Ancient Gold-Mercury Mining in the Takht-e Soleyman Area, Northwest Iran

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Keywords
Zarshuran, Agh-Darreh, Shakh-Shakh, Yaraziz, Takab

Abstract

The world heritage ancient site of Takht-e Soleyman and its assemblage of metal objects, together with the geological wealth and the vast ancient mining relics of the Takab area motivated the authors to conduct the investigation that led to this article. The ancient mining and ore processing sites of the Takht-e Soleyman area were surveyed and investigated in an area of 5000 km^2. This contribution introduces briefly the geology and mineral resources together with the traces of ancient mining and ore processing in the area of Takht-e Soleyman. Some archaeological sites were found and documented for the first time during this investigation.

Introduction

The archaeological site of Takht-e Soleyman is located some 750 km west of Tehran, in West Azerbaijan Province, within the Takab mountainous region, northwestern Iran. Takht-e Soleyman is an outstanding assemblage of royal architecture, combining principal architectural elements created by the Sassanians (5th to 7th centuries CE). The site includes a major Zoroastrian sanctuary that consists of a high oval-shaped travertine platform about 350 m by 550 m rising 60 m above the surrounding plain. The platform is formed by a mineral water spring in the middle of the platform (Figure 1). The spring has formed a pond of some 70 m in diameter and 60 m deep.

Figure 1: The aerial view of Takht-e Soleyman ancient site.

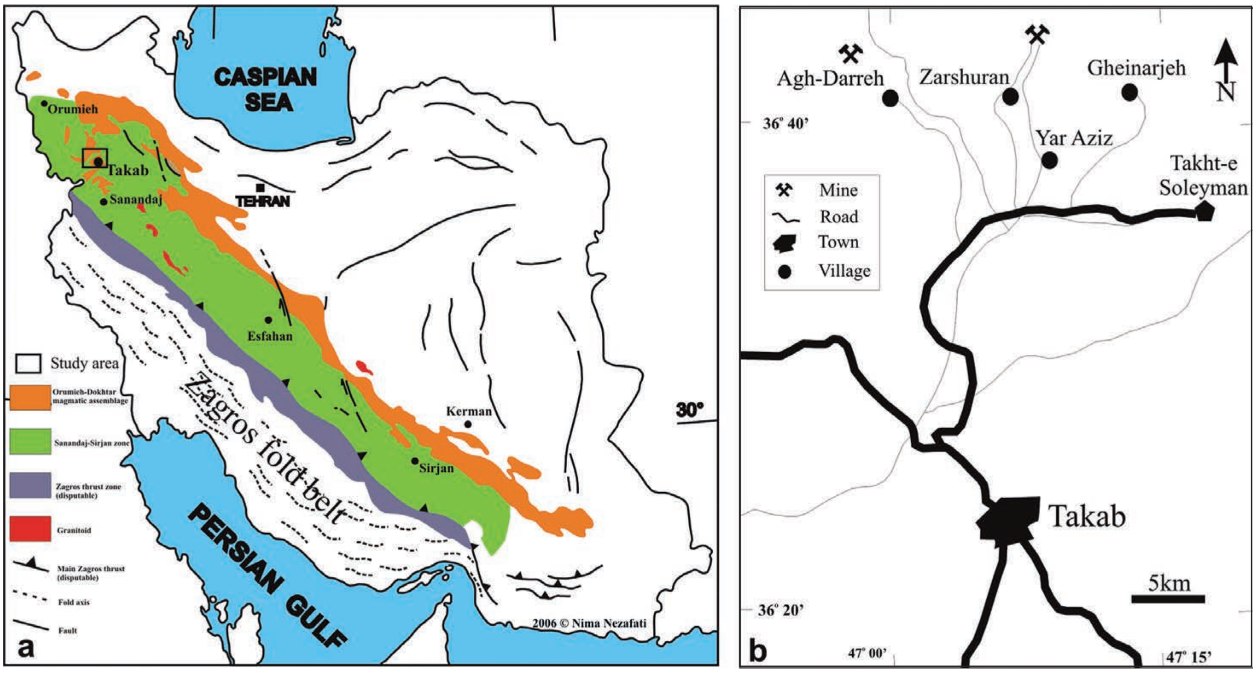

Figure 2: Location of the Takht-e Soleyman area, a) location of the study area in the geological subdivisions of Iran, b) the access roads of the study area.

Four channels carry water from the pond to surrounding lands in the valley which contains the remains of the Sassanian town (not excavated yet). The Takht-e-Soleyman site was destroyed at the end of the Sassanian period and left to decay. It was revived in the 13th century during the Ilkhanid (Mongol) period when some parts were rebuilt. The site has important symbolic significance. The designs of the fire temple, the palace and the general layout have exerted a strong influence, not only in the development of religious architecture in the Islamic period, but also in other cultures. Takht-e Soleyman was recognized as a Unesco World Heritage site in 2003. There are other ancient sites in the surroundings of Takht-e Soleyman (including Zendan-e Soleyman and the Belgheis "Queen of Sheba" Mountain); some have been dated to the 1st millennium BCE (http://whc.unesco.org). The Zendan-e- Soleyman conical topography is a travertine geological feature that is the remains a dried up mineral water spring (possibly due to an earthquake).

The Takab region (Figure 2) that hosts the Takht-e Soleyman ancient site is of significance, not only from the viewpoint of archaeology, but also for ancient and modern mining. Two major active gold mines of Zarshuran and Agh-Darreh together with several arsenic (orpiment), mercury, lead–zinc-silver deposits and occurrences are situated in this area. The significance of the region for mining has been known from ancient times, as it has been mentioned in the texts from the early Middle Ages (Abū Dulaf, 10th century CE).

The present paper is a brief report, which explains the results of a geological-archaeological investigation in the area. The fieldwork was carried out in ten days in the Summer of 2009. The project was funded by the West Azerbaijan branch of the Iranian Cultural Heritage and Tourism Organization and was performed by the Zarneh Research Group.

The above mentioned considerations motivated the authors to conduct a survey for finding and recording ancient traces of mining and metallurgy in the Takab area before modern mining destroys them. In this regard, the major objectives of the survey and the associated investigations were as follows:

1. Discovering the ancient mining and metallurgical sites in the Takab area that could give a chronological and technological framework for a regional mining history. This could lead to understanding the possible relation between the ore of the mines in the northern Takab area and the metal artifacts found at the ancient site of Takht-e Soleyman at different periods.
2. Investigation of ancient exploitation and extraction methods used in the mines.
3. Understanding the cultural, industrial, and economic relationships between the mining and ancient sites (in pre-Islamic and Islamic periods).
4. Identification of representative ancient mining sites that could be preserved from modern mining activities for the sake of cultural heritage.

Materials and Methods

First of all, the previous archaeological, geological and mining data of the area were gathered and reviewed. This helped to outline the fieldwork strategy which took place in an area with a radius of 40 km around the Takht-e Soleyman site. The next step was a 10-day field survey including visiting the ancient mines and ore processing and extraction sites in the area, this was followed by sampling. The samples were investigated using inductively coupled plasma mass spectrometry (ICP-MS at Zarazma Laboratories, Tehran, Iran) and were studied mineralogically (including heavy mineral analysis and ore microscopic investigations). For chemical analysis, the samples were first digested in a four acid solution and (after dilution) were analyzed using a HP 4500 ICP-MS system manufactured by GMI (detailed procedure of analysis is available under http://zarazma.com).

Geological Setting

The study area, as part of the Takab geological quadrangle map, lies within the Alpine-Himalayan chain whose northeastern part is located in the Alborz-Azerbaijan (Nabavi, 1976) or Urumieh-Dokhtar zones (Stöcklin, 1968) and the rest of it in the Sanandaj-Sirjan zone (Figure 2a). A sedimentary sequence of more than 13,000 m in total thickness is exposed, mainly in the northern part of the Takab quadrangle area, (Alavi Naiini, et al. 1982; Mehrabi, et al., 1999), and ranges in age from Precambrian to Recent. Volcanic activity occurred in late Precambrian, Cretaceous, Eocene, Oligocene-Miocene and post Miocene times. Volcanic intrusions are associated with several of these events (Mehrabi, et al., 1999, Figure 3). This region hosts an active geothermal field, where thermal springs, locally precipitate exceptionally high amounts of gold and silver (Daliran, 2003; 2008).

There are several mineral occurrences in the area that are associated with Cenozoic volcanic–hydrothermal activity and are often of Carlin or epithermal type of mineralization. These include deposits of As–Au (Arabshah), Sb (Agh-Darreh, Balderghani, Bakhirbulaghi), Hg (Shakh-Shakh), Mn (Dabal-Kuh), Fe (Shahrak and Kuh-Baba), Pb–Zn (Ay Qalasi and Arpachay), and Zn (+Au+Fe Chichaklou). Fault-hosted, vein and disseminated sediment-hosted deposits of gold, arsenic and antimony in the Takab area coincide with numerous dissected outcrops of travertine up to 100 km^2 in area and with thermal springs. The location of the thermal springs is commonly controlled by faults, e.g. the intersection of NE-SW- and E-trending faults at Takht-e-Soleyman (and Zendan-e-Soleyman). Solfatara of native sulphur and gypsum are closely related spatially to the sites of travertine deposits (e.g. at Gougerdchi), and liquid mercury has been reported by local villagers from some wells located within the red beds. Thermal springs continue to precipitate travertine that locally contain Cu, Sb, Pb and As in the percent range, up to several thousand ppm Hg, and Te, and high amounts (ppm) of Au and Ag (Daliran, 2003). These various observations suggest that hydrothermal activity has continued from Miocene to the Recent (Daliran, 2008).

