Sustainable Earth Trends 4(2) 2024 39-54

Shahid Beheshti University

Sustainable Earth Trends

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

The stone sources of the Takht-E-Soleyman complex: A reconnaissance

Hamid Amanollahi*

Department of Archeology, Faculty of Literature, Tehran University, Tehran, Iran

ABSTRACT

Although numerous archaeological studies have been carried out on the "Takht-e-Soleymān" (TS) site, a better and deeper understanding of this fire-temple complex requires more investigation and research. Petrographic analysis of the stone blocks used to construct this complex is worthwhile from several aspects: firstly, the present study particularly identifies, for the first time, the physical properties of the stone pieces (color, texture, physical strength, luster, etc.) and their petrographic characteristics in thin-section (including rock type, mineral constituents, and textures/microstructures). In addition, this study helps identify the suitable materials for protecting and repairing the stone pieces used in the construction of the "Takht-e-Soleymān complex" (TSC). By close petrographic and micropaleontological examination of rock samples collected from the ancient quarries and from the TSC complex, and through the comparison of the data, the following results were achieved: the detailed study of 12 rock samples collected from different parts of the TSC including Sassanid buildings (ramparts and towers number 4,15, 35, the northern vestibule, Anahita Temple, Fire Temple's southern portico and the western or Khosrow portico) are comparable with those of Tepe Chāl (A and B), Kochka Barz ancient quarries. The quarries used in Ilkhanid buildings (the twelve-sided building, the four-columned building or the council hall, and the hunting palace) are comparable with rock samples from the Sur and Bābānazar Mountains. This facilitates the selection of materials for subsequent restorations.

ARTICLE INFO

Keywords:
Ancient Quarries
Petrography
Stone sources
Takht-e-Soleymān complex

Article history:
Received: 25 Feb 2024
Accepted: 19 Apr 2024

*corresponding author
E-mail address:
amanollahi.hamid@ut.ac.ir
(H. Amanollahi)

Citation:
Amanollahi, H., (2024). The stone sources of the Takht-E-Soleyman complex: A reconnaissance, *Sustainable Earth Trends:* 4(2), (39-54).

DOI: 10.48308/set.2024.235577.1051

1. Introduction

Despite differences in geographical environments, settlement, and subsistence patterns in ancient civilizations such as China, Iran, Mesopotamia, Egypt, Greece, and the Andes Mountains in South America, one common characteristic draws attention, to the techniques of the exploitation of natural resources: Historical records demonstrate the techniques and the ways by which the ancient artisans processed and exploited the natural raw materials. Today by applying the techniques and scientific approach used in earth sciences to archaeological problems in the form of interdisciplinary sciences such as geoarchaeology, we are looking for traces to reconstruct and understand the ways by which these basic building materials were supplied and fabricated for constructing such monuments in the ancient world (Amanollahi, 2010).

The utilization of stone as a fine and durable material in ancient civilizations has always drawn attention to itself. However, the question is how and from where ancient people gained access to these materials and how they utilized the specific geological and geomorphological conditions to exploit stone materials optimally. The Takht-e-Soleymān area contains one of the greatest concentrations, of travertine spring deposits in Iran (Heydari-Guran et al., 2009). The region enjoys a high potential for metallic and non-metallic minerals (Fig. 1). The existence of such mineral resources in the region is one of the most important factors in the attraction of human groups during different periods from the middle Paleolithic to Islamic times (Amanollahi, 2011). TSC has been constructed upon a stone platform enclosed within an oval-shaped wall with 101667 square meters area (Qadri, 2009) including 38 oval-shaped towers, two great gates of the Sassanid period, fire-temple, the Ānāhitā's Temple, the Khossrow Portico, etc. Around this site and across an area of about 7500 hectares a large number of archaeological sites of prehistoric, historic, and Islamic periods particularly Sassanid fortifications and temples and old mines exist (Heidari, 2015). The stone buildings of Takht-e-Soleymān Complex have been so far investigated from archaeological, historical, artistic, and architectural points of view and many facts have been revealed about them. However, some questions remain to be answered, i.e., from which mines the stone blocks used in this complex were extracted? How did the miners use the general geological conditions of the region for the optimal extraction of stones? By discovering the stone sources used for the TSC, another step can be taken in the archaeological studies of the Sassanid and Ilkhanid (Mongol) periods as the evidence acquired from the mines is part of the history, architecture, engineering, and human activities of these two historical periods of Iran contributing to the reconstruction of socio-economic conditions in Sassanid and Ilkhanid periods. The first to introduce the mines of the TSC region was the Arab Traveler, mineralogist, and gemologist Abu Dolaf Moss-ar ibn-e Al-Mohalhel Al-Khazradji. After he refers to the location of Shiiz in his itinerary in 341 Hijri, he names the mines of the Takht-e-Suleymān region expounding the quality of the materials extracted from the mines. He says, "Shiiz" is a town located near Maragheh, Zanjan, Sohrevard and Dinvar within mountains containing gold, silver, mercury, lead, orpiment, and amethyst mines" (Abu Dolaf, 1963). After Abu Dolaf, the other writer and historian Mohammad ebn-e Mahmud ibn-e Ahmad-e-Toossi, in his book 'Ajayeb ol Makhlooqat' says the following remarks about Shiiz town and its fire-temple: "Shiiz is a town between Maragheh and Zanjan (Zangan) within mountains, and has mines of gold, lead, orpiment and mercury. However, firewood is precious and silver is rarely smelted" (Toossi, 1966). Since the 19th century, western travelers and scientists have visited the TS region and have frequently described it. In 1881, Schindler visited the TS region, recorded the existing minerals across the region in a map and described the ruins on the stone platform (Schindler, 1881). In 1907, Stahl carried out a geological survey in the region and by mapping the routes presented a comprehensive report of the geological structures and rock formations. Also, in 1964, Elizabeth Naumann, a member of the archaeological excavations group of the 'Zendan-e-Soleyman' site, examined the geographical and geological aspects of the region. In this survey, the map of the travertine platform of TSC and its surrounding lands was prepared and the water samples of TSC Lake and the springs of Zendan-e-Soleyman were analyzed. In the late 1960s, while Wolfram Kleiss was involved with opening trenches near Zendan-e-Soleyman, Damm investigated the geological aspects of the region (Damm, 1968). In 1991, Babakhani and Chehriaq carried out some studies about the travertine-maker springs of Takab and TSC region for the Geological Survey of Iran (Babakhani and Chehriaq, 1991). In 2006, Zarneh Research Institute studied and investigated the silver, lead, and zinc mines of the Takab region with emphasis on a part of TSC. In 2008, the same institute managed to survey, discover, and document the ancient mines of the TSC region. This article is an 'abstract' of a greater geoarchaeological project on the Takht-e-Soleymān region, directed by the author" carried out in 2006, and financially supported by the Takht-e-Soleyman World Heritage Organization. The purpose of the article is identification the specific stone quarries utilized in the construction of Takht-e-Soleymān, introduce the historical significance and context of these quarries, locate them, providedetails about the types of stones extracted from these quarries for building purposes, and analyze of the impact of these stones on the architecture and aesthetics Takht-e-Soleymān.

