combination is consistent with a position at the limit of the two biogeographic realms during climatic conditions similar to those of today. Furthermore, the study period is thought to correspond to MIS3, which had conditions similar to the modern climate. Because there is no indication of faunal change between layers 4 and 5, the available evidence suggests that the cultural change was not related to climatic or environmental changes.

Methods

Radiocarbon dating. Radiocarbon dating of the five charcoal samples (listed in Table 4) was performed at the Oxford Radiocarbon Accelerator Unit (ORAU). The samples were chemically cleaned using the acid-base-wet oxidation-stepped combustion (ABOx-SC) protocol (after Brock and Higham[51], also see ref. 52) or a modification of the same. The ABOx-SC method was employed as it has been shown to remove contaminants from Palaeolithic-aged charcoal more efficiently than the routine acid-base-acid (ABA) protocol, often yielding significantly older dates (e.g. refs 51, 53–59). The analytical data obtained are shown in Table 4, and no data fall outside the expected ranges for well-preserved charcoal. The calibration of all the resulting AMS radiocarbon determinations was performed using the OxCal 4.2 software[60,61] and the IntCal13 calibration curve[62].

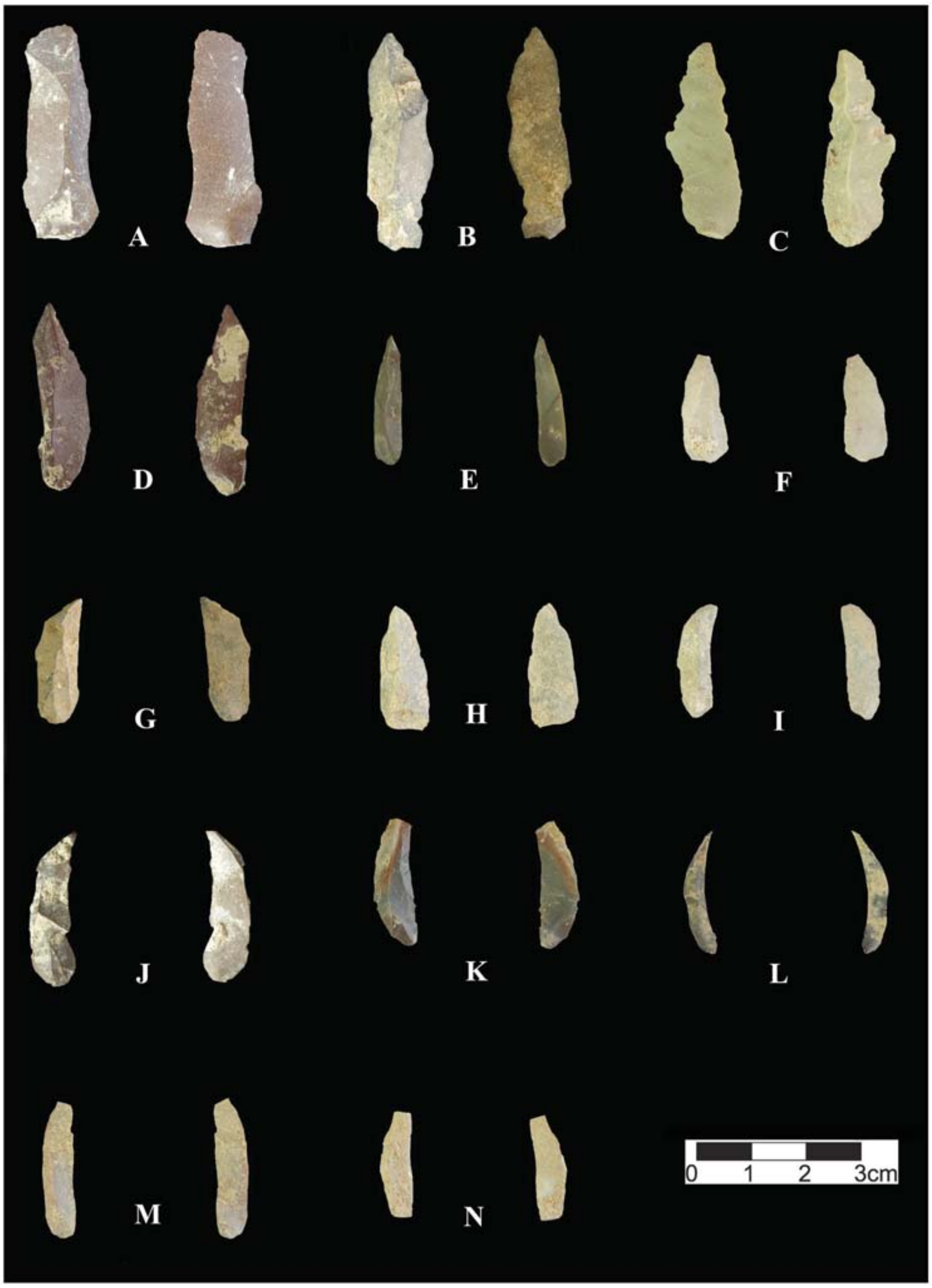

Figure 6. Selection of Upper Palaeolithic blades and bladelets from Kaldar Cave (Layer 4). (**A**) Elongated blade, (**B**) to (**D**); elongated pointed blades, (**E**) to (**H**); Pointed bladelets, (**I**) and (**N**); Dufour bladelets, (**J**) to (**M**); Twisted bladelets. Created by B. Bazgir.

Among the seven charcoal samples submitted, five yielded enough material for AMS radiocarbon dating after chemical preparation (see Table 6). Only three of these, however, yielded reliable radiocarbon dates following a congruent age-depth pattern; the two others were substantially younger. This is almost certainly due to taphonomic influences. While it would be useful to incorporate the Palaeolithic-aged results into a Bayesian model, we cannot as we have too few results at this time. More dating work is currently underway, and we hope to be able to report new results in the future. In Fig. 8, we show the calibrated results for the Palaeolithic specimens (see Table 2 for the data).

Figure 7. Selection of Upper Palaeolithic cores from Kaldar Cave (Layer 4). (**A**): Flake core, (**B**,**C** and **F**); Bladelet core, (**D**); Broken carinated core (**E**); Carinated core/carinated scraper. Created by B. Bazgir.

TL dating. Thermoluminescence dating was performed on five heated samples (four heated sediments from two fire places in the upper most part of Layer 4 and one burnt flint from Layer 5) at the Research Centre for Conservation & Restoration of Cultural Relics of the Research Institute of Iranian Cultural Heritage (RICHT). At present, the samples from Layer 4 have successfully been dated. Three of the dated samples come from a fireplace within squares E6/7 and one from square E5 (Table 1).

For the sample preparation and instrumentation, the outer surface (3 mm) of the samples was removed. To account for the alpha radiation contribution to the natural dose measurements, the fine grain technique is used (ibid). Alpha radiation travels an extremely short distance in heated objects (approximately 25 μm[63]). Thus, we used grains less than 10 μm in size. The samples were crushed and treated with 10% HCl to remove carbonates and organic material. Then, all samples were washed with distilled water and then with acetone. Finally, the grains were suspended in acetone and deposited on aluminium discs that were 10 mm in diameter and 0.5 mm in thickness.

The TL measurements were performed using an ELSEC7188 instrument. The potassium contents of the samples were determined by flame photometry. To determine the contributions from U and Th, the "pairs" technique was used; thus, the dose rate was measured using a 7286 low-level alpha counter[64]. External dose rates were measured by in situ dosimetry[65]. The CaF2 TL-Dosimeter was located in site for 36 days. These values were calculated for different levels, up-level: 0.787 mGy/a, down-level: 0.660 mGy/a. Measurements of the water content and fading test for all samples were considered (Table 1).

Conclusions

The newly excavated sequence in Kaldar Cave provides evidence for the replacement of the Mousterian industry, usually associated with Neanderthals, by the Baradostian industry, similar to the Aurignacian, which is unique to anatomically modern humans. Radiocarbon dates suggest that this may have occurred prior to 49,200 ± 1800 BP, probably during the relatively warm MIS3. The faunal evidence is consistent with the replacement occurring

Layer 4 (sub-layers 5, 5II, 6 and 6II)			N	%
	Cortical flake	16		
Cortical piece	Cortical blade	1	19	**4.4**
	Nodule	2		
	Pointed blade	6		
Blade	Blade with truncated faceted butt	1	54	**12.5**
	Blade	47 (2 counted in retouched tool)		
	Twisted bladelet	8		
Bladelet	Bladelet point	2	56	**13**
	Bladelet	46 (5 counted in retouched tools)		
Blade core		1	1	**0.2**
Bladelet core		7	7	**1.6**
Other types of core		6 (1 is a centripetal core)	6	**1.4**
	Nosed scraper	1		
	End scraper on blade	1		
	Blade scraper	1		
	Side scraper	1		
	Arjeneh point	4		
	Tanged point	1		
	Retouched pointed bladelet	3		
Retouched tool	Retouched bladelet	2	22	**5.1**
	Retouched pointed blade	2		
	Retouched point	2		
	Unfinished retouched point	1		
	Retouched flake	1		
	Retouched blade	1		
	Retouched piece on a broken blade	1		
Other types of tool	Borer	1	1	**0.3**
Pointed flake		4	4	**0.9**
Blank/fragment		3	3	**0.7**
Byproduct		15	15	**3.5**
Debris		243	243	**56.4**
Total			431	**100%**

Table 5. Quantified results of the lithics attributed to the Upper Palaeolithic Layer 4 of the 2014–2015 excavation season at Kaldar Cave.

during MIS3 and does not support a coincident climatic change. Kaldar Cave is situated in the southernmost part of the Palaearctic biogeographic realm. Evidence from Kaldar Cave is among the oldest to show that AMHs were capable of exploiting the Palaearctic fauna and were thus well adapted to this new environment, which they colonized shortly after the period of time recorded in the cave.

Excavations at Kaldar Cave have yielded evidence for Baradostian (Layer 4) and Mousterian assemblages (Layer 5) in stratigraphic superposition. This is an exceptional find in the Zagros. The preliminary technological analysis on the lithic industry from both layers indicates a clear shift from flake production to blade and bladelet technology. Furthermore, despite the small size of the lithic assemblage so far, the quantitative comparative analysis shows a significant difference between elements within the Middle and Upper Palaeolithic layers. The homogeneity of the differences between all the compared elements—that is to say, the greater weight and size of the items in the Mousterian assemblage compared to those of the Upper Palaeolithic assemblage—could be a reliable foundation for interpretation and understanding the two industries.

We have obtained new chronometric data from the site. Four TL dates from the uppermost Layer 4 revealed ages that ranged from 23100 ± 3300 to 29400 ± 2300 BP.

The three ^{14}C dates from Layer 4 and sub-layers 5 and 5II produced results in the ranges of 38650–36750 cal BP, 44200–42350 cal BP, and 54400–46050 cal BP, respectively (all at 95.4% probability). The wide chronometric ranges and few dates do not allow us to make a confident and precise assessment of the age of the transition to the Upper Palaeolithic. Further work is needed to refine the chronology.

In addition to the presence of a clear Mousterian industry in the >0.5-m-thick Layer 5 and despite the need for more chronometric data, the obtained dates from the lower part of the Upper Palaeolithic sequence in Kaldar

OxA	Species	Used (mg)	Yield (mg)	%Yld	%C	$\delta^{13}C$ (‰)
X-2645-11	*Prunus* cf. *amygdalus*	59.91	8.71	14.5	81	−23.4
X-2645-12	*Prunus* cf. *amygdalus*	93.41	6.23	6.7	82.2	−24.5
32238	*Prunus* cf. *amygdalus*	107.6	10.81	10	69.7	−23.0
32239	*Quercus* sp. deciduous	105.16	16.65	15.8	71.7	−23.1
32240	*Quercus* sp. deciduous	9.83	6.5	66.1	75.1	−27.1

Table 6. Analytical and sample data for the charcoal dated from Kaldar Cave. OxA-X determinations involved a modified ABOx-SC preparation. The other determinations involved the ABOx-SC method. All data are acceptable and within expected parameters. **Denotes an AMS result in fraction Modern. This determination post-dates AD 1950.

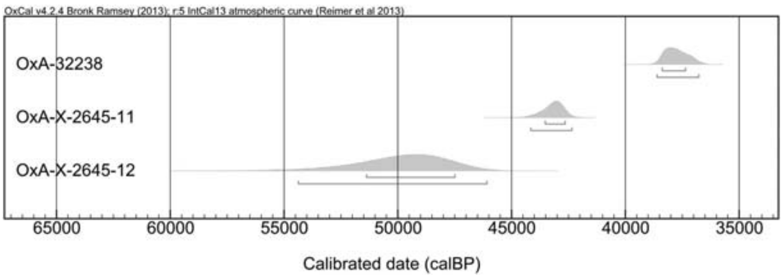

Figure 8. Calibrated results of the Palaeolithic specimens. Created and modified in the Research Laboratory for Archaeology and the History of Art, University of Oxford, by T. Higham, K. Douka and L. Becerra-Valdivia.

Cave are some of the earlier dates attributed to a lithic industry produced by AMHs in western Asia. Although we do not intend to challenge the Levantine dispersal theory, previous work has noted that the Aurignacian may not have originated in only one area[22] (see also Groucutt[66]). It has been suggested that the ages of the so-called "transitional" or Initial Upper Palaeolithic layers at Ksar Akil may represent that the transition from the Middle to Upper Palaeolithic in this area (and possibly in the wider northern Levant) occurred later than previously estimated. This finding would cast doubt on the assumed singular role of the region as an origin for human dispersal into Europe[67].

Another important clue derived from the preliminary quantified results of the Mousterian and Upper Palaeolithic lithic industries in Kaldar Cave is the high percentage of points and pointed elements in both the layers. This abundance may indicate that the site functioned as an important hunting camp in the Zagros Mountains during both the Middle and Upper Palaeolithic times. This hypothesis appears to be supported by the zooarchaeological evidence. Hence, Kaldar Cave provides one of the oldest examples of modern human existence in this part of the world and provides data on how these populations coped with the Palearctic climatic and environmental situations, which were new to them.

To reach a consensus regarding the Middle to Upper Palaeolithic transition/continuity, several lines of evidence are required. Indeed, accurate information and maximum control of the context, including careful sampling for chronometric dating from well-stratified sites and detailed techno-typological analysis, are crucial factors. Our understanding of the behavioural dimension of the transitional phenomenon would also benefit from more excavations using multidisciplinary methods, including spatial analysis and functional aspects.

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Acknowledgements
We would like to thank the directors of RICHT and ICAR (Seyed Mohamad Beheshti and Hamide Choubak) for their support and for issuing us the necessary permission to conduct this excavation season. We also thank Kamran Ahmadi (director of Research Centre for Conservation & Restoration of Cultural Relics of RICHT) for supporting us with the TL dating. We thank A. Mohajeri Nezhad, former director of Lorestan Cultural Heritage Organization for all his supports during the field-work. The unsparing efforts by M. Jayez, N. Hashemi, I. Beheshti, S. Azadbakht, S. Horshid, M. Hashemi, F. Bakhtiari, Z. Feiz, R. Khazaeli and A. Baharvand, who participated in a period or full season of the excavation, are greatly appreciated. This research is conducted in the framework of a signed scientific agreement between RICHT and IPHES. This project is funded by IPHES and the Department of Prehistory at the University of Liege. Radiocarbon dating was undertaken through the ERC-funded PalaeoChron Project, and the TL dating was performed in conjunction with the RICHT. This research was supported by the projects CGL2015-65387-C3-1-P (MINECO/FEDER), SGR 2014-899 (AGAUR, Generalitat de Catalunya), 2014 PFRURV-B2-17 and 2015 PFR-URV-B2-17 (Universitat Rovira i Virgili), and developed within the framework of CERCA Programme/Generalitat de Catalunya. L. Tumung and M. Fernández-García are beneficiaries of PhD scholarships founded under the Erasmus Mundus Programme – International Doctorate in Quaternary and Prehistory. A. Picin is the beneficiary of a Humboldt Postdoctoral Research Fellowship from the Alexander von Humboldt Foundation. B. Bazgir is a beneficiary of a predoctoral scholarship from the Fundación Atapuerca. J. van der Made contributed to the project CGL20l5 65387-C3-3-P (MINECO/FEDER).

Author Contributions
B. Bazgir, A. Ollé, and L. Tumung investigated the site in detail, studied the lithic industry, and monitored the data recovered from the stratigraphy. L. Becerra-Valdivia, K. Douka and T. Higham performed the ^{14}C dating and helped revise the draft. J. van der Made and D. Arceredillo studied the macrofauna. A. Picin collaborated on the early phases of writing the draft and contributed to some excavation days. P. Saladié performed the zooarchaeological studies. J.M. López-García, M. Fernández-García and I. Rey-Rodríguez studied the small mammals. H.A. Blain studied the amphibians and reptiles. E. Allué studied the charcoal assemblage. F. Bahrololoumi and M. Azimi performed the TL dating. M. Otte and E. Carbonell provided the research strategy and acted as the senior archaeological advisors. B. Bazgir wrote the paper and all the co-authors contributed to the final version of the manuscript.

Additional Information
Supplementary information accompanies this paper at http://www.nature.com/srep

Competing Interests: The authors declare no competing financial interests.

How to cite this article: Bazgir, B. *et al.* Understanding the emergence of modern humans and the disappearance of Neanderthals: Insights from Kaldar Cave (Khorramabad Valley, Western Iran). *Sci. Rep.* **7**, 43460; doi: 10.1038/srep43460 (2017).

SUPPLEMENTARY INFORMATION

Understanding the emergence of modern humans and the disappearance of Neanderthals: Insights from Kaldar Cave (Khorramabad Valley, Western Iran)

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Description of the new material of large mammals from Kaldar Cave

Remains of large mammals have been described from a previous excavation at Kaldar Cave[1]. Recent excavations yielded new material, including new species. The updated faunal list is given in Table 3. The most relevant new fossils are described below.

An incisor (Fig. S11/2) from Layer 4 (sub-layer 5 II) belongs to *Equus*. Its size suggests a large horse, such as the caballoid horses, and not a small one such as *E. hydruntinus* or *H. hemionus*. Caballoid horses are seen as a single species[2], two[3] or even more species[4]. We assign the material to *Equus* sp.

A right upper canine of a cervid comes from Layer 5 (Fig. S11/1). The genera *Axis* and *Rucervus* do not have upper canines, the genus *Dama* only rarely has them[5], but in *Cervus elaphus*, both males and females have upper canines. By the criteria of D'Errico & Vanhaeren[6] and Arceredillo[7], the specimen from Kaldar belonged to a female, but it is not possible to infer the age of death. In Europe, the size of *Cervus elaphus* changed in time and the same changes seem to have occurred even South of the Caucasus[8,9,10]. However, the red deer material from Kaldar Cave does not allow to establish whether it belonged to a large or small sized population.

Caprini indet. cf. *Capra aegagrus* was previously identified on the basis of dental material. A lower third molar from Layer 5 (sub-layer 7) (Fig. S11/3) is peculiar in having an additional distal lobe. Normally there is a third lobe, consisting of a single cusp, but here there is a relatively wide third lobe, consisting of a single cusp, and a similar but narrower fourth lobe. The fourth lobe is worn by occlusion with the upper M[3]. *Hemitragus* and *Capra* differ in that the latter has upper third molars with a distal extension at the buccal side, which is like a very narrow third lobe. *Hemitragus* and nearly all other bovids lack such an incipient third lobe. A short M^3, without such an extension, would never cause wear on the tip of a fourth lobe of an M_3. This tooth confirms thus the presence of *Capra* in Kaldar Cave.

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Supplementary figures

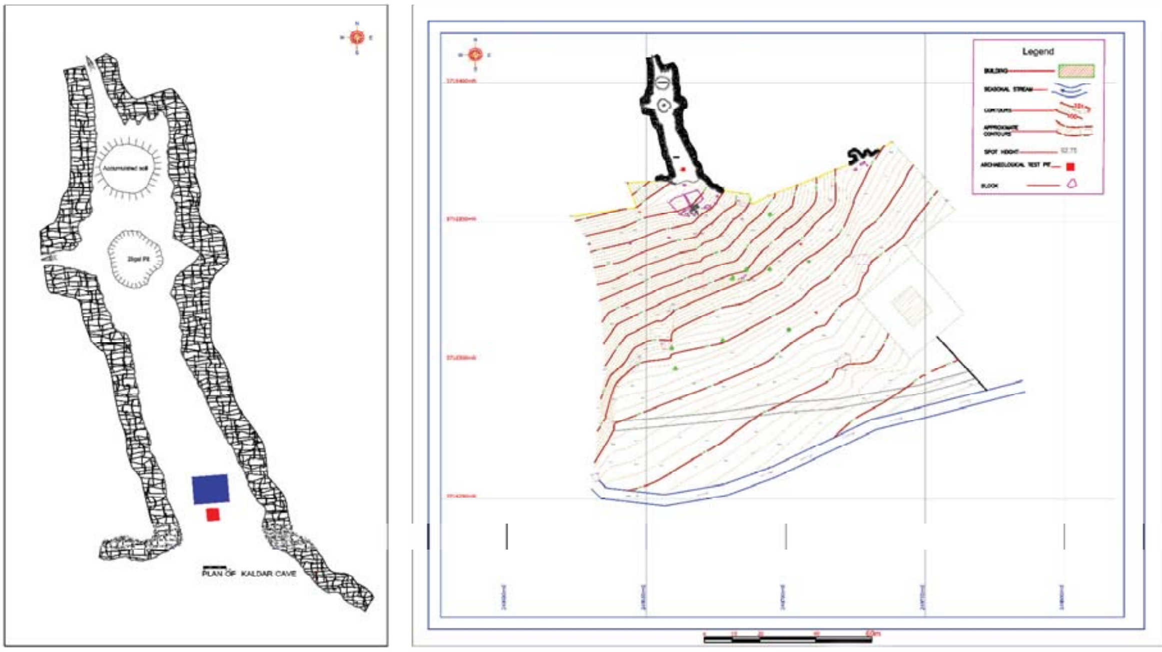


Figure S1. Detailed topographical map of Kaldar and its sounding area. The location of the new trench is shown in blue colour. Created by B. Bazgir, using AutoCad, Photoshop and Corel Draw softwares.

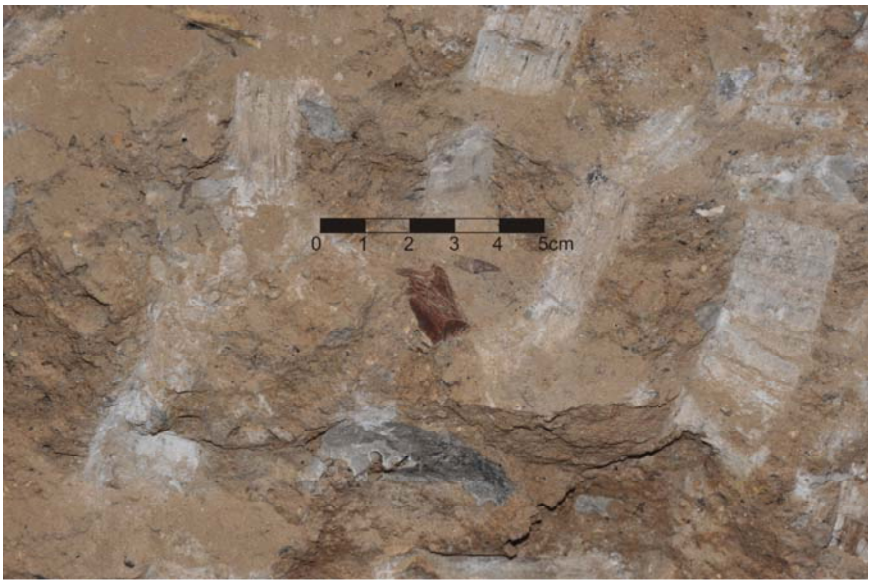


Figure S2. The high density of the deposit can be clearly seen with the traces of chisel marks. Photo by A.Ollé, modified by B.Bazgir.

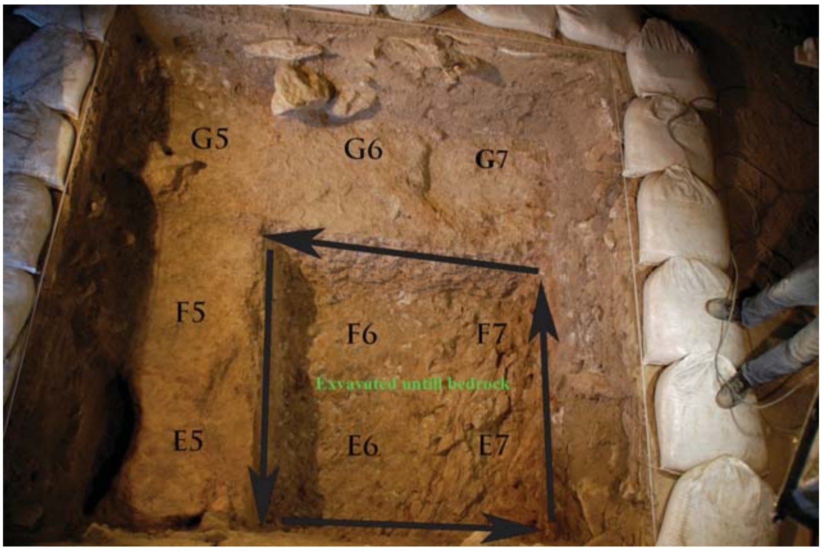


Figure S3. General view of the excavated trench. The squares between the arrows reached to the bedrock. Photo by B. Bazgir.

Figure S4. Examples of taphonomic modifications on Kaldar cave fauna specimens. a) Tibia shaft fragment of Cervidae with two groups of slicing marks (Layer 4); b) Percussion impact on the shaft of a Caprini humerus (Layer 4); c) Dorsal and ventral view of burned epiplastron of *Testudo* sp. (Layer 4); d) Slicing marks on a fragment of the shaft of a tibia of Caprini with two groups of slicing marks (Layer 5); e) Fragment of a long bone with carnivore score marks (Layer 4). Created by P. Saladié.

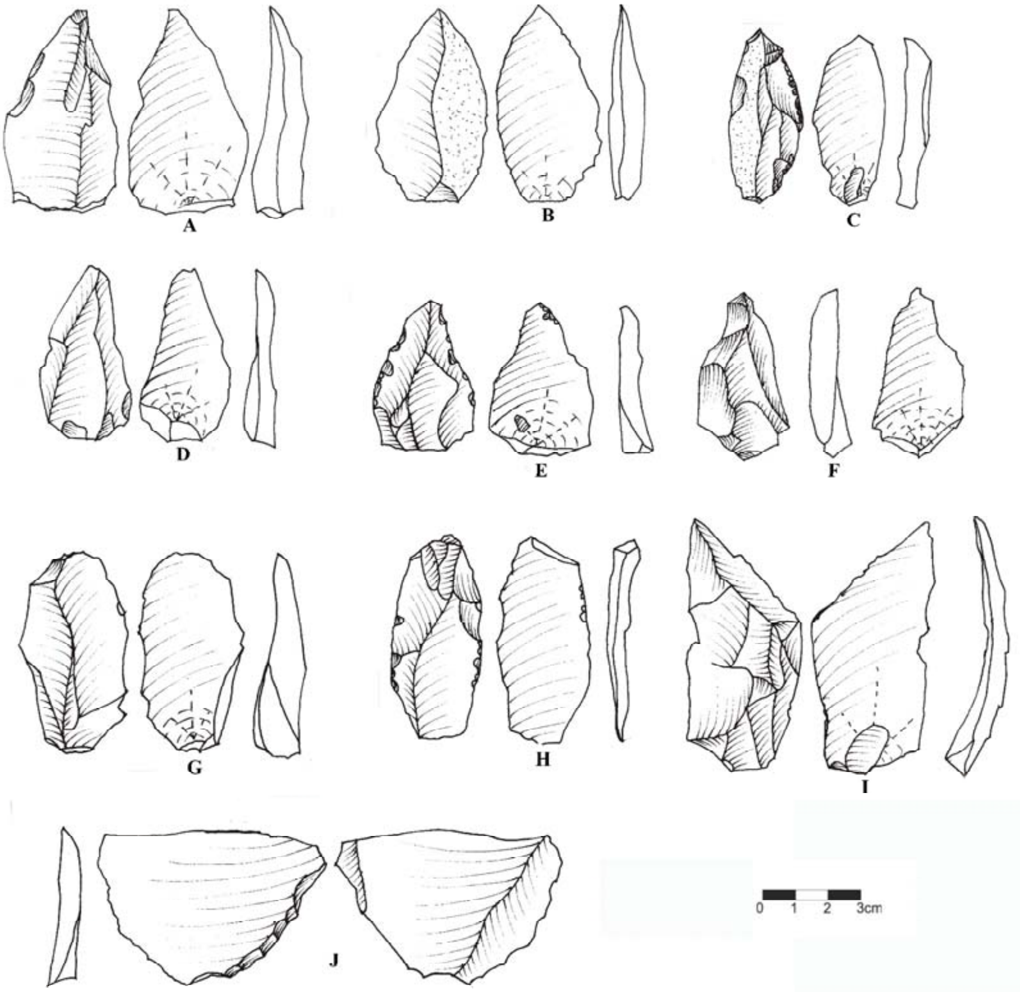


Figure S5. Selection of Levallois pieces from the Middle Paleolithic from Kaldar Cave (Layer 5). A&B; Point, C; Elongated cortical point/pointed flake with cortical butt, D to F; Levallois point, G&H; Elongated Levallois flake, I; Levallois elongated pointed flake, J; Levallois flake. Drawings by L. Tumung.

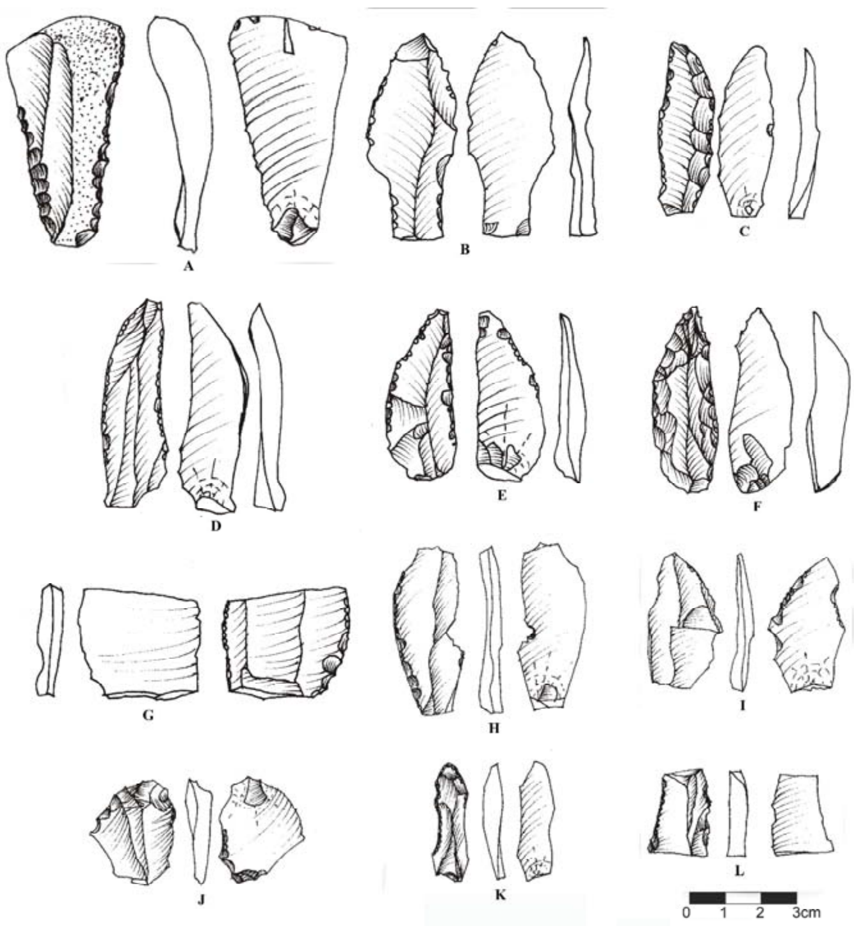


Figure S6. Selection of retouched pieces from the Upper Paleolithic of Kaldar Cave (Layer 4). A; Cortical retouched double scraper, B; Tanged point, C to F; Arjeneh points, G; Retouched blade, H; Elongated retouched blade, I; Point on blade with retouches on the distal portion of the ventral face, J; Retouched end scraper, K; Retouched bladelet point, L; Mesial portion of a retouched bladelet point. Drawings by L. Tumung.

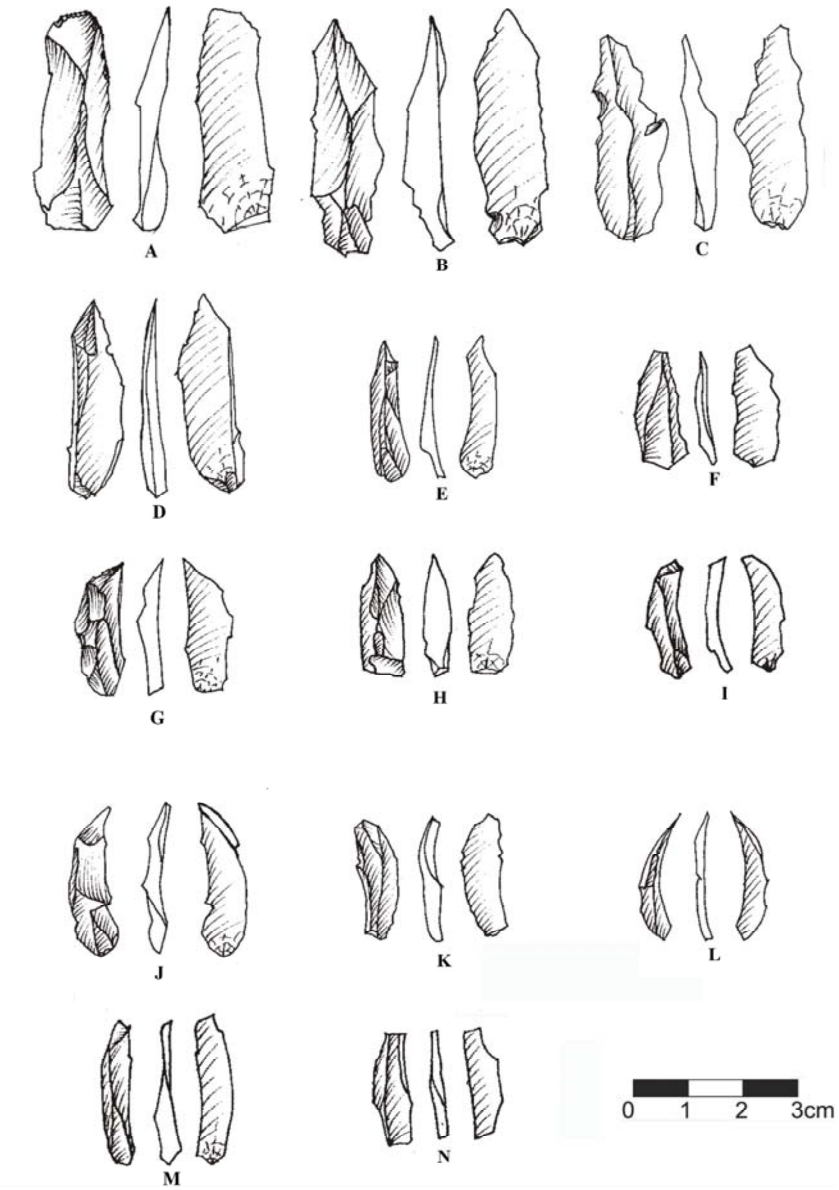


Figure S7. Selection of blades and bladelets of Upper Paleolithic from Kaldar Cave (Layer 4). A; Elongated blade, B to D; elongated pointed blades, E to H; Pointed bladelets, I &N; Dufour bladelets, J to M; Twisted bladelets. Drawings by L. Tumung.

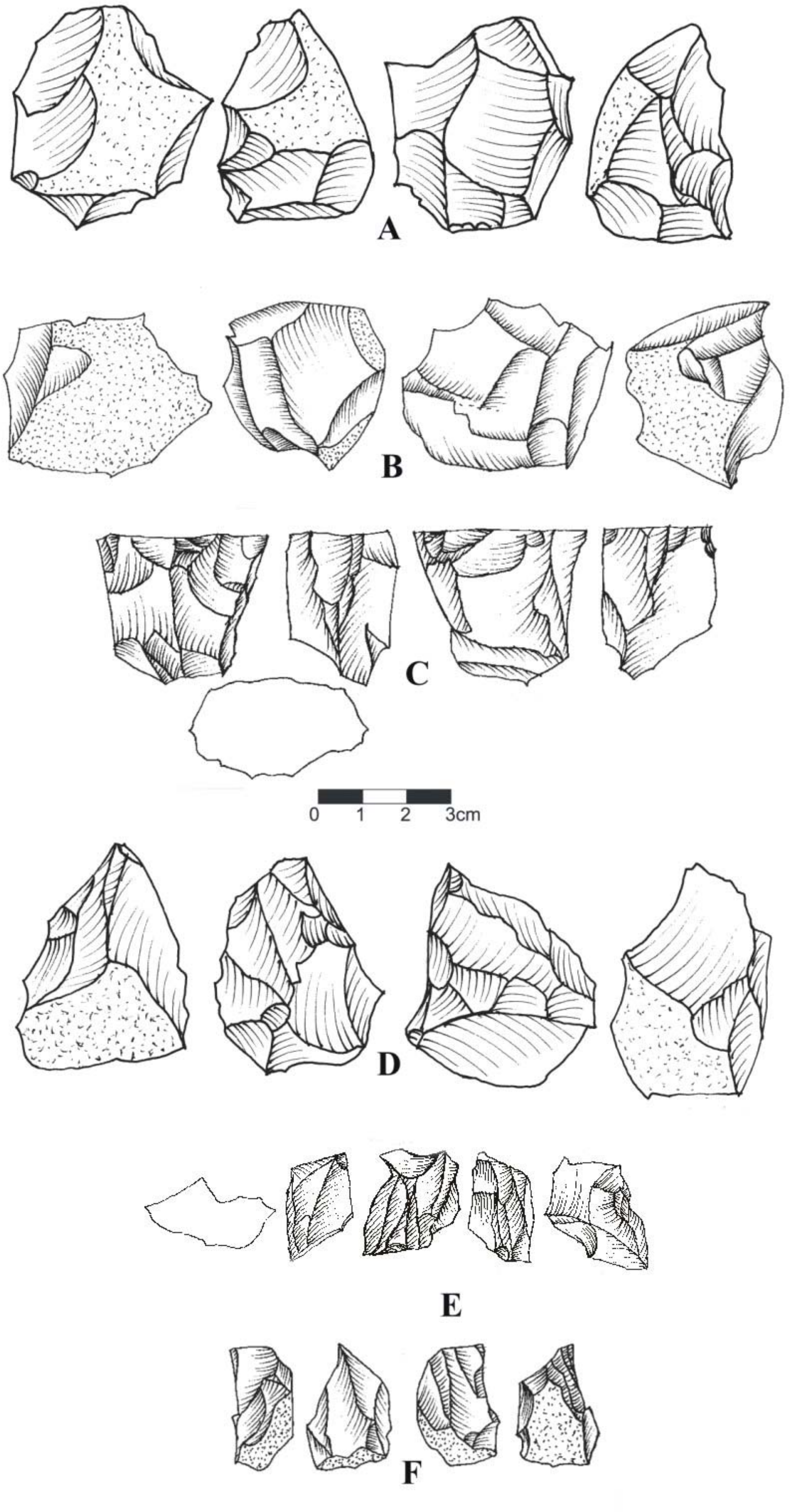


Figure S8. Selection of cores of Upper Paleolithic from Kaldar Cave (Layer 4). A: Blade core, B,C & F; Bladelet core, D; Broken carinated core E; Carinated core/carinated scraper. Drawings by L. Tumung.

Figure S9A: Selection of retouched pieces from the Middle Paleolithic of Kaldar Cave (Layer 5). A to G; Mousterian points, H&I; Retouched side scrapers, J; Limace. Created by B.Bazgir.

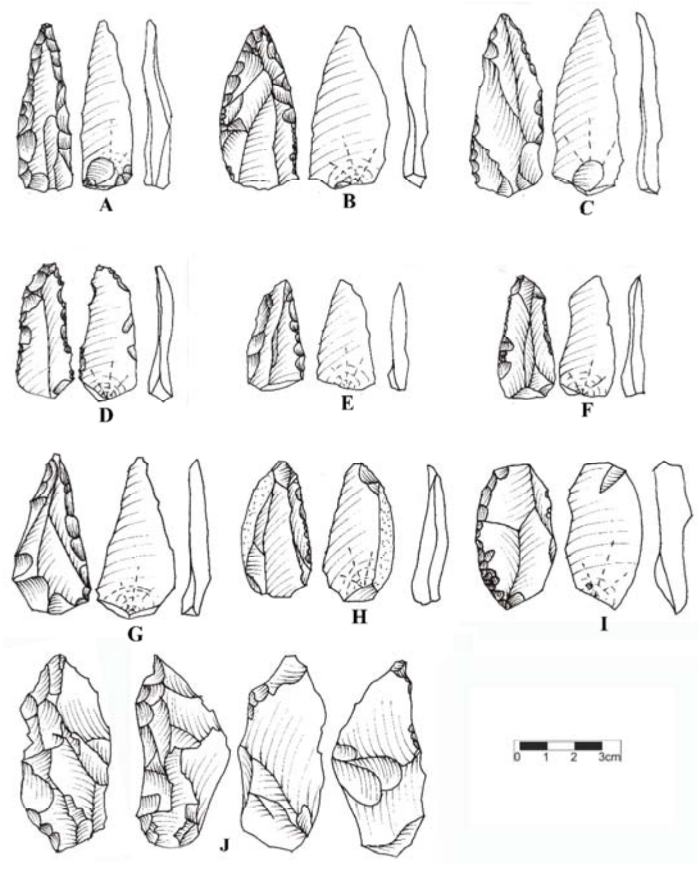


Figure S9B. Selection of retouched pieces of Middle Paleolithic from Kaldar Cave (Layer 5). A to G; Mousterian points, H&I; Retouched side scrapers, J; Limace. Ddrawings by L. Tumung.

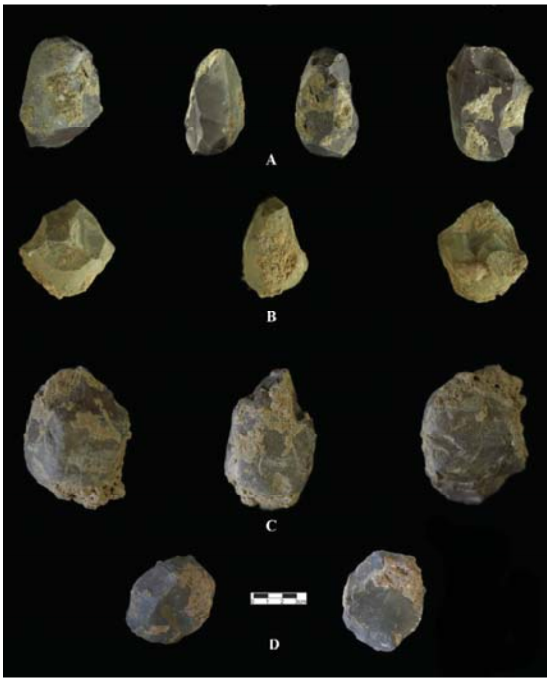


Figure S10A. Selection of cores of Middle Paleolithic from Kaldar Cave (Layer 5). A; Cortical Levallois unidirectional core, B; Cortical unidirectional core C; Predetermining centripetal core, D; Levallois centripetal core. Created by B.Bazgir.

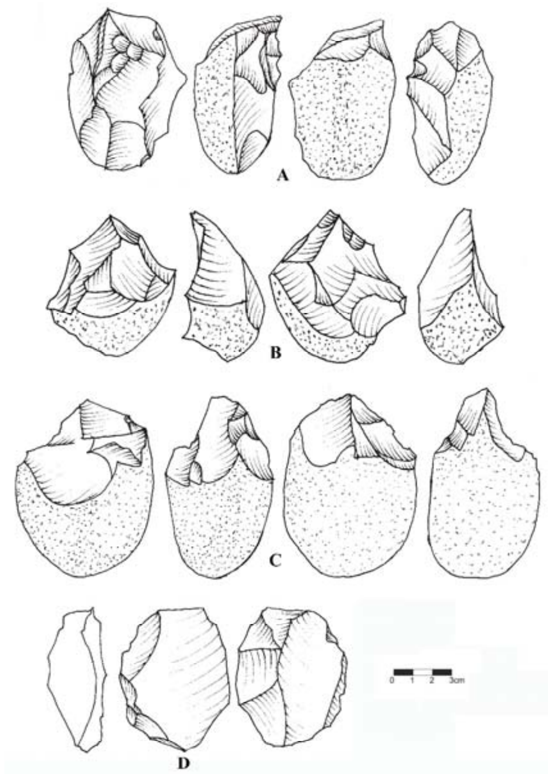


Figure S10B. Selection of cores of Middle Paleolithic from Kaldar Cave (Layer 5). A; Cortical Levallois unidirectional core, B; Cortical unidirectional core C; Predetermining centripetal core, D; Levallois centripetal core. Drawings by L. Tumung.

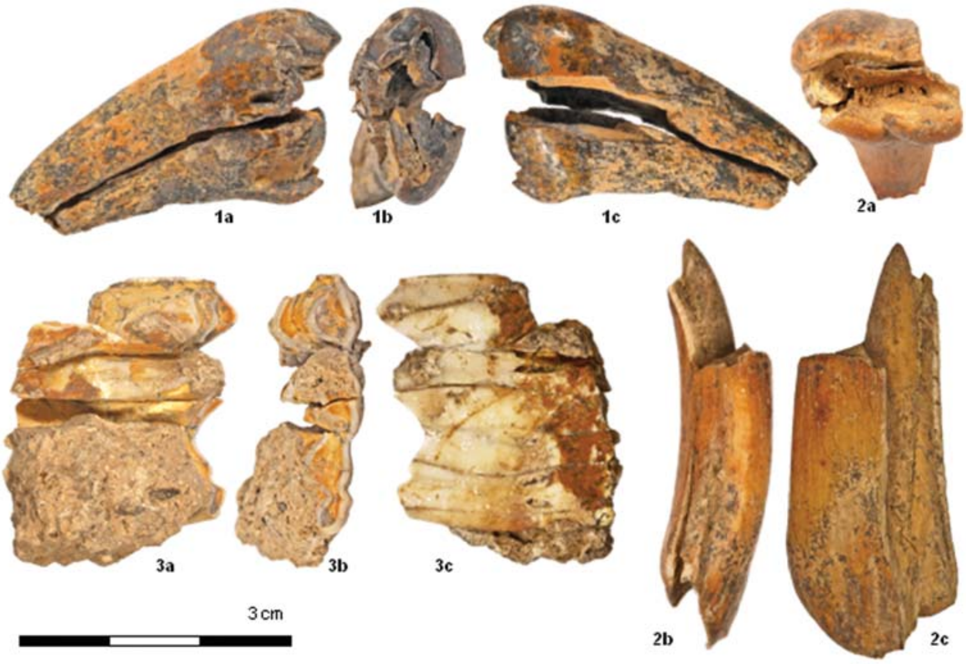


Figure S11. Fossils from Kaldar Cave: 1) KLD-2014- E5-1430 - right upper canine of a female of *Cervus elaphus* from Layer 5: a) lingual, b) occlusal, and c) buccal views; 2) KLD-2014-E6-879 - left upper incisor of *Equus* sp. from Layer 4 (sub-layer 5 II): a) occlusal, b) mesial, and c) labial views; 3) KLD-2014-F6-814 - left lower third molar of *Capra* sp. from Layer 5 (sub-layer 7); Figure 1/2 not to scale. Created and modified by J.van der Made.

Supplementary diagrams

Diagram S1. Comparison of different elements between “Levallois cores vs blade & bladelet cores” within Layers 4 and 5. Created by B.Bazgir.

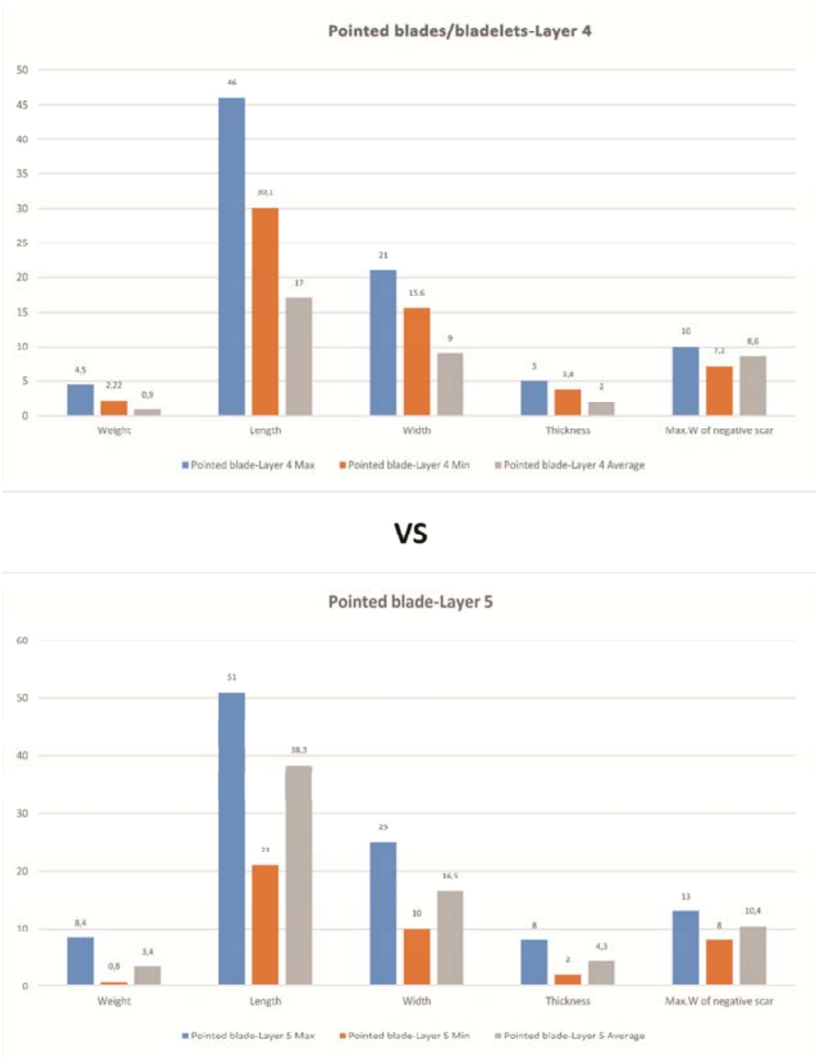
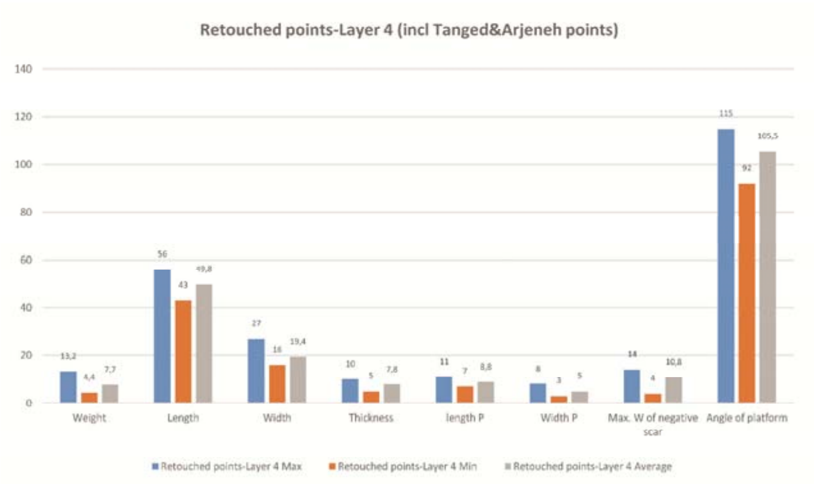


Diagram S2. Comparison of different elements between “retouched points” within Layers 4 and 5. Created by B.Bazgir.



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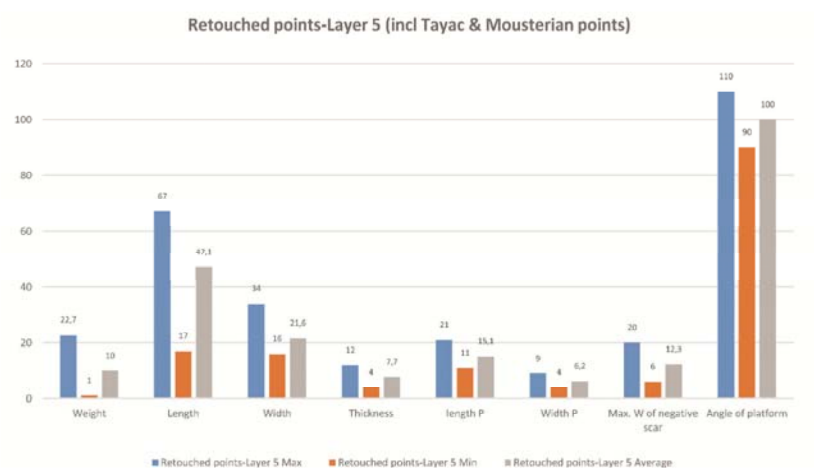


Diagram S3. Comparison of different elements between “pointed blades” within Layers 4 and 5. Created by B.Bazgir.

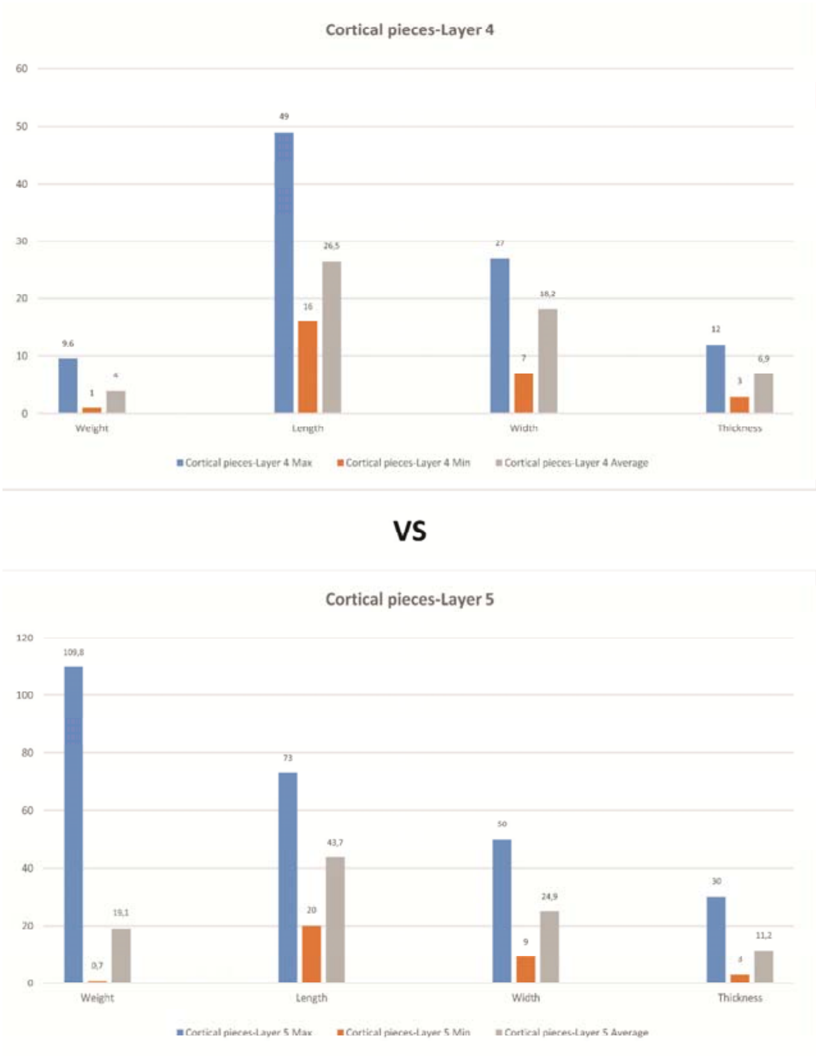
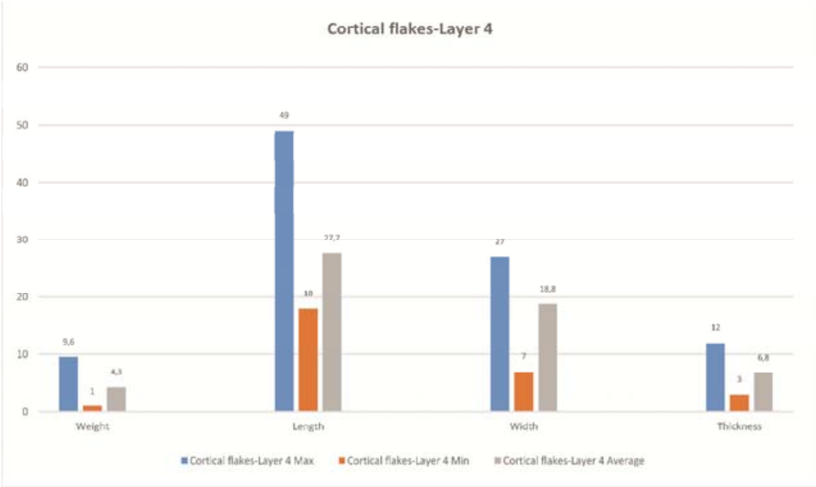


Diagram S4. Comparison of different elements between “cortical pieces” within Layers 4 and 5. Created by B.Bazgir.



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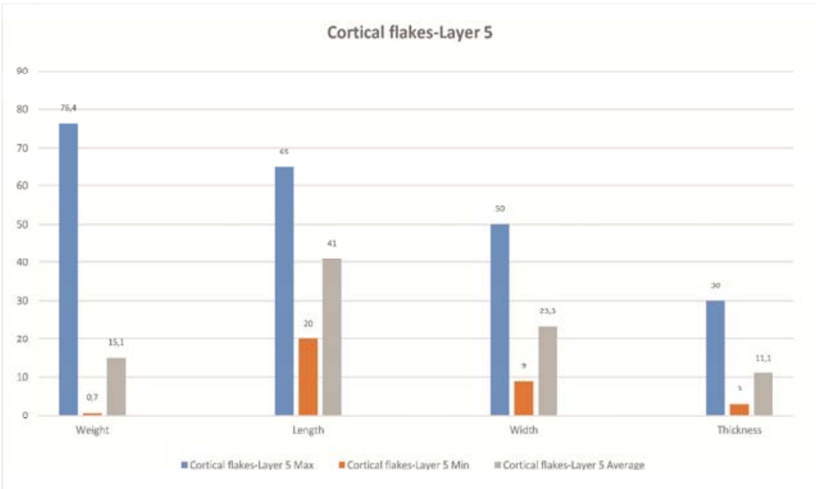

Diagram S5. Comparison of different elements between "cortical flakes" (among the cortical pieces) within Layers 4 and 5. Created by B.Bazgir.

