Sustainable Earth Review 3(3) 2023 77-90

Shahid Beheshti University

Sustainable Earth Review

Journal homepage: http://sustainearth.sbu.ac.ir

Investigations at “Chakherbaz Holes”, western Iran, Kurdistan: A possible ancient mining/smelting site

Sarem Amini[a], Elham Fotuhi Dilanchi[a], Khabat Derafshi[*b]

[a] Geoarchaeology Research Group, Zaminrizkavan Research Co., Tehran, Iran

[b] Department of Natural Heritage, Research Institute of Cultural Heritage and Tourism, Tehran, Iran

A B S T R A C T

Chakherbaz Holes are two contiguous semi-circular holes, one larger and more preserved than another, on siliciclastic base rocks firstly identified as possible meteorite impact structures. In search for the evidence of meteorite impact, metal-bearing slag fragments and partially oxidized iron particles were founded along with iron-stained mineralized breccias fragments within soil and rubble covering the inside and outside surfaces of the holes suggesting a mining/metallurgical site for the origin of them. Native iron was detected by the EDAX analyses of the metallic globules enclosed in two small slag fragments found at the site. During the magnetic survey within soils covering the inside and outside surfaces of them, metallurgical iron particles were detected as proved by their respected EDAX spectra. Whether the metal particles of smelting or smithing origin are not yet clear. The observation of copper sulfides within matrices of iron particles are evidences for possible iron-fluxed copper metallurgy at the site. Further prove for this hypothesis is the presence of copper ore minerals associated with breccia fragments around the holes. The collective evidence suggests the Chakherbaz Holes to be an ancient mining site with negligible smelting practices. This is supported by the discovery of a Sherd in the fill materials. The abundance of iron in the metallurgical finds and inasmuch as no typical hammerstones have been identified imply an age probably not older than Iron Age for the site which is compatible with the age of most archaeological sites, like Ziwiyeh and Ghalaichi, at this part of western Iran.

A R T I C L E I N F O

Keywords:
Ancient Mining
Archaeometallurgy
Copper
Iron Age
Northwest of Iran
Smelting

Article history:
Received: 28 Mar 2023
Accepted: 05 Jun 2023

*Corresponding author
E-mail address:
kh.derafshi@richt.ir
(Kh. Derafshi)

Citation:
Amini, S. et al., (2023). Investigations at “Chakherbaz Holes”, western Iran, Kurdistan, *Sustainable Earth Review:* 3(3), (77-90).

DOI: 10.48308/SER.2024.234381.1033

1. Introduction

Mining has been a human endeavor for thousands of years. Sites located in South America, Europe, Africa, North America, Asia and even Australia attest to its global nature (Sagona, 1994; Kassianidou, 1998; Knapp, 1998; Bamforth, 2006; Salazar et al., 2011). Both mining and smelting are inherently destructive operations. Whatever was being sought in terms of ore will, in most cases, have been extracted, then processed, and finally removed from site. Primitive mining, involving the time-consuming hand-crushing, hand-picking and separation of mineral can be a highly efficient operation. So much so in fact, that what might at first sight seem a perfectly straightforward question - for example, whether this was a copper or lead mine - can sometimes prove difficult to answer (Bick, 1999; Mighall et al., 2000; Timberlake, 2007; Novo et al., 2012). If it was a copper mine, then was it the sulphides or the carbonate minerals formed from the surface oxidation of these sulphides (or a combination of the two) that was being extracted (Craddock, 1995; Timberlake, 2003; Tucci et al., 2014; Zibret et al., 2018). Still more rarely do intact smelting operations survive within the archaeological record. Furnaces are broken down to extract metal from incomplete smelts, components of the furnace wall and tuyeres are recycled, while slags produced as part of earlier and more primitive smelting operations could have been broken up and crushed to release prills of metal, the residue being used as temper within ceramics or refractory materials. Indeed, 'proper' slags may never have been produced in these operations (Killick, 2015; Camizuli et al., 2018; Bourgarit, 2019). The first evidence of extractive metallurgy dates from the 6th millennium BC in the Near East (Hauptmann, 2007; Radivojević et al., 2010). Since then, mining and smelting activities have developed almost everywhere that humans have settled (Tylecote, 1992; Craddock, 1995), resulting in the emission of unexpectedly large amounts of metals into the environment, e.g., during the Roman Empire (Nriagu, 1996; Rosman et al., 1997). With geographical shifts of human settlements over time, some mining and/or smelting sites may have vanished from collective memory (Didier, 2009; Monna et al., 2011; Camizuli et al., 2014). The Iranian Plateau or the Persian Plateau is a geological feature in Central Asia, South Asia and Western Asia. It is the part of the Eurasian Plate wedged between the Arabian and Indian plates, situated between the Zagros Mountains to the west and the Alborz Mountains to the north. With regard to early metallurgy, the mountains are of major importance: as part of the Tertiary Aplitic formation, they host an abundance of metalliferous mineralization with ores of copper, lead, silver and others (Helwing, 2013). The "Chakherbaz Holes" are enigmatic features about 21 km to the northeast of city Saqqez at 1680 a.s.l (western Iran, Kurdistan Province) (Fig.1). They include two adjacent, rather circular holes, one bigger than another, at the base of a ridge composed of Oligo-Miocene limestone. The holes are known by most of the local folk as the scars left by lightning strike! However, it is well understood scientifically that lightning doesn't make holes in the ground other than tubular features known as "fulgurites" resulting from the fusion of soil sand component. The current research was initially stimulated by reconnaissance visits to the site during which the holes were identified as candidates for meteorite impact structures. In line with the significance of the subject, three questions and hypotheses were considered when initiating the present research: 1) Considering the importance of Kurdistan from the point of mining studies, in which period did the oldest mining evidence in this region emerge? 2) The evidence of extraction of which metals from mines and furnaces was identified? and 3) What are the evidences for a meteorite impact, fragments and particles suggesting mining/metallurgical site for the origin of the holes. By studying Chakherbaz Holes which are two contiguous semi-circular holes, we can better understand the process of the metalworking industry, including mining, metal extraction, and smelting, and finally, recognize the metalworking of the region and the socio-economic role and effects of the metalworking industry in the context of historical and cultural developments in Kurdistan.

Our view about the site changed during the examination of the materials to find definite evidence for impact. Despite much endeavor to find the evidences for impact, most of our finds prove to be anthropogenic and of metallurgical origin. Following are the results of these studies since 2006 beginning with an introduction to the holes followed by a rather detailed account of the ideas on the origin of the holes.

1.2. Archaeological Background Research

Iran is rich in ancient mining and metallurgical relics. Nevertheless, the studies on these relics have so far been mostly unsystematic. Ancient mining remains, in addition, they are important trackers for modern mining as annoying surface components, usually they are the first forms to be disappear (Nezafati et al., 2018). The low visibility of off-site areas that would be of high importance for understanding the metal working process from the onset, such as mines and open-air workshops, strongly distorts the record, early mining traces that were probably located in the gossan zone close to the surface were likely destroyed by long term exploitation (Helwing, 2013). A bead made from a rolled sheet of copper, found in the Aceramic Neolithic site Tape Ali Kosh in Susiana is a very early usage of copper for Neolithic period (Hole and Flannery, 1962; Smith, 1969). A main question is that where are the sources of supply of mineral raw materials for mass production of artifacts and objects made in ancient periods?