Background: Ancient Mining in the Takht-e Soleyman Area

Many modern mines have been rediscovered through the relics of ancient mining in different parts of Iran; this is the case in the Takab region. Data about ancient mining and metallurgy in regions with long historical traditions can be obtained via different information sources; 1) examining the physical traces of mining, e.g. ancient diggings, mining tools, slag heaps (including crucible and furnace traces), ruins of miners' residences, etc. 2) reviewing cultural and historical documents, including historical itineraries, historical texts, place names, and information from local people, etc. In the Takab area, both of the two abovementioned sources attest to a strong background of mining and metallurgy.

Abū Dulaf, the Arab traveler, poet, and frequenter of the Buyid court (ca. mid-10th century CE, Bulliet, 2014) has an interesting account about Takht-e Soleyman and the mining activities therein; "Sheez (an ancient city near Takab and Takht-e Soleyman) is a city among Zanjan, Maragheh, Sohrevard, and Dinvar and is located in the mountains that contain gold, mercury, arsenic (orpiment), lead, silver and amethyst". He particularly mentioned the gold mine of Sheez, which produced three types of gold, including gold dust (Ghumesi gold) obtained by panning and washing. This type of gold was mixed with mercury to be purified. The other type is in the form of gold nuggets (Shahrabi gold) with a bright and unchanging color, while the third type is in the form of electrum (Sagabadi gold) with a whitish color (Abū Dulaf; Zavosh, 1969).

Much older than this account, a number of third millennium BCE Sumerian texts (in Mesopotamia) refer to place names, which some scientists, have been suggested to be somewhere in the Iranian Plateau. Among the ancient textual references the place names of Zarshashum, Zarshu, and Zarshur are of interest (Nezafati, Momenzadeh and Pernicka, 2008; Pettinato,

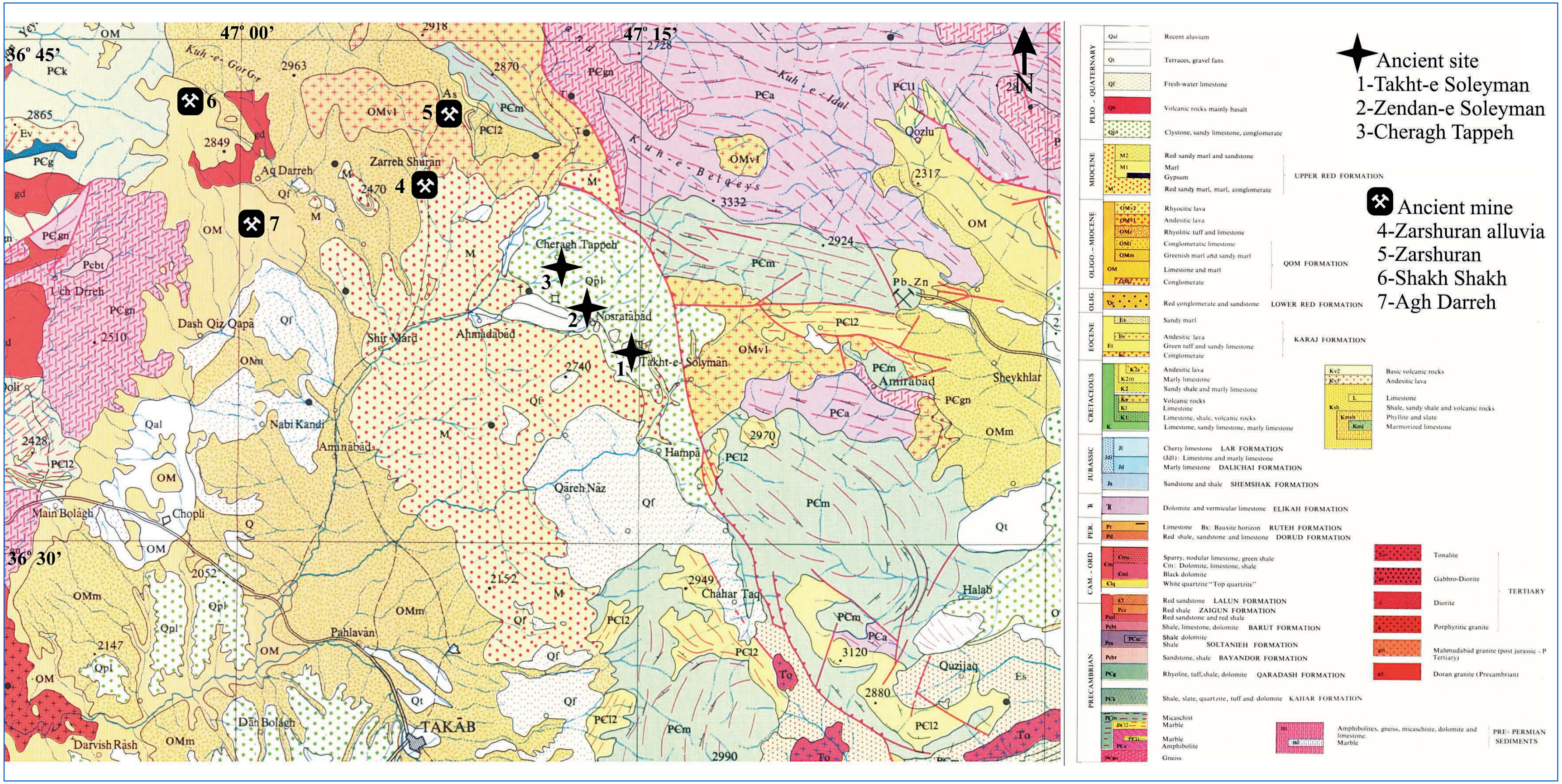

Figure 3: Geological map of the study area (part of the Takab geological map, after Alavi, 1976).

1972; Potts, 1994). These names, that resemble the name of Zarshuran (an ancient mine in the Takab area), have been mentioned in the lexical texts of Sumer as sources of gold, silver and tin (Nezafati, Momenzadeh and Pernicka, 2008).

Another interesting account is the report of a piece of 5 x 2 in^2 litharge from Zarshuran (river) by A. Scott (1914) who found that the rather pure litharge sample (with minor impurities of copper and antimony) was a crystalline litharge that showed many similarities with synthetic litharge samples. Nevertheless, he was not able to confirm the artificial nature of the sample.[1] Anyhow litharge rarely occurs in nature, especially in large pieces, and no other geological or mineralogical report on Zarshuran has ever reported litharge from the natural veins of the mine. On the other hand, litharge is the result of ancient gold-silver production by cupellation in ancient times, and therefore the report of such a lump of litharge from Zarshuran could be another indication of ancient precious metal extraction in the area.

Amalgamation was another method to gold extraction in ancient times and its utilization has been reported from the Zarshuran area. As Stöllner (2004) asserts the numerous ore mills prove that the gold-bearing ore was finely ground and it may be supposed that in many cases further separation was done by help of water. It remains unclear when production of gold by amalgamation began; early Islamic sources such as al-Hamdani have mentioned this method (Allan, 1979; Stöllner, 2004; Toll, 1968, pp.152). Native mercury and cinnabar have already been reported from the Zarshuran area in the river or in the surrounding hills of alluvial sand; also they have been reported in the form of pure metal in rock near the villages of Kiz Kapan, Karakeya, and Sandjud (Diehl, 1944; Houtum-Schindler, 1881; Ladame, 1945; Stöllner, 2004; Tardieu, 1998). Interestingly, some droplets of mercury have been reported from the mills of Madan Kharabeh (literary "the ruined mine") at Zarshuran (Diehl, 1944; Weisgerber, 1990), while some droplets have also been reported from Takht-e Soleyman northern gate (Naumann, Huff and Schnyder, 1975).

Several archaeological excavations have been undertaken on the Takht-e Soleyman site (1959-1975: Huff, 2002; Naumann and Huff, 1965; Naumann, Huff and Schnyder, 1975: and 2001-2006: Moradi 2001; 2002; 2005), during which several metal artifacts, among the other things, have been unearthed mainly from the Sassanian and Islamic (mainly Ilkhanid) and to some extent Achaemenid layers. The artifacts are of different types such as dagger blades, nails, needles, rings, bracelets, spearheads, earrings, vessels, and coins, which are composed of bronze, copper, silver, iron, and gold. Additionally, mercury droplets have been recognized in the clay soil of the northern defending gate. Metallurgical slag pieces also have been unearthed from the Ilkhanid period, probably from iron production.

The ancient mines of gold, mercury and arsenic of the Takab area (Zarshuran, Agh-Darreh, and Shakh-Shakh localities, Figure 3) are mainly located in the west-southwest of the 1:100,000 geological map of Takab area and some 10 to 30 km northwest of the Takht-e Soleyman site.

The ancient workings in the Takht-e Soleyman area are of two major types; 1) ancient workings in the bedrocks and 2) gold panning workings in the alluvial sediments of the river beds. The traces of mining in the bedrocks occur as trenches and pits, which are in some cases accompanied by the residential sites and cemeteries presumably for the ancient miners. The ore processing sites are usually not far from the mining sites in the bedrocks. Several ancient gold panning sites (Yaraziz, Yengikand, and Zarshuran sites) have been identified beside rivers where there are gold placer deposits.

Ancient Gold and Mercury Mining Sites

Zarshuran gold mine

The ancient Zarshuran gold-orpiment mine, with the general coordinate of 36° 43' 20" N and 47° 08' 45" E is located 50 km north of Takab and 8 km NNE of the Zarshuran village. The mine is accessible via the asphalt road of Takab-Shahin Dezh. Today, the Zarshuran mine is one of the major gold deposits of Iran.

