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Salt Mining and Salt Miners at Talkherud–Douzlākh, Northwestern Iran: From Landscape to Resource-Scape

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Abstract
The Douzlākh salt deposit (region: Māhneshān, Zanjān Province, Iran) is unique for its pure and crystal rock salt and was an important supplier of culinary ('table') salt in Achaemenid, Sassanid and Middle Islamic times. At the same time, the site was of central importance to the economic life of the rural populations in the Talkherud Basin. This article focuses on the question of which strategies were decisive for the exploitation of the salt mountain and how a potential supra-regional interest in the culinary salt was perhaps reciprocally connected with a rural hinterland. This hinterland was recently investigated in greater detail by our ongoing research. Did a resource-scape based on salt develop with specific economic and social strategies and practices around the Douzlākh? And was this development triggered by state or imperial control and demand? These questions are being pursued from a perspective utilising a variety of subjects and methods in archaeology, archaeobiology, archaeometry and geoarchaeology. In addition to a detailed on-site artefact study, several on- and off-site datasets have been collected and analysed within a multidisciplinary framework. This article synthesises the results of a major 12-year project to identify the organisational principles and daily practices within this specific salt-scape. The sensational finds of the Douzlākh salt mummies, along with the generally outstanding preservation of organic ecofacts and artefacts, allow insights into antique lifeworlds that are otherwise hard to come by. The multidisciplinary study of on- and off-site data allows far-reaching insights into interdisciplinary topics, such as the social system, supply and logistics, or the presence of non-local or non-indigenous populations.

Keywords Salt · Mining · Achaemenid · Sasanian · Mummies · Resource-scape

Extended author information available on the last page of the article

Introduction to the Chehrābād International Project

The Resource-Scapes as Research Topic in (Pre)historic Archaeology

People usually both construct and perceive their environment intuitively at first and rarely in a planned way. Research in cultural studies and anthropology has described such processes and has embedded them in spatial contexts (Ingold, 2000). The (cultural) appropriation and use of natural materials can therefore be considered as interwoven with their transformation into a socially accepted resource. This transformation can also be described as a dialectical learning process that involves different kinds of knowledge transfer within human lifeworlds in regard to use and exploitation, technical and sensorial properties and the narratives that are connected with understanding and discovery. The basic experience with a raw material depends on its affordances (*sensu* Gibson, 1977) and the different experiences people can have with it. The process of appropriation is therefore based on reciprocity between these different notions and inextricably interwoven with human practices. Locations and space play a central role in this process and become appropriated as resource at the same time, which allows us to understand mining landscapes as 'resource-scapes'.

Two important basic conditions have shaped the development and social, organisational, technical and economic structures of mining landscapes (Stöllner, 2003, 2015). Firstly, the nature of the supply of natural resources, such as the type and yield of a deposit, and secondly the practices by which they are appropriated. In this respect, the extraction of raw materials is no less dependent on the fundamental differences between environments than on the knowledge complexes associated with appropriation. The archaeology of raw materials can explore these processes—and the stock of knowledge woven into them—particularly well in landscapes that have been especially shaped by the extraction of raw materials. The landscape around the Douzlākh salt mine seems to have been one such, and it is the aim of this article to further elaborate on the connections between mining and the surrounding rural communities.

Of particular importance in such resource-scapes are the spatial relationships between the primary subsistence conditions of a society and its mineral resources (e.g. Bartels & Küppers-Eichas, 2008). These in turn depend on the agrarian conditions in the individual vegetation and climate zones. Thus, subsistence and raw material regimes have often also developed under mutual influence. A classic example is the Dolpo in the western Himalayas, who acted as traders and transporters of grain or salt between climatic and vegetation zones, exchanging grain from the lowlands with rock salt extracted from the Tibetan plateau (Seeber & Grafen, 1993; Valli & Summers, 1994). Commodity regimes have formed and mutually influenced latent spatial and social practices.

Bearing in mind this theoretical background, one should be careful not to take too deterministic a view of the interactions between various economic practices. Practice develops very differently in relation to different kinds of knowledge and experiences (e.g. Reckwitz, 2016). Therefore, even the traditional concept of the mining landscape requires a more comprehensive and holistic scientific approach, taking account of mental, cultural, religious and other social processes, as well as those 'hard' facts that we commonly consider as environmental and raw material factors, transport topography, available technical knowledge or subsistence factors. What we observe in a mining landscape, supported by archaeological sources (e.g. mining sites, settlement sites, production sites and workshop paths), is the result of networked practices that were usually able to establish themselves over a longer period of time, and in turn influenced targeted actions and economic and social concepts. In this regard, it is especially interesting to look at mining landscapes that have been targeted by institutional, and specifically state-controlled activities. The Talkherud mining landscape appears to be a revealing example that helps us understand targeted transformation processes within a 'resource-scape'.

The Talkherud-Douzlākh Resource-Scape: Research Question and Methodology

The Douzlākh salt deposit is located approximately 340 km northwest of Tehran (1350 masl; 470 51′ E, 360 55′ N) at the confluence of three watercourses that form the basis for the agricultural use of the landscape in the Talkherud Basin. The Talkherud flows to the north where it drains into the Qezel-Ouzan River (Fig. 1). Here, numerous villages still bear witness to the advantageous living conditions in the Māhneshān region. Horticulture and irrigated agriculture are still possible at lower altitudes, while rain-fed agriculture and pastoralism are possible at higher altitudes around the deeply incised river valleys (Boenke, 2020c, in particular pp. 210–213). Salt was used in food preservation, for cattle, and the salt requirements of the surrounding populations had to be met. A salt mountain, especially one as easily accessible and mineable on the surface as the salt dome of Douzlākh (Fig. 2), thus assumed a central role in the economic life of rural populations. The landscape—which has evidence for settlements since at least the Chalcolithic and the Bronze Age, between the 4th and the 2nd millennia BC (see below)—would have needed salt, especially to satisfy the basic needs of an agriculturally oriented population. However, the question remains, why mining and the evidence of salt extraction in Douzlākh from these earlier periods are unknown. Does the lack of evidence relate to a type of underground exploitation that is different from surface salt collection from outcrops, or does it relate to the lack of administrative and governance structures for the exploitation of salt?

The salt from Douzlākh is very pure and tasty, of the type known as white salt, *namak sefid*. This was considered high quality salt in ancient Iran and was widely traded until it became a special food salt (Schachner, 2004, pp. 518–525). Unfortunately, there is not much evidence on salt in the Persepolis fortification tablets (oral inf. W. Henkelmann), but more about meat and grain as provisions of the palace and the king's vassals. But the texts indicate that a substance like *madukka* was often used at the king's table; this may be table salt, highly valuable in its best quality, as presumed by R. Hallock (Hallock, 1969, pp. 25–26: Persepolis Fortification Archive Tablets 719, 721–722; Garrison, 1996, p. 24). D.

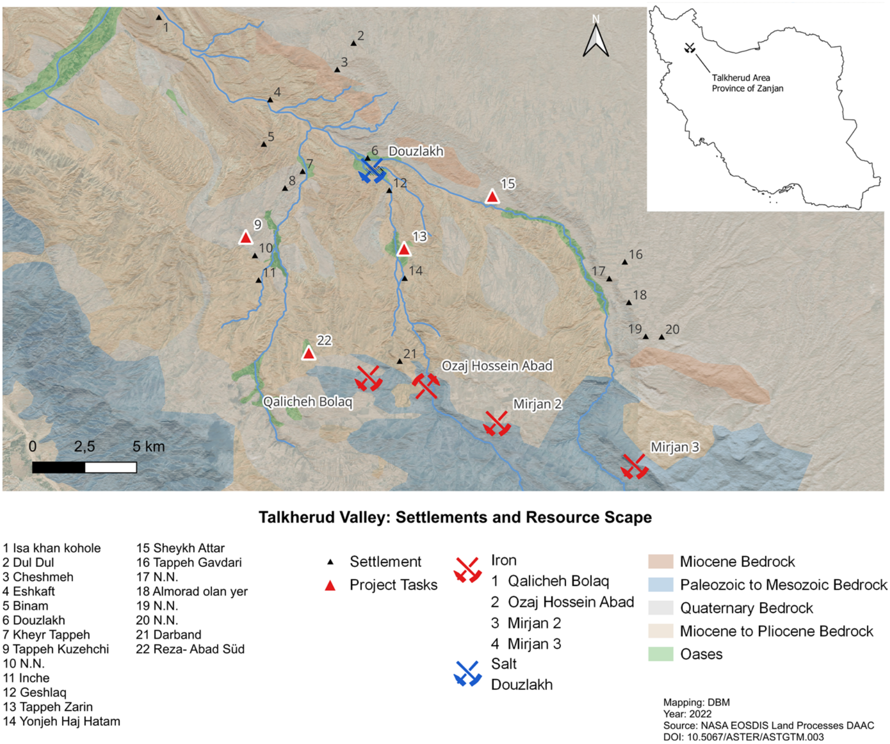


Fig. 1 The Talkherud watershed region showing simplified geology, the location of the Douzlākh salt deposit and salt mine, surrounding ancient settlements, and valley oases. Base credit: F. Schapals/Th. Stöllner

Potts and St J. Simpson collected important information about salt use and consumption from the Mesopotamian lowlands that imply taxation and control of salt since at least the 3rd millennium (Potts, 1984; Simpson, 2001); however, there is not much evidence concerning rock salt exploitation, more about the taxation and storage of salt in general especially for the Sasanian period (Simpson, 2001, p. 66).

Although salt was most likely gathered by professionals (e.g. nomads: Potts, 1984, esp. p. 253) most of the time, the salt from the Douzlākh also lent itself to targeted mining by (pre-)state institutions—established on the central plateau since the Iron Age at the latest—with the formation of an empire in (pre-)Achaemenid times. During this period, however, important questions arise about the presence of foreign miners (see below), about changes in the settlement landscape of the region, and about the interactions between mining and the environment. This article, therefore, focuses on the questions of which strategies were decisive for the exploitation of the salt mountain, and how a potential supra-regional interest in the common salt of the Douzlākh was combined with rural land use, involving a specific type of complementarity between different kinds of settlement and

Fig. 2 The Douzlākh salt deposit seen from the west at the confluence of the Mehrābād and Chehrābād rivers. Credit: S. Saeedi

occupation type. Did a salt landscape develop around the Douzlākh with specific economic and social strategies and practices in the sense of the 'resource-scape' concept described above?

These questions are being investigated by a project established in 2009/2010 with the support of the DFG (Deutsche Forschungsgemeinschaft/German Research Foundation), with a multidisciplinary perspective utilising various subjects and methods in archaeology, archaeobiology, archaeometry and geoarchaeology. In addition to a detailed on-site artefact study, several on- and off-site data sets have been collected and analysed within the framework of archaeobotany, archaeozoology, parasitology, palaeomedicine (including palaeopathology, histology and genetic research), geophysics, geology and soil sciences, some of which are part of ongoing multidisciplinary investigations (Fig. 3).

The sensational finds of the Douzlākh salt mummies, along with the generally outstanding preservation of organic ecofacts and artefacts, allow an insight into antique lifeworlds and the associated salt mining that are otherwise hard to come by. Results from long-term research into the salt mines of Hallstatt and Dürrnberg (Austria) and their economic environments has also contributed to the discussion presented here (Boenke, 2020a; Kern et al., 2008; Kowarik et al., 2015; Stöllner, 2012; Stöllner et al., 2020). The multidisciplinary study of on- and off-site data from Douzlākh allows for far-reaching insights into shared (i.e. interdisciplinary) questions about, for example, the social system, supply and logistics or the presence of non-local ethnicities. The salt mines themselves allow further research perspectives – the 'material worlds' associated with them provide access to a certain

Fig. 3 Integrated research design of the Chehrābād salt mining and landscape project. Credit: N. Boenke/ Th. Stöllner

sensory 'environmental experience' and insight into strategies for resilience, and patterns of crisis management, as triggered by the numerous mining accidents at the Douzlākh (Stöllner, 2021). We start our discussion with an environmental approach to the salt mountain, with a focus on different geoarchaeological methods, and then discuss the results of on-site data from the salt mine, before incorporating off-site data and data from the surrounding settlements to finally gain perspectives on the cultural, social and economic conditions of the Talkherud resource-scape.

The Environment

Mineral Deposits and Geology of the Talkherud Mining Landscape

The Chehrābād salt mine is located in the northwestern part of the Māhneshān Mountains in the northwestern part of the Iranian Plateau at approximately 1380 m above sea level. The area is part of the Central Iranian tectonic unit, which in turn is part of the Alpine–Himalayan Mountain belt. In addition to the saline, salt-bearing geological units, older volcanogenic units also allowed access to iron and other metal ore deposits (possible important sources for the iron supply for the salt mining), thus completing the resource base of the Talkherud mining landscape. The local sediments were deposited during the Neogene in the Zanjān Basin, an intramontane basin, which was then a sub-basin of the Eastern Paratethys. The basin shows a sequence of marine limestones and marls of the Qom Formation (late Oligocene to early Miocene), which were overlain by continental sediments after a separation from the sea during the middle to late Miocene.

The continental sediments above the Qom Formation consist mainly of beige and pink to brick-red marls and sandstones (the so-called ‘Upper Red Bed Formation’), with local occurrences of evaporitic minerals such as gypsum and rock salt in their lower parts (Lotfi, 2001; Reichenbacher et al., 2011; Ballotto et al., 2016). The low mountains from Andabād to Moshampā (Fig. 4; Lotfi, 2001), which embrace the mine, are composed of a row of detrital sediments of the Oligo-Miocene together with intercalations of red and green beds of the Neogene associated with shallow evaporate environments, which are described as wolds. Further south is a NW–SE trending mountain range extending from Habash to Nassir Abad, where Precambrian and Phanerozoic rock units have cropped up (Lotfi, 2001).

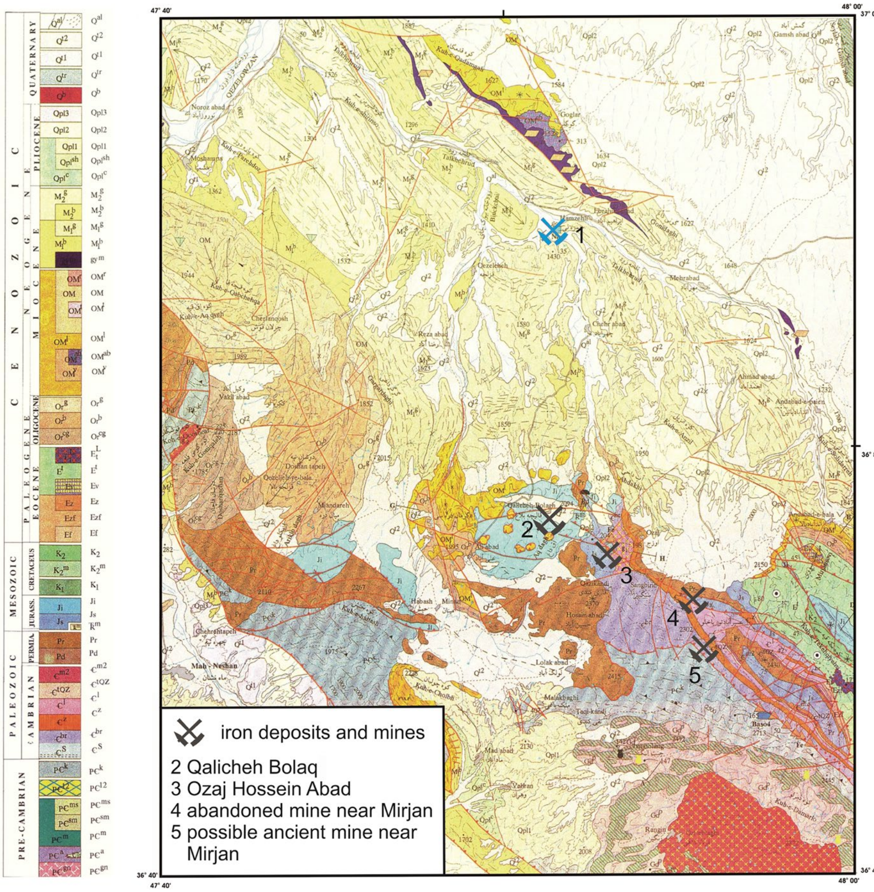


Fig. 4 Detail of the geological map of Māhneshān focusing on the study area. N. Nezafati after Lotfi (2001)

Based on the geological map of Māhneshān, the rock units of the Upper Red Formation (hereafter URF; dating to the Upper Miocene) compose the major part of the outcrops of the mine's surroundings. These units (see Fig. 4; Lotfi, 2001) include a basal white gypsum bed, an alternation of green and brown marls with occasional tuffaceous layers, and sandstone.