2.6.3. Central Iranian Zagros Mountains

2.6.3.1 Ghar-e-Boof

Details of the site mentioned in Publication 1 (Becerra et.al. 2017)

2.6.3.2. Qaleh Bozi Rock shelter

The Qaleh Bozi sites are located about 25 km south-southwest of Isfahan, northeast of Mobarakeh and north of Hassanabad town. The sites include two rock shelters and a cave located at altitudes between 1750 to 1810 m above sea level at 32º 24´ N 51º 33´ E, on the southern face of a limestone mountain of lower Cretaceous age that rises to more than 500 m above the plain floor. Qaleh Bozi 2 cave is more than 38 m deep, 16 m wide and nearly 18 m high. It is the largest cave among the other two rock shelter. The sites overlook a steep rocky slope, and their distance from each other is between 80 – 100 m. The archaeological potential of the sites was realized by Hossein Soleimani, a resident of the nearby small town of Hasasan Abad in 1999. The later introduced the sites to M. Yazdi at the University of Isfahan. A team from the Department of Geology, the University of Isfahan, directed by M. Yazdi, studied the sites and undertook excavations at Qaleh Bozi 1 in 2004 (Elhami *et al.* 2004; Javeri *et al.* 2004). The deposit of the site is rich with micro, and macro mammals remain as well as with the lithics belonging to Middle Paleolithic.

2.6.3.3. Eshgaft-e-Gavi

Eshkaft-e Gavi is a large cave on the Marv Dasht plain on the lower Kur River Valley, about 14 km southwest of Persepolis, southernmost Zagros (29 52 19.49 N, 52 44 53.85 E). The cave has a rough figure-eight shape, with each section of the eight being about 15 mx7m. It is approximately 20 m above the plain and faces northeast, and the Kur River flows just 750 m to the northeast. W. Sumner discovered the site in 1969 during a survey, and M. Rosenberg investigated it in 1978 from Sumner's lead. He found that substantial disturbance had occurred from the mechanical excavation of the talus slope and partial collapse of the roof from blasting. Fortunately, the interior cave preserved an intact deposit, and Rosenberg initiated excavations for two weeks in July of 1978 (Rosenberg, 1985) as part of the Malyan Project, directed by W. Sumner and R. Dyson. Two test pits were opened, one 3x3 m and 2x2 m and excavations were carried out within 10-cm arbitrary levels within natural stratigraphy. The Upper Palaeolithic lithic artefacts of this site shows the Baradostain affinity and in this level various human remains also discovered (discussed in 2.4 section) (Scott and Marean 2009)

2.7. Recent development in functional analysis

Compare to the western Palaeolithic sites, functional studies in Zagros Palaeolithic sites are very few. Since recent years, archaeologists have started to test the possibility of functional studies on the stone, bone and shell tools in this area (Gregg et al. 2007; Claud et al 2012; Bazgir and Tumung 2013; Hunt 2017). Till date, the most functional studies are more focused in the Iranian Zagros Palaeolithic sites.

Recently in Iraqi Zagros, the functional studies first time introduced to analysed an incised fragment of a land snail shell (*Assyriella* sp). It belong to the layers C of Shanidar Cave (which characterised by Upper Palaeolithic Baradostian technology) and discovered during the new excavations season (Hunt et al 2017). According to Hunt (et al. 2017), this object seems unlikely to result from natural causes, or human consumption, or use in the manufacture of other technology. It is possible, however, that it was manufactured as part of a composite object for visual display. Although composite lithic technology is one of the marks of Upper Palaeolithic industries such as the Baradostian, it is rather unusual for composite ornamental pieces of this period to be found. All mollusc remains were identified under low-power binocular microscopes; A Meiji zoom (4–50×) stereomicroscope with a Luminera Infinity 1-3C digital imaging system was used to image the object.

Contrary to the Iraqi Zagros sites, in Iranian Zagros great enthusiasm has been seen by the archaeologists in the recent years to apply functional studies to the sites. The very first study was applied to the Neolithic sites Ali Kosh Chagah Sefid and Tepe Tula'i of Deh Luran Plain of western Iran. These sites were excavated between 1960s and 1973 by Hole and his colleagues (Hole 1977; Hole et al 1969a, 1969b). In the excavated material, they reported pottery fragments adhere with black residue (possibly used for the waterproofing of the potteries). Gregg (et al. 2007) applied GS-CM method to analyse these black bitumen residue adhere with the pottery fragments. The results obtained with GS-CM showed the biomarker and isotopic analysis that they are bitumen from the natural deposit resources from Deh Luran Plain and Susa. Their results also indicate that these Neolithic bitumen shares many molecular and isotopic characteristics with the local modern sources in Khusistan and Lorestan.

The very preliminary use-wear analysis for stone tool was performed by Claud (et al. 2012) and Bazgir and Tumung (2013) to test the feasibility of functional study for the Palaeolithic sites. Claud and her colleagues analysed 3 points (2 bifacial points and 1 Mousterian point) from the Middle Paleolithic site of Qaleh Bozi 2 Rock shelter, central Iran. For their study, they use two types of microscopes for their analysis: 1) Binocular Olympus

SZ 30 microscope (between 10× to 30× magnification) for possible edge damage (fractures, scarring, rounding), 2) Leica Leitz DMR metallographic optical microscope (between 100× to 200× magnification) for the micro-polishes, micro-rounding, striations and pits on edges and surfaces. Their results showed petrological the stone qualities are in very good condition with slight shiny patina possibly due to chemical alteration, but does not hinder with the analysis. Out of the three points, two points were must have been used for butchery, especially for cutting meat. Their work is interesting to see that points were used for butchery but not for hunting purpose.

Contrary to their work, we analyzed 105 lithic artefacts from four Middle and Upper Paleolithic sites (Kaldar, Gilvaran, Ghamari and Gar Arjeneh) of Khorramabad Valley (Bazgir and Tumung 2013). The lithic artefacts were recovered during test excavated in 2011-12 and it was an attempt to check if functional studies are feasible for the sites. For the analysis, OLM and SEM were opt to identify the use-wear and residue on the samples. In the article, we mainly focused on the use-wear analysis results and saw the possible evidence of hunting activity around the Khorramabad Valley.

The use-wear and residue traces identified for the 2011-12 excavation lithic material, made us to be more careful with the recording and sampling of lithic artefacts in the excavation of Kaldar Cave in 2014-15. During the course of Khorramabad project, we improved our research methodology for the functional studies for better interpretation of the usewear and residue traces. Along with OLM and SEM, we also applied the 3D DM and assess the various complementary aspect of this microscope with other microscopes. For the residue analysis, we applied SEM with EDX, FTIR and μXRD for understanding the chemical characterization of the residue. Finally, this research becomes the foundation of present PhD research and the new results (both use-wear and residue) obtained for the sites of Kaldar and Gilvaran are discussed in the chapter 4 and 5.

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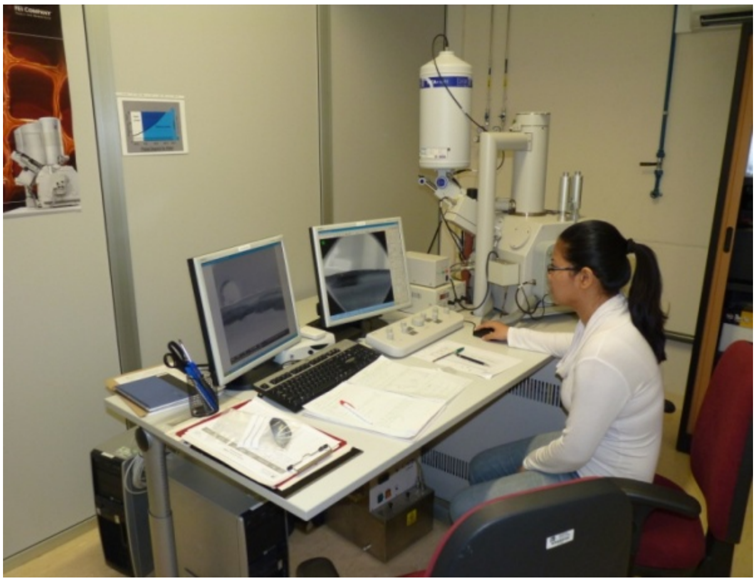

CHAPTER 3

RESEARCH METHODOLOGY

"Within the context of a controllable imitative experiment to replicate past phenomena in order to generate and test hypotheses to provide or enhance analogies for archaeological interpretation"
(Mathieu, James R.; 2002)

CHAPTER 3

RESEARCH METHODOLOGY

3.1. Archaeological material

Archaeological material comes from the four M-UP sites (Kaldar, Gilvaran, Ghamari and Gar Arjeneh) of Khorramabad Valley, western Iran. In 2012, we did some preliminary analysis of the stone tools to check the feasibility of the functional studies for the sites and how well is the preservation of the flint to identify the types of use-wear and residue. Microscopic analysis of the materials recovered according to conventional fieldwork procedures were submitted to a basic traceological study, based on optical microscopy observation. Good preservations of the artefacts were attested, and use-wear traces and potential residues identified pointed to the existence of projectiles likely related to hunting activity. Basing on these first promising results, we decided to expand the research in two main senses. First, we decided to incorporate wider archaeological samples, for which dedicated fieldwork precautions were taken in terms of potential functional studies to be taken. And second, a multi-technique approach was adopted in order to better handle the limitations of the optical microscopy for use-wear and residues analyses.

In the initial stage of the research, goals were set to analyse all the four sites lithic materials but as the project proceeded, the goals seemed very ambitious. Finally, only Kaldar Cave was considered as the main case study and Gilvaran Cave as the complementary site to compare the results. These two sites were selected as in the excavation they reached till the bed rock and stratigraphy was well described. They are discussed in detail in the archaeological functional analysis results chapter 5.

3.2. Precaution in the excavation and Laboratory

Since the very beginning of functional analysis, it is always emphasized precaution should be taken during excavation as they can lead to modern contaminations or PDSM, hence, can create misinterpretation of the tools function.

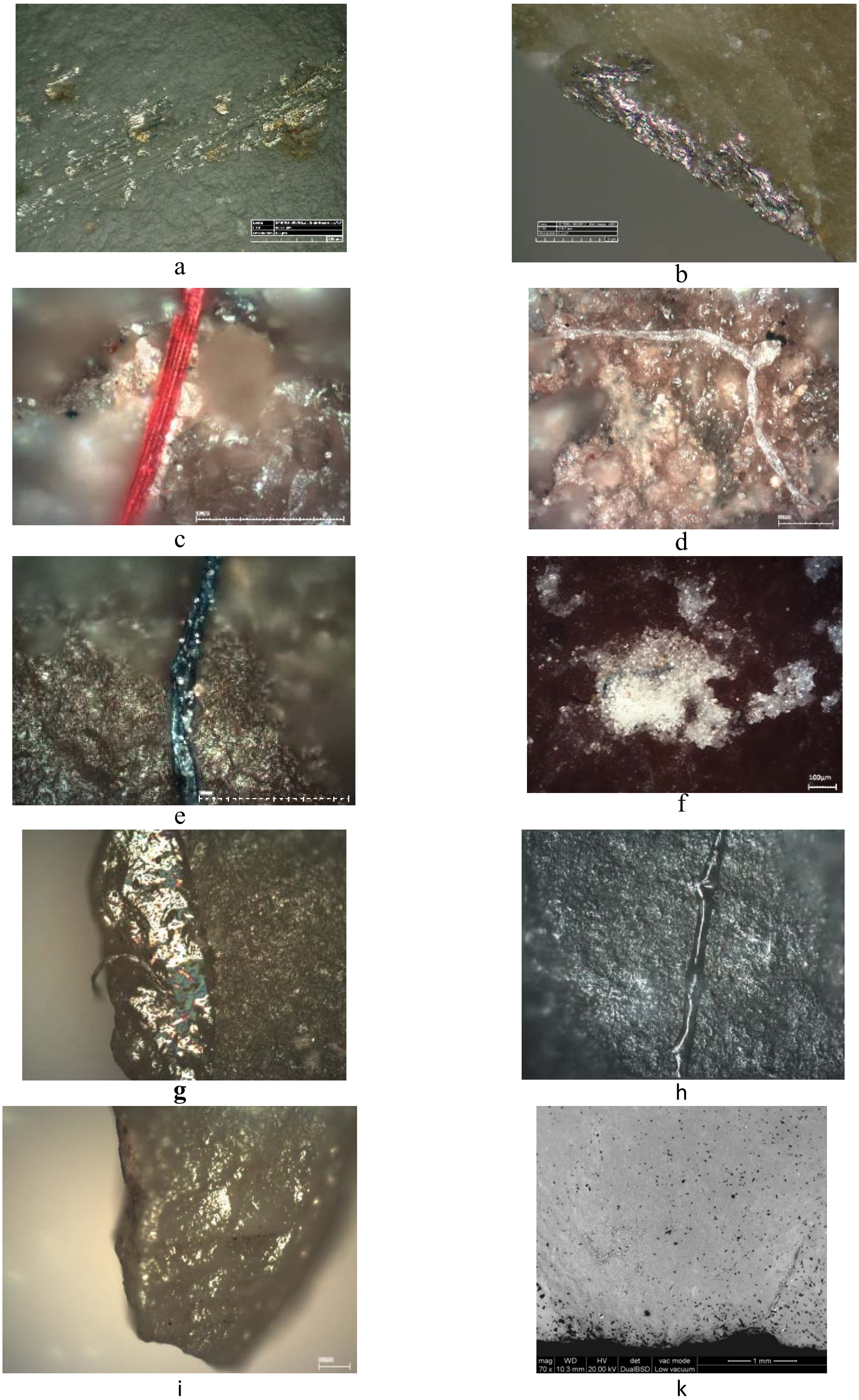

Figure 3.1: Modern contaminations on the 2011/12 excavation tools; a)metal tool mark with deep parallel striations; b) pencil mark; c) clothing fibre; d) paper fibre; e) hair; f) molding clay; (g-i) Transparent nail paint; k) skin flakes

In the preliminary examination of the 2011-12 excavation stone tools, we observed various types of residue which were modern contaminations both happened from the excavation and in laboratory (fig. 3.1, 3.2). This happened as for this excavation season, a functional study was not part of the multi-disciplinary approach to understand the sites assemblages. All the modern residues were documented by using OLM and SEM with EDX.

In 2014-15 excavation at Kaldar, a structured excavation protocol was applied to minimize any modern contamination and also to test till which limit it is successful. In this way, these excavation seasons became like the case study for the present study to test the potential of this excavation and laboratory methodology. In this excavation, all the excavators were asked to wear nitrile powder free gloves; they were instructed not to rub the lithic surface to remove the sediment when collected in the site. These stone tools were not washed to perform the residue analysis. In the laboratory, all the stone tools documented in the site were not marked with pen nor were used transparent nail paint and fractured piece were not glued as well. For the fractured pieces, each broken fragments were kept in the separate zip-lock plastic bags to avoid any post use-wear traces. They were always handled by wearing nitrile gloves, while performing any techno-typology and microscopic analysis to avoid any finger grease or skin flakes to transfer on the tool. The stage (on which the tool was mounted to perform microscopic analysis), was always covered with the new cling plastic film to avoid the direct contact between the molding clay and the artefact. For the SEM analysis, artefacts were not mounted on the metal stab to avoid any chances of losing the residue. The samples were supported with the molding clay (again covered with cling plastic film) and placed in the desired angle the tool needed to be analyzed for the identification of the use-wear and residue (fig. 3.3).

During the cleaning process, before putting them in the ultrasonic bath the samples were photographed with the respective plastic bags with the references, in order to not to misplace them in the wrong plastic bags as they were marked. The cleaning method applied for the archaeological tools are mentioned in the section 4.3.

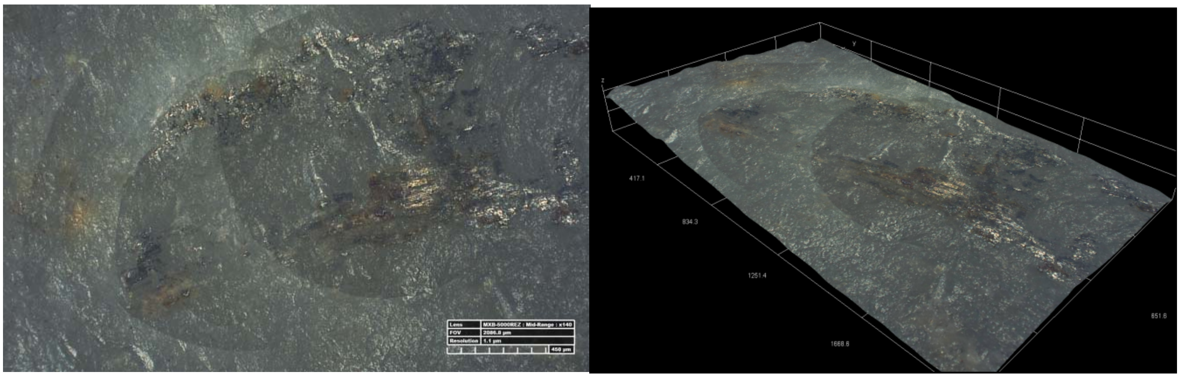

Figure 3.2: KLD-F7-7II-1048 showing the metal wear on the artefact surface and 3D of the residue and the impact fracture on the artefact, originated during excavation

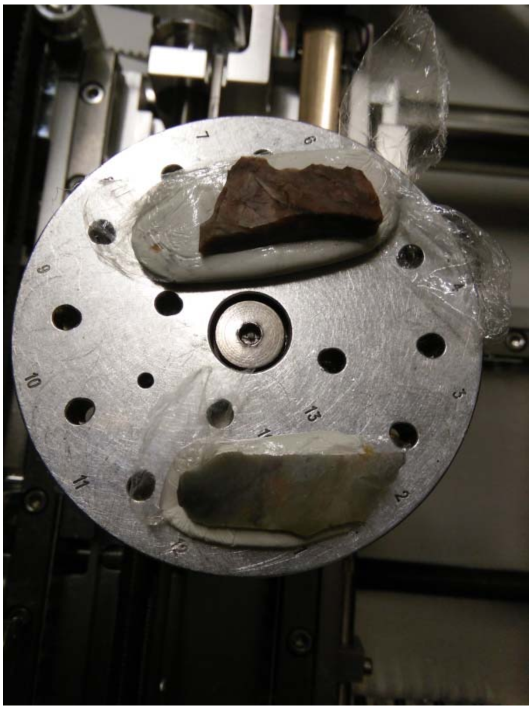

Figure 3.3.In the SEM chamber, archaeological tools placed on the molding clay which is covered with cling plastic film

3.3. Reference collection

This part is explained in detail in the article (predraft) no. 5, in the chapter 5.

3.4. Experimental protocol

3.4.1. Raw material and knapping activities

We collected the raw material from Khorramabad valley during our field survey in November 2015-January 2016 for a cross reference that what kind of use-wears can occur on them and compare with the archaeological material. The nodules were given numbers from 1 to 6 and all the lithic pieces coming out of them were also given the reference of the nodule. Our good friend Miquel Guardiola knapped these nodules, and also some ones of Monegros-type chert, from Zaragoza, Spain (García-Simón and Domingo, 2016) to replicate the Khorramabad tool types. General techno-typological criteria were used to replicate the artefacts, as the information available for the archaeological collections lacked of long refitted sequences or detailed *chaîne opératoire* reconstruction.. The tools knapped from the Khorramabad nodule were limited, as only few points were able to extract as the nodules had lots of feature, hence breaking apart while knapping. Besides these points, we selected the non-retouched flakes which were of a reasonable length and had enough space to hold it for performing the experiments. All the experimental pieces are given reference number as KF (Khorramabad flint), number of the nodule, the action performed with the piece (hide, bone scraping, butchery and wood scraping).

3.4.2. Mold and cast

As sometimes photographic images are not enough to compare the before and after changes occurred on the tool surface and only can be understandable in microscopic level. Hence, molds and cast helps to solve this problem and showed effective results (Tumung et.al 2012, 2013; Pedergnana 2011; Martín-Viveros 2016a). As we published in detail in Tumung et al. 2015, molds were prepared with silicon based dental impression material, *Provil® novo Light* (Heraeus Kulzer, Inc.). The two components, a base and a catalyst in a ratio of 50%, were placed on the impression material sheet and mixed under room temperature for 20-30 seconds so that it takes a uniform color to prevent bad polymerization (fig. 3.. Then the mixture was applied onto the stone edges using a spatula and left to dry. The molds were not removed for the stone tools until they used for making cast to avoid any contamination inside the moulds.

For preparing casts, a bicomponent rigid polyurethane resin, *Feropur PR-55* (Synthesia Española S.A.) was used. First, a small amount of the mixture, mixed in equal proportion is poured in the mold with the help of thick opening needle syringe in the molds as they were having narrow opening for pouring the mixture in them. The molds were kept standing still position and the syringe was moved inside the molds so that the liquid penetrated the pores and then the rest of the mixture is poured rapidly as the resin starts hardening quickly. Then the cast and mold kept together until the microscopic use.

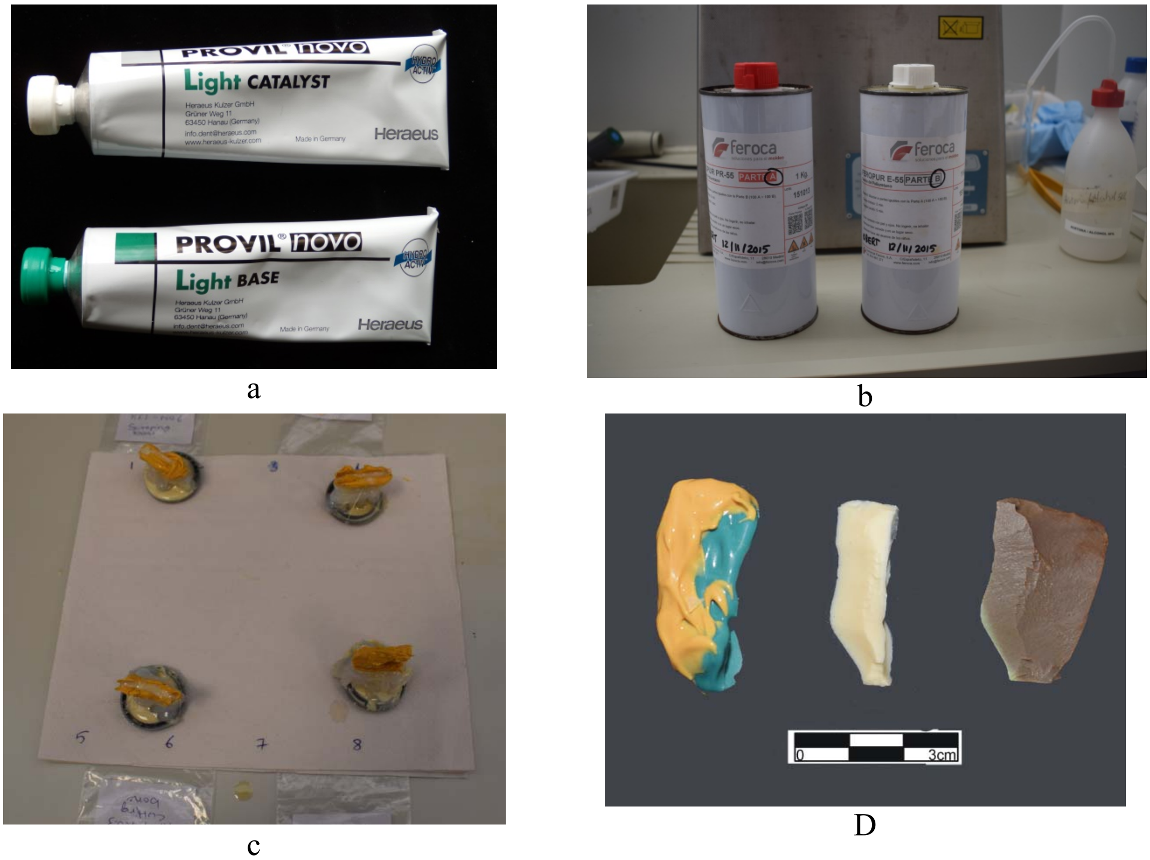

Figure 3.4: a) Provil® novo Light (Heraeus Kulzer, Inc.); b) , *Feropur PR-55* (Synthesia Española S.A.); c) preparation of cast and mold ; d) unused tool, cast and mold

3.4.3. Cleaning methodology

The importance of proper cleaning is very crucial in the functional studies for both experimental and archaeological artefacts. Since the very beginning works by Semenov (1964:24-26) have specifically emphasized on the cleaning method of the artefacts. This process enhances the visibility of traces on the samples by removing various organic deposits which get deposited on the edge in the course of their use and which are unlikely to survive on ancient archaeological specimens (Keeley, 1980). Depending on the type of raw material used as tool, various types of cleaning procedure have been suggested by the previous researchers and has been shown to yield good results (e.g. Keeley 1980; Levi-Sala 1996; Byrne *et al.*, 2006; Ollé and Vergès 2014; Tumung et al. 2015).

Cleaning process we employed in our study:

a) Cleaning with water and soft brush or fingers to remove the dirt from the archaeological stone tools,

b) 15 mins ultrasonic bath with normal water to remove the dirt from the archaeological stone tools,
c) 10 min in an ultrasonic bath of H_2O_2 (10% vol.) to soften any adhered organic tissues on the experimental sample;
d) 10 min in an ultrasonic bath of the neutral phosphate-free detergent Derquim®, with ionic and non-ionic surfactants to eliminate all the residues from the tool surface,
e) Rinsing under cold running water to remove any detergent or acid from the tool surface,
f) 2 min in an ultrasonic bath of acetone to eliminate any fatty residue resulting from the handling,
g) 1-15 mins in an ultrasonic bath in HCL to remove the concretion from the stone tools and less likely to have adverse effect on the flint,
h) 15-20 mins in boiling water to remove the adhesive from the experimental hafting tools,
i) 15 mins for a thermal ultrasonic bath in H_2O_2 (130% vol.) to remove the adhesive residue which were difficult to remove with boiling water,
j) in order to remove surface contaminants, we blow them gently with compressed air

In the 2011-12 excavation, the samples that were well documented in the site underwent thorough cleaning steps a, c, d, e and f. For the 2014-15 excavation samples, for the residue analysis we did not perform the cleaning of the samples as sometimes intensive scrubbing and cleaning with various strong acids can remove or dissolve the residues (Lombard 2005). After the residue analysis, the samples with no residue underwent the cleaning process included step c-g and j, whereas, samples with residue after performing all the analysis with different techniques underwent mostly b and j cleaning method. Step g was mostly performed for the pieces with the concretions. While cleaning the samples as they were not labeled I placed each tool on the respective plastic bag and took the photo to keep as reference not to misplace the samples with one another.

For the experimental butchery samples cleaning procedure comprised of steps c-f. On the other hand, for the projectile experimental samples, cleaning procedure included c-i. For the projectile experiments, steps c-f and h were performed but as the adhesive was not removing then the step (g) was applied to remove any remaining adhesive from the tool surface.

3.4.4. Recording methods and documentation

Before the experiments, a standardized form for each tool was prepared by mentioning their relevant independent variables, in relation to both the tools (raw material, dimensions, and features of the active edges) and to the replicated actions (worked material, type of movement, working angle). , and their illustrations along with observations of contact material were recorded in detail (Fig. 3.5). For the projectile experiment, each shot detail related to the changes on the tool and its contact with soil, skin and bone were noted. Similar for the butchery process the changes while performing the action, contact with the bone etc. was noted and recorded. The experiments were systematically monitored with photography, and occasionally video-recorded.

For the microscopic analysis documentation, a form was prepared with the line sketch of the tool (dorsal and ventral face) and all the locations of the observations were plotted on them. For the diagnostic use-wear and residue traces photographic record was kept in a photo catalog mentioning the photo number, number of micrographs taken and magnifications.

EXPERIMENTATION DOCUMENT FILE

Ref. Zaragoza no 1 Raw Material Zaragoza (Monegros-type chert)

Length 54mm Breadth 19mm Thickness 8mm

Weight 9.6gm Working Edge Tip

Angle Delineation

Worked Material

Type of action Hand

Movement

Time Angle Experimentor

Cleaning

Moulds

Observations

Type of experiment

Date

Figure 3.5: Standardized form used for each tool for the experiment

3.4.5. Projectile experiment

In our previous articles, Bazgir et al. 2014 and Bazgir et al. 2017 we have already discussed about the lithic technology and in both the excavation the assemblages showed the dominance of various types of points (such as Arjeneh, Levallois, Mousterian) in all the four sites. After the preliminary use-wear analysis in 2013, it made me curious how they were hafted and used. Indeed, all the preliminary observations not only in techno-typological terms, but also after the identification of impact fractures in the tips and possible impact traces, were suggesting a significant presence of projectiles in the assemblages.

For this experimental program, a very small set of experiments were performed using only six points made from Khorramabad flint (green and white color) and Zaragoza/Monegros-type chert.. I am well aware to conclude any hypothesis; the current experimental program is not sufficient compare to other previous works (e.g; Fischer et al 1984; Sisk and Shea 2009). However, still was enough able to provide some important information about the projectiles use in the valley. For this study previous works have been referred and compared with this research results.

For the **hafting arrangement**, there are various methodological proposals available (e.g. Kamminga 1982; Rots 2010, Sisk and Shea 2009 and Monod 2013) were various types of hafts such are mentioned, as juxtaposed (LD), lateral hafting (L), female haft, Male haft (M), and Male split haft (MS) (Fig. 3.6). For my research, only LD and MS hafting techniques are applied. LD hafting was chosen, because similar to Sisk and Shea (2009) experimental piece my samples were also thick and this method was quick, effective, and yielded consistent hafts. Following their methodology, the opposite side to the notch was shaved down to present a smooth plane from the distal end of the foreshaft to the base of the notch. The points (dorsal side facing the notch) were mounted in such a way as to minimize the difference in central planes between the foreshaft and the point (Sisk and Shea 2009: 2041).

On the other hand, only for one piece (Zaragoza no.2) MS method was used to secure it on the spear shaft. For preparing MS or slot haft, a split was made up to a certain height where the tool is covering till the half proximal area (Fig.3.6).

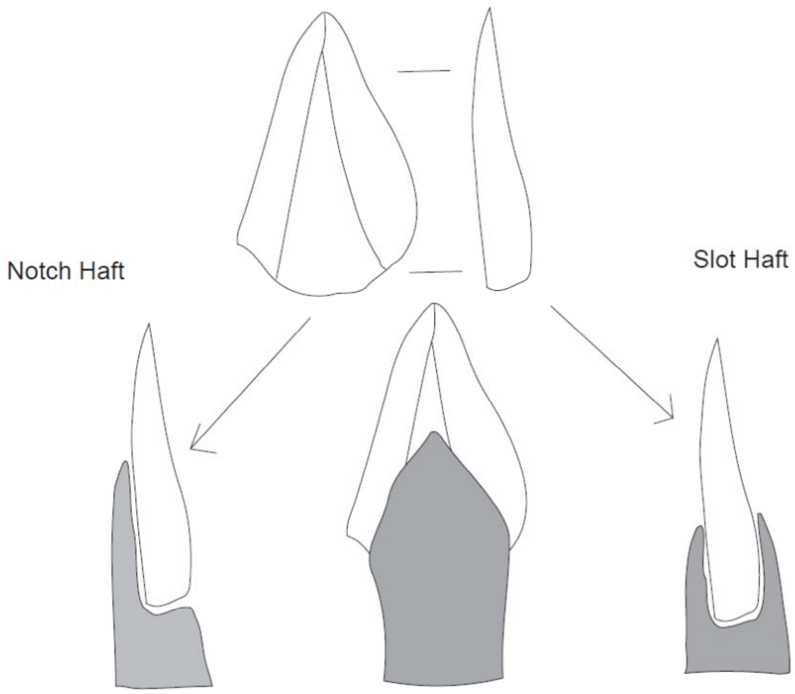

Figure 3.6: The hafting method applied for the projectiles (Source Shea et al. 2001)

a b

Figure 3.7: a) normal wrapping and b) criss-cross wrapping

For the shafts, hazelnut wood (*Corylus avellana*) was used for the arrowhead foreshaft and hackberry *Celtis australis*) for the spearhead shaft. The points were fixed to the foreshaft/shaft by using an adhesive mixture of beewax and pine resin, which applied on the hafting area with a wooden spatula and secure with the industrial hemp twine. The binding of the twine for the points was used as normal wrapping but only for (KHR-6 no. 1) criss-crossed wrapping was applied (fig. 3.7).

Reference	Shell/Flint Variety	Species	Activity	Contact Material	Movement Direction	working Angle	Time (Minutes)/number of shots
AKF1-H1	Khorramabad flint	*Cervus elaphus*	Scraping	Fresh hide	Transverse-unidirectional	90º	45
AKF1-B1	Khorramabad flint	*Cervus elaphus*	Scraping	Bone	Transverse-unidirectional	45º	35
AFK1-Bu1	Khorramabad flint	*Cervus elaphus*	Cutting/defleshing	Meat-Bone	Longitudinal-unidirectional	45º-90º	90
AKF1-W1	Khorramabad flint	*Prunus dulcis*	Whittling	Stem of fresh wood	Transverse unidirectional	45º	40
KF1-No.5	Khorramabad flint	*Capra* sp.	Cutting/defleshing	Meat-Bone	longitudinal-bidirectional	75º-90º	30
KF1-No.6	Khorramabad flint	*Capra* sp.	Scraping	Meat-Bone	Transverse-unidirectional	45º	30
KF1-No.7	Khorramabad flint	*Capra* sp.	Cutting	Bone	Longitudinal-bidirectional	90º	30
KF4-No.1	Khorramabad flint	*Capra* sp.	Cutting/defleshing	Meat-Bone	Longitudinal-unidirectional	75º	30
KF4-No.2	Khorramabad flint	*Capra* sp.	Cutting/defleshing	Bone	Transverse unidirectional	45º	90
KF4-No.3	Khorramabad flint	*Capra* sp.	Scraping	Bone	Transverse unidirectional	45º	30
KF6-No.1	Khorramabad flint	*Capra* sp.	Cutting/defleshing	Meat-Bone	Longitudinal-unidirectional	75º	30
KF6-No.2	Khorramabad flint	*Capra* sp.	Scraping	Bone	Transverse unidirectional	45º	30
KH4-no.1	Khorramabad flint	*Cervus elaphus*	Arrowhead projectile	meat,bone and sediment	projectile	-	2 shots
KHR6-no.1	Khorramabad flint	*Cervus elaphus*	Arrowhead projectile	meat,bone and sediment	projectile	-	10 shots
KHR6-no. 4	Khorramabad flint	*Cervus elaphus*	Arrowhead projectile	meat,bone and sediment	projectile	-	10 shots
Zarragoza no 1	Zarragoza flint	*Cervus elaphus*	Arrowhead projectile	meat,bone and sediment	projectile	-	8 shots
Zarragoza no 2	Zarragoza flint	*Cervus elaphus*	Spearhead projectile	meat,bone and sediment	projectile	-	1 shot
Zarragoza no 3	Zarragoza flint	*Cervus elaphus*	Arrowhead projectile	meat,bone and sediment	projectile	-	1 shots

Table 3.2: list of experiments showing the principle variables

For the arrowhead, the foreshafts were then fitted and secured with tape to over the ends of previouslt modified commercial carbone arrows (c. 800 mm long). In the experiments, we selected number of shots (1 to 10) per piece to perform the projectile activity. Number of shots also depended on the successful impacts, till the moment the points cannot be used any further. The projectiles were shot with a commercial bow from 18-22 pounds (INITECH2) from a distance of 7m to 10m depending on the comfort of the subject in performing the task. For the target animal *Cervus elephus* was used, and all the experiments (projectile and butchery) were performed in the outdoor location of National Hunting Reserve of Boumort, in northern Catalonia (la Pobla de Segur, Lleida) on the border with France.

3.4.6. Butchery activity

For the butchery activities, bone working (scraping and cutting), disarticulating and defleshing were performed. According to the movement of the object, the angle of active edge, and its orientation with respect to the contact material and the angle of work, different actions can be carried out (Agarwal 2008). In this study, for the experiments only (scraping) transverse and (cutting) longitudinal actions have been used. These particular actions were chosen because they were adaptable to a variety of materials, and allowed direct comparisons to be made between tools used in the same fashion on a variety of different materials (Keeley 1980).

a

b

Figure 3.8: Transversal unidirection and longitudinal bidirectional images

a). ***Cutting*** - consists of bi- or uni directional strokes with the edge (straight active edge) of the tool held parallel to the direction of use and usually at high angles, in the vicinity of 90° to the material being cut. In this study, bone and flesh were cut.

b). ***Scraping*** - It is a unidirectional movement with the tool edge being drawn transversely to the contact surface. The angle between the contact material and the active edge is medium and varies between 50° -70°. In this research wood, hide and bone scraping tasks were carried. For the bone and hide scraping, the tool was pulled towards the user in a single motion with the leading edge aspect being the ventral face of the tool. It may be noted that the angle at which the tool is held varied a few degrees in either direction during the course of the activity.

Determine the **material worked** on the instruments of labour is one of the main objectives of the application of functional analysis methodology to the archaeological material, and also one of the most influential in generating the traces (Clemente, 1995, 1997: 29; González & Ibáñez, 1994: 28). Therefore, it is a significant variable and unchangeable, despite the state of the material worked with the instrument may vary depending on whether the material moist, dry, among others (Clemente, 1995; 1997:29). Therefore for this study, the use-wear materials were chosen based on the categories outlined by Shea and Klenck (1993), (table).The yielding classes are soft, medium (semi-rigid), and hard (rigid), while the resistance categories were animal (non-siliceous), vegetal (moderately siliceous), and inorganic (highly siliceous). In the course of this research, as the archaeological residue indicated towards bone working or association to bone through impact striations, for which we initially concentrated our interest mostly on the butchery and projectile experiments to understand the formation of those wear traces and residues. Hence, being aware that complete archaeological interpretations will require widening the experimental programs, we essentially focused mostly the animal matter (meat, bone and hide) in their fresh, natural and raw state was used.

Material worked in the study based on Shea and Klenck, 1993		
Yielding category	Resistance category Animal matter	Vegetal matter
Soft	Meat	-
Medium	Hide	Stem of wood
Hard	Bone	-

Table 3.3: Material worked in the study and their degree of hardness.

For butchery activity, goat (*Capra* sp) and deer (*Cervus elephus*) was used to achieve the aims of the experimental program. These species were used as they are also available in the faunal assemblage of the sites. Further various parts of a contact material have qualities which could differentially condition the development of microwear. In the butchery process there was incidental contact with bone and cartilage while cutting flesh, therefore, frequency of such contact during an experiment was recorded.

The **duration of use** of the instrument is another important variable affecting instrumental in the formation of traces of use in the working tools (Clemente, 1995, 1997: 34; González & Ibáñez, 1994, 31). For each stone tool, elapsed time was chosen as a variable rather than the number of strokes to perform a specific activity such as hide scraping, bone cutting etc; although, both the methods have been used by different researchers and showed significant results in understanding the wear formation (Tringham *et al.*, 1974; Keeley, 1980). It has been found in most studies that it takes some amount of time before a set of distinctive wear traces characteristic of a particular use material develops on a tool edge. Many researches have shown that observing the tool in sequential time interval one can understand in how many minutes the use-wear appear and the distribution of them on the tool (Ollé and Vergès 2008, 2014; Pedergnana 2017). Use-duration is therefore an important variable to investigate in order to avoid potential confusions between use-materials that can be distinct, having similar polishes through underdevelopment (Agarwal, 2008)

The **angle of the tool** to contact surface can tell so much about the distribution of the use-wear and residue. Therefore, during each experiment, the angle between the ventral edge-aspect of an experimental tool and the contact surface as well as any changes in the angle of work was noted. The angle usually varied 20° to 90° degrees depending on the shape, topography of the contact material, the sharpness of the edge and comfort of the subject while perform the task. No effort was made to keep this angle artificially constant throughout the experiment (Tringham *et al.*, 1974).

For the **data analysis**, previous experimental and theoretical work on flint have been used to determine which independent and dependent variables should be studied and why. As only a limited number of experiments have been performed, so quantitative data is not presented. Therefore, observations have been described verbally and are supplemented by photographs.

3.5. Non-invasive multi-analytic approach

From the decades of work in functional analysis it is noticeable that only one specific approach is not sufficient to interpret the wear and residue traces (e.g. Monnier et al. 2013, Zupancich et al. 2016a; Padergnana et al. 2016). Till date various types of methods and techniques have assessed and applied by previous researcher and have shown some significant development in the understanding of the tool function. For the multi-analytic approach, to analyze use-wear most used microscopes are the OLM and SEM and occasionally Confocal Microscope. On the other hand, for residue analysis, SEM with EDS or EDX is mostly preferred followed by other techniques such as FTIR, XRD, GS-CM etc.

For this study, these facilities of OLM, 3D DM, SEM with EDX, μXRD were available in the institute and university labs. Hence, taking the advantages a multi-analytic approach was followed to answer the set objectives of the studies.

3.5.1. Microscopic analysis

Several methodological issues have been explained in detail in other sections, and especially in the articles (predrafts) no. 5 and article (predraft) no. 7 (in chapter 5). Here, only general information about the microscope and other different techniques used have been explained very briefly.

3.5.1.1. OLM

Since, the very beginning of the traceological studies, OLM is the most preferred microscope compare to others. This microscope is very easy to use and can identify different traces with the magnifications between 50x to 500x. Though, widely used, various previous researches have shown that it is better to use it as a complementary approach with other microscopic approach for the better identification of the traces (Monnier et al. 2013; Borel et al. 2014. And Pedergnana et al 2016). This aspect is discussed in detail in the article no. 5 (predraft) in comparison to 3D DM and SEM.

3.5.1.2 SEM with EDX.

This microscope is second most favoured microscope by the traceologists especially due to its benefit of depth of field for analyzing and capturing micrographs. Other than that, this microscope when paired with Energy Dispersive X-ray (EDX) or Energy Dispersive Spectroscopy (EDS) provides the additional benefit of identifying the residue in molecular level. Although unlike other microscopes, this too has many advantages and drawbacks which is explained in detail in the article no 5 (predraft).

3.5.1.3. 3D Digital Microscope

3.5.1.4. Article 5: Tumung L, Borel A., and Ollé A. (Predraft*). Assessing the application of Digital 3D microscope for functional analysis on stone and shell tools: A complementary approach*

This is a preliminary draft of a paper still under construction. Here, I tried to assess the potential of the 3D DM in comparison to OLM and SEM for providing a solid methodological approach for functional studies. During the course of the research, I realized that 3D DM (especially Hirox brand) is new to the traceological study and the variations in the observations of traces with all the three microscopes were noticeable. Hence, this microscope is applied for identifying different types of use-wear and residues traces, and to check till which limit it is adaptable as a single microscopic approach or should be used as a complementary approach together with OLM and SEM.

Assessing the application of Digital 3D microscope for functional analysis on stone and shell tools: A complementary approach

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Abstract

Functional analysis (combining wear and residue analyses) has become a potent approach to understand the past human activities. For decades, this field has developed its methods and techniques to better interpret the function of the ancient artefacts but still requires some more advancement to improve the reliability and repeatability of the analysis. For decades, researchers have shown the importance of Optical Light Microscopy and Scanning Electron Microscopy to interpret the functionality of the tool. Digital microscopy is now becoming common among traceologists to analyze (flint and shell tools) surfaces for functional analysis. However, none of the previous works has ever discussed its potential and efficiency, alone or as a complementary tool. Here, we propose to examine for the first time the advantages and disadvantages of digital microscopy, focusing mainly on the fully automatized Hirox KH-8700 and RH-2000 models. The results obtained show that digital microscopes have significant benefits for analyzing wear and residue traces. It offers high magnifications compared to OLM and allows quick 3D modelling and profiling of the surfaces. Automatic stacking and stitching combined with a wide range of magnifications are powerful for describing the distribution and organisation of traces. Also, the possibility to connect different light sources allows highlighting different types of features on different raw materials. Being a very efficient tool for use-wear and residue qualitative description (both as a standalone or complementary microscope with OLM and SEM), more advanced research still needs to be carried out to demonstrate its adequacy for quantitative analysis.

Keywords: *Functional analysis, Stone and shell tools, Digital 3D microscope, OLM, ESEM with EDX*

1. Introduction

In Palaeolithic studies, functional analysis plays a fundamental role in our ability to reconstruct past activities, subsistence strategies and social organisation, aspects of behavior that are crucial to understanding human evolution.

Microscopes play a crucial and integral role in the functional analysis. It helps traceologists not only to get a closer view of the wear and residues traces but also to describe their nature/pattern, direction and distribution on the artefacts to interpret their function. Various previous works have described the evolution of functional analysis and different types of microscopes used (Olausson 1980; Grace 1996; Levi-Sala 1996; Marreiros et al. 2015; Stemp et al. 2016). According to Stemp et al. (2016), the first use of magnifying lenses and microscopes to study the edges and surfaces of tools dates back to the late 19th century (Olausson, 1980; Vaughan 1981). But microscopic approach boomed after the translation into English in 1964 of the work by S. A. Semenov *Prehistoric technology*. This study introduced the systematic use of the microscope for analysing use-wear traces on stone tools and utilized structured experimentation of stone tool use. S. A. Semenov already emphasized the importance of the lighting, surface treatment and photography for the identification of the wear traces under the microscope. Since then, functional analysis was seen as one of the essential proxy/keys to interpret human behaviour and to reconstruct their social-cultural human behavior and organisation (Streud 1978; Redman 1973; Marrieros et al. 2015).

During the following years, two approaches emerged: the Low Power Approach (LPA) (Tringham et al. 1974; Odell 1981; Kamminga 1982) and the High Power Approach (HPA) (Keeley, 1974, 1976, 1980; Keeley and Newcomer 1977). The LPA is mostly focused on the classification of fractures, whereas, HPA mainly focused on the identification and interpretation of use related polishes. For sometimes these two approaches were considered as separate approach and strongly supported by their respective pioneers by providing their advantages and disadvantages (Yerkes and Kardulias 1993). But in Uppsala conference (1989), where LPA and HPA was the center of discussion, researchers agreed that both the approaches are complementary to each other and provides better solutions as combine rather than alone (Unger-Hamilton 1989; Olausson 1993; Grace 1996).

Since, various types of observation and data acquisition implements have been used by wear analysts to better interpret the wears and residues on different types of raw materials as well as to quantify surface texture. The types of microscopes used are: Optical/light microscopy (O/LM) (e.g Bruier 1976; Shafer and Holloway 1976; Kamminga 1982; Odell and Odell-

Vereecken 1980, 1981, 2004; Tringham et al. 1974; Grace 1996; Van Gijn 1998; Rots 2002); Scanning Electron Microscopy (SEM) (e.g. Hay 1977; Del Bene 1979; Aderson 1980; Mansur-Franchomme, 1983; Unger-Hamilton, 1983; Knutsson 1988; Ollé and Vergés 2008; Borel et al. 2014; Tumung et al. 2012, 2015; Pedergnana and Ollé 2018); Laser Scanning Confocal Microscopy (LSCM) (e.g. Derndarsky and Ocklind 2001; Evan and Donahue 2008; Evans and Macdonald 2011; Stemp and Chung 2011; Stemp et al. 2013; Evans et al. 2014; Ibañez et al. 2014, 2016; Bonito-Clavo et al. 2017); Atomic Force Microscopy (AFM) (e.g. Kimball et al. 1995; Anderson et al. 1998; faulks et al. 2011); Laser Profilometry (e.g. Stemp 2014; Stemp and Stemp 2001, 2003; Stemp et al. 2008, 2009, 2010); Optical Rugosimetry (e.g. Anderson et al. 1998; Vargiolu et al 2003; Anderson et al. 2006); Variable Focus Microscopy (FVM) (e.g. Dubreuil 2004; Evans and Macdonald 2011; Macdonald 2014); Interferometry (Astruc et al. 2011; Bofill et al. 2013); 3D Digital Microscopy (3D DM) (Revedin et al. 2015; Ronchitelli et al. 2015; Bowosachoti 2016; Martín- Viveros 2016a, 2016b; Marciani et al. 2018). Despite that many trials have been done with this wide variety of microscopes, the reality shows that traceologists mostly rely on LM, and, to a lesser extent, on SEM and confocal microscopy. Many analysts have tried to compare these microscopes to test their feasibility and efficiency for image resolution and quantification of traces as well as their complementary aspects (for, eg. Keeley 1974, 1980; Tringham et al. 1974; Odell 1975; Anderson et al. 1998; Borel et al. 2014; Evans and Donahue 2008; Ollé and Vergés 2011; Ollé et al. 2016; Stemp et al. 2017; Tumung et al. 2015; Cuenca-Solana et al. 2017).

With the microscopic approaches improved, many analysts started to test variability of wear patterns depending on the raw material (e.g. Greiser & Sheets 1979; Beyries 1982). Since 1970's till present, micro-wear studies are more focused on the fine-grained raw material, mainly flint or chert (e.g.Tringham *et al.*, 1974; Odell, 1977; Anderson, 1980; Keeley, 1980; White, 1982; Buller, 1983; Moss, 1983; Unger-Hamilton, 1983; 1984; 1985; Vaughan, 1985; Van Gijn 1990; Aldenderfer 1991; Levi-Sala 1996; Rots 2004, 2010; Martín-Viveros 2016a, 2016b). One of the reasons is that it is the most represented raw material in many of Middle and Upper Paleolithic archaeological assemblages. Surface alteration on fine grain flint elements occurs within few minutes of work. Diagnostic traces are thus likely to develop quickly. Other stone types which gained more and more attention from traceologists are obsidian (Hurcombe 1985, 1992; Kamminga, 1978; Vaughan, 1981; Stemp and Chung 2011), chalcedony (Kazuo Aoyama's 1995), basalt (Price-Beggerly, 1976; Stafford, 1977; Kamminga, 1978; Odell and Odell-Vereecken, 1980; Plisson 1982; Schutt, 1982; Richard, 1988; Asryan and Ollé, 2016), quartz and quartzite (e.g. Broadbent and Knutsson 1975, Sussman 1985; Knutsson 1986, 1988; Knutsson et al 1988, 2015; Pedergnana et.al. 2017c, 2018; Pedergnana and Ollé, 2014; Pedergnana et al 2017d; Ollé et.al 2016), shale (Akoshima 1979; Kajiwara and Akoshima 1981), ground stone (Del Bene and Shelley 1979, Adams 1988, 1989; 2002, 2004; Adams et.al. 2010; Dubreuil 2004; Dubreuil and Grosman 2009, Dubreuil and Savage 2014) and granite (Agarwal 2008).

Besides stone tools, use-wear analyses were also performed on bone tools (Olsen 1979, 1980, 1984, 1989; Choyke 1983; Runnings et.al. 1989; Russell N. 2001a, 2001b, Stone 2011; Watson 2015; Watson A. and Gleason M. 2015) and shell tools (Cleghorn 1977; Eaton 1974; Lima et al 1986; Keegan 1984; Masson 1988; Toth and Woods 1989; Kamminga 1982; Fullagar 1986; Cooper 1988). But unlike stone and bone tools, shell tools received the most attention for use-wear analysis from 2000 onwards (Schmidt et.al. 2001; Lucero 2004a, 2004b; Choi and Driwantoro 2007; Douka 2011; Cuenca-Solana 2010, 2015; Cuenca-Solana et.al. 2011, 2013, 2014, 2017; Tumung et.al. 2010, 2012; 2015; Joorden et.al 2009, 2015; Manca 2016; Mărgărit et.al. 2017). They are mostly analyzed by using light microscope for use-wear (e.g., Schmidt et al 2001, Lucero 2004a, 2004b, Cristiani et al 2005; Hunt et.al. 2017; Light 2005, Marcela and Jackson 2005, Mansur and Clemente 2009, Cuenca-Solana et al 2010, 2011, 2013, Douka 2011, Cuenca-Solana 2015; Manca 2016; Mărgărit et.al. 2017) and residue analysis (Barton and White, 1993; Schmidt et al., 2001). Till date, very few SEM analysis has been performed on shell tools. Michel Greut (et al. 1999) and his team were the first to apply SEM for the use-wear studies of shell tools, and later Zilhão et al. (2010) applied it for residue analysis. But L. Tumung (2010) did the first assessment of the feasibility of SEM for the use-wear studies on shell tools (Tumung et al. 2010, 2013, 2015). On the other hand, Cuenca-Solana supported both the OLM and SEM as an optimal methodology for the study of the shell tools (Cuenca-Solana et al. 2017).

Since the 1970s, residues analysis also emerged as a complementary approach for inferring past tool function (Grace 1996). These residues, which get stuck on tools surface can be use related such as worked material (Briuer 1976; Shafer and Holloway 1979; Anderson 1980; Crowther and Haslam, 2007; Hardy and Garufi, 1998; Hardy and Moncel, 2011; Lombard and Wadley, 2007; Wadley and Lombard, 2007; Wadley et al., 2004), hafting resins (Barton et al., 2009; Boëda et al., 1996; Holdaway, 1996; Dinnis et al., 2009; Rots, 2010; Rots and Williamson, 2004) as well as possible modern day contaminations (Wadley and Lombard, 2007; Pedergnana et.al 2016; Rots 2010; Cnuts and Rots 2017;). They can be identified by their colour (only LM) and morphological detail under various microscopes (mainly reflected and transmitted light as well as SEM microscopes).

Recently, 3D DM have gained immense interest among archaeologists for use-wear and residue analysis. Few articles mentioned about this new microscope with some brief description about its unique features useful for the functional studies (Arrighi and Borgia 2009; Revendin et.al. 2015; Ronchitelli et.al. 2015; Arrighi et.al. 2016; Martín-Viveros 2016b; Marciani et.al. 2018; Pedergnana 2017a). On the other hand, many new researchers have discussed about their works using 3D DM in various conferences such as: Vth International congress of Experimental Archaeology, Tarragona (Spain) (Tumung et.al. 2017), AWARANA, Nice (France), XVIII UISPP, Paris (France) (Tumung et.al. 2018; Martín-Viveros and Ollé 2018a, Fernández-Marchena et.al 2018a) and European Archaeologists Association, Barcelona (Spain) (Martín-Viveros and Ollé 2018b; Fernández-Marchena et.al., 2018b; Mateo Lomba et.al. 2018; Winnicka 2018)). Many recent unpublished Master's and PhD theses have also used this microscope (Bowosachoti 2016; Martín-Viveros 2016a, Luengo Cortés, 2017). Since, 3D DM is gaining immense popularity among the traceologists, so it will be very beneficial to assess the various features of this microscope in interpreting the traces. Hence, in the present research, we are performing a qualitative analysis of two types of 3D DM (KH-8700 and RH-2000) compared with OLM and SEM. In this article we are trying to assess the various features of this microscope for the functional studies on stone and shell tools and try to justify the assessments with the help of images.

2. Material and Methods

The study is built on three integrated types of research, where 3D DM was used as a complementary microscope for functional analysis on flint (archaeological and experimental) and shell artefacts (experimental) to check the variability of the use-wear and residues. First research is use-wear and residue analysis on archaeological material belonging to an Upper Paleolithic level of Kaldar Cave, Iran (Layer 4, Sub-layer 5, 5II 6 and 6II). Second research was built on experimental tools to analyze the distribution of the residue on the flint stone tools and to interpret the function and direction of the action performed. The third research was use-wear analysis on modern-day non-retouched shell tools.

2.1.Archaeological material

Kaldar Cave (48° 17′ 35″ E longitude, 33°33′ 25″ N latitude) is located in the North of Khorramabad Valley, Lorestan Province of western Iran. This cave is 16 m long, 17 m wide, and 7 m high and situated at the height of 1,290 m above sea level and. It was first discovered by Z. Bakhtiari in 2007 and later excavated for two seasons (2011-12 and 2014-15) by Dr Behrouz Bazgir. The excavated stratigraphy reveals five layers of occupations with Upper and Middle Palaeolithic remains. Upper Palaeolithic Layer 4 (sub-layer 5, 5II, 6 and 6II) provides AMS radiocarbon dates of 38650–36750 cal BP, 44200–42350 cal BP, 54400–46050 cal BP. Middle Palaeolithic Layer 5 (Sub-layers 7and 7II) based on the lithic industry and till date, no date is available for this level (Bazgir et al. 2014, 2017; Becerra-Valdivia et al. 2017). This site also provided the earliest evidence of *Prunus* sp. (Aullé et al. 2018) as well as the exploitation of the Palearctic fauna as resources (Bazgir et.al.2017). The lithic assemblages are dominated by flints in very well preserved condition along with evidence of use-wear and residues.

Figure 1: Map showing the location of the Kaldar Cave

2.2 Experimental samples

For the experimental program, we have selected two types of raw material (flint and shell). For shell tools, we selected different species *Pecten maximus* (Linnaeus, 1758), *Mytilus galloprovincialis* (Lamark, 1819), *Ruditapes decussatus* (Linnaeus 1758), and *Glycymeris violascens* (Linnaeus, 1767) for variation in size, morphology and strength of shell. For the stone tools, flints were collected from Iran (Khorramabad Valley) and Spain (Zaragoza, Moegros-type chert) (Gracía-Simon and Domingo, 2016). Details of the experiments and principle variables are mention in the (Table 1).

Ref. Number	Shell/Flint Variety	Species	Activity	Contact Material	Movement Direction	working Angle	Time (Minutes)/ number of shots
AKF1-H1	Khorramabad flint	*Cervus elaphus*	Scraping	Fresh hide	Transverse-unidirectional	90^{0}	45
AKF1-B1	Khorramabad flint	*Cervus elaphus*	Scraping	Bone	Transverse-unidirectional	45^{0}	35
AFK1-Bu1	Khorramabad flint	*Cervus elaphus*	Cutting/defleshing	Meat-Bone	Longitudinal-unidirectional	45^{0} -90^{0}	90
AKF1-W1	Khorramabad flint	*Prunus dulcis*	Whittling	Stem of fresh wood	Transverse unidirectional	45^{0}	40
KF1-No.5	Khorramabad flint	*Capra* sp.	Cutting/defleshing	Meat-Bone	longitudinal-bidirectional	75^{0} -90^{0}	30
KF1-No.6	Khorramabad flint	*Capra* sp.	Scraping	Meat-Bone	Transverse-unidirectional	45^{0}	30
KF1-No.7	Khorramabad flint	*Capra* sp.	Cutting	Bone	Longitudinal-bidirectional	90^{0}	30
KF4-No.1	Khorramabad flint	*Capra* sp.	Cutting/defleshing	Meat-Bone	Longitudinal-unidirectional	75^{0}	30
KF4-No.2	Khorramabad flint	*Capra* sp.	Cutting/defleshing	Bone	Transverse unidirectional	45^{0}	90
KF4-No.3	Khorramabad flint	*Capra* sp.	Scraping	Bone	Transverse unidirectional	45^{0}	30
KF6-No.1	Khorramabad flint	*Capra* sp.	Cutting/defleshing	Meat-Bone	Longitudinal-unidirectional	75^{0}	30
KF6-No.2	Khorramabad flint	*Capra* sp.	Scraping	Bone	Transverse unidirectional	45^{0}	30
KHR6- no. 1	Khorramabad flint	*Cervus elaphus*	projectile	meat, bone and sediment	-	-	10
KHR6-no.4	Khorramabad flint	*Cervus elaphus*	projectile	meat, bone and sediment	-	-	10
KH4-no.1	Khorramabad flint	*Cervus elaphus*	projectile	meat, bone and sediment	-	-	2
Zaragoza no.1	Zaragoza flint	*Cervus elaphus*	projectile	meat, bone and sediment	-	-	8
Zaragoza no.2	Zaragoza flint	*Cervus elaphus*	projectile	meat, bone and sediment	-	-	1
Zaragoza no 3	Zaragoza flint	*Cervus elaphus*	projectile	meat, bone and sediment	-	-	1
MY01	*Mytilus galloprovincialis*	*Cervus elaphus*	Cutting/skinning	Skin-meat	Longitudinal bidirectional	90°	15
MY02	*Mytilus galloprovincialis*	*Cervus elaphus*	Cutting/defleshing	Meat-bone	Longitudinal bidirectional	90°	10
MY03	*Mytilus galloprovincialis*	*Celtis australis*	Cutting wood	Stem of fresh wood	Longitudinal bidirectional	90°	10
MY04	*Mytilus galloprovincialis*	*Celtis australis*	Scraping wood	Stem of fresh wood	Transverse bidirectional	70°	10
PE01	*Pecten maximus*	*Cervus elaphus*	Cutting/skinning	Skin-meat	Longitudinal bidirectional	30°-90°	15
PE02	*Pecten maximus*	*Cervus elaphus*	Cutting/defleshing	Meat-bone	Longitudinal bidirectional	90°	15
PE03	*Pecten maximus*	*Celtis australis*	Cutting wood	Stem of fresh wood	Longitudinal bidirectional	90°	10
PE04	*Pecten maximus*	*Celtis australis*	Scraping wood	Stem of fresh wood	Transverse bidirectional	90°	10
RU01	*Ruditapes decussatus*	*Celtis australis*	Cutting wood	Stem of fresh wood	Longitudinal bidirectional	90°	10
RU02	*Ruditapes decussatus*	*Celtis australis*	Scraping wood	Stem of fresh wood	Transverse bidirectional	90°	5
GL01	*Glycymeris violascens*	*Cervus elaphus*	Cutting/defleshing	Meat-bone	Longitudinal bidirectional	90°	10
GL02	*Glycymeris violascens*	*Cervus elaphus*	Cutting/defleshing	Meat-bone	Longitudinal bidirectional	90°	10

Table 1: List of experimental pieces and the principle variables used in the experimental programs. Delineation h-d (horizontal delineation), p-d (profile delineation)

2.3.Microscopes

For the comparative analysis, use-wear and residues were analysed using a Reflected Light Microscope (Zeiss Axio scope A1), a variable pressure Scanning Electron Microscope with EDX (FEI QUANTA 600 ESEM) and two 3D Digital Microscopes (Hirox-KH-8700 and Hirox-RH-2000) (Fig. 2). Line-up of these microscopes is summarized in the (Table 3).