2. Material and Methods

The TS is a geologically complex region. Lithological variability, the existence of numerous faults with different trends, the tectonic character of the region, the occurrence of multiple intrusions, and the age variation of the rocks have all resulted in complex geological conditions. The travertine deposits that are widespread as well as the terrace-like structure of the Takht-e-Soleyman travertine deposits are derived from high discharge springs. Those with dome–shaped as well as high conical structures, e.g. Zendan-e Soleiman are formed from low discharge springs (Heydari-Guran et al., 2009). Naumann (1972) reports that “The geological characteristics of this region are as well-known and interesting as its historical sites. Considering the existence of gold, silver, mercury, lead, arsenic, and vermilion mines around the hill as well as numerous hot springs along the western borders of Zendan-e Soleyman which have always been symbols of mysterious powers in the public view (today they are used to cure some illnesses), one realizes the attractiveness of this region as a place for settlement and as a place worthy of respect to nature. As a result, paying attention to these natural geological phenomena is essential for understanding the temples”. Takht-e-Soleymān region exhibits a complex geological situation due to various factors. These include the diverse lithology, numerous faults with varying orientations, the tectonic configuration of the area, rock transformations, the intrusion of igneous masses between layers, and significant differences in rock ages. Notably, this region has both historical significance and intriguing natural features. According to Navman, the valley around Takht-e-Soleymān is rich in minerals such as gold, mercury, lead, silver, arsenic, and shale. Additionally, hot and cold-water springs are abundant, adding to the area’s mystique. The allure of this region for habitation and reverence toward nature becomes evident when considering these geological phenomena. From a construction perspective, Takht-e-Soleymān lies within the Sanandaj-Sirjan zone (Stocklin, 1968) and the Khoi-Mahabad zone (Nabavi, 1976). It serves as a meeting point for the Alborz-Azarbaijan, Central Iran, and Sanandaj-Sirjan construction zones. Consequently, the tectonic activity associated with each of these zones significantly influences the region’s overall construction conditions. Late Precambrian movements, particularly the uplift in northwest Iran (notably in Takab and Koh Siah), have resulted in angular slopes at various locations (Eftekharnezhad, 1980). The Takht-e-Soleymān region primarily consists of metamorphic rocks, including schist, marble, gneiss, and amphibolite. These rocks form the highest elevations, with Balqis Mountain reaching 3200 meters and Qiblah Mountain at 3208 meters. The geological trend in this area is northwest-southeast. Directly overlying the metamorphic rocks are Oligo-Miocene sediments. It appears that these metamorphic formations, spanning from the Precambrian to the upper Paleozoic period, likely formed the elevated terrain during the second to the middle of the third terrestrial period. During this time, little to no sedimentation occurred due to elevation and erosion processes.

The rock units significantly influencing the structural composition of the region can be categorized as follows (based on Fig. 1 of the geological map):

1.2.1 **Metamorphic Belt:** This belt exhibits an almost northwest-southeast trend and is considered part of the Sanandaj-Sirjan zone.

1.2.2 **Intrusive Masses:** These intrusive rocks are exposed as relatively narrow masses in the northern and eastern regions and as smaller spots within the central area of the Takht Sulaiman sheet. Most of these intrusive masses belong to the second geological period, while only a few small spots date back to the Pliocene depths.

1.2.3 **Sedimentary and volcanic deposits** significantly shape the surface of the Takht-e-Soleymān region, exhibiting remarkable diversity in terms of age, lithology, and morphology. Let’s explore the key components of this geological complex: **Upper Red Formation (Qom Formation):** Thick rock units from the Upper Red Formation or Qom Formation are present in the southwest and east outcrops. These formations contribute to the overall composition. **Aligo-Miocene Volcanic Rocks:** This volcanic rock unit, dating back to the Aligo-Miocene period, plays a crucial role in the region’s geology. **Conglomerates:** Alongside the aforementioned rock types, conglomerates are also part of the complex. These consist of sedimentary rocks such as limestone, marl, sandstone, and conglomerate. **Volcanic Units:** The volcanic component includes lava flows and pyroclastics, such as tuff, cut tuff, welded tuffs, and volcanic breccias. These volcanic materials, composed of dacite, andesite, and basalt, are widespread throughout the sheet. These rock formations interact with various geological processes, including erosion, tectonics, weathering, and dissolution, shaping the structural units of the region. Additionally, one of the more recent deposits is travertine rock. These rocks are scattered across the southern and southwestern parts of the Takht-e-Soleymān sheet. Most notably, they occur along the Great Qainerja Fault and the Takht-e-Soleymān Fault. The formation of travertine is likely linked to calcareous springs, both hot and cold. Integral deposits are concentrated in the southern part of the range, while scattered masses are found in parts of the central and northwest regions. Geographical and geomorphological phenomena, as objective manifestations of geological factors, play a direct role in shaping human settlements and habitats in the Takht-e-Soleymān region. By examining geological features, geomorphology, and mineral deposits, we can summarize the following points:

a) Platform Formation: The buildings at Takht-e-Soleymān were constructed on a platform formed by a geological phenomenon—the presence of a mineral water spring and gradual travertine deposition. Despite being approximately 25 meters higher than the adjacent plain, this platform served as a natural defense against potential threats, both human and natural (such as floods).

b) Abundant Travertine Deposits: The sedimentation of mineral water springs resulted in abundant travertine deposits. These deposits, found directly on the platform or in the surrounding plain, provided essential materials for constructing fortifications and structures atop the platform."