However, the Tale Eblis (5th millennium BCE) is the earliest known metal smelting site in Iran onwards to have obtained raw materials from the major source of Talmessi, some 400 km away (Frame, 2009; Helwing, 2013). Among the researches done in this regard, the following can be mentioned: Joint project of Iran and Germany on the ancient mining sites of Arisman and veshnoveh started since 2000 (Malek Shamirzadi, 2004); Field research by Theodore Wertime, cyril Stanley Smith and Radomir Pleiner on the search for ancient mining and metalworking works in the Great Desert of Iran, during which the mines and sites of Moute in Nain, Anarak, Nakhlak, Khur, Tabas, Sehchangi in Naiband, Tars, Chupanan, Kerman, dasht-e-Lut, Tal-i-Iblis, Bardsir, Baft, Yazd, Pasargad, Persepolis and Haneshk were visited in 1966 (Smith et al., 1967); wartime's team had reached Tehran/Iran, from where they went on to visit Uzbek Kuh, Deyhook, Tappeh Yahya, Deh-i-Sard, Sechah, Tall-i-Iblis, Qatru, Kuh-i-Sorkh, Istebanat, Persepolis, Sar Cheshmeh, Pasargadae, Haneshk, Talmessi, Meskani in 1968 (Wertime, 1968; Arab and Rehren, 2004); Studies on metal workshops in Tal-e-Iblis, tape Yahya, Tape Ghabristan and Shahdad (see Pigott, 1989; Heskel, 1980, 1982); Report No. 13 of the Geological Survey of Iran entitled Iranian copper deposits in which a description of ancient mining works in metalworking sites related to mines is presented (Bazin and Hubner, 1069); in 1350, Hoeltzer and Momenzadeh studied the ancient copper mine in Veshnaveh (Weisgerber, 1990); Arisman International Project (2000-2005) which was published in the form of a preliminary report and a final report (Malek Shahmirzadi, 2006). The main reason for the formation and development of some ancient sites could be the existence of mineral resources and their exploitation; in this case, we can mention the great copper belt of Kerman and the ancient sites of Tal-e-Iblis and Shahdad (Momenzadeh, 2006). The existence of these mines is so important that shifting use a source to another could be occurred (Frame, 2009). Iran from Mesopotamian archives, is a land of rich resources on copper. In ancient cuneiform texts, it is mentioned several times that copper, bronze and tin come from the East. Among these texts, the text from Kanesh which refers to tin coming overland through the Zagros Mountains to Mesopotamia from northwestern Iran (Muhly, 1973; Helwing, 2013). Beside many factors, recent field works in Iran with a wealth of new data is helped to emphasized to develop "highland Models" (see Helwing, 2013; Nezafati et al., 2009; Stollner et al., 2004; Vatandoust et al., 2011; Weeks, 2007) and we are now in a much better position to identification of metal sources in Iran "heartland of metallurgy" as V. Pigott once called it (Pigott, 1999; Helwing, 2013). In northwest of Iran, valuable data and treasures of Hasanlu, Zivieh, Qalaichi and other sites show the superior economic position of Mandaeans people compared to other ethics in the region (Mollazadeh, 2012) and these sites are notable for their wealth. In Deh Hossien (located in the northern part of the Sanandaj - Sirjan tectonic zone) ancient workings occur numerous big ellipsoidal open depressions, along the mineralized horizons, in an area of 4.5 x 6 km2 (Nezafati et al., 2009). During the study and identification of metalworking sites in the area of Kanirash village in Mahabad city and Barikayeh of Sardasht city, along with residential areas and cemeteries, a set of 18 iron extraction sites were obtained, which according to thermo luminescence tests Metalworking areas of Kanirash village belong to the Parthian period (around the first century AD) and the Islamic and those in Barikayeh belong to the Parthian period (Salimi et al., 2018). Recently an important site discovered near of Chakherbaz holes. The archaeological site of Kani-Zarin is located about 11.9 km west of Ziwiye archaeological site, 1.5 km west of Aliabad village and 34 km east of Saqqez county in Kurdistan province. It belongs to the Late Bronze Age with burials from the Iron Age III and evidence of metal melting has been obtained in it. The most important point is the big mine of Kuh-e-Soltan Mountain next to this area. Impressive results will be obtained if a survey is done on this mountain and its surroundings (Hozhabri, 2017). Such considerations highlight the important of searching for the source of metal used in the region at in the Iron Age.

2. Material and Methods

2.1. Geologic and Geomorphologic Setting of Chakherbaz Holes

The area is located at the margin of the northern part of the Sanandaj-Sirjan Zone (SSZ) which is a metamorphic–magmatic belt associated with the Zagros Orogen and part of the Alpine-Himalayan orogenic system (Mahmoudi et al., 2011). Area is actually at the intersection of Sanandaj-Sirjan, Khoy-Mahabad and Alborz-Azerbaijan Zones (Derafshi, 2020). The geology of the area is composed of meta-sedimentary, meta-volcanic and meta-plutonic rocks of SSZ and the sedimentary rocks of Alborz-Azerbaijan Zone (Derafshi, 2020). According to the geological map, the Precambrian to Quaternary units are exposed in the study area. The oldest units are the Kahar, Bayandor and Soltanieh Formations with Precambrian to Cambrian age (Fig. 2). The Permian sediments, the Ruteh and Doroud Formations, include sandstone, shale and carbonate. The Jurassic units are found in the northwest of the region, and include sandstones and shale. The Cretaceous sedimentary units are located in the south of the study area. These sediments contain sandstone, limestone, silty-limestone, shale and dolomitic limestone. During Late Cretaceous-Early Paleocene era the Saheb granitoid intruded within the oldest units and caused Fe skarn type deposits in the Saheb area. The Saheb granitoid have been cut by a series of diabase dikes. The base rocks of The Chakherbaz holes are comprised of weakly metamorphosed slates and metasandstones of Kahar F. of Neoproterozoic age characterized by a low, undulating topography. Indicated as “Chakherbaz Suspected Hole” in figure 3 is the Chakherbaz “big hole” which is the main subject of our research. The hole is a semi-circular feature measuring about 45 m in at the largest diameter with a max. Depth of ca. 5.5 m. It is surrounded by a raised rim except at the side joining the slope where it has been eroded up (Fig. 4). The rim is largely composed of fine to coarse rubble. Very limited exposures of the base rocks occur at the washed-out side. Unfortunately, the “small hole” has been intensively subdued and no more be discussed hereafter.