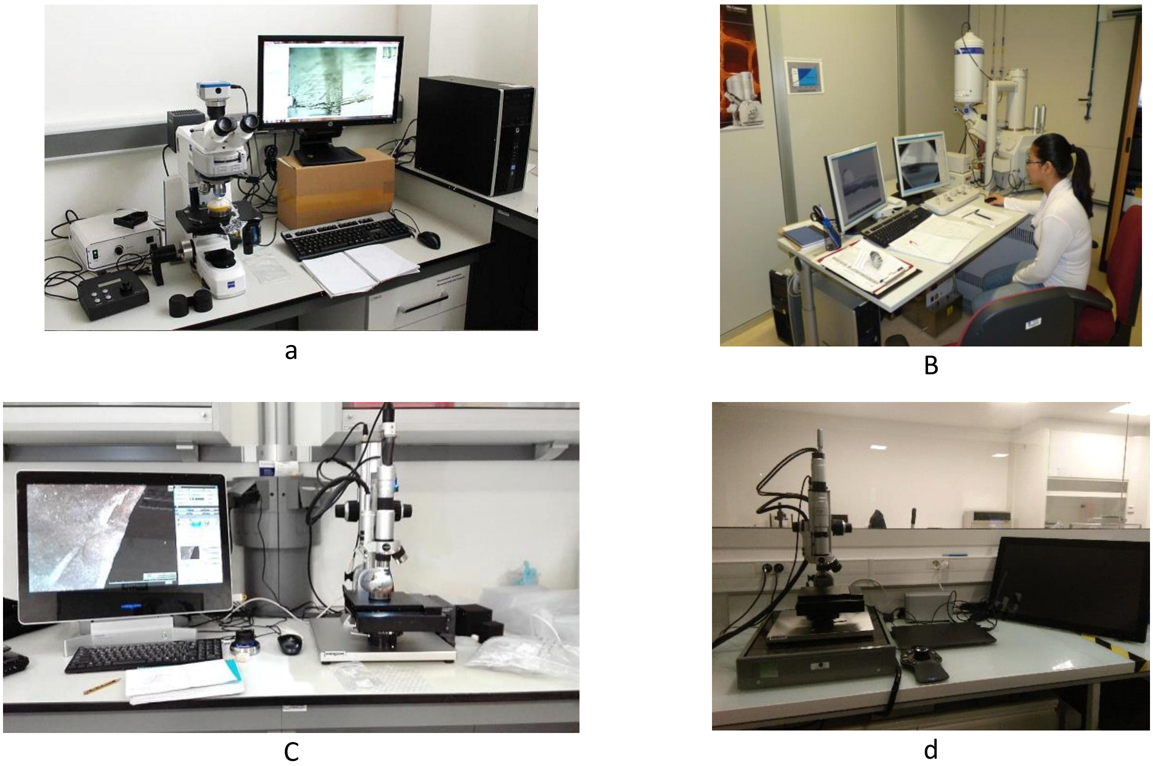


Figure 2: The types of microscopes referred to in this study: a) Zeiss Axio scope A1, b) ESEM with EDX (FEI QUANTA 600 ESEM; c) Hirox-KH-8700; and d) Hirox RH-2000

2.3.1. Digital 3D Microscope (3D DM)

Although there are various types of 3D DM available to be used for functional analysis, here we are only referring to Hirox 3D DM (Japanese Company). Hirox model KH 7700 was pioneering used by analysts from Università degli Studi di Siena, Italy. Thus, many archaeologists from this university used it for conducting different types of studies such as taphonomical studies (Boschin and Crezzini 2012; Crezzini et.al. 2014; Moretti et.al 2015), dental wear (Ricci et.al. 2014) and use-wear analysis (Revedin et al. 2015; Ronchitelli et al. 2015; Arrighi et.al. 2016; Marciani et.al. 2018). Most of articles published by them provided brief description about this microscope and its unique features.

Other two new versions of Hirox have been used in this study: the KH-8700, located at IPHES (Catalan Institute of Human Paleoecology and Social Evolution), Tarragona, Spain and the Hirox-RH-2000, located at Musée de l'Homme, Paris, France (Figs. 2c and 2d). The access to these two microscopes for our functional analysis offered us the opportunity to assess the feasibility of this microscope for traceological studies.

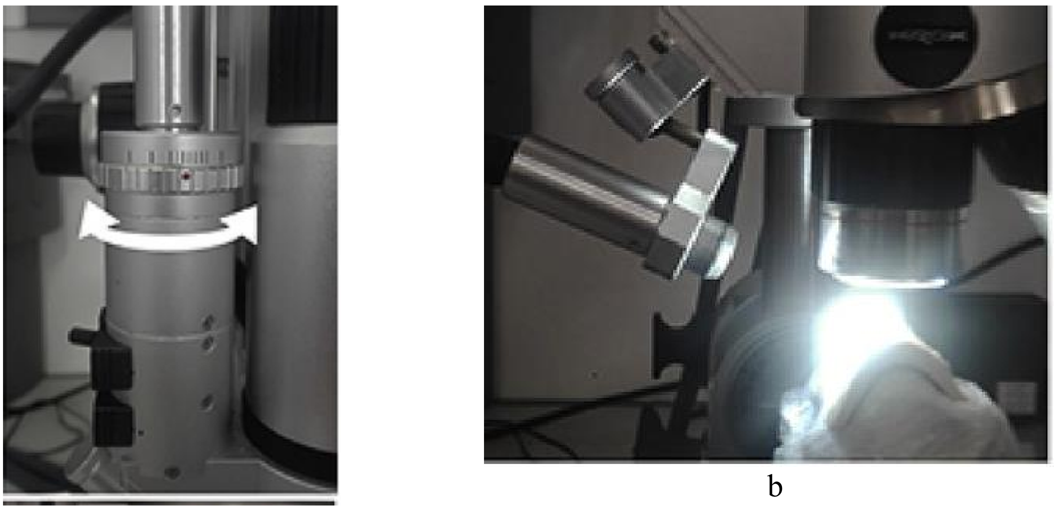
Recently, many articles have been published in which KH-8700 was used for taphonomical studies (Blasco et.al.2016; Maté-González et al., 2017a, 2017b; Saladié et al. 2017; Pineda et al. 2019; Rufà et al. 2017), palynology (Expósito and Burjachs, 2016) and use-wear analysis (Martín-Viveros 2016a, 2016b) and briefly explained about this microscope. Other than these researches, there are some commendable work by few researchers, who assessed the efficiency of the 3D DM (KH-8700) for taphonomical studies for observing cut-marks (Maté-González, 2017a, 2017b) and trampling marks Courtenay et al. (2019). Their works are mostly focused on the quantitative aspect of the 3D DM, whereas, our research questions are mostly qualitative based.

For functional analysis, the group from Università degli Studi di Siena, Italy wasthe first who introduced the 3D DM (Hirox KH-7700) in their researches (Revedin et al. 2015; Ronchitelli et al. 2015 and Arrighi et.al. 2016). In their articles, they have briefly explained some of the unique features of this microscope and how it helps in the identification of traces. Revedin et al. (2015) have also shown few images captured with this microscope, whereas Ronchitelli et al. (2015) only mentioned about the microscope in the article. On the other hand, Arrighi et.al. (2016) provided many images with the use-wear on the bone spatula. These researchers mostly analyzed their artifacts on 15" LCD monitor by using two types of optics: 1) to analyze the macroscopic traces of manufacture and use-wear, they used MX-G 5040Z body equipped with an AD-5040Lows and an AD-5040HS lens working at lower magnification (20-50x), and 2) aMXG-10C body equipped with OL-140II lens working at high magnification (up to 700x), for micro-wear observation (Arrighi et. al. 2016).

Although they are the first to apply 3D DM, their works have not fully explained about the efficiency of this microscope, and with the lack of visual evidence, it is difficult to assess till which limit this microscope is comparatively beneficial for the functional studies. Hence, we focus our research aims to the unique features of this microscope 1) to check the its feasibility for functional studies of stone and shell tool, 2) 3) how they complement the other microscopic (OLM and SEM) for the interpretation of the function of the tool.

3D DM (KH-8700 and RH-2000) has a multi-viewer function that allows easy inspection at various angles by using various types of optics and attachments of lens. It allows various types of observations, and a very wide range of magnifications For our studies, for KH-8700 we have used the lens (MXG-5000 REZ), whereas, for RH-2000 we used (MXB-5000 REZ) with a magnification range from 35x to 5000x plus a field of view from 8mm to 0.06mm at an operable distance of 3.4mm–10.0mm.

These optics (dual illumination revolver zoom lens) incorporated with three range objectives turret: Low-Range objective (35 x and 250 x), Medium-Range objective (140 x to 1000 x) and High-Range objective (700 x to 5000 x). This microscope is accompanied by the light source from high-intensity LEDs optics which provides the possibility of combining ring light and co-axial light, while presenting the possibility of using polarized filters and directional light adaptor. This light source provides a temperature of 5700 k, closely portraying daylight color and producing the highest quality real-time images with no warm up time needed (Courtenay et.a.2019). These lamps allow uniform illuminations of high quality, but at the same time can generate strong dispersions of light depending on the sample to be observed and the depth of field required.



b

a

Figure 2: a) Lighting position from above, providing the option of combining ring (turning the wheel to the right) and coaxial (turning the wheel to the left) lighting conditions. B) Lighting position from the side, movable using the HIROX's adjustable light support. (Courtsey of Courtaney et al. 2019)

For our studies, we have used both ring and coaxial types of light, depending on the optimum working conditions of each one of them. We have used ring light to observe chipping, fractures and residues at low and medium range magnifications (35 x - 600 x), whereas, the co-axial light was used to identify polish, striations and edge rounding at high magnifications (400 x - 2000 x). Sometimes we have also used a portable light source to incise the light sideways (Fig. 3b) to highlight the topographical characteristics of the artefact, for the observation of use-wear, residues and the realization of 3D mosaics (Fig. 5).

This microscope is having a built in compact CCD camera attached directly to the HD LCD monitor which allows the opportunity for many people to see the images at once. In case of KH-8700, the camera is connected to the 21.5" full HD LCD monitor with high intensity pixel reproduction as well as the capacity to display up to 16.77 million colour with a contrast ratio of 1000:1 and brightness of 300 cd/m2. The combination of state of the art hardware and the Genex Engine graphics processor ensures maximum quality when carrying out any type of microscopic analysis (Courtenay et.al 2019).

A notable advantage of these microscopes is to generate 2D and 3D mosaics by automatic stacking and stitching different images into a single image to obtain entirely focused areas combined with a wide range of magnifications. In Both 2D and 3D models, it is possible to perform a wide range of measurements and calculations (point height, 3D profiles to measure roughness and ripple, area, volume, distances, etc.) but in our studies we are not discussing about this feature. These microscopes are capable of quickly producing of 3D digital reconstructions using a combination of quick auto focus and depth synthesis functions. The additional use of the tiling function helps to create a mosaic and complete digital reconstruction of the sample under analysis. The optics is attached to the integrated stepping motor which allows for an accurate scanning with 0.05 um pulse–1 precision at an operable distance of 3.5mm–10.0mm.

3. Micrographs comparison

The effectiveness of microscope for traceologists mostly depends on the visual identification of the use-wear and on the micrographs it can generate to identify the use-wear and residues. Various previous works have shown that how OLM and SEM generate the micrographs and their feasibilities for identifying certain type of traces. Here, we are comparing the micrographs capture with 3D DM and comparing with the micrographs of OLM and SEM.

3.1. Topography

Previous works using OLM and SEM, has already shown that these two microscopes produce different micrograph to understand the topography of the tool in relation to use and residue traces (Borel et al. 2014; Monnier et al. 2013; Fernández-Marhena et al. 2018). Micrographs obtained with the help of 3D DM are having better resolution and depth of field compare to OLM. But with the high range (700x to 5000x) both with Mid-Range and High-Range lens have less depth of field compared to SEM micrographs. The digital image staking is done automatically by the hardware attach to 3D DM.

Besides the 2D and 3D micrographs, 3D DM also provides the option of tiling to capture the mosaic of the edge. This helps to prepare the panoramic view of the edge for the observation of different traces distribution on the edge (Fig. 5). In this regard, Martin-Viveros (2016a, 2016b) have shown many tiling images which is very useful in explaining the traces continuation and their distribution on the tool. For capturing the mosaic, we have realized that the mosaic are coming better when the lateral incident light (with the portable light from the side) is used (Fig 3b). However, micrographs of the tiling are sometimes very tricky and not always perfect, if the higher and lower Z points are not selected properly and also when the tool topography varies a lot (Fig 5.).

The best part of the 3D DM, we can also extract the 3D images of the micrograps taken. These 3D images help to identify the location of the trace and as well to understand mechanism of the tool used and which part of the tool edge was in most contact with the contact material. In this article all the figures (Fig 4-11, 13, 15) are provided with the 3D images of the same location to see the locations of the traces on the topography of the tool.

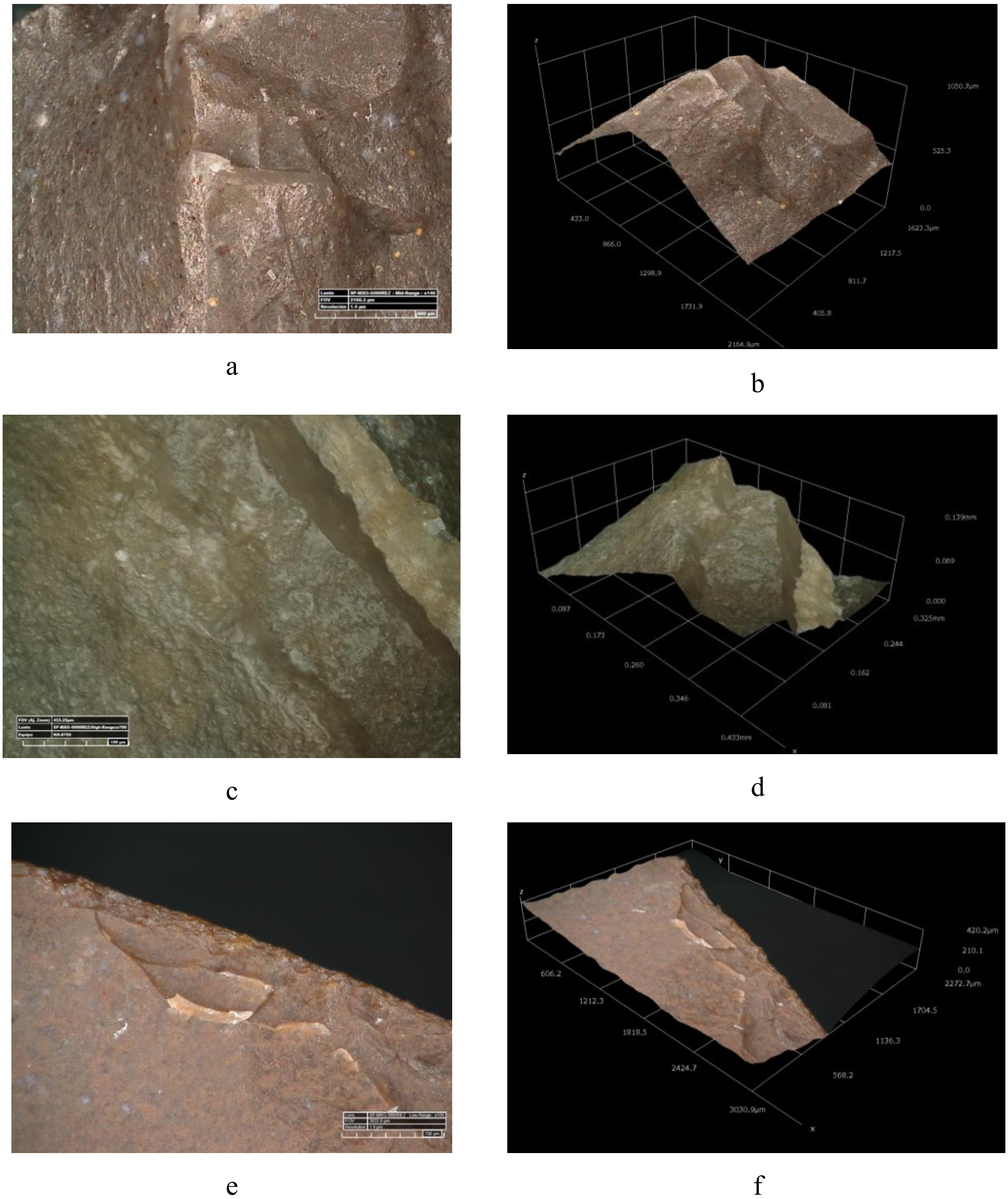


Figure 4: (a-b) KLD-F6-7II-1145 (archeological piece from Middle Paleolithic level); (c-d) AKF 1-Bu1 (disarticultation and defleshing 90 minutes); (e-f) KF1-B1 (35 mins bone scraping); (a) 2D image of the tip showing the location of light polish at 140x with ring light; (b) 3D image showing the different topography of the tool; (c) showing the polish and residue trap in the topography of the tool at 700x (high-range lens with coaxial light); (d) 3D of the same location showing the polish and the residue trapped between the edge topography; (e) Edge fracture after bone scraping at 100x (Low-Range lens with ring light); (f) 3D of the (e) edge fracture

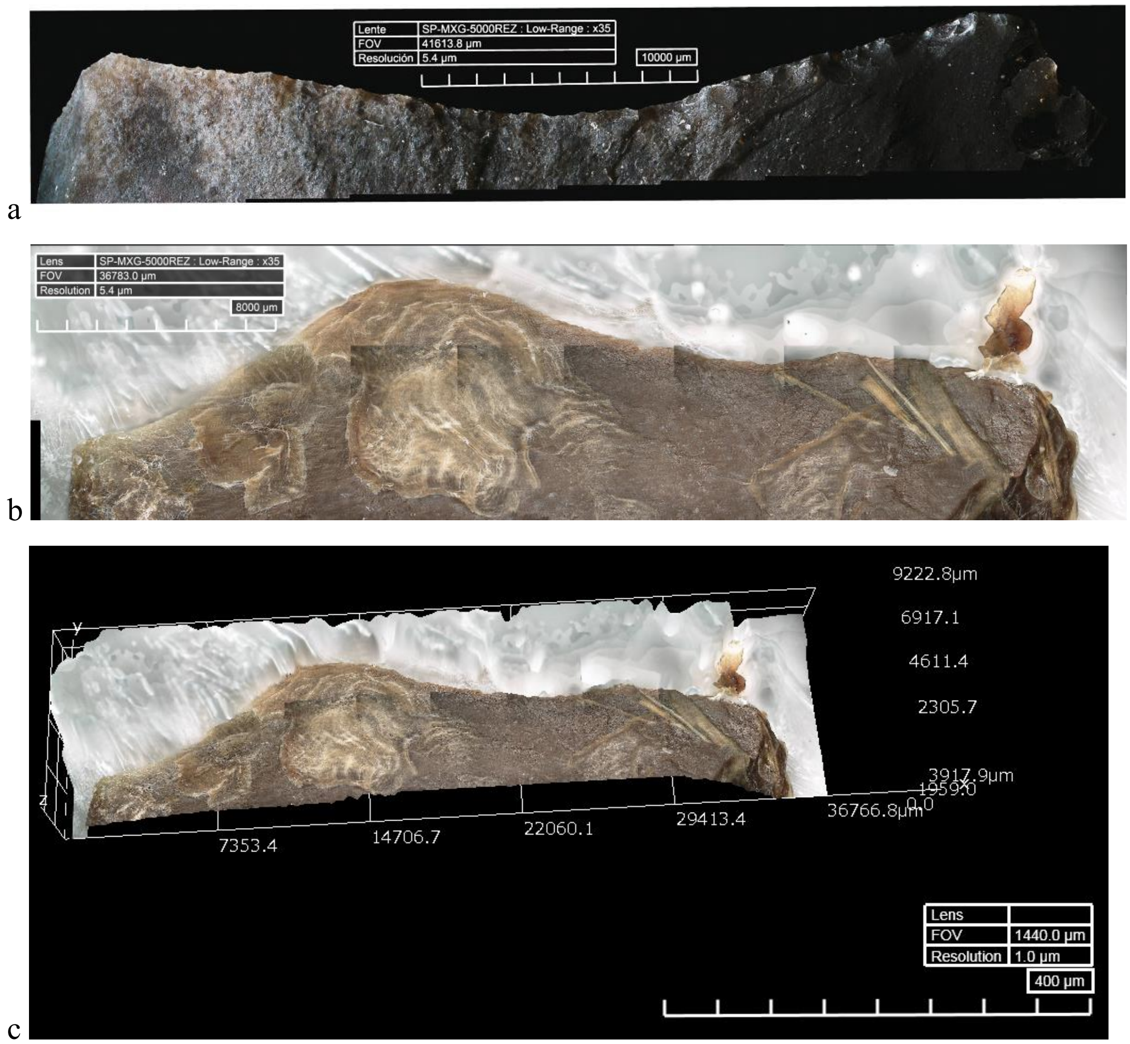


Figure 5: Tiling (mosaic) of the working edge (A) showing the mosaic of the edge with the continuous micro-edge fracture at 35x, 10000µm (Courtesy of Martín-Viveros 2016a), (b) showing the mosaic with the distribution of the residue on the edge at 35x, 5000 µm and (c) showing the 3D of the distribution of the residue on the tool 35x, 400µm

3.2. Fractures and scars

Edge fracture and scars occur of the tool based on the type of worked material (hard wood, bone, flesh, hide etc.) and the performed action (cutting, sawing, scraping etc.) and later the resulting detached micro-particles sometimes get incorporated between the tool and the worked material, which helps to develop further use-wear (polish, striations, etc) on the tool edge. This feature is very easily detectable on stone tools (except for white, crystalline ones) with all three microscopes, but the OLM sometimes face the drawback while capturing the image. The better view of these fractures and scars as well as their distribution on the tool topography are visible by means of tilling option of 3D DM (Fig. 5a).

For the stone tools, the greater depth of field, together with the highlighting of the topography that achieved at low magnifications with lateral incident light, makes the digital microscope the most suitable for the observation of this type of traces. By using coaxial light, these relief and the characteristics of flaking and fractures are much more noticeable. The coaxial light, but incised laterally or flushes on the surface of the material observed, which highlights, even more, the topographic characteristics of the chipped than in the other two microscopes. Also, the possibility of realising 3D models of the observed surface allows an increase in the depth and morphology of the micro-chip in a more remarkable way compare to the OLM and ESEM.

For shell tools, depending on the type of shell species the fracture and scars can be identified by the microscopes. Under OLM and 3D DM, *Mytilus galloprovincialis* are having better visibility of the edge fracture compared to *Ruditapes decussatus* and *Pecten maximus* (Fig 6 and 7). The surface of later two species are white and glossy, hence, reflect too much light while examining with OLM (Fig 7a, 7b) and 3D DM (Fig. 7d, 7e) and lose some of the feature details compared to SEM (Fig 7c, 7f). SEM images usually appear matt on screen and does not get effected that much with the lustrous surface of the samples and provide better details of the fracture, as well as other details such as micro pitting, polish, striation and micro-structure of the shell surface (Fig. 6, 8, 10). For example, on the *Mytilus galloprovincialis* the fracture is sometimes accompanied with polish (Fig. 6f) or striations and micro-pits (Fig. 6i) on the shell surface. These features are visible with the SEM, but appear very subtle with OLM and 3D DM (Fig. 6d, 6e).

Usually the micrographs generated by these microscopes are showing the fracture, but 3D DM provide the benefit of generating the 3D image to understand the depth of the fracture and its distribution on the edge (Fig. 3e, 6j, 6k). While analyzing with the 3D DM, one have to be careful of the light source (coaxial and ring) and type of shell tools being analyzed. Fractures can be visible with the ring light with low range magnification (35x-100x) but in high magnification (400x-700x) the combination of coaxial light and polarizer is need to enhance the detail of the fractures on the shell tools.

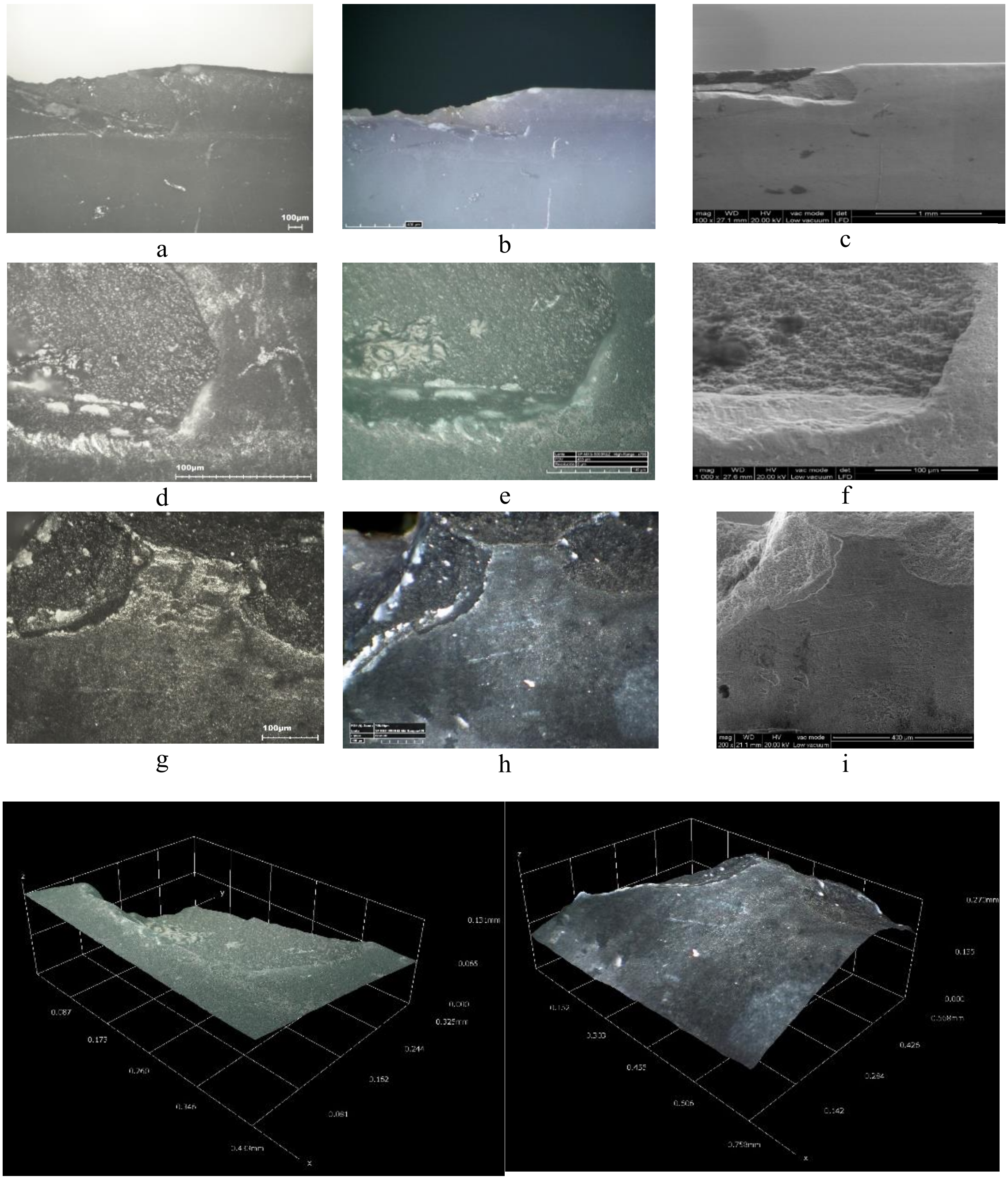


Figure 6: Edge fractures on (a-f, j) MY02 (disarticulating and defleshing 10 mins) and (g-i, k) MY03 (cutting wood 10 mins); (a-c) show the location of the Hinge-type fracture with OLM at 50x, 3D DM at 100x (with ring light), SEM at 100x; (d-f) Detail of the hinge-type fracture with OLM at 500x, 3D DM at 1000x (with coaxial light), SEM at 1000x; (g.i) edge fracture with striations parallel to the edge with OLM at 200x, 3D DM at 400x (with coaxial light), SEM at 200x; (j-k) 3D of the edge showing the pattern of the edge fracture

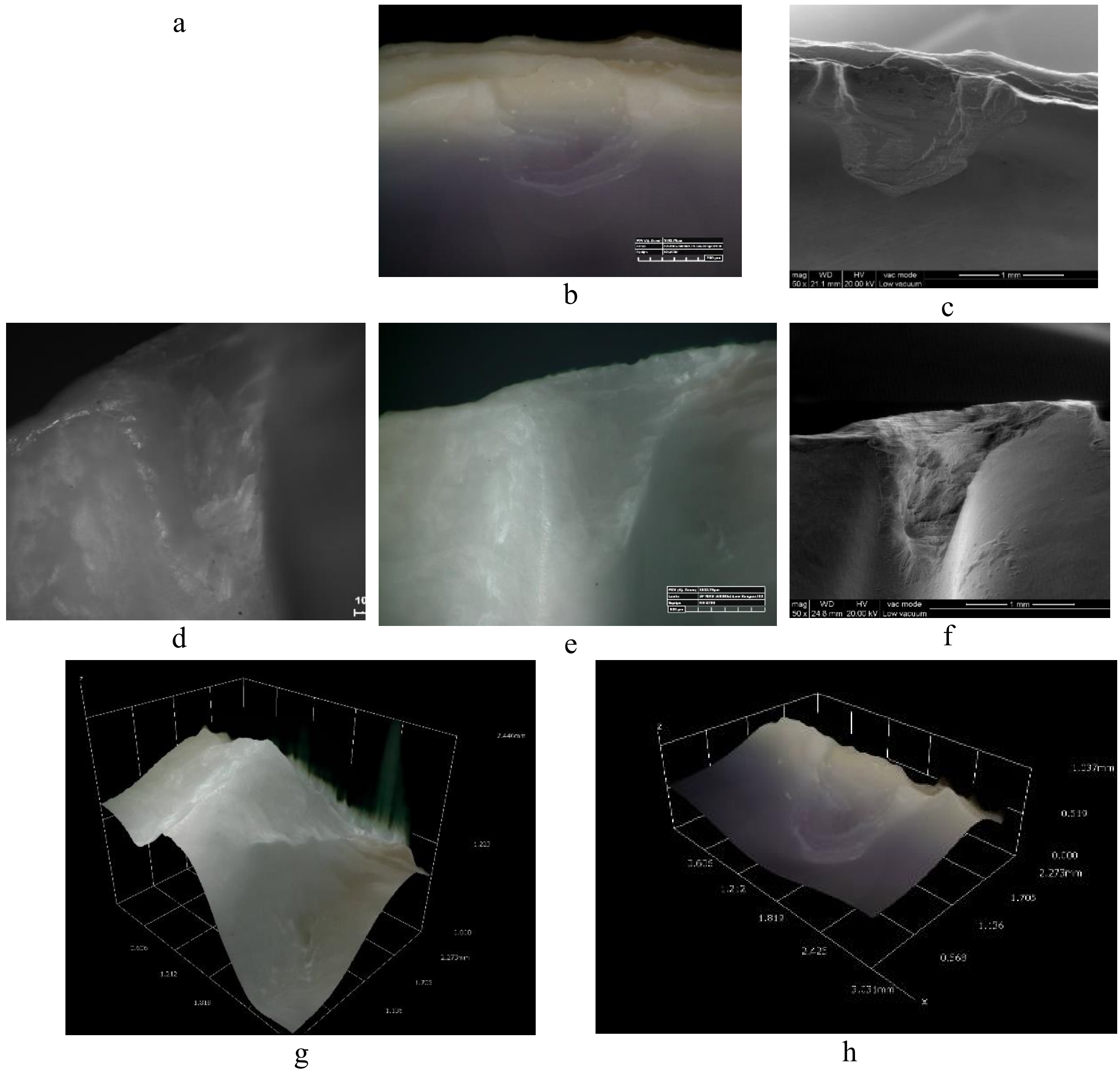


Figure 7: Edge fractures on (a-c, g) RU01 (cutting wood 10 minutes), (d-f, h) PE02 (disarticulating and defleshing 15 minutes). Micrographs magnification for OLM at 50x, 3D DM at 100x, SEM at 50x; showing the 3D image of the fracture on the tool topography. 3D DM micrographs used mixture of ring light and coaxial light

3.3. Polish

Polish can be described in terms of its brightness or dullness and its roughness or smoothness as well as presence or absence of certain topographical features, like pits, undulations and so forth (Keeley 1980: 22). When observed with the OLM at low magnification (50x-100x) polished surfaces appear glossy and bright and at high magnification (200x-500x) they are less glossy and smoothen surface than the unused area of the tool edge. On the other hand, under SEM they tend to appear as smooth and dark areas that are well different from the rugged and irregular fresh topography (Borel et al. 2014).

Similar to OLM, under 3D DM polishes appear bright at low magnification with low range lens at (100x-150x) and with mid-range lens (140x-400x), depending on how much light it reflects and light mode (ring and coaxial) used to analyze them. Coaxial light is very beneficial in such cases as it highlights the glossy surface of the polish (Fig. 9), hence can be cross-checked at high magnification (700x-1000x). Even in the high magnification they can provide different topographical information depending on the type of lens used to observe them. At mid-range magnification (600x onwards) they appear very bright and glossy (Fig. 9a-e), but with the high-range (700x onwards) they appear matt (Fig 9b, 9f). Therefore, it is better to cross-check the polish observe with the mid-range lens (400x-600x) with the high-range lens (700x-1000x) for the better view of the polish (Fig.9). Further, the 3D extracted with this microscope also help to understand the formation of the polish on the tool topography (Fig. 9c-g).

In our research, we also realized that for the detection of polish on shell tools it is better to use SEM compared to the other two microscopes (Fig 8c, 10c, 10f). Especially, depending of the shell species they are difficult to distinguish with the OLM and 3D DM, as they don’t provide that much depth of field to images and some information get lost even at high magnification (Fig. 8d, 8e, 10a, 10b, 10d, 10e).

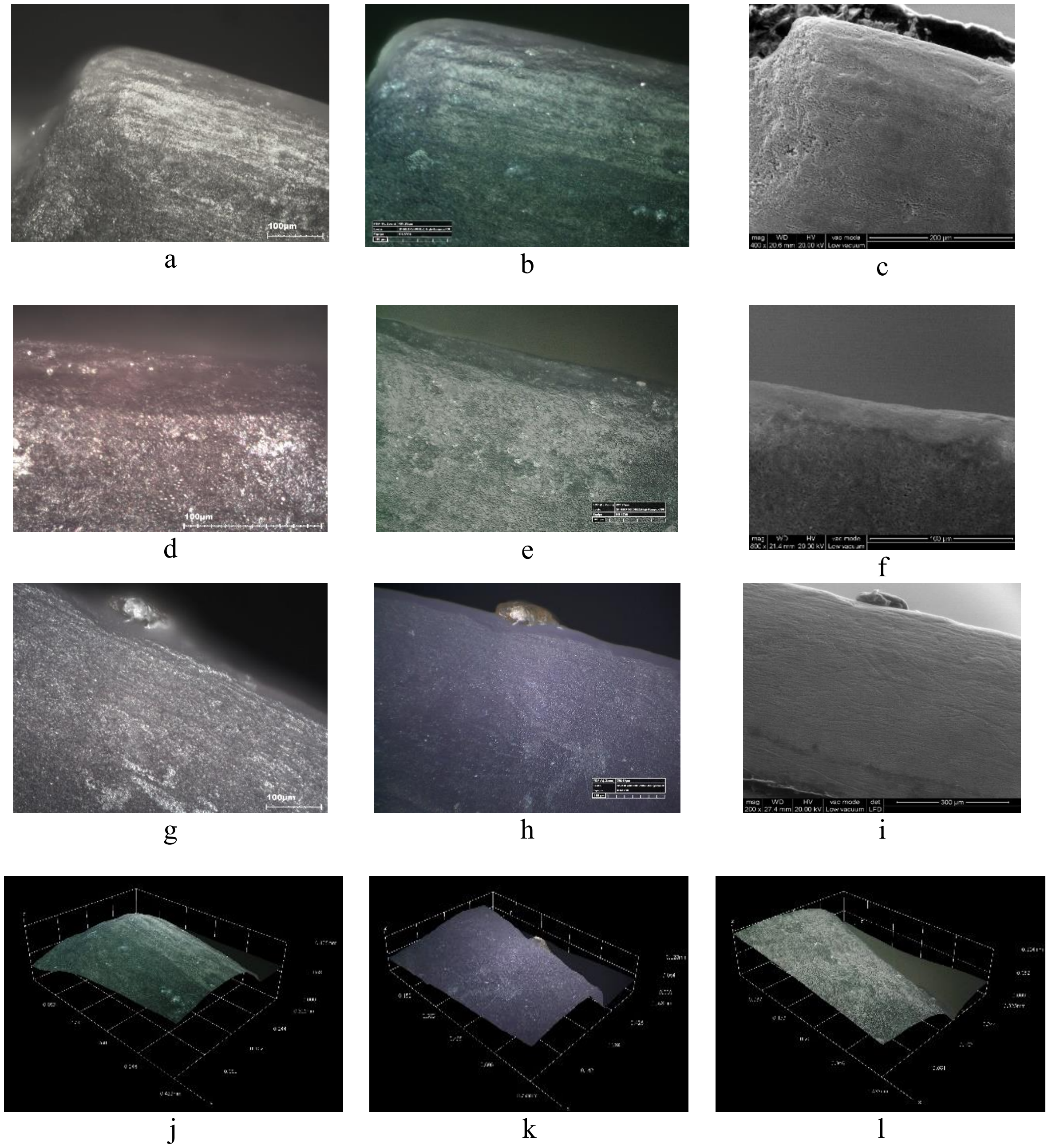
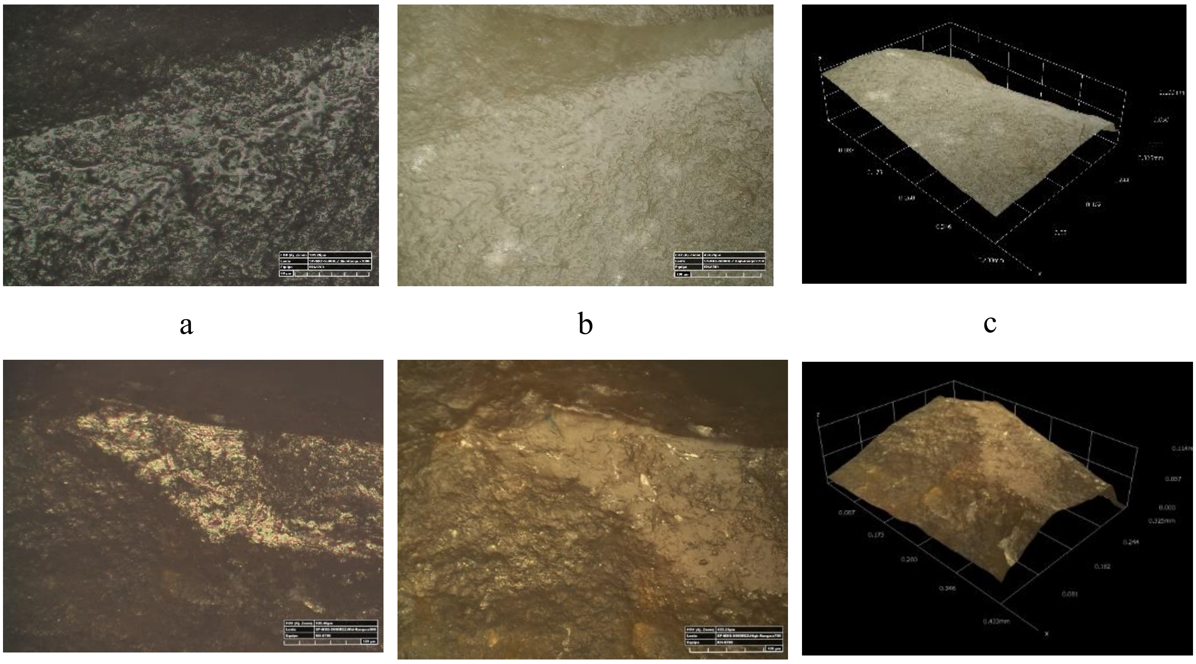


Figure 8: (a-c) MY03 (disarticulating and defleshing 10 mins) and (g-i) MY03 (cutting wood); a) OLM micrograph of Polish and edge rounding (mag=200x, 100µm), (b) 3D DM micrograph of same point as (a) with High-Range lens (mag=700x,), and at 400x with SEM; d) Polish at 500x with OLM but not distinctive and blur, e) same point as (d) with 3D DM slight shell micro details are visible but similar to OLM is blur at the part of Polish; g) same point as (e-f) at 800x with SEM, micro details are visible with the detail of continuous polish with some micro pits in them; g) at 200x with OLM and (h) at 400x with 3D DM edge is blur and lose the detail of the polish, edge rounding and striations on the edge; (i) the polish, edge rounding and striations are visible with SEM at 200x; (j, k, l) showing the 3D of the polishes location on the shell tools. All the 3D DM micrographs used coaxial light.



a b c

e f g

Figure 9: (a-c) KLD-E7-5-276 (archaeological flake) and (e-g) KF1-B1 (experimental tool used for bone working) ; (a-e) Mid-Range lens; (b-f) High Range lens; (e, f, g) taken at mid-range 600x, High-Range700x and 3D image showing the location of polish on the topography of the tool. All the micrographs used coaxial light.

3.4.Striations

Striations are linear features, which is depend of the use motion and occur on the edge due to the contact between the abrading particle and the tool. They are the best indicators of the tool working motion by looking at the direction of the striations (Semenov 1964). For the observation, Borel (et al. 2014) have already noticed that sometimes these striations can be optical illusion seen with the metallographic. Still it gives the good results for medium and deep striations between 200x-500x, but for weak striations it is better to use 3D DM and SEM as they provide the option of higher magnifications. Although, 3D DM provides higher magnification (upto 5000x) compared to OLM, but it is having its own limitations. The depth of field for the images of 3D DM is best suited till 700x of High Range (HR), but after 1000x (HR) onwards the images starts to get blurry (Fig. 13d, 13e), which is not the case with SEM (Fig. 10f). The 3D imaging option provides by the digital microscope shows how these striations are situated on the topography of the tools (Fig. 8k, 10j, 10k, 11e, 11f, 13g, and 15j). Depending of the raw material (such as white, crystalline and glossy type), these linear features observation is little difficult with 3D DM as they reflect too much light, hence sometime lose some of the details even at high magnification (Fig 10b, 10e, 10h). Therefore, for the preliminary inspection of the grooves and linear figures OLM and 3D DM are best, but for detail view and capturing images at high magnification (1000x onwards) is better to use SEM.

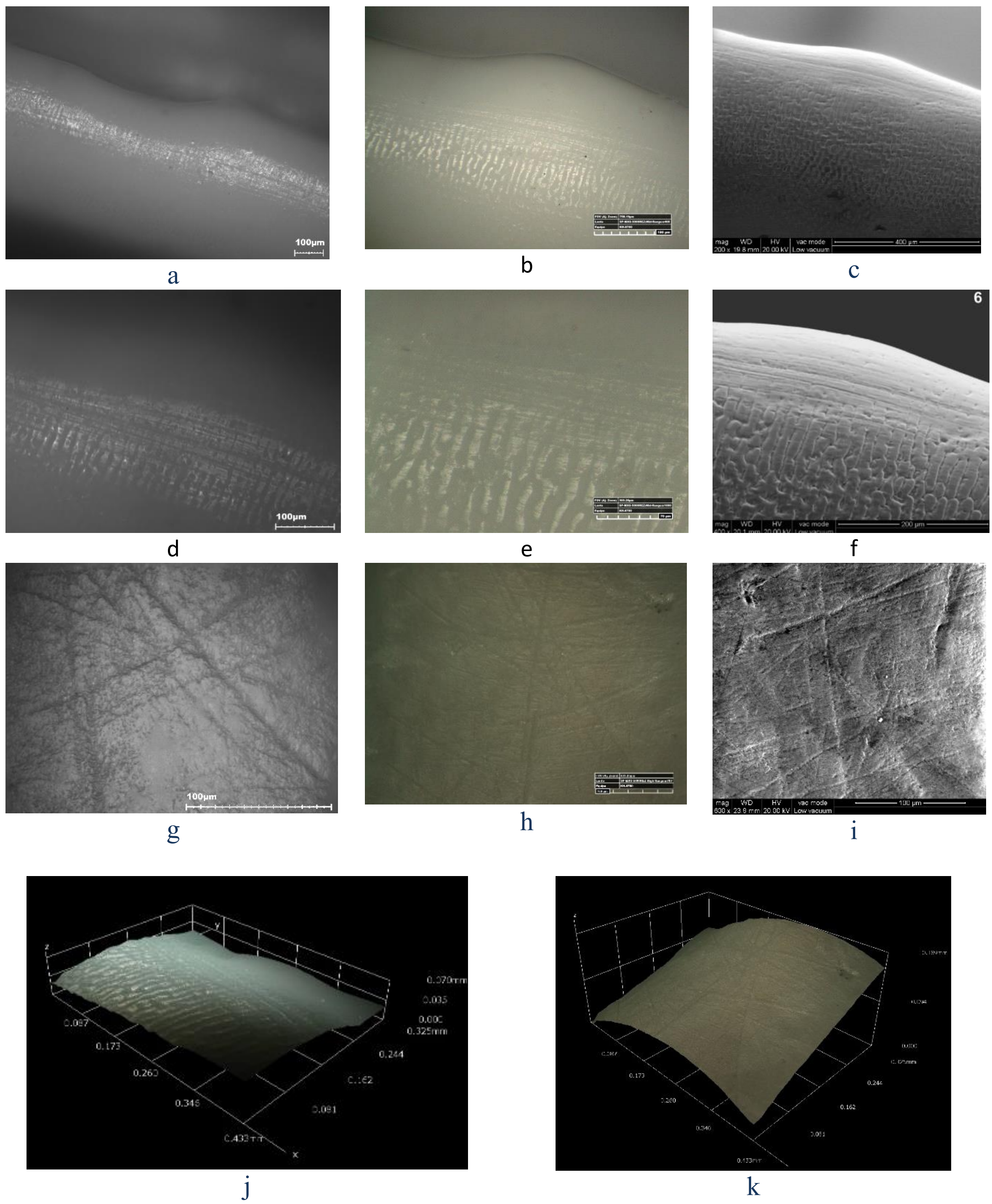


Figure 10: (a-f, j) RU01 (cutting wood, 10 minutes), (g-i, k) PE02 (disarticulating and defleshing 15 minutes); (a-c) location of the parallel striations to the edge with OLM at 100x, 3D DM at 400x, SEM 200x; (d-f) detail of the parallel striations to the edge with OLM at 200x, 3D DM at 1000x (high-range lens), SEM at 600x; (g-i) deep criss-cross striations with OLM at 500x, 3D DM at 700x, SEM at 600x; (j-k) 3D of the edge showing the location of the striations of the shell tool topography.

3.5.Residues

Residues, depending on its colour, size and morphology, can be observed with all microscope at different magnifications. OLM and 3D DM are best for the preliminary analysis of the residues, as they are rapid and allow better identification of various colour palette residues. Whereas, SEM lacks colour but provides phase contrast observation (if equipped with a back-scattered electron detector), which also proved to be very effective for residue identification (Fig. 11b, 11c, 11b,), particularly when residue colours are similar to stone colours as viewed with OLM and 3D DM (Fig. 11a, 11d, 12a, 12b, 14c, 14d, 14f, 14g).

3D DM gives benefit over OLM due to high magnification for observing residues. For example, (Fig. 11) when the sample observed with OLM only showed deep parallel striations but when analysed with 3D DM (especially with high range lens 700x) it also showed the residue adhere to it and on the 3D image can be seen its location on the tool surface. This residue is also easily visible with the SEM with EDX and further chemical composition analysis confirm of bone residue. Thanks to SEM microanalysis systems (EDS or EDX) yield the chemical composition of the residues. The element map produced by the EDX for the element detection also helps to understand the distribution of various elements on the residue to interpret the type of residue (fig 12, 14, 16).

Moreover, the high resolution of the SEM makes it possible to observe the residues at high magnification with sharp details and accuracy. The similar thing is observed by Pedergnana et.al. 2016 that some of residues are much better understandable under the SEM such as the skin flakes or pencil marks.

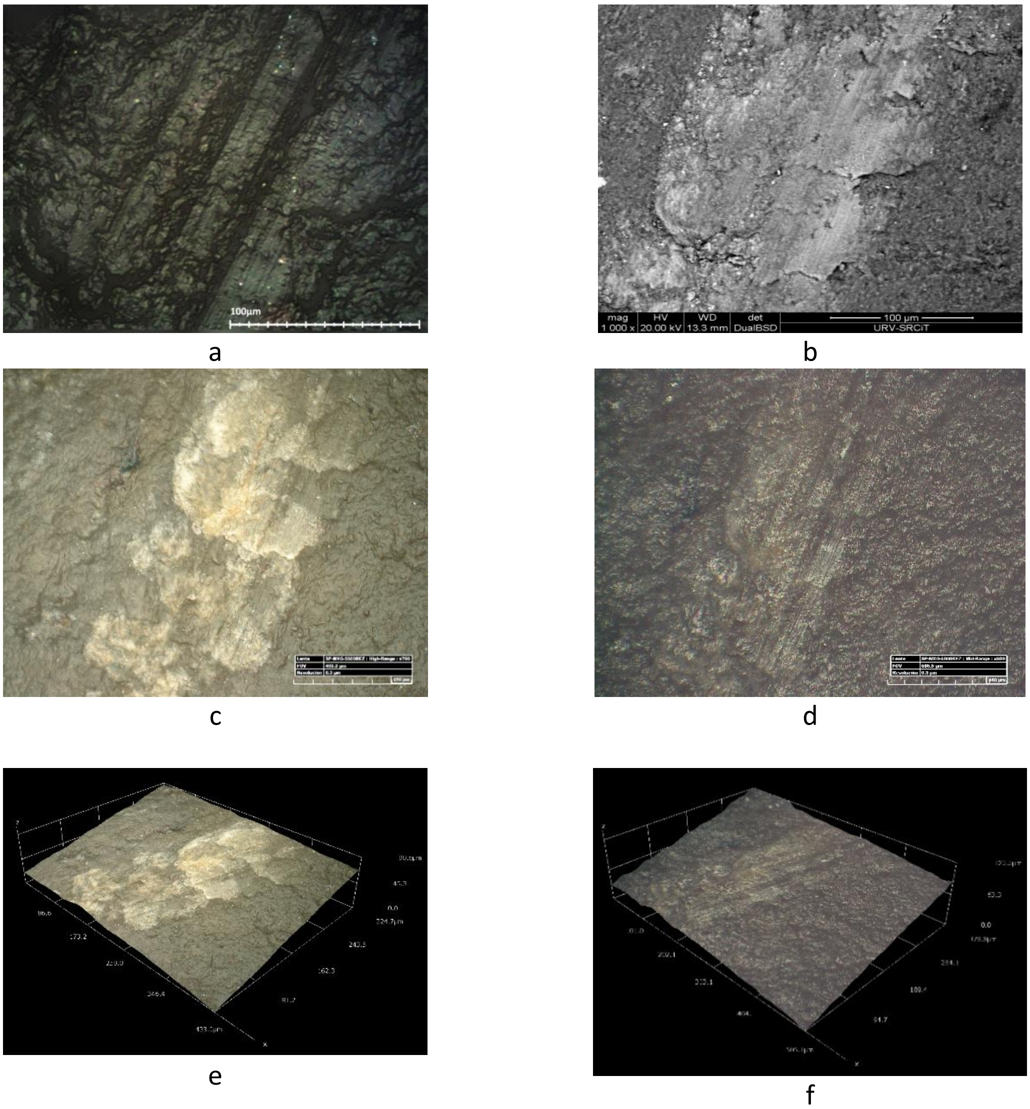


Figure 11: (a-f) KLD-F6-5-741 (Archaeological pointed bladelet; (a) deep striations under OLM at 500x; (b) detail of the striations showing bone residue adhere to it. Micrograph at 1000x; (c) same striations under 3D DM at with high-range lens at 700x; (d) same striations under 3D DM with Mid-Range lens at 600x with coaxial light.