In the final stage of the Middle Miocene, an intense tectonic movement occurred in the area. This had an epeirogenic effect and caused—among other things—evaporitic shallow basins, which generated vast green and brown marls (URF; Lotfi, 2001). The URF overlies the Qom Formation with a marker layer of gypsum (GYM) with a thickness of up to 40–50 m (especially to the north of Hamzehlou). Varicoloured gypsiferous marls characterise the lower part of the URF (M1), with a thickness of up to 3000 m (Lotfi, 2001). A number of salt deposits have been found and exploited in the lower part of the URF in the area (the rock unit of M1). These deposits include the Seyyedlar, Douzkand, and the Douzlākh (Hamzehlou) mines. In addition to the salt and gypsum that formed in the URF, some hydro-borates such as ulexite have occurred as pebble-shaped masses and small needle-shaped crystals throughout evaporative–exhalative processes in this rock unit.

In the Douzlākh mine, rock salt with a thickness of 30 m is located in the plunged front of an antiform (a convex upward fold) of colourful marls of the unit M1 (Herd, 2020). The salt mass of the Douzlākh has been emplaced as a layer in an evaporitic environment while no diapiric form has been observed in the area (Herd, 2020; Lotfi, 2001).

The URF also hosts some stratiform Cu–Pb (Zn–Ag) mineralisation in the region, which can also be found in northwestern Iran (Azizi et al., 2018). The five Cu–Pb (Zn–Ag) mines of Chehrābād, Qezeljeh, Ebrahimābād, Chorlangosh and Moshāmpā were mined in the past but are currently not in operation. In these mines, copper and lead grades ranged between 2 and 4%, while silver (with a grade of 30–70 g/t) was recovered as a by-product (Azizi et al., 2018). The Cu–Pb (Zn–Ag) mineralisation of the area was formed within isolated grey bleached sedimentary rocks that contain abundant organic matter (Azizi et al., 2018).

Approximately 10 km south of the Chehrābād salt mine lies another NW–SE trending but rather high mountain range (Habash-Nassir-Abād). This range is an elongated thrusted subdomain that was formed by the accumulation of thrusted plates to the northeast and is composed of Precambrian and Phanerozoic rock units (Lotfi, 2001). Additional mineral deposits include some volcano-sedimentary (and a few magmatic) iron deposits in the Habash-Nassir-Abād range, some of which are currently in operation as mines (e.g. Mirjan and Qalicheh Bolagh). Lotfi (2001) believes that the Mirjan deposit occurred due to exhalative submarine activities in a marine sedimentary environment. Within this deposit, some discontinuous stratiform lenses of iron ore (mostly goethite and lepidocrocite) have settled in the dark shale and sandstone with intercalations of dolomite from the Barut Formation (Lotfi, 2001).

In fact, the Barut Formation (Cambrian Barut: Cbr) is the favourable formation for the mineralisation of iron in this region and hosts several iron occurrences (Fig. 4). It is noteworthy that a short survey in the dolomite of the Barut Formation north of Mirjan village revealed potentially ancient (but previously unknown)

Fig. 5 Mirjan, showing fire-setting traces in the premodern mine near the village. Photo: F. Schapals

iron-mining activities (Figs. 4, 5) in the form of an elongated vein-following mine (the site of Mirjan 3, Fig. 5). The Kahar Formation (Precambrian Kahar: PCk) and the granite unit of G1 also show some iron mineralisation. The site Mirjan 3 (Fig. 5) is located above the village of Mirjan and could be considered an old mine. It is a small-scale underground working, which follows the ore vein for about 15 m in a slightly ascending section in a northeast direction.

In front of the mine, there is a strongly eroded dump with gangue material containing small amounts of azurite and malachite. The vein, which is exposed along the gallery in the southeastern workface, mainly contains iron oxides and small amounts of azurite and malachite associated with quartz. The gallery shows irregular workfaces with hourglass profiles together with traces of soot on the ceiling. Small mining pockets can be found in the southeastern workface. The floor of the mine consists of small-scale backfill along its entire length. Neither tool marks nor remains of blasting work (e.g. drill holes in walls or ceilings) were detected. In summary, the findings suggest an earlier dating for the mine, although the extraction technique of the so-called fire-settings cannot serve as the sole indicator of ancient working. However, recent mining activities cannot be ruled out. Based on the structure of the mine, it can be assumed that the fire-setting technique was first applied in a northeast direction and later in the direction of the ceiling to exploit the ore vein.

Geology of the Deposit and the Filling of the Valleys Around the Douzlākh

The Douzlākh salt deposit is situated on the southwestern side of the Douzlākh, a conical elevation that is located directly southeast of the village of Hamzehlou. The area consists of alternating layers of greenish and brownish marls, which belong to the URF of the Upper Miocene age (Lotfi & Kiani, 2001). These geological layers are strongly folded and generate synclines and anticlines with periods of 1 km, often formed along a NW–SE axis, which is clearly visible to the northwest and west of the Douzlākh (Fig. 6). These brownish and greenish marls are discordantly overlain by coarse conglomerates with pebbles up to several tens of centimetres in size. These sediments date from the Pliocene and are only found in relicts due to erosion. The Douzlākh salt deposit consists of two salt (NaCl) layers of several metres, which are folded and embedded in the marl layers. The above-mentioned Geological Map of Iran marks the Douzlākh salt deposit with a cross for NaCl but no salt formations are shown within the stratigraphic sequence of the geological formations (Fig. 4). At first glance the Douzlākh looks like a typical round salt dome or diapir (Fig. 6). Recently conducted structural geological investigations by the author

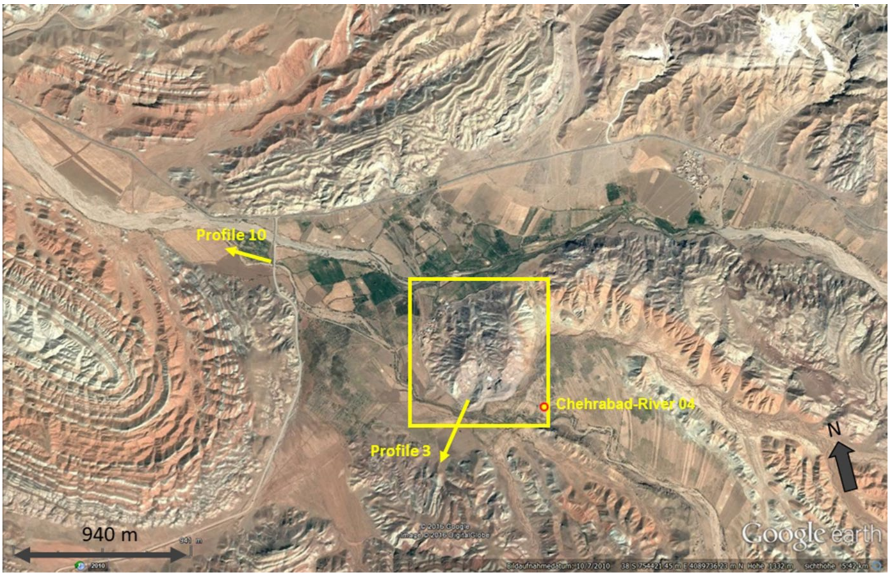


Fig. 6 Location of the Douzlākh salt deposit (yellow box) and its environs, the location of the 2011 digger trench and of ERT-profiles 3 and 10. Graphic: R. Herd

support a different origin. The relatively low rock salt thickness of a few metres and the appearance of the salt formation with two layers separated by marly sediments, as well as their main dip to the NW, indicate a folded flow rather than a diapir (in contrast to Khoshraftar, 2015, p. 16, Fig. 13). The large-scale structures (synclines and anticlines) in the vicinity show NW–SE trending folding axes that indicate a SW–NE compression. It is conceivable that younger sediments slid down on one of the salt layers that acted as a slip horizon when the area was uplifted from the south (Fig. 7), hence the salt-bearing layers could have been folded and pushed to the surface. Young conglomerates, which can be found in relicts in the surrounding area, testify to the presence of a large relief that is chronologically after the salt deposition and support this thesis (Herd, 2020). In several areas of the Douzlākh salt deposit, geoelectric investigations have been performed. The aims of these investigations were: a) to obtain information about the internal structure of the Douzlākh; b) to clarify the presence and distribution of salt; and c) to detect further collapsed mining galleries that may have buried miners from different periods of production. The geoelectric investigations were performed as Electrical Resistivity Tomography (ERT) measurements with profile lengths of 117–376 m and investigation depths of 15–70 m (Fig. 8). They were mainly conducted around the archaeological excavations. The ERT investigations revealed that only small amounts of compact salt (dark red areas in Fig. 9) are still present in the deposit. This salt is located in the area of the archaeological site. Further single salt blocks and collapsed areas were detected (yellow parts within and around the dark red areas in Fig. 9). Green colours indicate marly sediments and dump material, whereas blue colours indicate marly sediments and dump material that was affected by salt dissolution.

The area around the Douzlākh is made up of brown and green marls of the Upper Red Formation (URF). These brown and green marls are overlain discordantly by coarse conglomerates, which can be found only in relicts. The brown and green marls are soft and weather easily. They form silty and clayey sediments, which fill the small valleys in the vicinity of the Douzlākh. This can clearly be seen in Fig. 10, which shows the result of an ERT measurement on Profile 3 located perpendicular to the valley of the Chehrābād River south of Douzlākh (Fig. 6). The measured

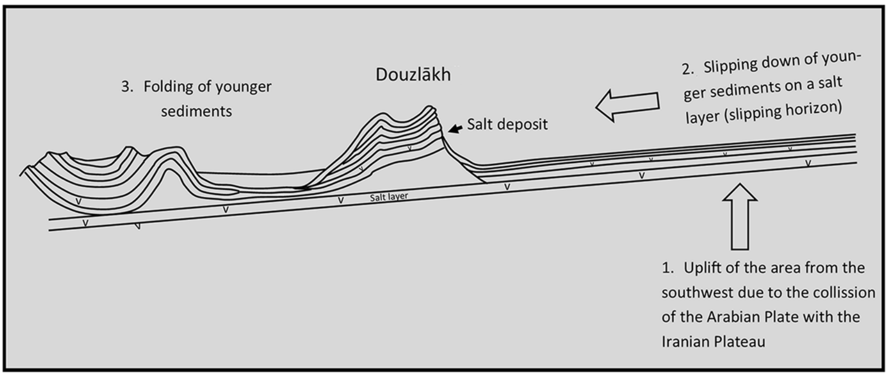


Fig. 7 Genesis of the Douzlākh salt deposit. Graphic: R. Herd

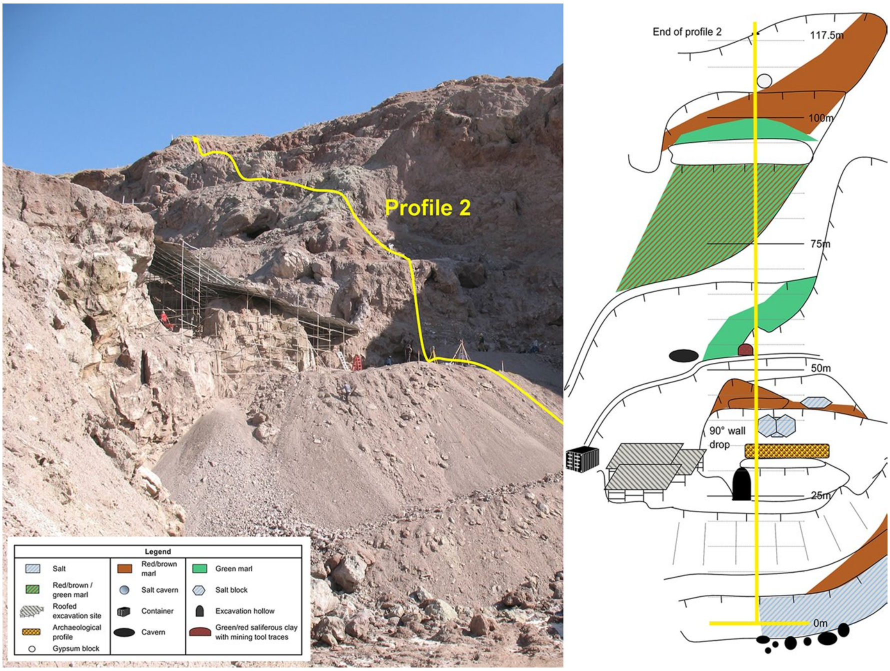


Fig. 8 (Left) Electrical Resistivity Tomography (ERT) measurement along Profile 2 (yellow line); (Right) sketch of observations on Profile 2. Sketch taken from Friedrich, 2017. Graphic: R. Herd

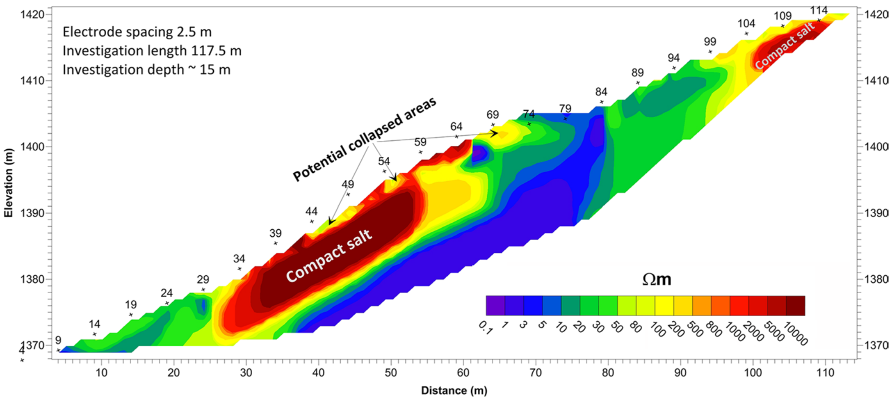


Fig. 9 Result of Electrical Resistivity Tomography (ERT) measurement on Profile 2. Graphic: BTU Cottbus/ZCHTO, R. Herd

resistivity indicates that the underground is made up of fine-grained silty and clayey sediments. The result of the ERT measurement coincides with the result of rotary drilling to a depth of 10.2 m performed close to profile metre 214 of the ERT measurement, which also revealed mainly fine-grained sediments partly intercalated with

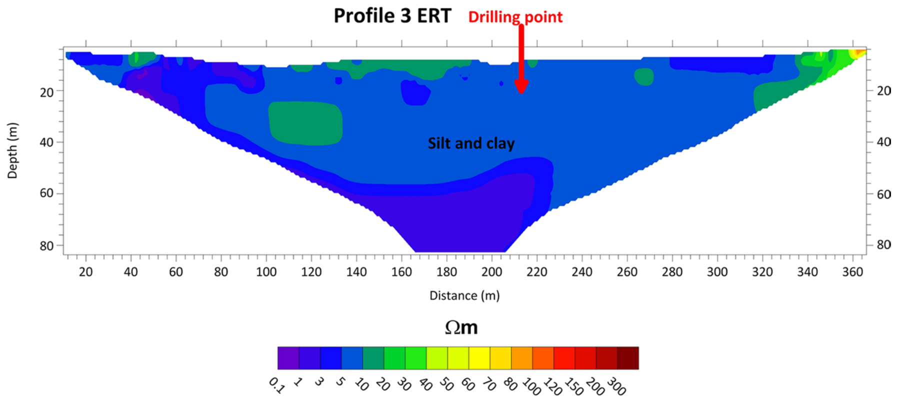


Fig. 10 Result of an ERT measurement in the Chehrābād River valley south of Douzlākh (for exact position see Fig. 6: Profile 3) showing mainly fine-grained sub-surface sediments. (Note that the ground water is saline and thus the resistivity of the sediments is lower than in a freshwater environment.) Graphic: BTU Cottbus/ZCHTO, R. Herd

tiny layers of conglomerates (see below). Because of the fine-grained nature of these sediments, ground water storage and ground water extraction is not possible most of the time. The accumulation of coarse materials (sand, conglomerates) is necessary for the storage of ground water. The Talkherud and its tributaries transported coarse materials from distant regions and produced local lenses of coarse sediments. Lenses of coarse sediments were found in several ERT-investigations performed in the valleys around the Douzlākh in order to detect groundwater (e.g. Figs. 10, 11, location Fig. 6). Due to the saline pore fluid, the resistivity values are low and not comparable to the resistivity values of sediments in a freshwater environment. One of these lenses most likely originated from an old riverbed and was documented within a dredger sounding in 2011, where fluviatile gravel layers appeared after 4 m of clay sediments. The profile provided datable organic material in the clay sediment (OxA-27172; 382–204 cal BC) as well as on top of the gravel layer (OxA-27265;

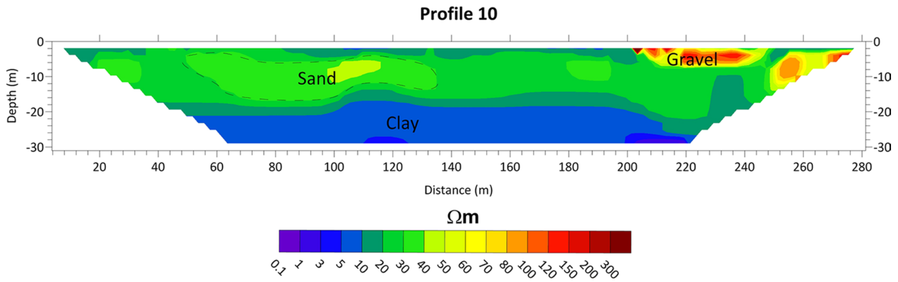


Fig. 11 Result of an ERT measurement in the Talkedrud River valley (for exact position see Fig. 6, Profile 10) indicating some lenses of sub-surface coarse sediments. (Note that the ground water is saline and thus the resistivity of the sediments is lower than in a freshwater environment.) Graphic: BTU Cottbus/ZCHTO, R. Herd

399–209 cal BC), each at a depth of about 4 m contemporaneous with the Achaemenid mine (Aali & Stöllner, 2015, pp. 25–26).