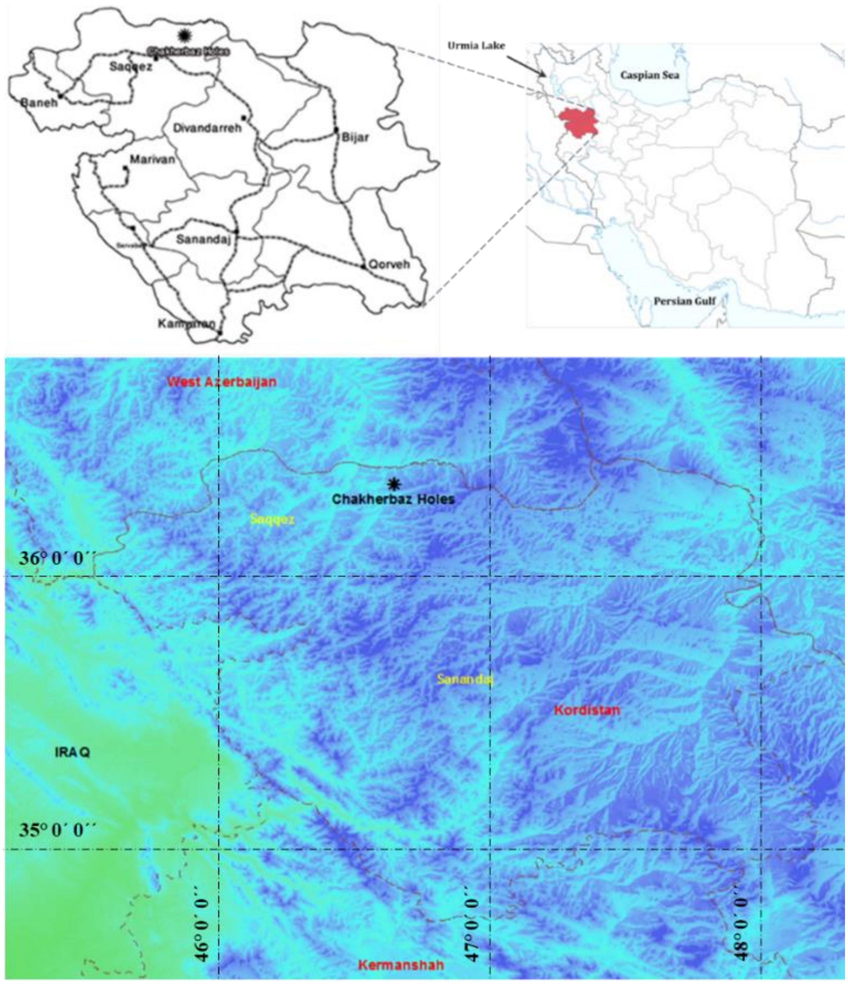

Fig. 1. The approximate location of the Chakherbaz Holes, ca. 21 km to the northeast of Saqqez City in the simplified map of Kurdistan province

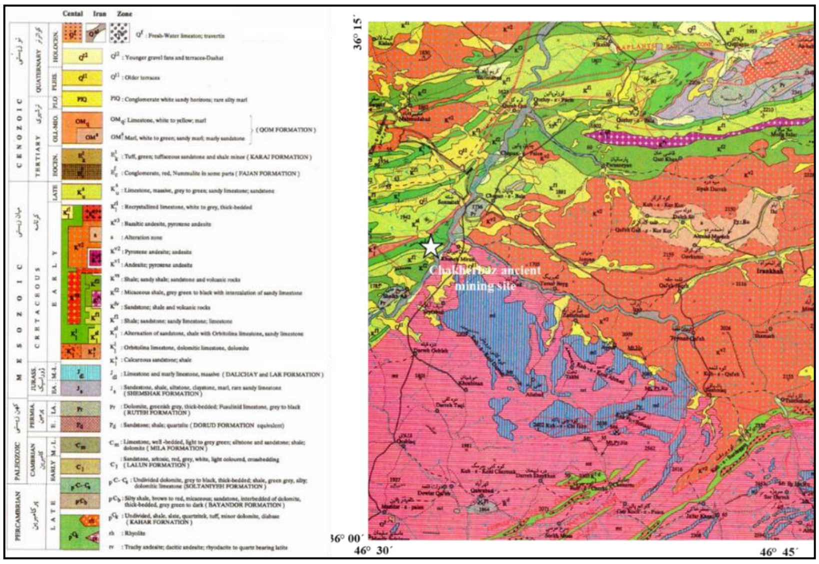

Fig. 2. Geological map of Chakherbaz Holes ancient mining site

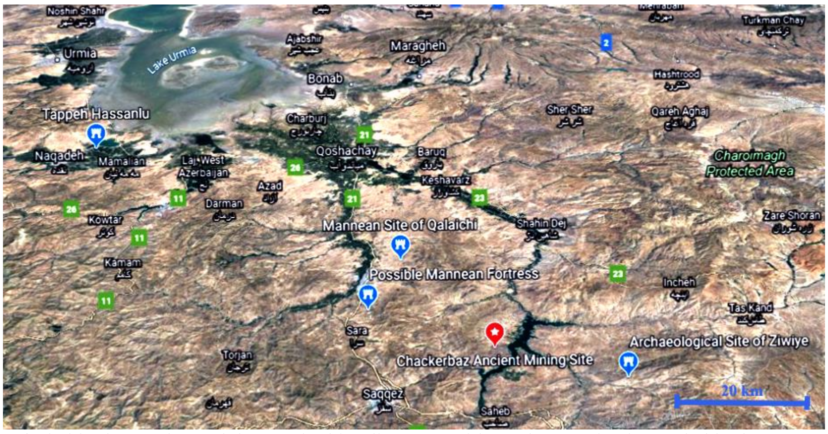

Fig. 3. Bird's-eye view of Chakherbaz Holes and the overlooking limestone ridge. Characterized as “Chakherbaz Suspected Hole” is the more preserved big hole. Note the small hole to the left of the big hole.

The composition of the base rocks of the holes (i.e. weakly metamorphosed siliciclastic rocks) is clearly in contrast to similar features in karstic and volcanic terrains. Furthermore, the morphology of the holes is in marked contrast to the morphology of the adjacent drainage network. Although wind may create comparable features in desert areas, however it seems very unlikely for the wind to excavate such holes in the solid rock.

Fig. 4. A view overlooking the big hole from near distance. Note the raised rim of the big hole relative to the surrounding plane. The smaller hole occurs to the left of the big hole. View to the south. The man standing in the center of the big hole is for scale.

2.2. The Best-Fitted Hypothesis! A Possible Impact Structures

Considering the morphology of the holes, i.e,. a circular outline and the presence of a raised rim, a possible meteorite impact structure was first proposed for the origin of the holes (esp. the big one); the features often seen in such young impact craters as Meteor Crater in Arizona. Other people also considered the big holes to be a good candidate for an impact structure (e.g., Prof. Bevan M. French, 2007; written comm.) which encouraged further searches for definite evidences for the hypothetical impact. To test the impact hypothesis, material constructing the rim, largely composed of rubbles and rock debris, and scattered around were carefully inspected for possible evidences of impact; suspected samples were collected to be further examined. Iron-stained with brecciated rocks are abundant among the materials constructing the rim. Although most of the samples we examined were pressure-affected, however none of the samples showed the definite shock metamorphic effects so characteristic of “impactites” (i.e. rocks affected by meteorite impacts). Among the interesting samples found on the rim of the big hole was a dark-colored rock consisting of spherical bodies which was first suspected to be a chondrite-type stony meteorite. However, careful examination by Dr. Jamshid Hassanzadeh (Professor emeritus of The University of Tehran; now a visiting associate at Caltech, USA) identified the sample as “Ironstone” iron ore.