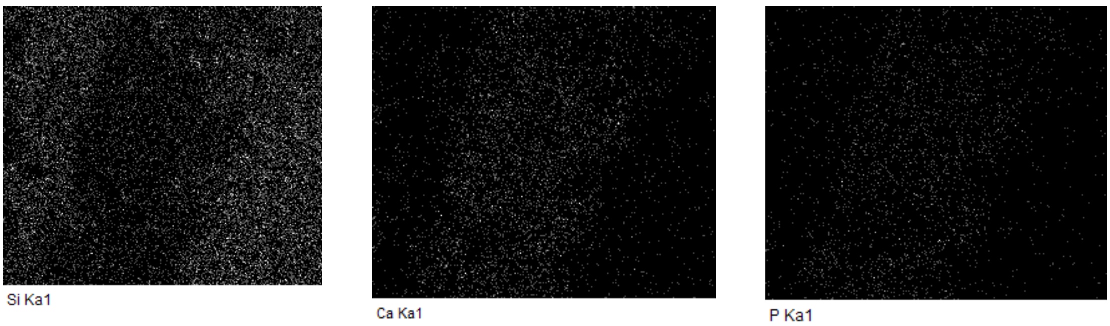


Figure 12: KLD-F6-5-741 (Archaeological pointed bladelet) element maps of the bone residue in figure 9 extracted form SEM with EDX showing the presence of Ca and P (main components of bone)

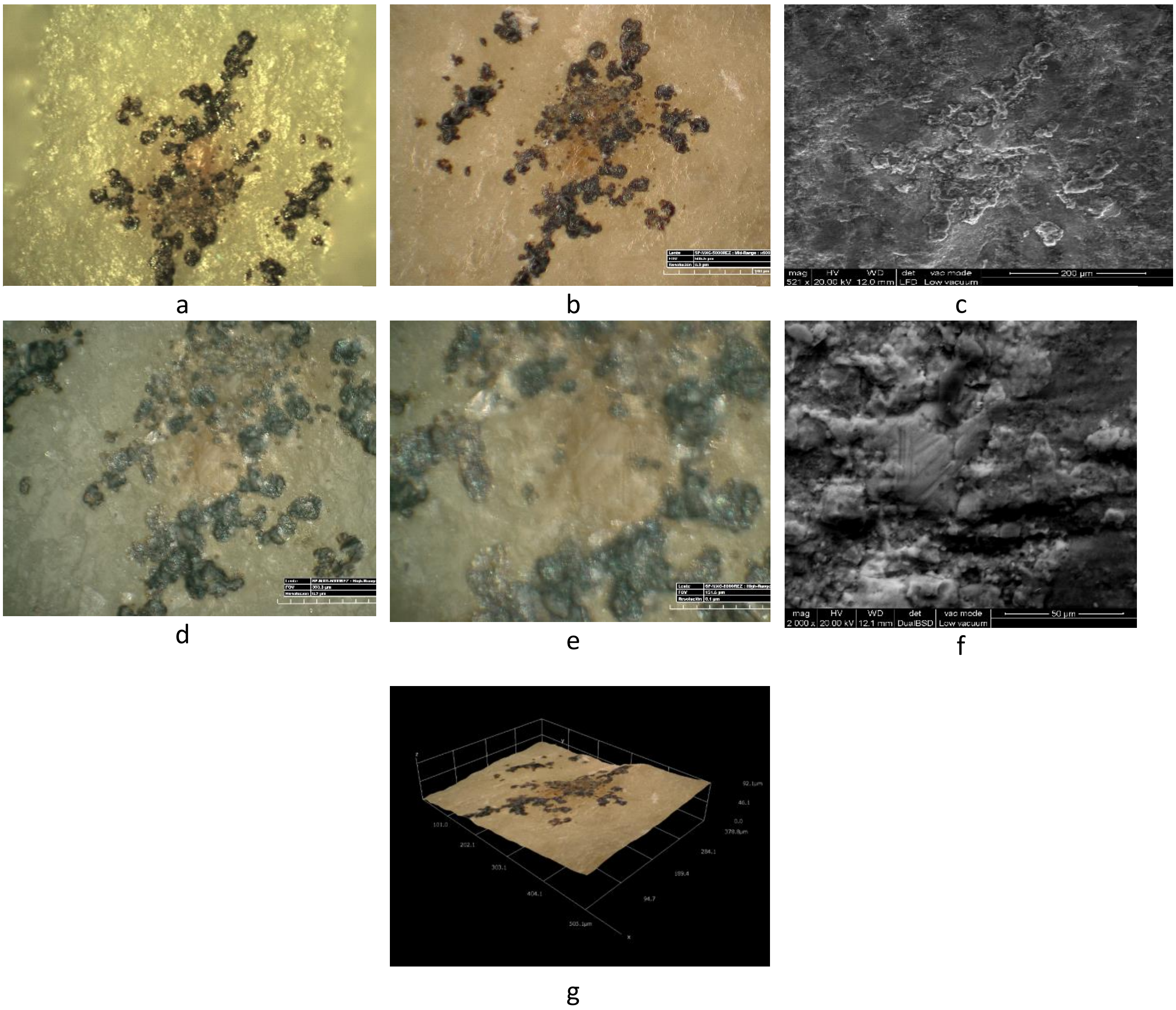


Figure 13: Kld 59 (Levallois Point) (a) Black residue with the pale brown residue underneath OLM at 100x magnification; (b and d-e) images with 3D DM showing the same residue at 600x (Mid-Range lens), 1000x and 2000x (high-range lens); (c-f) images with SEM showing the same residue as (a) at 521x and at 2000x residue with striations on them. 3D DM micrographs (a) is taken with ring light and (d-e) are taken with coaxial light)

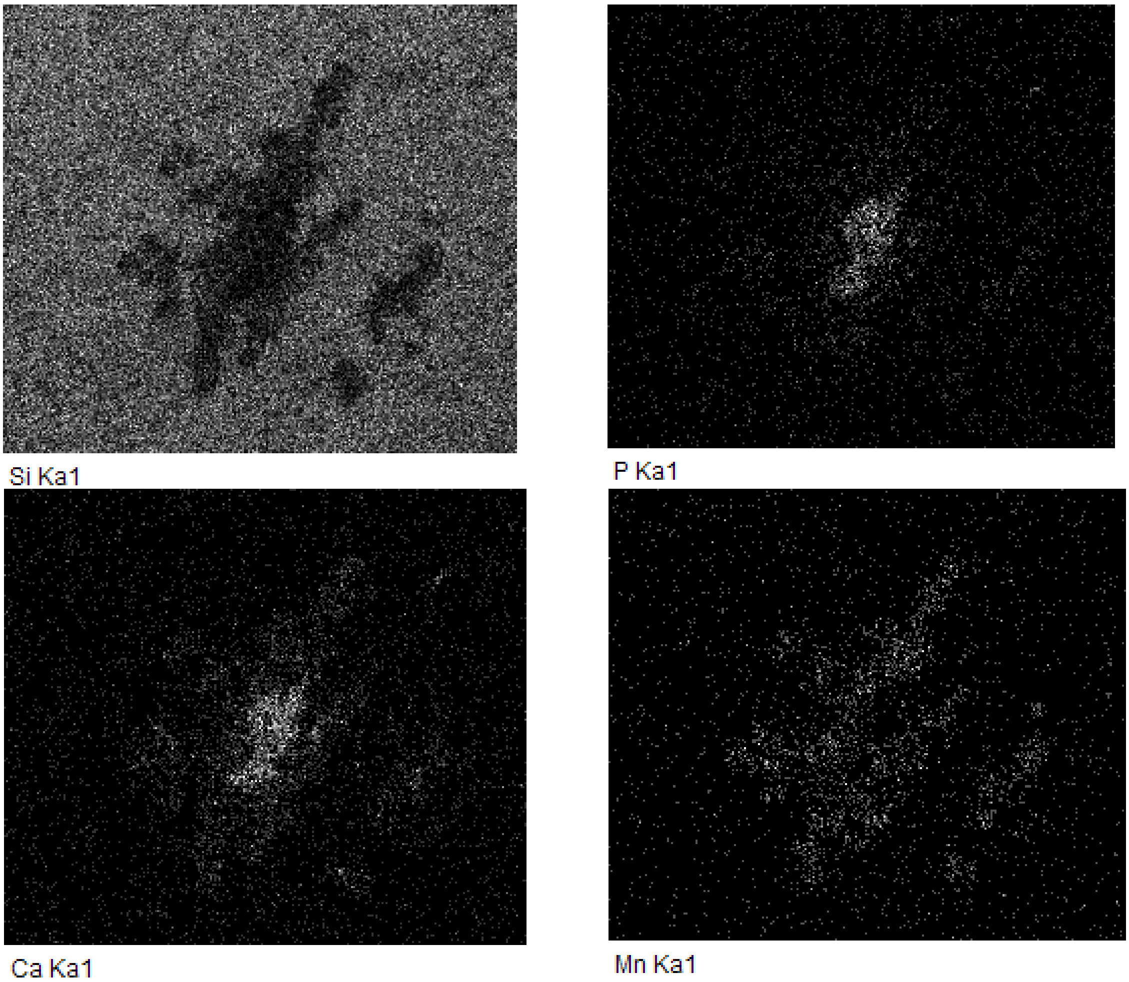


Figure 14: Showing the different elements extracted with the EDX of the residue in figure 11. Si (the flint), P and Ca (bone residue) and Mn (black residue surrounding the bone residue)

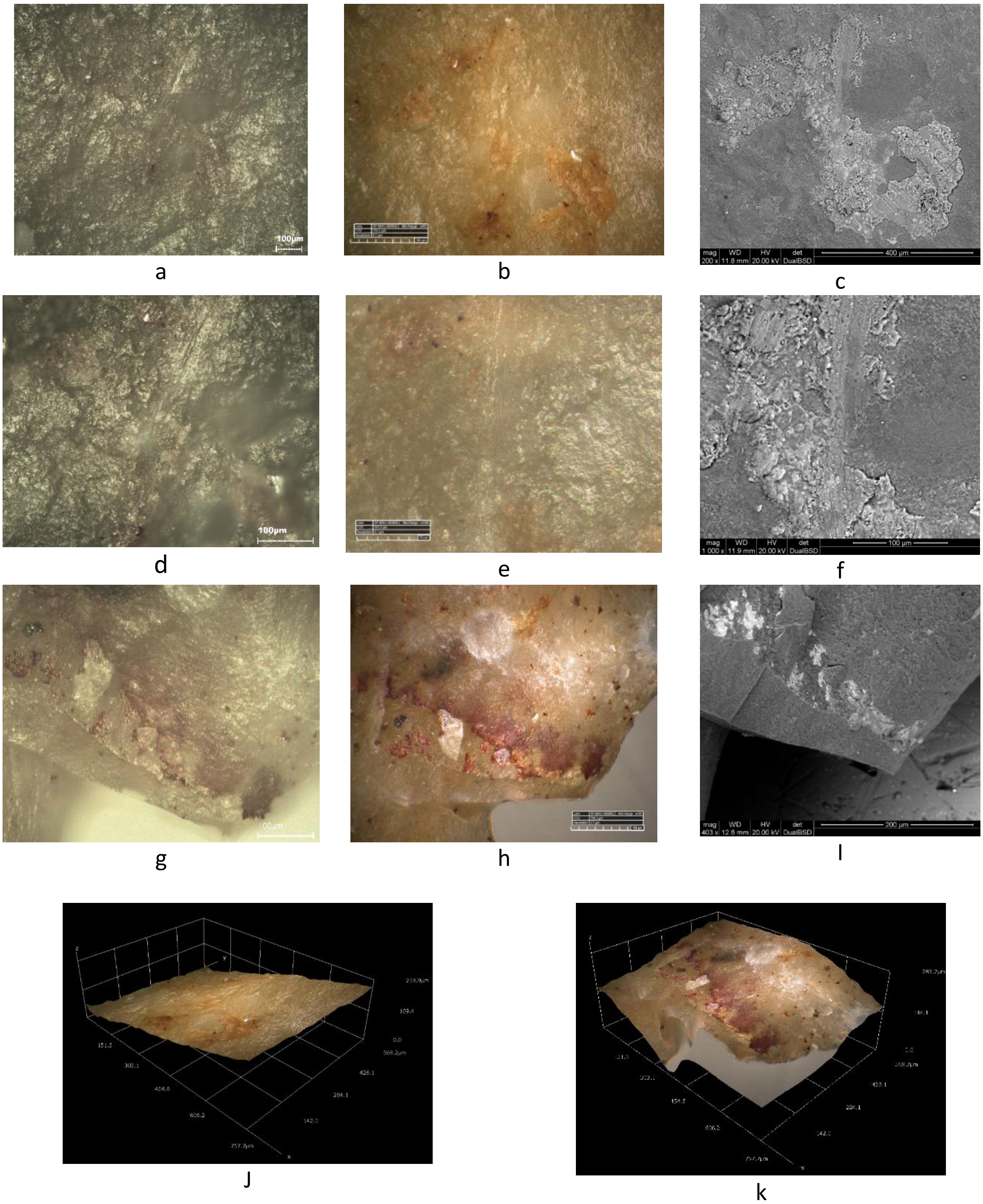


Figure 15: KLD-E6-5II-912 (Flake) (a-f) showing the location of the amorphous colour bone residue and striation analyzed under SEM with EDX (at magnification 200x, 1000x), Hirox KH 8700 (at magnification 400x, 1000x), and Zeiss Axio scope A1 (at magnification 100x, 200x) and (j) 3D of the residue on the tool topography; (g-i) KLD-E5-5-238 (Twisted bladelet) showing red residue (Iron oxide) with bone residue with SEM with EDX (at mag 200x), Hirox 8700 (400x) and Zeiss Axio scope A1 (at 200x); (k) 3D of the residue location on tool topography

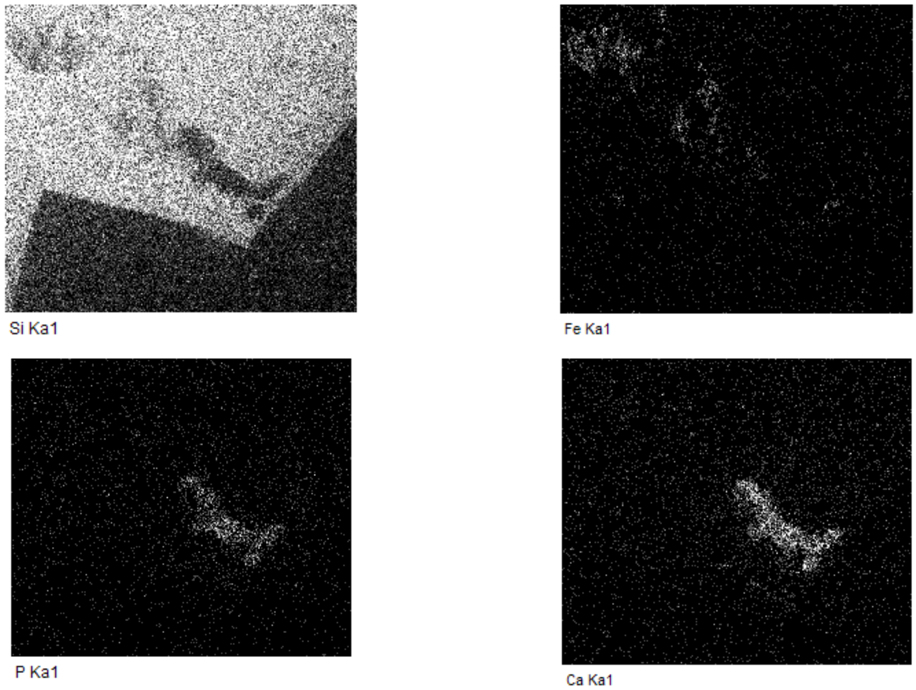


Figure 16: Showing element maps extracted from SEM with EDX for the residue of figure 13 (g-k). The elements are: Si (flint tool surface), Fe (for red residue), P and Ca (for bone residue)

4. Discussion and Conclusion

3D DM is very versatile for analyzing different types of raw material (such as stone, bone, shell, charcoal etc.). The 3D model generated by the microscope enables versatile observation of artifacts in three dimensions. This device has proved to be a very effective tool for distinguishing between the worn areas and the different features caused by the utilization on various materials or for different uses (Revedin et.al.2015; Ronchitelli et.al.2015; Martín-Viveros 2016a, 2016b).

Although, SEM provides greater depth of field to generate better image of the traces and along with EDX extract useful information about the residue composition, one cannot rule out that this method is insufficient to specific questions and small samples size. The reason behind is it is very time consuming very well known to the traceologists. Sometimes before observation, the samples need special coating of gold or carbon depending on the type of material to be analyzed. As well as SEM requires special maintenance which involves keeping a steady voltage, currents to electromagnetic coils and circulation of cool water which is not the case with other two microscopes. On the other hand, OLM and 3D DM provide the freedom to analyze as many samples in small duration as they do not need any special sample preparation before analysis apart from a proper cleaning. These two microscopes also provide greater sample mobility during examination for getting better angle to observe and to capture the micrographs which is sometimes difficult with SEM as the sample is placed inside the chamber and can only be manipulated by mechanical instructions to the hardware.

To observe the sample light source plays an important role as it not only enhance the quality of the micrographs, but also to identify the type of wear and residue traces. 3D DM has different types of light sources (ring, co-axial and portable light) helps to study different kinds of traces and residues. Ring light are best to observe residues and edge fractures and can be used till the magnification of 100x. Coaxial light are specifically useful for identifying striations and polishes on the edges; they are visible from 140x to 5000x. These light sources are managed by the wheel attached to the lens by simply rotating it right or left depending on the intensity of the light required for the identification of the traces (Fig 2a). When rotate the wheel towards the right ring light functions and On the other hand portable light enhance the topography of the tool and useful while taking a panoramic view of the working edge to observe the distribution of the use-wear traces. Depending on the raw material, different use-wear is visible by combining both ring and coaxial light sources. Also the option of the polariser and directional light adapter can enhance the traces for taking micrographs. For example, for the shell tools, edge fractures can be seen with the ring light at the setting of low or medium contrast and by adjusting polarizer. While the polishes and striations are better visible with the coaxial light as they are having a shiny appearance coaxial light helps to tone the reflective light.

In traceology, magnification of the microscope plays a vital role to observe the traces. All the three microscopes provide different magnification ranges as explained in the (Table 2). In the OLM microscope the live magnification is increased by multiplying the lens magnification in the eyepiece. This allows observing the traces through eyepiece as well as on the monitor when connected with the camera but the magnification changes when translated to the computer screen, as the actual magnification directly depends on the screen's size and the adapter used (which in our case is a 0.63x one). Unlike optical microscopes, 3D DM allows observation of the sample without the use of eyepieces. It can achieve thanks to hardware integrated with the microscope unit itself. For comparative analysing of the traces, the only way to strictly compare spots of the same size is taking into account the Field of View or horizontal field width (FOV) got ad different magnifications by different equipment's. To enable that comparison, we build a table with the closest ranges of magnifications leading to more or less equivalent FOV (Table 2). In the table explained the comparison of the magnification and the FOV of each microscope. Our study we have seen that, in 3D DM the observations of traces and capturing of images are best between 35x to 2000x. After that the images gets very blur or foggy appearance in the images. Also at high range of 3D DM if the artefact topography is very high, without capturing the image it is difficult to understand the traces as only the highest points are visible and the lower points are blur.

Hirox (also ESEM Fei Quanta)	FOV (field of view) KH8700/RH2000	Zeiss	FOV
140	2166/2086(MR)	50	2280
200	1516/1586(MR)	100	1146
400	758(MR)/782(MR)		
600	505(MR)/521(MR)	200	573
700	433(HR)/416(HR)		
800	379/389(MR)		
1000	303(MR)/316(HR)	500	229
2000	150-155.8(HR)		

Table 2: Showing the details of the magnifications and their field of view (FOV) for 3D DM, SEM and OLM while analysing for comparative micrograph. MR (Mid-Range lens), HR (High-Range lens)

3D DM provides a variety of magnification range using different objective lenses. It offers high magnifications compared to OLM and allows quick 3D modelling and profiling of the surfaces. Automatic stacking and stitching combined with a wide range of magnifications are powerful for describing the distribution and organisation of traces.

3D DM is having an option of "tiling", which produces the image in mosaic by stitching micrographs. The problem of this option is that the mosaics are perfect when the topography of the edge is flat or slightly varies in topography. Artefacts with very uneven topographic variation mosaics are not coming perfectly. In such cases, the best option is by taking individual micrographs and stitching them together by means of other online software such as Mosaically, Maczaic etc. At lower magnification 35x to 200x vast area of the edge can be prepared in mosaic but in high magnification 400x to 1000x only a part of the edge can be taken into as a mosaic. The mosaic images are created taking a sequence of frames depending largely on the intensity and incidence of light. That means that depending on the lighting the image might vary, so it depends on the observer (Maté-Gonzalés et.al. 2017). For capturing the images, 3D DM automatically decide the number of micrographs suitable for capturing the final image (depending of the topography of the tool) and the images are captured in small duration time. Whereas, for OLM the number of micrographs are manually set and sometimes the end results are not satisfactory. At the low magnifications, the micro-graphs depending of the the topography varies from 8-20 micrograhs. In high range they can be between 30-200 micrographs.

In traceology, price of the microscopes also plays an important role to be considered as if the laboratory can buy or rent it for uses. Considering the price to buy or rent the microscopes, OLM and 3D DM are much more budget-friendly compared to SEM. As the SEM needs some special treatments such as cool nitrogen for it to function proper; hence most of the time the users need to rent it. On the other hand, OLM and 3D DM do not need any such special precautions.

Finally, 3D DM give some advantages over OLM with the magnification to analyze the traces at high magnification but still have some limitations when observe at more than 2000x. For the residue analysis, for the preliminary analysis OLM and 3D DM are very efficient as in less time one can check the whole surface of the sample compare to SEM. On the other hand, as in our study we realised that some of the residue can be missed or overlooked due to lack of detailed images at high magnification or understanding of the residue elements (which can be extracted by the EDX attached to SEM). According to the shell artifacts, we believe especially for the polishes SEM provides better results compare to OLM and 3D DM.

Besides OLM and SEM, 3D DM shares many similarity to the Laser Scanning Confocal Microscope (LSCM) in many senses such as generating a 3D profile of the tool surface and various measurements. Similar to LSCM benefits over SEM (higher contrast imaging, ability to study objects without placing it in a chamber, hence ability to easy mobility of the sample while analyzing. The first is that the LSCM can be used as an optical, reflected light microscope, much like standard metallographic microscopes used by high-power lithic use-wear analysts, as well as producing three-dimensional surface scans of the same surface. 3D DM images at high magnification their resolutions are not as good as SEM. 3D DM also provides various 2D and 3D measurements options similar to LSCM. However, till now we are not able to quantify the use-wear using 3D DM. Hence, this research future prospect is to investigate and test the efficiency of 3D DM to quantifying the traces and compare the results with LSCM.

Finally, 3D DM being a very efficient microscope for use-wear and residue qualitative description (both as a standalone or complementary microscope with OLM and SEM), more developed research still needs to be carried out to demonstrate its adequacy for quantitative analysis.

Specifications and Qualities	3D DM		OLM	ESEM with EDX
Model	KH-8700	RH-2000	Zeiss Axio scope 1	FEI Quanta 600
Price	Moderate	Moderate	Cheaper	Expensive
Acessibility	Moderate	Moderate	Easy	Difficult
Capture image Resolution	0.248 (H) x 0.248 (V) mm	????	3.3 Megapixels	Up to 4096 x 3536 pixels (used resolution: 1024 x 943 pixels)
Sample size for analysis	Large	Large	Large	Selective pieces (depending on type of issue dealt by the traceologist)
Sample preparation	NO	NO	NO	YES at High Vaccum NO low vacuum
Observation method	21.5" HD LCD screen	Touch screen	Eye piece And screen	Screen
Lens	MXG-5000 REZ	MXB-5000 REZ	EC epiplan 5 x HD, EC epiplan 10 x HD, LD epiplan 20 x HD DIC, LD epiplan 50 x HD DIC	
Camera/ Sensor/Detector	1/1.8 type, 2.11 million pixel CCD image sensor		5 Mpx Invenio 5S vII	Secondary electron Everharte Thornley Detector (ETD) when working at high vacuum Large Field Detector (LFD) when working at low vacuum Back-scattered electron detector (Dual BSD) for both high and low vacuum EDX-EXL II system Link Analytical Oxford
Magnification Ranges	**Low-Range objective** (35 x and 250 x), **Medium-Range objective** (140 x to 1000 x) and **High-Range objective** (700 x to 5000 x)	**Low-Range objective** (35 x and 250 x), **Medium-Range objective** (140 x to 1000 x) and **High-Range objective** (700 x to 5000 x)	50x to 500x	35x to 15000x

Working distance	10 mm	10 mm	50x 14.5mm, 100x 14.3mm 200x 7.1 500x 6.5	Variable (optimal at 20 mm)
Light source	Ring light and Co-axial Light	Ring light and Co-axial Light	Upper stand part M27 e HD/FL reflected-light illumination for HAL 100	Beam energy set up at 20 kv
Extended focus	YES	YES	YES	NO
Working stage	Automatic motorized stage	Automatic motorized stage	Automatic motorized stage	NO
Sample analysis environment	Open environment	Open environment	Open environment	Pressure chamber High or Low Vacuum according to type of sample analyzed
Mobility of sample during analysis	Easy	Easy	Easy	Moderate
Element maps	NO	NO	NO	YES
3D models	YES	YES	NO	NO
Profile of edge	At any magnification with tiling option	At any magnification with tiling option	Not directly	Not directly
Type of Image captures	2D, 3D, Tiling	2D, 3D, Tiling	2D	2D
Color quality	Excellent	Excellent	moderate	Grey scale
Detection of residue	Color and texture	Color and texture	Color and texture	Detailed structure (Large field Detector, LFD) Elementary composition (Back-scattered electron detector, BSD) Electron dispersive X-Ray analysis, EDX-EXL II system Link Analytical Oxford (spectra and element maps)
Detection of location	Easier	Easier	Easier	Moderate

Table 4: Discussing the advantage and disadvantages of OLM, 3D DM and SEM.

Acknowledgement

We would like to thank the microscopy laboratories of IPHES, URV Scientific Resources Centre (Tarragona, Spain) and Museé de l´Homme (Paris, France) for providing all the necessary access to conduct the microscopic analysis. This Research has been developed in the framework of signed MOU between RICHT (Iran) and IPHES (Spain) for which we are thankful to the directors of RICHT and ICAR (Seyed Mohamad Beheshti and Hamide Choubak). As well as the Spanish Ministerio de Economi y Competitividad project CGL2012-38434-C03-03 and the Catalan AGUAR project 2014SGR899. Special thanks to Dr. Behrouz

Bazgir (director for Kaldar Cave excavations) for giving access to archaeological material as well as Miguel for knapping of the stone tools for the experiments. We would also like to thank David Cuenca-Solana for sharing his work and articles on shell tools. L. Tumung is the beneficiary of PhD scholarship funding under the Erasmus Mundus Program-International Doctorate in Quaternary and Prehistory.

3.5.2. Analytic techniques

During the burial process, the archaeological residue goes through various degradation processes due to attack by the microorganism as well as depositional process and reacting with the soil chemical properties. The archaeological residues lose its morphological distinctive feature which hampers the identification of the residue unlike the fresh residue. Since many years archaeologist have started to analyze the residue using different techniques such as FTIR, GC-MS, Raman etc. For analyzing the residue, some of these methods require extracting of residue. Hence, the question come weither or not residues should be extracted from the tool or not? A number of researchers contest the usefulness of residue extraction (Lombard and Wadley 2007; Langejans 2011, Cnuts and Rots 2017), while others view is to preserve the residue as a necessary step in an analytical protocol with the advantage of long-term preservation of the residues for identifying the residue with different techniques (Monnier et al. 2013; Rots et al. 2016). For the extraction method Fullagar (et al 1996), have argued that many times residue analysts perform ‘whole tool' extractions in the process of analysis, a procedure which is often inappropriate for archaeological material as it is both destructive and does not target particular residues with their visible structures and associations with utilized edges. The similar thing Monnier (et al. 2013) mentioned that how the previous bitumen residue extraction for the Hummal site (Isreal) was destructive and suggested various other non-invasive techniques. Following these previous works, for the present study, the residues were not extracted to keep the context (location on the tool surface) of the residue in order to be able to study them by applying various other techniques suggested by the previous researchers.

3.5.2.1. Fourier-transform infrared spectroscopy (FITR)

This section is explained in the Article no. 6 in multi-analytic approach.

3.5.2.2. µX-Ray Diffraction (µXRD)

This section is explained in the article no. 6 in multi-analytic approach.

CHAPTER 4

FUNTIONAL ANALYSIS OF THE EXPERIMENTAL LITHICS

Looking first at the material apparatus of culture, we can say that every artefact is either or else an object of more direct use, that is, belonging to the class of consumers goods. In either case, the circumstances as well as the form of the object are determined by its use. Function and form are related

Malinowski, 1944

CHAPTER 4

FUNTIONAL ANALYSIS ON EXPERIMENTAL LITHICS

4.1. Projectile experiments

The aim of this experiment was to analyze the results of a set of experimental projectiles made of Khorramabad and Zaragoza (Monegros-type) flint that reproduced the type of points present in the archeological sites. We wanted to explore how they perform efficiently, if they can pierce the prey as well as in how many times of using the point possible tip fracture or other macro-fractures occurred on the lithics. Although the experiment was very small, it gave us some valuable information about the different flints and the types of wears and fractures. Most of the points were used as arrowheads except for one piece (Zaragoza no. 2) that was used as a spearhead. The hafting methodology is already explained and discussed in the chapter 3. Here, all the changes happened during the course of experiments were noted and taken photo as the future reference and have been explained verbally. Below I have explained all the experiments as well as the traces found on the respective lithics.

4.1.1. Zaragoza no. 1

This tool was used as an arrowhead (Fig 4.1) and the experiment was performed at the distance of 7m. The initial two shots did not touch the prey and hit the ground. Shots number 3-5 and 7 hit the target but repelled by the skin. In the third shot slight tip fracture and residue of blood was noticed on the tool which we recorded in the form and also taken the photo for the later reference (Fig. 4.2a, 4.2b). By the sixth shot the point hit the ground and got inserted till the haft area. When removed the sediment was still attached to the tip (Fig.4.2d). Shot number 8 also missed the target and fell 1m away by hitting the ground because of which the piece of misplace at the hafting area (Fig. 4.2e, 4.2f) making it impossible to use any further.

For the distribution patterns of the residue, after the experiment the hafts were removed and photographed (Fig.4.3) as well as microscopic details of the residues were also recorded in photograph catalog. On the tip a small residue shows deep criss-cross striations.

The use-wear analysis, showed the polish and edge rounding on the tip fracture (Fig. 4.4). On both the dorsal and ventral face, the micro-fractures of the tip are visible (Fig. 4.4a, 4.4b, 4.4e, 4.4f). On the ventral side, even with all the cleaning procedure some sediment residue was still present on the tip fracture showed very heavy polish (Fig.4.4g). After cleaning with the alcohol the tip fracture the actual extend of the polish and the edge rounding was visible (Fig. 4.4h).

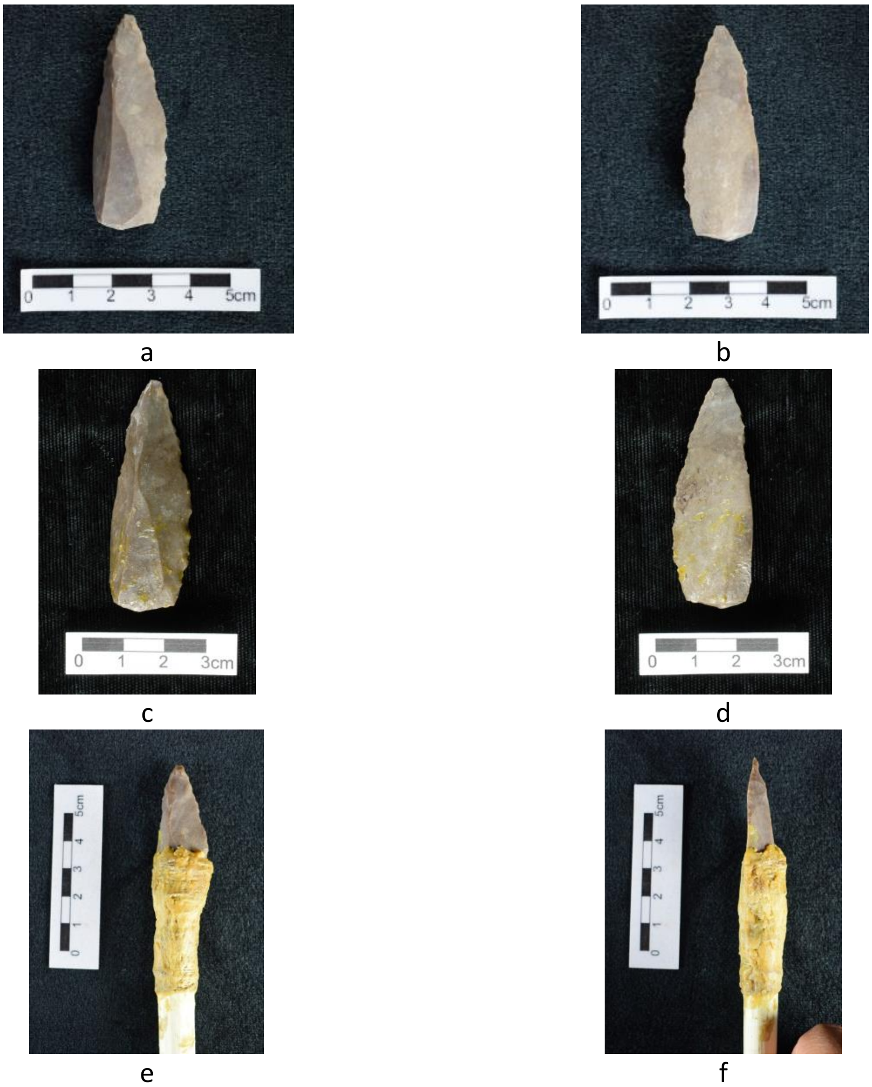


Figure 4.1: Zaragoza no. 1 (arrowhead, 8 shots were performed) (a-b) dorsal and ventral face of the tool before use, (c-d) after use with the resin residue and blood residue; (e-f) showing the hafting arrangement.

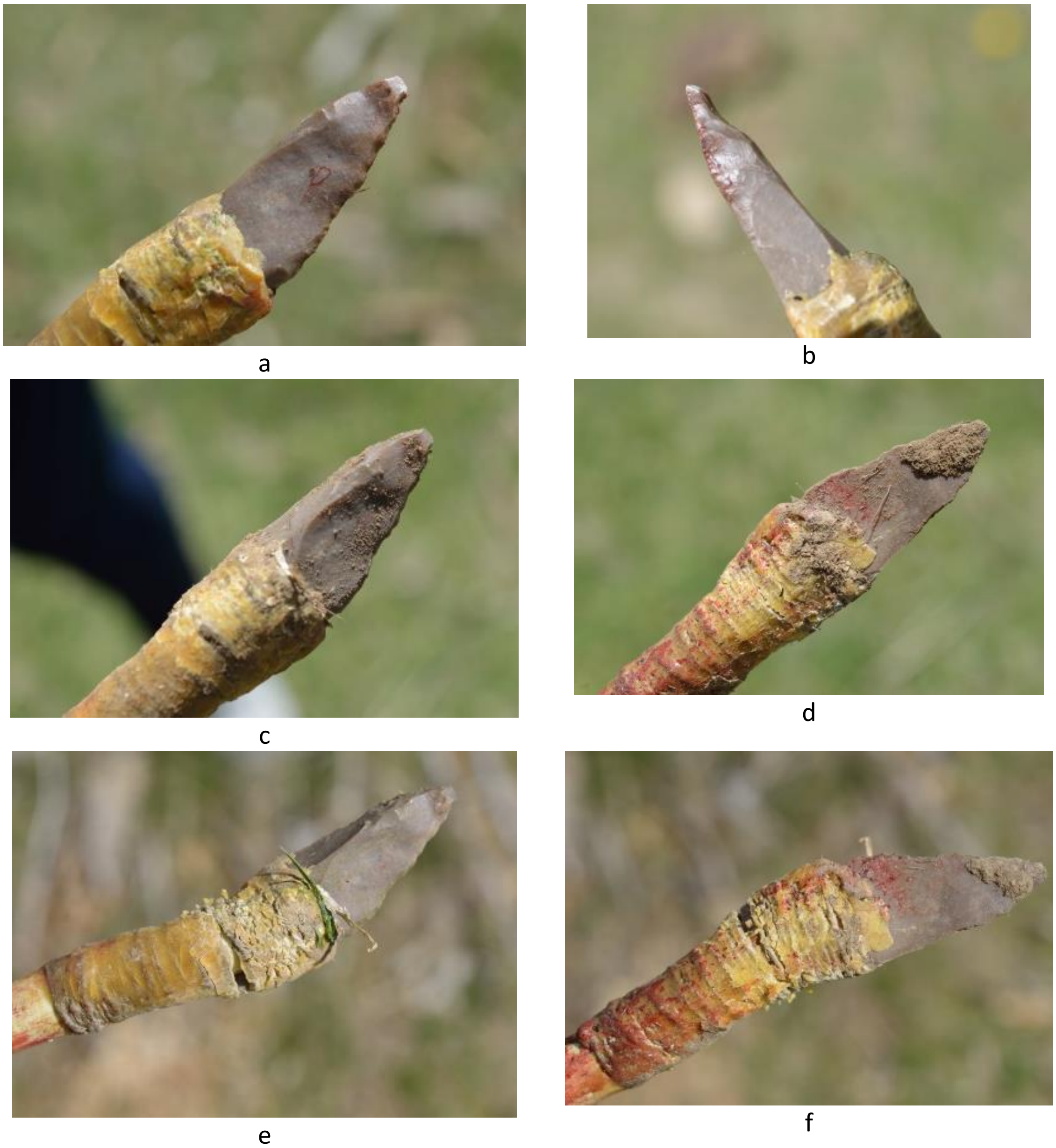


Figure 4.2: Zaragoza no. 1 (arrowhead, 8 shots were performed) (a-b) tip fracture and blood residue on the tool surface, (c-d) attempt 3 tool penetrate inside the ground till the haft area; (e-f) attempt 8 the tool misplaced on the haft after hitting the ground

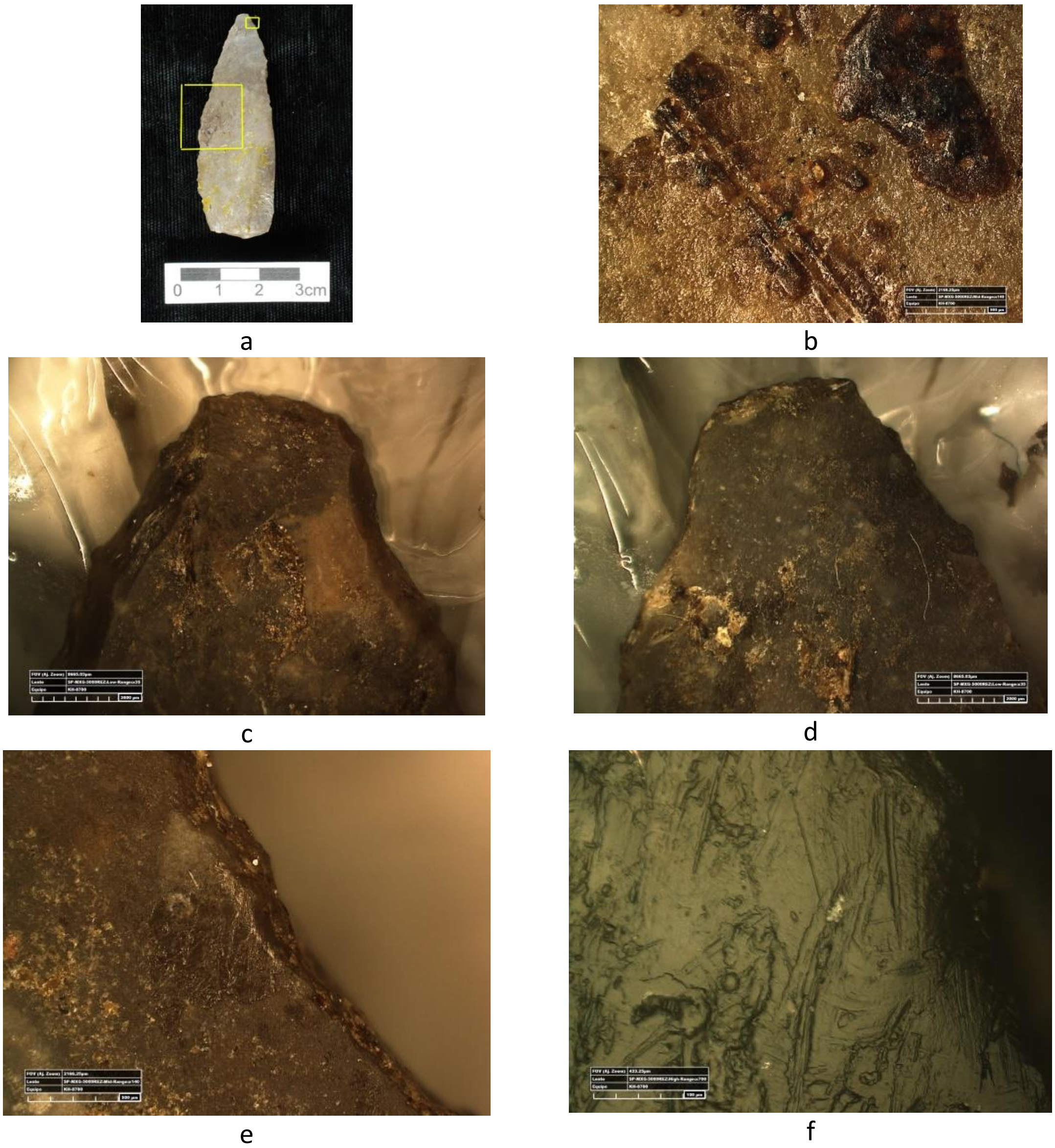


Figure 4.3: Zaragoza no.1 (arrowhead, 8 shots were performed) (a) ventral face showing the distribution of the residue; (b) detail view of the (a) at 140x; (c) dorsal face of the tool showing the blood residue distribution at 35x; (d) ventral face with the tip fracture and residue distribution a 35x; (e) location of the residue of small yellow square with striations at 140x and (f) detail of the residue with striations at 700x. (images taken with 3D DM)

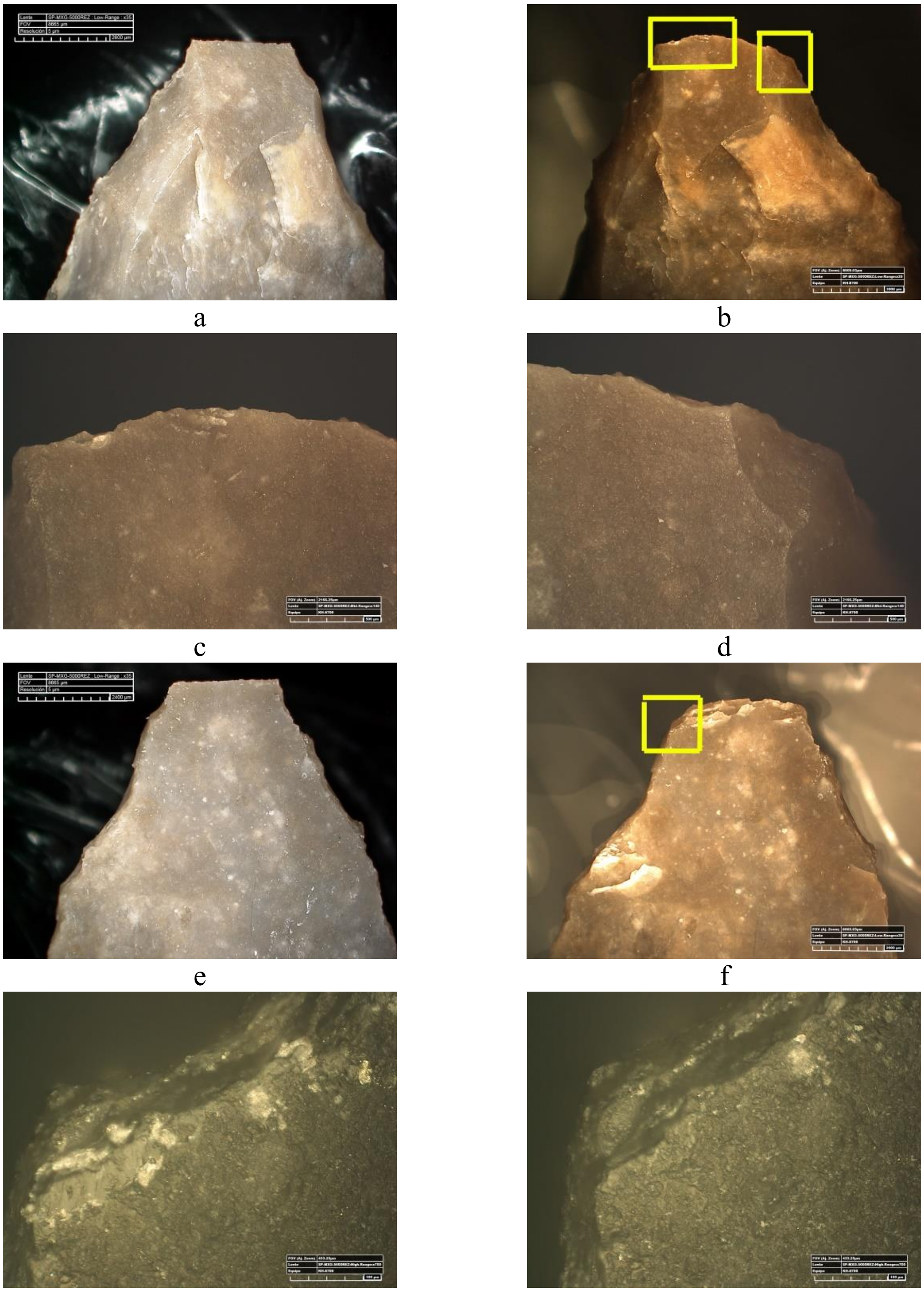


Figure 4.4: Zaragoza no 1 (arrowhead, 8 shots were performed) (a) dorsal face fresh tip before use at 35x(b) after use showing the location of tip fracture in Yellow Square at 35x; (c) detail of the fracture at 140x; (d) detail view of the small yellow square at 140x; (e) ventral face showing the fresh edge at 35x; f) after use the impact fractures at 35x; g) edge rounding and polish at 700x; h) same location after cleaning with ethanol and cotton at 700x actual edge rounding and polish distribution is visible (images taken with 3D DM)

4.1.2. Zaragoza no. 2

This piece was used as spearhead (Fig.4.5h). For the experiment, the spear was thrown from the distance of 10 m on the target but in first attempt only it missed the shot and hit the ground. From the tip till the hafting area the point got buried inside the soil (Fig. 4.6a). After hitting the ground the sample broke into two major halves and many microchips (Fig. 4.6b). The fracture (bending fracture) is very visible with naked eye, showing the impact scars (Fig.4.5d).

Use-wear analysis on the ventral side showed the polish on the fractures happened due to the rubbing of the stone and soil particles (Fig.4.5e, 4.6f). There are also some bright residues may be the due to the rubbing of the soil particles (Fig 4.6f). On the dorsal side, small bright spot polish seen on the tip as well as some transverse striations and polish (Fig. 4.7)

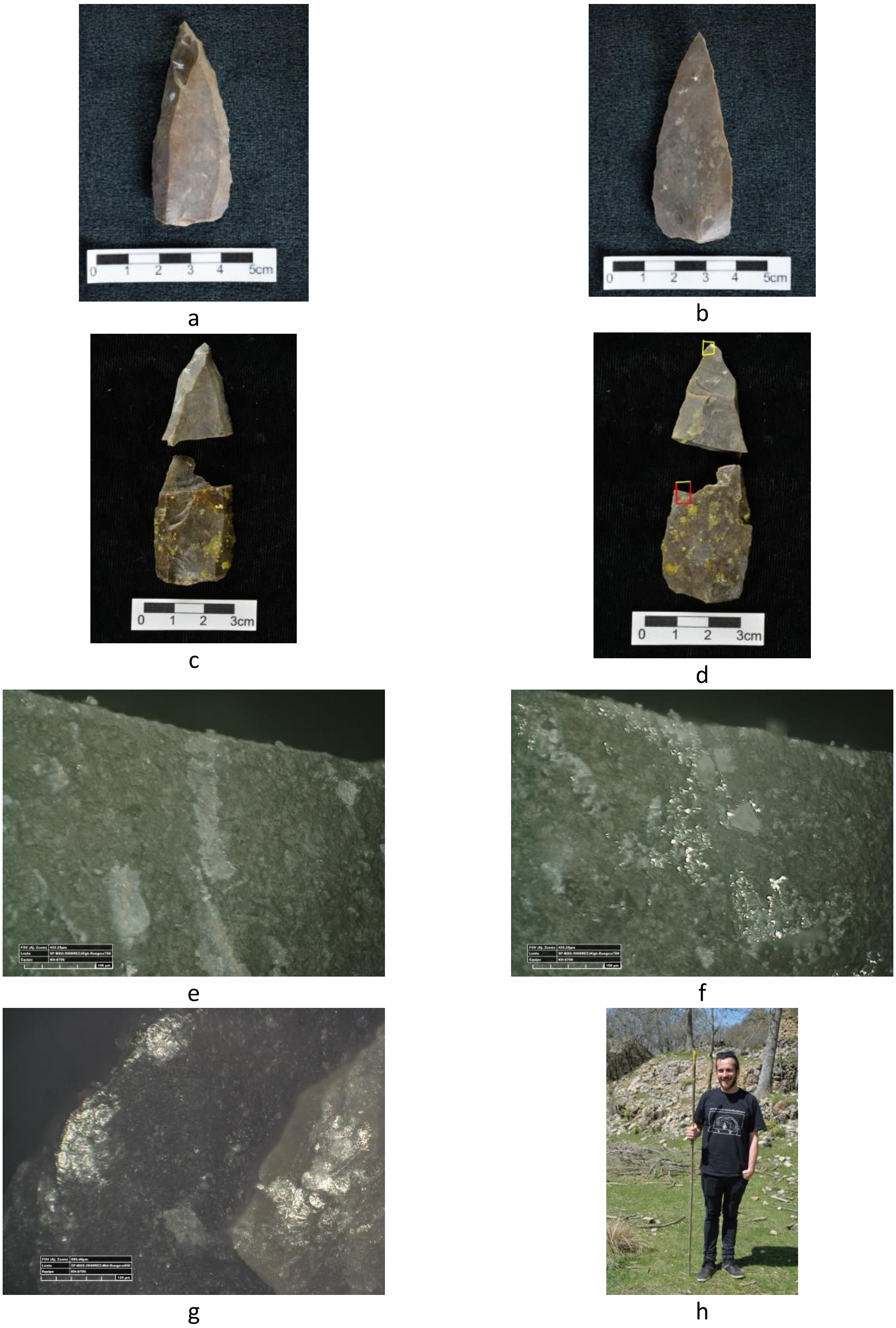


Figure 4.5:Zaragoza no 2 (spearhead, 1 shot was performed) (a-b) unused dorsal and ventral face; (c) after use dorsal side with the adhesive ; d) ventral side showing the venting fracture; (e-f) detail of the red square showing the polish at 700x; g) detail of the polish at 700x on the tip mark in yellow at 600x(d; (h) spearhead with scale to an adult person (images taken with 3D DM)

a

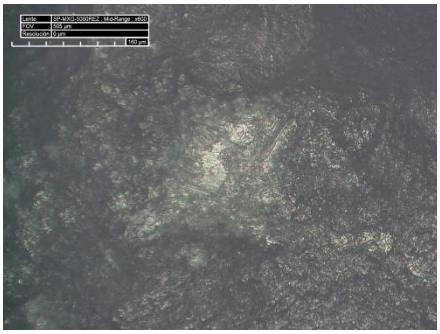
b

Figure 4.6: Zaragoza no 2 (spearhead, 1 shot was performed) (a) showing the spear point embedded inside the sediment till the hafting area (b) micro-chips happened due to impact fracture

a

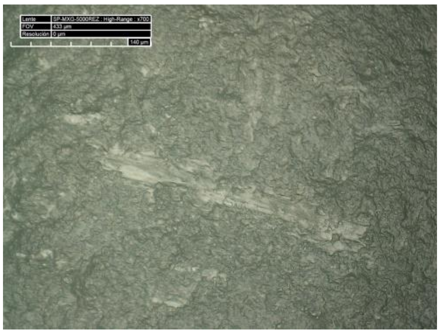
35x

b

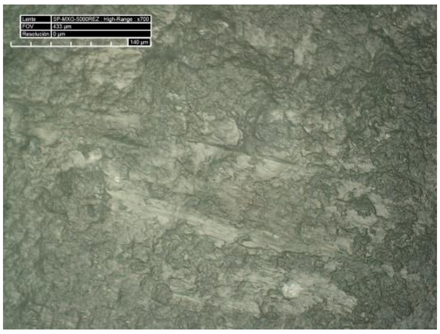


c

d



e



f

Figure 4.7: Zaragoza no 2 (spearhead, 1 shot was performed) (a) dorsal side of the tool showing the location of the traces; b) tip fracture; c) polish on the tip at 600x (; d) detail of the polish and striation in small yellow square at 400x; (e-f) detail of the polish and striations at 700x (images taken with 3D DM)

4.1.3. Zaragoza no. 3

This piece hit the target from the distance of 7m but missed the target and hit the ground in the first attempt itself. The tip fracture is very visible with the naked eyes (Fig. 4.8f) The use-wear analysis show polish on the tip fracture (Fig. 4.9c-e) and bright spot is present on the proximal part of the tool (Fig. 4.9f). Residue analysis show, plant residue attached to the tool at hafting area with the adhesive (Fig 4.10).

Figure 4.8; Zaragoza no.3 (arrowhead, 1 shot was performed (a-b) unused tool, (c-d) after use showing the fracture and the distribution of the residue on the tool; e) hafted on the shaft; f) after 1 attempt tip fracture

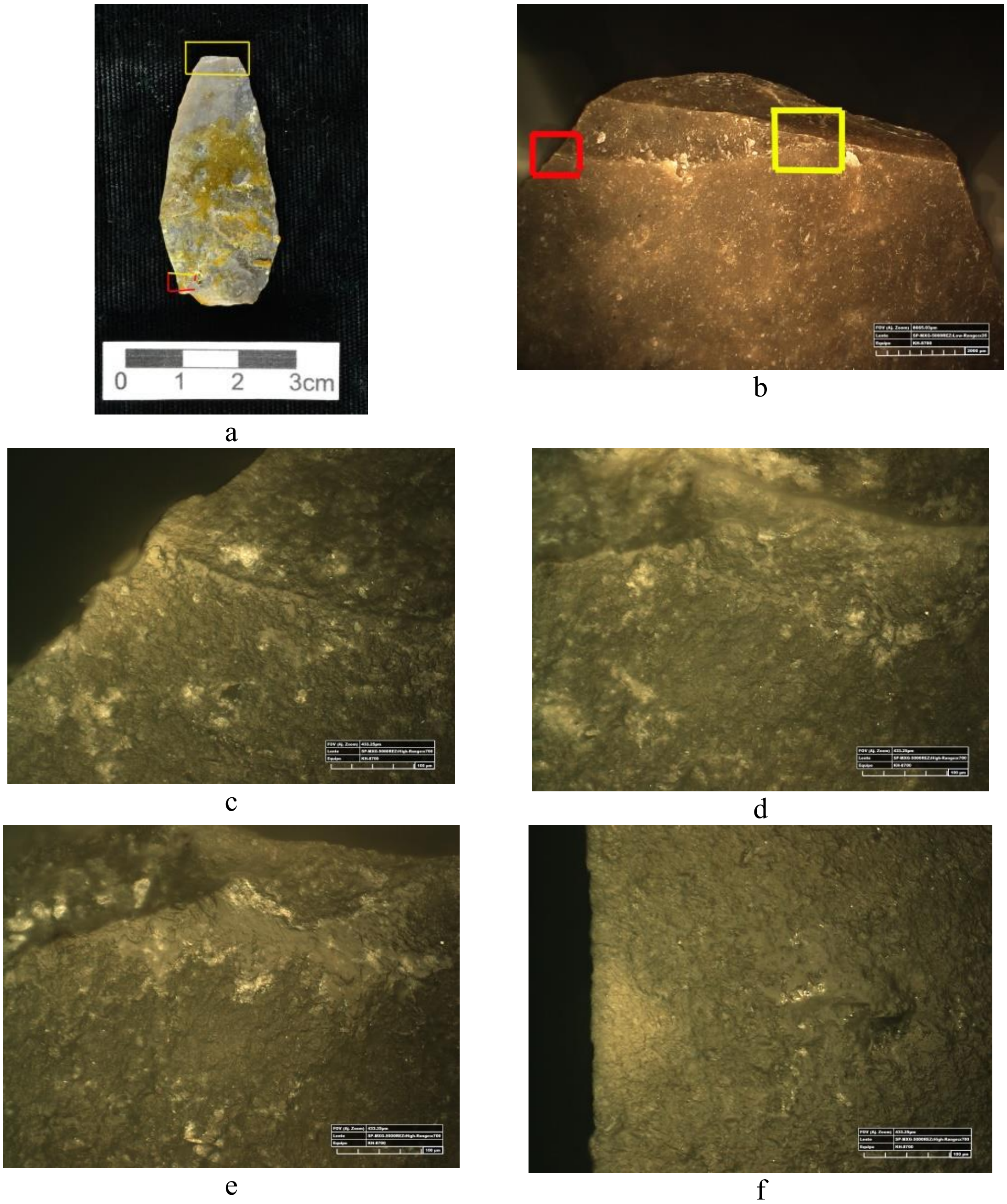


Figure 4.9: Zaragoza no 3 (arrowhead, 1 shot was performed) (a) showing the locations of the use-wear traces; b) detail view of the tip fracture (at 35x) showing the location of polished areas in (c-e) (at 700x; f) detail view of the polish on the tool marked in red box in Fig. (a) at 700x

Figure 4.10: Zaragoza no. 3 (arrowhead, 1 shot was performed) (a-b) showing the locations of residue; (c) plant residue at 140x; (d) plant residue at 700x; (e) tip fracture on dorsal side at 35x; (f) adhesive residue with the industrial twine impression on it at 200x

4.1.4. KH4 no. 1

This is green flint from Khorramabad, Iran. In the first attempt, it pierced in the neck of the animal touching the vertebrae (Fig. 4.12a-b). In the second attempt, it hit the target and broken into two halves exactly till the haft (Fig.4.12c-d)

Residue analysis showed hair and blood on the tip of the tool (Fig. 4.13a-b) and adhesive distribution on the tool (Fig 4.11c-d). Use-wear analysis showed the polish and striation of the tip (Fig 4.13c-f)

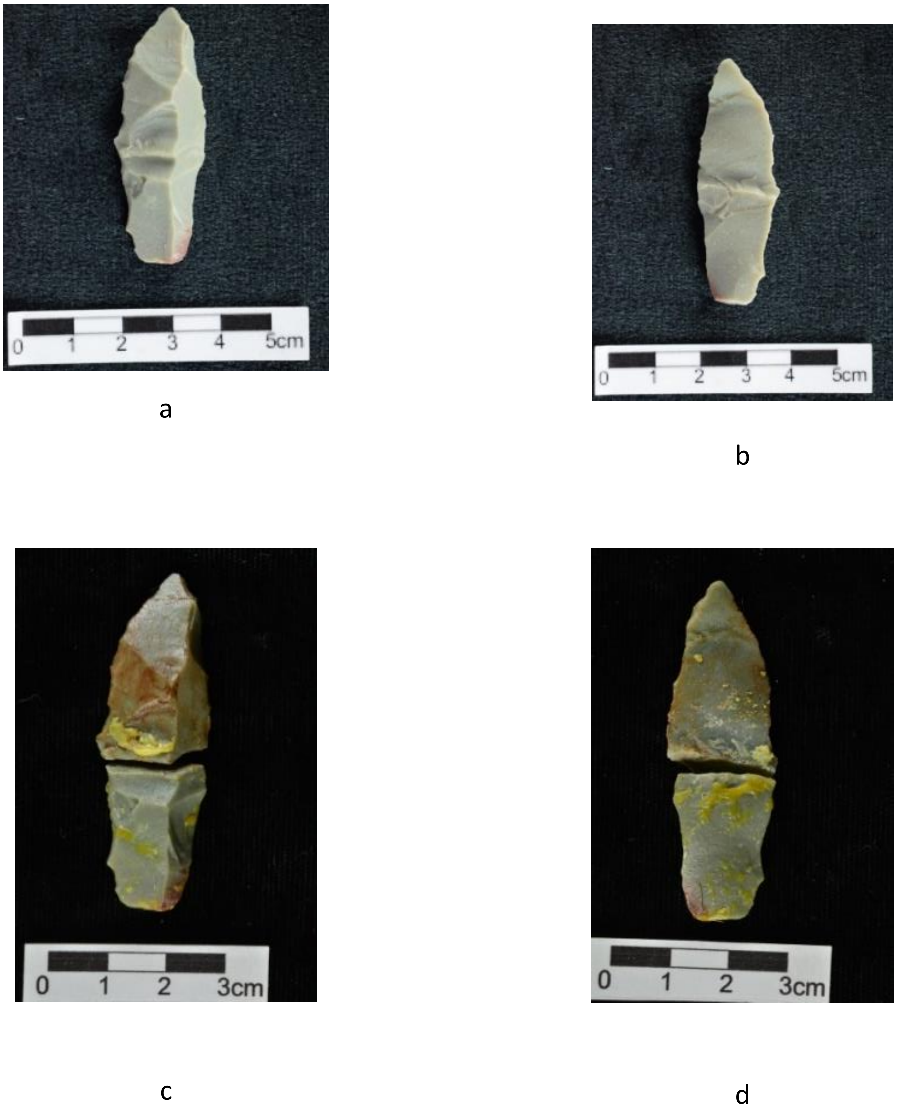


Figure 4.11: KH4-no1 (arrowhead, 2 shots were performed) (a-b) dorsal and ventral face of the unused tool; (c-d) after use with the fracture and showing the distribution of the residue (adhesive, blood)

Figure 4.12: KH4 no.1 (arrowhead, 2 shots were performed; a) arrow inside the neck part of *Cervus elaphus; b)* showing the limit the arrow pierce inside the target; c) second attempt the tool fractured and fell in different direction; d) fracture till the haft limit

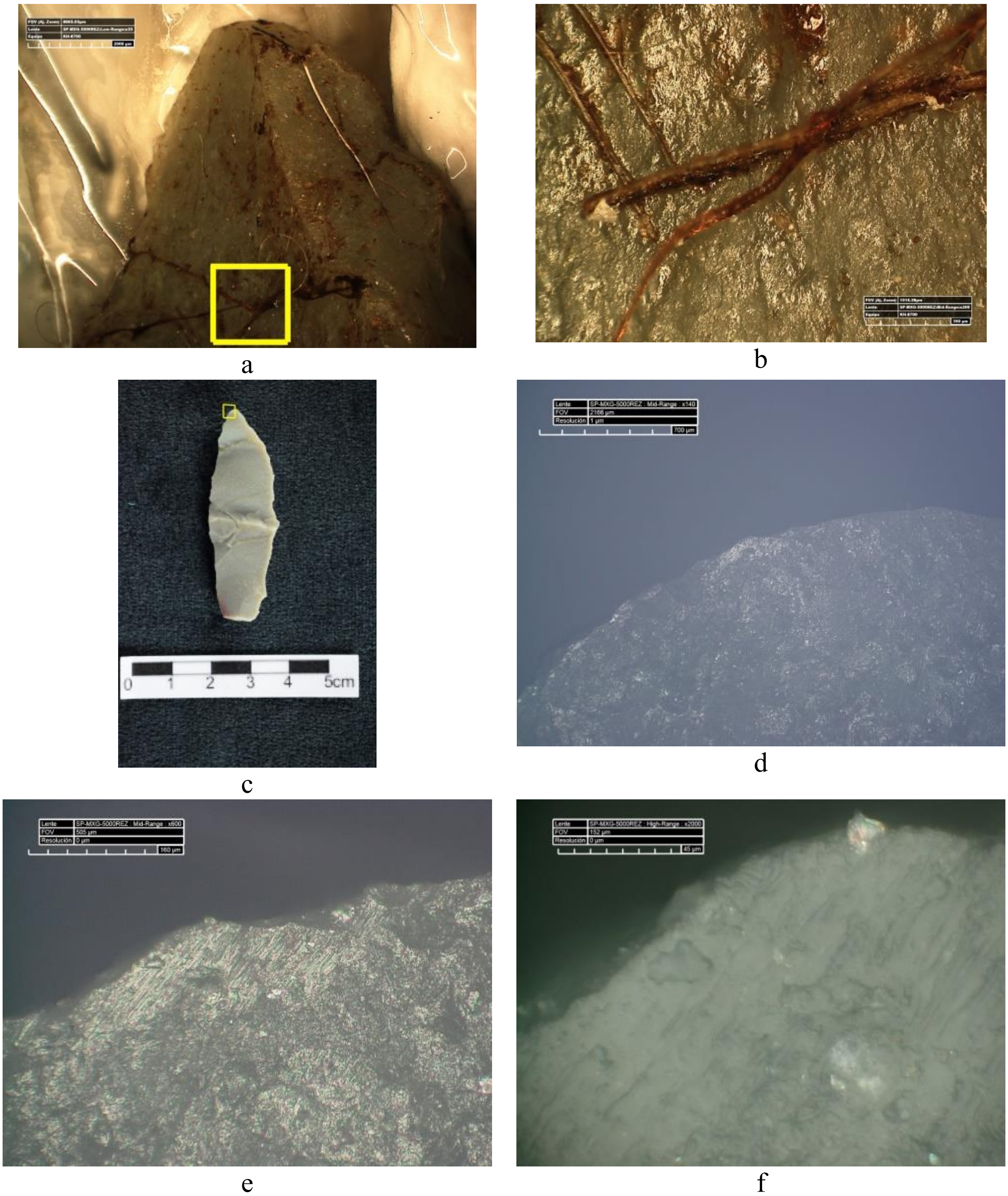


Figure 4.13: KH4-no 1 (arrowhead, 1 shots were performed) (a) tip with the residue of blood and hairs of *Cervus elaphus* at 35x; b) detail view of the (a) at 200x; c) showing the location of the use-wear; d) location of polish at 35x; (e) detail of (d) showing polish and striations at 600x; f) showing the detail of (e) at 2000x

4.1.5. KHR6 No 1

This is a white flint from Khorramabad and the hafting of the tool was in criss-cross binding with the thread. This point used for 10 attempts. In the attempt 1, 4, 7, 9 and 10 touched the target but got repelled by the skin. In 1st attempt the point touched the neck and got repelled but on the tip hair of the *Cervus elaphus* got stuck (Fig. 4.14c). In 2 and 3 shot hit the ground (Fig. 4.14g-h). By the 4th attempt, the point entered till the hafting area. out of which in the fourth attempt slight fracture occurred on the right side of the tip (Fig. 4.14e) and in 8th attempt it pierced near scapula of the left forelimb until the half of the shaft (Fig. 4.14f). Other times either it touched the ground or propelled by the skin (Fig. 4.14g-h)

Residue analysis, showed the tool covered with the sediment, plant residues as well as hair and blood of the *Cervus elaphus* (Fig. 4.15)

Use-wear analysis shows the tip fracture, polish, striations and edge rounding on the tool (Fig. 4.16). In this piece we can see the hafting polish on the edge (Fig.4.16c-f). This piece was very crystalline therefore was difficult to analyze with the mid-range lens as it appear very shinny. High-range lens was best apt for this type of the flint. With the low-range lens, the light disperse in a wavy pattern while capturing the images (Fig. 4.16a).