The project's geoarchaeological investigations were intended to document geomorphological processes and forms and to relate climatic characteristics to erosion, sedimentation and fluviatile processes in order to reconstruct the evolution of the valleys surrounding the Douzlākh salt mountain (Draganits, 2020). Various geoarchaeological boreholes and trenches have been made in the vicinity of the mine since 2011 to document the soil structure of the valley sediments. In 2016, five additional geotechnical rotary drill cores, to a depth up to 10 m, were taken to better quantify the fluviatile processes. The sediments from the core drilling were documented in detail with regard to their layer thickness, colour and grain size and sampled for ^{14}C dating, pollen analysis and plant fragments. Only the investigations on the valley floor of the Chehrābād River, 300 m southwest of the salt mine, are discussed in more detail here. The borehole reached a depth of 10.2 m in a field at c. 1360 masl.

Due to the position of the borehole in the valley of the Chehrābād river, fluviatile sediments were to be expected. The fine-grained sediments were therefore interpreted as flood-plain sediments in the broadest sense, and the coarse-grained sediments as fluviatile channels (Fig. 12). The very rare organic remains were dated using the radiocarbon method to relate them to the chronology of salt mining (Fig. 12). Using the ^{14}C age of c. 987–1115 cal AD in the upper part of sediment layer 25 at a depth of 4.9 m (Fig. 12) gives an average sedimentation rate for the sediments above of about 5 mm/year. Using the ^{14}C age of c. 351–96 cal BC from layer 35 at 8.8 m depth (Fig. 12) results in average sedimentation rates of c. 4 mm/year. Two results of this drilling clearly contradict observations made during geoarchaeological fieldwork. Firstly, the dominance of fine-grained sediments is surprising, as in recent times the rivers have predominantly transported coarse-grained sediments; and secondly, the relatively high sedimentation rates contradict the observation that all rivers in the vicinity of the mine are now partially located a few metres below the valley floor and, therefore, currently indicate significant erosion. How can these contradictions be resolved? By incorporating ethnogeoarchaeology and information from the local population, it was possible to understand the two important components of the local irrigation systems that have a significant influence on fluviatile draining events and erosion/sedimentation. Firstly, coarse-grained boulders provide erosion protection that prevents rivers from eroding fields uncontrollably during floods. This erosion protection reduces the shifting of river courses, which is why coarse-grained sediments are so rare in boreholes. Secondly, water is taken from the rivers through artificial channels; these channels have slightly lower gradients than the rivers themselves and can thus be directed downstream to the higher terraced fields and distributed via numerous branching irrigation channels, where fine-grained sediment particles in the water are deposited, thus increasing sedimentation rates. Preliminary ^{14}C age data indicate that this type of field irrigation has been carried out in this area for a long time and has most likely occurred since Parthian– Sasanian times. The geoelectrical tomography revealed that fine-grained sediment dominated valley fillings, many of which are up to 10 m thick (Figs. 10, 11), indicating that agriculture around the Douzlākh—due to the salinity of the surface water—was more successful using an irrigation system that had to supply water

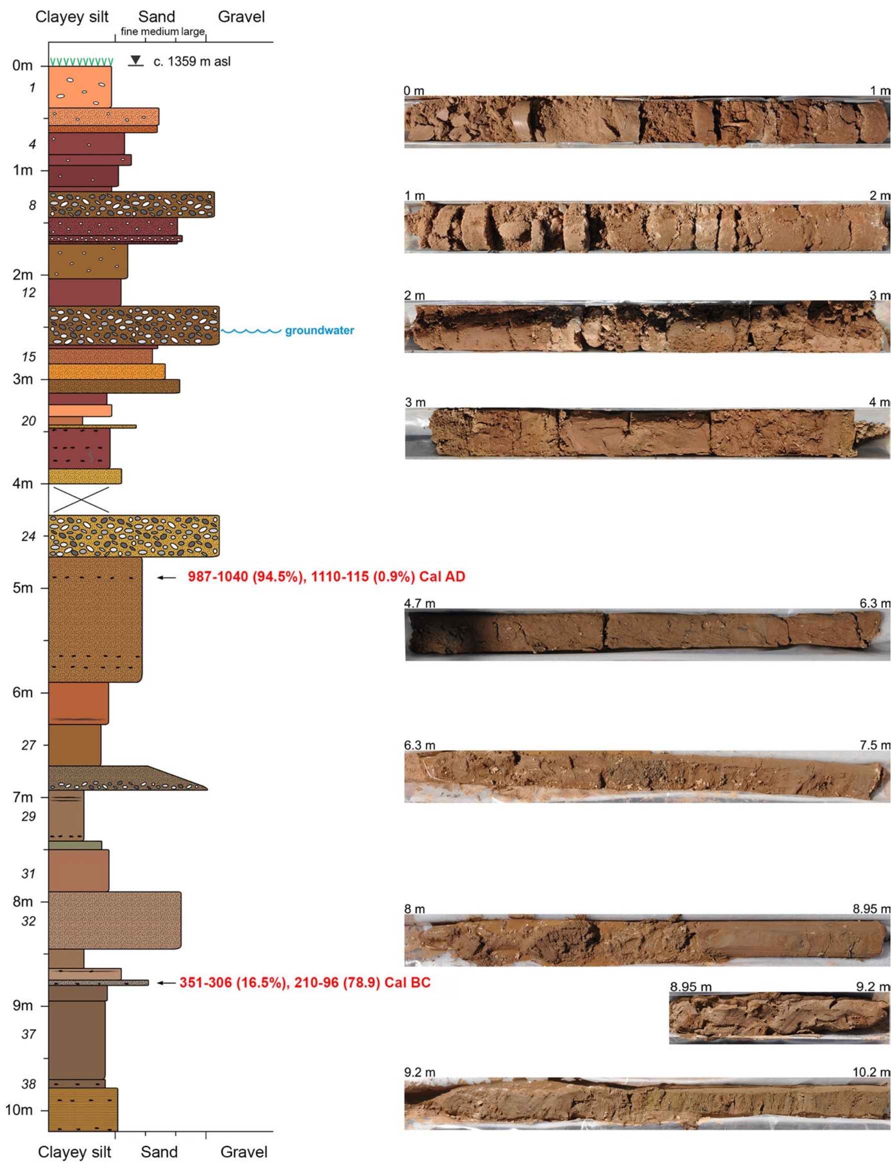


Fig. 12 Lithostratigraphic profile of drilling (2016). (Left) horizontal width of single sediment layers indicates grain size; colours suggest natural colour. (Right) corresponding segments of core. All datings were on organic residues. Graphic: E. Draganits

from the upper valley areas, as several arable crops have a limited salt tolerance. This technique has accelerated the natural filling of the valleys and results today in thick, fine-grained deposits.

Water supply is one of the most important topics for understanding the social and economic practices of ancient salt-mining communities. One of the most important problems in the daily life of people in the Talkherud river region is the provision of sweet and drinkable water for daily use, as well as water for agriculture. In the past, the entire plain was structured by an irrigation system to make better use of water resources (Fig. 13), especially during wet periods, when sufficient surface water allowed the farmers of Chehrābād village to cultivate intensively.

The seasonal riverbed next to the fields is almost 2 m lower than the fields themselves. It is therefore of great benefit that the water-channels control the water pressure and soil erosion. Temporary pressure of the water flow is broken by using stones. The arable land is divided among the villagers and each head of a household receives a certain share. Whilst the river-stream slowly entrenches itself, the sediments of cultivated areas grow steadily along the riverbed, forming large flat terraces structured by small channels. At the edges of the cultivated areas these channels lead excess water back into the river if the amount of irrigation water exceeds agricultural demands. Based on the anthropological evidence, it is likely that this kind of regulated access to arable land was used in different historical periods to provide a scheme that guaranteed long-lasting irrigation systems. According to the dating of the drilling results, this kind of irrigation may have started in the later Achaemenid and Parthian periods (see above).

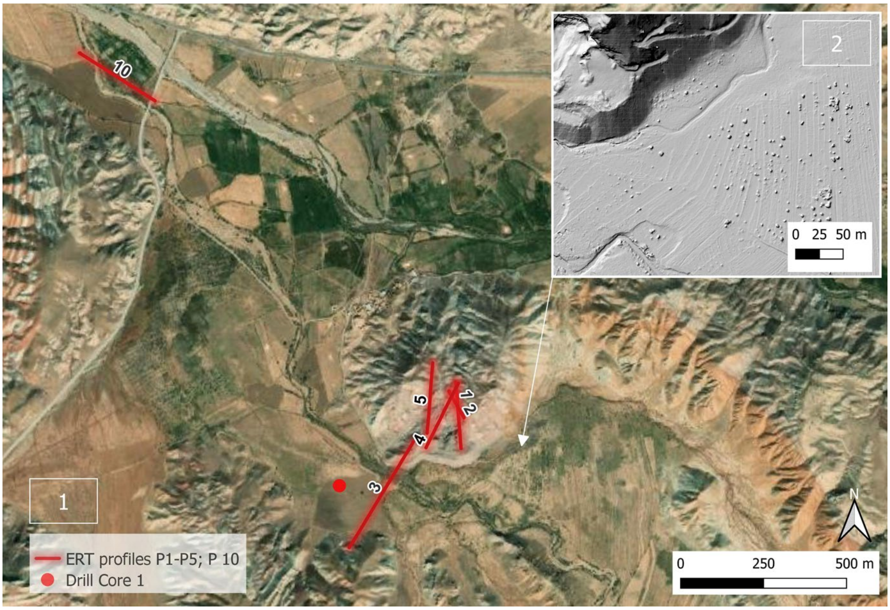


Fig. 13 Grey shaded DTM-model of the Douzlākh salt mountain and its surrounding valleys, as calculated by structure-from-motion photogrammetry (SFM); the magnified areas show the presumed early modern irrigation terraces southeast of Douzlākh salt mountain. N. Schimerl/F. Schapals

Pastoral and Agricultural Background

Today, vegetation is extremely scarce around Chehrābād and the land is characterised by massive erosion processes due to the lack of vegetation cover (Fig. 14). Especially in the dry summer months, there are areas that resemble an arid steppe. This changes completely during the spring months after the seasonal winter rains provide sufficient water for plants to grow. Agriculture and horticulture are not only practised within the irrigated valleys, but also on the high plateaus covered with green fields of barley. Even if water is often insufficient today, these circumstances show that in earlier periods the situation may not have been so bad. Over centuries, pastoralism with herds of cattle and—even more invasive—sheep and goat destroyed the vegetation cover. We are dealing with an increasingly destructive system here. Due to the lack of vegetation, the soil cannot hold the water, and erosion starts, which constantly increases the pressure on the remaining vegetation. The evidence from the ancient mining layers now offers the possibility of reconstructing the ancient landscape (Boenke, 2020c). We can expect farming subsistence in the region to be functional during various phases of mining (cf. 3.5.), and a much more intact vegetation (including forest stands) than is imaginable today (cf. 3.5.1.).

Fig. 14 Landscape around the Chehrābād salt mine during spring 2010. Photo: T. Riese

Ancient Salt Mining at Douzlākh

Research History and Modern Excavations

The discovery of the first mummy fragments in 1993 directed the archaeological gaze for the first time into this hitherto little-explored landscape. Initial excavations by Housheng Sobouti and later by Ali A. Mirfatah led to a first engagement with the salt mountain and its archaeological remains. These findings, including the involvement of the Central Restoration Department in Tehran, quickly became known nationwide (Vatandoust, 1998; see also Aali, 2005, 2022; Aali et al., 2012a) but remained misunderstood. This only changed with a new mummy find in 2004: rescue excavations initially led by Amir Elahi quickly led to proper excavations, which were subsequently taken over by Abolfazl Aali. However, more mummy parts were revealed during modern mining activities undertaken by the Nasr-e Zanjān Company; these were recovered as Mummy 3. Later, it was discovered that these mummy parts originated from several individuals, who have now been called Saltmen 3 and 7 (Öhrström et al., 2021; Vahdati Nasab et al., 2019). These events led the Zanjān Province and its Cultural Heritage Office (ZCHTO) to decide that excavations should be carried out more systematically. Since 2005, a total of seven systematic archaeological campaigns have been conducted (Stöllner, 2015; Stöllner & Aali, 2020): The well-preserved Saltman 4 was discovered in 2004 and Saltman 5 was excavated from under a rubble block in 2005. It was thus clear that the miners must have died in mining accidents. The finds drew renewed attention to the site. In 2005, a group of scientists from the Deutsches Bergbau-Museum Bochum (DBM) visited the site for the first time, and in 2007, a joint workshop with British, German, Swiss and Iranian colleagues was organised in Zanjān. This conference was the springboard for two successful funding proposals for further research. These were granted by the German Research Foundation (DFG) in 2009 and the British Arts & Humanities Research Council (AHRC) in 2010 (Aali et al., 2012b; Pollard et al., 2008). In parallel, however, salt mining continued in the southwest, and it was not until 2009 that the Iranian Cultural Heritage Organisation succeeded in stopping mining activities.

Comprehensive studies of the salt mine and the surrounding landscape, as well as of the findings, began with the start of the Iranian–German joint project in 2010. Excavation of the salt mine took place in 2010–2011, 2016–2017 and 2021 and included the area that had been excavated in previous years, the large northern profile, the southwestern part and the area called Küllük (Fig. 15). The Küllük site marks a cove-shaped area at the western foot of the Douzlākh salt mountain that is protected from the weather and, therefore, favourable to habitation. Locals report a settlement mound that was damaged by bulldozing during recent mining operations, which explains the partly damaged stratigraphy found at the site during the 2016/2017 soundings. Nonetheless, some undisturbed features were discovered, of which pits, fireplaces and a layer of potential smithing slag from the Safavid to the Qajar period are worth mentioning.

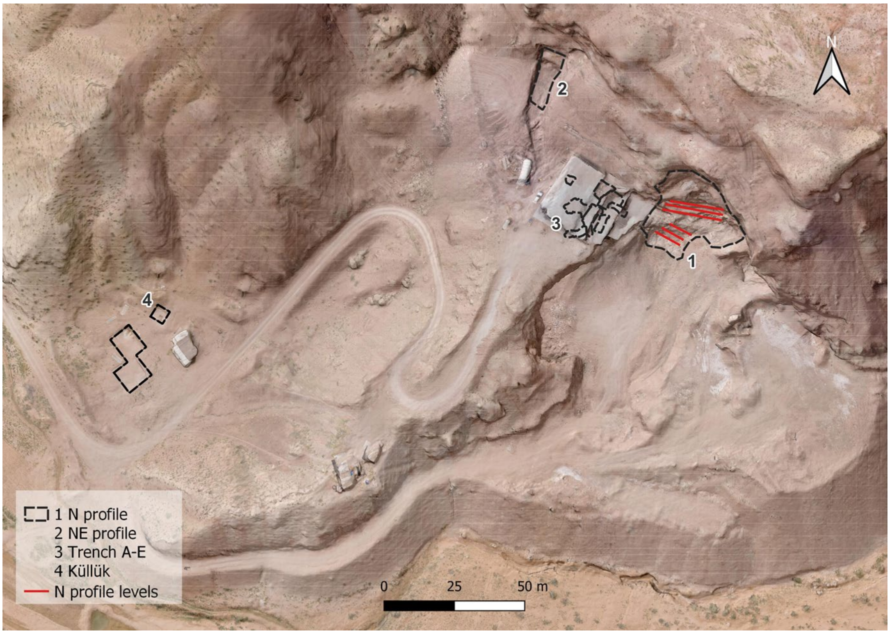


Fig. 15 Douzlākh salt mountain, excavation areas 2010–2021. Graphic: F. Schapals

A deep latrine pit from the Ilkhanid period indicates a camp-site that had been used from the Middle Islamic period onwards. Although earlier-dating pottery sherds are scattered in the excavation trenches, no in situ features from the Achaemenid and Sasanian periods have been discovered so far. In addition, a large part of the Talkherud area was archaeologically surveyed between 2005 and 2017. Here, it was possible to intensify archaeological landscape studies around the mine by identifying the sites of the Talkherud basin more accurately and studying their surface finds. As a result, excavations began at Tappeh Kūzehchi in autumn 2020; further intensive surveys were carried out in 2021. In addition to field research in and around the Douzlākh, the study of the findings from the archaeological excavations and interdisciplinary research on various topics have led to important results (Aali et al., 2012a; Aali & Stöllner, 2015; Ramaroli et al., 2010; Stöllner et al., 2020).