2.3. Data Preparetion

Full characterization of archaeological sites by conventional archaeological techniques can take years. Moreover, drilling and excavations, the most often applied methods for archaeological assessment, are ground disturbing. Therefore, nondestructive geophysical techniques have been used to detect and map underground features in a fast and noninvasive manner (Conyers and Goodman, 1997; Bevan, 1998; Kvamme, 2003; Gaffney, 2008). To search for metal particles, a magnetic survey was conducted in the soils within and around the holes. It was first stimulated in looking for possible meteorite particles to further examine a meteorite impact hypothesis. Magnetic particles were collected during the magnetic survey out of which the ones with rounded or suspected were picked under binocular for further examinations. To access the possible buried evidences within the fill materials, two test trenches were dug to a collected depth of 6 m at the lowest point of the big hole.

3. Results and discussion

3.1. Metallurgical Finds: The Trace of Man

Among the challenging samples found accidentally on the North side of the big hole were two small, porous, metal-bearing glass particles (Fig. 5) lately confirmed to be archaeological slags. These were among the only slag materials found at Chakherbaz Holes site. Under the microscope, the slag fragments show textures ranging from equigranularity (Fig. 6) to skeletal; the characteristic “quench texture” indicate crystallization under rapid cooling conditions (Fig. 7). The slag fragments contain sparse blebs of metallic iron evident in reflected light and also in BSE images (Fig. 8; Table 1).

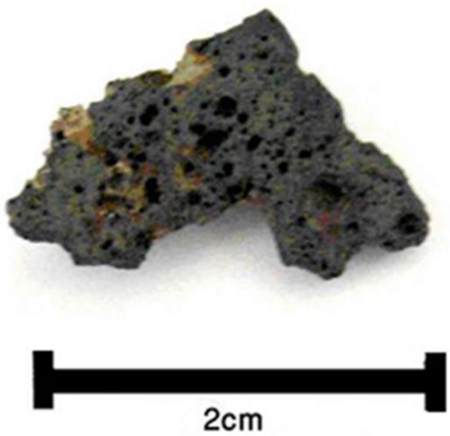

Fig. 5. The slag fragment found on the rim of the big hole. Note the porous fabric. The slag piece attracts magnet due to the presence of sparse metal blebs within the silicate matrix.

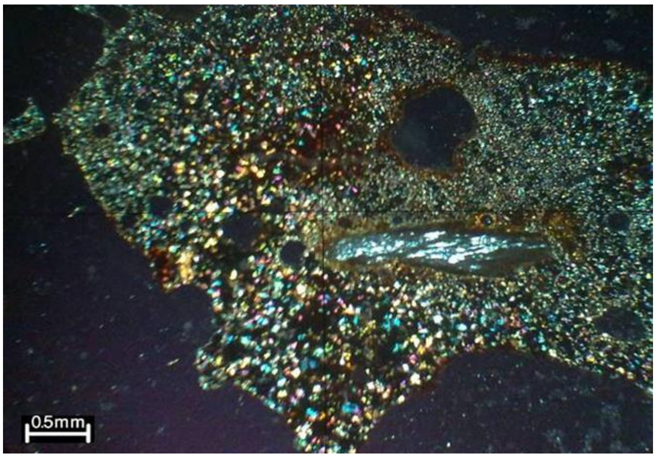

Fig. 6. The microstructure of the slag piece showing granular texture (XPL). Note the lithic inclusion and the brownish glassy material lining the vesicles.

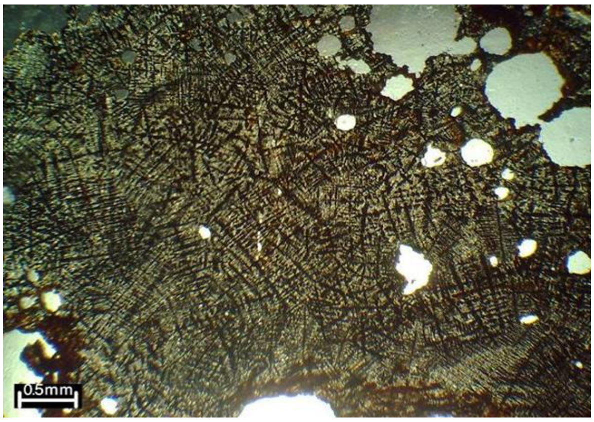

Fig. 7. The same fragment as in Fig. 5 showing quench texture indicating crystallization under undercooling conditions (PPL). This has a distinct boundary with another part of the fragment showing granular texture.

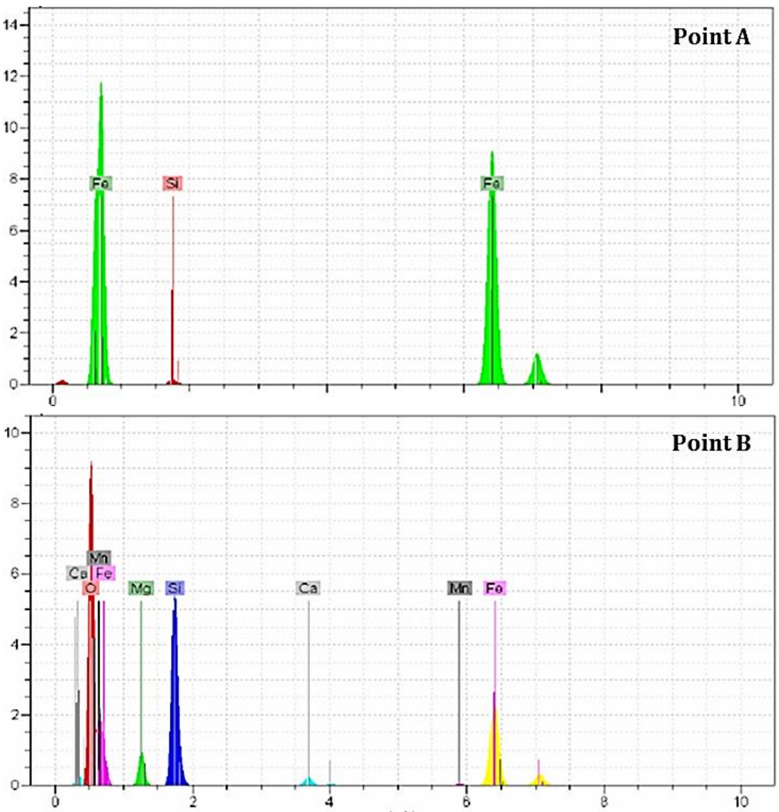

Fig. 8. BSE image showing metallic blebs (A) within the silicate matrix (B). the SEM-EDS spectra of the phases is presented below.