c) Young magmatic and tectonic activity during the Upper Miocene, which continues to the present day with its peak in the Pleistocene, has had significant geological consequences in the Takht-e-Soleymān region. Notably, mineral water springs such as those at Zandan Suleiman, Ahmedabad, and Qainerja, along with travertine deposits in Agra, Zarshouran, and other areas of Takht Suleiman, owe their existence to this dynamic geological activity.Moreover, the same magmatic and tectonic processes have contributed to the formation of valuable mineral deposits. Gold, silver, mercury, arsenic, lead, zinc, and other minerals have been created in the Takht-e-Soleymān region. These geological processes played a pivotal role in shaping the landscape and establishing settlements in the past. The presence of mineral deposits resulting from Iran's young magmatic-tectonic activity in the Takht-e-Soleymān region has been a key factor in the historical and contemporary development of settlements. Looking ahead, further exploration and utilization of mineral reserves, as well as the region's travertine and hot/cold mineral waters, could play an even greater role in the future.

d) Faults are significant geological features resulting from tectonic activity in a region, and they play a crucial role in shaping the current topography. One prominent example of this is the **Balqis-Gorgur outcrop**, which constitutes a major part of the region's rugged landscape. The formation of this outcrop can be attributed to the **Qinerjah-Chahartaq thrust fault**. The operation of the Qinerjah-Chahartaq thrust fault has several important consequences, including the creation of alluvial cones due to the fault's movement, contributions to mass movements like landslides and rockfalls, influence on karst features such as sinkholes and caves, and alterations to river courses.

e) Karst shapes, in particular, provide valuable insights into the local geology and climate. To ensure the preservation and restoration of this unique landscape, it is essential to develop and implement plans that consider these specific conditions.

f) Some of the **geomorphological phenomena** in the Takht-e-Soleymān region are as captivating and renowned as its historical monuments, making them potential attractions for tourists. This region boasts remarkable diversity in its formation units, shaped by a combination of climatic factors, lithological features, erosion processes, weathering, and tectonic movements. The landscape features steep slopes, sharp peaks, narrow valleys, and deep canyons—all evidence that the Takht-e-Soleymān region is in a **young stage** from a geomorphological perspective.

g) Tectonic activity has played a significant role in shaping the region's topography over time, leaving behind numerous fractures and faults. These geological features provide insights into the dynamic processes that have shaped the landscape.

h) Beyond its natural beauty, the area surrounding the Takht-e-Soleymān platform holds **exceptional mineral potential**. Metallic minerals such as lead, zinc, copper, chromite, arsenic, antimony, mercury, gold, and iron are abundant. Additionally, non-metallic minerals—including kaolin, polyite, fluorine, asbestos, feldspar, silica, gypsum, and decorative stones—contribute to the region's geological richness. These mineral deposits have been crucial factors in the emergence of human settlements across different historical eras, from the Middle Paleolithic to the Achaemenid, Parthian, Sassanid, and various Islamic periods (Amanollahi, 2023).

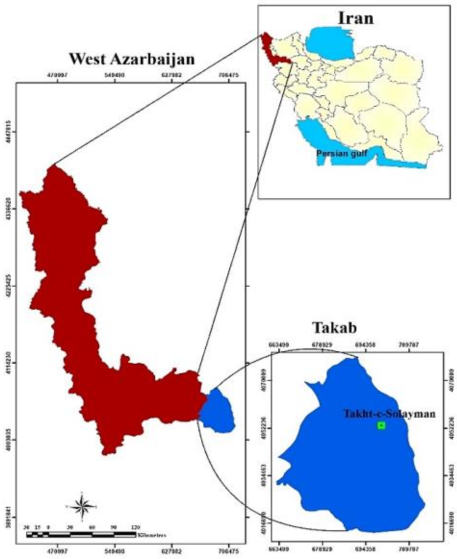

Fig. 1. Geological map of Takht Suleiman, scale: 1:100/000

The area under study is located between 36˚ 33´ - 36˚ 38´ northern latitude, and 47˚ 06´ - 47˚ 18´ eastern longitude in the northeast of Takab city on the western mountains of Iran bordering western Azerbaijan province from the southeast, Zanjan province from east and Kurdistan province from the south (Qadri, 2003). In Aug. 1986, in order to identify the stone mines used for the construction of the TS buildings, a 30 km radius zone with TS as the center was surveyed. In conducting the survey different kinds of published maps such as the topographic maps of the National Geographical Organization of Iran (1:250000 Shahin Dej quadrangle, 1:50000 TS quadrangle, and 1:50000 Ghareh Naz quadrangle), 1:100000 geological map of TS, aerial photographs taken by Erich Schmidt in 1937 and Georg Gershter in 1976 were utilized during geological fieldwork done with the collaboration of two experts in this field. A GPS system was used to determine the geographical position of the mines utilized. To identify and distinguish the types of stone blocks used in the buildings of TSC, two methods were employed: naked eye or macroscopic studies and microscopic studies. By macroscopic studies, the researchers inspected the stones frequently and in different times. Those parts that were different from the other parts in terms of visual physical characteristics were sampled. At this stage, 12 stone samples from the main part of the complex including Sassanid buildings (ramparts and towers No. 4, 15, 35, the northern vestibule, the Anahita Temple, the southern portico of the fire-temple, and the western portico or Khosrow portico) and Ilkhanid structures (the twelve-sided building, the four-columned building or the council hall, and the hunting palace) were taken to be analyzed (Fig. 2).

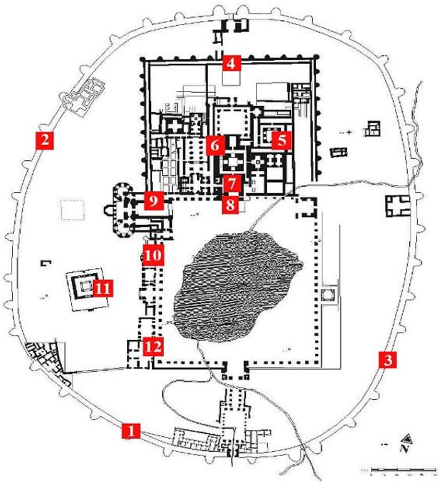

Fig. 2. The locations of the samples taken from the complex

This research is based on microscopic (petrographic) studies and archaeological records. Accordingly, some samples from the stones used in Takht-e-Soleyman buildings were selected from which thin-sections were prepared.