Stratigraphical and Chronological Remarks

In the Douzlākh mountain, a large and very pure rock salt bed was mined, and numerous adit systems and mine workings were driven into a thick salt block (Fig. 16). This created large underground mining halls, which were refilled with debris from mining operations, providing insight into the chronology and technology of individual mining operations. Preserved mining pillars and unmined rock faces also allow the distinction of mining traces according to different periods and their preferred mining techniques. However, the mining halls have repeatedly

Fig. 16 Douzlākh salt mountain. View into the recently re-uncovered modern opencast and the salt-bed and its antique and historical mining. The salt-bed has been tilted over towards the north and lifted up towards the south. Photo: Th. Stöllner

undergone changes during mining, which makes a simple interpretation difficult. As the mine workings were regularly backfilled, the reconstruction of mining operations such as those of extraction and refilling depends on a correct interpretation of the mining debris (see below, contribution by F. Schapals). One advantage of the ancient Douzlākh salt mine is its exposure to daylight—it can be explored from above, which is unusual in mining excavations. Similarly, the layers in, for example, the southwestern parts were excavated according to their stratigraphical succession, which allowed the establishment of a chronological sequence of mining debris (Aali & Stöllner, 2015, pp. 26–55).

According to the stratigraphy and AMS ^{14}C dating the mine was intensively exploited during the Achaemenid period (c. 550–330 BC); in the later Parthian to the Sassanid periods (c. 150/220–630 AD); in the mining phase of the Seljuk period (eleventh and twelfth centuries AD) (Fig. 17); and again during the Safavid, Qajar and Pahlavi dynasties (seventeenth–twentieth centuries AD). The long stratigraphic sequence allows extensive studies of the multitude of organic finds that were deposited as waste in the debris layers of the mine.

^{14}C-Chronology and Catastrophes

A total of 96 AMS-^{14}C dates have already been obtained in the laboratories of Oxford (UK), Zurich (Switzerland) and Mannheim (Germany). The Achaemenid sequence consists of 28 dates, between the second half of the fifth and the early fourth centuries BC (Figs. 17 and 18; Supplementary Information 1). Only one date

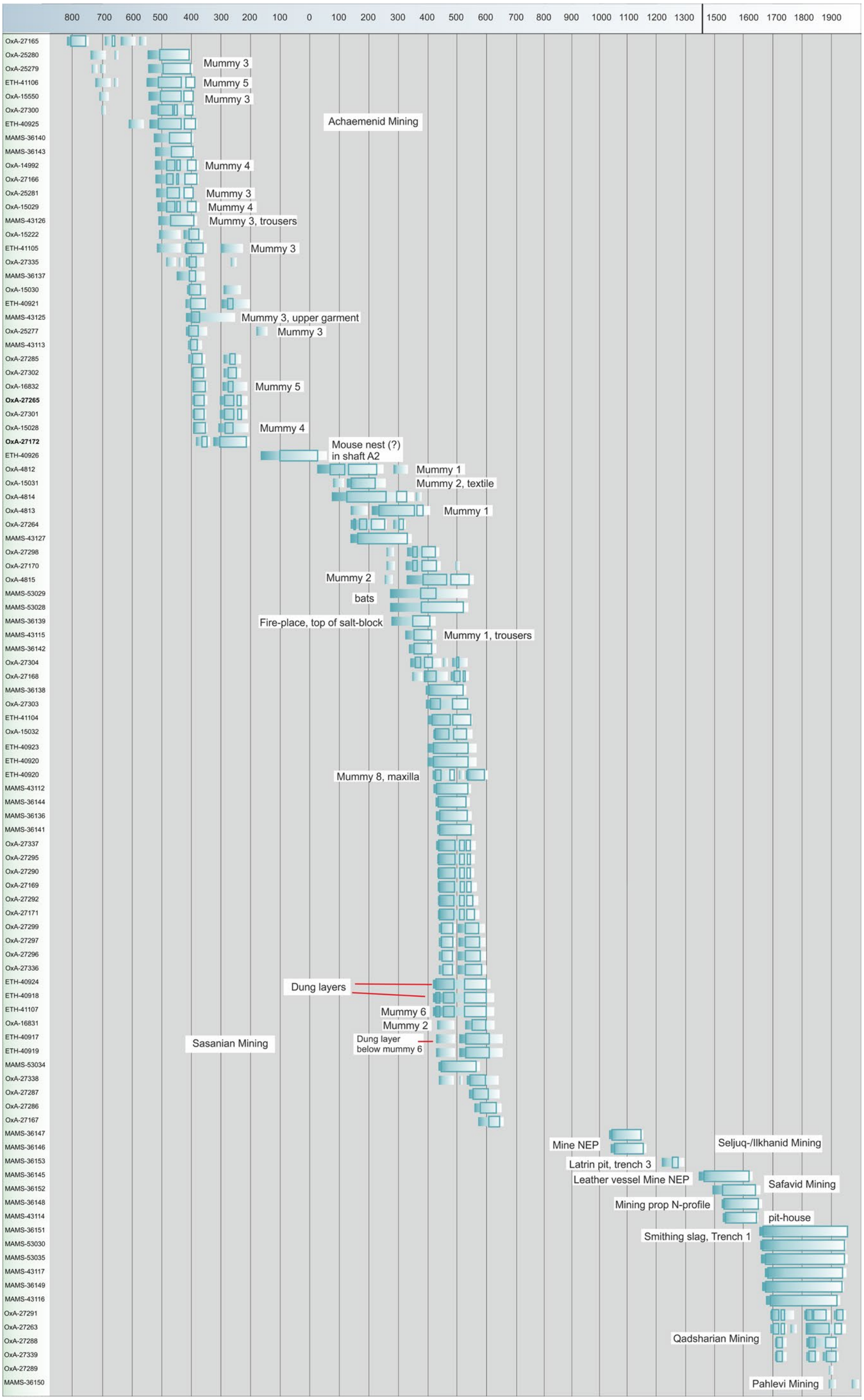


Fig. 17 AMS-^{14}C-dating of findings from the Douzlākh salt mine, current stage of the art (1σ/2σ-standard deviation). Graphic: Th. Stöllner

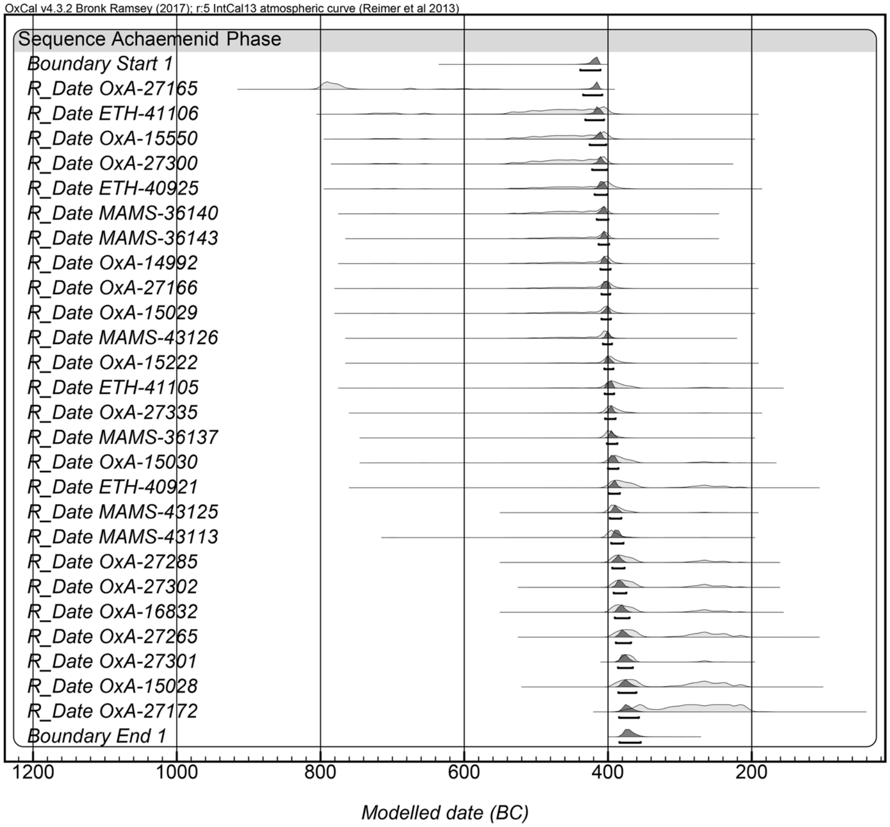


Fig. 18 Douzlākh salt mine, Bayesian modelling of 26 AMS-^{14}C-dates from the Achaemenid period, after OxCal, Version 4.3

ranges from 811 to 567 cal BC (OxA 27165) and thus lies on the Hallstatt plateau. The sample derives from a wooden handle that was discovered during rescue excavations in 2004/2005 and was made from branch wood. It seems possible that an old wood stock was used in its production or that the handle was used over a longer period, since its surface appeared very smooth.

Apart from this outlier, an operation period of only a few decades between the second half of the fifth and the fourth century can be postulated. But we should bear in mind that apparently older pottery has been reused as lamps, which makes it possible that mining activities had already started before the abundance of data from the fifth and fourth centuries BC (A. Aali in Aali & Stöllner, 2015, esp. p. 87). The Achaemenid mine was abandoned after a mining catastrophe that cost the lives of three miners. This catastrophe can be dated between 405 and 380 BC, as previously emphasised by several authors (Aali et al., 2012a; Pollard et al., 2008; Stöllner, 2021) (Fig. 17). AMS-^{14}C dates (no = 48) from the Sasanian period cover a long timespan, especially trenches A and C which show a clear stratigraphical sequence that corresponds with the chronological sequence between the second/third centuries and the fifth/sixth centuries AD (e.g., Aali & Stöllner, 2015). The dates scatter over a timespan of more than 300 years. The Bayesian modelling curtails the range from the beginning/middle of the third century until the beginning of the seventh century. However, the beginning of the Sasanian operation period can be stratigraphically defined, and some fireplaces settled on top of the Achaemenid debris, indicating first activities in still-open mine galleries around the third century (MAMS-36139). Two mummified bats were found within debris layers (30001/25002) above the Achaemenid layer sequence. Their presence allows us to draw some additional conclusions about the recommencement of mining, as they clearly died at a time contemporary with a clean-up of working areas and the relocation and consolidation of older debris from mining galleries that had not been touched since the Achaemenid catastrophe. Bats and small ruminants might have settled the cave-shaped holes of the destroyed mine-parts before the new activities started. The situation with Saltman 1 is rather uncertain and some accompanying artefacts gave slightly earlier dates (OxA-4812, 4813, 4814, OxA 15031) than the salt-mummy itself; as these artefacts were not found during archaeological excavations, their exact find location is unknown and their contextual relation to Saltman 1 is unclear. They range between the first and third centuries AD and correspond with a date for the lowest Sasanian layer (31000) at trench A–B, which is even older than the above-mentioned fireplace (OxA-27264), and the debris with the above-mentioned mummified bat (MAMS 53029). Consequently, a slightly earlier date is suggested for the beginning of the Sasanian mining phase, which possibly started in the second or early third century AD, perhaps in other parts of the collapsed mine that are yet to be excavated. The next step suggests that larger parts of the mine were cleaned, and the mine was put into operation in the third century. Debris was re-dumped in this working area between the fourth and fifth centuries (e.g. layer-feature 30000). There is no reason to conclude a discontinuity of mining operation. The latest step of Sasanian activity falls in the fifth to the early seventh century, which evidence another catastrophe (mummies 2 and 6).

The later periods are not as well documented with a much smaller sample number, and the exact dates of various mining operations are uncertain. There are three dates from the Seljuk and Ilkhanid periods, which may indicate mining activities between the eleventh and thirteenth centuries AD. Four dates from the Safavid period show a better concurrence. They originate from two features at the Küllük camp site and from two mining layers at the salt mine and are therefore more informative for the discussion of an operation period. Bayesian modelling provides an argument for a mining period that spans from the end of the fifteenth to the seventeenth century AD, covering perhaps 150–200 years. Considering 12 later Qadsharian and Pahlevi dates it seems probable that there was no hiatus to the younger mining period. This is also supported by the stratigraphical sequence of the large north-profile that shows seemingly continuous overlying strata between the Safavid and the Qadsharian periods. This would indicate a much longer, continuous, mining operation between the late fifteenth and the early twentieth centuries AD.

Layer Types and Their Succession

As a result of its long use, the stratigraphy of the Chehrābād mine reflects complex formation and alteration processes. In addition to human activities, we must consider the geological and tectonic genesis of the Douzlākh deposit; together they influence the structure of the mine and its decay over the centuries.

The interpretation of the archaeological stratigraphy at Chehrābād is based on the taxonomic classification of the deposited layer types. Nine kinds of strata, with features in common, have now been identified in excavation areas A–D in the western part of the Douzlākh. The classification criteria relate to each stratum's composition, including type of sediments, position, dumping direction and deposited finds within the stratum. In classifying the activities and processes observed at Douzlākh we have built on the systems and terminology already developed for mine archaeology, in particular for the Austrian mines of Dürrnberg bei Hallein (Stöllner, 2002, 2003) and Hallstatt (Kern et al., 2008). Thus the layer types in the Douzlākh salt mine will be described here by referencing waste material, backfill, gallery roof collaps, etc., and units of occupation horizons will be described as walkways, facility areas, etc.

Over the centuries, extraction locations and the system of extraction changed many times. As mining shifted to more productive locations, space created during earlier operations could be used for other purposes. Any space underground that is used for moving and extraction must first be opened. This means that large amounts of material need to be extracted, with great effort, and then moved. This haulage of material often requires greater physical and logistical effort than the actual mining of salt. The miners therefore made use of the space they had laboriously created earlier and integrated it into mining operations in the best possible way. These spatial-use strategies can be seen today in the complex stratigraphy of the mine and the almost complete backfilling of most areas.

The central part of the northeast profile in excavation areas B–C in the Douzlākh mine gives an example of how space was subsequently used in the context of mining operations during the Sasanian period. Layers 31103 and 31090 in the central eastern part of the profile (Fig. 19) are similar in composition but are interrupted by a thin layer of ash in the eastern area (Layer 31009). The layers are mainly characterised by their east–west direction and by highly fractionated material in the grain-size range of 0.06–200 mm. Larger blocks of more than 200 mm are represented as well. The spectrum of finds is homogeneous (see below for the kinds of finds in the Douzlākh salt mine), with wood finds predominating, as in the entire mine; the discovery of a fur-lined leather glove was exceptional. Layer 31009 follows in the central and western part of the profile. It consists of highly compressed salt and bedrock, is a few centimetres thick and lies flat on the surface. The find spectrum consists of macrobotanical remains, wood fragments and occasionally charcoal and ash particles. The underlying layer 31185 displays a similar position and composition, but the material contains more paleofaeces. Layers 31090 and 31103 can be interpreted as backfill layers; after the termination of salt extraction in this part of the mine, the resulting space was used to deposit and/or relocate material. The material consists of secondary rock with no salt content but is interspersed with

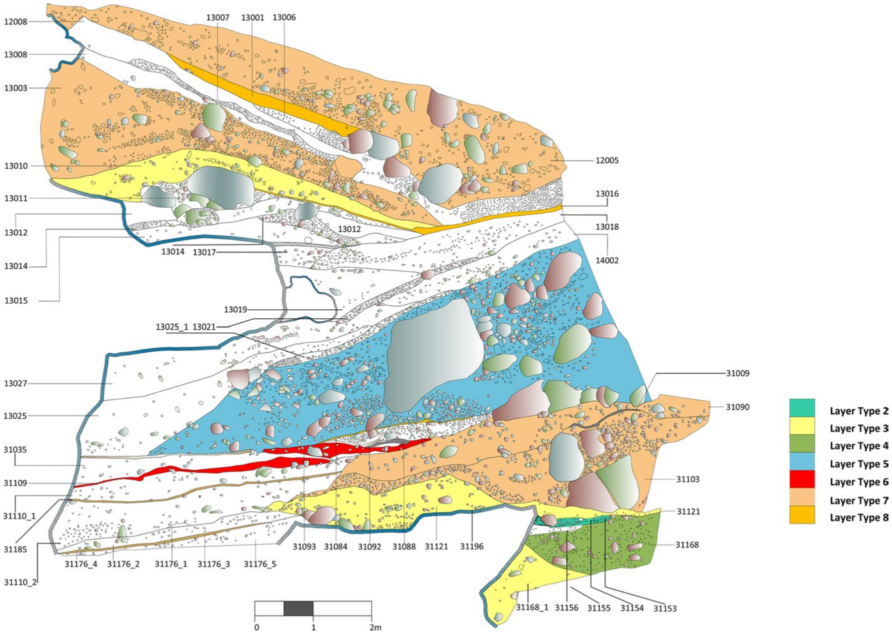


Fig. 19 Douzlākh salt mine, trench B/C N Profile, layer succession of Achaemenid and Sasanian layers according to layer types 2–8. Graphic: F. Schapals

archaeological finds. This kind of underground dump saves the costly transport of waste material and waste products to the surface.