Table 1. BSE results showing metallic blebs (A) within the silicate matrix (B)

Point A.

Element	Series	unn. C [wt. -%]	norm. C [wt. -%]	Atom. C [wt. -%]
Silicon	K series	0.35	0.37	0.73
Iron	K series	94.97	99.63	99.27
			Total:	95.3 %

Point B.

Element	Series	unn. C [wt. -%]	norm. C [wt. -%]	Atom. C [wt. -%]
Oxygen	K series	34.27	35.78	60.44
Magnesium	K series	2.73	2.85	3.17
Silicon	K series	13.00	13.57	13.06
Calcium	K series	1.02	1.06	0.71
Manganese	K series	0.29	0.30	0.15
Iron	K series	44.46	46.43	22.47
			Total:	95.8 %

The SEM-EDS analysis of the metal blebs within the slag pieces show nearly pure iron (>90wt % Fe) with minor impurities of other elements, mainly Si. Silicon is in the EDAX spectra of the metal blebs might have its origin from the silicate matrix. This observation is in clear contrast to the composition of metal grains in similar "impact glasses" which, in addition to iron, contain significant amounts of such elements as Ni and Co. The implications of such metallurgical slags for the origin of the holes have been discussed further below.

3.2. Magnetic Survey

After preparing a grain mount from the suspected particles, two partially oxidized metal grains, with elongated form, were detected during the subsequent reflected-light microscopy (Fig. 9). Interestingly, similar to the composition of the metal blebs in the slag fragments, the composition of the metal particles is also dominated by the metal, iron (~100% Fe) suggesting an Archeometallurgical origin for the metal particles (Fig. 10). Copper sulfide grains (chalcopyrite?) were identified enclosed in the oxidized margin in one of the metal particles (Fig. 11, Table 2). These observations collectively suggest possible smelting practices at the site. However, assuming the possibility of Chakherbaz Holes as abandoned ancient mining shafts, there is good reason to suggest that the metal particles could be Smithing slags from ancient iron tools used at the site (Thilo Rehren, 2009; indirect written comm.).

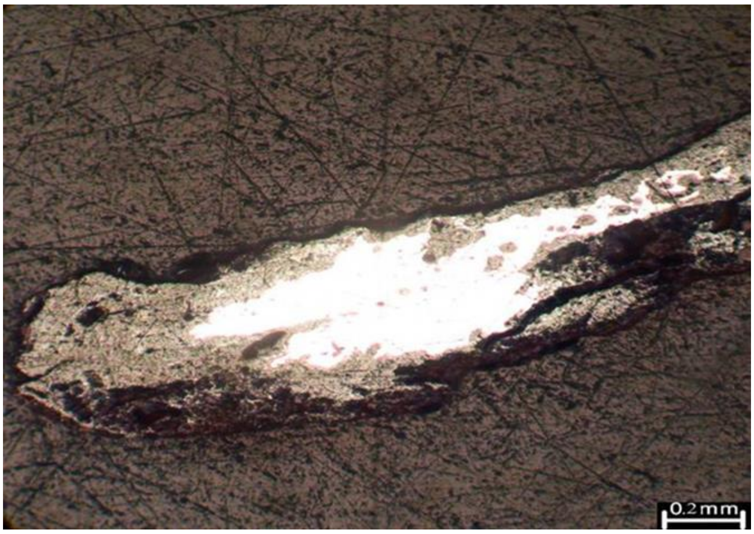

Fig. 9. Partially oxidized iron particle collected during magnetic survey of the soils covering the inside surface of the big hole.

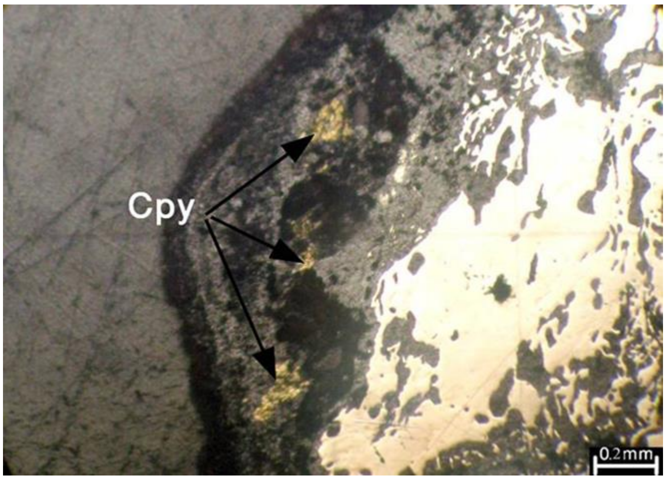

Fig. 10. Copper sulfide grains enclosed in the oxidized portion of the iron particle. In the EDAX spectra of Fig. 10, the Unoxidized metal and the sulfide grains are characterized as “Base” and “CuS”, respectively.

Table 2. BSE results showing the microstructure of the iron particles

Base.

Element	Series	unn. C [wt. -$^0/_0$]	norm. C [wt. -$^0/_0$]	Atom. C [wt. -$^0/_0$]
Iron	K series	103.56	100.00	100.00
				Total: 103.6 $^0/_0$

Cus.

Element	Series	unn. C [wt. -$^0/_0$]	norm. C [wt. -$^0/_0$]	Atom. C [wt. -$^0/_0$]
Oxygen	K series	11.82	11.57	27.06
Aluminium	K series	2.60	2.55	3.54
Silicon	K series	0.70	0.69	0.91
Sulfur	K series	27.53	26.95	31.45
Iron	K series	34.56	33.83	22.67
Copper	K series	24.94	24.41	14.37
				Total: 102.1 $^0/_0$

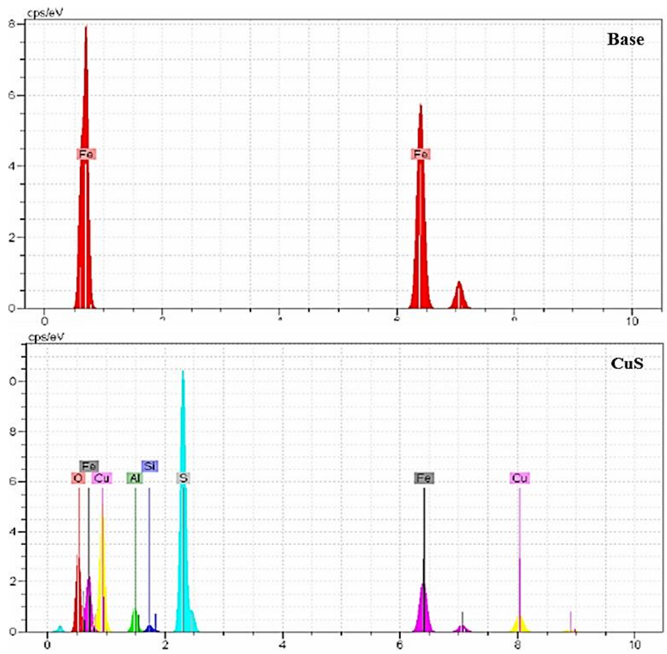

Fig. 11. BSE image showing the microstructure of the iron particles. Also presented are the EDAX spectra of the phases referred to in the text.