3. Results and discussion

3.1. The Investigation of Stone Variety in TSC Buildings

Most of studies on the stone buildings of TSC have shown that this complex has mainly been made up of freshwater limestone called travertine. These stones have been vertically and horizontally and in square forms used in the main part of the building. They have also been used in cobble and rubble forms (Amanollahi, 2006) it should be mentioned that these claims are merely based on eye witnessing and not on scientific experiments, because in recent petrological studies of the complex in addition to the stones previously identified at least three other kinds of stone were identified as follows:
a) Yellow sandy limestone used in the Sassanid structures.
b) Red sandstone used in the Ilkhanid buildings.
c) Yellow limestone used in the floor and stairs of the northern portico (the coronation place).

3.2. The Characteristics and Mode of Formation of Different Kinds of Stones Used in TSC

Travertine is a freshwater limestone and is considered as belonging to chemical sedimentary rocks, in which formation processes are mainly dominated by the chemical factors of the environment. In this respect, it has considerable differences with other kinds of limestone that are formed in great sedimentary basins such as marine environments and continental shelves. Those kinds of limestone that are formed in marine sedimentary environments are mainly of biological or biochemical origins. That is, the living organisms of the sea (mainly Halimeda and Penicilus sea algae) play an important role in their formation. Limestone is also formed from the shells of sea living creatures such as bivalves, echinoderms, brachiopods, gastropods and corals. After death, the shells of these invertebrate creatures are amassed and by cementing and sticking to each other form a kind of stone whose components are the shells of sea creatures.

3.3. Formation of Calcium Carbonate in Warm and Cold Springs of the Region

The principal factor in the deposition of calcium carbonate in the springs is the decrease of CO_2 dissolved in spring water caused by temperature and pressure decrease. Such kinds of sediment left at the mouth of the springs are called travertine or tufa (Tucker, 1994). Travertine rocks are layered porous limestones mainly consisting of calcium carbonate with minor iron oxides, organic and Sulphur compounds in the form of iron and calcium sulfates. The reason for the porous characteristic of these rocks is that during deposition at the mouth of the spring, the dissolved gases are trapped in the resulting sedimentary rocks causing hollowness. Thus, travertine is a relatively undurable stone relatively easily breaking and spalling along depositional layering and is easily dissolved when it is exposed to mildly acidic water. The alternation of colorful strata in travertine is the result of the deposition of compounds other than calcium carbonate. For instance, the black layers formed are the result of the deposition of iron compounds or organic matter. The stratification of these stones is also the result of the slow deposition of carbonate material with regard to temperature and chemical changes of spring water resulting in compositional and/or mineralogical layering in the travertine rock formed.

3.4. The Travertine Used in the Buildings

Takht-e-Soleyman structures buildings have been mainly built with Travertine water sedimentations of the Quaternary period. In various parts of the buildings, travertine has been used in rectangle cube shapes, in $120\times60\times30$ cm dimensions. These stone blocks have been installed vertically and horizontally on the outer walls of the ramparts and towers, and in the inner installations (Figs 3 and 4).

Fig. 3. The stone blocks used in rampart No. 2

Fig. 4. The stone blocks used in the northern hall of the Khosrow portico

This stone has been vertically and horizontally used on the outer surfaces of the ramparts and towers for decoration and creating flat surfaces. As far as we know, one of the characteristics of Sassanid architecture in TS was the utilization of carved stone blocks to construct the façade of the walls of the buildings filling their interior with rubbles, gypsum or limestone. The reasons for using this kind of stone in constructing the buildings were:

a) Easy access to this kind of stone and the vicinity of its mines;

b) Being the only abundant stone available near the region;

c) Easy to cut and shape;

d) Physically appropriate characteristics for extracting from the mines such as their being easy to cut to turn into building materials;

e) Considering the fact that the region is a mountainous one with abundant rainfall and freezing weather, the extant stones in the region such as sandstone and limestone which belong to the older formations are older than the travertine rocks. Hence, they have been severely damaged and lack the physical durability to be turned into appropriate building materials in large dimensions. Besides, the outcrops of other kinds of stone near the buildings of TSC are hidden beneath a thick layer of soil and are not hence available (Figs 5 and 6).

Fig. 5. Rough and sharp-angled rubbles

Fig. 6. Rounded rubbles

3.5. Travertine mines

During investigations in the region several travertine mines were visited as follows:

3.5.1. The Tepe Chāl stone mine

This stone mine is the nearest travertine outcrop to TSC and is located 1 km away from the southeast of its platform (36°, 35´,14″ north latitude, and 47°, 14´, 43″ east longitude, and 2273 m above sea level). Probably most of the building stones of the complex were extracted from this mine. Considering the extant evidence of mining, at least two quarries can be observed in this region: a) in the southeast of this region there is a cliff on which there is evidence of ancient mining activities. Near the cliff the ground has a slight and relatively horizontal slope. The investigations of all stone extraction mines show that a slight horizontal slope had been taken into consideration for extraction of stone (Fig. 7). This is because travertine strata have smooth surfaces in a horizontal position and hence the dissolving effect of rainfall is not very deep in these stones. Therefore, only a thin layer of the upper surface of the stones was susceptible to the dissolution by rainfall. By removing the weathered and dissoluted surface layers, the more intact underlying layers are exposed which are more suitable for extracting large stone blocks. In addition, the nearly horizontal travertine strata have only been slightly by post-depositional deformation events which cause layers to break or wrinkle and hence the strata have largely preserved their original horizontal state. Consequently, few secondary fractures have been developed in these layers, and the dissolution by rainfall has been minimal. In more steep regions such as the steep hillsides of Tepe Chāl Mountain more intense fracturing of the rock masses could be observed. The secondary fracturing and joints seem to result from the weight of the strata and the motion of the layers along slope direction which lead to the crushing and break-up of travertine layers. b) The southern quarry of Tepe Chāl; The remains of a vast big quarry with an approximate area of 650×210 m^2 can be observed on the southern slope of Tepe Chāl. Mining remains abound here and cover vast areas of the region. Here too the stones have been extracted from the layers (of travertine) horizontally. Considering the fact that horizontal strata extend across much of the slope in this part, this place seems to have been the most suitable place for extracting large dimension stones (Fig. 8).