A. History

The word "Zarshuran" means "the place of gold-washing or gold panning". It is the name of the river in which several old gold panning sites are located. It is the name of this particular gold mine, but Zarshuran is also the name of a village on the bank of the Zarshuran River. The Zarshuran gold mine is located inside the watershed of the Zarshuran River. Despite the relics of mining in the Zarshuran area, as well as extensive traces of gold panning in several sites at Zarshuran River and its banks, the gold mineralization in the area was not rediscovered until recently (and indeed it was forgotten for several centuries at least from the Safavid dynasty to the present time). For several decades up to the present time, modern miners neglected the gold mineralization and operated the Zarshuran mine for the exploitation of arsenic sulfides (orpiment and realgar) for the production of depilatory substances.

The first modern documents mentioning gold mineralization in the Zarshuran mine are a set of reports and articles by Bariand and co-authors (1962, 1965, and 1972), Urdea, Momenzadeh and Enayati (1970), Ghasemipur and Khoii (1971), and Momenzadeh, et al. (1987) who studied the Takab area for its mineral resources. This information did not stimulate any interest for reopening the Zarshuran mine for gold production at the time. In 1990, the Ministry of Mines and Metals started the study of the Zarshuran deposit, under the "Zarshuran Exploration plan".[2] The exploration for gold revealed that Zarshuran is a medium-sized gold deposit on a global scale. The mine is planned to be in operation in near future.

Since the whole area is under rather intensive modern mining activities, it seemed necessary to document the ancient mining activities and select representative remains of old mining in order to protect cultural heritage. In this regard, seven ancient mining sites have been investigated that will be described in the following sections.

B. Geology and ore mineralization

Several researchers and mining companies have studied the area and the mine locality in recent times, mostly on a geological-mineralogical basis (Alavi Naiini, 1990; Asadi Haroni, 2000; Bariand, 1962; Bariand and Pelissier, 1972; Bariand, et al., 1965; Damm, 1968; Diehl, 1944; Ladame, 1945; Issakhanian and Plissier, 1968; Ghasemipour and Khoii, 1971; Karimi, 1993; Khoii, 1982; Mehrabi, 1997; Mehrabi, et al., 1999; Mohajer, et al., 1989; Momenzadeh, et al., 1987; Momenzadeh, 2000; Urdea, Momenzadeh and Enayati, 1970). The mine area has been rarely studied from the archaeological point of view.

The NW-SE trending Iman Khan anticline, with some 7 km length and 2 km width, is the host of the Zarshuran gold mineralization. The Infracambrian limestones and dolomites at the southwest side of the anticline make up the country rocks. The sequence is truncated by a high angle reverse fault at the northeast end of the anticline, which juxtaposes late Precambrian and Oligocene-Miocene sequences. Oligocene rocks transgress, with a basal conglomerate, marl, tuff and sandstone over older rocks (Precambrian and Cambro-Ordovician). Miocene volcanic rocks, mainly andesite and rhyolite, disconformably overlie the Oligo-Miocene formations. Several sub-horizontal travertine patches of sub-Quaternary age are exposed in several places in the area (Alavi Naiini, 1990; Asadi Haroni, 2000; Mehrabi, 1997; Mehrabi, et al., 1999).

The oldest and the lower most unit of the Iman Khan anticline is the Iman Khan schist unit (Precambrian) which is mainly composed of a locally serpentinized chlorite-amphibole-schist with intercalations of thinly bedded marble. This unit is succeded by the Chaldagh limestone unit (Precambrian). The Zarshuran black shale unit (Precambrian) is composed of intercalations of limestone and dolomite (with up to 7.38% carbon), which overlies the Chaldagh limestone. The Qaradash shale (Precambrian), tuff, and sandstone unit covers the Zarshuran unit. An Oligocene-Miocene granitoid body intruded the mineralized Precambrian Zarshuran formation and is highly altered and mylonitized (Alavi Naiini, 1990; Asadi Haroni, 2000; Mehrabi, 1997; Mehrabi et al., 1999).

Gold and arsenic mineralization at Zarshuran deposit occurs in the Precambrian limestone and black shale and is mainly hosted by the Zarshuran black shale and the upper part of the Chaldagh limestone. The exact age of the host rock is not known for sure, although lithostratigraphy suggests late Precambrian. Decalcification, silicification (including jasperoids), potassic argillisation, dolomitisation, minor oxidation and acid leaching and supergene alteration are the main alteration types of the host rocks (Mehrabi, et al., 1999). Gold and arsenic mineralization is mainly restricted to the shale and limestone beds of the Zarshuran formation for some 1000 m. The ore-bearing beds dip SW-wards. The Zarshuran Unit is exposed for about 5 km and mineralization has been reported to occur to different degrees in different parts of this unit (Mehrabi, et al., 1999; Samimi, 1992). The thickness of the mineralized zone varies between 5 to 60 m with an average of 15 to 20 m. The main arsenic mineralization being restricted to the Zarshuran formation unit is in the form of a series of pods, lenses and veins; the average thickness of lenses is about 3 m (Mehrabi, et al., 1999; Samimi, 1992).

According to Mehrabi, et al. (1999), the unoxidized ore from Zarshuran can be divided into five types on the basis of mineral content and association of gold; (1) silicic ore, (2) arsenical ore, (3) pyritic ore, (4) carbonaceous ore and (5) normal ore (gold-bearing black calcareous shale). The gold content varies from below detection limits in some parts of the host rock to 110 ppm in the arsenical ore, while the arsenic values reach more than 62% in the orpiment rich zones (Asadi Haroni, 2000; Bariand and Pelissier, 1972; Kyazimov, 1993; Mehrabi, et al., 1999; Samimi, 1992; Taddaion, 1991).

The arsenical ore occurs mainly at the intersection of two sets of dominant faults between three valleys in the Zarshuran mine area. Irregular masses and lenses of yellow-orange color arsenic sulfides, which account for most of the arsenic in the rock, are prominent against the black host rock. The ore contains arsenic sulfides

Figure 4: a) A view of the Zarshuran Mountain with ancient mining traces on the top, looking east wards. b) The entrance of the main adit for underground mining for arsenic sulfide production. The ore contains gold at an economic grade, but the miners have ignored this fact for over 50 years of arsenic sulfide production. c) Orpiment crystals; note the bright yellow color and coarse orpiment crystals and d) and e) Arsenic ore of two different grades and different sizes. f) A closer view of the Zarshuran Mountain, looking eastwards.

in quantities from a few percent up to more than 40 % (commercial arsenic ore). The main arsenic mineral is orpiment, which is associated with lesser amounts of realgar and various sulphosalts and sulphoarsenides. The main gangue mineral is quartz. Small subhedral to euhedral pyrite crystals occur as inclusions in quartz and orpiment. The arsenic sulfides occur as very small veinlets, up to mineable lenses, and show a variety of textures and crystallinity, including open space filling, brecciated, colloform, botryoidal and radial textures (Mehrabi, et al., 1999).

C. Ancient mining

Gold production in ancient times at Zarshuran was of two different types; 1) gold mining in the bedrocks, 2) gold panning in the alluvium of the Zarshuran and the Ghourouchay Rivers.

The old workings in the bedrocks are mostly in the Chaldagh limestone and black shale members of the Zarshuran formation. Smaller diggings occur in the upper parts of the Iman Khan schist, at its contact with the Chaldagh limestone formation. The main concentration of old workings is in the Dalikdagh Mountain

(mountain of holes or mountain of diggings). The Dalikdagh Mountain is the area between the Karbalaii Abbas and the Maldarasi Valleys. Fewer old diggings occur in the heights, east of the Maldarasi Valley. The total length of the old diggings reaches 700 m, along the strike of the limestone-black shale unit (Zarshuran Formation). There are old workings in the western parts of the mining area. Some of the old diggings east of Maldarasi Valley seem to be for mining of silver, rather than gold (possibly similar to the Anguran Zn-(Pb-Ag) deposit).

The ancient workings are mostly in the form of trenches that can end as larger cavern-like holes at depth or particularly underneath the higher peaks. The trenches and open workings are from several meters to more than 100 m long and more than 10 m wide in size. Many of the ancient working have been eroded or covered by debris. It seems that, these workings have a highly irregular distribution in the mining area and follow the ore-bearing horizon. The exploitation of gold-bearing ore has continued until the ore grade became uneconomic. In many cases, the main part of the old diggings has been filled with waste from the mining activities, showing a primitive type of cut-and-fill mining method. The mining waste are mainly dark grey to black inhomogeneous angular low grade ore-bearing pieces (black shale), which are accompanied by orpiment and some cherty silica. The sizes of pebbles do not exceed a few decimeters, and are usually in the order of millimeters to 10 cm.

In the Dalikdagh Mountain area, especially in the lower part of the Chaldagh limestone, the underground ancient workings are very large and in the order of several tens of meters along the strike of bedding. The width of some of the old diggings reaches several meters. Hundreds to thousands of tons of mining waste materials are piled up near some of the old diggings. Some of the cave-like formations are currently inhabited by animals, such as bears. On Chaldagh Mountain, west of the mine valley, several holes and large open pits, underground mines and work areas are observed. Many pottery sherds and a few pieces of grinding stone have been reported in the area between Karbalaii Abbas and Maldarasi Valleys (Momenzadeh, Ojaghi and Maghdouri, 1993).

Except for an unpublished report (Momenzadeh, Ojaghi and Maghdouri, 1993) and two articles describing short visits to the mine (Stöllner, 2004; Weisgerber, 1990), no archaeological studies have been performed on the ancient Zarshuran gold mine. The names of Zarshuran (the place of gold panning) and Dalikdagh (mountain of holes) are the place names which indicate the traditional awareness of the local people about mining activities, although modern people have forgotten the etymology of these place names.

Concerning the history of mining for gold production at Zarshuran, there is no exact dating. But the Zarshuran mine is most likely one of the gold resources mentioned by Abū Dulaf. It is likely that the Zarshuran mine has been in production during several episodes from prehistoric to Islamic times (see also Momenzadeh, 2004; Momenzadeh, et al. 1994).