3.3. Test Excavations at the Site: The Sherd Piece

To access the possible buried evidences within the fill materials, two test trenches were dug to a collected depth of 6 m at the lowest point of the big hole. The only significant find by these excavations was a thick-walled, crude sherd at a depth of ca. 2.25 m (Fig. 12) associated with little decayed bone and charcoal materials. The sherd is suspected to be fragment of a cookery pot (Dr. Rezaei, Institute of Archaeology, Tehran, personal communication, 2008). The discovery of a sherd in the fill materials adds weight to the notion that Chakherbaz Holes might indeed be an ancient mining/metallurgical site; an issue which is further treated below.

3.4. Suspected Stone Tools: Possible Evidences for Ancient Mining

Among the recent finds scattered on the rim of the big hole were "lithic" suspected to be possible stone tools (Figs. 13, 14). A brief description of these finds is presented below (numbers refer to the same in the figures):

Sample No.1 is a curved, elongated lithic fragment of metasandstones lithology. It has a pointed head and when kept in hand, the fingers would lay on depressions making a tight grip on it possible.

Sample No.2 is a rather flat, pointed, lithic sample also of metasandstones lithology. Two notable features of this sample are the existence of a protruded medial ridge bisecting two oppositely- sloping surfaces and a marginal circular notch thought to be cut admittedly for a kind of handle to be fixed to it. If so, the ragged point of this piece now covered with lichens, could be an artifact of tool wear (Hamid Rezaei, 2008; Institute of archaeology, Tehran, personal comm).

Sample No.3 is a small, also pointed, volcanic piece (?). Similar to the sample No.2, this sample also show a central, but more prominent, ridge between two oppositely-sloping, symmetrical surfaces at the ventral side; dorsal side in this sample is otherwise flat. To the opinion of this author, this sample could represent the "distal fragment" of a kind of stone pick (Erling Midtgard, 2008; university of Oslo, Stone Tool Collection Reference).

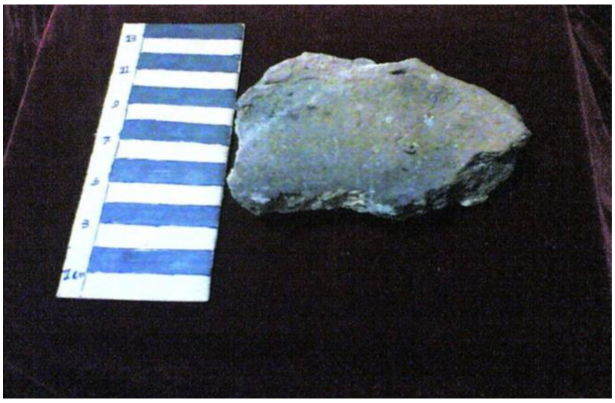

Fig. 12. Ventral side of the sherd piece recovered from a depth of 2.25 m beneath the big hole. Note the overbaked fabric suggesting the possible use as a cookery pot. The scale is in centimeter.

Fig. 13. Ventral side of the rock samples described in the text. Note possible finger imprints in sample No.1; the notch, central ridge, ragged point in sample No.2; and the prominent central ridge in sample No. 3. Sample No.4 is a quartzite fragment associated with item No.1. The scale is 16 cm long.

Fig. 14. The dorsal side of the same samples showing the notch at the margin of the sample No.2, the flat surface of sample No.3, and the slightly polished surface of the quartzite.

Sample No.4 is a piece of quartzite found associated with sample No.1. Interestingly it is of a rock uncommon to rock types of the area, however similar rock types can be found elsewhere in the surrounding region. The sample seems to represent a broken pebble (?) brought from the nearby stream beds. The sample seems to be polished at one side which together with its great hardness suggest its possible use as a "grindstone" at the site (Tim Shaw, 2008; written comm.). In summary, the collected evidences (i.e., the archaeological and metallurgical finds) hint to possible ancient mining/archeometallurgical activities at the site (Tim Shaw, written comm, 2008; Thilo Rehren, 2009, indirect written comm.). In this view, the holes represent abandoned ancient surface mine(s) shafts. The idea of an ancient mining site further gain support while there are some indications of copper mineralization at the holes, as coatings of secondary copper minerals (mostly malachite) (Fig. 15) and scattered limestone fragments containing chalcopyrite mineralization.

Fig. 15. Malachite coatings on iron-stained breccia sample. Cut slabs of such iron-stained samples often reveal a brecciated fabric.

4. Conclusion

Considering that the majority of the finds at Chakherbaz Holes are metallurgical in origin with additional indications of mineralization within the associated materials, we tend to agree that the holes might be actually an ancient mining/metallurgical site, compatible with the existence of possible mining stone tools at the place and the discovery of sherd piece in the fill materials. In fact, ancient shafts to recover flint are known from the area called Grimes Graves, UK, which bear many similarities to Chakherbaz Holes in shape and morphology. The composition of the slag materials indicates possible iron metallurgy had been going at the site, although it is not yet clear that the slags are of smithing or smelting origin (Thilo Rehren, 2009; indirect written comm.). Likewise, traces of copper mineralization at the area and the detection of chalcopyrite within the iron particles present evidences favoring copper mining/metallurgy at the site. If so, then iron ore could be used as a kind of fluxing material in the smelting process (Tim Shaw, written comm.). However, the ubiquity of iron associated with metallurgical finds seems to contradict with a copper metallurgy notion. Nevertheless, the abundance of native iron and the seemingly lack of typical hammerstones, suggest Iron Age at the earliest for the site. Unfortunately, no reliable age could be inferred from the fabric and style of the sherd piece. The volume of the slag maetrials found at the site is by no means comparable with the dimension of the hole(s) which is not in favor of significant metallurgical activities at the site. Chakherbaz Holes seem to be more a mining site than a metallurgical center. We reiterate the statement by Thilo Rehren that, "a fuller assessment would have to consider the total slag quantity archaeologically present, as well as the morphology and microstructure of the slag pieces, and the nature of the ore potentially mined". Briefly, existence of rock fragments containing Malachite or Chalcopyrite and iron ore fragments at the edge of the holes, existence of small metal particles of iron resulting from metallurgical or blacksmithing activities and slag particles, lack of conclusive evidence for the collision of a celestial object and the existence of two holes at very close distances that make it very impossible for two meteorite pieces to collide at this distance, lack of suitable calcareous bedrock for the formation of Karst dissolution cavities, lack of loose sediments and suitable natural conditions for the formation of these cavities caused by wind erosion and not being located of cavities in the path of natural waterways, which also denies their formation caused by the widening of natural waterways and existence of a pottery shard and ground stones in the site are the reasons for ancient mining in Chakherbaz holes. According to recent surveys, carrying capacity of this area to supply metal resources and existence of special and rich sites that metal works are their indicator as one of their distinguishing features especially in the Iron Age, we think this source was used to supply copper in the Iron Age. Although a positive assignment is not possible out of principle, Chakherbaz in terms of distance is the closest source to mentioned sites based on geographical evidence. Mapping and sampling for chemistry and lead isotope studies in future field work can help us to identify the ancient sources of the Northwest important sites like Ziwiyeh and Qalaychi. In conclusion, it is important to note that our archaeological data about this part of Iran is very scarce and limited to some well-known sites, "Tapeh Ziwyeh" and "Karaftu Cave" and we hope that future investigations at to Chakherbaz Holes help in recognition of potential ore sources in ancient times in this part of Iran.