Fig. 7. The remains of large-scale mining on gentle slopes

Fig. 8. A view of the southern quarry of Tepe Chāl

3.5.2. The Kuchka Barz quarry

Another stone quarry with a dimension of 980×140 m is located at a distance of 100m from Takahb-Dandi road and 4 km southeast of TS (- 36º, 35´, 18˝ north latitude, and 47º, 14´, 21˝ east longitude, and 2280 above sea level). This quarry is called Kuchke Barz by the local people. Apparently because of the steep travertine strata with many fractures and joints this region was not considered suitable for extracting stone. The remains of small-scale mining can be observed in this region (Fig. 9).

Fig. 9. Kuchke Barz quarry

3.5.3. Trifah Mountain quarry

This quarry is located on the Trifah Mountain (36º, 34´, 51″ north latitude, and 47º, 12´, 27″ east longitude, and 2580 above sea level) in the southwest of TS (Fig. 10).We did not find any evidence of mining and stone extraction in this quarry. However, many scholars who have worked in TS in the past conjectured and believed that the stones of Trifah Mountain had been used for constructing the buildings of TS. In his report, Neumann also refers to this place as a stone mine (Naumann 1974). For two reasons one may conclude that no stone has been extracted from this place in constructing the buildings of TS.

a) The horizontal distance of this rock mass from TS is 8 km and besides, the rock is 400m higher than TS. Thus, the access route to this region seems very difficult and unsuitable for transferring stones.

b) This area is regarded as a relatively high place with a height of 2570m from sea level. Hence, the rocks are much subject to weathering and shattering here. Thus, it seems that this source was not suitable for extracting stones especially when we consider the fact that there are several mines in the vicinity of TS site.

Fig. 10. The probable quarry of Trifah Mountain

3.5.4. Laboratory work on Travertine mines

During fieldworks, necessary samples from various travertine mines and from the buildings of TS were collected. Macroscopic (Fig. 11) and microscopic thin-section photos (Fig. 12) are shown below. Considering petrographic characteristics, most samples show a micrite composition (i.e., the stone is mainly made up of fine-grained carbonate) in thin-section and sparry calcite crystals (bright) have been developed in some of them. The latter kind (the observation of sparry crystals in micrite groundmass) is called dismicrite. In some rock cuts the calcite crystals represent ribbon, wavy and cauliflower shapes giving a special appearance to the stone, also observable in microscopic thin-sections. After studying the thin-section prepared from the selected rock samples, we compared travertine samples from the stone mines with those of the buildings of TSC. The structural and compositional similarities between the mines' samples and those of the buildings were used as the basis of the comparison. Contrary to biochemical limestone (as represented by fossiliferous limestone), the comparison of these stones is very difficult. The variable chemical composition of these rocks is represented by color changes.

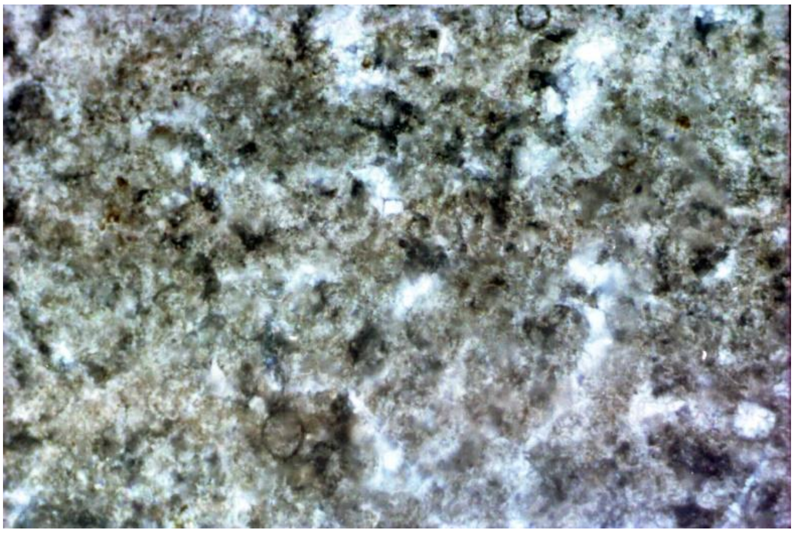

Fig. 11. Photomicrographs of travertine thin-section from the buildings of TS (photo sc ×10)

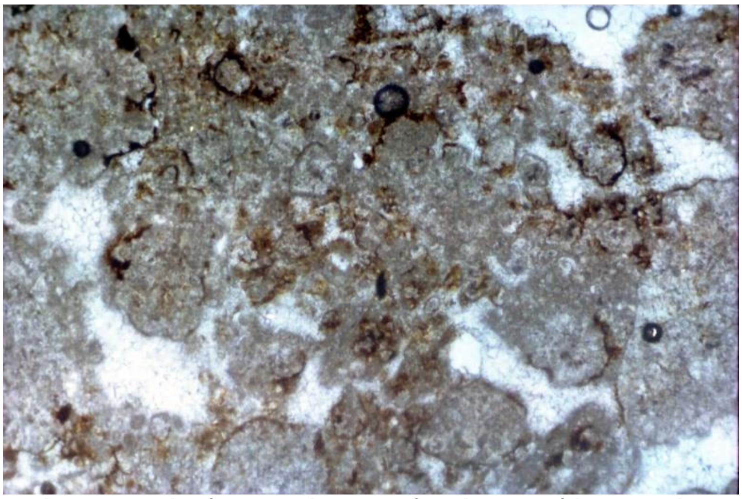

Fig. 12. Photomicrographs of travertine thin-section from the mines of the region (photo sc ×10)

3.6. Yellow limestone

Close inspection of the stone blocks used in TSC buildings led to the discovery of yellow-colored limestone blocks with 150×70×70cm^3 dimensions (Fig. 13) used in the stairs of the northern portico and in other places of TSC buildings dispersedly which was different from the other rock types in TSC. The surveys conducted in the region could not locate the geological source or ancient stone mine for this rock type. Probably this kind of stone had been used prior to or after the Sassanid dynasty. Otherwise, because of its special physical characteristics including compactness, slight porosity, coarse grained texture and its relatively high hardness, the Sassanids would certainly have used it more had they been acquainted with its mines. Considering the petrographic characteristics of this kind of stone in thin-section, it can be said that a micrite groundmass with sparse quartz grains on its surface are the main textural characteristics of yellow limestone samples as observed in two thin-sections (Fig. 14).