As the old diggings may be mistaken for natural cavities in the country rocks, the following points have been considered in order to recognize the diggings:

- Mining waste be accumulated at the threshold of the holes.
- The grain size of the waste materials is limited. The largest are not bigger than the size, which can be carried by a man (not bigger than a few decimeters).
- There are sporadic pottery sherds within the waste materials at the thresholds and openings of the digging holes and pits.
- The fragments of waste materials are usually angular and sharp-edged, not rounded
- Pieces and fragments of ore materials can be found in the waste materials in front of the digging holes.
- The inner surface of the mining pits usually shows relics of digging by miners' picks and is not very smooth (unless prehistoric fire setting process -burning by fire and picking by stone picks- has been utilized).
- The mining workings usually were found in the geochemical anomalous zones and/or known ore-bearing formations (like the black shale of Zarshuran formation and limestone of Chaldagh formation). These zones and formations still show relics of weak mineralization in their surroundings.

Agh-Darreh ancient gold mine

The Agh-Darreh gold-mercury mine, with general coordinates of 36° 39' 48" N - 47° 01' 24" E is located 40km north-northwest of Takab and 12 km west-southwest of the Zarshuran mine (Figure 3). The mine was first recognized by ancient mining traces found by an exploration group from the Geological Survey of Iran (Momenzadeh, et al., 1987). In 1992 and 1993 the Agh-Darreh area was studied in two phases for its gold mineralization (Momenzadeh, 1993; Momenzadeh, Ojaghi and Maghdouri 1993). Ancient mining traces are scattered and can be found in an area of some 200 hectares.

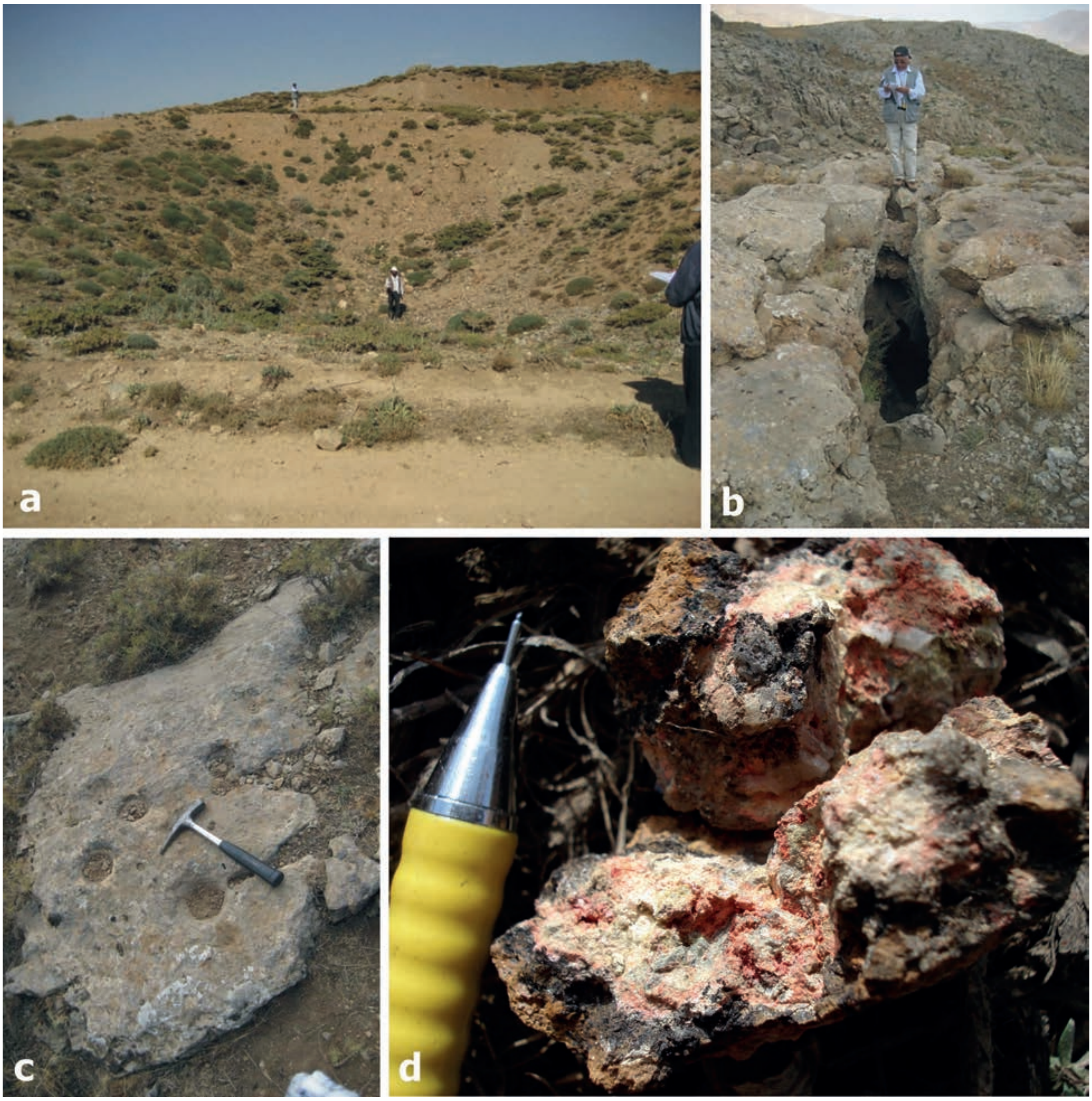

Figure 5: a) an ancient digging as a conical depression, b) a tunnel-like ancient digging in a more resistant silicic tuff and limestone, c) an anvil stone at the entrance of one digging, d) mercury mineralization as cinnabar found in the ancient diggings.

A. Geology and mineralogy

The Agh-Darreh deposit nowadays is in operation for gold by the Zarcan Company. The estimated gold reserve is of 24.5 t Au with a potential gold resource of 30–60 t at a grade of 3.9 g / t Au (Daliran, 2008).

The Agh-Darreh gold deposit is hosted by a massive cream-colored reefal limestone of the Qom Formation (Aquitanian–Burdigalian). The reefal limestone overlies detrital and marly sequences of the Qom Formation and is disconformably overlain by conglomerate, sandstone and red marl of the Upper Red Formation. The host limestone is composed of biosparite to microsparite and micrite and contains tabulate corals. It is up to 150 m thick and occupies an area of almost 100 km^2. Weak karstic topography and a thin cover of terra rossa soil characterize the surface of the limestone. The structure of the limestone in the Agh-Darreh area is that of a gently folded dome. A series of subparallel normal faults and fractures cut the limestone, the most prominent of which are vertical to steeply inclined with a NNE to NW strike. Karst features, zones of weak hydrothermal alteration and brecciation and soil geochemical anomalies all occur along NE and NW directions (Daliran, 2008).

Gold is associated with silicification and is enriched in the Fe–Mn-rich oxide blanket on top of the host reefal limestones. Mineralization occurs from the surface down to 30 m in depth (Daliran 2008). The hydrothermally altered and mineralized rocks occur in two areas that is Agh-Darreh East and Agh-Darreh West, which are divided by a structurally controlled NW-trending valley. Zones of silicification at Agh-Darreh East form NNE-aligned outcrops parallel to the fault system. At Agh-Darreh West, the silicified zones occur close to the NW-trending contact between the host limestone and the non-mineralized Upper Red Formation. Silicified bodies are blanket-like (Daliran, 2008).

B. Ancient mining

The mining remains in the Agh-Darreh area are divided into two chronologically diverse parts; the ancient mining traces and the recently abandoned workings. The latter are located one kilometer south of the Agh-Darreh-Bala village.

The ancient workings are situated in the heights of south Agh-Darreh-Bala in a rectangular area of 3 x 2 km^2 with a general WNW-ESE trend. From a lithostratigraphic point of view, the ancient workings are located in the Qom Formation including tuff, marl, and altered carbonates and acidic tuffs of lower Miocene age. In this regard, the ancient diggings are located in two types of rocks. The first is an alternation of tuff, marl, and carbonates. The second is silicic tuffs. The first set of diggings is located as a crescent area of about 1.5 km, south to southwest of the Agh-Darreh-Bala village. Here, due to the weathering of the host rocks, the original morphology of old workings has been altered and turned into smoother saucer-shaped pits of several meters in diameters. Therefore, in some cases, it is difficult to recognize the ancient workings at the first glance. The criteria that make these workings recognizable include their location in the ore-bearing sequences, presence of traces of mineralization or traces of ore debris, as well as the presence of pottery sherds. These ancient workings, which in some cases are observed as shallow conical depressions, are usually located densely beside each other, although isolated cases are present as well (Figure 5a).

The second type of diggings is situated on the southern heights of Agh-Darreh-Bala village. These diggings are densely located beside each other in the red iron-bearing acidic and silicic tuff which is intercalated with the grey limestone layers. Since the main outcrops of the mineralized tuffs are present in the southeastern and southwestern parts, the old diggings are only observed in these areas and not in the grey limestone between the aforementioned tuffs. These ancient diggings which are situated along the faults and fractures at the contact of the mineralized tuffs and the limestone unit are, due to the greater resistance of limestone to erosion, better preserved and show a rough, rocky morphology (Figure 5b). Dimpled bedrocks (used as anvil) are observable at the entrance of such diggings (Figure 5c).

The ancient diggings in the mineralized tuff are smoother and are sometimes not easy to recognize at the first glance due to erosion. As a whole, the ancient diggings that have been dug in the limestone to reach the mineralized lower part are well preserved, while the diggings in the mineralized tuff unit have been eroded and remained as smooth shallow depressions (Figure 5a and 5b). These diggings are recognizable on aerial photos as a row of subterranean canals (qanat-like). The diameter of the mouth of these depressions differs from several meters to several tens of meters and reach locally up to 100 m (Figure 5a).