The western part of the profile with layers 31184, 31185 and 31109 shows that an underground space concept must also include infrastructural areas that serve as travelling, working and recreation areas. The existing space was divided into a dump area and an area where the miners could stay, move and relieve themselves, protected by the low roof of the hall.

During later mining periods at Chehrābād in, for example, the later Sasanian mining period, underground spatial strategies remain the same in general concept, but were adapted to the increased mining activity. Strata 12,005 and 13,003 (Fig. 19) in the upper part of the northeast profile in area B–C, for example, show that the mined areas continued to be used in the context of relocation and for making room, but strata such as 13,016 and 13,001 show that intensified mining is also accompanied by increased haulage requirements, whether for salt or for rock fill. In both cases, layers 13,016 and 13,001 are compact, homogeneous straw packages interspersed with animal faeces. They adapt to the direction of repose of the previous layer but have a regular surface. They do not show any interspersion with salt or bedrock, indicating that the layers were not subsequently moved. The layers suggest stable horizons within the dump context. By the late Sasanian period at the latest, the miners used donkeys to meet increased demand for haulage (e.g. Askari et al., 2018) and integrated the space requirement of this new hauling method into the existing space-use concept of the mine.

Most of the layers excavated so far date to the Sasanian and later periods. In the lower area of trenches A and B, there are a few sections that give reason to discuss Achaemenid layer types. These strata are different to those from the Sasanian period, and most are characterised by fine-grained debris, often rich in salt, sulphates and clay. This is best observed in the southwestern corner of trench A, the same trench where Saltman 4 was found. Several narrow layers lie flat on the surface (layer sequence: 31011-1 to 31158-3). The sequence of layers demonstrates a continuous deposition of mining debris in the course of salt production. These layers are successively deposited on top of one another and tend to have a high salt content. Grain sizes range between 0.06 and 6.3 mm, and the components appear to be heterogeneously distributed as well as deposited in a regulated manner. Wood waste and processed wood residues constitute a high percentage of what is found within these layers. These characteristics indicate that the layers consist of in situ small crushed exploitation debris known as *Hauklein* (Fig. 20).

The composition of these layers indicates that larger and richer pieces of rock-salt had been extracted and selected. In terms of extraction technique, it is likely that during the Achaemenid period rock-faces and debris were crushed using hammers and wedges rather than with iron picks.

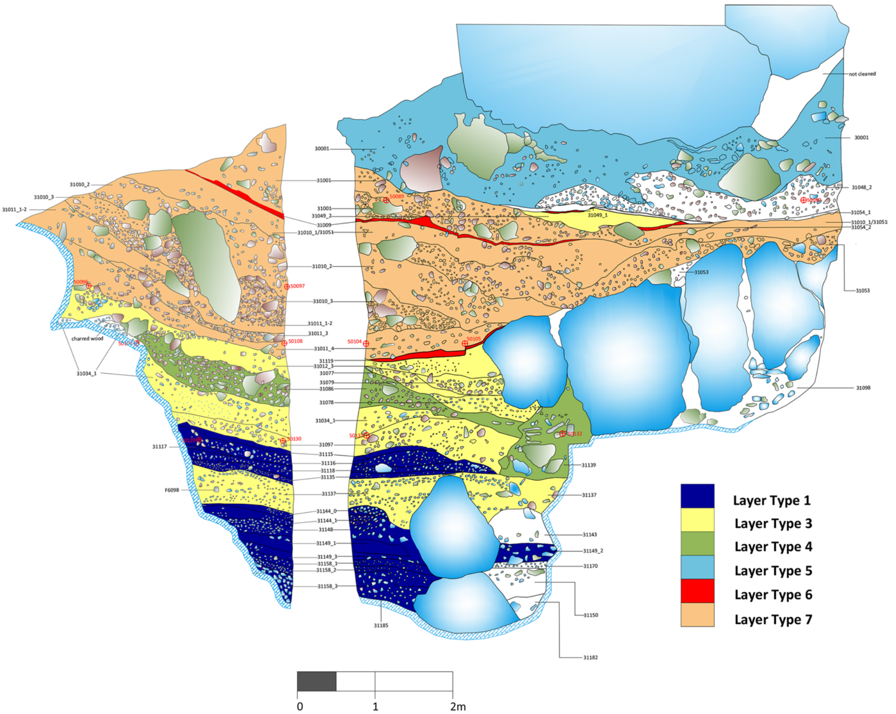


Fig. 20 **a** Douzlākh salt mine, trench A, W and S Profile, layer succession of Achaemenid and Sasanian layers according to layer types 1–7; **b** Trench A, W Profile during the 2016 excavation. Graphic/Photo: F. Schapals

Mining Techniques and Catastrophes

In the excavation area southwest of the open pit, which has been investigated since 2004, the southwestern end of the ancient salt mine was uncovered. The discovery of a southwestern workface over 9 m high revealed different mining zones and techniques, ranging from Sassanid wedge-hewing in the upper section to more wedge-working of salt slabs in the lower section (Figs. 21 and 22, 3).

The distance between the individual mining levels of the workface is slightly more than 2 m. The uppermost level is lost in the broken roof and is over 3 m in height (Kosczinski, 2019, p. 44). The workface is visually separated by the western profile of trench C, and it is likely that a larger mining hall still extends into trench D and westwards of trench C. During the 2021 campaign, a supposedly new mine face was uncovered on the opposite side of the excavation trenches in the northwestern corner of trench D–E. Future excavations will lead to a better understanding of the overall extent of mining at Douzlākh.

There are also two driving galleries (galleries 2 and 3, Figs. 21 and 22, 2) that show how the ancient miners prepared galleries before mining them to the side. The mining tools discovered enable an effective reconstruction of both mining techniques (Fig. 23). In the Sassanid period, wedge hews (Persian *Kolang*, German *Keilhaue*) and lighter adze-shaped hews (Persian *Tiche*, German *Querhaue*) were used. It can be assumed that the lighter adzes were used in the more clayey layers to expose the rock salt, but also to loosen and remove trampled debris. In one case, traces of such hewing work are also visible on a rock-salt face, but it is not clear whether they stem

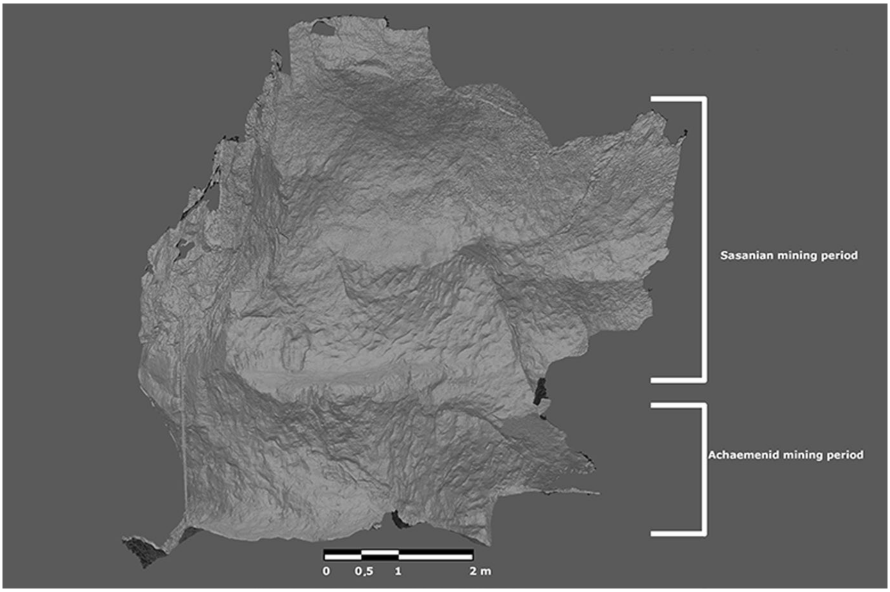


Fig. 21 3D model of the southwestern mining wall at trenches B/C (state of excavation 2017). Graphic: N. Schimerl

Fig. 22 **1** Trench C, showing the southwestern mining wall and parts of the solid rock face at the mine bottom during documentation; **2** view of Gallery 2 towards the southwest; and **3** view from north to a working ledge with Sasanian mining pick traces (upper part) and Achaemenid wedge-work (lower part). Photos: Th. Stöllner

from deliberate mining or a random trial (by an inexperienced worker). The heavy wedge hoe, on the other hand, is perfectly suited to driving long scrapes of up to 50 cm into the rock salt from above and finally loosening the ridges that remain in-between (Kosczinski & Vollmer, 2020). The tracks left behind mostly run from top right to bottom left and are based on the natural movement of a right-handed person (Kosczinski, 2019, p. 44). Long traces of pick hoes on the southwestern workface indicate that small, chopped lumps of salt were removed when the ridges between

Fig. 23 Douzlākh salt mine: tool types from the (**1**, **2**) Achaemenid and (**3**, **4** and **5**) Sasanian exploitation periods. Photo/Graphic: Th. Stöllner/K. Kosczinski

the hoe-tracks were dislodged. Moreover, there is ample evidence of donkey stabling in the mining areas of the Sassanid period, which suggests that salt in fragmentary or finer chunks or smaller pieces was transported in sacks and baskets out of the pit (Askari et al., 2018; Boenke et al., 2020).

In contrast, the Achaemenid mining technique is more difficult to reconstruct. Since fewer wooden hafts have been identified from Achaemenid than from Sasanian contexts, and since no metal picks have been discovered so far, it may be suggested that pick work was used less often than metal and wooden wedges (although reconstructing associations between surviving organics, such as wooden hafts, and metal elements is in itself challenging). A recently identified stone hammer with a biconical hole for its shaft likely related to this kind of work (Fig. 23, 2), either for hewing down already loosened blocks or for crushing blocks into smaller pieces. The only known metal mining tool is a steel hammer with a handle (Persian *charkush*), which was found at Saltman 3. Numerous boulder stones probably served additionally as base for crushing the broken salt directly on site. The technique is therefore similar to quarry work. The traces of extractive work at the lower level of the mine workface are irregular with debris of fairly uniform size that is sometimes roundish in shape. This hints at the extraction of larger, irregular salt slabs during Achaemenid times. Nevertheless, small lumps of salt must also have been extracted, as evidenced by the leather bag with small, very pure rock salt found at Saltman 5. Fine salt was most likely swept up from the soles with hand brushes and was probably also hauled out of the tunnels.

The evidence shows that groups of workers worked side-by-side in the pit, but it is uncertain whether work-gangs involved a handful, or even dozens of miners. In any case, Achaemenid and Sassanid mining was initially carried out on one level, that is, horizontally across the width of the pit. The deposition of the debris layers also shows that mining was only advanced over time at the abutments and finally in the ridge construction. It is also possible that due to the collision of clay deposits and a poor salt quality in the deposit, miners were forced to dig tunnels at different levels to access and explore the deposit; scaffolds—as well as, principally, the clay-rich debris—were used to reach corresponding standing heights. Through fractures and collapses, of which there must have been several, material rich in clay and gypsum was certainly also transported into the mining pits, which then had to be relocated for further mining. The level of the filled galleries during the operating period is therefore uncertain; in the caverns, which were many metres high, only individual salt pillars would have offered a degree of safety. However, completely preserved pillars have not yet been discovered and they were most likely extracted at the end of each mining process.

This mining technique was also observed in other areas at Douzlākh, for example at the northern profile, where a cross profile with a width of approximately 60 m and a height of 40 m has been created by historical mine workings since the Safavid times (Fig. 24). In many places, ridge fractures were observed in this profile, as well as in the salt-extraction galleries in the southwestern part of the mine. These may have posed the main threat to the mine and the miners, in addition to the geological structure, with the slightly inclined and northwest dipping rock salt floe of Douzlākh lying in a salt clay cap and being tilted and shifted to the north by tectonics. This causes tension in the rock salt deposit, which thus breaks into floes or can easily fracture during tectonic tremors such as earthquakes.

In addition to the salt mummies, there are also historical reports of such accidents (Vatandoust & Hadian Dehkordi, 2005; Pollard et al., 2008; Aali & Stöllner, 2015, pp. 51–52; Aali, 2022; Öhrström et al., 2015, 2021; Vahdati Nasab et al., 2019). These suggest that there have been at least four different accidents, one during the Achaemenid period, two in the Sassanid mining period and probably also one in the twentieth century. We can observe the latter on the northern profile by collapsed mine roofs (Fig. 24). Nevertheless, such accidents can rarely be traced in detail. However, in the case of the accident in which Saltmen 3, 4 and 5 died, precise modelling of numerous ^{14}C data allows the accident to be narrowed down to approximately 405–380 BC (Fig. 17) (see above). According to observations in the vicinity of trench A, the ridge must have collapsed. Large blocks killed at least three miners. Unfortunately, the location of Saltman 3 could not be documented. However,

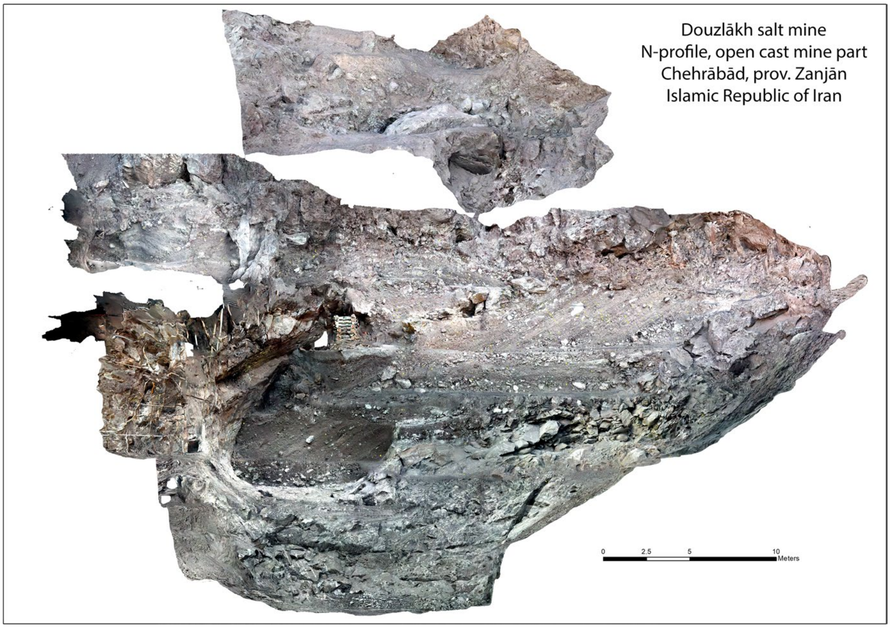


Fig. 24 Douzlākh salt mine, N profile (on the basis of SfM technique) of the 2015–2017 excavation at the modern open-cast mine that demonstrates the layer succession of the Achaemenid and Safavid to Pahlavi period. Graphic: N. Schimerl

this was possible with Saltman 4—a young man aged 15 or 16—and Saltman 5—an older adult—who were both killed by the impact of large blocks of rock salt and were thrown face downwards. Saltman 5 initially saved himself with his sack of salt by climbing on to the ledge to the east of the mine but was killed there. Saltman 3 was also found under a salt block. However, the block fell on the mummified remains and destroyed parts of the largely skeletonised feature. Thus, it is not clear at present which of the fractures were perimortem and which postmortem. Nevertheless, it is likely that Saltman 3 was also killed by falling rocks.

It is not possible to estimate how extensive the fall was. The ridge must have been torn into slabs by the aforementioned stress cracks and tectonic faults (such as at gallery 2) before another event caused the ridge to collapse. Earthquakes are a very likely occurrence, being very common in this region, and also recorded in antiquity. Duris of Samos, for example, reports earthquakes in the area of Rhagae—today's Shahr-e Ray, a suburb of Tehran—in the late fourth century BC:

Duris remarks that the place of Rhagae in Media takes its name from the fact that the country around the Caspian Gates was torn apart by an earthquake, so that many villages and towns were destroyed and the rivers suffered various changes (Strabo *Geography*, I.3 0.19; see also Ambraseys & Melville, 1982, p. 35).