Fig. 13. The hand specimen photo of yellow limestone rock type obtained from the Southern yard of the fire-temple

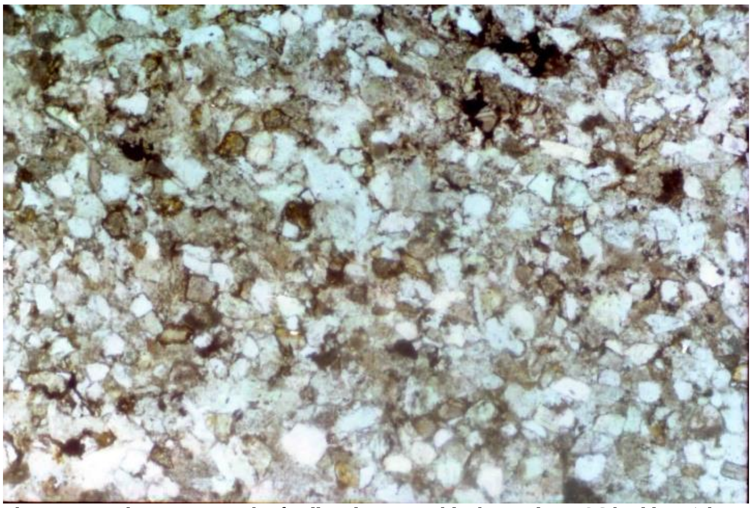

Fig. 14. Thin-section photomicrograph of yellow limestone blocks used in TSC building (photo SC ×10)

3.7. Sandstone

Sandstone is a detrital sedimentary rock largely formed in marine sedimentary environments, although it could also form in several other non-marine environments such as lakes and sites of sand dune accumulation. Sandstone mainly consists of sand particles smaller than 2 mm in diameter the spaces between them is occupied by a finer-grained matrix or by a chemical binding material called cement. Any sandstone contains various amounts of quartz particles and when the portion of quartz is more than %90 in these rocks it would be called quartzitic sandstone or quartzarenite. The other constituents in sandstone other than quartz include feldspar, rock fragments, mica, and minor amounts of heavy minerals in addition to variable amounts of cementing or matrix material like carbonates, silica, clay, iron oxides and organic matter. The factors which determine the relative hardness and durability of sandstone rocks are the composition of sand particles, the kind of cement material binding quartz particles together, the size of sand particles and the degree of packing and compactness. High compactness diminishes the porosity between the quartz sand grains which leads to their dissolution so that the dissolved quartz grains act as cement sticking the particles to each other and increasing the physical stability of the stone in the process. The type of cement is also important in chemical as well as physical durability of sandstone. If the cement essentially consists of carbonate, it may be affected by acidic waters leading to its dissolution and the development of secondary porosity. As a result, the sand grains loosen and would be easily dislodged which make the stone to lose its original coherence and strength.

As mentioned above, two types of sandstone have been used in the architecture of TSC buildings:

6-3-1-Yellow sandstone used in the floors of the Sassanid buildings (northern vestibule)

6-3-2-Red sandstone used in the Ilkhanid buildings

3.7.1. Yellow sandstone

Near the vestibule which borders the religious complex, yellow sandstone blocks with 60×40 cm dimensions could be observed covering part of the floor. The geological source(s) or the probable mine for this type of stone could not be located during fieldwork in the region. As seen in thin-section, since the cement of this type of sandstone is composed of carbonate, its durability seems to be relatively low (Fig. 15).

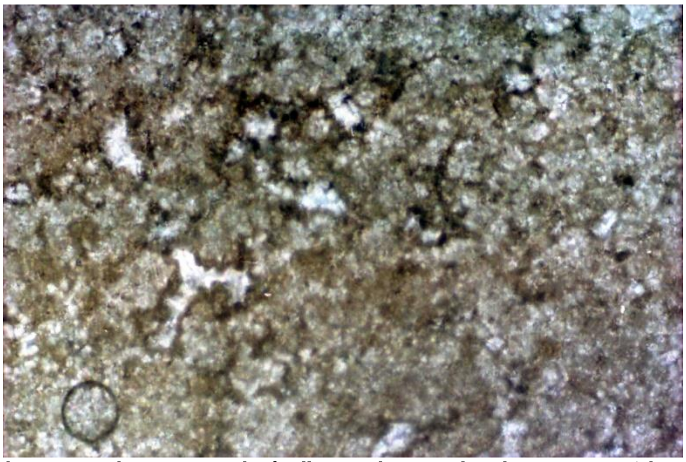

Fig. 15. Thin-section photomicrograph of yellow sandstone with carbonate cement (photo SC ×10)

3.7.2. Red sandstone

Red sandstone has been extensively utilized in the architecture of the buildings of the Ilkhanid complex for wall lining of octagonal hall, columns, column bases and bodies of the two sides of the gates as decoration and bearing materials. It can be said that this kind of sandstone, was used as a favorite material of the Mongols in many buildings of this period (Sarfaraz, 1968). There are abundant outcrops of this type of stone in the region belonging to Upper Red Formation. The cement of this red sandstone consists of iron oxide which is very unstable and easily disintegrated. As a result, it was impossible to obtain proper microscopic thin-sections from this type of stone. In the process of cutting the hand sample the stone particles are pulverized producing a red powder. As can be observed in those parts of TSC in which this type of stone has been used, the columns sculpted of this type of red sandstone have been rapidly affected by erosion and dissolution so much so that the decorative elements and carvings on these columns have been severely damaged and are being destroyed (Figs 16 and 17). Generally speaking, red sandstone is not very suitable for construction, and two reasons for its utilization in the Ilkhanid architecture were most probably its softness and intactness to produce large easily sculpted blocks neglecting its durability. This fact probably reflects the architect's inadequate familiarity with the physical characteristics of this type of stone. As can be observed no use has been made of this type of stone in the Sassanid period despite its abundance, accessibility and the ability to be easily shaped.