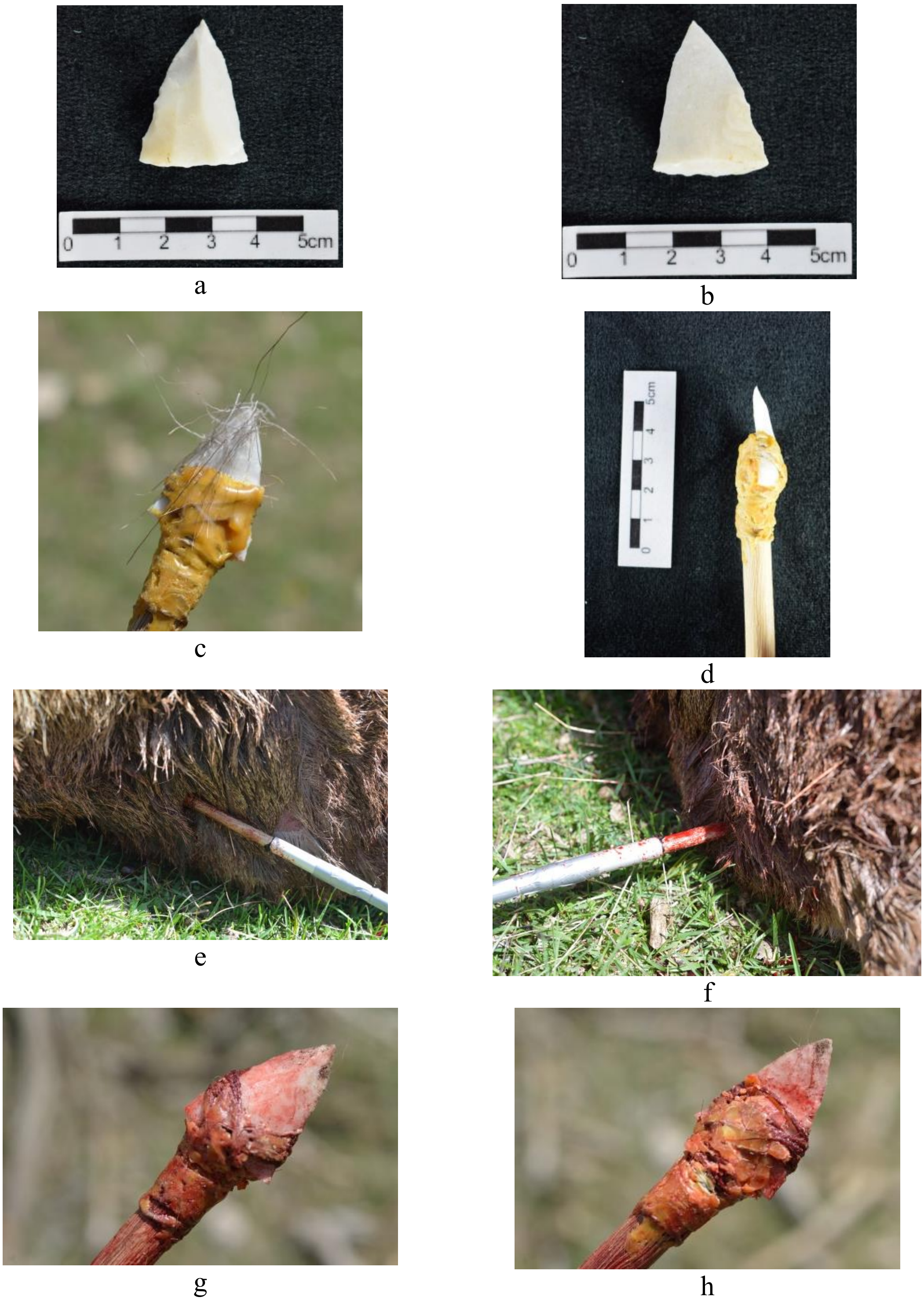


Figure 4.14: KHR6 no.1 (arrowhead, 10 shots were performed) (a-b) unused sample dorsal and ventral face; (c-d) hafted piece; (e) In attempt 4, pierced in the neck of the *Cervus elaphus* till the hafting area; (f) In attempt 8, pierced near the scapula of the left forelimb till half the foreshaft; (g-h) after getting hit on the ground showing the sediment on the tool.

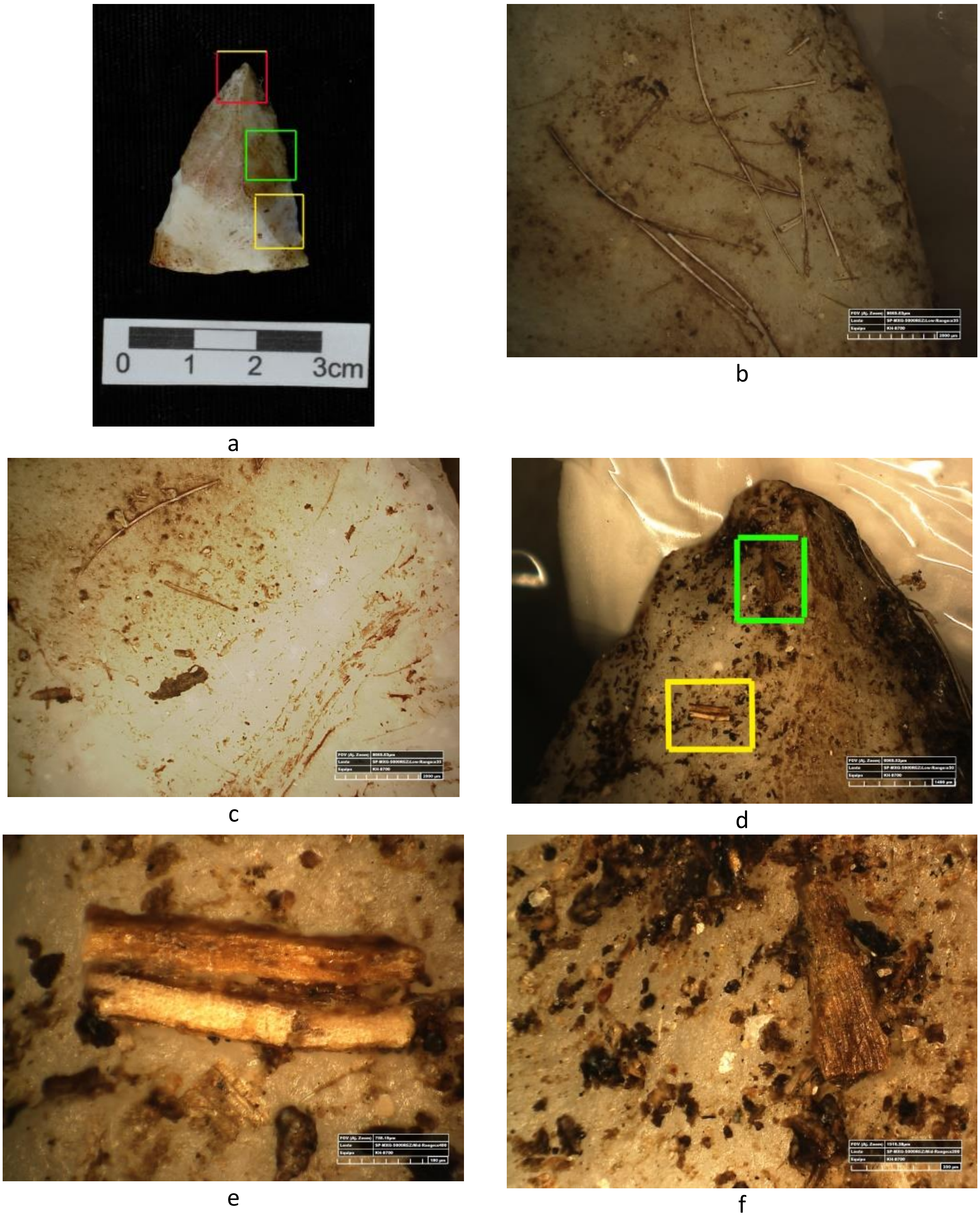


Figure 4.15: KHR6 no 1 (arrowhead, 10 shots were performed) (a) showing the distribution of residue after use, b) the green square on (a) detail view of hair of *Cervus elaphus*, c) detail view of the location indicated with yellow showing the resin and blood residue at 35x; (d) same location as (a) showing the plant residues on the tip at 50x; (e and f) showing the detail view of the plant residues at 400x and 200x. (Images captured with 3D DM)

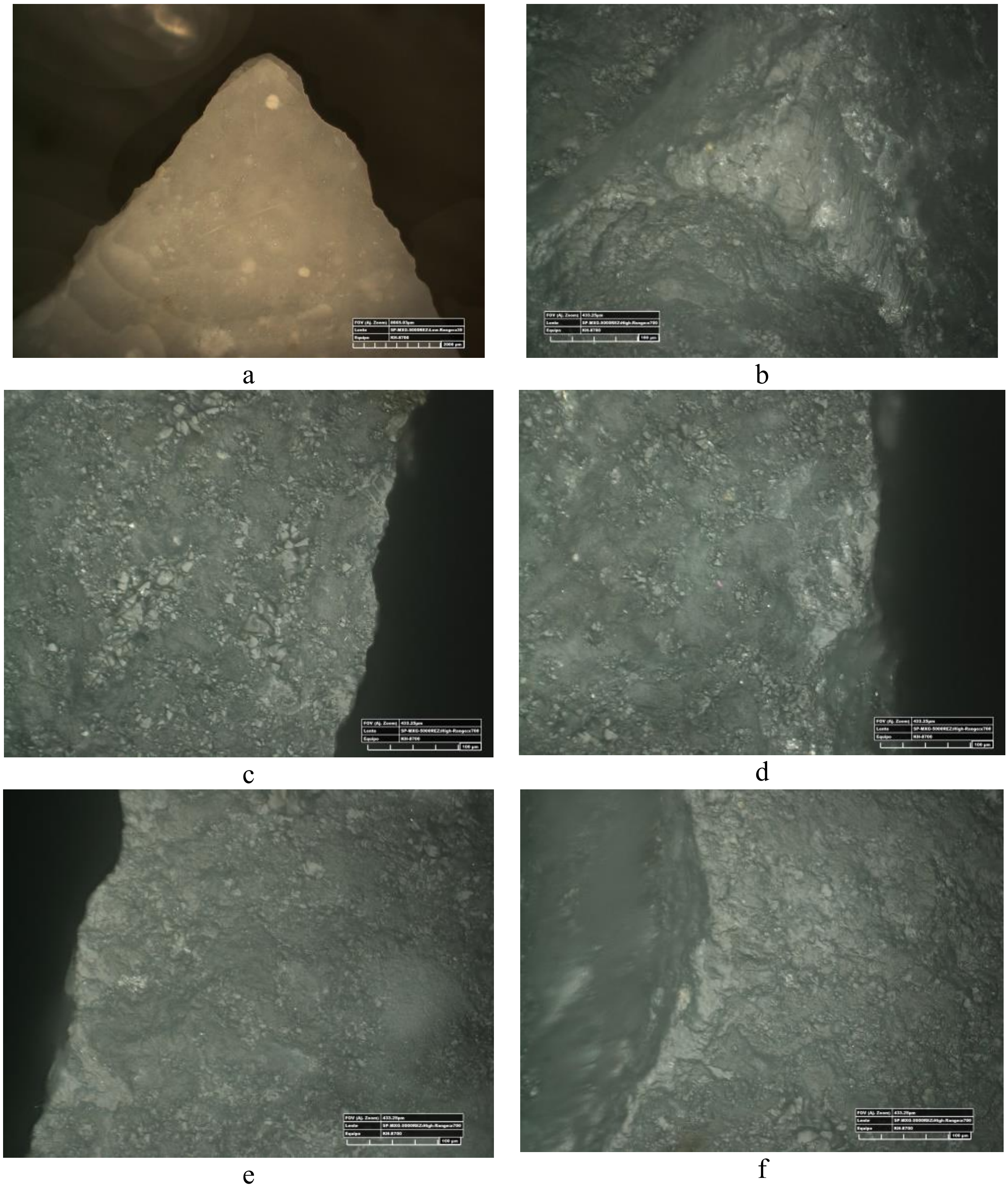


Figure 4.16: Ventral side of KHR6-no 1 (arrowhead, 10 shots were performed) (a) tip fracture at 35x; (b) polish with the striations; (c-f) hafting polish and edge rounding on the hafting area

4.1.6. KHR6 No 4

This tool used for 10 attempts and all the time it missed the target and hit the ground due to which in the 6th and 8th attempt small tip fracture occurred (Fig. 4.17). For the residue analysis, only general view of the tool with the adhesive distribution was photographically recorded.

Use-wear analysis was mostly observed on the ventral side of the tool. Tip fracture caused by the impact with the ground is observed (Fig. 4.18a-b) and also some micro-fracture with polish happened due to rubbing with the sediment (Fig 4.18c). Hafting polish and edge rounding was observed on the hafting area (Fig 4.18d-f)

Figure 4.17: KHR4 no 4 (arrowhead, 10 shots were performed) (a-b) dorsal and ventral of unused tool; (c-d) showing the distribution of the adhesive on the tool surface; (e-f) after pierced in the ground tool covered with the soil on it.

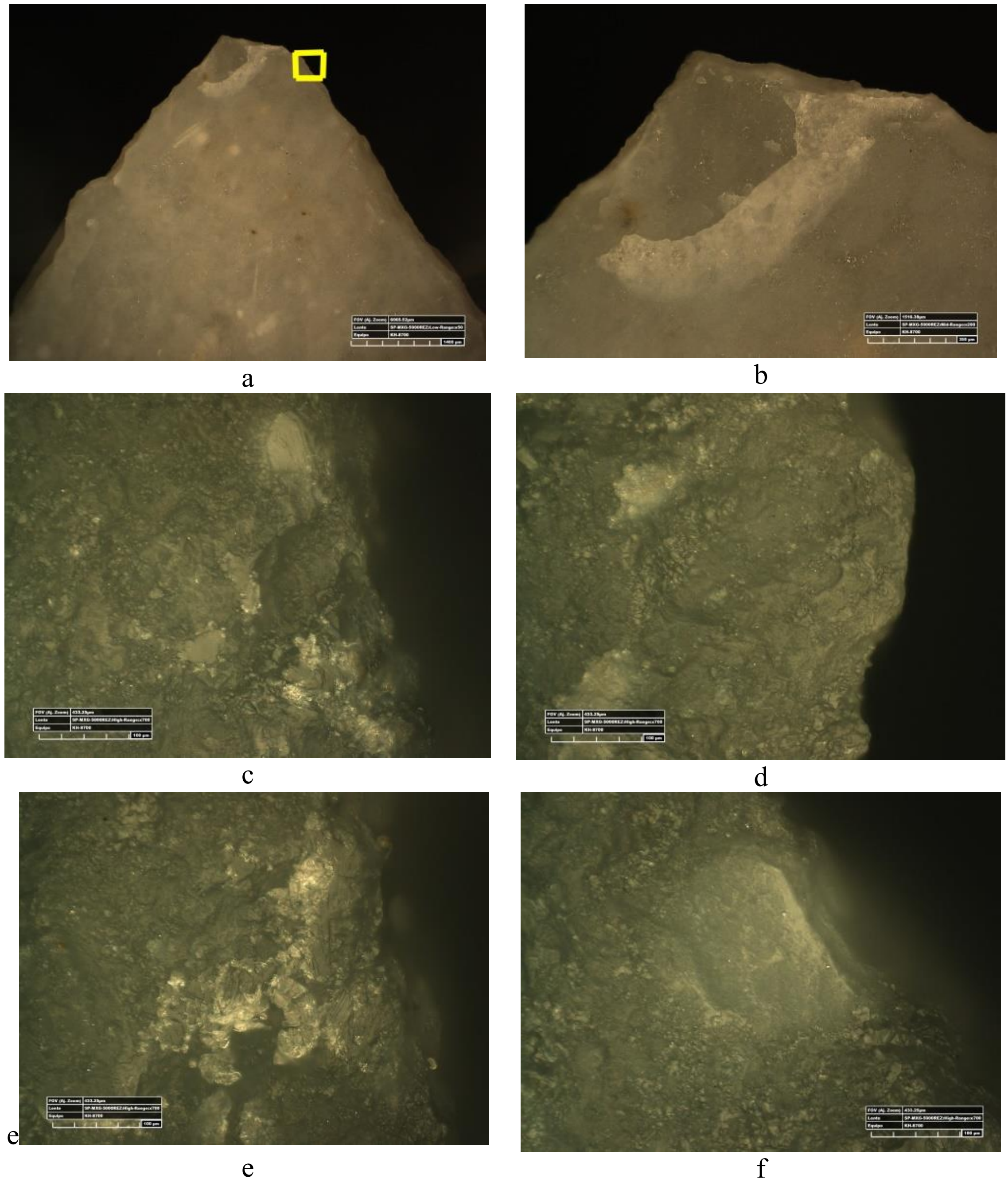


Figure 4.18: KHR4 no 4 (ventral face)((arrowhead, 10 shots were performed) (a) tip fracture at 50x; b) detail of the fracture at 200x; c) detail edge fracture with polish location shown in Fig. (a); (d-f) at the hafting area edge rounding and polish on the edge fracture at 700x (images taken with 3D DM)

4.2. Butchery and derived activities

For the butchery activities, *Capra* and *Cervus elaphus* was used as the worked material. In fact, here we reproduced several actions in some sense deriving from butchery, all of them implying contact with animal matters, as bone and hide basic processing. Initially, all the tools were used for 30 minutes and after the microscopic analysis as the use-wear was not developed they were used for another 30 minutes. Below they are explained by action and described verbally all the changes on the tool.

4.2.1 Disarticulating and defleshing

4.2.1.1. AKF1-Bu1

For this tool two active parts were used to complete the function (Fig. 4.19). The right forelimb of the *Cervus elaphus* was used to perform the task. Initially the distal left edge was use to deflesh the animal but later it lost it sharpness; then the proximal area of the edge was used to cut the tendon with striking motions. For the residue analysis, I let the residue dry on the edge and later captured the distribution of the residue on the tool (Fig. 4.20). After 90 minutes of use, the tool showed the edge reduction, some polish and edge rounding on the edge (Fig. 4.21)

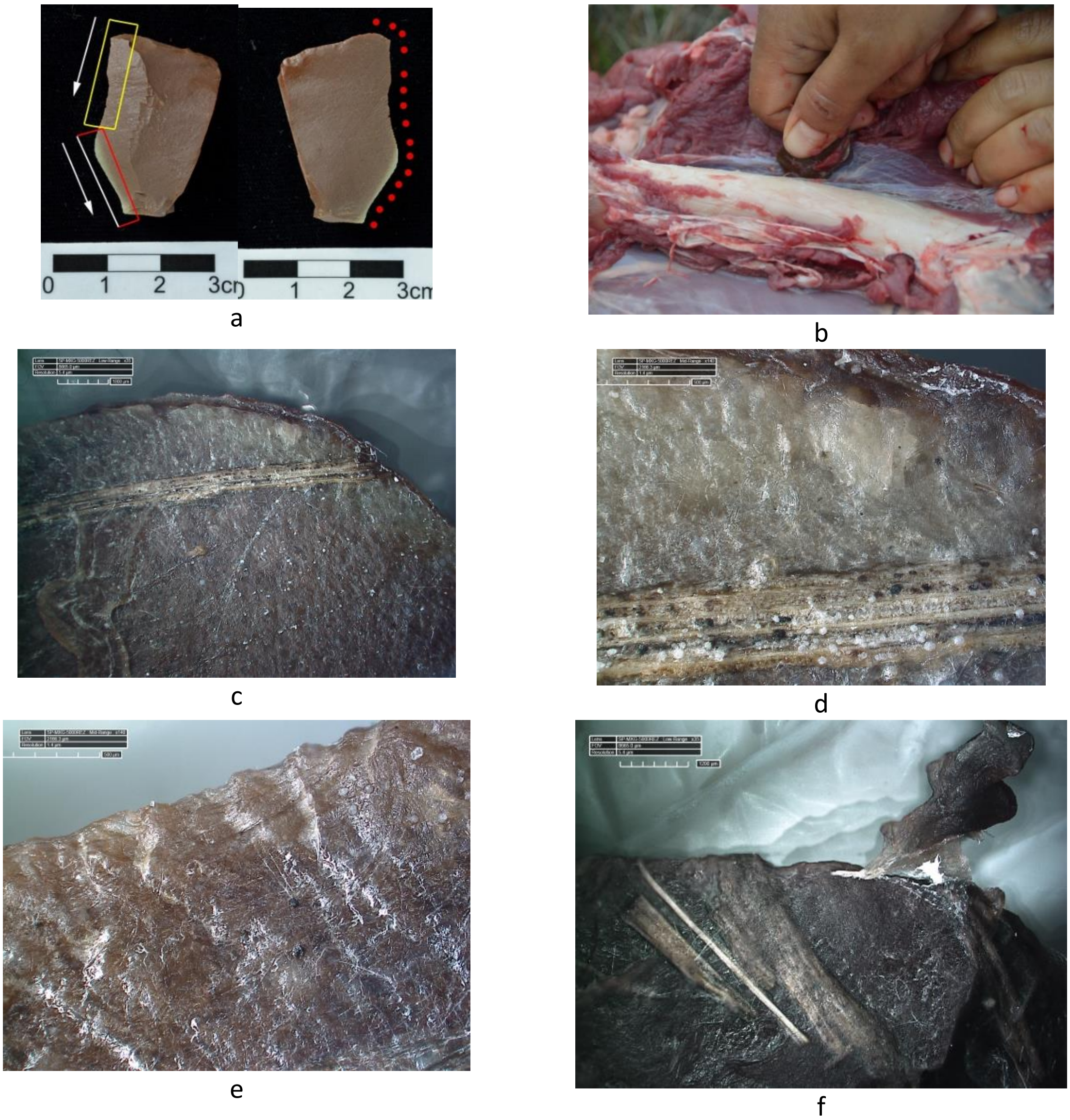


Figure 4.19: AKF1-Bu1 (60 minutes disarticulating and defleshing); a) active parts shown in yellow and red and the direction of the tool used; b) tool in action touching the bone and producing abundant superficial cut-marks; c) long tendon on the proximal part of the tool at 35x; d) detail of the tendon (c) at 140x; e) micro-fracture on the edge; f) tendon on the distal part of the tool

Figure4.20: AKF1-Bu1 (90 minutes disarticulating and defleshing) showing the profile of the residue distribution of flesh and tendon on the tool edge

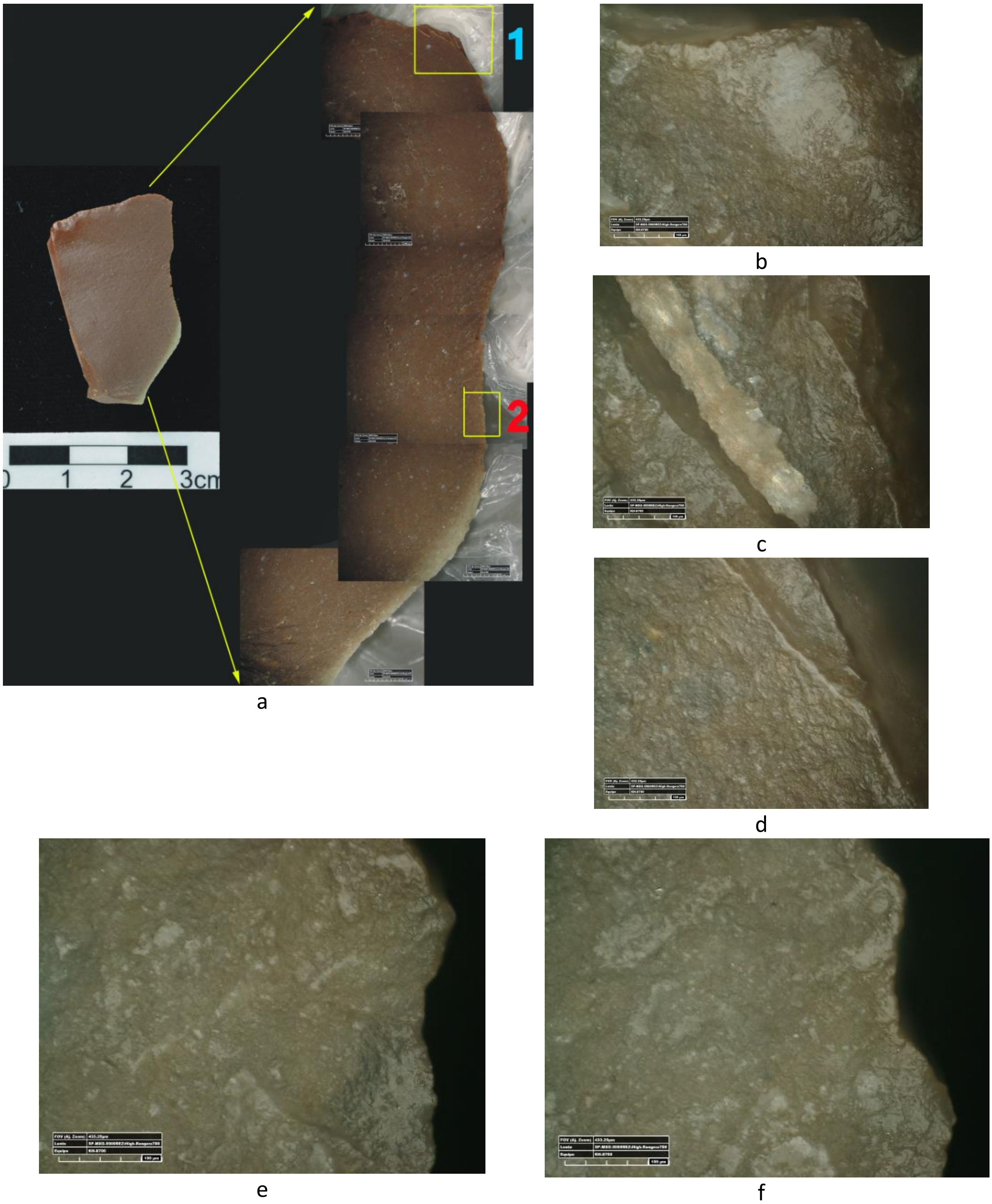


Figure 4.21: AKF1-Bu1 (90 minutes disarticulating and defleshing) a) ventral edge shows the edge reduction and micro edge fracture (micro-graphs at 35x each); (Point 1 (b-c) showing the polish, edge rounding and residue trapped in the gap of the fracture; Point 2 (e-f) polish and edge rounding at 700x.

4.2.1.2 KF6-no. 1

This tool was used to deflesh *Capra. sp*. right forelimb, using both uni-directional as well as bi-directional motion. It was not cutting that efficiently as the other red and green flint tool used for the similar experiment. Use-wear showed as edge rounding and polish (Fig. 4.22c-d).

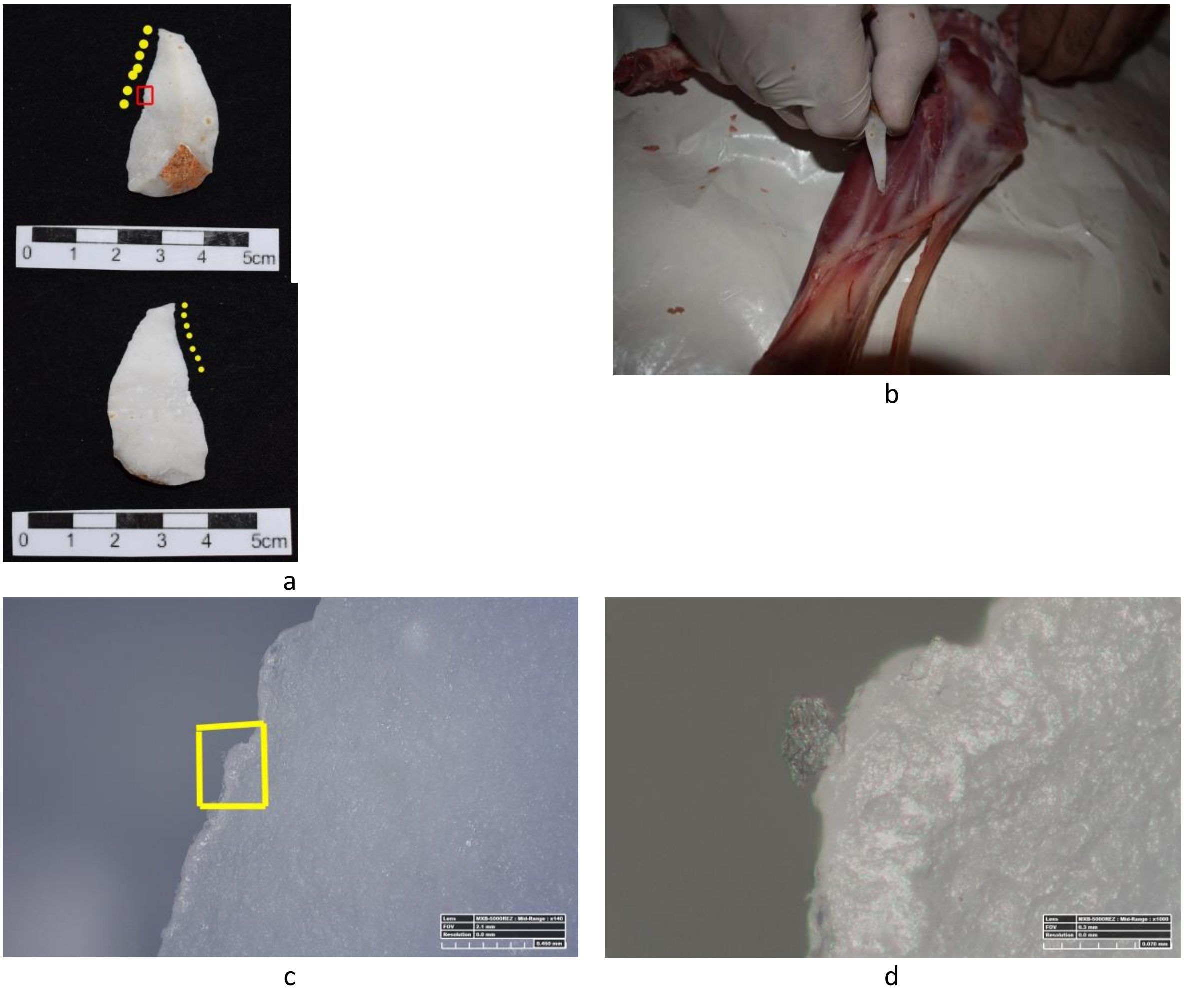


Figure 4.22: KF6-no.1 (defleshing and disarticulating 30 mins) a) unused tool with working edge and location of the use-wear; b) defleshing action angle; c) detail location at 140x of the red square in image (a); (d) detail of (c) polish, edge rounding and residue still attached after cleaning at 1000x

4.2.1.3. KF1-no.5

This tool was used for defleshing right forelimb of *Capra Sp.* by using unidirectional motion for 30 minutes. Initially, the tool was cutting very well like a knife and occasionally touching the bone. After 20 minutes, it was difficult to cut the tendon, therefore striking action was used to cut the tendon. In the last 7 minutes the tool was touching the bone a lot.

The use-wear on the tool was concentrated on the distal part (Fig.4.23c-d); the use-wear noticed were the edge fracture, edge rounding and slight polish on the edge (Fig 4.23e).

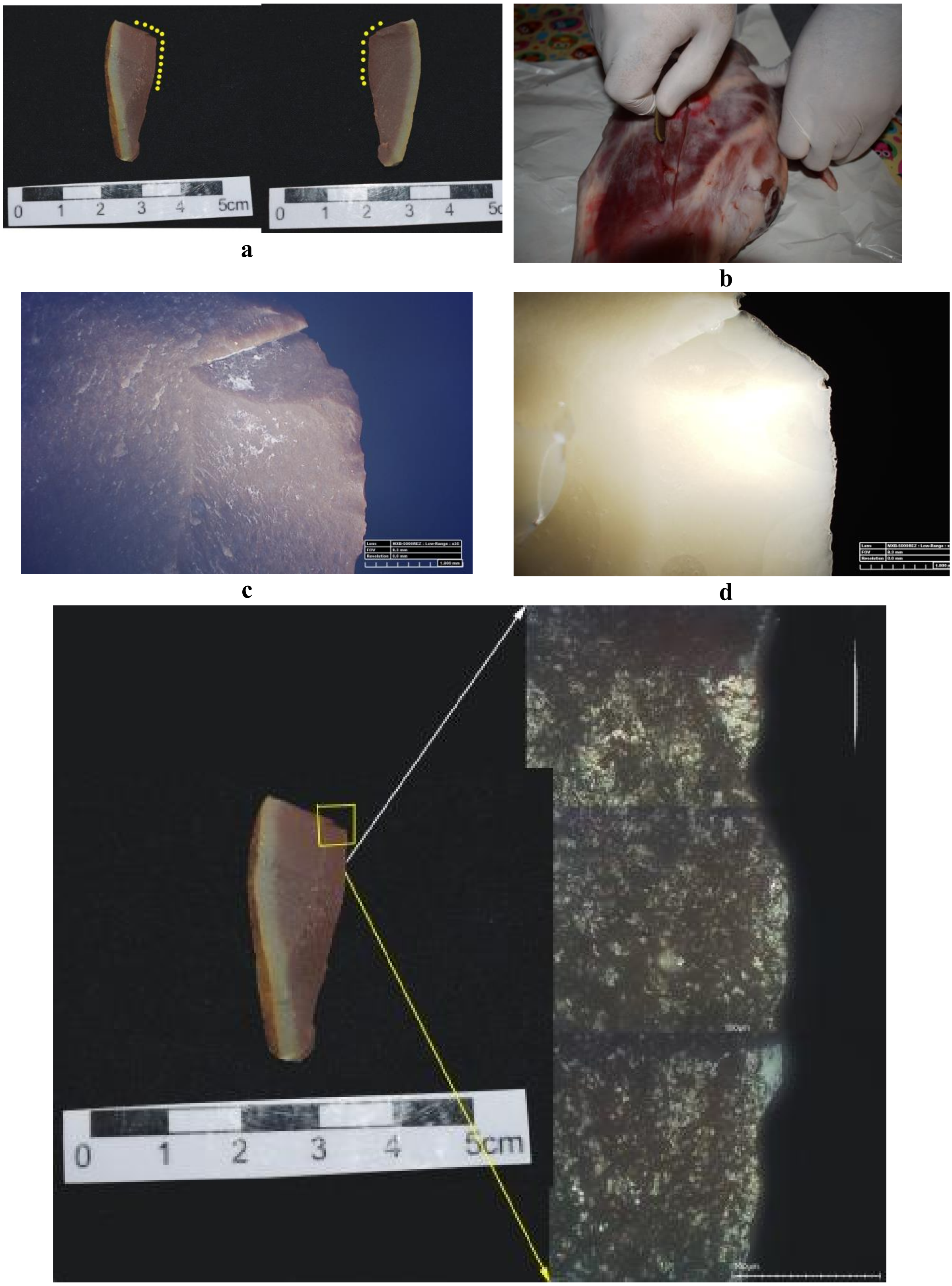


Figure 4.23: KF1-no.5 (disarticulating and defleshing 30 minutes); a) unused tool showing the working edge; (b) microfracture on the dorsal side of the edge at 35x; (c) cast showing the same location as (c) at 35x; (e) polish and edge rounding image at 500x

4.2.2. Scraping bone

4.2.2.1. KF1-no.6

For this tool, *Capra sp.* was used as worked material. For 11 mins, unidirectional movement was used with some striking action to remove the flesh attached to the bone (Fig. 4.24c-d). Later bidirectional movement was used to scrap the bone. Use-wear analysis showed heavy polish on the edge (4.24e-f)

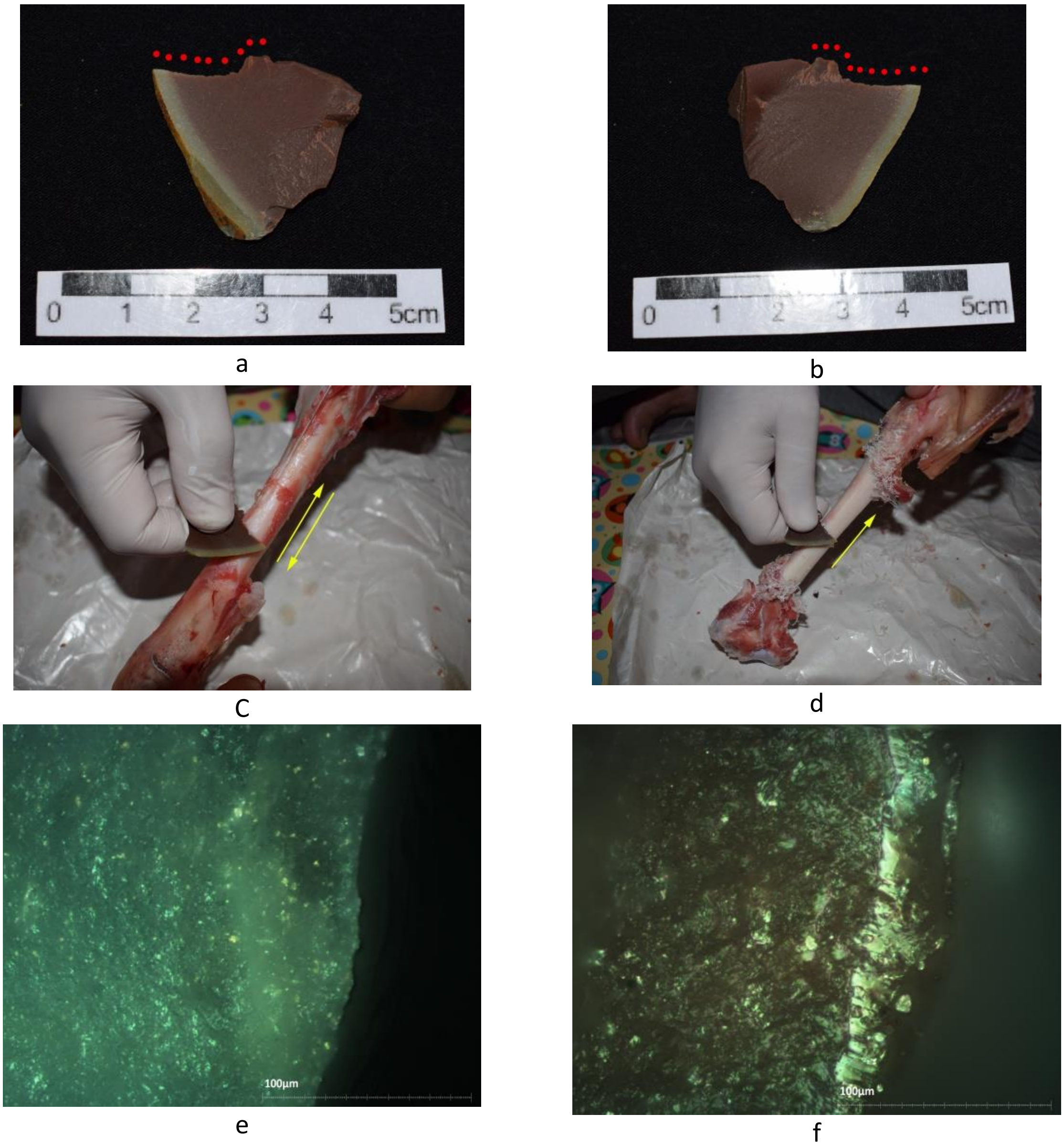


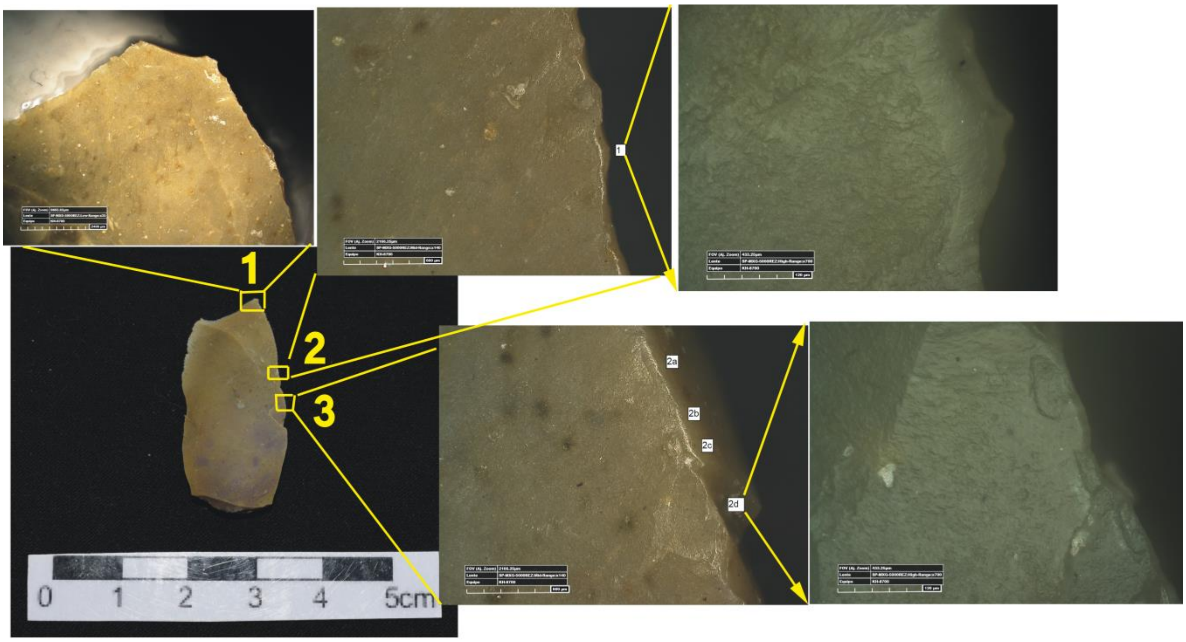
Figure 4.24: (a-b) unused tool with location of the working edge; (c-d) showing the working motion; e) cast unused of the tool edge at 500x; f) heavy polish on the edge with edge rounding at 500x

4.2.2.2. KF4-no.2

This tool was used on *Capra sp*. for 90 mins in unidirectional motion. The tool was working very well and sometimes going diagonal due to which produing cutmarks on the bone and edge fracture on the tool (Fig 4.25c). This tool produce very heavy polish and edge rounding.

a

b



c

Figure 4.25: KF4-no 2 (scraping bone for 90 minutes); a) unused tool showing the working edge; b) showing the working motion; c) showing the location of the use-wear on the ventral side of the edge at magnification 35x, 140x and 700x.

4.2.2.3. AKF1-B1

This tool was used on the femur bone of the *Cervus elaphus* for 35 minutes in transverse unidirectional (pushing) movement (fig 4.26). At the beginning, removed the meat and then later scrap the extreme part of the bone. Residue analysis was perform to check the distribution of the residue on the tool (4.27)and use-wear observed was micro-edge fracture, polish and striations (Fig.4.28).

Figure 4.26: AKF1-B1: Scraping bone (35 minutes) a) unused tool marked with the worked area; b) showing the working motion uni-directional transverse movement

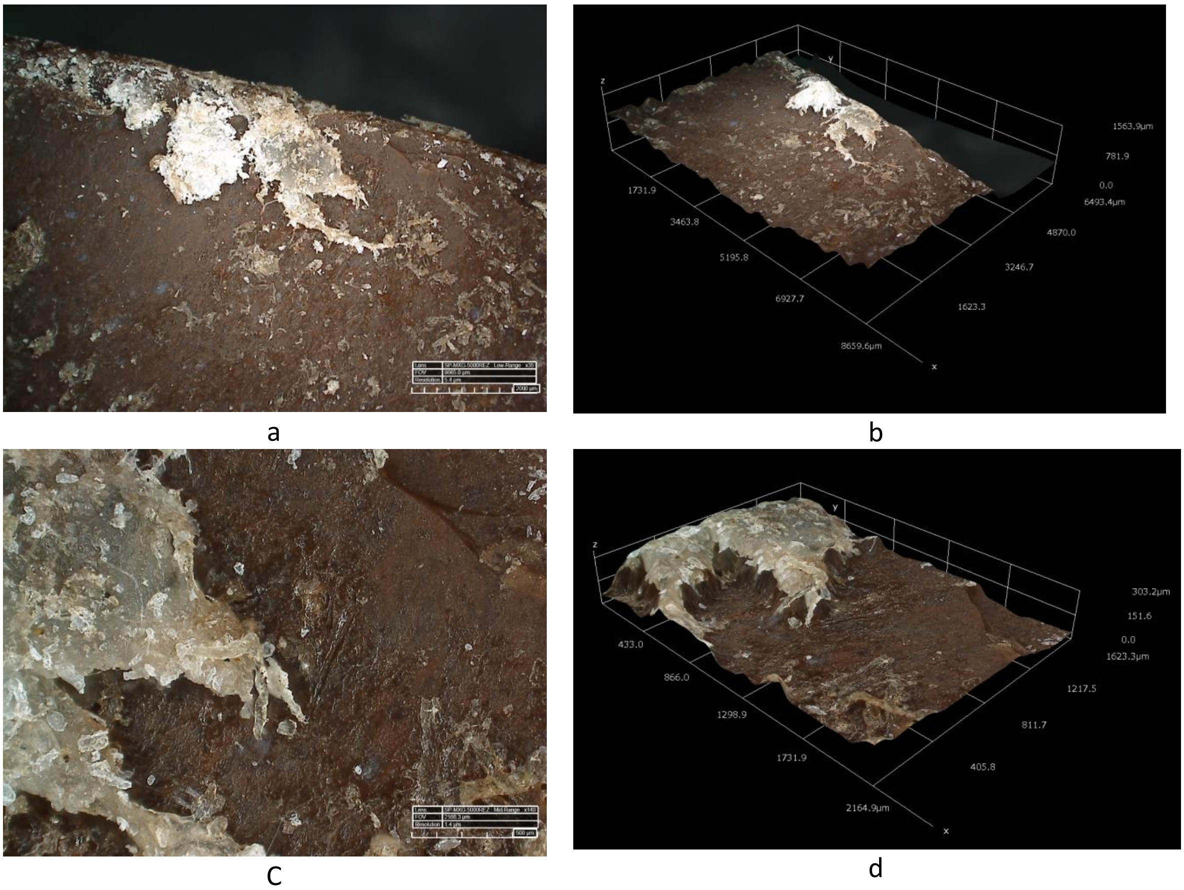
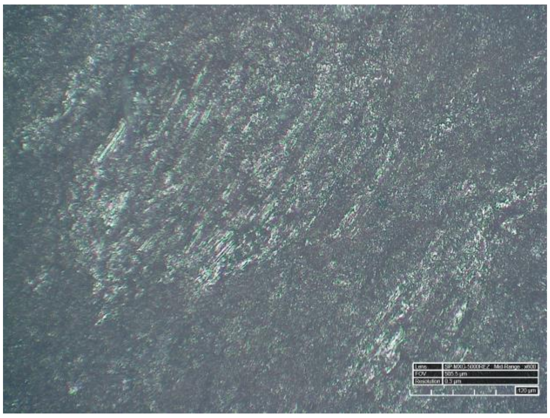
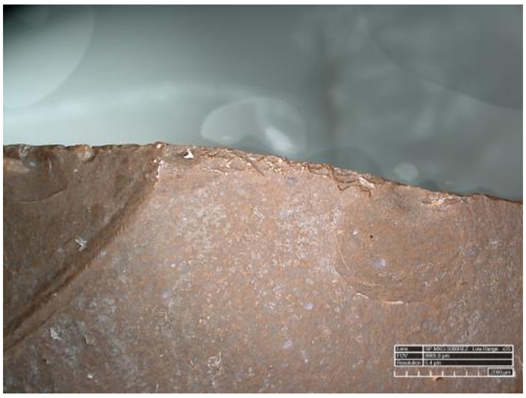


Figure 4.27: AKF1-B1: Scraping bone (35 minutes) showing the distribution of the residue and 3D image showing its location on the tool.

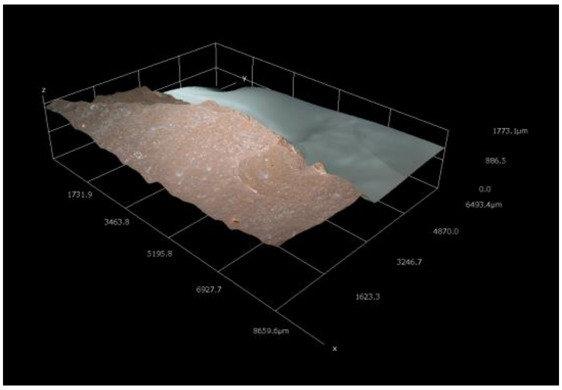


a

b



c



d

Figure 4.28: AKF1-B1: Scraping bone (35 minutes a) striations 600x; b) macro and micro-fracture at 100x: micro fracture at 35x; d) 3D of the micro-fracture

4.2.3. Cutting bone

4.2.3.1. KF4-no3

This tool was used on *Capra sp*. for cutting action (bidirectional). The tool was working well but in 5 mins of working the edge was showing many chipping visible to naked eyes giving the appearance as retouched tool. Use-wear analysis showed polish and edge rounding on the edge with a few small striations parallel to the edge.

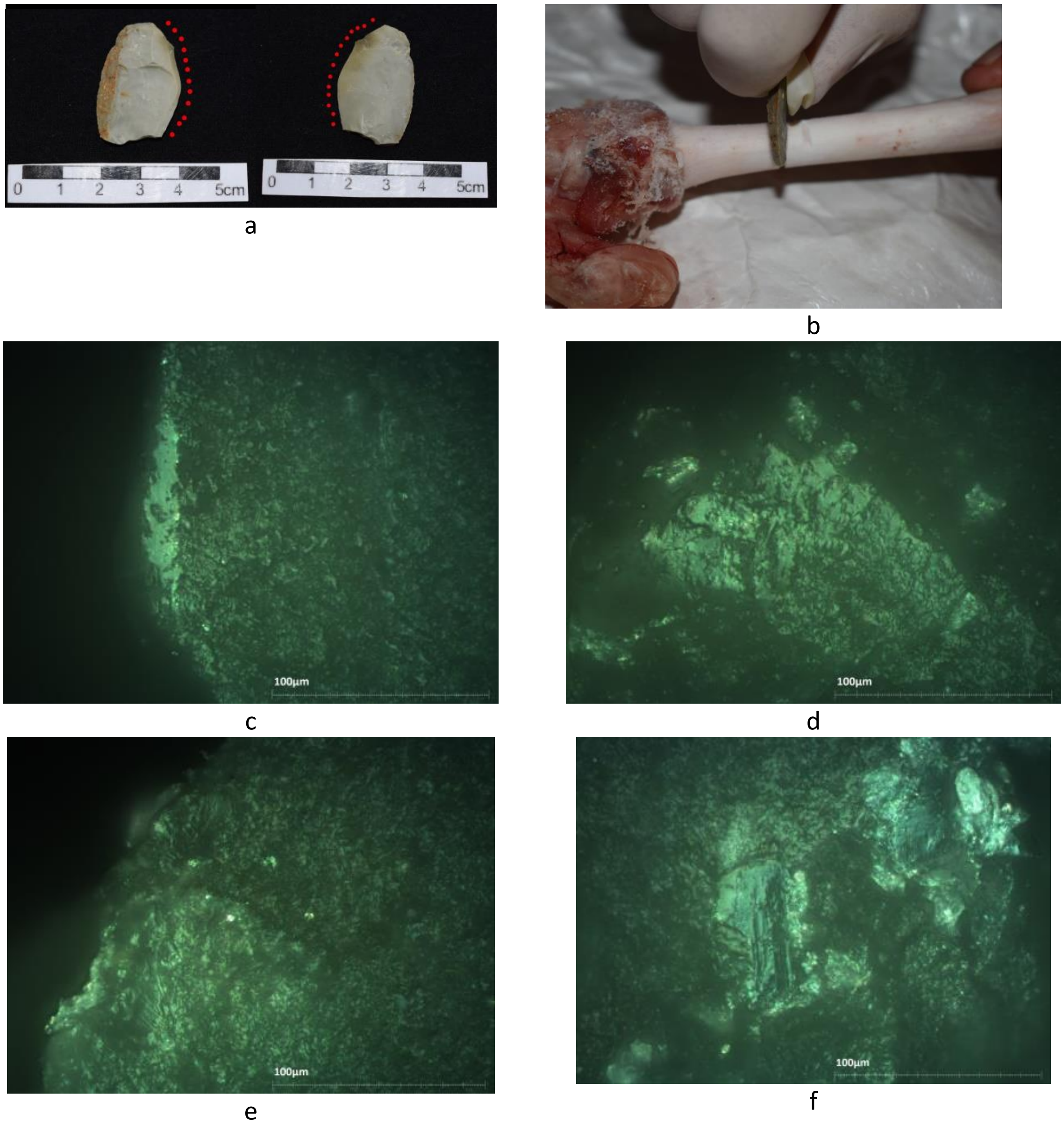


Figure 4.29: KF4-no 3 cutting bone (30 minutes) a) unused tool showing the working edge on dorsal face (c-e) polish and edge rounding; f) ventral face polish and small deep striations parallel to the edge.

4.2.3.2. KF1-no7

This tool was used to cut the femur bone of on *Capra sp*. in bi-directional moment for 30 minutes (Fig. 4.30a-b). For the first 10 minutes, macro fractures can be seen. After 18-20 minutes the tool was difficult to work but still finished the task till 30 minutes.

Use-wear traces were present in the form of polish, edge fracture, edge reduction and polish. A few striations were observed on the edge running parallel to the edge. Polishes are present on the edge fracture. Distribution of the polish is scattered with pits in between them (Fig 4.31).

Figure 4.30: KF1-no7 (cutting bone for 30 minutes) a) unused tool showing the working edge; b) bone cutting motion

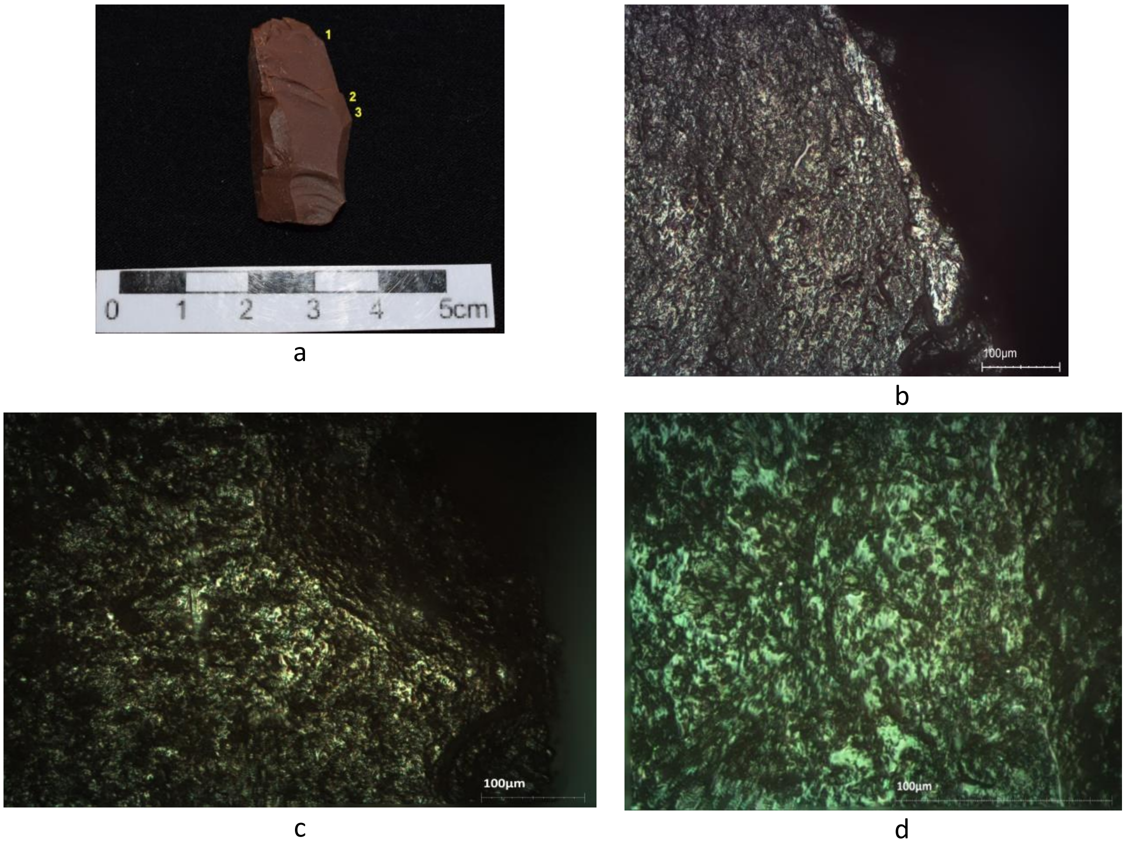


Figure 4.31: KF1-no7 (cutting bone for 30 minutes) a) showing the locations of the use-wear on the dorsal side; b) detail view of the location 1 in image (a) polish and edge fracture on the edge at 200x; b) location 2 polish on the edge fracture at 200x; c) location 3 polish on the edge at 500x

4.2.4 Hide scraping

4.2.4.1. AKF1-H1

This tool was slightly retouched on the edge with quartz hammer stone. Hide of *Cervus elaphus* was used as the worked material (fig.4.32a-b). Initially, the tool was working efficiently due to the meat and fibre on the hide. After 10 minutes when all the meat was removed it was working very well on hide. The motion was pulling straight towards the user and sometimes it was going diagonally due to the wooden log it was place on for performing the activity.