Thus, it is not unlikely that earth tremors affected the already unstable structures of the mine workings. We should also consider the possibility that mining itself overstretched the load-bearing capacity of the ridges, particularly as the tectonically fissured rock is not always easy to assess in underground mining.

Artefacts in Daily Use

The archaeological excavations in the Douzlākh salt mine revealed a wide range of finds. Given the long timespan of exploitation of the site, a diversity of working material and miners' personal equipment was to be expected, but deposition in salty sediments resulted in outstanding preservation. The large variety of botanical artefacts also allows a glimpse of the lifeworld outside the mine and its subsistence practices (see below).

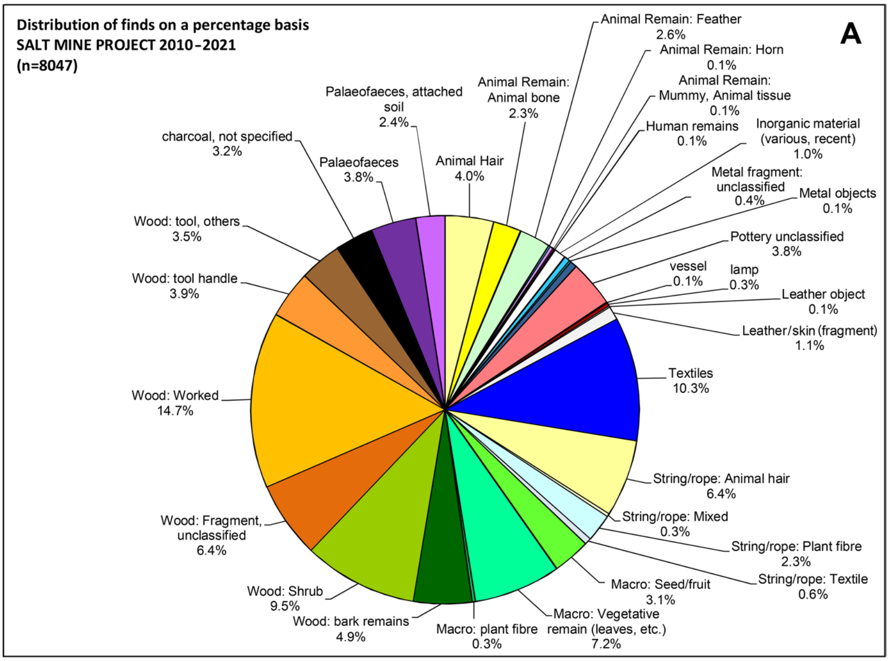
The pie chart in Fig. 25 (top) shows the large variety of materials and object categories excavated between 2010 and 2021. The fact that less than 6% of the finds are from inorganic materials should remind us how reduced the archaeological record of the material background is at sites with less favourable preservation conditions. Here, the settlement of Küllük, which lies at the foot of the salt mountain, offered a direct comparison to the mine (Fig. 25B). In addition to a collection of stray finds, different sections were excavated as part of the project in 2016 and 2017. More than half of the artefacts are made from inorganic materials, with pottery sherds predominating. Around 30% of the finds are animal bones; wood is preserved as tiny charcoal fragments and all further organic finds are underrepresented as usual.

Methodologically, the archaeological excavations from 2010 to 2021 took a more comprehensive approach than the preceding rescue excavations (Fig. 25A), which focused solely on the rescue and collection of the miners' (or the mummies') equipment (Aali, 2022). In the campaigns from 2010 to 2021, all kinds of find categories were documented. This includes not only elaborated goods such as fabrics but also tiny wood fragments and faeces, allowing for a more comprehensive reconstruction of the miners' world.

Along with facts about working life, information was also gathered about the environment, agriculture, resource management, technical skills and the health status of the population (Aali & Stöllner, 2015; Askari et al., 2018; Askari, 2022; Boenke, 2020b; Boenke, 2020c, Boenke et al., 2020; Kosczinski, 2019; Kosczinski & Vollmer, 2020; Mashkour et al., 2020; Nezamabadi et al., 2013a, 2013b, 2013c; Öhrström et al., 2021; Ruß-Popa, 2020; Stöllner et al., 2020; Vanden Berghe & Grömer, 2022).

The data presented below offer a brief overview of characteristic assemblages from different periods, from the earliest Achaemenid mining to more recent activities in Douzlākh. The context of exploitation at the mine differs from period to period.

In this paper, we focus on the well-studied Achaemenid and Sasanian periods. The finds from the Seljuq, Safavid and Qajarian periods (which were smaller in number and therefore less representative) are tentatively grouped into an early Islamic find complex from the Middle Islamic to the Late Safavid/Early Qajarian periods, and a more recent find complex from the later Qajarian and the Pahlavi periods to recent times (Fig. 26). This brief evaluation includes only material from undisturbed and in situ layers and excludes finds from backfills (see "Layer Types and Their Succession" section), as the dating of organic finds such as wooden artefacts, ancient seeds, fruits, faeces or bones without chronologically diagnostic values would require radiocarbon dating of every single find. Therefore, the number of



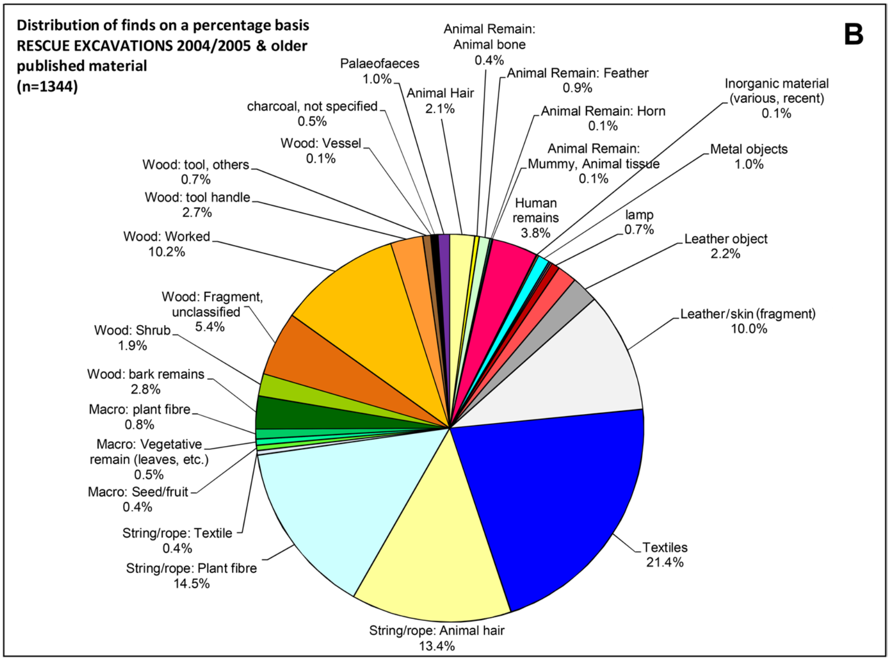


Fig. 25 The pie charts represent the appearance of finds at different stages of the excavations. The main figure shows the distribution inside the mine according to the 2010–2021 campaigns, on a percentage basis (total number of finds 8047). Separately depicted are the older rescue excavations (**A**) with a total of 1344 finds and the settlement excavation at Küllük (**B**) at the foot of the salt mountain, with a total of 422 finds. Graphic: N. Boenke

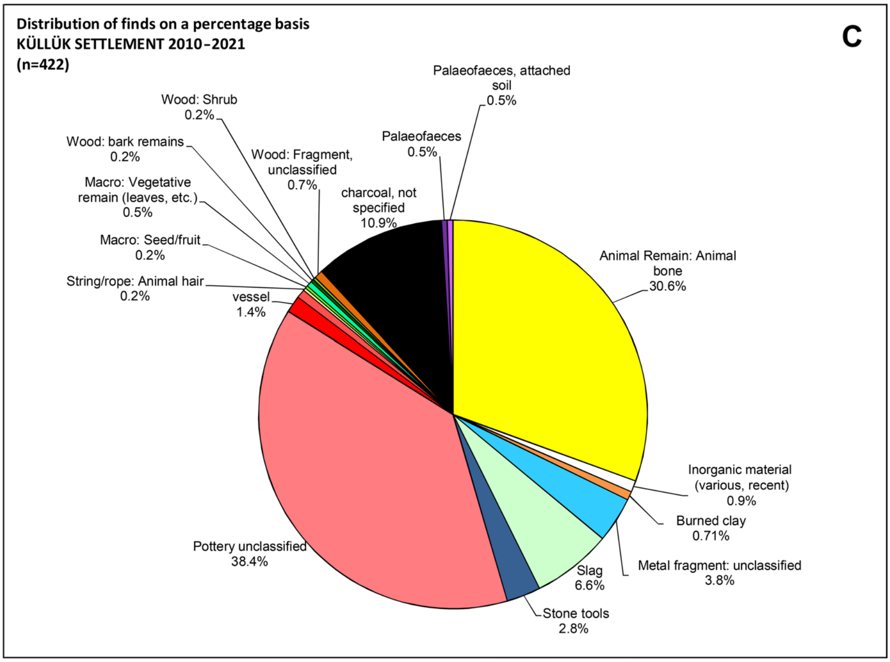


Fig. 25 (continued)

usable datasets or find numbers had to be reduced to 4674 datasets. Depending on the find category, a find-number describes either a single artefact (e.g. human bodies and palaeofaeces as well as elaborated objects, fabrics and tools) or a bulk collection of shrubs, vegetative remains, charcoal, pottery sherds and worked or unworked wooden fragments. The proportion of wooden remains is notably higher than presented in the pie chart in Fig. 25.

Achaemenid Period

The Achaemenid mining is the earliest recorded period of extraction in the Douzlākh salt mine. The number of finds is significantly lower than from the Sasanian period and, therefore, this phase is the most challenging to reconstruct (Fig. 26). After the outstanding results of the 2004/2005 rescue excavation (Aali, 2022) an intensive examination was needed to study these early mining phases from the stratigraphical unit at the lower levels of the excavated area. Since several centuries of mining activities and several metres of fillings and other archaeological layers had to be excavated before the Achaemenid mine was reached, the Achaemenid levels have not yet been excavated to a significant extent. The largest Achaemenid context excavated so far is in trench A (see above). Although preservation is not always optimal due to intermittent moisture penetration, almost all categories recorded in the salt mine are also attested to in the Achaemenid period.

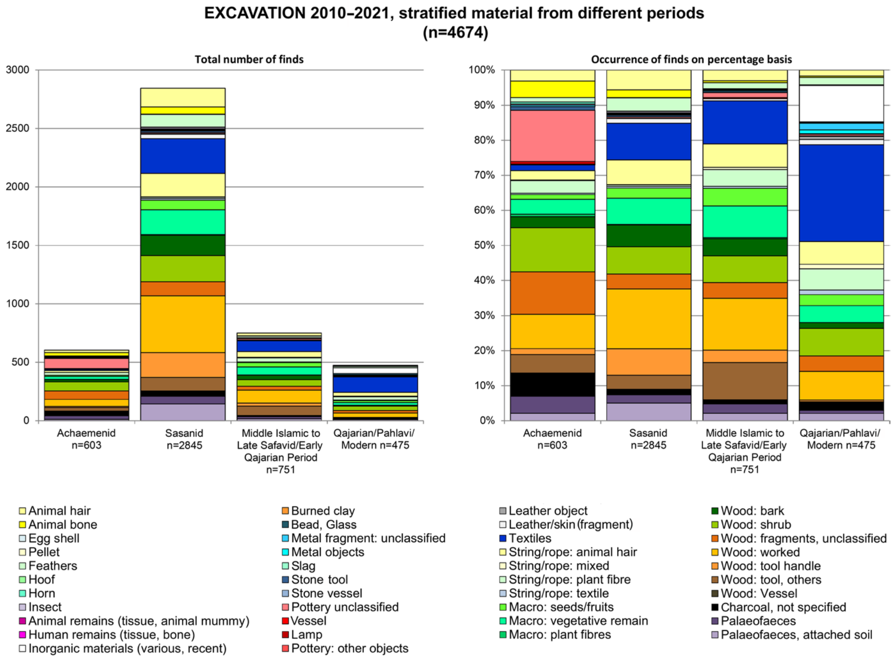


Fig. 26 Diachronic overview of the number and ratio of finds at Chehrābād Douzlākh in different periods. (Left) total number of finds per category; (Right) proportion of find type by period. Charts are based on 4674 finds dated stratigraphically or by radiocarbon. Graphic: N. Boenke

Finds from the Achaemenid layers show the use of a wide and differentiated range of materials. Particularly striking is the fact that the amount of pottery from the Achaemenid layers is much higher than that from the Sassanid or younger periods at Douzlākh. Most of the pottery is highly fragmented, with the exception of some lamps (Fig. 27, 2). A large number of pottery sherds show surface soot traces, indicating secondary use as lamps after they have been used as vessels or containers for storage and preparation of food or other supplies (Fig. 27, 4).

The high amount of animal bone, in particular, indicates cooking activities underground and an Achaemenid awl proves that smaller tools were also made from the bones. Charcoal remains are present in greater quantities than in layers of other periods, and indirectly prove the presence of fireplaces. Light sources are particularly important for underground work. Lamps and fireplaces indicate both mobile and stationary sources of light in the mine. Illuminated places with fireplaces most likely represent a kind of shelter in the darkness or a social gathering point. Besides charred wood, wood is present in several find categories. Most of the pieces belong to unclassified fragments and shrubs, but different tool types have also been found. Wooden finds are less represented in Achaemenid layers than in those from other periods. Whether this is due to the state of preservation or to an ancient resource management strategy is still under discussion. The wooden tools in particular (Fig. 27, 1) are clearly connected to mining activities. Other categories of finds such as stone tools and metal artefacts are scarce. A special stone tool that may be

Fig. 27 Typical artefact types from the Douzlākh mine: **1** Achaemenid mining-tool handle with hafting split [3302-0]; **2** Achaemenid lamp [3427-0] used with tallow or oil; **3** Achaemenid basalt stone tool [6137-0] with biconically-drilled mounting hole; **4** Achaemenid pottery vessel rim [6103-0]; **5** Sasanian tool handle [5535-0]—the incision and discoloured (burnt) area provide information about the hafting technique; **6** Sasanian wooden wedge [4957–0] with attached cords [4957-1-2]; **7** Sasanian leather glove (mitten) [4582-0-1] sewn together from several pieces with wool-insulated thumb; **8** Sasanian trouser-leg [3944-0-4] constructed from several layers of textile; **9** Islamic-period torch constructed of cotton fabric [4602-1] wrapped around a stick [4602-0]; **10** Middle-to-late Islamic lamp [6202-0] with wick [6202-1]; **11** Islamic-period/Safavid textile fragment [6726-0] with dark pattern. Photos: H.-J. Lauffer, F. Schapals, K. Kosczinski; graphic K. Kosczinski ▶

associated with mining activities was also discovered within an Achaemenid context in 2021 (Fig. 27, 3). Its size and shape indicate that this basalt tool was more or less circular, with a central biconical hole. This kind of tool is so far unique for the site. In addition to the (metal) hammer discovered with Saltman 3, and several wooden shafts and wedges, this find adds a new tool to the Achaemenid toolkit (see above). Other types of stone tools are more common but are mostly not attributed to Achaemenid contexts. They are also associated with the grinding of salt or the preparation, production and maintenance of tools rather than with salt production per se. There is hardly any evidence of metal finds from the Achaemenid period at the site. This is most likely because—unlike wooden finds—the valuable metal was not left behind in the mine, but tools were probably repaired and re-hafted at the surface, or the metal may have been recycled. However, the hammer of Saltman 3 (Fig. 23, 1) attests the existence and use of such tools in Achaemenid times. Some smaller and heavily corroded iron fragments from Achaemenid contexts could be mining waste that was unintentionally left behind in the mine. Another find category associated with mining at the site is cords and ropes. They are most likely part of the working processes inside and outside the mine and may also have been used for tying, fixing and repairing textiles and sometimes leather (Grömer et al., 2020). Cords occur as elements of (fragmentary) clothing and fabrics reused for other items such as bags or fastenings. Another category of finds related to animals is the horn sheaths from Achaemenid contexts. Some of these are probably not the remnants of underground consumption: they were most likely used for the transport or distribution of lamp oil or tallow.

Sassanid Period

The Sassanid period is extensively represented in excavated parts of Douzlākh, and an enormous number of finds have come to light (Fig. 26). Most of these are wooden artefacts, textiles, strings and ropes. The majority of the Sasanian finds were excavated in trenches B and C. This large find collection allows a more detailed picture of mining activities during the Sasanian period. The large quantity of finds is probably due not only to the thickness of the archaeological layers and the more favourable conditions for the preservation of the artefacts within these layers, but possibly also to the resource management of the Sasanian miners.