Figs. 16 and 17. View of red sandstone rock type in the source mine and as used in a column in TSC

3.7.2.1. Red sandstone mines

The outcrops of this stone are located in the two regions of Baba Nazar Mountain and Sur Mountain (between Zendan-e-Soleyman and the Ahmad Abad-e Bala). Because of the lower stability of this type of stone to weathering agents and such modern human activities as mining, no traces of ancient extractions from Sur Mountain mine remains, though in his report, Naumann takes Sur Mountain as a probable source for extracting this type of stone (Naumann, 1972).

a) The red sandstone mine of the Sur Mountain

This mine is located between Zendan-e-Soleyman and Ahmad Abad-e Bala at 36º, 34´, 32″ northern latitude and 47º, 15´, 47″ eastern longitude, 8 kilometers northwest of TSC buildings, 2055m above sea level. Due to recent land leveling activities by Agricultural Jihad Organization, the field survey identified no evidences for ancient mining in this area. Although Naumann refers to an ancient rock-cut inscription near the place where the rocks have been cut for exploitation (Naumann 1972), the modern blasting operations, as evidenced by abandoned blast holes on the ground, have totally destroyed the area. While surveying the region we witnessed some mining activities on the mountain and raised our protest to the responsible authorities.

B) The Baba Nazar Mountain mine

Baba Nazar Mountain mine is located near Baba Nazar village at 36º, 34´, 18″ north latitude and 47º, 15´, 2″ east longitude, 5 kilometers south of TSC, and 2140m above sea level. The investigations of this mine show that because of the instability of these stones under climatic conditions, not much evidence of mining and extracting stone has remained in this quarry (Fig. 18). Actually, it should be mentioned that the existence of high amounts of iron oxides from the weathering and erosion of red sandstone rocks imparted a reddish color to the soil of this area.

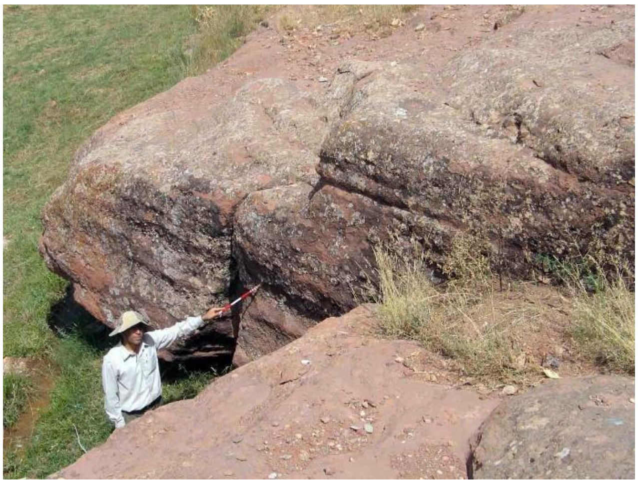

Fig. 18. View of Baba Nazar red sandstone mine

3.8. Travertine mines

As mentioned above, one of the reasons for selecting travertine apart from its local abundance was its appropriate physical characteristics. Travertine is a banded freshwater limestone occurring as sheet-like outcrops with rather smooth surfaces not require much faceting work. The methods of extracting travertine blocks could be somewhat constructed noting the remaining evidence in the mines. Probably the miners, using stone cutting tools, created 20 cm deep narrow holes on three sides of the horizontal layers of travertine splitting the block from three sides. Then they made a number of shallow holes along the fourth side of the stone block and by inserting wedges into the holes and striking on them the stone block was completely detached from the rock mass. The traces of such operations can be observed in the mines (Fig. 19). After the stone was detached from the mountain, the cutting and shaping operations were done on rough stone blocks.

Fig. 19. Traces of mining activities in ancient quarries

4. Conclusion

Based on the content provided, here are the summarized points regarding the stone quarries used in Takht-e-Soleymān buildings (Amanollahi, 2023):

a) The areas around TS are of high mineral potential in terms of metallic and non-metallic mineral deposits, including dimension stone and building materials. Metallic minerals include lead, zinc, copper, chromium, arsenic, antimony, mercury, gold, and iron. Non-metallic minerals consist of kaolin, perlite, fluorine, asbestos, feldspar, silica, gypsum and decorative stone. The existence of such mines in the region must have been one of the most important factors in the formation of human groups during different periods of time from the middle Paleolithic to the 1st millennium B.C. (the Mannaeans), Achaemenids, Parthians, Sassanids, and Islamic era.

b) Considering the mentioned points and references concerning why this region has been called “Ganzak” or “Ganj-e” (literally “treasure”) in Pahlavi documents, we can say that the name given to this area has been determined by the existence of rich resources of gold, lead, zinc, silver, mercury, iron, building materials and other minerals in the region. Thus, as mentioned above, the Persian names of Shiiz include: Ganjak, Ganzak, and Ganjeh which seem to be used for the region because of the existence of ancient and rich resources of gold, lead, zinc, silver, mercury, iron, building materials and other minerals. According to Abu Dolaf, “in that city, there are abundant mines of gold, silver, mercury, lead, orpiment and amethyst (Al-jamsat)” (Abu Dolaf, 1963)

c) Based on petrographic studies, at least four types of stone have been identified in different parts of TSC. These are travertine, yellow limestone, yellow sandstone with carbonate cement, and red sandstone.

d) The probable stone mines used for this complex are Tepe Chāl workshops (a, b), Kuchka Barz, Baba Nazar, and Sur Mountain mines (Fig. 20).

e) Travertine mines were mostly used in Sassanid buildings, whereas red sandstone was used in Ilkhanid buildings. Nevertheless, we know that the Ilkhanid workers supplied a great deal of their required material from the extant materials on the platform. That is, they reused the Sassanid materials as raw materials to construct their own buildings.

f) The sources and mines of the two types of stone, that is, yellow limestone and yellow sandstone which have been used in Sassanid buildings could not be identified. Their sources are probably located outside the limits of the study area. Thus, identifying the geological source and ancient quarries for these two types of stone used in the buildings could be considered for future research project plans. The question that is raised after identifying these mines is the ways of extracting and transferring these stones from the mines to TSC, particularly during the Sassanid period. We hope that future studies can find some explanations and supporting evidence for these questions.