After 45 mins of use, tool showed the edge reduction (Fig 4.33a-b). Other use-wear showed in the form of edge rounding, polish and a few striations. The striations were small and perpendicular or diagonal to the edge due to the tool movement explained above (Fig.4.32c). The distribution of the residue can be seen in the figure also presented with the 3D DM.

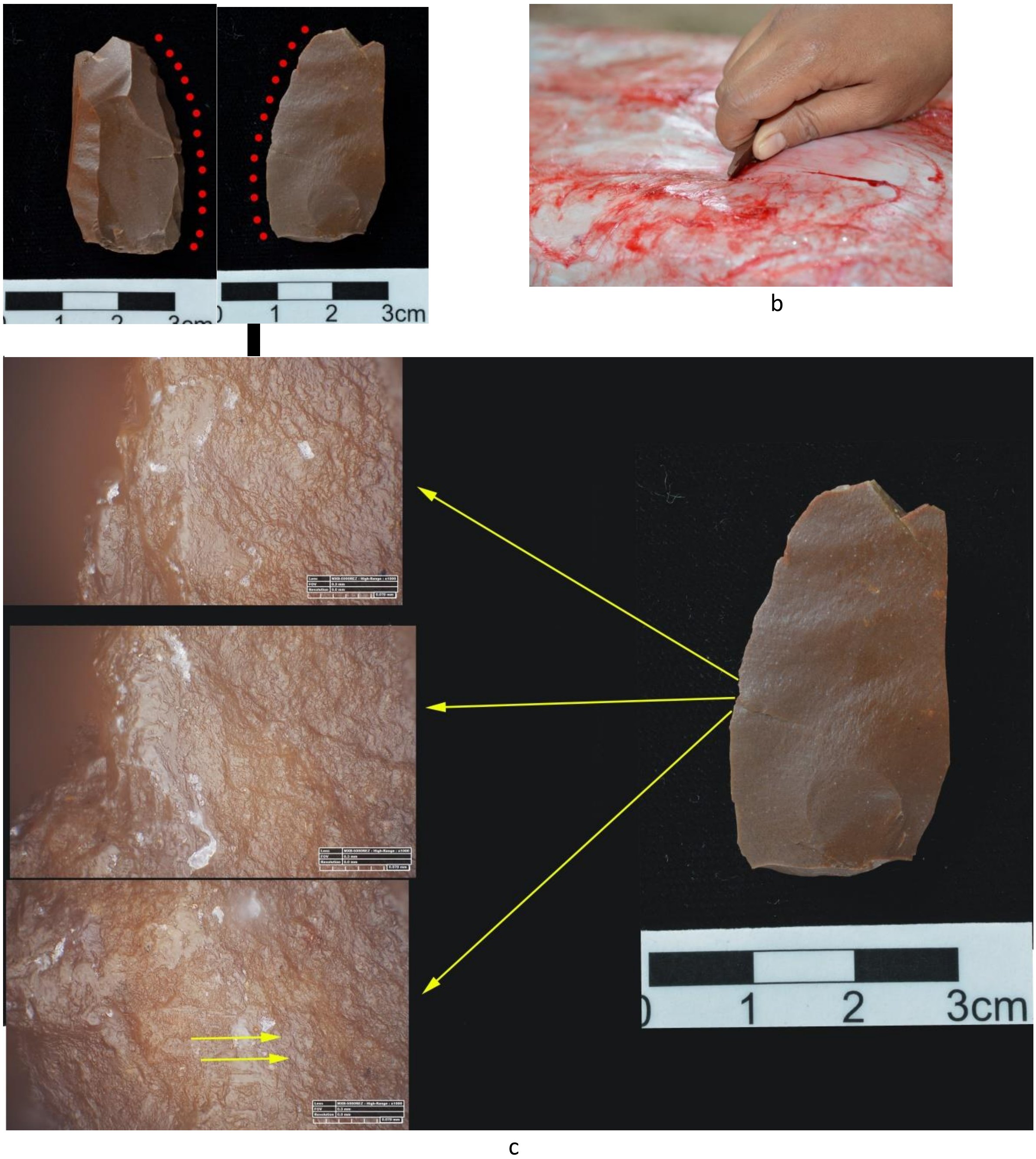


Figure 4.32: AKF1-H1 (scraping hide for 45 minutes)**;** a) unused tool showing the working; b) scraping hide; c) showing the edge rounding with the polish and a few small striations

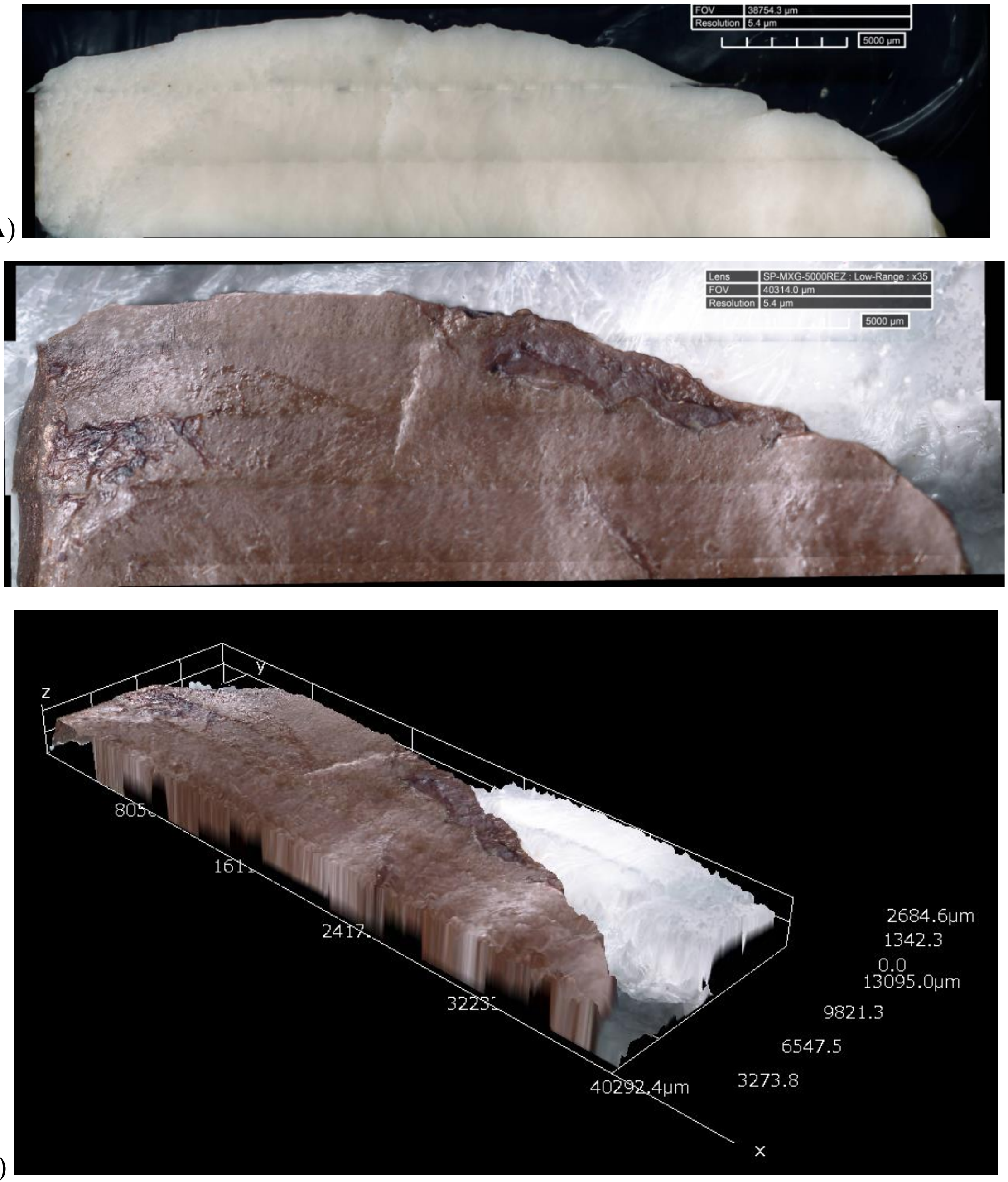


Figure 4.33: AKF1-H1 (scraping hide for 45 minutes); A) Cast of the unused tool showing the fresh edge; b)profile of the edge after use, showing the distribution of the residue and edge reduction; c) 3D of the image (B) showing the distribution of the residue on the topography of the tool

4.3. Final Remarks

Although the experimental program was not very extensive, it resulted highly illustrative. First of all, we obtained a direct experience that helped to understand what has been published on experiments involving projectiles and a variety of actions on different animal matters. Secondly, we got a repertoire of examples of fractures, use-wear traces and modern residues occurring on replicas of the archaeological pieces we were studying, some of them made on the same exact types of flint. Altogether, provided useful references for our archaeological interpretations.

For example, it gave an insight that till how many time the point can be used as a projectile. In the course of each shot, what types of changes can be expected as well as how many times it can actually hit the target and what kind of possible residue can get deposited on the tool surface. Hence, the preliminary observation of the experiment is discussed very briefly. First of all, as for the projectile experiment only a few points were available, therefore, the attempt was to use the projectile in a more or less natural way to replicate the prehistoric hunting activity rather than controlling it a lot. For example, the distance from the target to perform the action depended of the user's comfort and all the missed attempts were also considered as a parameter to judge the kind of changes happen due to them. In the same way, we observed that impact fractures, polish and striations can occur due to the contact with the soil and also due to rubbing between the tool surfaces with the fracture. For the residue distribution, besides the blood or hairs of animal, other residue such as sediment, different kinds of plant materials also can get deposited on the tool surface.

Tool fractures can depend of the raw material and its quality to bear the impact (let it be with the target or the ground) the projectile can be used for more or less than 10 times until the tool completely become unusable as observed in the experiment. Other than this, it is also noticed that not all the tools recorded hafting traces, possibly because the duration of use was very less compared one to the other (or simply because ones remained better fixed to the shaft than others).

For knapping activity, the selection of the raw material plays an important role. The cobbles selected from Khorramabad Valley had lots of fissures and were small in size; therefore, it was slightly difficult to knap the desired tool shape. In the butchery experimental program, use-wear analysis showed that the archaeological lithics have been used for a longer duration of time as the use-wear traces on the experimental pieces are not as developed as in the archeological ones. More experiments with longer duration are needed for a better interpretation. In defleshing and disarticulating action, the lithic tools worked efficiently but after long duration they lose the sharpness and cannot cut through tendons. Bone scraping gives much developed polish compared to the other scraping actions (fresh hide and wood). In cutting bone action, we lose the use-wear traces as micro-chipping of the edge happens during the experiment which gives the appearance of retouched tool. In the experimental program realised that, the choice of the specific flint variety also effects on the efficiency of the function and use-wear development. Red flint worked much better than the green and white flint. This is in agreement with the dominancy of the red flints within the recovered archaeological assemblage.

CHAPTER 5

FUNTIONAL ANALYSIS ON ARCHAEOLOGICAL LITHICS

"I stressed that the differences or contrast arising from such comparison could prove more rewarding than the similarities. Similarities after all confirm what one already knew from present-day observation but contrast could force us to recognize how the prehistoric past may have differed from the present-day analogues"

(A.Gould, 1981:35)

CHAPTER 5

FUNTIONAL ANALYSIS ON ARCHAEOLOGICAL LITHICS

This chapter embodies the results of the use-wear and residue observed on the archaeological samples to understand their functions. Here, the results are presented in two sections: residue analysis and use-wear analysis. For the residue analysis, the results are presented in a pre-draft of an article (article no. 7) explaining all the residues identified on the archaeological tools. For the use-wear analysis, an accepted article (article no. 6) is presented for the Upper Palaeolithic level of Kaldar Cave. Later a few examples from the Middle Palaeolithic level of Kaldar and Gilvaran caves are presented with small descriptions.

5.1. Residue analysis

Article 7: Tumung L. (Pre-draft) Understanding the bone and black bituminous residue from M –UP sites of Khorramabad Valley, western Iran

This section is presented in the form of a scientific article pre-draft. This research is a part of wider investigation program focused on the non-invasive or non-destructive multi-technique characterisation of the archaeological adhesive substances and bone residue. These projects initially launched in 2014 for investigating black spots (possible adhesive material) on the archaeological stone tools by the traceology team of IPHES in collaboration with the researchers of ICFO (Catalan Institute of Photonics) and later in 2017, another project for the bone residue started to take shape.

Results presented here are those directly related to the characterisation of some residues identified on the Khorramabad archaeological tools, which from the very beginning took a central role in these research.

The final transformation of this pre-draft into a manuscript to be submitted for publication will depend on the evolution of some ongoing research (FTIR, Raman, GC-MS etc.), and on the progress of a methodological paper deriving from a communication presented at the 2018 UISPP conference.

Finally, the results and discussion provided here directly derive from the research activity developed by the author in the framework of this Ph.D. thesis.

Understanding the bone and black bituminous residue from M –UP sites of Khorramabad Valley, western Iran

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Abstract

Residue analysis combined with use-wear analysis can tell so much about the past human activities. For the present study, archeological material comes from Kaldar and Gilvaran caves located in Khorramabad Valley belonging to M-UP respectively. 178 stone tools were analysed, 143 belong to Kaldar and 59 belong to Gilvaran. All the stone tools are made from flint and all of them are in a well preserved condition except for a few with slight shiny patination. For the residue analysis, we applied a non-destructive multi-analytic approach. OLM and 3D DM (KH-8700 and RH 2000) were used for the preliminary inspection of the residue on the tool surface. SEM with EDX was used for the detailed view of the residue and also to understand the chemical composition of the residue for the interpretation. To solidify our interpretation we also applied FTIR, and μX-ray diffraction. We also created the reference collection of modern adhesive substances and performed small set of experiments for the reference collection for the archeological residues. Black residue results, under SEM with EDX shows that it mostly contains manganese oxide and is sometimes associated with the bone residue with striations in some cases. Further analysis with FTIR showed that they are not resins but some type of bituminous material. Five samples with light cream colour residue, under SEM show the presence of P and Ca. Only one sample confirm bone residue with the presence of hydroxyapatite under μX-ray diffraction. Two points also showed striations along with the bone residue on the tip. These residues co-related with other evidences such as the nearby bitumen natural deposits from the sites, presence of large number of points in the assemblages and taphonomical evidence of cut-marks in the form of scraping, defleshing and disarticulating. Finally, the results are indicating the tools were hafted to make projectile and the presence of bone residue indicating towards for hunting and butchery activities, but with the present state of work we cannot completely accept them as well.

***Keywords**: Functional analysis, Kaldar, Gilvaran, multi-analytic approach, black bituminous spots, bone residue*

1. Introduction

Functional analysis, the combined study of use-wear and residue analysis was developed after the famous work of S.A.Semenov (1964) *Prehistoric technology*. Although, it's a complementary field to use-wear analysis, it's potential was better understood after 1970's when a number of traceologists reported various types of residue (such as phytoliths, pollens, starch, blood, fibre, bone, resins etc.) on the archeological artifacts (Briuer 1976; Shafer and Holloway 1979; Anderson 1980; Loy and Hardy1993; Boëda et.al. 1996, Boëda 1998; Rots 2011; Rots and Williamson 2004; Croft et.al.2018). Traditionally, lithic residue analysis is based upon the morphological identification of micro-residues preserved on the surfaces of stone tools (Briuer, 1976; Shafer & Holloway, 1979; Anderson, 1980; Monnier et.al 2013)

Although, various methods and techniques have been developed in the past decades, it still has its own limitations similar to its complementary field (use-wear analysis) (Jahren et.al. 1997; Monnier et.al 2013; Pedergnana et.al. 2016). First of all, residue preservation in most of the archeological sites is very rare and by chance if they are preserved they lose some of their diagnostic features or properties depending on the soil condition, to identify them in full authenticity (Grace 1996; Haslam 2006; Huisman 2017; Croft et.al. 2016, 2018). Besides this issue, sometimes residue can be a result of contamination rather than human use (Wadley and Lombard, 2007; Crowther et.al 2014; Pedergnana et.al 2016; Cnuts and Rots 2017; Rots 2010). Hence, residues can be identified incorrectly due to insufficient information (Croft et.al. 2018). For the residue analysis, there are two ways traceologists perform the identification of residue; some who favor extraction of residues for better identifications (Lombard and Wadley 2007; Langejans 2011; Rageot et al. 2016; Cnuts and Rots 2018; Cnuts et.al. 2018; Shafer and Holloway 1979; Kealhofer et al. 1999; Fullagar 2015), and others, who prefer non-invasive or non-destructive methods, to preserve the residue for long duration and not lose the context of the residue (Fullagar et.al. 1996; Rots et.al 2016; Zupancich et al.2016;). Many residue analysts do 'whole tool' extractions in the process of analysis, a procedure which is often inappropriate for archaeological material as it is both destructive and does not target particular residues with their visible structures and associations with utilized edges (Fullagar et al. 1996).

In the decades of traceological work, one can observe that the western archaeologists have applied the functional studies to their various researches (experimental and archaeological). On the contrary, less enthusiasm can be seen among the Middle East archaeologists for such studies in the Middle Eastern sites, especially, in the Zagros region. The only residue analysis performed in this zone is from the Neolithic sites of Ali Kosh, Tepe Tula'I and Chagah Sefid of Deh Luran plain of Khusitan province (Gregg et.al. 2007). In his study, he identified the presence of bitumen on the pottery with Gas chromatography–mass spectrometry (GC-MS) analysis.

Since 2013, a few traceologists have performed some preliminary functional studies on the Zagros Middle and Upper Palaeolithic sites (Claud et.al. 2012; Bazgir et.al. 2014; Hunt et.al. 2018). These studies were conducted on the shell and stone tool. The previous two team's preliminary study was more to test the possibility of functional studies on the lithic assemblages of Iranian Zagros sites. Claud and team analysed 3 points (2 bifacial points and 1 Mousterian point) from Qaleh Bozi 3 Rock Shelter belonging to Middle Paleolithic and concluded the results that two of the points were used for butchery activities (Claud et.al 2012). Bazgir and Tumung (2013) analyzed 105 lithic diagnostic Levallois-Mousterian and Aurignacian points belonging to the Middle and Upper Palaeolithic layer of Gilvaran, Ghamari and Kaldar caves. The use traces and residue were analysed under OLM and SEM with EDX. The evidence of impact fracture, use-wear traces on the hafting area along with the black residue showed some possible early evidence of hunting activity around Zagros Mountains. Finally, one incised shell (*Assyriella* sp) belonging to the layer C (Upper Paleolithic) of the Shanidar have been reported to have striation marks on it (Hunt et.al. 2018). Till date no residue analysis has been performed on the Iranian Zagros sites belonging to MP and UP, except for our preliminary work in 2013. All these previous studies were based on microscopic results with no experimental references.

Hence, the present work is an attempt to understand the type of residues that have survived on the lithic assemblages and what type of information we can derive for the subsistence pattern of Khorrambad Valley site belonging to MP and UP respectfully. Besides this, for identifying the residues, we have also tried to apply non-destructive or non-invasive methods and techniques not to lose the context of the residue on the tools.

2. Sites description

Since 1930's, Khorramabad Valley has been one of the important zones in Iranian Zagros Mountains. Till date various field expeditions have been performed in the valley by Iranian as well as foreign archaeologists. The important Middle and Upper Paleolithic sites of this valley are Yafteh, Ghamari, Kunji, Gar Arjeneh, Pa Sangar, Gilvaran and Kaldar (Fig 1) (Field 1939; Hole and Flannery, 1967; Otte et.al 2007, Shidrang 2011; Mashkour et.al. 2009).

Figure 1: Map of Iran showing the location of the sites in red, the nearby bitumen natural deposits in black and Neolithic sites with the evidence of bitumen in yellow (modified after Connan 1999)

In this study, we are focusing on the lithic assemblages coming from Gilvaran and Kaldar caves. Gilvaran Cave is situated at the north-western part of the Khorramabad Valley, whereas, Kaldar Cave is situated at the northern part of the valley. Although, Gilvaran and Kaldar were explored by previous Iranian archaeologists, A. Parviz in 2002 and K. Roustaei in 2007; they were for the first time test excavated by Dr Bazgir in 2011-12 with his Indo-Iranian team. Both the sites were selected for the "Khorramabad Project" field expedition along with previously excavated sites of Ghamari and Gar Arjeneh, to understand the M-UP transition in the valley and to find the global positioning for these sites.

In 2011-12, in Gilvaran two test pits of 2x2m were opened (named AY1 and A8). Both the trenches were dug at the southern side of the cave, A8 dug 4m from dripline, whereas AY1 was dug 20 m away from the dripline. A8 revealed 3 levels in 1.5m deposit before reaching the overlaying heavy fallen rocks and revealed 3 main levels out of which, Level 3 lithic assemblage belong to the Middle and Upper Paleolithic. On the other hand, AY1 exposed 5m of deposit with five distinct levels, where Level 4 and 5 belongs to Middle and Upper Paleolithic. Till date no radiometric data is available for this site (Bazgir et al. 2014).

Kaldar Cave test pit was 1x1m and exposed the deposit of 1.5m with five main levels, out of which level 4 and 5 belong to the Middle and Upper Paleolithic (Bazgir et al. 2014). After seeing the potential of this site, it was again excavated on a large scale in 2014-15 by the

Spanish-Iranian team under the directorship of Dr. Bazgir. In this excavation, 3x3m trench was opened near the entrance keeping 50 cm bulk from the older trench. The deposit was 195cm and revealed five major levels, including Middle and Upper Paleolithic assemblages. Radiocarbon dates for the Upper Paleolithic levels dates 54,400-46,050 cal BP (95.4% confidence level), which makes Kaldar one of the oldest site in the western Asia (Bazgir et al, 2017) and stretched the onset of Upper Paleolithic of Zagros Mountain between 45,000-40,250 cal BP (68.2% probability) (Becerra-Valdivia et al. 2017). Till date, no radiometric data is available for the Middle Paleolithic level. This site also provided the earliest evidence of *Prunus* sp. in the area (Allué et al. 2018) as well as the exploitation of the palearctic fauna as resources by AMH (Bazgir et.al.2017).

3. Method and material

3.1. Archaeological material

For the functional analysis, total of 178 samples were studied out of which 143 belong to Kaldar and 59 belong to Gilvaran. All the stone tools are made of flint and the availability for the flint raw material resources are plenty around the valley (Bazgir et.al 2014, 2017). The preservation of the flint in the sites is well preserved. Similar to Claud (et.al 2012), her observation made on the Qaleh Bozi 3 flint stone tools, we also have observed slight shiny patination on a few samples but it doesn't interfere with interpretation of use traces. In our preliminary analysis of the lithic artefacts from the 2011-12 excavation, we identified various use and residue traces. In the residue analysis, we identified a few modern contaminations as well, therefore, for the 2014-15 excavation we were very cautious in the site while collecting and documenting the samples. All the excavators were instructed to wear powder-free gloves while handling the artefacts. All the pieces were documented but not marked with the reference number on them with permanent marker pen and transparent nail polish. Fractured lithics were not glued to avoid any modern contaminations. All the samples were only taken out of the plastic bags when studied for techno-functional studies. In the lab, the powder-free nitrile gloves were always worn while handling them for analysis (Monnier et.al. 2013; Pedergnana et.al. 2014; Croft et al. 2018).

3.2. Experimental material

Small set of experiments were conducted to understand the distribution of residue and use-wear traces. The stone tools were knapped from the local Khorramabad flint and Zaragoza (Monegros-type) flint (Spain) to check the variation of the wear traces on the two types of raw material. Khorramabad flint varies in different colours red, green and white types were used to replicate the assemblage stone tool. Details of the experiments are given in the table (Table 2).

Reference	**Shell/Flint Variety**	**Species**	**Activity**	**Contact Material**	**Movement Direction**	**working Angle**	**Time (Minutes)/n umber of shots**
AKF1-H1	Khorramabad flint	*Cervus elaphus*	Scraping	Fresh hide	Transverse-unidirectional	90º	45
AKF1-B1	Khorramabad flint	*Cervus elaphus*	Scraping	Bone	Transverse-unidirectional	45º	35
AFK1-Bu1	Khorramabad flint	*Cervus elaphus*	Cutting/defleshing	Meat-Bone	Longitudinal-unidirectional	45º-90º	30
AKF1-W1	Khorramabad flint	*Prunus dulcis*	Whittling	Stem of fresh wood	Transverse unidirectional	45º	40
KF1-No.5	Khorramabad flint	*Capra* sp.	Cutting/defleshing	Meat-Bone	longitudinal-bidirectional	75º-90º	30
KF1-No.6	Khorramabad flint	*Capra* sp.	Scraping	Meat-Bone	Transverse-unidirectional	45º	30
KF1-No.7	Khorramabad flint	*Capra* sp.	Cutting	Bone	Longitudinal-bidirectional	90º	30
KF4-No.1	Khorramabad flint	*Capra* sp.	Cutting/defleshing	Meat-Bone	Longitudinal-unidirectional	75º	30
KF4-No.2	Khorramabad flint	*Capra* sp.	Cutting/defleshing	Bone	Transverse unidirectional	45º	30
KF4-No.3	Khorramabad flint	*Capra* sp.	Scraping	Bone	Transverse unidirectional	45º	30
KF6-No.1	Khorramabad flint	*Capra* sp.	Cutting/defleshing	Meat-Bone	Longitudinal-unidirectional	75º	30
KF6-No.2	Khorramabad flint	*Capra* sp.	Scraping	Bone	Transverse unidirectional	45º	30
KH4-1	Khorramabad flint	*Cervus elaphus*	Arrowhead projectile	meat,bone and sediment	projectile	-	2 shots
KHR6-1	Khorramabad flint	*Cervus elaphus*	Arrowhead projectile	meat,bone and sediment	projectile	-	10 shots
KHR6-4	Khorramabad flint	*Cervus elaphus*	Arrowhead projectile	meat,bone and sediment	projectile	-	10 shots
Zarragoza no 1	Zarragoza flint	*Cervus elaphus*	Arrowhead projectile	meat,bone and sediment	projectile	-	8 shots
Zarragoza no 2	Zarragoza flint	*Cervus elaphus*	Spearhead projectile	meat,bone and sediment	projectile	-	1 shot
Zarragoza no 3	Zarragoza flint	*Cervus elaphus*	Arrowhead projectile	meat,bone and sediment	projectile	-	1 shots

Table 2: The principle variables of the experimental program

3.3.Cleaning method

For the better observation of the wear traces, processing and cleaning of the (experimental and archeological) is very crucial in the use-wear analysis to minimise the misinterpretation of the traces (Pedergnana et.al 2016). In decades of the development of functional studies, many traceologists have provided various cleaning methods depending on the type of raw material (among others, Keeley 1980, Levi-Sala 1986; Ollé and Vergès 2008, 2014; Tumung et.al 2010, 2013, 2015 and Pedergnana et.al. 2016)

a) Cleaning with water and soft brush or fingers to remove the dirt from the archeological stone tools,
b) 15 mins ultrasonic bath with normal water to remove the dirt from the archeological stone tools,
c) 10 min in an ultrasonic bath of H_2O_2 (10% vol.) to soften any adhered organic tissues on the experimental sample;
d) 10 min in an ultrasonic bath of the neutral phosphate-free detergent Derquim®, with ionic and non-ionic surfactants to eliminate all the residues from the tool surface,
e) Rinsing under cold running water to remove any detergent or acid from the tool surface,
f) 2 min in an ultrasonic bath of acetone to eliminate any fatty residue resulting from the handling,
g) 1-15 mins in an ultrasonic bath in HCL to remove the concretion from the stone tools and less likely to have adverse effect on the flint,
h) 15-20 mins in boiling water to remove the adhesive from the experimental hafting tools,
i) 15 mins for a thermal ultrasonic bath in H_2O_2 (130% vol.) to remove the adhesive residue which were difficult to remove with boiling water,
j) in order to remove surface contaminants, we blow them gently with compressed air.

In the 2011-12 excavation, the samples which were well documented in the site underwent thorough cleaning steps a, c, d, e and f. For the 2014-15 excavation samples, for the residue analysis we didn´t perform the cleaning of the samples as sometimes intensive scrubbing and cleaning with various strong acids can remove or dissolve the residues (Lombard 2005). After the residue analysis, the samples with no residue underwent the cleaning process included step c-g and j, whereas, samples with residue after performing all the analysis with different techniques underwent mostly b and j cleaning method. For the experimental butchery samples cleaning procedure comprised of steps c-f. On the other hand, for the projectile experimental samples, cleaning procedure included c-i. This cleaning procedure has been shown to yield good results (Keeley 1980; Byrne *et al.*, 2006; Vergès, and Ollé, 2011; Ollé and Vergès 2014;; Tumung et.al 2010, 2013, 2015; Pedergnana 2017).

3.4.Modern adhesive reference collection

After the famous work by Rots (Rots 2002a, 2002b, 2003, 2008, 2010; Rots and Williamson, 2004; Rots et.al 2006, 2011) our understanding of the traces associated to hafting and prehension has increased. Archeologically, various types of hafting residue (adhesive) evidence has been reported from different parts of world such as birch tar, plant resin, ochre and bitumen. There is evidence for the use of birch bark pitch as an hafting adhesive, mainly from several Middle Palaeolithic sites of Europe including Campitello in Italy (Mazza et al., 2006), Inden-Altdorf and Königsaue in Germany (Pawlik & Thissen, 2011; Koller et al., 2001; Grünberg, 2002), and some Upper Palaeolithic sites as Les Vachons, in France (Dinnis et al., 2009). Plant resins have been reported in South African MSA and LSA sites including Dieplkloof Rock Shelter and Border Cave (Charrié-Dunhaut et al., 2013; Villa et al., 2012), as well as more recent sites from the Yukon and Selwyn mountains, Canada (Helwig et al., 2014). The earliest evidence of the bitumen as hafting material is reported from the Near-East Middle Paleolithic sites, including Umm el Tlel and Hummal in Syria (Boëda et al., 1996, 1998, 2008; Connan 1999; Hauck et al., 2013; Monnier et al., 2013). Bitumen has also been identified at the Palaeolithic site of Gura cheii-Râsnov Cave, in Romania (Cârciumaru et al., 2012). These hafting adhesives can be used alone and sometimes with some additives such as sand or earth to make stronger haft (Lombard 2005; Rots 2011). In the South African sites, ochre mixed with the hafting material for the better binding of the haft (Lombard 2005; Wadley 2005; Wadley et.al 2004; Rots et.al 2011).

In the Near East and European sites of the Middle Palaeolithic have been reported of adhesive materials such as resin (Mazza et.al 2006; Mania and Toepfer 1973; Hedges et.al 1998; Bosinski 1985), birch tar (Clark 1954; Regert et.al 1998; Koller et al., 2001; Grünberg, 2002; Van Gijn and Boon 2006; Dinnis et al., 2009; Pawlik & Thissen, 2011), ochre (Lombard 2005), bitumen (Bar-Yosef 1985; Boëda et.al 1996, 1998; Boëda 2008; Cârciumaru et.al. 2012; Monnier et.al 2013).

The lithic assemblages of Kaldar and Gilvaran show a wide techno-typological variety, specially in terms of retouched points. In our functional study, we observed that a high proportion of our samples are having black residue on them distributed on the tool surface, mainly around the supposed hafting area (in various shapes and quantity). It was very curious for us, whether they were hafted and if they are a result of hafting adhesive, then which type of adhesive was used?

In the backdrop of no available reference collection of the modern day resins in their purest form and their poor preservation or insufficient residue on the archeological artifacts, makes it very difficult to identify them. Hence, we tried to identify the various types of the resin or adhesives available around the valley which can be possibily used for the hafting.

Pure products	Code	Observations
Bitumen	**IB-01**	**Untreated lump, Khorramabad valley outcrop (Lorestan, Iran)**
Bitumen	**IB-02**	**Untreated lump, Khorramabad valley outcrop (Lorestan, Iran), deeper in the section**
"Mimenai"	**IM**	**Unclear substance traditionally used for medicinal purposes (soot? liquefied substance from the limestone cave walls?). Deposit from the roof of Yafteh Cave (Khorramadad, Lorestan, Iran)**
Beeswax	**BW**	**Centre d'Interpretació Apícola Muria, el Perelló (Tarragona, Spain)**
Pine resin (int)	**RPPi**	***Pinus pinaster*, internal secretion; Cangas (Pontecedra, Spain)**
Pine resin(ext)	**RPPe**	***Pinus pinaster*, external secretion; Cangas (Pontevedra, Spain)**
Pistacia resin	**RPA**	***Pistacia atlantica*, Khorramabad valley (Lorestan, Iran)**
Arjan resin	**RA**	**Arjan tree. Khorramabad valley (Lorestan, Iran)**
Yew pitch/tar	**TTB**	***Taxus bacatta*, produced under laboratory conditions (Univ. of Bradford, UK)**
Alder tree pitch/tar	**TAG**	***Alnus glutinosa*, produced under laboratory conditions (Univ. of Bradford, UK)**
Birch bark pitch/tar	**TB-01**	***Betula (pubescens*), commercial product (Univ. Exeter, UK)**
Birch bark pitch/tar	**TB-02**	***Betula pubescens* ,experimental product (IPHES, Spain)**
Bat guano	**BG**	**Azokh Cave (Nagorno Karabagh)**
Ochre	**FO**	**Untreated lump, Francolí river (Tarragona, Spain)**
Mixtures code		**Observations *(% in weitgh*)**
MIX1		**Ochre (Francolí) + BW + RPPi + pine wood charcoal (not controlled quantities)**
MIX7		**20% Ochre (Francolí) + 60% RPPI + 20% cow fat**
MIX8		**20% Ochre (Francolí) +60% RPPI + 20% BW**
MIX9		**75g RPPI + 15% BW + 10% pine wood charcoal**
MIX5		**70% RPPI + 15% BW + 15% ochre (Francolí)**
MIX13		**70% RPPI + 15% BW + 15% shell powder**

Table 3: Showing the reference collection of the adhesive material collected from Iran (Khorramabad Valley), Spain (Pontevedra and Tarragona) and UK (Bradford).

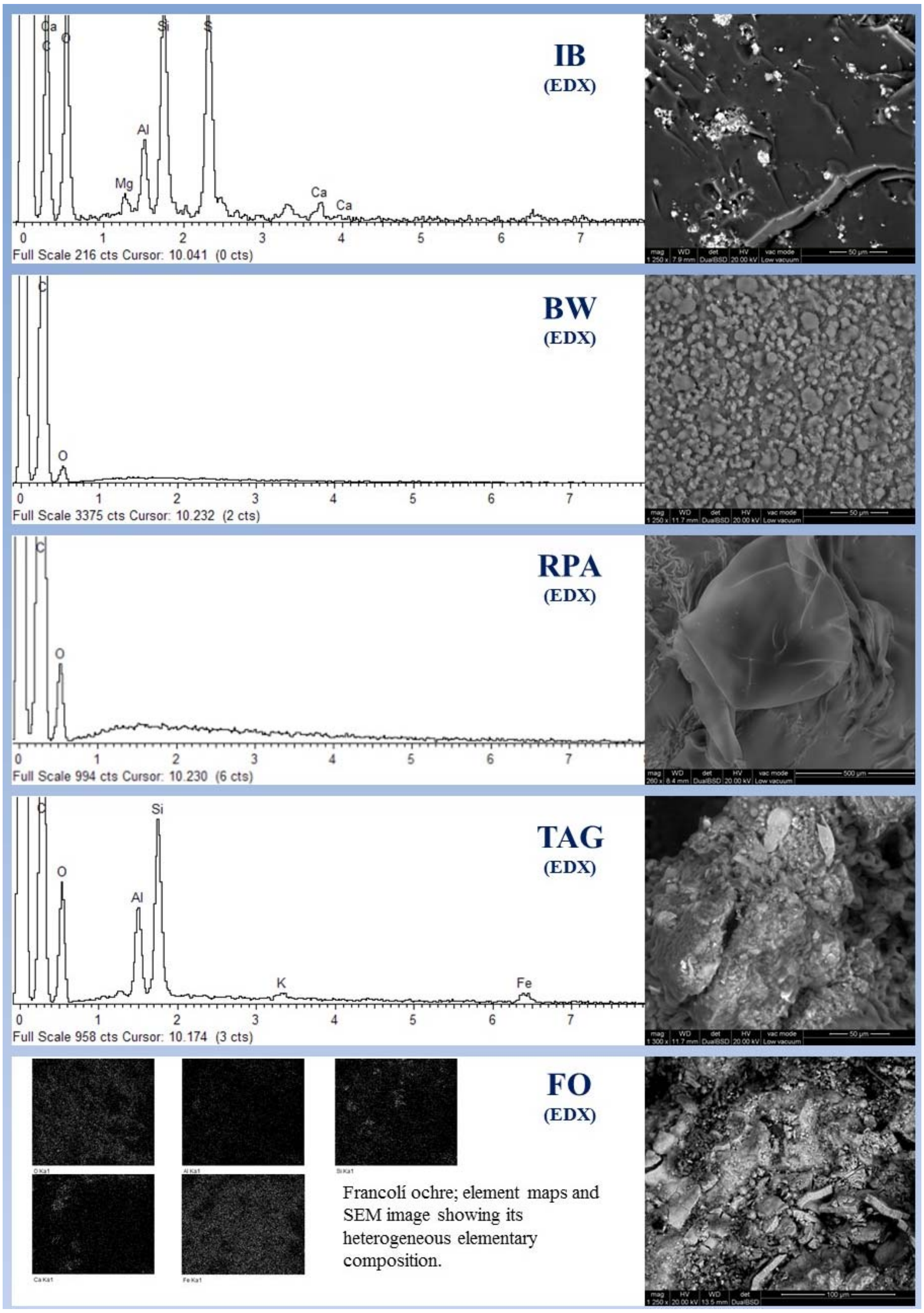


Figure 2: Element graphs maps generated under ESEM with EDX; 1) IB (Khorramabad Bitumen, Iran), 2) BW (Beewax), 3) RPA (Pistacho resin, Iran), 4)TAG (Adire tree pitch) and 5) FO (Francoli Ocher, Spain)

In order to interpret our archeological residue, we also prepared a reference collection of some the present day resins. It was a collaborative work involving of the traceology team of IPHES (Spain) along with scientists of the Catalan Institute of Photonics (ICFO, Barcelona) and the Scientific and Technical Service at URV microscopy lab (Spain). In recent studies, a number of sites have reported of black residues in the various archaeological sites located in Iran (Kaldar and Gilvaran), Spain (Cova Eiros) and Armenia (Azokh Cave). Hence, the present day resins were collected from Iran (Khorramabad Valley), Spain (Pontevedra and Tarragona) and UK (Bradford) (Table 3). In this study, we are only mentioning about the results from the Khorramabad valley sites.

3.5.Multi-analytic approach

In the decades of residue studies, one can observe that only one method or one type of microscope is not sufficient to interpret the residue type. Be it the extraction method or the microscope and spectroscopy analysis, methodology for residue analysis have evolved a lot but still we face some problem in identifying the residue. Factors responsible are the preservation of the residue in the sediment which goes through various alterations and degradation in the course of deposition (Croft et.al 2016; Cnuts and Rots 2017). Although numerous studies have investigated the morphology of residues (Jahren et.al. 1997; Monnier et.al. 2012, 2013), chemical analysis of residues on stone tools has not been extensively explored, an exception being the analysis of blood residues on tools (Loy, 1983; Nelson, 1986; Gurfingel & Franklin, 1988; Loy and Wood, 1989; Kooyman, et al. 1992, Loy and Hardy, 1992; Smith & Wilson, 1992). Many archaeologists have applied multi-analytic approach combining different microscopes and spectroscopy for identifying the residues and also to check which method is better for identification of the specific type of residue (Mazza et.al 2006, Modugno et.al 2006; Dinnis et.al. 2009; Cârciumaru et.al 2012; Monnier et.al.2013; Yaroshevich et.al 2013; Bradtmoller et.al. 2016; Zupancich et.al 2016; Pedergnana and Ollé 2018; Pedergnana et.al. 2016)

For decades, OLM is the most commonly used microscope with regards to functional analysis. Other than this microscope, SEM with EDX is mostly used (Pawlik and Thissen 2011; Monnier et al. 2013; Borel et.al. 2014; Pedergnana et.al. 2016; Ollé and Vergés 2004, 2008) and in recent years, 3D DM microscopes started to gain popularity among the traceologists (Revendi et al. 2015; Ronchitelli et al. 2015; Bowosachoti 2016; Martín-Viveros 2016a, 2016b; Marciani et al 2018; Luengo Cortés 2017; Pedergnana 2017a. Other techniques involve are application of spectroscopy such as Fourier-transform Infrared spectroscopy (FTIR) (e.g. Cârciumaru et.al 2012; Bradtmoller et.al. 2016) and Gas Chromatography –Mass Spectrometry (GC-MS) (Regert et.al 1998; Boëda et.al. 1996, 1998, 2008; Koller et.al 2001; d'Errica et.al. 2012; Villa et.al. 2012; Charrié-Duhaut et.al 2013; Hauck et.al. 2013; Nardella et al. 2019). GC-MS analyses are good when the residue is sufficient to identify (Rots 2011) or else one has to only depend on the SEM with EDX (Pawlik 1996).

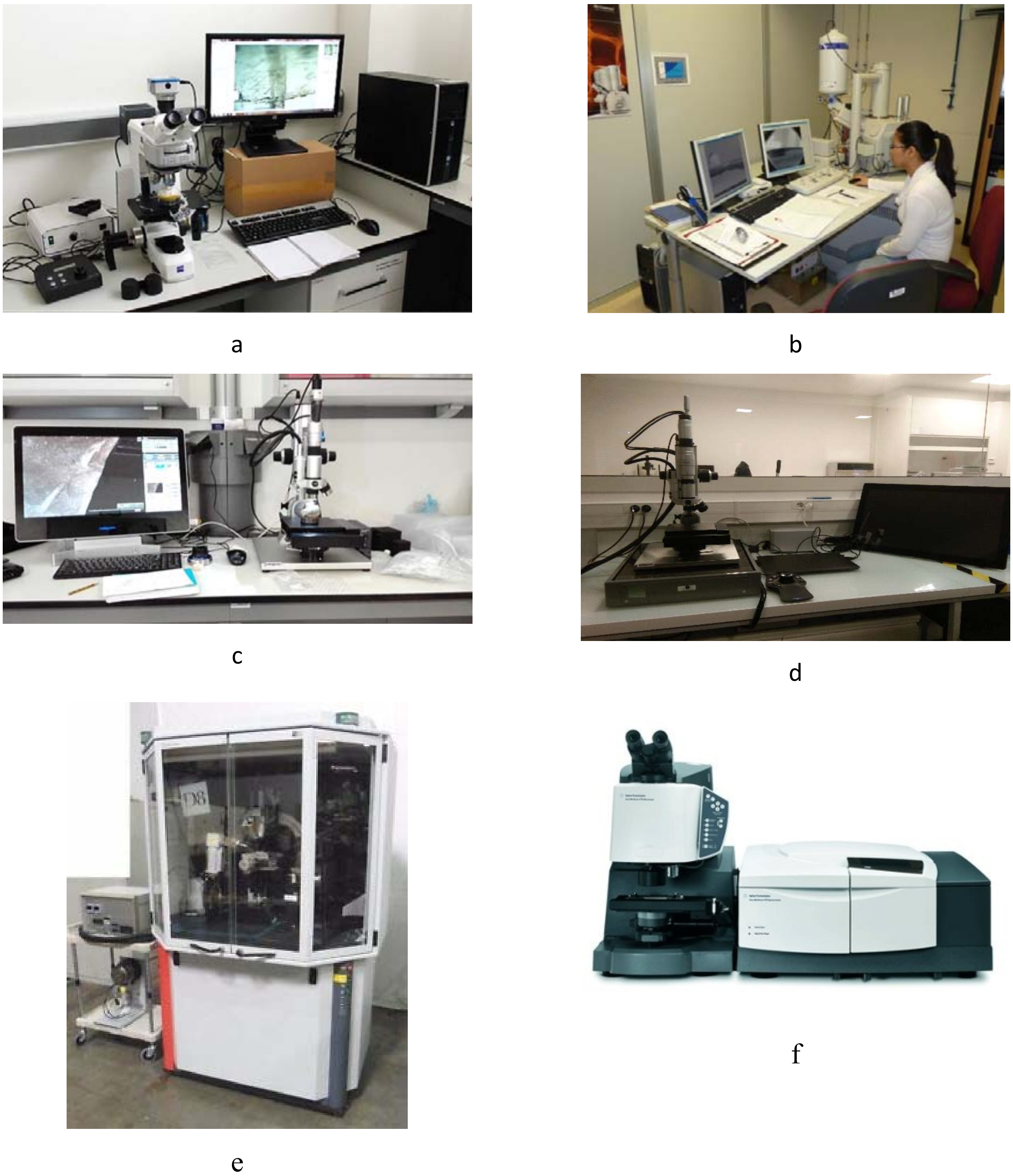


Figure 3: Microscopes and spectroscopy used for the studies, a) Ziess Axioscope A1; b) FEI QUANTA 600 ESEM; c) KH-8700; d) KH-7700; e) Bruker-AXS D8-Discover diffractometer and f) FTIR Agilent model Cray 620

Hence, keeping in account previous studies on residue analysis for our study, we have used OLM (Zeiss Axioscope A1), 3D DM (Hirox KH-8700 and RH 2000), SEM with EDX (FEI

QUANTA 600 ESEM), FTIR, Raman spectroscopy and μX-ray diffraction (μXRD). For the black residue we applied OLM, 3D DM, SEM with EDX and FTIR. On the other hand, for the bone residue we opted for similar microscopic application as for the black residue combined with μXRD.

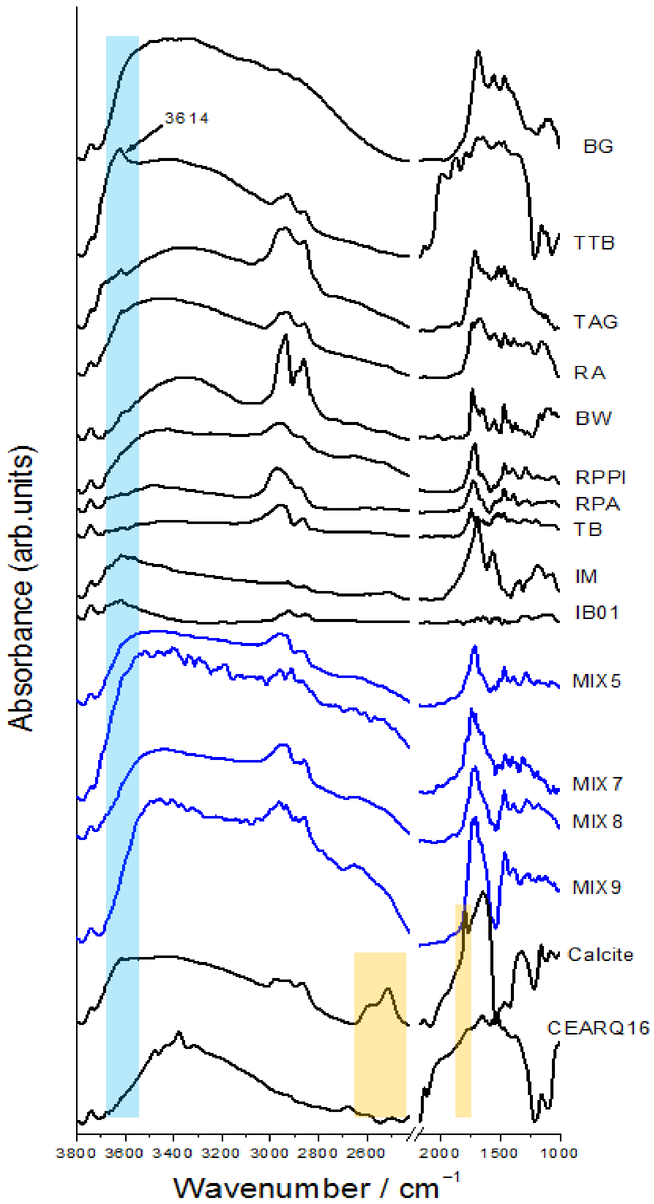
For both experimental and archeological material, Zeiss Axioscope A1 and 3D DM (Hirox KH-8700 and RH 2000) were used for the preliminary examination of the residues and its distribution on the artefact surface. Zeiss Axioscope A1 (OLM) and Hirox KH-8700 are located at IPHES (Tarragona, Spain), whereas, Hirox RH 2000 is located at Museé de l'Homme (Paris, France) (fig. 3a, 3c-d). Under OLM we analyzed the samples between 50x to 500x (that is, from Field of Views from 2260 to 226μm) and with the help of 3D DM we analyzed the samples between 35x to 1000x (in this case, FOV from 8665 to 303 μm). Occasionally). Lower magnifications were used to inspect the distribution of the residue and high magnification applied for the residue morphological identification. Analysis with 3D DM gave us the benefit of 3D imaging to check the location of the residue on the tool topography.

After the preliminary examination, the selective pieces were analyzed under ESEM with EDX (FEI QUANTA 600 ESEM) (fig 3b) to understand the chemical composition of the residue for the interpretation before approaching other techniques. Under SEM, we analyzed the residues with the similar magnification (35x to 1000x) as for OLM and 3D DM for comparison and reference. All the samples were analyzed under Low Vaccum mode at 20KV with the minimum working distance of observation 10mm. With the attached EDX we tried to extract the chemical composition of the residue. Following the analysis we also accompanied (GC-MS), Raman Spectroscopy, μX-ray diffraction and FTIR to strengthen our interpretation of the residue. FEI QUANTA 600 ESEM and μX-ray diffraction are located at the Scientific Resources Centre of Universitat Rovira I Virgili (Tarragona, Spain).

We applied **μXRD** to cross-check our bone residue result with SEM with EDX. μXRD measurements were made using a Bruker-AXS D8-Discover diffractometer equipped with parallel incident beam (Göbel mirror), vertical θ-θ goniometer, XYZ motorized stage and with a GADDS (General Area Diffraction System) (fig 3e). Samples were placed directly on the sample holder for reflection analysis. An X-ray collimator system close-to-the-sample allows to analyze areas of 500 μm. The X-ray diffractometer was operated at 40 kV and 40 mA to generate Cu kα radiation. The GADDS detector was a HI-STAR (multiwire proportional counter of 30x30 cm with a 1024x1024 pixel) placed at 15cm from the sample.

We collected one frame (2D XRD pattern) that covered at such distance a rage from 20 up to 55º 2θ. The exposition time was from 900 to 3600s per frame. The resulting images were 2θ integrated to obtain a 2θ conventional diffractogram.

For the black residue, **FTIR** analysis was performed by the scientists of ICFO (Barcelona, Spain) (fig 3f). We provided them with the samples as well as the figures of the artefacts with the location of the residue to easily identify them. FTIR spectra were collected by using the microscope FTIR Agilent model Cray 620. In reflection mode with resolution of 4 cm^{-1} in the spectra range of 4000 to 650 cm^{-1}. Measurements were carried out over an area of 24x24µm. Different black spots were analyzed for each sample and an average of 10 spectra were collected for each black spots.



Code	Substance
BG	Bat guano
TTB	Yew pitch/tar
TAG	Alder tree pitch
RA	Arjan tree
BW	Beeswax
RPPI	Pine resin
RPA	Pistacia resin
TB	Birch bark pitch
IM	Fine carbon powder
IB	Bitumen
MIX5	Pine resin + beeswax + ochre
MIX7	Pine resin + cow fat + ochre
MIX8	Pine resin + beeswax + ochre
MIX9	Pine resin + beeswax + ochre

Figure 4: FTIR spectra for the reference collection and the codes for various adhesive material. Spectra of TTB showing the peak at 3614 related to the bituminous substance.

3.6.Results

In our study, we encountered three types of residue: 1) modern residue, 2) black or bituminous residue and 3) bone residue. Below they are explained separately with the results obtained with different microscopes and spectroscopy.

3.6.1 Modern day residue

Modern day contaminations is the most common problem faced in the functional studies (Wadley et.al. 2004; Wadley and Lombard 2007; Croft et.al. 2016; Pedergnana et.al. 2016). Although, many traceologists talked about this problem and how to eradicate it, some of these residues are difficult to control (Pedergnana et.al. 2016). In this regard, Pedergnana and her team's research work is commendable for presenting the reference collection of various types of possible modern day contamination to identify them and cleaning techniques to eradicate them. In our analysis, we also found the similar modern residue as observed by others on the 2011-12 excavation stone tools. As for the Khorramabad Project, previously functional study was not considered. After the 2013 preliminary work to check the possibility of the traceological studies, while analyzing we encountered various types of modern residues such as excavation metal tool marks, moulding clay, pencil mark, fiber, hair, transparent nail paint and glue (Fig 5.).

To control these modern contaminations, in the second season of 2014-15 excavation, we took various control measures during the excavation and in the lab. As explained above, during excavation powder-free gloves were worn while handling the tools, while documenting artefacts were not labelled with pen and nail paint which is the common practise in most of the sites. In the lab first and foremost we tried to keep the working area clean; while doing microscopic analysis the artifacts were mounted on the moulding clay (which we covered with cling film). Each lithic was handled with gloves which were changed between samples to prevent cross-contamination (Croft et al. 2018). The results showed that the modern residue were very less with the applied control measures.
Despite all the control measures, some of the modern contaminations are difficult to control such as the excavation metal tool mark, which is a common problem in most sites and difficult to control during excavation.

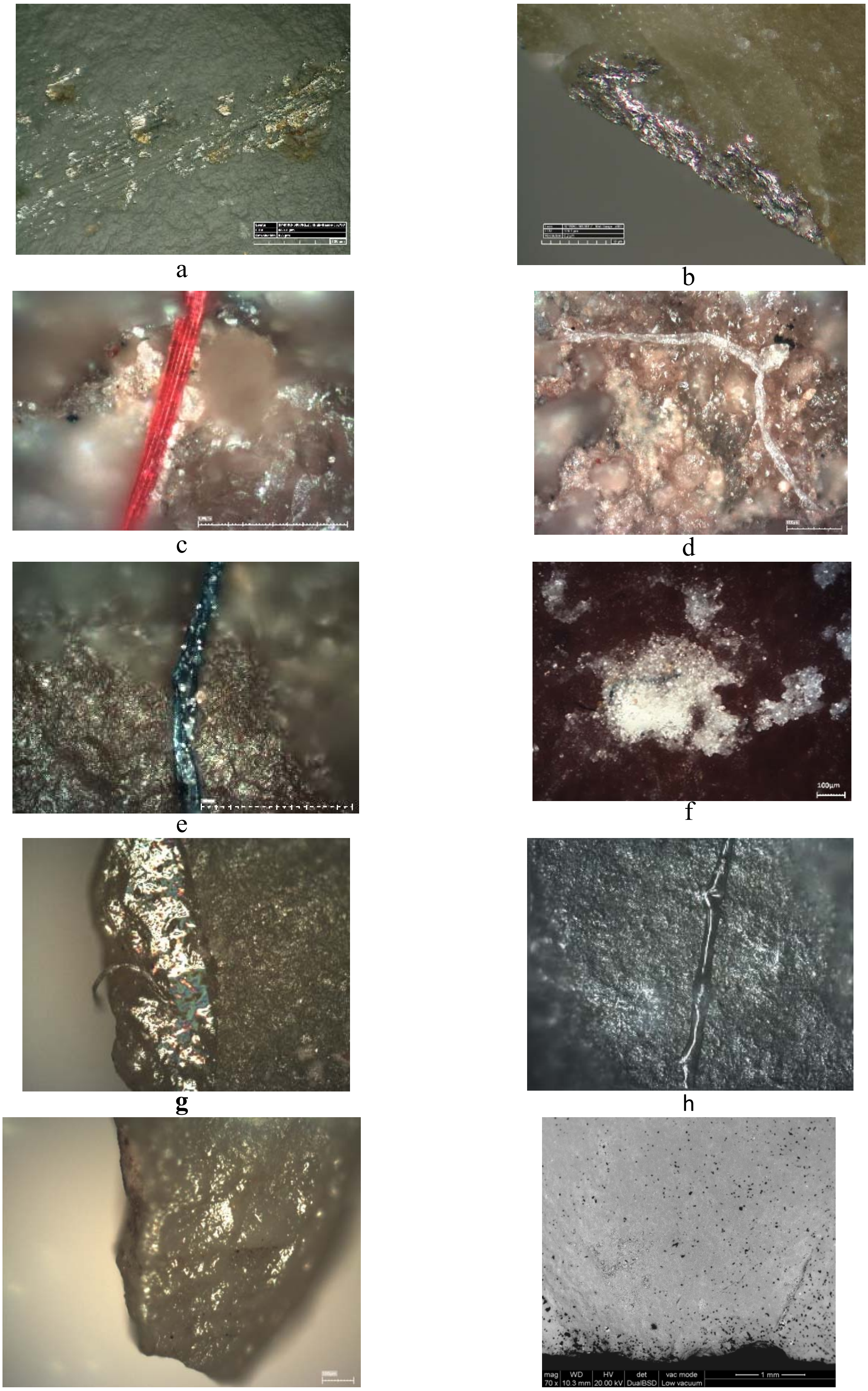


Figure 5: Modern contaminations on the 2011/12 excavation tools; a)metal tool mark with deep parallel striations; b) pencil mark; c) clothing fibre; d) paper fibre; e) hair; f) molding clay; (g-i) Transparent nail paint; k) skin flakes

3.6.2. Black or bituminous residue

Black residue, when observed under OLM and 3D DM, we identified two types: 1) like worm, chain of four oval shape or cluster of more than 5 oval shapes, and 2) brownish black stains that appear as isolated drops, sometimes in lichen shape and flower/dendrite shape (fig 6, 7). In most of the cases they are very small like few microns and sometimes distributed on major part of the tool. The residues occur on both faces, in many cases but not all distributed around those parts of the tool which were likely grasped or hafted.