Acknowledgment

Many people contributed to the current research to whom this work belongs. First of all, it was Mr. Mohssen Hosseini who introduced the holes to us. Our family, especially, Nezam, Hesam and Hashem, were of great help which made the investigations possible. They provided generously much of the financial support and greatly assisted during fieldworks. Our colleague, Shaho Karimi, was with us at the beginning who aided partly during the fieldworks. Our friends, Khalil Rahmani a Mohammad Hosseini assisted in the excavations; we are grateful to both of them. We are especially indebted to our supervisor, Dr. Saeed Alirezaei, and Dr. Jamshid Hassanzadeh whose inputs and criticism during the investigations was very critical to be without. We are grateful from Dr. yuseff Hassanzadeh, Dr. Sajjad Alibeygi and Rahmat Naderi for sharing related Paper and Archaeological guidance. We also highly benefited from the comments by Dr. Richard Grieve (Geological Survey of Canada) and especially Dr. Bevan M. French (Smithsonian Institution) that greatly help in the development of initial ideas on the origin of the holes. Dr. Richard Herd (Curator of the meteorite collection; Geological Survey of Canada) did part of the identification of the glass samples to whom I am highly indebted. The Razi Metallurgical Research Centre performed the SEM-EDAX analyses. The fellows from the IAMS, Dr. Tim Shaw and Dr. Thilo Rehren were of great help developing the current ideas on the origin of the holes. Their advices are highly appreciated. Also, I enjoyed the comments by Dr. Hamid Rezaei (Institute of Archaeology, Tehran) who helped in the identification of the pottery and lithic samples. Lastly, but not least, we acknowledge the helps and support by all of those who in any way contributed to this work.

References

Arab, R. & Rehren, T., 2004. The pyro technological expedition of 1968. In Stollner, T., slotta, R., (eds.), Persiense Antike Pracht, Bochum: Deutsches Bergbau-Museum: 550-555.

Bazin, D. & Hubner H., 1969. Copper deposits in Iran. Geological Survey of Iran, Tehran, 232 p.

Bevan, B.W., 1998. Geophysical exploration for archaeology: an introduction to geophysical exploration. Midwest Archaeological Center Special Report 1, U.S. Department of the Interior, National Park Service, Lincoln, Neb, USA, 90 p.

Bick, D.E., 1999. Bronze Age copper mining in mid Wales - fact or fantasy? Historical Metallurgy: 33, 7-12.

Bourgarit, D., 2019. Mineralogy of slags: a key approach for our understanding of ancient copper smelting processes. *European Mineralogical Union and the Mineralogical Society of Great Britain and Ireland*: 20, 203-231.

Camizuli, E., Monna, F., Scheifler, R., Amiotte-Suchet, P., Losno, R., Beis, P., Bohard, B., Chateau, C. & Alibert, P., 2014. Impact of trace metals from past mining on the aquatic ecosystem: A multi-proxy approach in the Morvan (France). *Environmental Research*: 134, 410-419.

Camizuli, E., Scheifler, R., Garnier, S., Monna, F., Losno, R., Gourault, C., Hamm, G., Lachiche, C., Delivet, G., Chateau, C. & Alibert, P., 2018. Trace metals from historical mining sites and past metallurgical activity remain bioavailable to wildlife today. *Scientific Reports*: 8, 1-11.

Conyers, L.B. & Goodman, D., 1997. Ground penetrating radar: An Introduction for Archaeologists. AltaMira Press, Walnut Creek, London and New Delhi, 232 p.

Craddock, P.T., 1995. Early metal mining and production. Edinburgh: Edinburgh University Press, 363 p.

Derafshi, K., 2020. Dating of Late Pleistocene and Holocene fluvial sediments using OSL, uranium series and 14C methods in the Saqqez River, Iran. *Sustainability Earth Review*: 1(2), 30-42.

Didier, C., 2009. Post-mining management in France: situation and perspectives. Risk Analysis: 29, 1347-1354.

Frame, L., 2009. Technological change in southwestern Asia; metallurgical production styles and social values during the Chalcolithic and Early Bronze Age. A dissertation submitted to the Faculty of the Department of Materials Science and Engineering, University of Arizona, 706 p.

Gaffney, C., 2008. Detecting trends in the prediction of the buried past: a review of geophysical techniques in archaeology. *Archaeometry*: 50, 313-336.

Hauptmann, A., 2007. The Archaeometallurgy of Copper. Evidence from Faynan, Jordan. Springer, Berlin. Part of the Natural Science in Archaeology book series (Archaeology), 397 p.

Helwing, B., 2013. Early metallurgy in Iran - an innovative region as seen from the inside. In: S. Burmeister/S. Hansen/M. Kunst/N. Müller-Scheessel (eds.), Metal matters. Innovative technologies and social change in Prehistory and Antiquity. Menschen - Kulturen - Traditionen: Forschungs Cluster: 2, 105-135.

Heskel, D.L., 1982. The development of phytotechnology in Iran during the fourth and third millennia B. C. Boston, 215 p.

Heskel, D. & Lamberg-Karlovsky, C.C., 1980. An alternative sequence for the development of metallurgy: Tepe Yahya, Iran. Wertime. T. Muhly. J. (Eds.), New Haven, Yale University Press, 229-266.

Hole, F. & Flannery, K.V., 1961. Excavations at Ali Kosh, Iran. *Iranica Antiqua*: 2, 97-148.

Kassianidou, V., 1998. Small-scale mining and smelting in ancient Cyprus. In Knapp, B., Piggott, V., & Herbert, E., (Eds.), Social Approaches to an Industrial Past: The Archaeology and Anthropology of Mining, New York, USA: Routledge, 226-241.

Killick, D., 2015. Archaeometallurgy as archaeology. Proceedings of the Archaeometallurgy in Europe III: Proceedings of the 3rd International Conference, Deutsches Bergbau-Museum Bochum. Deutsches Bergbau-Museum Bochum (Der Anschnitt. Beiheft, 559-575.

Knapp, A.B., 1998. Social approaches to the archaeology and anthropology of mining. In Knapp, B., Piggott, V., & Herbert, E., (Eds.), Social Approaches to an Industrial Past: The Archaeology and Anthropology of Mining. New York, USA: Routledge, 1-23.

Kvamme, K.L., 2003. Geophysical surveys as landscape archaeology. *American Antiquity*: 68, 435-457.

Mahmoudi, S., Corfu, F., Masoudi, F., Mehrabi, B. & Mohajjel, M., 2011. U-Pb dating and emplacement history of granitoid plutons in the northern Sanandaj–Sirjan Zone, Iran. *Journal of Asian Earth Sciences*: 41(3), 238-249.