Concerning the ore that has been exploited in the ancient times at the Agh-Darreh mine, it is of interest that despite extensive traces of ancient mining, no traces of slag or metallurgical remains have been found. The only traces that remained after mining in and around dug out areas are occasional scattered pieces of cinnabar, orpiment, galena, and barite (Figure 5d). Also the analysis of the ancient waste dumps showed low contents of gold (Samimi, 1992). The recent exploration showed that the average gold content in the Agh-Darreh mine is more than 2 g / t (Daliran 2008).

Shakh-Shakh ancient mercury mine

The Shakh-Shakh ancient mercury mine with the general coordinates of 36° 42’ 45” N, 46° 58’ 30” E is located on top of the Shakh-Shakh Mountain (Figure 6a), some 40 km northwest of Takab and 30 km northwest of Takht-e Soleyman (7 km northwest of the Agh-Darreh-Bala village, Figure 3). An arduous unpaved path is the only accessible road to the ancient Shakh-Shakh mine.

Extensive ancient mining traces, mainly in the form of pits and holes in the ground, are observable in an area of 100 hectares in which pottery sherds are scattered. Mineralization in the ancient Shakh-Shakh mining area occurs in the Qom formation (Oligocene-Miocene) and the Lower Red Formation (Eocene-Early Oligocene). The host rock is composed of tuff, marl, and limestone (silicic sparite limestone) of Oligocene-Miocene age. The ore is mainly observed in the lower contact of limestone and the upper part of tuff and shale units. Some cinnabar is observed in the limestone. The ore-bearing zones, especially in the iron-bearing silica parts, are in the form of disseminations and veins and veinlets. The ore is mainly composed of cinnabar and minor arsenic sulfides (realgar and orpiment) which are in part accompanied by

Figure 6: a) an overview of the Shakh-Shakh ancient mining area situated in the high mountains, b) ancient diggings as shallow conical depressions, c) cinnabar mineralization with silica as found in an ancient diggings, d) a possible entrance of an ancient diggings.

barite and manganese oxides. Iron oxides and silica are almost always associated with the mercury ore. It seems that the mercury concentration has occurred simultaneously with the deposition of limestone and marl in an Oligocene-Miocene sea; afterwards tectonic activity together with hot springs and hydrothermal vents during the Pliocene-Quaternary have mobilized and concentrated the ore in the present form.

There are extensive ancient workings of different sizes in the Shakh-Shakh area. The workings are in shape of pits and conical shallow depressions around which the debris of mining activities is observed (Figure 6b). Traces of mercury mineralization in the form of cinnabar together with silica and iron oxides are observable in some diggings (Figure 6c). The diameter of the conical depressions reaches to several tens of meters. In one case a depression, suspected to be the result of mining, was observed with a 300 m diameter. Most of the ancient diggings are densely located beside each other, although some isolated diggings have also been detected (Figure 6d).

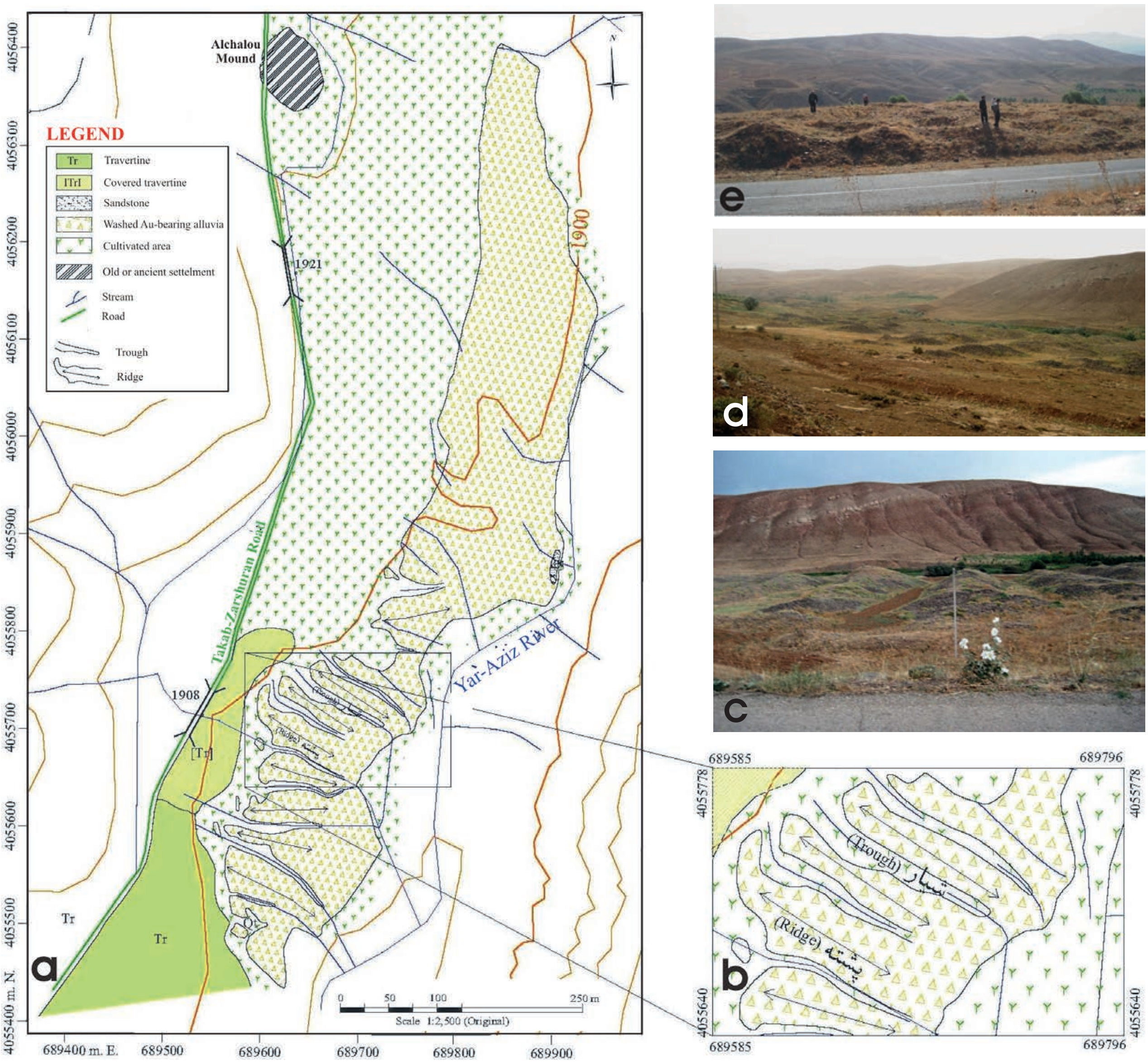

Figure 7: a) Sketch map of the Yaraziz gold panning site; "A" (after Momenzadeh, et al., 1985). The panning waste is left in the site. The location of the Alchalou archaeological site (settlement) is shown on the topmost of the sketch map. b) The enlarged sketch of the ridge and trench of the panning site. c) and d) Two closer views of the panning site (note the ridge- trough pattern of the waste dumps, as well as the boulder and coarse pebble size of the piled wastes), e) a view of the Alchalou mound.

The ancient gold panning sites

A. Yaraziz sites

The Yaraziz "A" ancient gold panning site is located some 2 km south-southwest of the Yaraziz village, some 700 m long along the Zarshuran River bed which flows southwards (general coordinates: 36° 37' 34" N, 48° 07' 20" E, Figure 7a). There is a crescent-shaped depression at the western bank of the river over the Upper Red Formation of Miocene age. There are several elongate parallel piles of boulders and coarse pebbles, with a general trend of E-W (perpendicular to the river axis) as ridges and troughs in an area of 500 x 200 m^2 (Figures 7a and 7b). The average size of each ridge is 100 m (length) x 20 m (width) x 5 m (height). Most of the boulders and pebbles are 20 to 30 cm in size, although smaller pebbles of several centimeters size may compose about 30 % of the ridges. The pebbles are rather well-rounded and are mainly made up of (more than 80 %) igneous holocrystalline basic to intermediate rocks. How and why the old workers panned gold from alluvium of the Zarshuran River is described in detail in an unpublished report by Momenzadeh, et al. (1985). According to Momenzadeh, et al. (1985), the water was channeled to the piled alluvium in the crescent-shaped depression. The sandy part of the alluvium was being panned, while the coarser portions were separated out, making the ridges. The troughs between the ridges were channels for water flowing back to the river after usage for panning gold (Figures 7c and 7d). An ancient settlement (Alchalou) in the form of a