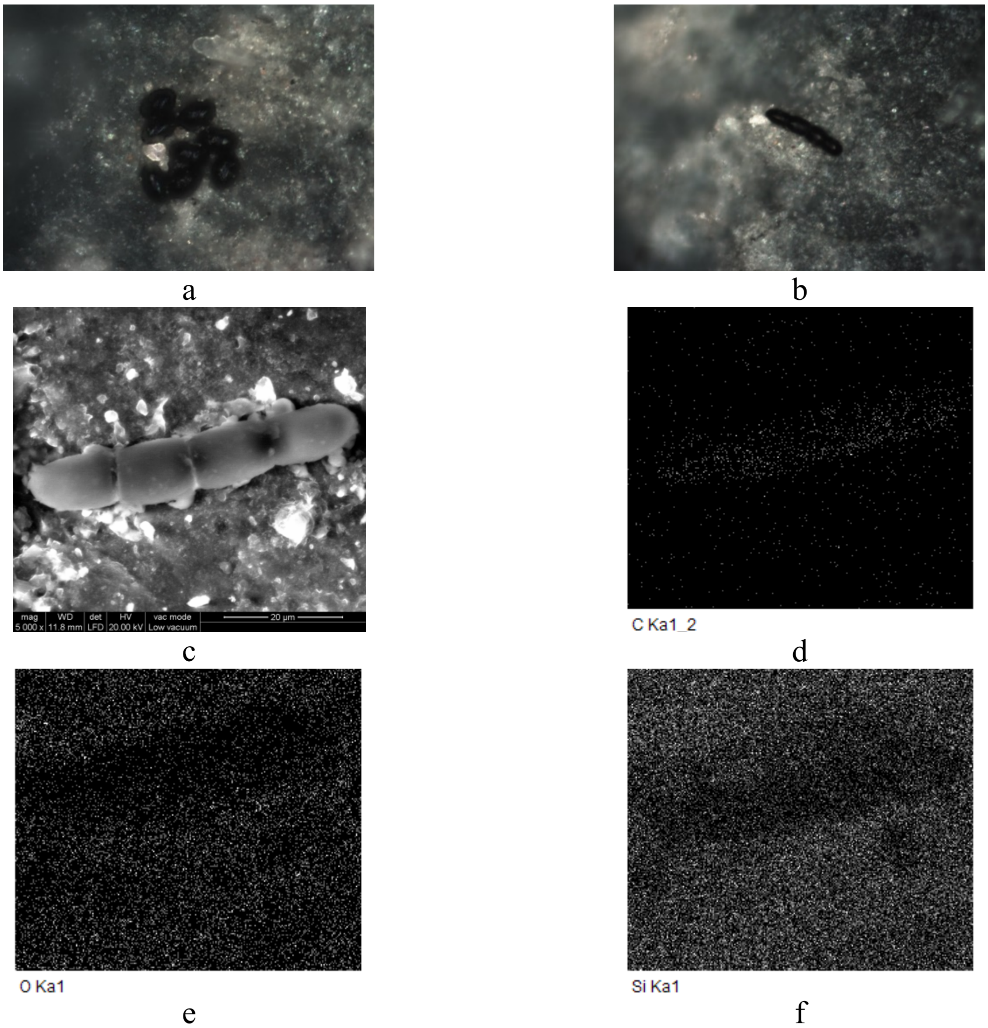


Figure 6: Sporormiaceae a) cluster shape at 500x; b) chain of four oval shapes at 500x; c) same as (b) at 5000x; (d-f) element map of the worm showing presence of Carbon, Oxygen and Silicon

We observed some black worm type of residue on two artefacts from Gilvaran samples and the similar residue was found on one stone artefact from Gar Arjeneh Rock shelter. When observed under OLM, they mostly appeared in chain of four oval shape worm type and in rare cases in cluster (Fig 6). When analyzed under SEM with EDX, they show organic chemical element Carbon and oxygen. Our colleague from MNHN (Paris, France) identified them as ascospores of microscopic soil fungi or coprophiles of the family Sporomiaceae, probably of the genus Preussia or Sporormiella. At 5000x magnification we can notice a small circle on the left which would be the footprint of the pedicel that held the fixed spore. Members of Sporormiaceae are widespread and are most commonly found on various types of animal dung, but they also occur on soil, wood, plant debris, decaying textiles and exceptionally human tissue (Kruys 2007). Sporormiaceae can be found in ancient soil samples and sediments and are thus, useful tools in paleoecological studies (Hausmann et al. 2002; van Geel et al. 2002; Burney et al. 2003).

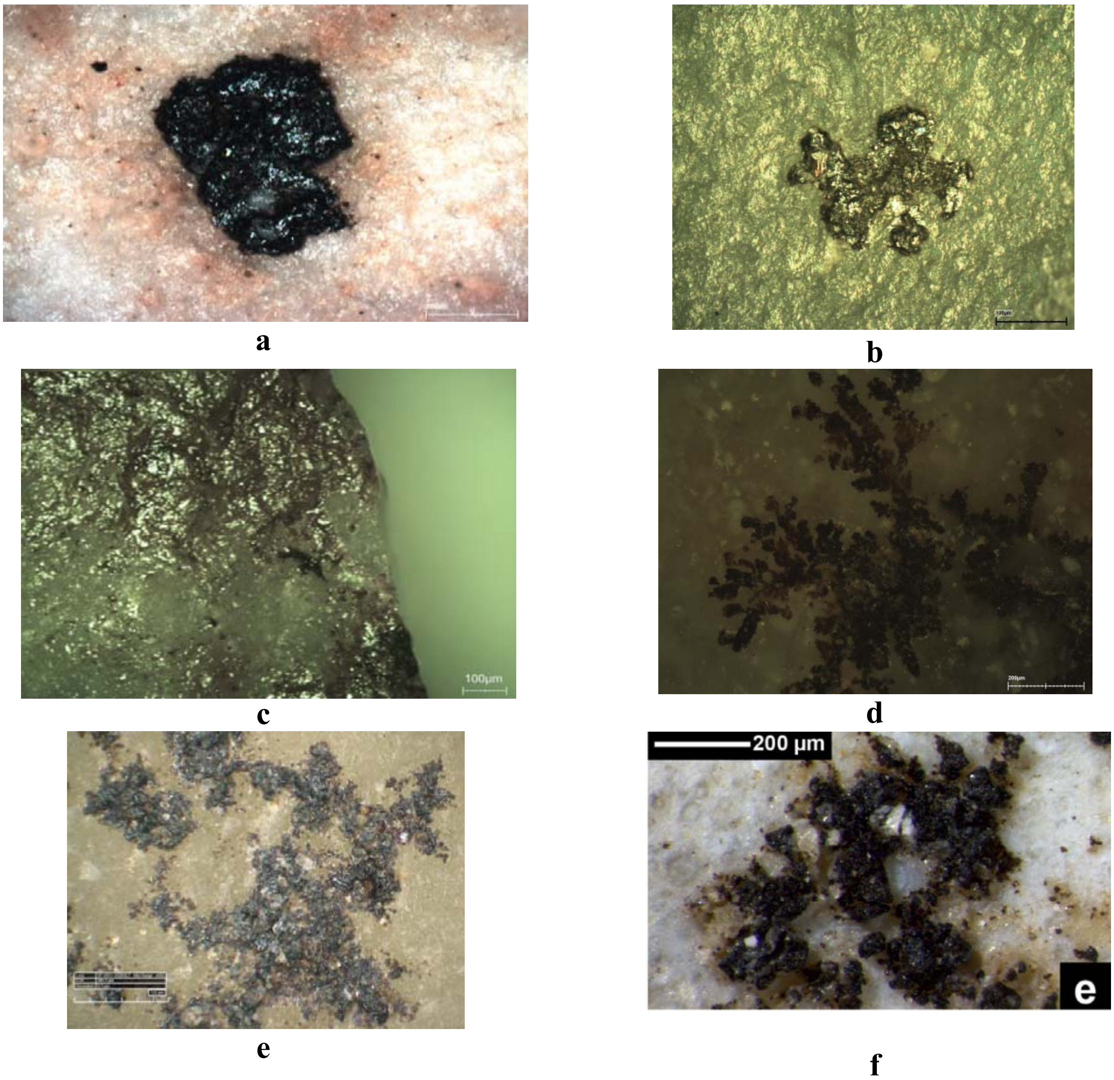


Figure 7: Type of black residue identified on the tools; a) black spot at 200x; b) in flower pattern (200x); c) greasy appearance 200x; d) like a lichen shape (100x); e) random shape (600x); f) black residue from Hummal Cave, Isreal (Courtesy of Monnier et al. 2013)

Apart from this worm type residue, we analysed the black residue on Kaldar (62 samples) and Gilvaran (59 samples) with black residue. Selective pieces were analysed for the determination of the chemical composition for the identification of the residue under SEM with EDX. They appear as white color under the SEM and in the chemical characterisation of the residue with EDX. The results present the element map showing the presence of precipitated Manganese Oxide. Usually MnO^2 occur due to the decomposition of the organic material in the assemblage which can get deposited on the artefact (Marín-Arroyo et.al. 2014 and Boëda 1998).

For the FTIR analysis, seven samples (2 from Gilvaran and 5 from Kaldar) with black residue were selected. Fingerprint region of these samples shows a high overlap of bands which are mainly ascribed to C=C and C=O stretching vibrations, which can be related with the presence of organic substances present in the black spots as well as the bands at 2860 and 2925 cm^{-1} characteristics of the assymetric and symmetric C–H stretching modes, respectively.

On the other hand, some authors have reported that band located at *ca*. 3617 cm^{-1}, ascribed to stretching mode of free OH, it is a distinctive band observed in bituminous materials. Results obtained of the analysis of the FTIR spectra recorded from the lithic artefacts here studied, suggest that one of the major components of the "black spots" has a bituminous origin, showing characteristic spectral signatures observed in these type of substances. All the analyzed spots correspond to organic substances, what fits with the high amounts of Carbon and Oxygen revealed by the elemental analysis, which can be associated with some bituminous substances.

According to the database created and the literature, the more probable candidates to the possible adhesive substances would be bitumen and/or resin (as TTB). Both spectra show a characteristic band approx. 3610 cm-1 (which is not present ion any other sample).

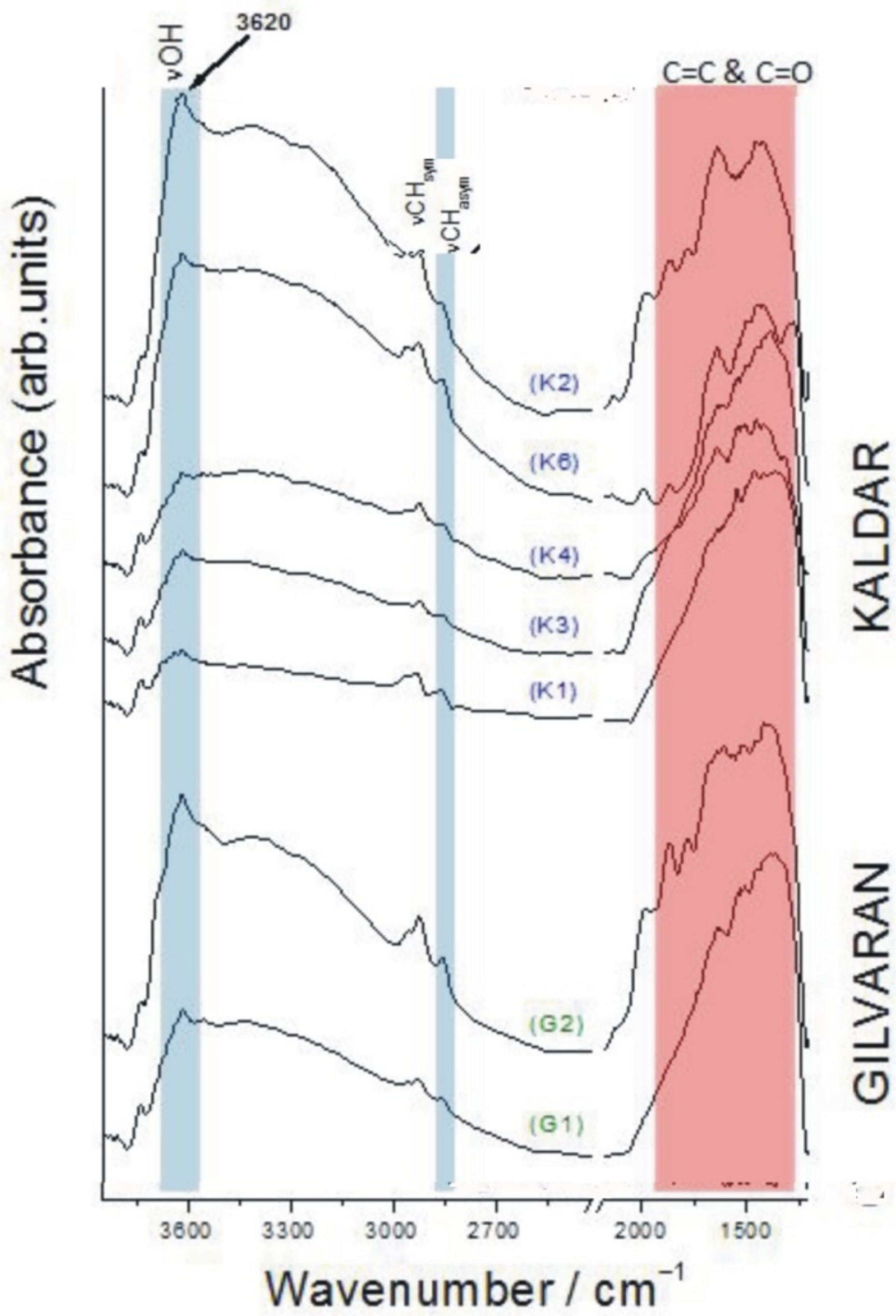


Figure 8: Shows seven representative spectra of one black spot recorded for each simple. Spectra fingerprint of these samples shows a high overlap of bands which are mainly ascribed to C=C and C=O stretching vibrations, which can be related with the presence of organic substances present in the black spots as well as the bands at 2860 and 2925 cm1 characteristics of the asymmetric and symmetric CH stretching modes, respectively. On the other hand, some authors have reported that band located at ca 3617cm1, ascribed to stretching mode of free OH, it is a distinctive band observed in bituminous materials.

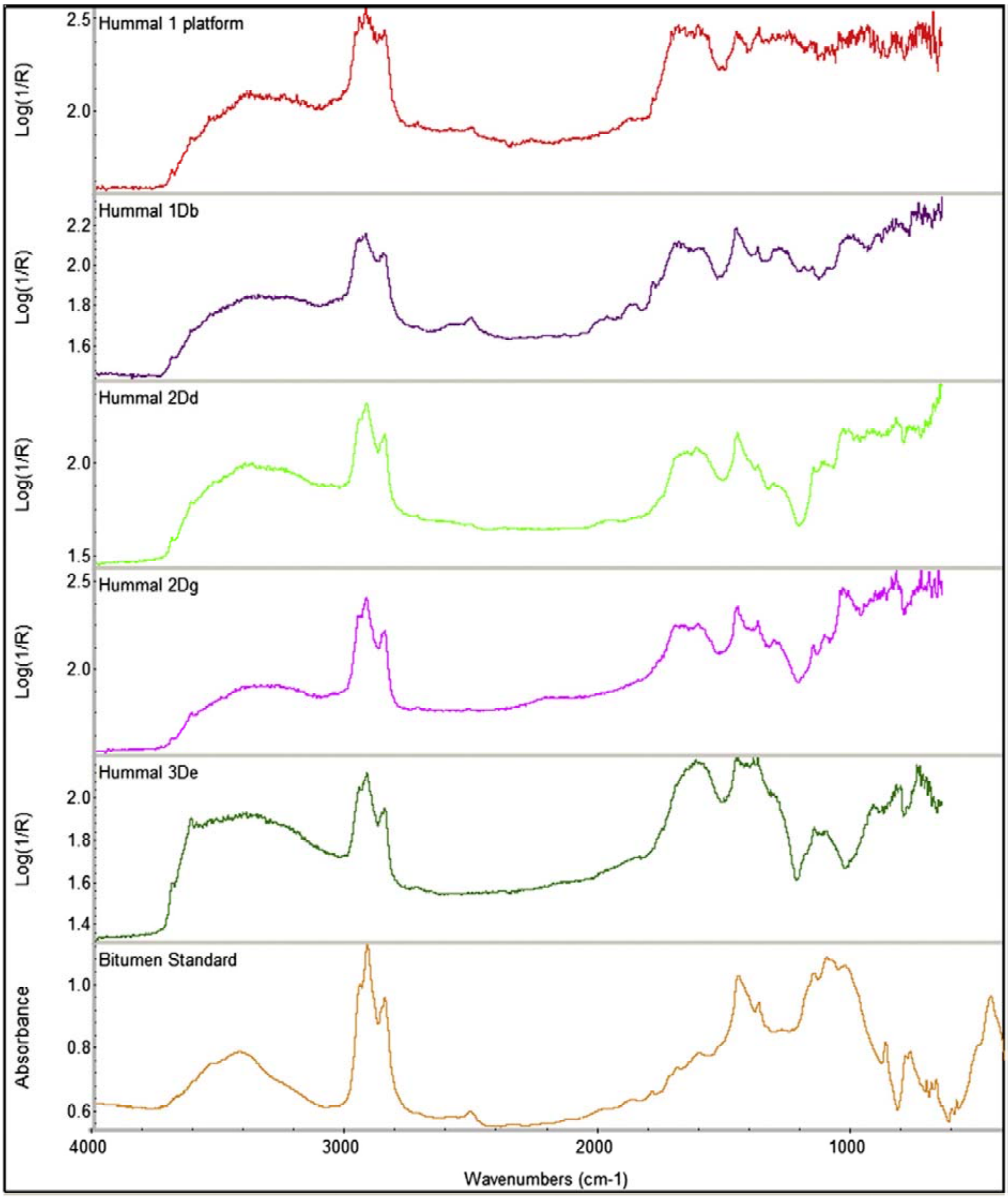
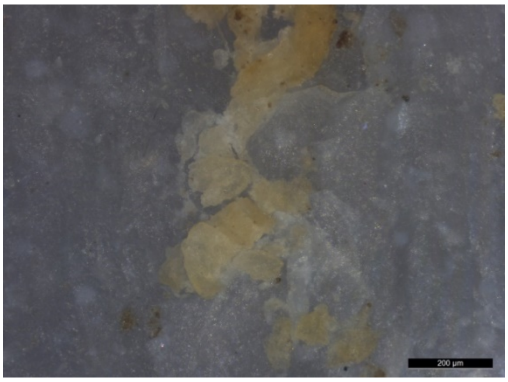


Figure 9: FTIR-M spectra from Hummal 1, 2, and 3 residues, as labeled; bottom spectrum, bitumen standard (from the FTIR Library, Kimmel Center for Archaeological Science, Weizmann Institute of Science, Israel) (Courtsey of Monnier et.al 2013).

3.6.3. Bone residue

This research is also a collaborated work and is in preliminary state. It started in the very later stage of the research when we got more evidences of bone residue along with the use-wears on the Kaldar samples (Fig 11). Parallel comparison can be made with other evidences on the bone residue from the sites of Azokh (Armenia), Abríc Romani (Spain) and Atapuerca (Spain). Here, we explain about the archeological bone residue from Kaldar Cave. To support our results, we prepared the reference collection of the modern as well as fossil bone. We performed SEM with EDX and µXRD report for a few bone experimental pieces with residue along with complete modern bone and fossil bone from Abríc Romani (Fig. 12, 13, 14, 15).

Under OLM and 3D DM analysis, bone residue in the fresh state are amorphous, opaque to translucent and compact, sometimes greasy and white mass as observed by previous researchers too (Jahren et.al. 1997; Lombard 2005; Croft et.al. 2016; Pedergnana and Ollé 2018; Martin Viveros 2016). After going through the post depositional alteration they change in colour and appear light creamish yellow or brownish or black color (Fig 10) depending on the type of soil condition they are buried.



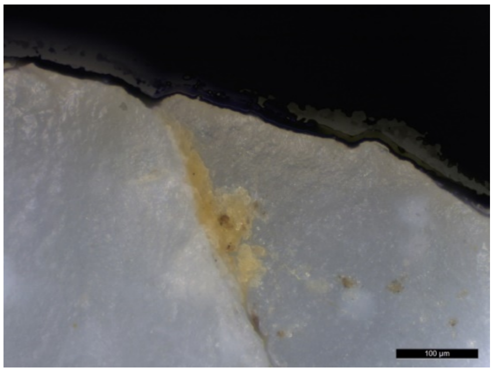


Figure 10: Star Carr experimental pieces with residue; a) alkaline 1 month and b) alkaline 11 month Croft et.al. 2015

In our observation, we found the evidence of bone residue on 4 stone tools (levallois point, pointed bladelet, twisted bladelet and small flake) in Kaldar Cave (figure a,b,c,d), whereas we didn't encounter them in Gilvaran assemblage. Under OLM and 3D DM analysis, two points and a small flake showed the presence striation on the artefact with light tinge of pale, opaque residue (Fig 12a-d). We analysed these sample under SEM to get the better view of the striation. Under SEM with EDX they appeared white colour in inspection and the element map extracted with the help of EDX, shows the clear presence of Phosphor and Calcium (Fig 12). SEM due to its depth of field is useful to see the details of the residue which sometimes get missed through OLM and 3D DM. When analyzed with the µXRD only one small flake showed the presence of hydroxyapatite as the amount of the bone residue was little bigger than other samples (Fig 13).

Figure 11: left column top to bottom showing the tools with the location of the residue and on the right two rows theirs magnified details. (a,b) KLD-E6-5II-912 (flake) (a) amorphous pale brown colour residue with striation under 3D DM at 400x (Mid-Range lens); (b) same location under SEM with EDX at 521x; (c-d) KLD59 (Levallois Point), (c) Black residue with the pale brown residue underneath with 3D DM at 600x (Mid-Range lens); (d) enlarge location of figure (c) marked in red identified as bone residue with striations under SEM with EDX at 2000x; (e-f) KLD-E5-5-238 (Twisted bladelet) showing red residue (Iron oxide) with bone residue with SEM with EDX (at 200x), 3D DM(400x); KLD-F6-5-741 (g-i) deep striation under OLM at 500x and at 520 under SEM with EDX

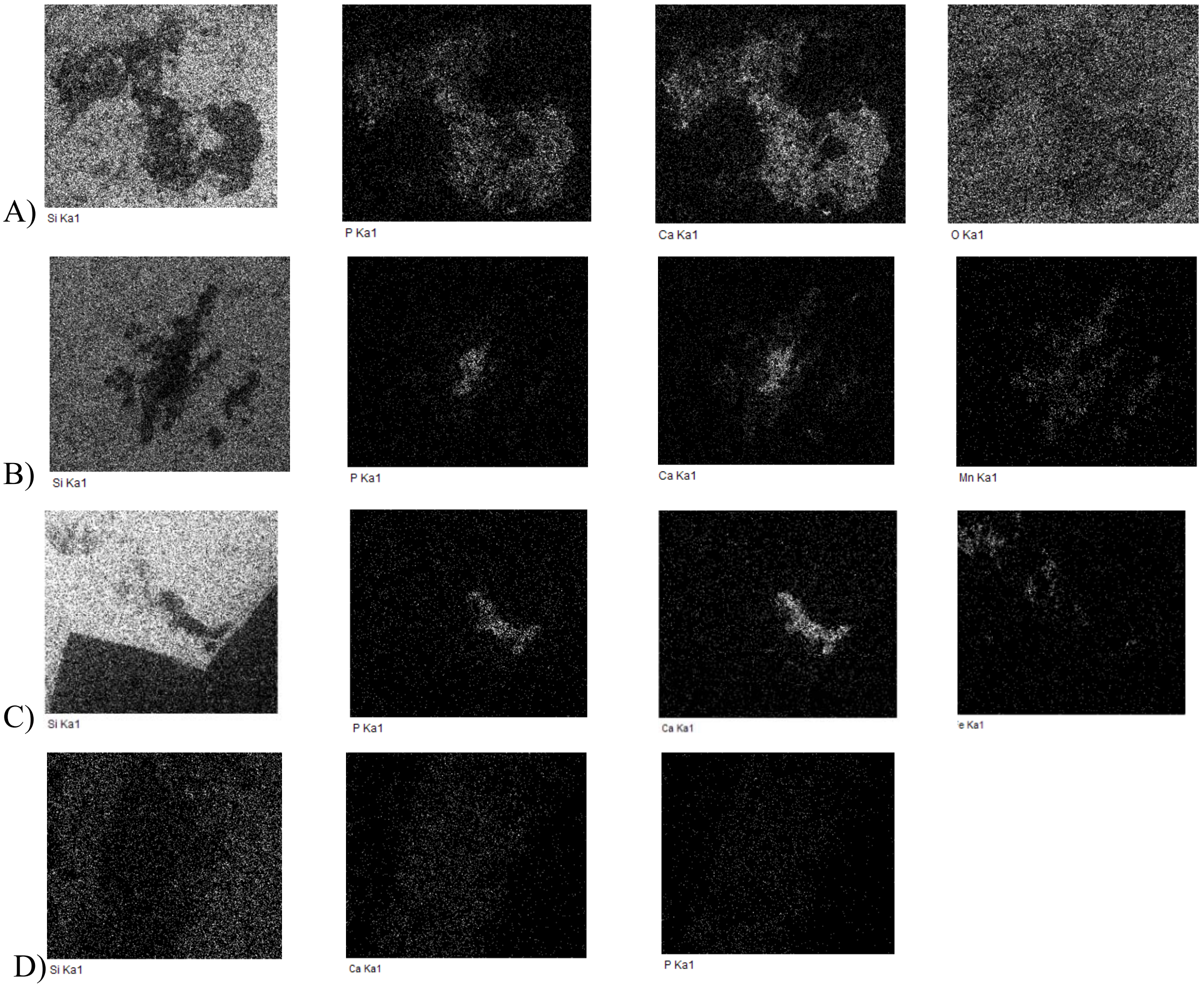
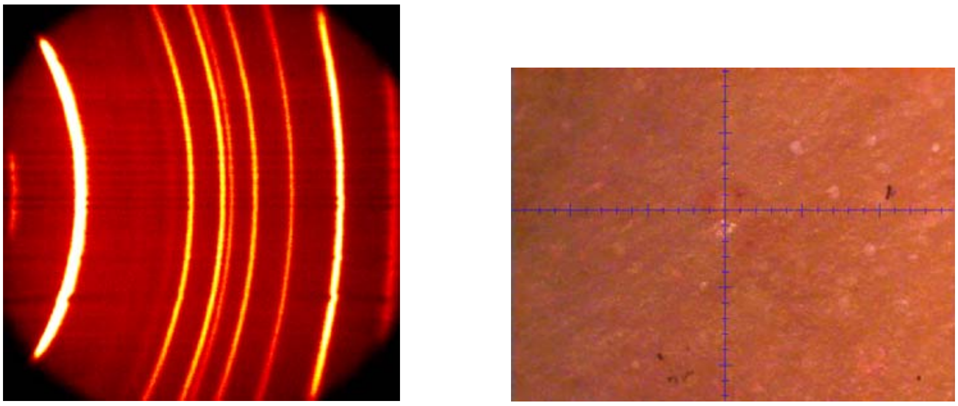


Figure 12: Element maps from SEM with EDX for the residue on the tools in figure 10. A)) KLD-E6-5II-912; B) KLD59; C) KLD-E5-5-238; D) KLD-F6-5-741. Elements Si and O related to tool, other residues are Mn (Manganese Oxide), Fe (Iron oxide) and P and Ca related to bone residue

In our preliminary reference collection of the bone residue with µXRD, the peak of the hydroxyapatite occurs in 31 to 35 and they are also dependent of the amount of bone residue available of the artefact (see the comparison of the graphs in fig. 15). When comparing the evidence of the reference collection with our archeological sample, the spectra peak falls in the exact location.

Along with the evidence of the residues, we also have the taphonomical evidence appears in three ways: cut marks, bone fracturing, and cremations. Cut marks were observed on bone specimens appearing in the form of slicing and scraping marks, and all instances are located on the shaft portions, indicating the defleshing of the carcasses (Bazgir et.al. 2017).



KDL-E6 Level 5II n.912, 500um, 15cm, 900.0s [002]

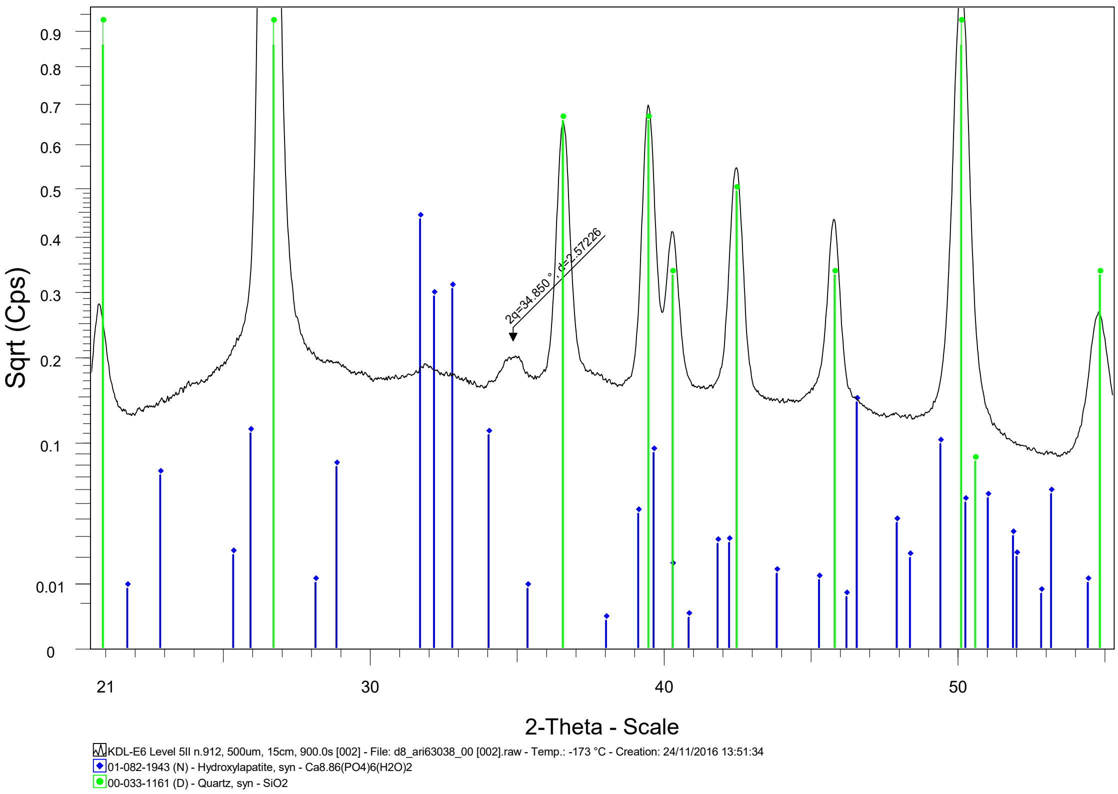


Figure 13: µXRD result showing the presence of Hydroxylapatite [$Ca_{8.86}(PO_4)6(H_2O)_2$] represented by blue peaks and Green peaks represent quartz, syn-Si02

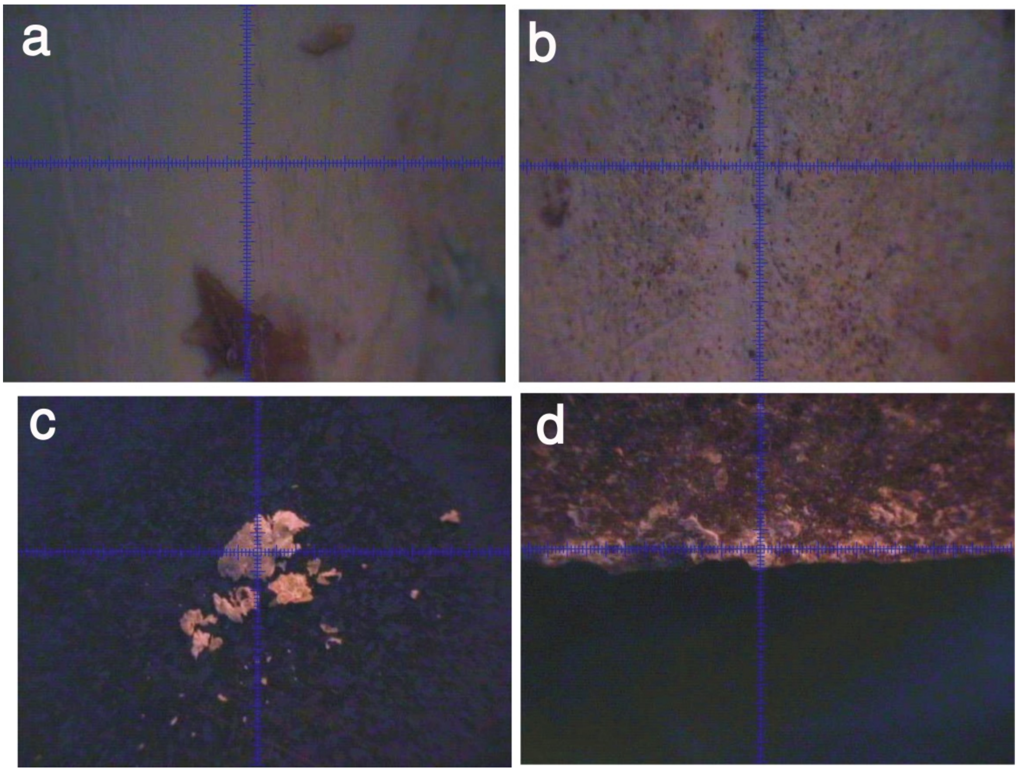


Figure 14: a) Modern day bone of *Cervus elephus* b) archeological bone from Abríc Romani; c) Bone powder and d) bone residues on the experimental pieces; showing the location from where the µXRD were extracted

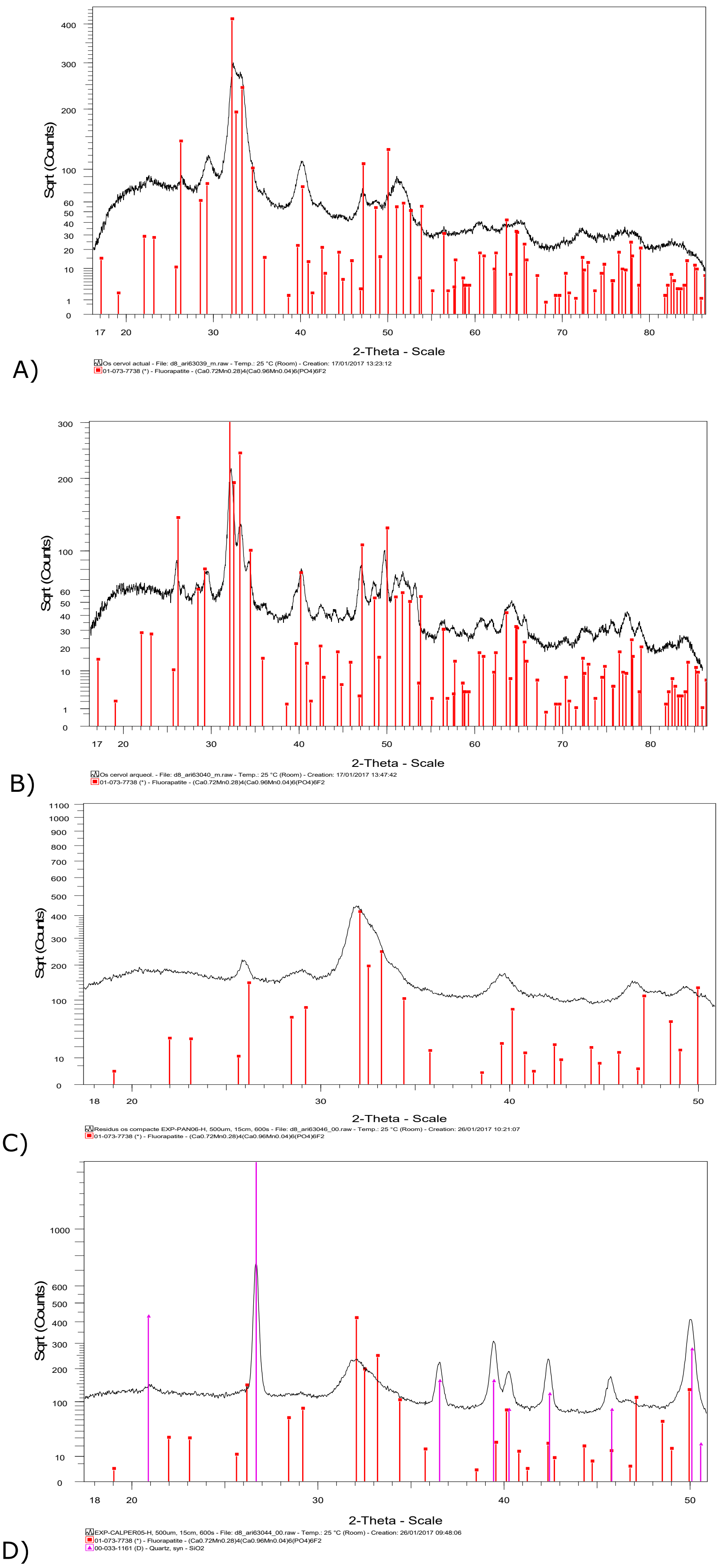


Figure 15: µXRD spectra a) powder of bone and b) experimental piece with bone residue on the edge, c) and d) Pink peak represent Fluorapatite and red peaks represent SiO_2

3.7. Discussion and conclusion

In functional analysis, archeological residues especially organic residues (such as starch, pollens, hair, blood, bone, adhesives etc.) reacts differently to different environmental conditions. The chances of their survival always depend on the material type and the types of burial environment (Fullagar et.al. 1996; Huisman et.al. 2017 and Neissen-Marsh et al. 2000). Artefacts from stable, dry and sheltered sites are generally promising for micro-residue studies, whereas those from unstable open-air sites might be less suitable (Langejans, 2010). Beside the preservation of the micro-residue, traceologists face another issue with the preservation and decay of these residues. Several experiments have shown that the morphological property of the residue gets highly affected after the decay process and can only be identified when observed at specific angle, magnification and light conditions (Langejan and Lombard 2006).

For a traceologist, when identifying the organic remains on the archeological artefact for examples, bone, plant or adhesive residue, one gets curious about how and how long they were used? If they were used for butchery or hunting activity, then how they were hafted and how these organic residues survived on the artifact? Here, we discuss the bone residue and the black bituminous evidence related to butchery and hunting activities.

Earliest evidences related to bone residue or bone working, comes from two Lower Paleolithic sites of Israel, Qesem Cave and Revadim Quarry. These evidences are supported by use-wear, residue traces and taphonomical results as well as association of the stone tools with the faunal remains in the stratigraphy (Solodenko et.al 2015; Zupancich et.al. 2016a, 2016b).

Living bone is made up of water, mineral and organics and its density varies according to the relative proportions of these three components (Eastoe and Eastoe 1954; Nielson-Marsh et al. 2000). Bone is composed of 70% bone mineral apatite $Ca_{10}(PO_4)_6(OH)_2$ and 20% collagen (Pedergnana and Ollé 2018). However, with time, bone degrades and the first step is the loss of collagen (Bordes et al. 2017). The best survival of the bone is the saturated or dry environment (Nielsen-Marsh et al. 2000).
In various previous bone experiments, when analysed under OLM or VLM, freshly scraped bone residue appeared as amorphous, opaque to translucent and compact, sometimes greasy and white mass (Jahren et.al. 1997; Lombard 2005; Croft et.al. 2016; Pedergnana and Ollé 2018; Martin-Viveros 2016b). Furthermore, when bone begins to degrade, the colour,

translucency, and shape may also be altered (Croft et.al. 2016) and difficult to identify as they often are amorphous and opaque (Lombard 2005). When analysed under SEM with EDX, they shows the high concentration of Phosphor and Calcium, which is the component of bone apatite $Ca_{10}(PO_4)_6(OH)_2$.

In our study, the micro-residues on the archeological samples had the high percentage of P and Ca and when analyzed with the μXRD they show the concrete presence of hydroxyapatite. We also noticed that the peak of the hydroxyapatite also depends on the quantity of the residue available with the mineral preserved in the sample; which we have explained in our archaeological and experimental samples. Other than our research, many other studies have applied different techniques (such as Raman Spectroscopy and FTIR) for understanding the bone residue on both archaeologcical (e.g. Zupancich et al 2016a; Bordes et al 2017) and experimental (e.g. Monnier et al 2018).

Zupancich (et al. 2016) and his team applied Micro-FTIR on two scrapers (one Quina and one demi-Quina) from the site of Qesem Cave, Isreal. Their Micro-FTIR spectrum of both the tools edge's dorsal surface, shows a shoulder on the low frequency side of the Si-O stretching mode (~913 cm−1); this suggests the presence of bone micro residues, as it is attributable to the PO3= stretching mode of calcium phosphate (apatite), which constitutes the bone's mineral component. They also confirm the results with SEM with EDS by which they identified the bone mineral particles and also bone collagen trapped in the fracture of the edge. These bone residues are also supported by the evidence of use-wear and the sawing cutmarks on bone indicating towards the non- nutritional activity by Qesem hominins.

Identifying the bone residue, one has to keep in mind that its identification alone is not sufficient to relate it with use as they can be post depositional in the site as well. This phenomenon of post deposition is already explained by many previous researchers (e.g. Levi-Sala 1986; Wadley et.al 2004; Wadley and Lombard 2007; Bordes et al. 2017).

As mentioned earlier bone residue has survived on the stone artefacts in a few archeological sites, but there are also evidences when they are not use related but post depositional and adhere to the tool during the burial process of the site. To explain this better, we give an example from sites of Atapuerca (Spain) and Liang Bua (Indonesia). Pedergana (2017) in her PhD research reported of 7 quartzite artefacts from TD10.1 level of Gran Dolina site, observed relatively big bone residue embedded with the concretion attached on stone artefact, which is also visible with naked eyes (Please see figure in Pedergnana 2017, pp301- 302). In the SEM with EDX analysis they show the presence of P and Ca. She didn't associate the bone residue with any function as the bone residue was not organised in recurrent distributional pattern and not always on the very edge of the implement embedded with the concretion. Another reason she mentioned that the TD10.1 unit (specially the bone bed identified in its lowermost part), showed the presence of bone everywhere and bone fragment mixed with sediments, often being attached to the lithics (Pedergnana 2017, pp 300).

On the other hand, Bordes (et al. 2017) and his team applied Raman Spectroscopy (RS) to identify the archaeological inorganic and organic residues from the artefacts of the site of Liang Bua (Flores, Indonesia). In their study, among the archaeological residues they also identified two types of apatite on an artefact by analysing a small white rods (10–20 µm in length), the sediment and a small piece of bone (removed from the surface by sonication). They didn't associate these apatite residues with any tool use. They presented the results, that how geological apatite and bone apatite differs with each other and how RS plays an important role to distinguish them. To do so, they compared their Raman spectra of the rods and geological apatite with a small piece of bone from the same artefact (removed by sonication) and the modern bone sample. Their results showed that the geological apatite spectra obtained differ from that of bone apatite with the totally symmetric P—O stretch vibration at a higher wavenumber (968 cm^{-1}) than in bone (965 cm^{-1}, and the 9 cm^{-1} full width at half maximum (FWHM) of the 968 cm^{-1} band, half the 20 cm^{-1} FWHM of the 965 cm^{-1} band in modern bone. As well as, the band at 1074 cm^{-1} attributed to carbonate in bone is also absent in the spectra of geological apatite, which they explain can be due to the cause of the bone degradation as these carbonate ions get replaced with Cl^- and F^-, the calcium ions by other cations including rare earth elements and complete recrystallization can take place. Other than that, they also observed that in the RS spectra, 1) peak associated to the collagen are present in the modern bone but absent in archaeological bone fragment indicating the degradation of the collagen (which occurs first in the bone degradation process).

To test the distribution pattern of the residue on the tool, a few of the experiments have been performed by us and a few of the results have been referred from the previous work done on this aspect. Martín-Viveros (2016a) in his Master thesis performed few bone experiment to check the distribution of the various worked material residues on the samples and how we can determine the action performed the artefact (Martín-Viveros 2016a, 2016b). In the both the experiments, we have observed that the residue is not only concentrated on the edge but distribute on most of the tool surface.

Besides identifying the bone residue, to strengthen the bone working or bone residue evidences they are always supported by the use-wear analysis along with taphonomical evidences in the form of cut-marks (Solodenko et.al 2015; Zupancich et.al 2016), or tool morphology, impact fracture (Shea 1988; Sisk and Shea 2009) to justify whether the bone residue on the artefact resulted from butchery activity or hunting activity as projectile (Boëda et.al. 1998; Claud et.al 2012; Zupancich et.al 2016).

Besides the taphonomical and use-wear evidences, archeologists also take into consideration the tool association with the bone and till date evidence comes from Umm el Tlel (Syria), where a fragment of Levallois Point (Medial part) was found embedded inside the neck vertebra of the wild ass (*Equus Africana*) (Boëda et al 1999) indicating hunting activity around the site. Besides the projectile evidence from Syria there are also evidences from the other sites from Israel such as Kebara, Qafzeh and Hayonim caves belong to M-UP (Shea 1988). This kind of evidence arise the question, then how the tools were hafted and used as projectiles.

Usually for the archaeological artefacts, the evidence of hafting is always supported by the evidence of use-wears in the form of impact fractures (Shea 1988; Sisk and Shea 2009), hafting wears (Rots 2010) and adhesive residue traces (Boëda et al. 1996, 1998, Hauck et.al. 2013). For our better knowledge of the hafting and prehension traces, Rots works are commendable, where she has already explained and described them in detail (Rots 2002a, 2002b, 2003, 2008, 2010; Rots and Williamson, 2004; Rots et.al. 2006, 2011).

For a good projectile a better hafting material is also necessary to secure the tool on the shaft. In decades of residue analysis, various types of hafing residues (plant resin, ochre, bitumen) have been reported from various sites around the world. The dominance of the plant base resins are mostly reported from European sites, whereas, ochre is reported from the South African sites. The majority of evidences of bitumen residues are present in the Near East sites.

Bitumen is a raw material, which is a very versatile used for various purposes element such as an adhesive, hydro-repellent, coating and sealing agent to produce stone tools, ceramic vessels, ornaments and works of art and in burial practices. The ancient people from northern Iraq, south-west Iran and the Dead Sea area extensively used bitumen until the Neolithic period (7000-6000 BC) and has been exported over long distances (e.g. from Iran to Bahrain) (Connan 1999). Molecular typology of bitumen, based on detailed patterns of biomarkers, permits identification of their origin and subsequently to trace their trade routes. If we refer to the map provided by Connan (1999), we can see the distribution of the natural asphalt deposit in Middle East, with the nearest sources in Lorestan and Khuzestan province of Iranian Zagros (especially where our studied sites Kaldar and Gilvaran are located). For the Khorramabad sites, the nearest sources of bitumen are Pol Dokhtar, Dizful and Ain Gir (Fig. 1, 16). In the 2016 field survey, we have also located some of the nearby sites having the bitumen deposits.

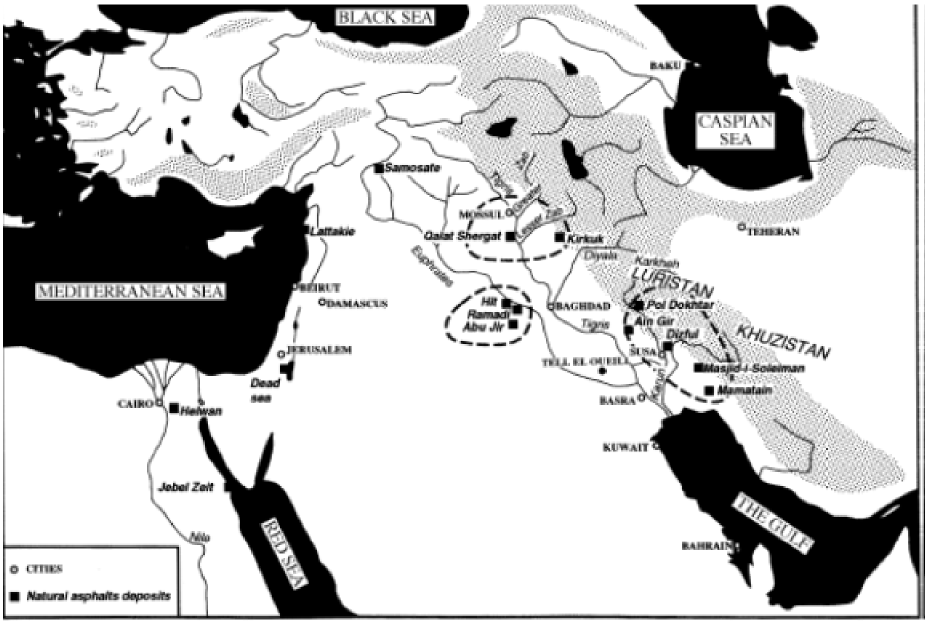


Figure 16: Map of Near East showing the locations of the major natural bitumen deposits (after Cannon 1999)

use of bitumen	examples	excavations with examples studied
mortars in construction building	temples, palaces, terraces, £oors, ziggurats, door threshold, courtyard	Mari, Babylon, Larsa, Haradum, Qal'at al-Bahrain,Mleiha, Failaka
waterproofng agent	mats, baskets, jars, water reserves, bathrooms, water pipes, cisterns, boats, sarcophagi	Tell es-Sawwan, Tell el'Oueili, Qal'at al-Bahrain, Saar, Baghdad, Ra's al-Junayz, Susa, Failaka, Tell Brak. Chagah sefid
adhesive and glue	sickles, tool handles, statues, jars, decoration (game, lyre, temple, pillar, ostrich egg)	Tell Atij, Netiv Hagdud, Umm El Tlel,Mari, Tell Atij, Netiv Hagdud, Umm El Tlel,Mari,Tell Atij, Netiv Hagdud, Umm El Tlel,Mari,Tell Halula, Ras Shamra, Susa
domestic artefacts	domestic artefacts spindle whorls, balls, dice, wall cones	Tell el'Oueili, Failaka, Saar?, Qal'at al-Bahrain, Susa, Tell Brak
jewellery	bead , ring, gold badges on clothing or for horse harnesses	Umm al-Qaiwwain, Ulu Burun, Susa, Saar
sculpture	sculpture, cylinder and stamp seal of Susa in bitumen mastic	Susa
mummi¢cation	mixed with conifer resin, beeswax, grease to prepare mixtures for embalming	Egyptian mummies from the Queen valley and from severalMuseums (Lyon, Hannover, Paris)

Table 4: After Connan 1999. Main uses of bitumen antiquity and prehistory

The earliest evidence of bitumen comes from the site of Umm El Tlel near El Kown Syria (Boëda 2008; Boëda et al., 1996, 1998, 2008; Connan 1999; Bonilauri, 2010) and Hummal (Hauck et.al 2013), where the Neanderthals used it as the hafting material (Boëda et.al 1996; Bonilauri, 2010). In 1998, a ball of natural oil-stained sand was unearthed from the same archaeological layer. Finding shows that the source is regional and located at Jebel Bichri which is the nearest source of bitumen from the site at the distance of 40 km (Cannon 1999). Boëda (1998) reported black residues from Hummal site which are not exclusively organic residue but also precipitated manganese oxide. His SEM images, coupled with X-ray spectrum, showed the major elements: silica, organic carbon, iron, and manganese oxide. These similar chemical elements were also observed in our archeological samples. It was observed in the tested cases that organic matter, when present, is generally associated with manganese oxide (Marín-Arroyo et al. 2014; Bordes et al 2017). Taking this phenomenon into account Boëda (1998) suggested that the bitumen may have played a role in the concentration and subsequently in the precipitation of manganese and iron oxide.

Till date in Iran Paleolithic research, the oldest evidence of the bitumen resource comes from the sites Ali Kosh, Tepe Tula'I and Chagah Sefid of Deh Luran (Hole 1977; 1974; Hole et,al 1969). During the excavation of the sites in 1967, various potteries were reported with black bitumen residue to make the pottery water proof (Hole 1977; 1974; Hole et.al 1969). Gregg (et.al.2007) analyzed the bitumen with GS-CM and the biomarkers provided with the analysis showed, that the bitumen of these sites are from the local source of Khusistan and this site is a few km away from our studied archeological sites. Still in the present day, people of Khorramabad valley use bitumen as roofing or construction material.

We can compare all our archeological examples, with the Iranian sites as well as sites of Near East, and the presence of the natural deposits of the bitumen in the 100 km of periphery from the archaeological sites (Figure 16). It seems very unreasonable why the AMH and Neanderthals of Zagros Mountains will not adopt these cultural traits in their daily life subsistence. From our functional analysis, we have seen use-wear traces (tip fractures, polish, striations hafting traces) and residue (bituminous substance and bone residue). Finally, if we relate these functional results to the taphnomical evidence of cut-marks resulting from scraping, defleshing and disarticulating of the bone is present in the Kaldar site (Bazgir et.al.2017).

Lastly, combining both these archaeological evidences from the neighbouring sites, natural resources of bitumen and presence of residue (bone and bitumen residue) on our own samples derived with the help of various methods and techniques. They indicate toward the hunting and butchery activity in and around the Khorramabad Valley. The tool technological variability also indicate that, to adapt better with the Palearctic environment these cultural traits were apt to survive and evolve in the valley.

However, If we refer to the previous literature, for bitumen analysis GC-MS is mostly used and with the help of the biomolecular and isotopic analysis the identification of the bitumen source can be identified (Connan 1999; Gregg et al 2007). Other than that, for the bone residue the FTIR analysis and Raman spectroscopy also has been used. Therefore, finally with the present state of this research, for the future prospect, to strengthen our archaeological evidences, GC-MS and Raman Spectroscopy analysis also have been considered.

Acknowledgement

We would like to thank the directors of RICHT and ICAR (Seyed Mohamad Beheshti and Rohollah Shirazi) for their support and cooperation with our Palaeolithic studies in the area. This research is conducted in the framework of a signed scientific agreement between RICHT and IPHES. Research has been developed in the framework of the Spanish Ministerio de Economía y Competitividad project CGL2015-65387-C3-1-P (MINECO-FEDER) as well as the Catalan AGAUR project 2014SGR899 and the URV project 2017PFR-URV-B2-91. We would also like to thank the Service of Microscopy at the URV Scientific Resources centre for providing the facilities for us to conduct the microscopic analysis. We are thankful to the scientists of ICFO for performing our FTIR analysis. We appreciate the help provided by Dr Behrouz Bazgir to let me (Laxmi Tumung) participate in both the excavation and trusting me for the functional studies of the archeological material. I also like to thank him for providing us with the archeological material as well in collecting the adhesive reference from the valley. Miquel Guardiola helped us with the knapping session for making experimental lithic, for which we are thankful to him. I also like to thank my colleagues Dr. Lena Asryan, Dr. Antonella Pedergnana, Juan Luis Fernández-Marchena and Juan Ignacio Martín-Viveros for their collaboration to the projects for better understanding of these residues. L. Tumung is the beneficiary of PhD scholarship funding under the Erasmus Mundus Program-International Doctorate in Quaternary and Prehistory.

5.2. Use-wear analysis

Article 6: Laxmi Tumug, Behrouz Bazgir and Andreu Ollé. (Accepted). Functional analysis on the lithic industry from the Upper Paleolithic sequence (Layer 4) of Kaldar cave, Khorrambad Valley, western Iran: A preliminary Report. (Gibaja, J.,Marreiros, J., Clemente, I. & Mazzucco, N. Eds). Hunter-Gatherers tool kit: A functional perspective

This article explains the preliminary functional analysis results for the Upper Paleolithic level of Kaldar Cave excavated in 2014-15.

CHAPTER TWENTY-FIVE

FUNCTIONAL ANALYSIS ON THE LITHIC INDUSTRY FROM THE UPPER PALAEOLITHIC SEQUENCE (LAYER 4) OF KALDAR CAVE, KHORRAMABAD VALLEY, WESTERN IRAN: A PRELIMINARY REPORT

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Abstract

Kaldar Cave is a key archaeological site dating between 38650-36750 and 54400-46050 cal. BP (C14 dating) for the Upper Palaeolithic occupations along with an underlying Middle Palaeolithic layer. The recently obtained dates from the lower part of the Upper Palaeolithic sequence shows one of the earliest examples of lithic industries made by anatomically modern humans in western Asia. These humans were not only able to migrate from western Asia into Europe, but they also were well adapted to their environment by exploiting the large Palearctic mammal resources. This research aims to analyse how the AMHs inhabiting this cave used their resources. We examined 67 well-preserved stone tools with rare post-depositional modification, out of which 38 pieces show traces of use-wear and 30 revealed presence of different types of residues. The use-wear traces are in the form of polish, striations, edge rounding, micro and macro edge fractures showing clear evidence of hafting as well as cutting and scraping actions. The evidence of linear impact striations on points with hafting traces in the form of use-wear and residues (such as bituminous substance as well as possible bone residue) indicates that inhabitants of this cave knew how to use these tools as projectiles, likely for hunting. However, this research is still in progress, and future works will shed more light on the subsistence patterns of the humans inhabiting this site.

Keywords: Khorramabad Valley, Kaldar Cave, Early Upper Palaeolithic, Zagros Palaeolithic

1. Introduction

Khorramabad Valley is situated in central Lorestan Province in western Iran and stretches from the northern highlands to the southern lowlands of Khuzistan, which also constitutes one of the important passage-ways for both humans and animals to cross the Zagros Mountain range (Bazgir et al. 2014). It is included within the border of the Palearctic and Saharan-Arabian biogeographic realms, not far away from the Orient (Holt et al., 2013). The presence of abundant water reservoirs, plants, animals, and numerous caves and rock shelters around the valley certainly made it a very favourable place to live. The palaeoenvironmental study of the area shows that it was very suitable for humans and must have played a significant role in their dispersals during Quaternary (Mashkour et al. 2009; Bazgir et al. 2014, 2017). The zooarchaeological evidence in the archaeological site of Kaldar Cave proves that the early Anatomically Modern Humans (AMHs) of the area not only lived with the large Palearctic mammals but also knew how to exploit them as resources (Bazgir et al. 2017: p 4-7). For these reasons, the valley comes under the UNESCO World Heritage Convention (Reserved List) Concerning the Protection of the World Cultural and Natural Heritage.

Since 1930´s, Khorramabad Valley has gained a lot of interest initially by the foreign archaeologists later by the joint Iranian and international archaeologists. In the valley number of Palaeolithic sites has been reported in the form of caves and rock shelters. Among the caves, the most important are Kunji, Ghamari, Yafteh, Pa Sangar, Gilvaran, Kaldar and the only one rock shelter studied up to date is Gar Arjeneh (Figure 1: 1). Henry Field (1939) was the first to excavate in the valley by digging a small test pit in Kunji Cave. Later during 1960's, Kunji Cave was re-excavated by Hole and Flannery (1967) and Speth (1969). In 1964-65, Hole and Flannery (1967) along with Kunji excavated three more cave sites (Ghamari, Pa Sangar, Yafteh) and Gar Arjeneh Rock shelter. After decades, Yafteh Cave was re-excavated by Iranian-Belgium team in 2005-2008 (Shidrang 2007; Otte et al. 2007). In 2012, Indo-Iranian team test-excavated Ghamari, Gilvaran, Kaldar Cave and Gar Arjeneh Rock Shelter (Bazgir et al. 2014). Most of these sites are located on the east, west, and south part of the valley except Kaldar Cave which is situated in the north. In 2014, Kaldar Cave was excavated in larger scale by the Iranian-Spanish team, with the aim to re-evaluate the Palaeolithic cultural materials to trace the transition from Middle to Upper Palaeolithic and also to obtain reliable dating (Bazgir et al. 2017).

Few important studies about these Palaeolithic sites related to their field survey (Field 1939, 1951a, 1951b; Roustaei, 2002, 2004; VahdatiNasab 2004, 2010; Jaubert et.al. 2005), excavation reports (Speth,1971; Otte 2007, 2009; Hole and Flannery, 1967; Bazgir et al. 2014, 2017), faunal and floral remains (Mashkour et al 2009; Allué et al 2018; Rey-Rodríguez et al. 2016, 2018), dating problems (Otte et al. 2011; Becerra-Valdivia et al. 2017) and lithic techno-typology studies (Shidrang, 2007, 2018; Tsanova, 2013; Baumler and Speth, 1993; Otte and Kozlowski, 2007; Bordes and Shidrang 2009, 2012; Otte et al., 2007) have been published. Most of these works mainly focused on understanding the Middle to Upper Palaeolithic transition, the Aurignacian culture of Zagros Mountains, the Baradostain culture of Iranian Zagros, the chronology of the region and the modern human dispersal from western Asia into Europe.