Malek Shahmirzadi, S., 2004. The potters of Sialk, Sialk Reconsideration Project Report III. Iranian Centre of Archaeological Research, Archaeological Report Monograph Series 5, Tehran: Iranian Cultural Heritage and Tourism Organization (in Persian), 125 p.

Malek Shahmirzadi, S., 2006. Sialk: the oldest fortified village of Iran. Sialk Reconsideration Project. Final report. Iranian Center of Archaeological Research, Tehran: Iranian Cultural Heritage and Tourism Organization (in Persian), 145 p.

Mighall, T.M., Timberlake, S., Grattan, J.P. & Forsyth, S., 2000. Bronze Age Lead mining at Copa Hill, Cwmystwyth - fact or fantasy? *Historical Metallurgy*, 34(1), 1-12.

Mollazadeh, K., 2012. Manna and its place in the history of archaeological and education in Iran, eighty years of Iranian archaeology, pazineh press with contribution of national museum of Iran, Vol. 2, edited by Hassanzadeh, Y., & Min, S., (in Persian), 248 p.

Momenzadeh, M., 2006. An Overview of Ancient Mines and Mining of Iran, Part 2, *Cheshmeh*: 6, 21-60.

Monna, F., Camizuli, E., Revelli, P., Biville, C., Thomas, C., Losno, R., Scheifler, R., Bruguier, O., Baron, S., Chateau-Smith, C., Ploquin, A. & Paul, A., 2011. Wild Brown Trout Affected by Historical Mining in the Cévennes National Park, France. *Environmental Science and Technology*: 45, 6823-6830.

Muhly, J.D., 1973. Copper and tin: the distribution of mineral resources and the nature of the metal trade in the Bronze Age. Transactions of the Connecticut Academy of Arts, 43, Archon Books, Hamden CT, 155-535.

Nezafati, N., Momenzadeh, M. & Ahmadi, K., 2018. A road map for the ancient mining and metallurgical studies in Iran. *Journal of Research on Archaeometry*: 3, 77-98.

Nezafati, N., Pernicka, E. & Momenzadeh, M., 2009. Introduction of the Deh Hosein ancient tin-copper mine, Western Iran: Evidence from geology, archaeology, geochemistry and lead isotope data. *Journal of the Turkish Academy of Sciences*: 12, 223-236.

Novo, A., Vincent, M.L. & Levy, T.E., 2012. Geophysical surveys at Khirbat Faynan, an ancient mound site in Southern Jordan. Hindawi Publishing Corporation, *International Journal of Geophysics*: 2012, Article ID 432823, 1-8.

Nriagu, J.O., 1996. A history of global metal pollution. *Science*: 272, 223-224.

Pigott, V.C., 1999. A heartland of metallurgy: Neolithic/Chalcolithic Metallurgical origins on the Iranian Plateau, in The Beginnings of Metallurgy, Hauptmann, A., Pernicka, E., Rehren Th., & Yalcin, Ü., eds.), Bochum: Deutsches Bergbau-Museum, 107-20.

Pigott, V.C., 1989. Archeometallurgical investigations at Bronze Age Tappeh Hesar, R.H. Dyson and S. Howard (eds.) Tappeh Hesar: Reports of the Restudy Project, 1976, 25-33. Monografie di Mesopotamia II, Casa Editrice Le Lettre, Firenze.

Radivojevic, M., Rehren, T., Pernicka, E., Sljivar, D., Brauns, M. & Boric, D., 2010. On the origins of extractive metallurgy: new evidence from Europe. *Journal of Archaeological Science*: 37, 2775-2787.

Rosman, K.J.R., Chisholm, W., Hong, S., Candelone, J.P. & Boutron, C.F., 1997. Lead from Carthaginian and Roman Spanish Mines isotopically identified in Greenland Ice dated from 600 B.C. to 300 A.D. *Environmental Science and Technology*: 31, 3413-3416.

Sagona, A.G., 1994. Bruising the Red Earth: Ochre Mining and Ritual in Aboriginal Tasmania. Melbourne University Press: Carlton, 194 p.

Salazar, D., Jackson, D., Guerdon, J., Salinas, H., Morarta, D., Figueroa, V., Manriquez, G. & Castro, V., 2011. Early evidence (ca. 12,000 BP) for Iron oxide mining on the Pacific Coast of South America. *Current Anthropology*: 52, 463-475.

Salimi, S., AmirKhiz, Ch. & Beheshti, A., 2018. An investigation of Metal Working Sites in Mahabad and Satdasht, West Azarbayjan, westrn Iran (2018-2019). Research Institute of Cultural Heritage and Tourism, Proceeding of 17th *Annual symposium of the Iranian Archaeology*: 1, 710-717.

Smith, C.S., Wertime, T.A. & Pleiner, R., 1967. Preliminary reports of the metallurgical project, In Caldwell, JR., (ed), Investigation at Tal-i-Iblis. *Illinois State Museum Prelim Reports*: 9, 318-326.

Stöllner, Th., Doll, M., Mir Eskanderi, M., Momenzadeh, M., Pasternak, R. & Steffens, G., 2004. Bronzezeitliche Kupfererzgewinnung in Veshnaveh. Persiens Antike Pracht. Bergbau-Handwerk-Archaologie. Katalog der Ausstellung des Deutschen-Bergbau-Museums Bochum, 240-257.

Timberlake, S., 2003, Excavations on Copa Hill, Cwmystwyth (1986-1999): An Early Bronze Age Copper Mine within the Uplands of Central Wales. BAR British Series 348. Oxford: Archaeopress. ISBN-13: 978-1841714868.

Timberlake, S., 2007. The use of experimental archaeology/archaeometallurgy for understanding and reconstructing early Bronze Age mining and smelting. The Digital Archeological Record, 25-37.

Tucci, A., Sayavongkhadmy, T., Chang, N. & Souksavatdy, V., 2014. Ancient Copper Mining in Laos: Heterarchies, Incipient States or Post-State Anarchists? *Anthropology and Archaeology*: 2, 1-15.

Tylecote, R.F., 1992. A history of metallurgy. Institute of Materials, London, UK, 205 p.

Vatandoust, A.H., Parzinger, H. & Helwing, B., 2011. Early mining and metallurgy on the western Central Iranian Plateau. Report on the first five years of research of the Joint Iranian German Research Project. Archaologie in Iran und Turan 9.

Weeks, L., 2007. early Iranian metallurgy workshop at the University of Nottingham. Iran: 42, 335-345.

Weisgerber, G., 1990. Montanarchäologische Forschungen in Nordwest-Iran 1978. *Archaol Mitt Iran*: 23, 73-84.

Wertime, T.A., 1968. A metallurgical expedition through the Persian Desert. *Science*: 159, 927-935.

Zibret, G., Gosar, M., Miler, M. & Alijagic, J., 2018. Impacts of mining and smelting activities on environment and landscape degradation. Slovenian case studies. Land Degradation Devotional, 4457-4470.