Like the Achaemenid layers, the Sasanian layers provide evidence for the importance of wood in mining. This raw material was essential to mining operations. It is

noteworthy that—unlike at other salt mines (Grabner et al., 2010; Boenke, 2020a, pp. 51–136)—there is no evidence for timber at Douzlākh, except for one Safavid prop. Most of the wooden finds are associated with work processes (Kosczinski, 2019; Boenke, 2015, pp. 67–72). Some artefacts can be clearly identified as tools, tool handles (Fig. 27, 5) or wedges (Fig. 27, 6). The handles in particular often show clear traces of production techniques and use (Kosczinski, 2019, Abb. 3; Kosczinski, 2020, p. 148, Abb. 3). They also provide an interesting insight into the miners' resource management. Some wedges show incisions and discolouration. It is thought that broken shaft heads were used as wedges, and discolouration would have occurred from contact between wood and metal during their original use as shafts. Their reuse as splitting wedges has also been considered (Kosczinski, 2019, pp. 36). Cords and ropes can also be more clearly distinguished from each other. In addition to their function in clothing, binding or gathering fabric and knotting textiles together in secondary use, they were also used to tie or fasten objects together, as seen, for example, on a wooden wedge with a string wound around it. These finds are therefore of particular interest for the reconstruction of working practices, since they are associated with repairs or tools made of different materials (Fig. 27, 6).

In contrast to the Achaemenid find-spectrum, pottery was rare in Sassanid times; textiles, however, were found in large quantities. As well as coarse rags, there were colourful fine fabrics. Some of these were sewn into garments such as trousers with multiple layers of fabric (Fig. 27, 8) (Grömer & Aali, 2020; Grömer et al., 2020); others had been used secondarily during the working processes. Remarkably, a well-preserved glove and a shoe were discovered at the site (Fig. 27, 7) (Grömer et al., 2020, pp. 172–174, Fig. 6). There are a number of other finds of animal-derived products, such as hooves, horn or bone. The occurrence of palaeofaeces of various species in the mine strongly indicates the presence of pack animals in the mine (Askari, 2022; Askari et al., 2018; Boenke et al., 2020). Furthermore, some animals may have been brought to the mine as a food reserve (see Logistics and Supply of the Mine section).

Islamic Period

As mentioned above, the Islamic period was subdivided into only two units; an earlier Islamic find complex from the Middle Islamic to Late Safavid/Early Qajarian periods, and a more recent find complex from the later Qajarian and the Pahlavi periods at the turn of the twentieth century AD, when remnants of explosives, matches, cigarettes, wires, paper and plastic found their way into the deposits inside the mine. While the earlier phase—aside from a larger quantity of pottery—displays the inventory known from Sasanian layers, the picture changes significantly in the modern period. Associated finds mainly derive from the northern profile, which shows a continuous stratigraphy from the Safavid to the Pahlavi period. Textiles are frequently represented in these layers. The textiles, like the cords and ropes from Islamic times, show considerable variation in quality and (in the case of fabrics) pattern. There are geometric designs as well as nature motifs (Fig. 27, 11). The pottery production is characterised by its careful execution. Although only seven fragments have been found, they are clearly different from previous pottery. Despite the small number of finds excavated (Fig. 26), several artefacts indicate mining activities. Among them are wooden shafts, various kinds of ropes and cords, and a spouted lamp with handles from a non-stratified context, which could be younger (probably Seljuq) (Fig. 27, 10). Although wooden tools were in use until recent times, their numbers are smaller, and the proportion of metal fragments, inorganic products and tools is greater. During the Islamic period there is the first evidence for torches at Douzlākh (Fig. 27, 9). In the twentieth century AD, fragments of print media, paper packages and plastic appear.

The total number of finds from both Islamic periods is small but for different reasons. While the earlier periods from Middle Islamic to Safavid times are rarely represented inside the excavated trenches, the layers from the later periods contain fewer artefacts due to the extraction method. Traditional manually driven underground work increases the possibility of waste accumulation in the deposits. Modern mining blasting operations, on the other hand, do not favour the accumulation of occupation layers, as the amount of waste is much smaller while the amount of salt and debris produced daily is much larger.

Logistics and Supply of the Mine

Archaeobotanical Data: Raw Material, Food and Fodder

Due to the excellent preservation of organic remains, the amount of plant material from different operation periods is extremely high. The majority of the finds are subfossil and preserved by salt, which prevents the decay of organic material due to its hygroscopic, noxious influence on bacteria and microorganisms. Only firewood and a few artefacts discovered in open fireplaces inside the mine are preserved. The study of botanical remains provides valuable data on the nutritional status of humans and animals, and on organic resources such as wood and fibres. The botanical record can also be used to investigate mining development, with a focus on the different actions and agents influencing the mining process, e.g.:

- Accumulation of human deposits versus natural cave-in.
- Waste material from working processes and diachronic differences.
- Dung layers of ancient stables in the mining context.
- Places for resting, open fireplaces and faecal concentrations inside the mine.

In this section, the focus will be on botanical residues reflecting the nutrition of miners and their animals, and on organic resources for mining equipment. Food residues are either present as human or animal palaeofaeces or as scattered residues of human food. The Douzlākh salt mine preserves a large variety of faecal material from domesticated to wild animals (Boenke et al., 2015, p. 119, tab 24; Boenke et al., 2020, p. 204, Fig. 1). The majority of evidence comes from small equid pellets, most likely from donkeys (cf. *Equus asinus asinus* L.) that were used for the transport of salt within the mine (Fig. 28). Scattered evidence (1 equid, 2 herbivore) is already known from Achaemenid layers, but it is unclear during which processes it came into the mine. In total, we have now recovered more than forty dropping samples from all periods. In addition, there is almost the same number of damaged and shapeless fragments of herbivore faeces, showing exactly the same consistency, content and parasitological record. During the Sassanid period, several dung heaps

Fig. 28 Palaeofaeces of a small equid, probably donkey [find number 3230-0]. Clearly visible is the content of chaff, cereal and grass stalks. Photo: N. Boenke

and evidence for the existence of a stable were discovered in the mine. The area of feature 13,016 shows a sequence of dung layers, preserved as a mixture of faeces pellets, chaff, straw and other vegetative plant remains used as litter. First analysis of the faeces showed that the animals were fed almost exclusively with residues from cereal cultivation. Most pellets contain large amounts of barley straw and chaff and the possibility of meadow grazing or hay fodder is evident in only a few cases (Askari et al., 2018; Boenke et al., 2020, p. 206, Fig. 4). In addition to information on the husbandry conditions of work animals, these layers provide additional data on human nutrition. Apparently, there were numerous cultivated fields in the vicinity of the mine during the Sassanid period, and donkeys were fed with waste from cereal production. The faeces contents from the Achaemenid period are more or less identical.

The cereal cultivation documented so far is probably based on barley, which clearly dominates the cereal straw; chaff retains evidence of both four-row hulled barley (*Hordeum vulgare* ssp. *vulgare* L.) and six-row hulled barley (*Hordeum vulgare* ssp. *hexastichon* (L.) Čelak). Barley is less demanding than wheat and more tolerant of the salinity caused by the naturally halite environment or by irrigation. Sowing as a winter crop, it is possible to grow barley on the high plains of the region with the help of the winter rain. Today, its cultivation is supported by irrigation in the valleys, which may also have been the case in ancient times. Wheat is only represented by a single sample that evidences Einkorn (*Triticum monoccum* L.), Emmer (*Triticum dicoccum* Schrank) and durum wheat (*Triticum durum* Desf.). So far, these species do not occur in the Douzlākh salt mine before the early Sassanid strata. Unfortunately, the excavated human faeces shed little light on nutritional habits, since the few faeces fragments, as far as they have been analysed, consist mainly of thoroughly cooked porridge. After meals are cooked and digested only tiny cereal particles are preserved in faeces, but both barley and wheat have been identified from theses (Boenke et al., 2020, p. 206, Fig. 3). Due to the taphonomy, further investigations are required to arrive at a satisfactory quantitative estimate. This also applies to the consumption of meat and its proportion in the human diet. The consumption of meat from ungulates, such as beef, sheep/goat and pork, is proven by tapeworms (*Taenia* sp. and *Echinoccocus* sp.). Nezamabadi and Le Bailly distinguished these genera from the parasitological record of human faeces (Nezamabadi et al., 2013a, b; Boenke et al., 2015, p. 121, p. 124). Further information about food was obtained from bones (see Faunal Remains Left by the Mining Communities of Douzlākh (Chehrābād) from Achaemenid to Pre-Modern Times), which were particularly spread across the floor of the mine; these were most likely leftovers, evidencing meat consumption. In contrast, the remains of a wide variety of fruits and nuts consumed underground are frequently present in all strata and periods. A peach (*Prunus persica* (L.) Batsch) stone was recorded in the Achaemenid layers and reflects the paucity of evidence for this period; for the Sassanid period there is much broader evidence, for example, for apricot (*Prunus armeniaca* L.), grape (*Vitis vinifera* L.), plum (*Prunus domestica* sensu lato), fig (*Ficus carica* L.), oleaster (*Elaeagnus angustifolia* L.) and walnut (*Juglans regia* L.). The Sasanian layers offer a greater variety of previously used crops, but the significance of this is difficult to interpret so far, as finds from the Sasanian layer are considerably more numerous (Fig. 26). In summary, it is clear that Douzlākh fits in with the broader long-term traditions of gardening and agriculture in this part of Western Asia (Boenke, 2020c).

The mine was certainly embedded in a well-developed supply system, especially from the early Sasanian period onwards. Local and regional supply is suggested by evidence such as the frequent use of cereal-production waste as litter and fodder, or the eaten-off panicles of grapes (Fig. 29) (indicating consumption of fresh rather than dried fruits) (Boenke, 2020c, pp. 213–214).

The establishment of a link between raw materials and consumption of products, such as textiles, is more difficult without provenance studies via isotope analysis. We

Fig. 29 Radiocarbon-dated grape panicle from a Sassanid context (436–633 cal AD, OxA-27338, 1508 +/− 29 BP) [find number 2806-0]. Photo: N. Boenke

know about ancient cotton trading (Alvarez-Mon, 2005), so the occurrence of cotton fabrics in the Douzlākh mine is generally plausible. However, based on the co-occurrence of raw cotton (*Gossypium* sp.)—discovered in the Douzlākh mine—and the possibility of irrigation in the area, local cultivation of cotton cannot be excluded at this stage (Boenke, 2020c, p. 215). Additionally, access to regional livestock products such as sheep wool or fur is very likely.

Another important element of the daily supply were the wooden tools used for mining, in particular wooden hafts. In contrast to ancient salt mines in Europe (Boenke, 2020a, pp. 55–68; Grabner et al., 2010), there is no evidence so far for use of large timber elements (such as pit props) in Douzlākh, in either the Achaemenid or Sassanid strata. What surviving wood is present shows a careful management of resources, with broken hafts being recycled into smaller artefacts such as wedges, or used as fuel (see 3.4.; Kosczinski, 2019). The production of wooden tools by the miners in order to have immediate access to repaired or new tools underground is evidenced by production waste in the mine's Sassanid strata (Boenke, 2020b, p. 200). Morphological analyses were conducted for a 10% sample of the stratified wood finds (cf. 3.4.). Analyses focused on the Achaemenid and Sasanian periods and included a range of worked wood (tools, tool elements and unidentified fragments). Although there are more Achaemenid wooden finds than Sassanid (n = 61 compared to n = 176: Figs. 26, 27), the species composition was similar across periods. The overall dominant taxon is poplar (*Populus* sp.), ranging from 60% for tools in general to around 80% for pickaxe hafts. All other represented species, such as ash (*Fraxinus* sp.) and oak (*Quercus* sp.) occur below 10%, with single instances of elm (*Ulmus* sp.), willow (*Salix* sp.), and various fruit trees (Prunoideae). There is no evidence of coniferous wood. Poplar and willow are typical trees of the meadow, and poplar trees are still present today in small plantations along the floodplain, but their sparse distribution (cf. 2.3.3) suggests that in antiquity most wood was imported.

However, seeds of some of the species mentioned above are also represented in the excavated layers. It can therefore be suggested that the ancient landscape, at least until the Sassanid period, was (in contrast to today) not characterised by erosion and provided a much more diverse habitat on the surrounding slopes (Boenke, 2020a, 2020b, 2020c, pp. 215–217). The wooden fragments in the find category 'shrub' or in firewood contexts belong predominantly to the tamarisk species (*Tamarix* sp.). These salt-tolerant plants may have grown in the immediate vicinity of the mine. From the younger periods, there is only evidence of poplar for tools and a single Safavid timber element, as well as some tamarisk in a firewood context.

Faunal Remains Left by the Mining Communities of Douzlākh (Chehrābād) from Achaemenid to Pre-Modern Times

The faunal remains from the Douzlākh salt mine constitute an exceptional collection that bears witnesses to various aspects of human and animal interaction in antiquity and the medieval periods of northwestern Iran. The taphonomic conditions in the mine have favoured the conservation of tissues that decay in ordinary edaphic conditions, providing an unusual insight into the wide range of animal exploitation and the wild species present in the human environment (e.g. Rossi et al., 2021, also: Nezamabadi et al., 2013a, 2013b, 2013c; Benda & Mashkour, 2021; Mashkour et al., 2020).

In this paper we focus on the overall analysis of the osteological remains. Noteworthy finds from each taxon have been presented in the figures. This paper aims to provide an overview of the results of previous research on the osteological remains in 2021, by reviewing the works of Nezamabadi et al., (2013a, 2013b, 2013c), Benda and Mashkour (2021), and Mashkour et al. (2020). This review will form the basis of an analysis of the overall findings; some of the most remarkable findings are presented in Fig. 30.

A total of 1088 animal bone remains from Douzlākh were studied between 2004 and 2017 (Table 1). In addition, four human bones have been analysed. The finds were discovered in two different areas; 350 bones were collected in the mine, and 736 were derived from the Küllük mining campsite; 8 stray finds were also studied.

The bulk of the assemblages at both sites consist of the remains of sheep and goat. Cattle are present on large scale at the mining camp Küllük, unfortunately from disturbed contexts (Fig. 30). Remains of hare were found rather exclusively in the settlement area, as were the remains of equid, even though their discovered faeces prove the frequent presence of equids also in the mine (Askari et al., 2018; Boenke et al., 2020).

It is noteworthy that pig/boar remains were exclusively found in the mine. The microvertebrate remains in the mine and in Küllük are both non-anthropogenic and anthropogenic. The vast majority of them were recovered in the mine. Among

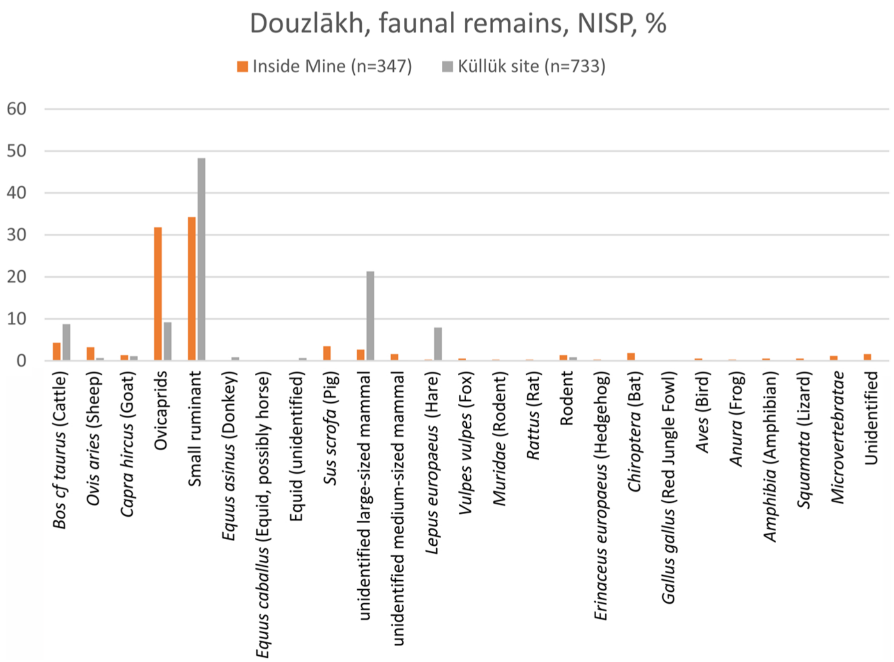


Fig. 30 Relative distribution of the faunal remains between the Douzlākh/Chehrābād mine and the Küllük settlement. Graphic: Th. Stöllner after data from M. Mashkour

Table 1 Distribution of the animal bone remains between the Douzlākh mine and the Küllük settlement (after M. Mashkour, H. Davoudi & H. Fathi)

Taxa	Underground mine	Küllük site	No information	Total
Bos cf *taurus* (Cattle)	16	64	1	81
Ovis aries (Sheep)	12	5		17
Capra hircus (Goat)	5	8		13
Ovicaprids	119	67		186
Small ruminant	128	354	6	488
Equus asinus (Donkey)		6		6
Equus caballus (Equid, possibly horse)		1		1
Equid (unidentified)		5	1	6
Sus scrofa (Pig)	13			13
unidentified large-sized mammal	10	156		166
unidentified medium-sized mammal	6	1		7
Lepus europaeus (Hare)	1	58		59
Vulpes vulpes (Fox)	2			2
Muridae (Rodent)	1			1
Rattus (Rat)	1			1
Rodent	5	6		11
Erinaceus europaeus (Hedgehog)	1			1
Chiroptera (Bat)	7			7
Gallus gallus (Red Jungle Fowl)		1		1
Aves (Bird)	2	1		3
Anura (Frog)	1			1
Amphibia (Amphibian)	2			2
Squamata (Lizard)	2			2
Microvertebratae	7			7
Bos cf *taurus* (Cattle)	6			6
Total	347	733	8	1088

those are the remains of amphibian reptiles and bats that have adapted to cave environments (Mashkour et al., 2020). Rodents from the Muridae family were also identified among the remains, and the most remarkable find is a rat tooth.