However, in the field of traceology, Iran Palaeolithic shows a lack of interest by the previous researchers. In the recent past, only two preliminary works (Bazgir and Tumung 2014; Claud et al. 2012) on the Palaeolithic stone tools have been published. Claud and her team did a preliminary use-wear analysis on 3 points from the Middle Palaeolithic level of Qaleh Bozi 3 rock shelter, Western Iran, which they believe used for butchery activities. On the other hand, Bazgir and Tumung (2014) analysed 105 diagnostic Levallois-Mousterian and Aurignacian points belonging to the Middle and Upper Palaeolithic layer of Gilvaran, Ghamari and Kaldar caves. The techno-functional results indicated some possible evidence of hunting activities in the area in the form of impact fractures, impact striation and hafting evidences. Both the previous works did not perform any experiments for comparison to understand the function of the tools. These preamble studies show the great potential of traceological studies in this area. Therefore, the present research aims to apply functional analysis approach to reconstruct and understand the past human activities of the Kaldar Cave.

2. Kaldar Cave

This cave is situated in the north of Khorramabad Valley at 48°:17’:35” E longitude, 33°:33’:25”N latitude and 1290 meters a.s.l. It is 16 m long, 17 m wide and 7 m high. This site is located in the “Wild Life Sanctuary” zone (Figure 1: 2). The site was visited by Z. Bakhtiari in 2007 and registered as an Epipalaeolithic site in the LCHTO archive with the file number 18796. Later in 2009, B. Bazgir as a part of his PhD research conducted a comprehensive field survey around the Khorramabad Valley which followed by test excavation at this site in 2011-12, along with other three sites (Gilvaran, Ghamari Caves and Gar Arjeneh Rock Shelter), all showing Middle and Upper Palaeolithic cultural materials (Bazgir et al. 2014).

Figure 1: 1) Location of Kaldar Caves with the other important Palaeolithic sites in Iran as well as in Iraqi Zagros Mountains, 2) The general view of Kaldar Cave

In 2011-12 test excavation, the fill of the cave was investigated with a test-pit of 1 × 1 m2 at the centre, inside the cave very close to the drip. The test pit revealed a 1.5 m stratigraphic succession of five levels and six sub-levels; Level 4 and Level 5 belonging to Upper and Middle Palaeolithic respectively. Among all the four test excavated sites, Kaldar Cave showed the huge potential to understand the transition between both time periods. Hence, in 2014-15, it was re-excavated in larger scale to better understand the stratigraphy with a multi-disciplinary approach, where a functional analysis study of the excavated lithic assemblage was also considered. A

3x3 meter trench opened near the entrance, by keeping a 50 cm bulk from the previous test-pit, using the same datum point and grid (Figure 2: 2).

In the techno-functional analysis on the 2011-12 excavation lithic material (Bazgir and Tumung 2014), we found possible hafting and bone residues along with very well developed use-wear traces, that encouraged us to be more careful with the handling of stone tools during and after excavation. As a precaution, during 2014-15 excavation, all the team members wore powder-free medical gloves while collecting lithic artefacts (Figure 2: 1). They were stored in separate plastic bags without cleaning nor marked with the pen on them, to avoid any post-excavation contaminations. The stone tools collected from the wet sieving were recorded separately under the general finds. The excavation was carried out using metric and contextual methods to plot any bioturbation or disturbance. The excavated trench exposed an approximately 2m (195cm) section of sedimentary deposit and characterised by five main layers.

Layer 1 to 3 (including sub-layers 4 & 4II) consist of ashy sediment with a blackish green colour containing both thick and lean angular stones. It varies in thickness from 60 to 90 cm and contains many phases of the Holocene time, more specifically materials from Islamic era, historical, Bronze Age, Iron Age, Chalcolithic and Neolithic. However, due to the presence of some bioturbation in these layers, the phases were recognised only by a preliminary study of the potsherds, metal artefacts and some diagnostic lithic artefacts from the lower layers.

Layer 4 (including sub-layers 5 & 5II) consist of a fine but dense sediment in dark-brown colour with cultural remains of Upper and Early Upper Palaeolithic. In the uppermost parts of this layer, four thermoluminescence dates obtained from two fireplaces made of clay, yielding age's ranging from 23100 ± 3300 to 29400 ± 2300 BP. The dates obtained from these fireplaces show that they were made or re-used from existing older sediment from the upper part of this layer in the later stages of the Upper Palaeolithic. The C14 dates of this layer has provided old dates ranging from 38650-36750 to 54400-46050 cal BP (all at 95.4% probability) which makes it one of the earliest examples of cultural remains attributed to Anatomically Modern Humans (AMH) in the western Asia (Bazgir et al. 2017; Becerra-Valdivia et al, 2017) (Figure 2: 3).

Layer 5 (including sub-layers 6, 7&7II) encompasses extremely dense sediment in reddish-brown colour with the presence of some small angular blocks and contain Middle Palaeolithic artefacts. Presence of evident Mousterian artefacts from this layer indicates a high potential for understanding the transitional phenomenon of both the layers. To date, this layer did not provide any date.

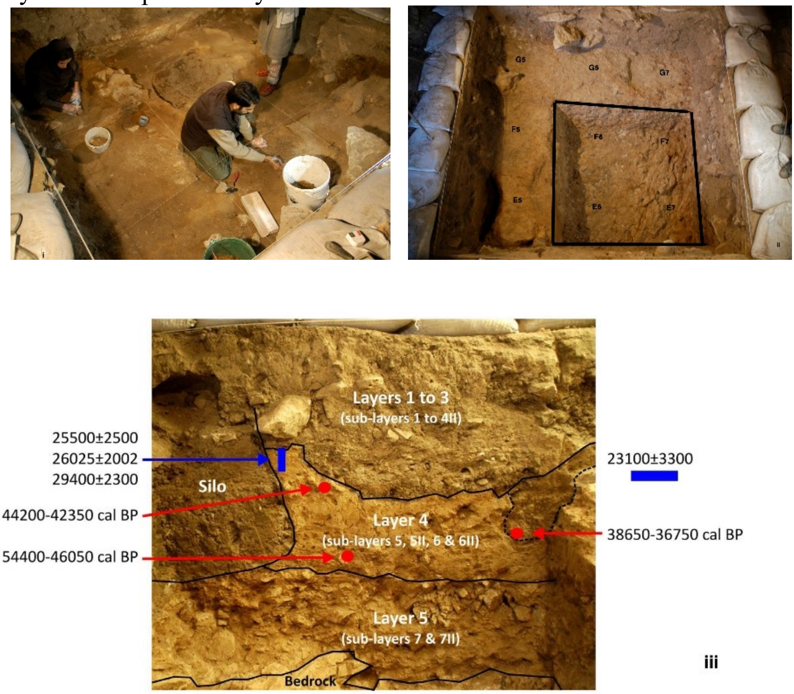

Figure 2: 1) Excavators with powder-free medical gloves to avoid any post-excavation contamination and finger flakes; 2) 3x3 m excavated trench and iii) Detailed stratigraphy of the excavation showing the layers and 3) the locations of the TL and C14 dating.

Flint completely dominates the lithic assemblage of Kaldar Cave. The surrounding area with the easy availability of the flint nodules proves its dominance in the assemblage. The Upper Palaeolithic level lithic assemblage is having total of 431 stone tools, which is comprised of bladelets (13%), followed by blades (12.5%), retouched tools (5.1%), cortical pieces (4.4%), by-products (3.5%), bladelet cores (1.6%), undetermined cores (1.4%), pointed flakes, blanks, and other types of tools (a borer and point; all less than 1%), a blade core (0.2%) and finally a considerable amount of debris (56.4%). Within the bladelet categories, there is a good representation of twisted bladelets (14.3%). Among the retouched tools, Arjeneh points are abundant, but pointed pieces (including Tanged, retouched points, pointed blades and bladelets and Arjeneh points) are more numerous (54.5%) compared to other types of retouched tools. Excluding the debris in this layer, the points and pointed elements comprise 11.2% of the entire assemblage. The next most abundant tools among the retouched pieces are the scrapers (including side-scraper, end scraper and nosed scraper), representing 18.2% of the tools. The number of flakes in this layer is very low (4.6% of the assemblage), and among the flakes, 3.7% are cortical flakes, 0.7% are pointed flakes and 0.2% are retouched flake (see Bazgir et al. 2017, Table 5).

3. Material and Methodology

Archaeological Material

For the functional analysis, we selected 67 archaeological pieces including retouched tools, side scrapers, tanged points, Arjeneh points, bladelets, blades, cortical flakes, and flakes. A first analysis was conducted without cleaning the samples, mainly aimed to identify residues adhered on the tool's surfaces. During this analysis, use-wear was visible on many samples. Consequently, a soft cleaning consisting of a 10-minute ultrasonic bath with just distilled water was enough to remove most of the dirt from the surfaces and adequately record the use-wear.

In the laboratory, as a precautionary measure while handing the stone tools for any type of studies (techno-typological or microscopic analysis), we have always worn powder-free medical gloves to avoid any modern contamination such as the skin flakes (Cnuts and Rots, 2017; Wadley et al. 2004; Pedergnana et al. 2016). While mounting the archaeological stone tools for microscopic analysis, we always avoided the direct contact of the plasticine with the tool using a cling film to prevent residual remain of plasticine on the lithic surface (Crowther et al. 2014; Pedergnana et al. 2016).

Experimental program

To understand the archaeological use-wear traces and to better interpret the possible function of the lithics, we organised a preliminary protocol. In 2016, we conducted a field survey in the Khorramabad valley and collected different types of flint raw materials (varies in colour such as red, green and white) from the surrounding area of the Kaldar Cave. The variety of flint was chosen to test which colour flint function better or produce the use-wear, as we observed the variation of flint in the assemblage. Hence, 12 experimental stone tools were selected (4 from each colour flint).

For the reference of the fresh working edge, before use, we took photographs of all the stone tools. Since in some cases, photographs cannot tell us how the use-wear on edge occurred; we also made a mould and cast to have a reference copy of the fresh edge which would make it possible to compare a given point after the experiment with the same spot on the edge of the mould. For making moulds, we used silicon-based dental impression material, Provil® Novo Light (Heraeus Kulzer, Inc.) and for the casts, a two-component rigid polyurethane resin, Feropur PR-55 (Synthesia Española S.A.) was used. In many previous works, this method has proven to allow proper monitoring of the wear changes on the tools (Ollé and Vergès 2008, 2014; Pedergnana and Ollé 2014; and Tumung et al. 2014, 2015).

Our experimental program included two major groups: butchery processes and wood-working. These were further sub-divided into skinning, defleshing and disarticulation, scraping the fresh skin, and whittling wood. As for the specific contact materials, these included the hide, meat (loin) and bone of *Cervus elaphus*, and *Capra aegagrus hircus* for butchery activities. For wood-working, we used the soft wood of *Prunus dulcis*. We selected these faunal and floral contact materials as they are reported in the archaeological assemblage of the site (Bazgir et al. 2014, 2017 and Allué et al. 2018). We decided to use a longitudinal uni- or bidirectional action (cutting or defleshing) and a transverse unidirectional movement (scraping or whittling) for 30-45 minutes (Table 1).

Lithic number	Worked material	Species	Working angle	Motion	Action	Time (in minutes)
AKF1-H1	Fresh hide	*Cervus elaphus*	90º	Transverse-unidirectional	Scraping	45
AKF1-B1	Bone	*Cervus elaphus*	45º	Transverse-unidirectional	Scraping	35
AFK1-Bu1	Meat-Bone	*Cervus elaphus*	45º-90º	Longitudinal-unidirectional	Cutting/defleshing	30
AKF1-W1	Stem of fresh wood	*Prunus dulcis*	45º	Transverse unidirectional	Whittling	40
KF1-No.5	Meat-Bone	*Capra*	75º-90º	longitudinal-bidirectional	Cutting/defleshing	30
KF1-No.6	Meat-Bone	*Capra*	45º	Transverse-unidirectional	Scraping	30
KF1-No.7	Bone	*Capra*	90º	Longitudinal-bidirectional	Cutting	30
KF4-No.1	Meat-Bone	*Capra*	75º	Longitudinal-unidirectional	Cutting/defleshing	30

KF4-No.2	Bone	*Capra*	45º	Transverse unidirectional	Cutting/defleshing	30
KF4-No.3	Bone	*Capra*	45º	Transverse unidirectional	Scraping	30
KF6-No.1	Meat-Bone	*Capra*	75º	Longitudinal-unidirectional	Cutting/defleshing	30
KF6-No.2	Bone	*Capra*	45º	Transverse unidirectional	Scraping	30

Table 1: List of experiments and principal variables of the program

After the experiment, for the cleaning process we did 10 minutes in an ultrasonic bath of H2O2 (10% volume) to soften any adhered organic tissues of the materials worked and neutral phosphate-free detergent Derquim® (with ionic and non-ionic surfactants) to eliminate all the residues from the surface. After that, we rinse the stone tools under cold running water to remove any detergent from the tool surface. Before the microscopic analysis, all the pieces went through 2 minutes in an ultrasonic bath of pure acetone to eliminate any fatty residue resulting from the handling.

Microscopic analysis

For the use-wear analysis, we used three types of microscopes to understand better and interpret the wear traces. For the preliminary examination of stone tools, a reflected light microscope (Zeiss Axio scope 1, 50x to 500x) had been used to capture the extended focus images obtained using the DeltaPix Insight software with the 5MP DeltaPix-digital camera (Invenio 5SII model) and DIC system (differential interference contrast).

Digital microscopes used for our study are the fully automatized Hirox KH-8700 and RH-2000. These microscopes with CCD imaging offer high magnification (compared to OLM), also generates quick 3D modelling and profiling of the surfaces. Images obtained by automatic stacking and stitching, combined with various ranges of magnifications are powerful for describing the distribution and organisation of traces on the topography of stone tool. These microscopes are also useful for the panoramic images of the working edge to understand the distribution of residues and directions of the motion on the stone tool surface (Martín-Viveros, 2018).

Finally, SEM is used for few selective stone tools with good use-wear traces as it provides a greater depth of field, better images at higher resolution and enables better identification of worked material (Shea, 1992; Ollé and Vergès, 2014; Borel et al. 2014; Tumung et al. 2015). An ESEM FEI QUANTA 600 (Environmental Scanning Electron

Microscope) was used to examine use-wear traces under magnifications from 20x to 2000x at a voltage of 20 kv, at working distances between 10 mm and 30 mm, depending on the size of the sample.

3. Results

Out of 67 analysed archaeological stone tools, 38 are having use-wear traces produced from hafting, cutting, scraping and production wear, whereas 29 did not show any use-wear traces (Table 2). Here, we are explaining few archaeological stone tool examples that showed the clear evidence of use with figures.

Tool Type	Total	Use-wear	No use-wear	Residues
Blades	17	9	8	9
Bladelets	12	7	5	7
Twisted bladelet	5	4	1	3
Flake	24	14	10	10
Arjeneh point	4	1	3	4
Side scraper	1	1		
End scraper	1		1	
Double scraper	1	1		1
Borer	1		1	1
Tanged point	1	1		1
Total	67	38	29	36

Table 2: Showing the type of tools analysed with a total number of stone tools with the presence of use-wear and residues

Among the points, two diagnostic points (tanged point and Arjeneh point) showed the evidence of hafting as both the tools have striations perpendicular to the edge or deep groove on the medial part of the tool (Figure 4 and 5). These kinds of striations and groove can be related to hafting as seen in the experimental program performed by Monod (2013). The Arjeneh point also showed a considerable amount of striations on the tip and the proximal part of the tool both on the dorsal and ventral surface. In the distal tip, the striations are deep and perpendicular to the tip, whereas in the proximal part the striations are long, parallel and criss-cross to the longitudinal axe of the tool and also have heavy smooth polish on the proximal end (Figure 5). Another bladelet point showed the evidence of deep linear impact striations on the tip running perpendicular to the tip (Figure 3). These kinds of impact striations appear on points when used as a projectile (see, e.g. Rots, 2011; Fischer et al. 1984). Hence, these impact striations on the tip of Arjeneh point and bladelet point indicates that they were possibly used as projectiles, likely for hunting purpose.

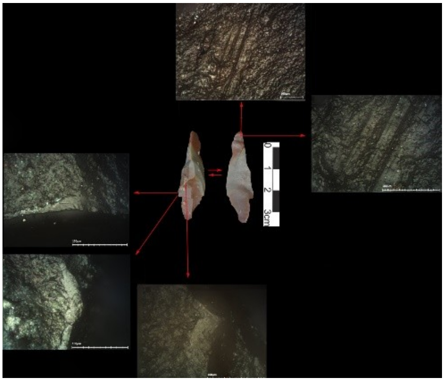

Figure 3: Pointed bladelet with impact striations on the tip.

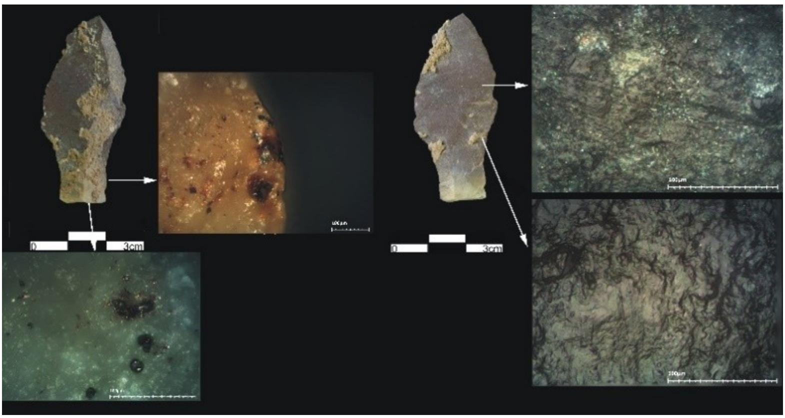

Figure 4: Tanged point with the perpendicular striations on the medial part and black residue on the proximal end.

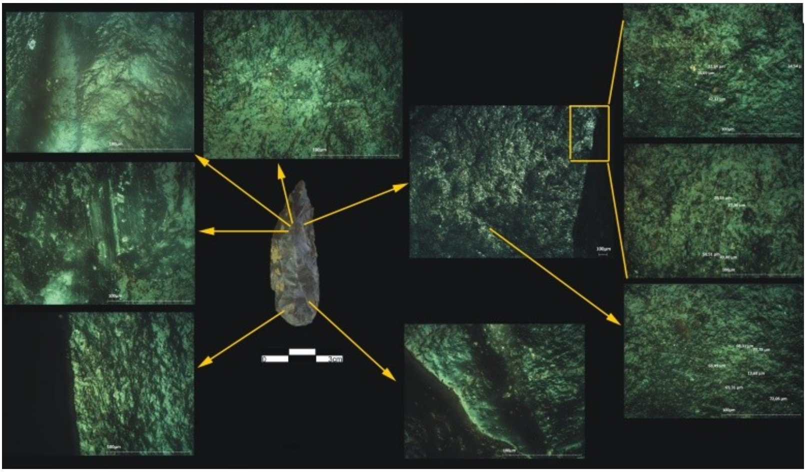

Figure 5: Arjeneh point with impact striations on the tip and deep striations with polish on the hafting area.

A cortical side scraper must have been used on the soft material for scraping as it shows the evidence of continuous polish, edge rounding from the tip to the bottom of the edge with few diagonal striations on the medial part of the tool (Figure 6).

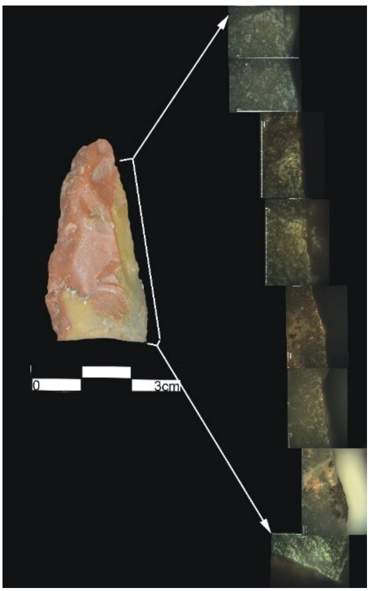

Figure 6: Heavy polish and edge rounding on the cortical side scraper

Among the blade and bladelets, six tools showed polish and striations on the proximal part related to tool production. Twelve small blades and twisted bladelets are with polishes; few are related to use-action, and others are undetermined. Among flakes, small flakes with no diagnostic features showed lots of striation, polish, edge rounding and micro-edge fracture covering all over the edge compared to the large stone tools. Some of the tools showed unusual smooth polish similar to the types of polishes analysed in the site of Micoquian site Inden-Altdorf, which possibly have been produced by mineral working (Pawlik and Thissen, 2017).

In our preliminary residue analysis with an optical and digital microscope, we have observed 36 stone tools with the presence of different colour residues (black, red, pale brown and silver colour) on the surface. Out of which 30 stone tools showed the presence of black residue. By analysing few of these samples under FTIR, they have shown the result of bituminous substance (Ollé et al. 2018). These kinds of black residue on the tool surface are often inferred as hafting resins by the previous scholars (Pawlik and Thissen, 2011, 2017; Boëda et al. 1996, 2008; Monnier et al. 2013). Therefore, we created a reference collection of the modern day resins collected from Khorramabad Valley and analysed them by applying different methods and techniques for future comparison with our archaeological stone tools (Ollé et al. 2014, 2018). In our current research program residue analysis is still an on-going process, but until now, three stone tools have been identified as a bone residue by combining morphological and chemical traits (Tumung et al. 2018). We have also observed few silver colour striations on the stone tools which are the results of the modern excavation tool marks occurred on five stone tools with some impact striations.

5. Discussion and final remarks

Although our experimental program was small, however, it provided the right amount of information about knapping techniques as well as the distribution of the use-wear and its development on the lithics. In our experimental study, we observed that the selection of raw material plays a vital role in knapping activities. The cobbles selected from Khorramabad Valley had lots of fissures and were small in size. Therefore, it was slightly difficult to knap the desired tool shape. Our use-wear analysis showed that the archaeological lithics had been used for a longer duration of time as the use-wears on the experimental pieces are not as developed as the archaeological ones. More experiments with longer duration are needed for a better interpretation. In defleshing and disarticulating action the tools worked efficiently, but after long duration they lose the sharpness and cannot cut through tendons. Bone scraping gives much-developed polishes compared to the other scraping actions (fresh hide and wood). In cutting bone actions, we lose the use-wear traces as micro-chipping of the edge happened during the experiment, which could mislead in the interpretation of some archaeological samples (mainly in case of bladelets cutting edges) resembling retouch appearance. In our experimental program, we realised that the choice of the flint colour also effects on the efficiency of the function and use-wear development. Red flints worked much better than the green and white colour flints. The experiment results are in agreement with the dominance of the red flints within the recovered archaeological assemblage although more petrological research is required to assess this observation accurately.

Finally, precautions during the excavation and in the laboratory are crucial steps to avoid any post-excavation contamination as well as for preserving archaeological residues. Comparing with our previous techno-functional and present use-wear analysis, we can see that there was some possible hunting activity around the site. However, this research is still under progress of analysing these stone tools with different microscopes for identifying different types of residues and reconfirming their chemical characteristics by using non-destructive methods such as micro X-Ray diffraction (µXRD), Raman spectroscopy and Fourier Transform Infrared Spectroscopy (FTIR). The results obtained until now have been positive. The future works will be compared with the techno-typological features of the stone tool as well as with the wider sets of experiments to interpret the function of the tools to recreate the subsistence patterns of the site.

5. Acknowledgements

We would like to thank the directors of RICHT and ICAR (Seyed Mohamad Beheshti and Rohollah Shirazi) for their supports and cooperation with our Palaeolithic studies in the area. This research is conducted in the framework of a signed scientific agreement between RICHT and IPHES. Research has been developed in the framework of the Spanish Ministerio de Economía y Competitividad project CGL2015-65387-C3-1-P (MINECO-FEDER) and as well as the Catalan AGAUR project 2014SGR899 and the URV project 2017PFR-URV-B2-91. We would also like to thank the Service of Microscopy at the URV Scientific Resources centre for providing the facilities for us to conduct the microscopic analysis. Miquel Guardiola helped us with the knapping session for making experimental lithic, for which we are thankful to him. B. Bazgir was beneficiary of a Fundación Atapuerca doctoral scholarship. L. Tumung is the beneficiary of PhD scholarship funding under the Erasmus Mundus Program-International Doctorate in Quaternary and Prehistory.

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5.3. Few examples of Middle Paleolithic Level

Figure 5.1: KLD-F6-7II-1145 (retouched Levallois point) showing the dorsal and ventral side of the tool. Dorsal side showing the use-wear locations

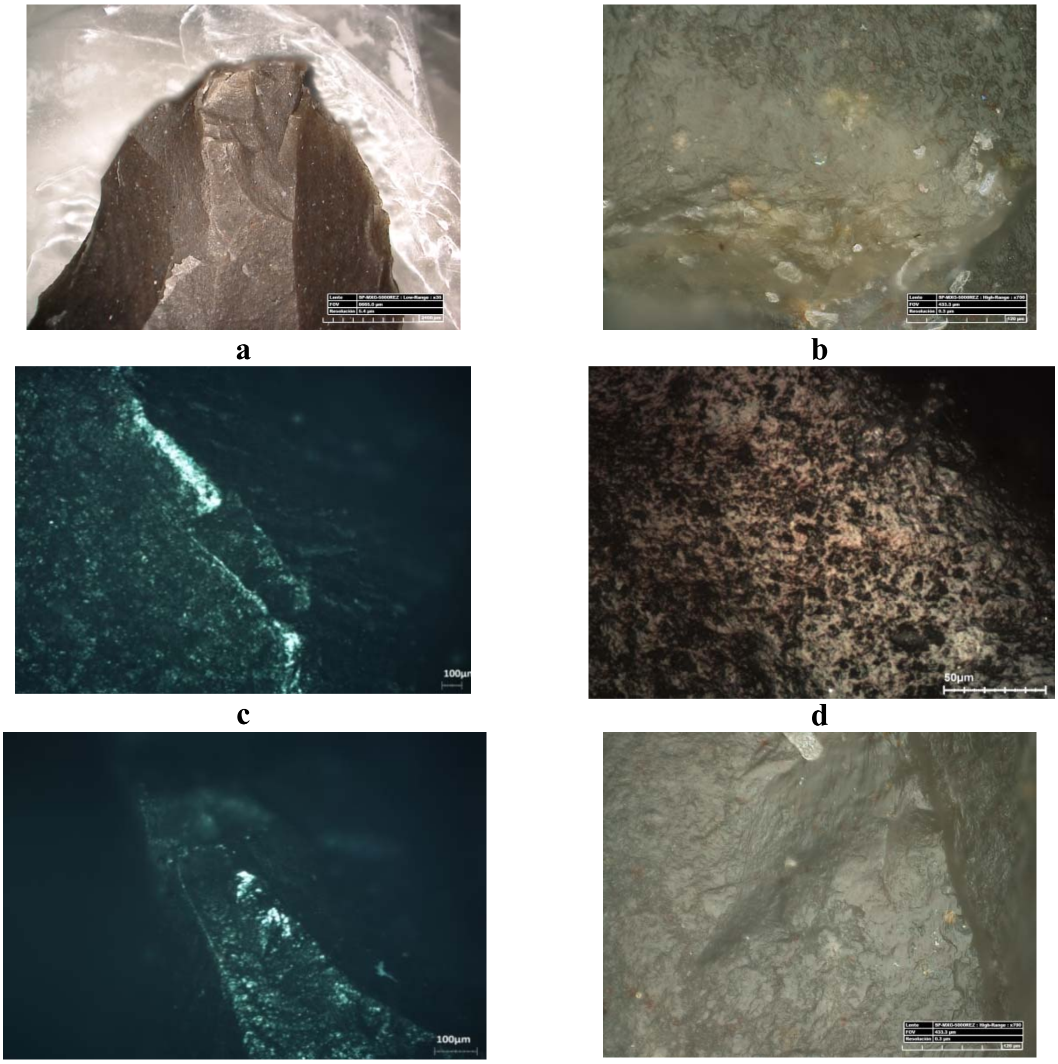


Figure 5.2: KLD-F6-7II-1145 (Retouched Levallois point) a) tip fracture at 35x; b) polish and striations at 700x green dot on the tool; c) location of the polish and fracture on the tip shown in yellow dot at 50x; d) same as (c) detail of the polish at 700x; e) polish on fracture at 50x; f) same as (e) detail of the polish at 700x

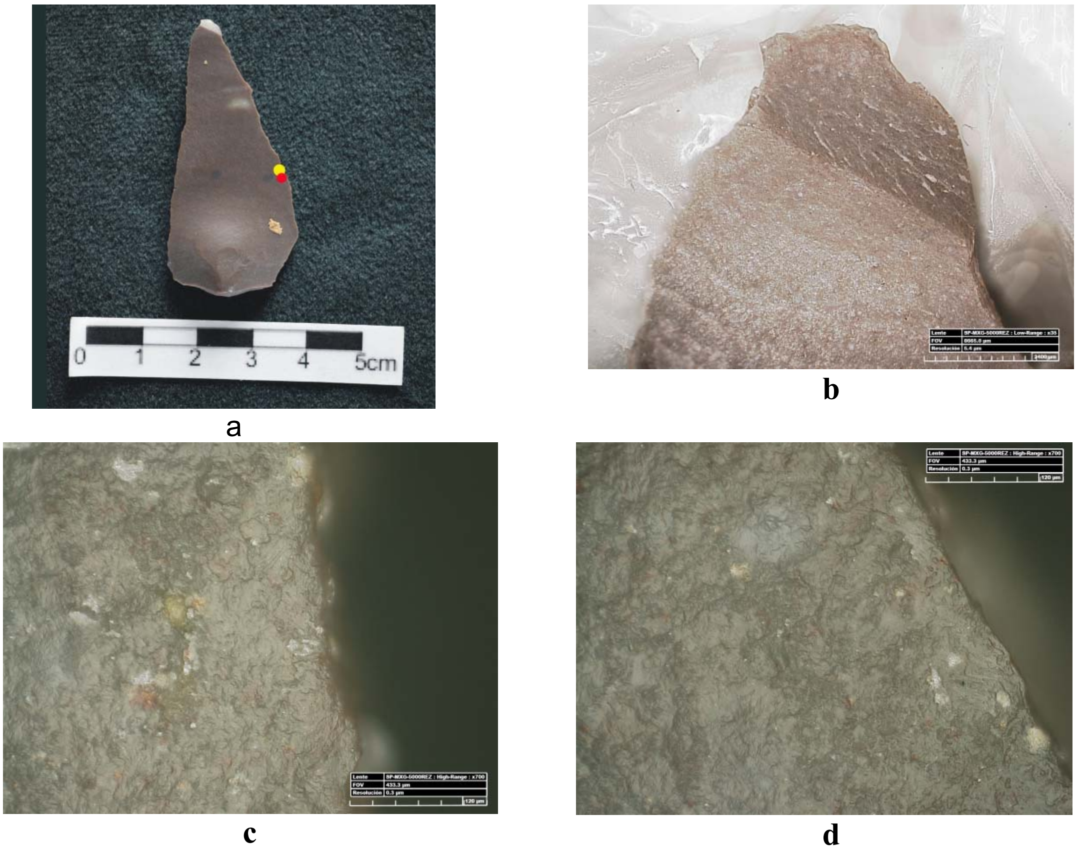
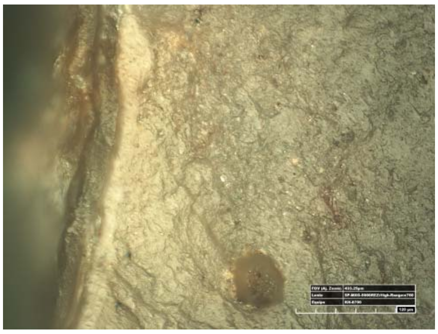


Figure 5.3: KLD-F6-7II-1145 (retouched Levallois point): a) ventral face of the tool with the locations of the use-wear; b) detail of the tip fracture; c) yellow dot showing the edge rounding, polish and small striations; d) polish and striations running diagonal to edge possible hafting traces.

Description: KLD-F6-7II-1145 shows the very clear tip fracture on the dorsal side as well as polish on the ventral side of the tool. On the dorsal site, tip is showing polish on the high topographical points with the fracture. No residue was attached to the tool. On the ventral side besides the tip fracture; there is also the edge rounding and diagonal striations on the edge showing the evidence of hafting traces. The use-wear indicates that this tool might have been used as a projectile.

Figure 5.4: KLD-F6-7II-843(Mousterian point) showing the dorsal and ventral side of the tool and the location of the use-wear


a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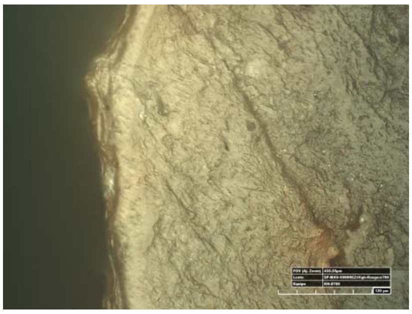
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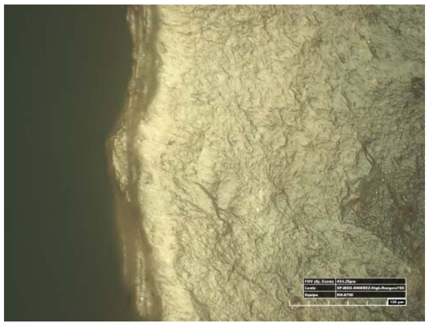
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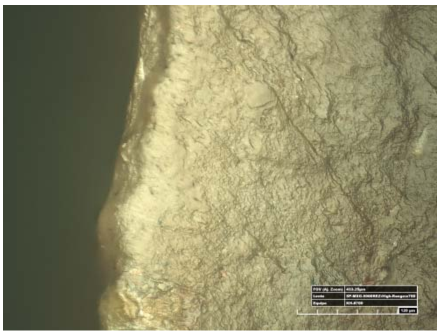
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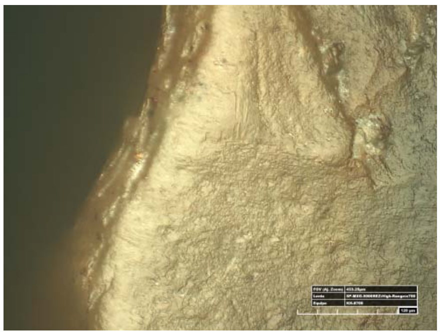
f

Figure 5.4: KLD-F6-7II-843 (Mosuterian point); a) point 2 on the figure 5.3 showing the location of the edge rounding, polish and striation locations at 50x; (b-f) same as (a) showing the details of the use-wears at 700x; (b-e) edge rounding and polish at 700x; edge rounding, polish and a few small parallel striations

Description: KLD-F6-7II-843 shows heavy polish and edge rounding with a few small striations on the edge. The polish is slightly diagonal to the edge. The type of polish if we compare with the experiment one they indicates towards scarping action.

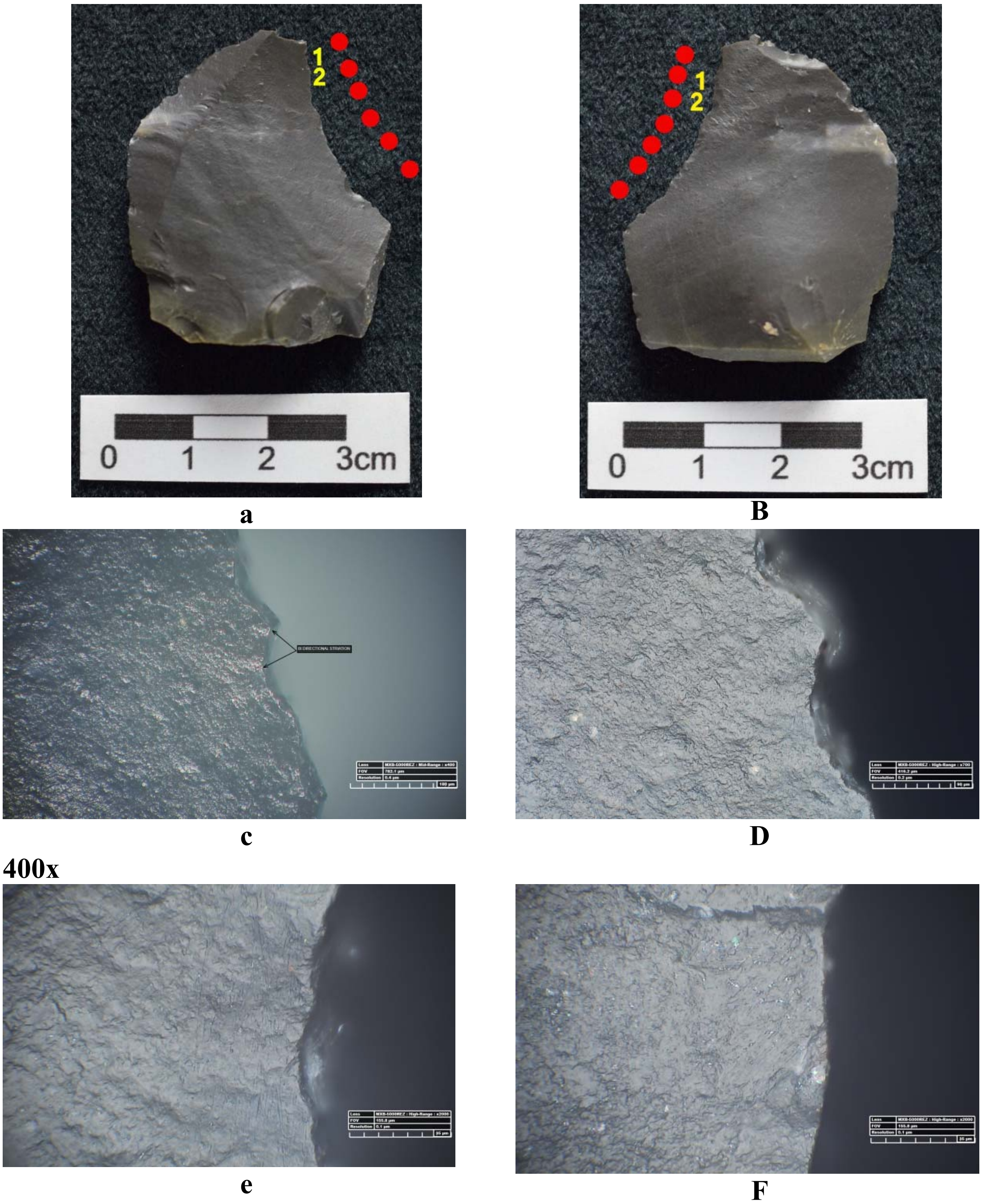

Figure 5.5: KLD-E6-7II-1078 (Levallois flake) (a-b) dorsal and ventral side of the tool showing the working edge; (c-f) use-wears on the dorsal side; c) location of the striation of point 1 at 400x; d) same as(c) detail of the criss-cross striations at 700x; e) same as (d) at 2000x; f) point 2 diagonal striations on the edge at 2000x

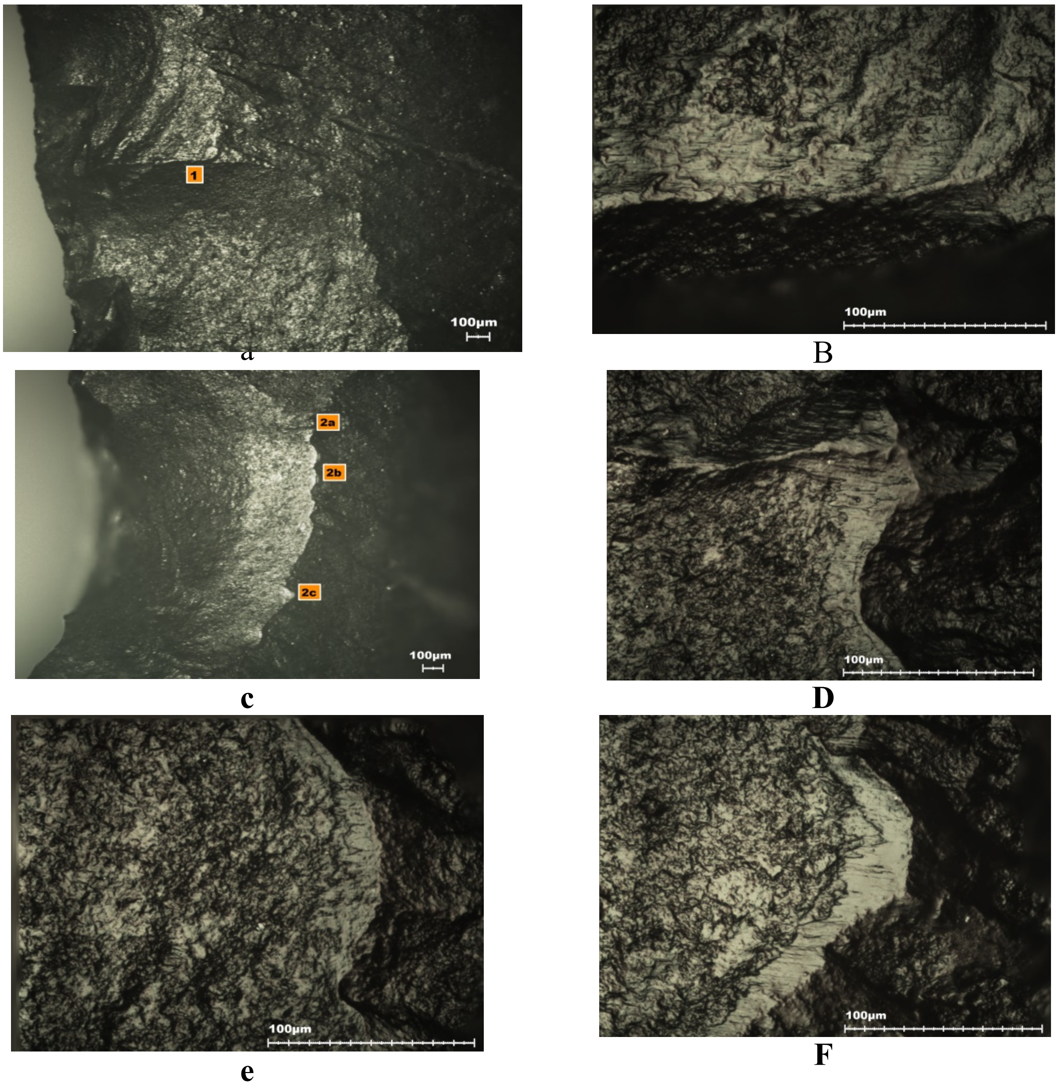

Figure 5.6: KLD-E6-7II-1078 (Levallois flake) (a-f) use-wear on the ventral side; (a) location of point 1 at 50x; b) same as (a) showing the striations running perpendicular to the edge 500x; c) location of point 2 at 50x; (d-f) showing the polish at 500x

Description: KLD-E6-7II-1078 (Levallois flake) shows polish, long parallel as well as criss-cross striations on the edge. Possible used for cutting action.

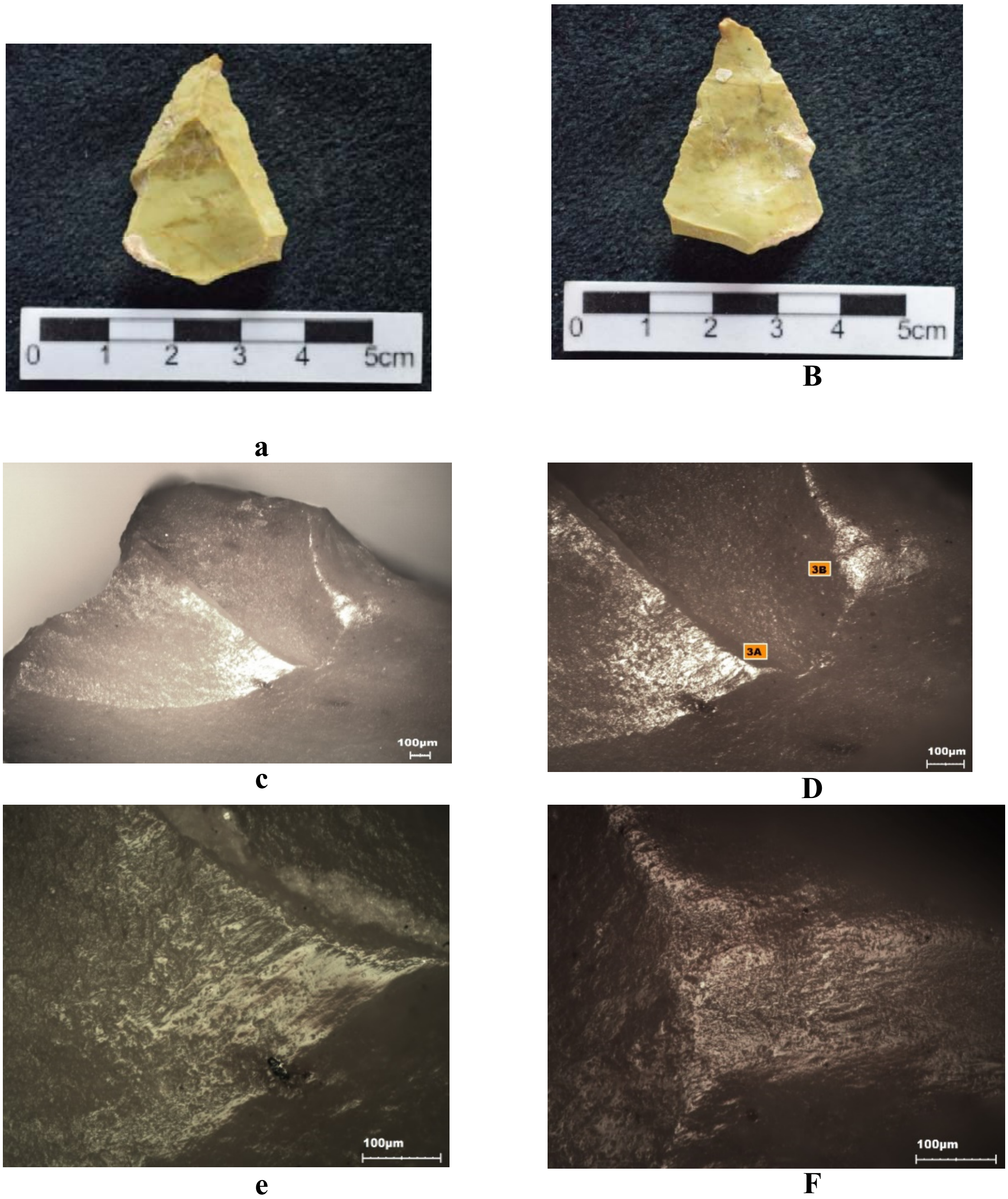

Figure 5.7: GLV-AY1-5-7710 (Levallois point); (a-b) dorsal and ventral side of the tool; tip fractrure and heavy polish formation on the fractur of the tip at 50x; c) closer view of the polished on the fracture at 100x; (e-f) the closer view of the polishes at 200x.

Description: GLV-AY1-5-7710 shows tip fracture and also the formations of the heavy polishes on the fractures. The polishes are very heavy and the direction of them indicates unidirectional motion. The polish direction on the tip does not suggest as borer but could have been used to scrap hard material for scraping.

CHAPTER 6

DISCUSSION AND CONCLUSION

Scientific research involves going beyond the well-trodden and well-tested ideas and theories that form the core of scientific knowledge. During the time scientists are working things out, some results will be right, and others will be wrong. Over time, the right results will emerge.

Lisa Randall

CHAPTER 6

DISCUSSION AND CONCLUSION

Zagros Mountains covering the major part of the Iran from northwest to Strait of Hormuz with some parts of Iraq and Turkey play a significant role in our understanding of the human evolution by decipher many interesting evidences associated to Neanderthals and AMH. Unlike the Iraqi Zagros, Iranian Zagros shows very scattered evidences of human remains. However, technologically the whole Zagros region have shown some interesting adaptions in the manufacturing of the stone tools.

Since decades, various technological studies have been applied for the understanding of the lithic assemblage. However, the functional studies are the recent adaptation to the Zagros Palaeolithic sites (Claud et al. 2012; Bazgir and Tumung 2013; Hunt et al. 2017). Therefore, the main aim of this research was to check the feasibility of the functional studies for the Iranian Palaeolithic sites. In the course of this research, the set goals to reach the desired results many new adaptations were made. Especially, developing a methodology which is effective for the functional analysis and applying them for the study of Iranian archaeological material. Finally, all the set goals for this research and their results have been addressed and discussed below.

6.1. Methodology

6.1.1. Control measures in the excavation and in the laboratory

In the functional analysis, it's well known that use-wear and residue are not always use related and many times it starts to form on the tool surface during the burial process as well as during excavation and later in the laboratory (if proper precautionary measures are not considered). Since decades it is emphasized by the previous researchers regarding the precautions while handling tools in the excavation or in the laboratory (for eg. Bordes et al 2017; Croft et al. 2016, 2018).

The adaptation of the functional studies for the Iranian Palaeolithic sites is very recent, therefore, the excavation methods usually are not controlled. This research first time addressing this issue for the Iranian sites and proposed a protocol of controlled excavation.

Here, I present the case study of the Khorramabad Valley sites especially focusing on the Kaldar Cave. This site was test excavated in 2011-12 in conventional way the excavations are done and later in 2014-15, where the control protocol for the excavation was applied for the functional studies. In 2011-12 excavation the aim of the Khorramabad project was to test the theory of M-UP transition and to acquire the samples for dating as well as to reconstruct the palaeo-environment and lithic technology. Therefore, no attempt was made to control the cleaning methods or for the curation of the tools. In this excavation season, Kaldar Cave along with other test excavated sites (Gilvaran, Ghamari and Gar Arjeneh) showed the high dominance of points in the assemblage (Bazgir et al. 2014). Consequently in 2013, out of curiosity 105 pieces diagnostic Levallois-Mousterian and Aurignacian points, were studied to check the feasibility of the functional studies, out of which 20 samples showed the results of possible use-wear and residue related to hafting and hunting activities.

The results presented both the archaeological post-depositional and modern contamination happened in excavation and in laboratory. Use-wear analysis showed the modern use-wear in the form of impact striations formed by excavation metal tool as well as fractures. Residue analysis, showed many modern contamination happened in laboratory while handing the tool such as traces of nail paint, glue, pencil marks, fabric fibre, hair, molding clay and finger skin flakes. Some of these residues can be confusing, for example, skin flakes or moulding clay can be thought of as organic residue due to their organic nature under SEM with EDX with the presence of carbon and oxygen as the main chemical component (Pedergnana et al. 2016).

Noticing these issues, 2014-15 excavation season, the functional studies were planned from the various beginning. Tools were not touch directly nor marked or glued that fractured pieces to avoid any further contamination. In the lab, also molding clay was always covered with the plastic film and user always wore nitrile powder free gloves while handling them to avoid finger flakes which is the common problem noticed by Pedergnana et al (2016) and difficult avoid. The plastic film and the nitrile gloves always changed between each use to prevent cross-contaminations between tools.

Although, these methods suggested to be very effective to prevent in controlling the modern contamination, in the recent work by Bordes et al (2017) cast some doubts. He and his team applied Raman Spectroscopy on the stone tools from the site of Liang Bua (Flores, Indonesia). Besides the archaeological residues, they also analyzed the nitrile gloves, plastic bags and Blu-Tack® with Raman spectroscopy. In their results it showed that nitrile gloves spectra fingerprint is different than the other organic micro-residue. However, materials like Ziplock® bags and Parafilm® are more problematic, because the main bands of their spectra are similar to those of unsaturated fatty acids and misinterpretation is possible in spectra with low signal-to-noise ratio (Bordes et al. 2017). However, for the present study this issue didn´t cast any problem in our residue analysis.

Although, various precautionary measures have been applied in the present research study to avoid modern contaminations, but they are still having some limitations such as metal tool wear (Gutiérrez-Saez et al. 1988) were difficult to control in our excavation as the sediment was very hard. Therefore, heavy metal chisel and hammer were used to excavate (Bazgir et al. 2017) which consequently resulted on the tool surface. However recently, Croft (et al. 2018) have discussed about the excavation protocol which they adapted in the Mesolithic sites of Star Carr. In this excavation, excavators collected each lithic for residue analysis by inserting a trowel into the soil just below the lithic and levered it directly into a polyethylene zip bag, without touching the lithic. This method can be very useful to prevent any possible metal tool mark on the tool but again it also depends of the sediment quality as observe in our excavations. Besides taking the precaution while collecting the tool, She also collected a small sediment sample (~5 g) taken from below each lithic with a trowel and placed in a zip bag, which were later stored in a fridge at 5 °C to slow the decomposition of any potential archaeological residues by fungi, bacteria, microorganisms, and/or worms and insects. This method is useful to understand weather the residue are use-related or post depositional.

Finally, if compared both the excavation seasons of the Kaldar Cave, 2014-15 excavation showed considerably less modern contamination compare to the previous test excavation except for some occasional metal tool wear.

6.1.2. Feasibility of Digital 3D Microscopy (3D DM) for functional studies

From decades, the application of OLM and SEM (pair with EDX or EDS) have already discussed by the previous researchers showing its efficiency in interpreting the traces (e.g. Ollé and Vergès 2008, 2014; Borel et al 2014; Pedergnana et al 2016). 3D DM (especially of Hirox) is the recent adaptation to the functional studies. Although, used for various discipline studies taphonomy, palynology and use-wear. Its efficiency for the functional studies was not widely explained by the previous researchers except for the brief detail of the microscope (Revedin et al 2015; Arrighi et al 2016; Martín-Viveros 2016a, 2016b; Bowosachoti 2016). In this study, it was noticed that this microscope has many benefits over OLM such as magnification (35x to 5000x) and better resolution of the images with 3D graphic to check the placement of the use-wear and residue on the topography of the tool. Still the micro-graphs of the traces captured with 3D DM lack some aspects of depth of field in relation to SEM. For example, it can capture the traces till the 1000x with high range lens and occasionally till 2000x but after the images starts to blur making the traces unidentifiable which is not the case with SEM.

For the residue analysis, 3D DM similar to OLM can only identify the residues till the morphological level (colour, microstructure and distribution on the artefact) but SEM with EDX provides the opportunity to identify the residue till molecular level. However, 3D DM can provide the high magnified view of the residue to check the morphological feature of the residue as well as its topographic view with the help of 3D imaging. Unlike the OLM, for capturing the image 3D DM automatically select the number of micro-graphs needed to capture depending on the topography of the tool surface as well the magnification used. For example, in 35x (low range lens) the images are usually captured between 8-20 micro-graphs of 500μm, whereas, for the 700x (high range lens) between 30-200 micro-graphs of 2μm. The light source provided by this microscope also enhances different type of traces depending of the magnification used. For the white, christaline or glossy raw material needed to be analysed by using the combination of ring and coaxial light as well as with the polariser and directional light adapter. For identifying the use-wear traces, especially the polish and striations at high magnification (600x above), coaxial light enhance the traces, whereas, for residue analysis, ring light can be used even in the high magnification of mid-range lens. For the capturing the mosaic images the lateral light source (place from the sidewise) is useful to enhance the micro fracture and captures an even panoramic view of the edge to understand the distribution of the traces. The automated working stage also helps in moving the sample without too much touching it. Unlike the SEM, this microscope does not need any special precaution for its maintenance.

6.1.3. Non-invasive multi-analytic approach

In the years of work in functional analysis, it is very notable that one specific approach cannot completely answers all the aims related to use-wear or residue. The multi-analytic approach proved to be more promising for identifying the traces and also to understand residue from macroscopic to molecular level (e,g. Boëda et al 1996; Monnier et al. 2013; Pedergnana et al. 2016).

Therefore, a multi-analytic approach was adapted for the present study which was suggested by various previous researches. The opportunity for such study was possible as these microscopes (OLM, 3D DM, SEM with EDX) and advance equipment's (FTIR, μXRD) were available in the laboratory of the university or the institute with whom this research project collaborated. The application of the non-invasive multi-analytic approach in this research showed that it is very helpful for identifying the residue and also to observe the similar residue for several times with different techniques.

6.1.4. Reference collection of modern day residue (adhesive and bone)

For the residue analysis, the problem of identification of residues are their degraded form after the burial process and in the absence of no reference collection it becomes difficult to identify the residues. Thankfully many previous works have provided the reference collection of the different types of modern contaminations (Wadley et al. 2004; Pedergnana et al. 2016; Croft et al. 2016; Bordes et al 2018) and others have provided the reference collections of the worked material (e.g Pedergana and Blasco 2016; Monnier et al. 2017, 2018) by using different microscopes and tecniques. Similarly, there are number of studies which presented the results of archaeological adhesive obtained with different methods and techniques (e.g. Boëda et al 1996, 1998; Pawlik and Thissen 2011; Monnier et al 2013). This helps in identifying the archaeological residue to some degree but when it comes to the identification archaeological adhesives a comprehensive study of the modern day adhesive material present around the site is necessary to strengthen the result.

In most of the cases, these adhesive reported from different sites appeared in black colour and the similar situations observe in the sites of Khorramabad Valley. Therefore, a through field survey of the valley was conducted in 2013 to collect all the possible adhesive material present in the valley. This research project also collaborated with the other research groups of IPHES where the similar blacks spots have been reported in their sites. To understand the common ocurrence of these black residues we applied many non-invasive techniques to analyse the residues. These modern adhesives were analysed with different microscope to understand their morphological features and also their chemical composition was check with different technique (SEM with EDX and FTIR) for future reference to identify the archaeological adhesives. Each adhesive material was showing different spectral graphs obtain with different techniques and it was very useful to compare the archaeological residues. For the bone residue, the reference collection was made by using modern bone as well as archeological bone for difference and simlimarities in the spectra distribution. This reference collection is not only helpful for the present studies but as well for the future studies. However, more analysis is still need to perform with other techiques also to strengthen the results.

6.2. Archaeological applications

6.2.1. Feasibility of the functional analysis for the Khorramabad Valley sites

The flint condition is remarkable well preserved except for a few samples with slight patination. Functional analysis of the stone tools has shown very good results with the use-wear as well as the residue adhered to the tool surface. Residue analysis have shown the results 1) black spots as bituminous substance 2) amorphous, pale brown colour residue as bone residue and 3) black oval shape chain type residue as Sporomiaceae (which are a type of fungi found in dung). The presence of all these residues on the tool surface indicates that the soil preservation for these residues were suitable.

Finally, the results indicate that functional analysis is feasible for the Iranian sites and should be considered as an important part of the research for the future excavations.

6.3. Final remarks

The research has shown that with a structured methodology followed in the excavation and in lab, it can help the traceologists a lot to identify the traces with more authenticity by minimising the possibilities of errors.

For the multi-analytic approach, the application of 3D DM is a very effective methodology for the functional studies. In the absence of OLM, this microscope can be used alone as it provides much higher magnification to identify the use-wear thanks to the possibilities of high magnifications (35x upto 5000x). However, for the residue it can only help with the identification till the morphological level. Hence, need to be paired with SEM with EDX for better view of the use-wear traces (above 1000x) and for the identification of the residue by extracting the chemical composition of the residues.

For the residue analysis, SEM with EDX is very efficient for certain residues identification, but it is better to combine it with other techniques (such as FTIR, μXRD, Raman spectroscopy) for strengthening the results. For the identification of the adhesives the reference collection we created with the collaboration of my traceology colleagues in IPHES and ICFO has provided a different insight for the identification of different types of adhesives. This reference collection was very helpful for identifying the archeological adhesive residue found on stone tools from Kaldar.

6.4. Future prospect

For the future prospect, first the processing of the already extracted functional results will be performed for the quantitative analysis to publish them later in indexed journals. Along with this the experimental program will be expanded by performing more butchery, projectile as well as plant base experiments. Even the petrological analysis for the Khorramabad flint will be introduced to understand the variations in the microwear in comparison to other varieties. For the microscopic analysis, 3D DM will be tested for the quantitative analysis and the results will be compared with the confocal microscope. For the residue analysis, Raman Spectroscopy and GC-MS also will be included for the identification of the residues.

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