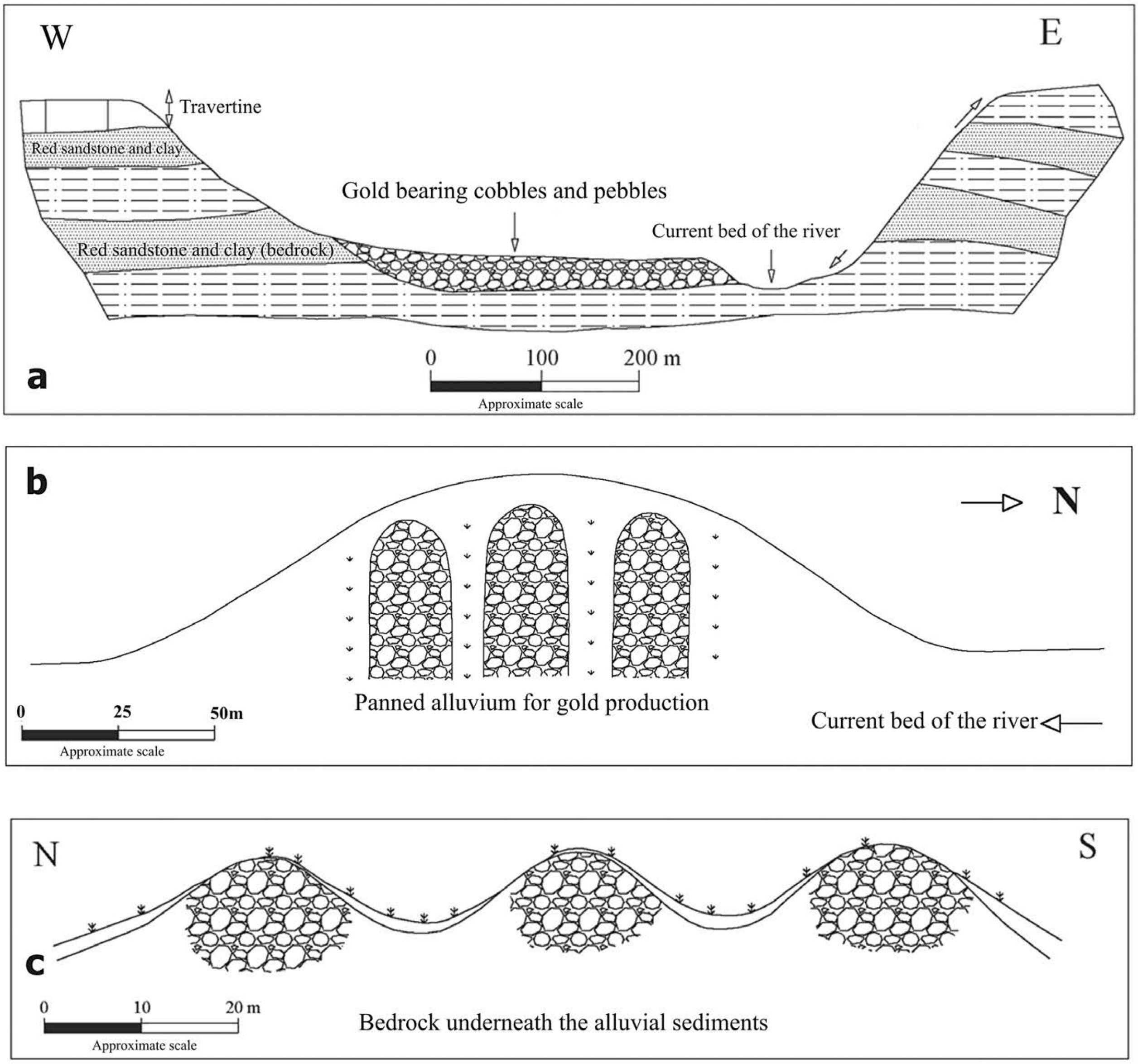

Figure 8: An interpretation of the panning at the Yaraziz site, along the Zarshuran River bed (after Momenzadeh, et al., 1985) a) a schematic profile of the Zarshuran River in the Yaraziz "A" panning locality. b) Schematic view of the ridge-through pattern of waste dumps remaining after gold panning. Water from the river was channeled to the crescent bay for panning, flowing back to the river after panning. C) schematic vertical profiles showing the ridge- trough pattern.

mound was found some 500 m north of the Yar-Aziz ancient gold panning site (Figure 7e).

There is a similar site of gold panning (Yaraziz site B) some 0.5 - 1.5 km south of the Zarshuran village on the eastern bank of the Zarshuran River (general coordinates: 36° 40' 20" N, 47° 06' 51" E). The total area of panning is some 1000 meters long, smaller than the Yaraziz site "A", but the panning process and the remaining waste dumps are quite similar to those at site "A". The boulder ridges here are some 30 to 70 m long, more than 20 m wide and up to 5 m high. The ridges and troughs are perpendicular to the axis of the Zarshuran River. Some parts of the surface of ridges and troughs are covered by soil. The vegetation, as well as cultivation in the troughs, may conceal parts of the panning site, and it is at times difficult at first glance to see the manmade nature of the morphological features.

The ancient miners have employed a special method for panning the gold from the river bed with little displacement of waste material combined with continual access to the water supply. The process is described by Momenzadeh, et al. (1985) as follows: The miners first pushed back and moved rubble in order to reach the finer grain gold-bearing sediments. They fed water from the river into the areas of placers beside the river bed with a channel. In the course of time, the old panners gradually piled up more rubble and liberated larger surfaces of finer grained sediments, which contained gold

Figure 9: Location of millstone quarries NE and ENE of the Zarshuran fortification ruins.

grains. It is likely that the placer was first panned from surface down to the bed rock in an area. Then this area was filled with the waste material (e.g. large boulders) in order to make room for the next area to be treated the same way. Since the bed rocks (underneath the alluvial sediments) in the river beds do not seem to be deeply buried, the whole volume of alluvial sediments seems to have been treated to its total depth. It seems that no unpanned sediments have been left underneath the troughs (Figure 8).

B. Yengikand and Ghourouchay panning sites

The Yengikand ancient gold panning site is situated in the eastern bank of the Ghourouchay River, west of the Yenkikand village (general coordinates: 36° 39' 38" N, 47° 07' 49" E). This site is some 500 by 250 m, extending N-S. The panning traces extend towards north-northeast along the eastern bank of the Ghourouchay River for about 1000 m. The method of gold panning is the same as described for the Yaraziz panning sites. Field observations show that the alluvial gold has been transported by water from the Zarshuran deposit to the Yengikand site, not via the Zarshuran River but via the Ghourouchay River, which flows from northeast to southwest. We took one sample from the sediments in the Ghourouchay River bed and panned it. The result showed two gold grains, several cinnabar grains and considerable amounts of magnetite. It is necessary to note that the Ghourouchay River merges into the Zarshuran River just at the Yaraziz village.

Ancient millstone quarries

There are several ancient millstone quarries some 700 meters west of the main adit entrance of the Zarshuran arsenic-gold deposit (general coordinates: 36° 43' 21" and 36° 43' 19" N, 47° 07' 34" and 47° 07' 37" E). The material is composed of coarse-grained sandstone to micro-conglomerate from the base of the Upper Red Formation. One of the biggest quarries is 200 m long, 50 m

Figure 10: a) A view of the stone wall (without any mortar) of the Faghih fortification, b) Some pottery sherds collected from the surface in the Faghih fortification.

wide and 10 m deep. The quarries are located just 150 m to 300 m northeast to ENE of the Zarshuran fortification ruins (Figure 8). The presence of millstone quarries and their possible relation to mining activities deserve more investigation.

Archaeological sites (Related to mining)

The extensive ancient mining activities for the production of gold and mercury, as well as millstones and the huge amounts of waste materials remaining after gold panning in several localities raised the question of where the habitation of the ancient miners could have been. Fortunately, the survey of the authors revealed ancient sites (including two residence mounds, two fortifications and two cemeteries), probably related to the ancient gold and mercury mining and gold panning sites. These sites are briefly described in the following sections:

Alchalou Paiin archaeological site

The Alchalou Paiin ancient mound is located some 500 m north of the Yaraziz ancient gold panning site and just 100 m south of the Alchalou Paiin village (coordinates: (36° 39' 58" N, 47° 06'40" E). The Takab-Zarshuran road passes through the mound and has already destroyed part of the mound (Fig 7e). This mound was most likely one of the administration and residential sites of the people who ran the gold panning operations in this area. The Alchalou Paiin archaeological mound is located just beside the Takab-Zarshuran Road (the site will be destroyed, most likely in the near future, during the development of modern gold mining in Zarshuran mine). This mound is named, by the authors, Alchalou Paiin mound, after the name of the nearest village. This place was not known as an archaeological settlement before.

Several pottery sherds were found in the site. Most of these sherds are plain and without embellishments, although one piece of a decorated rim was observed. The exterior surfaces of the pottery sherds are brown, orange, and buff, while their interior surface is brown and orange. The cores of the sherds are brown, orange, and gray. Traces of sands, pulverized gravel, chaff, lime, and mica grains are observed in the matrix of the pottery sherds. The preliminary study of the pottery sherds of the site indicates that the site has been the residence of the miners and their families together with the local governing officials in the Parthian-Sassanian time.

Faghih archaeological fortification

The fort of Faghih with coordinates of 36° 37' 37" N, 47° 02' 27" E and 2200 m height is located on a travertine mountain that overlooks a vast area including the ancient Agh-Darreh gold mining site. The height, the difficult accessibility, and the commanding vantage point over the surrounding areas, has given this stronghold good fortification value and a strategic importance, probably for controlling the Agh-Darreh gold mining sites, although the latter assertion needs more study.