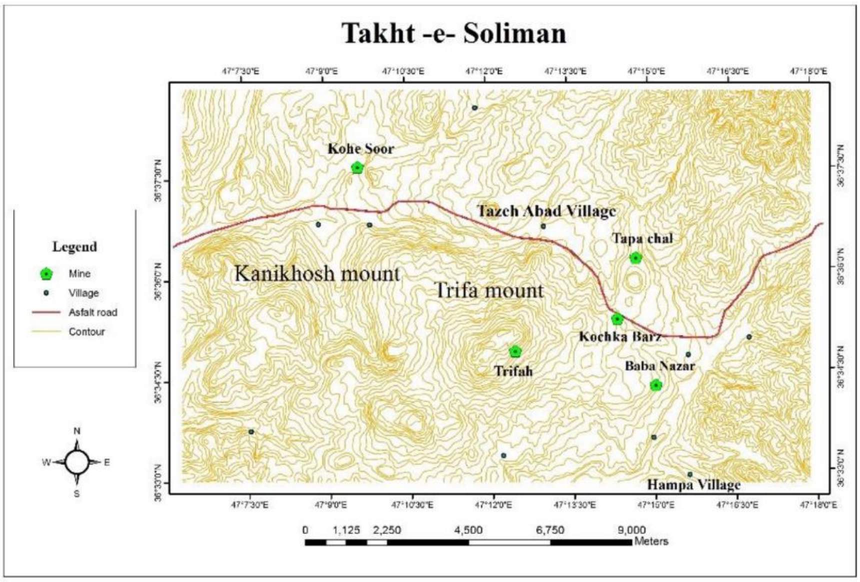

Fig. 20. The location of ancient stone mines in the study area (source: 1:50000 topographic Maps of Takht-e-Soleymān and Ghareh Naz, 1997).

Acknowledgment

I hereby thank the late Masoud Azarnoush, the former head of The Archaeological Research Center, Ebrahim Heydari, the former manager of Takht-e-Soleyman World Heritage Organization, and Naser Nourouzzadeh Chegini, the former manager of the historical department of The Archaeological Research Center. I would also like to thank the other members of the group Messrs Mahmood Alikahi and Mahdi Abdolzadeh (MSc graduates in economic geology). My thanks also go to Abbas Yalvaee who kindly translated the manuscript into English.

References

Amanollahi, H., 2023. Geoarchaeology Tahkte-e-Solyman, Ilam: Bashur Publications in collaboration with Icomos Cultural association of Iran.

Amanollahi, H., 2006. Geoarchaeological Studies of Takht-e-Soleymān Region. The Archive of Takht-e-Soleymān World Heritage, Unpublished.

Amanollahi, H., 2010. Petrography and Its Use in Identifying Archaeological Materials (Stone). Payam-e Bastanshenas Quarterly Journal, Abhar Azad University, 12, 22-28.

Amanollahi, H., 2011. Recent Studies of Achaemenid Stone Mines in Marvdasht. Iranian Journal of Archaeology and History, 2, 12-20.

Amanollahi, H., 2011. The Historical, Cultural and Research Background of Takht-e-Soleymān Region. Iranian Journal of Archaeology and History, 51, 12-23.

Armed Forces Geographical Organization of Iran. 1:50000 Topographic Map of Ghareh Naz. 1376 II sheets of 5463, Series K753. 2nd Ed.

Armed Forces Geographical Organization of Iran. 1:50000 Topographic Map of Takht-e-Soleymān. 1376 II sheets of 5463, Series K753. 2nd Ed.

Armed Forces Organization of Geography of Iran. 1:250000 Topographic Map of Shaheen Dezh. 1379 16 Sheets of NJ38, Series K551. 2nd ed., 2006.

Babakhani, A. & Amini Chohragh, M.R., 1992. Travertine Springs of Takab. Geosciences Scientific Quarterly Journal, 2, 50-59.

Damm, B., 1968. Geologie des Zendan-i Suleiman und seiner Umgebung, südöstiches Balqash-Gebrige Nordwst Iran, Wiesbaden.

Eftekharnezhad, J., 1980. Division of Different Part of Iran Base on Structural Position in Related to Sedimentary Basins. Journal of Iranian Petroleum Association, 82(1), 19-28.

Geological Survey of Iran, 1:100000 Geological Map of Takht-e-Soleymān, Tehran, Serial 5463.

Ghadri, M.R., 2003. Geomorphological Researches on Takht-e-Soleymān with Emphasis on the Characteristics of Limestone Rocks. M.A. Diss. in Physical Geography (majoring in geomorphology) with the supervision of Dr. Rezaee Moghadam, M. H. Tabriz University.

Ghadri, M.R., 2009. The Role of Morphotectonics in the Evolution and Development of Karstic Phenomena, Case Study: Takht-e-Soleymān Region. Ph.D. Diss. In Natural Geography (majoring in geomorphology) with the supervision of Dr. Muhammad Hossein Rezaee Moghadam, Tabriz University.

Heidari, I., 2015. A Summary of Fifteen Years of Organizational Work at Takht-e Soleiman (1993-2003), *Athar Journal*, 33(56), 77.

Heydari-Guran, S., Ghasidian, E. & Conard, N.J., 2009. Paleolithic Sites on Travertine and Tufa Formations in Iran. Proceedings of the XV World Congress UISPP, Lisbonne, 28, BAR International Series. 1968. 109-124.

Nabavi, M.H., 1976. An Introduction to Geology of Iran. Geologic Survey of Iran, Tehran, 109 p.

Naumann, E., 1964. Geographiche and geologische Einordnung in Teher Forsch. Shtahl, A. F 1907 Reisen in Nord-und Westpersien, Peternann, s Geographische Mitt.Wiegartz, H 1965 Archaologischer Anzeigr 788 (Tumulus Tepe Madjid). Schindler, A. Houtum 1881 neue angaben über den mineralreichtum persinens und notizen uber die gegend westlich von zendijan, in Jb. K. k. geol. Reichsanstalt 31.

Sarfaraz, A.A. & Kayani, M.Y., 1968. Takht-e-Soleyman. Faculty of Literature and Human Sciences, Tabriz University, Tabriz, Iran.

Schmidt, E.F., 1940. Flights over Ancient Cities of Iran, Chicago.

Stocklin, J., 1968. Structural History and Tectonics of Iran: A Review. AAPG Bulletin, 52(7), 1229-1258.

Toosi, Muhammad ibn Mahmood ibn Ahmad., 1966. Ajayeb al Makhluqat. Ed. Sotoudeh, M., The Anthology of Persian Works under the supervision of Yar Shater, E. The Institution of Translation and Publication of Books, Tehran.

Zarneh Ekteshaf Research Group., 2006. A Report on Silver, Lead and Zinc mines of Takab Region. The Archive of the Cultural Heritage, Handcrafts and Tourism Organization, Institute for Conservation and Restoration of Cultural Monuments.

Zarneh Ekteshaf Research Group., 2008. The Study, Identification and Documentation of Ancient Mines around Takht-e-Soleymān Region. The Archive of Takht-e-Soleymān World Heritage.