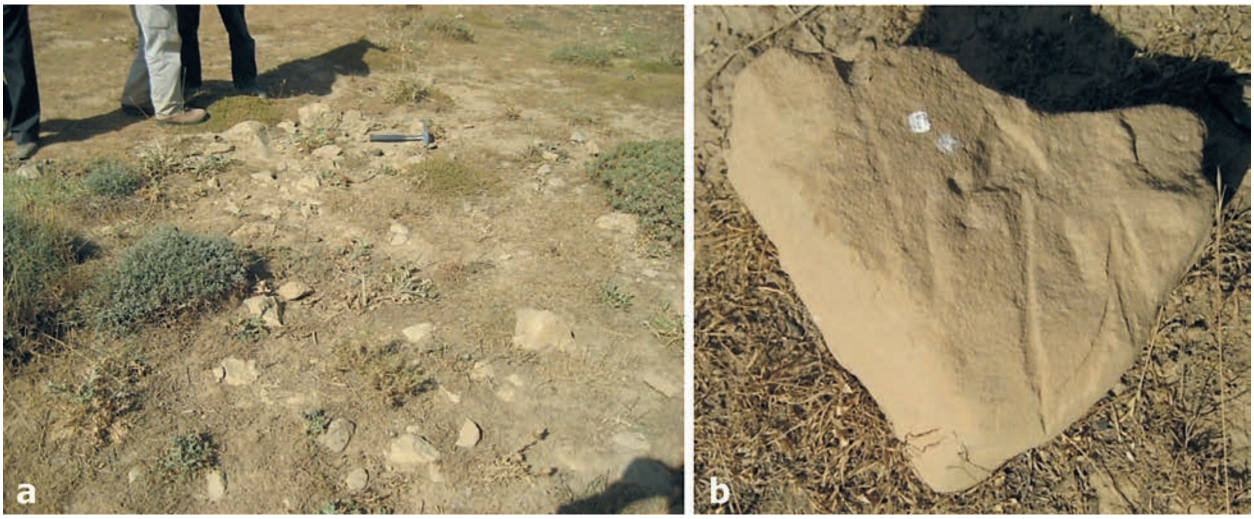

Figure 11: a) the Agh-Darreh cemetery, b) a carved stone with spearhead design.

The fortress is mainly made up of travertine (Figure 10a). No mortar traces were detected in the outer walls of the fort. A few plain, undecorated pottery sherds, similar to the sherds from the Alchalou Paiin mound were found in the fort (Figure 10b). The sherds are buff and brown in their exterior, while orange in their interior. Therefore, it seems that the fort could be dated to the Parthian-Sassanian period.

Tappeh Ghabrestan archaeological site at the Yaraziz village

The Tappeh Ghabrestan (literally cemetery hill) is a large mound (over 200 m in diameter with 5 m height) that is located inside the Yaraziz village (36° 39' 07" N, 47° 07' 58" E). The mound overlooks the plain that hosts the ancient Yaraziz panning site. Massive destruction threatens the site, especially because the local village road cuts through the mound. The local road has provided a complete section of the mound, from which several archaeological remains are observable that include pottery sherds, mud bricks, human bones (graves), charcoal, and ash. Many of the sherds from the lower strata are of so-called gray pottery type, which typically belong to (at least) first millennium BCE. This is the oldest known evidence for habitation in the Zarshuran mining area. Pottery sherds, similar to the Achaemenid period utensils were found on the upper layers of the mound.

Yengikand archaeological findings

Several pottery sherds were found in the ancient Yengikand gold panning site that look like the sherds from Yaraziz site "A" and Alchalou Paiin site. Therefore, it seems that there has been an interaction between these sites during the Parthian-Sassanian time.

Agh-Darreh archaeological site

There is a vast surface of about 200 hectares in the Agh-Darreh mining site that contains relics of ancient mining activities, including underground mines and open pits as well as traces of cemeteries and dwellings. An ancient cemetery (36° 40' 12" N, 40° 00' 27" E) already recognized by Momenzadeh, et al. (1987) was revisited (now under threat due to modern gold mining). The cemetery is situated in the middle of the modern mining workshops. The ancient cemetery is 85 x 70 m in size (Figure 11a). The rim of a stone vessel and a carved stone with a spearhead design and other unknown engravings were found in the cemetery (Figure 11b). These types of petroglyphs are typical of the cemetery engravings from the Sassanian time in different parts of Iran. Therefore, it can be concluded that this cemetery had been of use during the Sassanian mining activity in the area. The pottery sherds found in the site also attest to the Sassanian period activities.

Zarshuran mine fortification ruins

There is a ruined fortification at the junction of the Zarshuran and Balderghani Rivers where the Balderghani and Aghotagh road branches from the Zarshuran mine road. The fortification is located about 500 m west of the main Zarshuran arsenic mine adit (36° 43' 15" N, 47° 07' 32" E). The fortification has apparently been one of the administrative centers for the gold production from the Zarshuran mine. The site covers an area of 40 by 30 m^2. The authors found pottery sherds and broken pieces of millstones within the ruins (also mentioned by Weisgerber 1990 and Stöllner 2004). The period of activity of this site has a crucial impact on the chronology of the ancient mining in the Zarshuran mine; therefore this site deserves more archaeological studies.

Analytical Results

An extensive analytical work has been so far performed on some of the ore samples of the ore deposits, especially from the Zarshuran and Agh-Darreh mines (e.g. Asadi Haroni, 2000; Daliran, 2008; Karimi, 1993; Mehrabi, 1997; Mehrabi, et al., 1999; Momenzadeh, 2000), mostly for modern mining purposes. Therefore, within this research, we analyzed samples from ancient (mining) workings and dumps in order to identify which types of metals may have been extracted by the ancient miners. Toward this aim, several samples were taken from the mineralized parts of the ancient diggings as well as ancient waste dumps and related gullies, from which some were panned for heavy mineral studies, while some were analyzed using ICP-MS for trace elements including Hg (Table 1).

For the purposes of heavy mineral studies, six samples from the ancient Shakh-Shakh mercury mining site, two samples from Zarshuran, two samples from Agh-Darreh, and one sample from the ancient Yengikand gold panning sites were collected and panned. The mineral contents obtained by counting particles in the heavy portion of the panned samples and were converted into ppm, using the standard method of the Geological Survey of Iran. Three of six samples from the ancient Shakh-Shakh mercury mine show high contents of cinnabar from 129 to 160 ppm. These samples do not show high contents of any other mineral that could be of interest for ancient miners. Although no visible gold was obtained from the panning of the Zarshuran and Agh-Darreh samples, the ICP analysis of these samples confirms the presence of gold, probably in an invisible form (which is predictable from the Carlin-type of mineralization) in other minerals. The Zarshuran samples show high contents of orpiment and cinnabar, while the samples of Agh-Darreh show high contents of cinnabar. No other minerals that could be of interest for ancient miners have been detected in the samples of Zarshuran and Agh-Darreh. The absence of gold in the Yengikand samples could imply the perfect panning techniques of the ancient miners.

According to the (ICP-MS) analytical results (Table 1), one sample from the Shakh-Shakh ancient mine shows a high content of mercury (3670 ppm). Except for arsenic which shows anomalous contents, no other elements are in high concentrations in the ore of Shakh-Shakh. The gold content in the Shakh-Shakh old mining pits is low.

Ore samples from ancient workings of Agh-Darreh (Agh-16A, 17, 18A, 19A) show high contents of antimony, rather high contents of gold (0.9 to 1.13 ppm) and arsenic and considerable amounts of mercury (550 ppm). The sample taken from the ancient diggings of Zarshuran (ZSH-26) shows a high content of gold (2.9 ppm), arsenic, antimony and zinc.

As a whole, the results, together with the results from Asadi Haroni (2000), Daliran (2008) and Mehrabi (et al. 1999) indicate that there is a close geochemical and mineralogical correlation between the described depos-

Table 1: Trace element analysis results of the samples by ICP-MS. All values are in ppm, except for gold which is in ppb.

Sample No.	Au	As	Hg	Fe	Ba	Ca	Cd	Cu	Mn	Pb	S	Sb	Zn
SHAKH-5A	3	190	10	12000	60	279000	0.6	6	370	10	340	4	120
SHAKH-9A	<	400	50	14000	3600	195000	1	7	440	16	1100	17	50
SHAKH-10A	2	2100	<	344000	90	58000	6	14	170	170	440	6	1600
SHAKH-11	<	300	<	9700	80	273000	2	4	100	10	170	2	25
SHAKH-12A	<	58000	3670	53000	1600	23000	170	9	270	39	2600	220	110
SHAKH-14	<	300	10	9200	770	263000	1	8	3800	20	150	6	25
AGH-16A	900	24000	280	81000	5900	50000	170	200	165000	12000	980	24000	7300
AGH-17	1200	22000	550	91000	6900	26000	120	150	172000	3100	670	24000	7200
AGH-18A	1000	3400	90	16000	530	810	8	14	330	19	8600	70	35
AGH-19K	1100	139000	480	112000	5500	7800	440	6	320	40	1300	770	810
ZSH-26	2900	28000	260	27000	7	4800	680	100	1000	4800	128000	5500	56000

its of the Takab area, especially in relation to gold, arsenic, antimony, and mercury. Nevertheless, despite the similarities, there are some differences as well; Mercury (cinnabar) is the major element in the Shakh-Shakh site, and naturally the target element for the ancient miners. At the Agh-Darreh gold deposit despite the presence of mercury and antimony, gold has apparently been the only product of ancient mining activities. No ancient mining traces were found in the antimony-rich outcrops. Even in Zarshuran, which shows the highest percentage of orpiment among the deposits, there is no evidence that indicates that orpiment has been mined by ancient miners. Here also gold was apparently the only product and the only objective of ancient mining (it is notable that production of arsenic minerals in the present time for depilatory and sanitary purposes is not considered here as "ancient mining"). Concerning the antimony content of the ore in Zarshuran and Agh-Darreh deposits, we did not find any traces of ancient mining for such an ore. The high content of cadmium in the ore of all three deposits of north Takab area could be of interest, especially from the viewpoint of the future archaeometric investigations. Concentrations of cadmium in waste material or artifacts from archaeological sites may be a way to link production debris or objects to the processing of ore from this region.

The mineralographical and microscopical investigation of ten polished sections of the ore from Zarshuran, Agh-Darreh, and Shakh-Shakh did not reveal any free gold grains. This, together with the high content of gold obtained from analytical results, is in agreement with previous investigations (Asadi Haroni, 2000; Daliran, 2008; Mehrabi, 1999) that imply that highest percentage of gold occurs in an "invisible form" in the ore of these deposits. The mineralographical studies of six polished sections from Shakh-Shakh deposit revealed cinnabar, secondary Fe-oxides (goethite and limonite), pyrite, and minor/trace amounts of chalcopyrite. The same investigations on three samples from Agh-Darreh indicated stibnite, Fe-oxides, and manganese oxides as major constituents, and pyrite, galena, orpiment, and chalcopyrite as minor minerals. One polished sample from the Zarshuran deposit indicated high amounts of orpiment and stibnite and minor amounts of realgar. Some tiny grains of pyrite were observed in the section too.

Conclusions

This study has shown more than before, the importance of the north Takab and Takht-e Soleyman area in the history of ancient mining and metallurgy. Our investigations, together with the previous studies revealed that the area had been inhabited, at least from the first millennium BCE, through the Achaemenid, Parthian, Sassanian and Islamic times. The attested mining activities date back at least to the Parthian and Sassanian times under the rule of the local authorities.

The present study revealed that at Shakh-Shakh ancient mining was for the production of mercury, while it has been conducted solely for gold in the Agh-Darreh and Zarshuran mines, respectively. Mining activities, according to our studies, have had a crucial impact on the habitation of the north Takab area, including the Takht-e-Soleyman site. Not only in the Middle Ages but since at least the Parthian times.

The young magmatic and tectonic events of the Takab area that began during the Upper Miocene and are still active in the area reached their peak in the Pliocene-Pleistocene. One of the manifestations of such activities is the mineral springs (both hot and cold) that form travertine deposits. These geological events and their consequent travertine precipitation (including the landforms of the area) and mineral springs, as well as the Au-Hg-As mineralization have had a great impact on the establishment and development of civilization in the north Takab area. Takht-e Soleyman, itself, is located on a travertine flat raised structure (platform) over which a mineral water pond has formed. Several characteristics of this platform have made it a well-sited natural fort. These include the higher elevation of the platform to the surrounding plains, an appropriate and permanent water supply and availability of a good building stone (travertine). Other ancient places in the area enjoyed the same advantages, e.g. the Faghih fort (travertine platform and available building stones). The Zendan-e-Soleyman site, which is a dead mineral water spring, is another archaeological site, which was alive as long as the spring was active. The cessation of the Zendan-e Soleyman spring (likely by an earthquake in prehistoric times) led to the abandonment habitation on its foothills.

The other fundamental effect of the young magmatic and tectonic activity is the potential for diverse (Au, As, Hg, Sb, Ag, Pb, and Zn) mineral deposits in the Takab area. Such ore deposits have been the main reason for the continuous settlement, as well as the expansion of life and industry in the area during the historical (and prehistoric?) periods until up to the present day. Due to the importance of the Takht-e Soleyman area for ancient mining and also because of the extensive modern mining activities in the area that may cause the destruction of the important relics of ancient mining and metallurgy, it is recommended that representative sites (that have already been proposed by the authors) be preserved and archaeologically excavated. This is necessary to safeguard the ancient mining heritage of Iran on one hand and to obtain exact chronological documentation about the ancient mining in the area on the other. Archaeometric investigations on the ore deposits of the area and comparison of these results with ancient artifacts is another aspect that could be followed in the future studies of the north Takab and Takht-e-Soleyman area.

Some Complementary Comments

The authors' investigations in the study area, in addtion to revealing new information about ancient mining, has raised a number new questions. Some of these questions have been listed as follows:

1. How did the natural and geological events and features control the inception, development and continuation of habitation in the Takht-e- Soleyman and north Takab area?
2. How did the exploitation and utilization of mineral resources, including gold, mercury, arsenic, gemstones and building stones (especially travertine), impact/control the inception, development and continuation of habitation in the Takht-e-Soleyman and north Takab area?
3. Were the origins, development and resumption of habitation in Takht-e-Soleyman and ancient Sheez urban sites in ancient times (at least partly) caused by or the result of the mining activities in the north Takab area?

The Takht-e-Soleyman site and many other sites in the north Takab area, like Zendan-e-Soleyman, Belgheis castle, Faghih, Alchalou Paiin ancient mound, Tappeh Ghabrestan at Yaraziz, and other archaeological sites are likely to have been developed due to the presence of mineral resources.[3]

Mining activities in the Middle Ages at the Takht-e-Soleyman "Sheez" site are reported by Abū Dulaf and can be proved by the archaeology of area. The recording of mining and related industries can be traced in the nomenclature of some of the place names in the north Takab area. Zarshuran (place for gold panning), "Dalikdagh" (mountain of holes and cavities), and "Gharazagh" (Black Zagh which means vitriol) are some of these names that reflect old mining activities in the area.

Many old mines, from the archaeological point of view are different from other ancient heritage sites due to their economic value in the present times. Since an old mine, unlike other types of archaeological site, represents a mineral resource, hence is threatened by modern miners, especially if the resource is not yet exhausted and so can be a good target for modern mining.

In the case of the north Takab area, at least two periods of mining activities have occurred; one in the Parthian-Sassanian period and one in the Middle Ages. The Achaemenid archaeological settlement in the Yaraziz village (whose lowermost parts could be even older than Achaemenid period) may be also related to mining activities in that period.

The present study is very preliminary and gives only a general view of the relationships between ancient mining and ancient settlements in the subject area. Thus:

- It is likely that other ancient mining and settlement sites have been overlooked.
- Our studies are not precise enough to give an accurate chronology of the mining and settlement periods. Some of the mined minerals like gems (for example from the Kuh-e-Belgheis area), Amethyst (gemstone reported by Abū Dulaf), Vitriol (Zaagh or Zaaj), building stones (which are used in the construction of fortifications in Takht-e-Soleyman, Faghih and many other sites), and arsenic minerals (used as sanitary substance) have not been studied.

Our experience in archaeology of mines in the Iranian plateau shows that many of the deposits mined in the Middle Ages, were already mined before (once or several times) in older periods and perhaps since prehistoric times.[4] Therefore, we think that more precise and detailed archaeological studies in the north Takab area should reveal several successive mining stages before the present-day mining activities.

Recommendations for Further Research

- The north Takab area, including Takht-e-Soleyman, is one of the most informative regions for discovering the history of inhabitation from the prehistoric to the end of the Middle Ages. Accordingly our ideas about mineral resources being the main cause for establishment of the Takht-e-Soleyman culture including its Fire Temple, suggest that the study of ancient mines and related archaeological sites is a crucial task of archaeologists in this area. For this reason, we firmly recommend further archaeological studies in the north Takab area.
- As modern mining activities in the area are rapidly growing and the old mining relics, an asset of national heritage, are in threat of annihilation, we urge that archaeological recording to be carried out in those mines, where modern mining is being practiced, like Zarshuran and Agh-Darreh gold mines.

Acknowledgements

The authors would like to express their thanks to the Iranian Cultural Heritage Organization and the Zarneh Research Group for their financial support. The authors would also like to thank Mr. Ebrahim Heydari, then the director of the Takht-e Soleyman Cultural Heritage Center, for his kind assistance. The two respectful reviewers are thanked for their constructive comments.

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Notes

1 The first author has found a piece of litharge just in front of the Zarshuran village in 1991, during a reconnaissance survey for mineral resources in the Takab quadrangle area. He was convinced that the litharge was synthetic, probably a waste piece of a silver or gold production process.

2 The first author of this report led the "Zarshuran Exploration Project".

3 Although water is the prime requirement for all settlements, in the past and present, it has not been and is not the only factor. The modern Sarcheshmeh copper mine (the largest modern Iranian copper mine), as an example, has caused the establishment of the Sarcheshmeh settlement. It can be an argument that settlement and habitation in many archaeological sites like Takht-e-Soleyman are due to the mining of mineral in ancient times.

4 Veshnaveh (copper), Shakin (silver), and Kuhzar-e-Kashmar (gold) deposits are some examples which have experienced several periods of mining besides the modern mining activities.

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2016 | Nr. 22.2

METALLA

DBM

METALLA (Bochum)
Biannual journal (June/December)

Subscription Price: 30 € per year. Price includes postage and handling.
For subscription contact Stephen Merkel at the Deutsches Bergbau-Museum Bochum
Am Bergbaumuseum 28,
D-44791 Bochum, Germany
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Impressum

Publisher

Deutsches Bergbau-Museum Bochum
Museum Director: Prof. Dr. Stefan Brüggerhoff

Layout Design: Dipl. Ing. Angelika Wiebe-Friederich

Printing: Print Art GmbH, Bochum

ISSN 0947-6229

Cover Images

1 and 2: The entrance to an ancient subterranean gold / mercury mine in the Agh-Darreh mining area in the Takab region of the West Azerbaijan Province in Iran. Rocks containing cinnabar and orpiment can be found in the mine tailings. This is one of several ancient gold mines investigated in the Takht-e Soleyman area. See contribution Momenzadeh, et al.

3: Traces of Roman copper mining in Wadi Amram, in the southern Wadi Arabah. The ore deposit of Wadi Amram is the nearest copper source to the Chalcolithic / Early Bronze Age I settlements of Tall Hujayrat al-Ghuzlan and Tall al-Magass, settlements with evidence of early copper metallurgy. An investigation of copper ore from the Wadi Amram was undertaken and compared to ore from Faynan and Timna and copper-based metallurgical debris from the two aforementioned settlements. See contribution Ketelaer and Hauptmann. Photo: I. Löffler, DBM.

4: View of wooden support beams in a high medieval copper-lead-silver mine in northern Siegerland, Germany. The Alter Mann Victoria mine and two others in the region were studied as part of an ongoing multifaceted project to explore the meaning and importance of the non-ferrous metallurgy in northern Siegerland in the High Middle Ages. See contribution Zeiler, Garner and Golze. Photo: P. Thomas, DBM.

metallum, i, n:
Mine (often pl.)
Metal, also stone, mineral

μεταλλον, το:
Mine, shaft, gallery;
esp. a) Mine (usually pl.)
b) Quarry

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ISSN 0947-6229