The chronological distribution of the remains shows that half of them cannot be allocated to a specific period (Table 2). The bulk of the remains come from the Sasanian and Achaemenid levels. Some 12 remains were found at the Seljuq and Safavid levels and 35 are pre-modern and belong to the twentieth century.

The bulk of the assemblages at both sites consist of sheep and goat remains. Cattle are present on a large scale at the Küllük mining camp, unfortunately from disturbed contexts (Fig. 30). Remains of hare were found almost exclusively in the settlement area, as were equid remains, even though their faeces demonstrate the frequent presence of equids in the mine (Askari et al., 2018; Boenke et al., 2020).

Table 2 Chronological distribution of the faunal remains in the Douzlākh mine and the Küllük settlement

Taxa/NISP	Achaemenid	Sasanian	Islamic	Pahlavi	Unclear	Total
Bos cf *taurus* (Cattle)	7	3	0	5	66	81
Ovicaprids	58	123	11	12	500	704
Sus scrofa (Pig)	2	3	0	1	7	13
Equids	0	1	0	0	12	13
Vulpes vulpes (Fox)	1	1	0	0		2
Lepus europaeus (Hare)	0	0	1	0	58	59
Aves (Bird)	1	1	0	0	2	4
unidentified medium-sized mammal	0	4	0	0	3	7
unidentified large-sized mammal	3	5	0	17	141	166
Total	72	141	12	35	789	1049

It is noteworthy that pig/boar remains were exclusively found in the mine. The microvertebrate remains in the mine and in Küllük are both non-anthropogenic and anthropogenic. The vast majority of them were recovered in the mine. Among these are the remains of amphibian reptiles and bats that have adapted to cave environments (Mashkour et al., 2020). Rodents from the Muridae family were also identified, and the most remarkable find is a rat tooth (Figs. 31, 32).

The chronological distribution of the remains shows that half of them cannot be allocated to a specific period (Table 2). The bulk of the remains come from the Sasanian and Achaemenid levels. Some 12 faunal elements were found at the Seljuq and Safavid levels with another 35 being pre-modern and modern.

In summary, the faunal remains from the mine and the nearby Küllük camp are very similar and most likely related.

Further investigation is required to establish whether animals (mainly sheep and goats) were bred at the mining camp and kept there permanently or part-time, for food and the production of clothing and other commodities from by-products such as skin and wool.

Salt Mummies and Their Identification: Bioarchaeological Access to the Origin and Life of the Ancient Salt Miners (Interpretation of the New Data)

The salt mummies from the Douzlākh mine are certainly among the most exciting recent discoveries in the archaeology of mining. Several mining accidents are visible from the bodies, which reveal numerous details of these accidents and the life history of the individuals (Aali, 2005; Pollard et al., 2008; Aali et al., 2012a, 2012b; Aali & Stöllner, 2015; Aali & Stöllner, 2020). The mummies are special for several reasons. Unlike other famous human mummy finds, we are dealing not with a lone individual, but with several comparable people from different working teams. They afford a unique opportunity to study the effects of such preservation conditions on human soft tissue.

The first remains, discovered in 1993, were initially interpreted as belonging to a Parthian/Sassanid horseman. Sobuti (1997) believed Saltman 1 (now Saltman 1 and

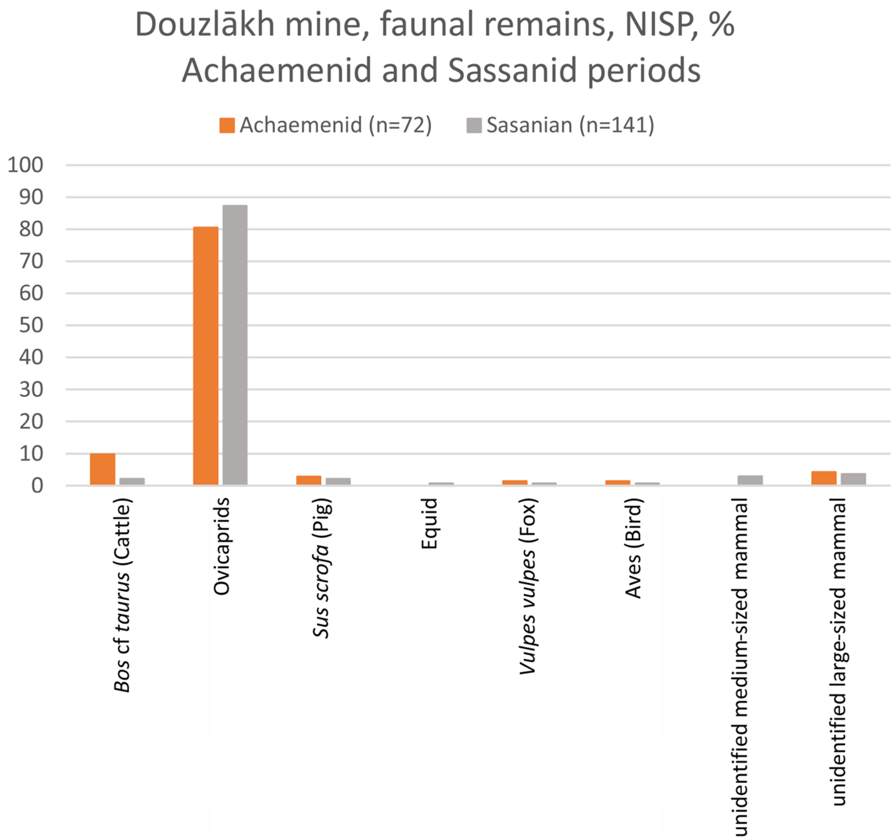


Fig. 31 Relative distribution of the faunal remains between the Achaemenid and Sasanian occupations, Graphic: Th. Stöllner after data from M. Mashkour

7) to be a grandee or an official of Scythian origin from the eighth century BC. It is not clear at present whether the finds, namely the famous head with (now) white hair (Saltman 1), and the boot and remains of a rib cage (known as Saltman 7), which were later delivered to the National Museum of Tehran, actually belong to a single person (Aali, 2022; Vahdati Nasab et al., 2019; Öhrström et al., 2021) (Fig. 33).

An initial standard (ancient) DNA investigation was probably contaminated (see also Aali et al., 2012a). The mummy parts were discovered with a pair of shorts (Grömer et al., 2020) (Fig. 34), a knife in a leather sheath, and small silver toilet spoon-cum-spatula. The trousers showed urine and excreta residue on the inside, which may indicate that they were worn by a person who died in an accident.

According to the findings so far, Saltman 1 is believed to have been an older adult male (about 30–40 years) when he died. Numerous fractures were discovered on the ethmoid bone as well as on the right upper and lower jaws, resulting from lesions that could have been caused by a fall or a strong impact (e.g. from a falling stone) (Öhrström et al., 2021). Based on isotope data (nitrogen δ^{15}N; carbon δ^{13}C), a

Fig. 32 Zooarchaeological material from Douzlākh, Küllük settlement: **1** *Capra hircus*, distal metatarsal end (Feature 70313, FN 20209); **2** *Capra hircus*, phalanx 1 (Feature 70330, FN 20321); **3** *Gallus gallus*, humerus (Feature 70,002, FN 20353); **4** *Bos taurus*, mandible (Feature 70302, FN 20225); **5** *Bos taurus*, calcaneus talus naviculo-cuboide (Feature 70341, FN 20362); **6** *Equus asinus*, humerus (Feature 70340, FN 20731). Photos: H. Fathi, H. Davoudi

regional origin can be assumed (Ramaroli et al., 2010) (Fig. 35). Only a few remains of Saltman 7 are preserved (Vahdati Nasab et al., 2019), who was most likely also a male but of a younger age, in his early to mid twenties.

Saltman 2 was found in 2004 during commercial salt mining. His ^{14}C data points to a date in the fifth or sixth century AD. The partially skeletonised mummy still has

Fig. 33 Head of Saltman 1 from 1993, now in the National Museum, Teheran. Photo: G. Najaflu

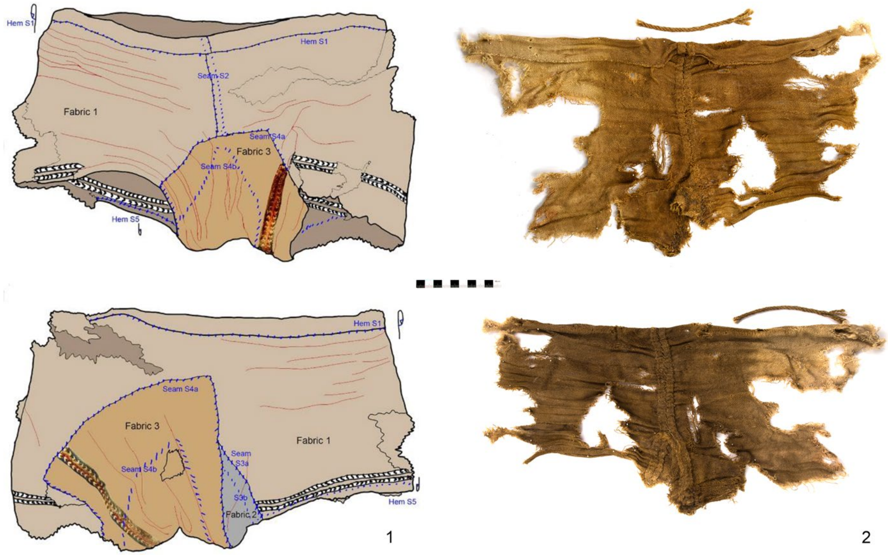


Fig. 34 Boxer-short style trousers, found with parts of the mummified Saltman 1 and Saltman 2. Graphic: K. Grömer. Photo: F. Schapals

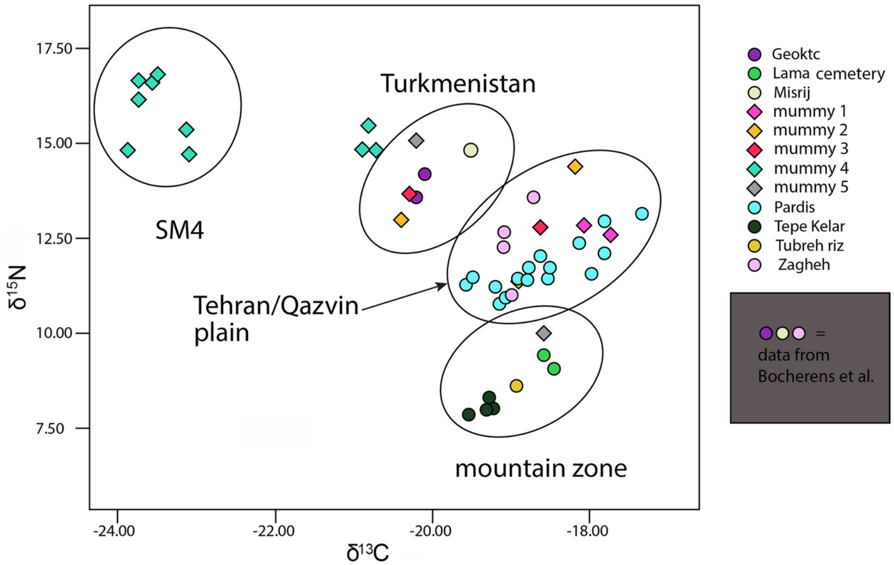


Fig. 35 Nitrogen (δ^{15}N) and carbon (δ^{13}C) isotopes of mummy parts from Douzlākh (Chehrābād), in many cases showing non-local isotope ratios. Graphic: T. Baldus after Ramaroli et al. (2010)

soft tissue, a beard and head hair. A detailed study of the well-preserved osteological remains is still pending, so that various recognisable fractures cannot be evaluated further at present. Like Saltman 1 and 7, the adult Saltman 2 had dark brown hair and a beard, and was still wearing parts of clothing, probably boxer shorts but also possibly leg wraps, of which only fragments were preserved (Krug-Ochmann, 2015, pp. 75–77; Grömer et al., 2020); the latter showed traces of blood. It is possible that well-preserved fragments of a Sassanid tunic discovered near the site came from the clothing of Saltman 2 (or Saltman 6) (Grömer & Aali, 2020). In addition, various fragments of knitwear, a small basket with a diameter of c. 15 cm, a relatively heavy wedge hoe, and 14 small wooden nails were found with the mummies. The aDNA results extracted from a rib have so far mainly provided some evidence of pathogens that are well known in Iranian but also European populations, such as lactase persistence (Warinner & Bouwman, 2015). His dietary habits and living environment may have changed a few months before his death, as indicated by the changing isotope values of his well-preserved hair (Pollard et al., 2008, pp.144–145, Fig. 10; Ramaroli et al., 2010).

Scattered human remains, especially a skull, are grouped together as Saltman 6. The remains were not found in situ, but displaced by later-Sasanian debris. The findings in this part of the mine, however, indicate that his death must have occurred shortly before the debris was cleared as backfill (see above) so that he may well have been part of a Sasanian mining gang (Aali et al., 2012a; Aali & Stöllner, 2015, 2020). Saltman 6 was a young adult male whose dental status showed only minor wear. Radiological examinations, reveal numerous skull fractures, but it is not clear whether these are due to positioning or to external forces. Genetic examinations, however, revealed a mitochondrial DNA haplogroup untypical for present-day Iran. This could—with all due caution—indicate foreign origin, for instance from the northern regions of Eurasia (Warinner & Bouwman, 2015, p. 96).

In 2004, Saltmen 3 and 8 were recovered in the area of the later excavation in trench A (Aali, 2020; Vahdati Nasab et al., 2019). The osteological remains have only recently been examined and show that only 40% of the body had been recovered, mainly parts of the skull and jaw, as well as parts of the postcranial skeleton from the hip downwards to the feet (Vahdati Nasab et al., 2019, Fig. 8). Finally, the find collection of the Zanjān Saltmen and Archaeological Museum contains another left mandible that cannot belong to Saltman 3 and is now called Saltman 8. His dating is late-Sasanian and, therefore, certainly does not belong to the same findspot as Saltman 3, who derives from the Achaemenid period (see above); the maxilla was probably intermingled later by chance. Saltman 3 was a young adult between 18 and 22 years of age. Isotopic examinations of the skin of Mummy 3 have yielded noteworthy data. The light stable dietary nitrogen δ^{15}N and carbon δ^{13}C isotope values indicate a non-local origin (e.g. Central Asia or Turkmenistan: Fig. 35). Saltman 3 was found with further remains of tools and clothing, including a steel hammer for crushing salt blocks (Fig. 23, 1), and leather shoes (Ruß-Popa, 2020). Textile fragments of trousers and a tunic, as well as the remains of a colourful textile belt, show that the clothing of Saltman 3 was somewhat similar to that of Saltman 4 (Grömer et al., 2020).

Saltman 5 was found during the second excavation season in 2005. The miner was apparently killed by falling stones on a ledge at the eastern edge of the pit (Fig. 36). Saltman 5 was equipped with a leather sack filled with 'small salt' and a large block of salt, which had obviously just been mined or was about to be carried out (Aali, 2005, 2022, pp. 105–107; Aali & Stöllner, 2020). The context suggests that the miner died in a collapse of the gallery around 400 BC. Two ^{14}C analyses confirmed the dating (Aali et al., 2012a, pp. 76–77). Gas chromatography revealed a greasy oily substance on his hand and skin, indicating that Saltman 5 had applied some

Fig. 36 Saltman 5 in situ during the 2005 excavation. Photo: ZCHTO, A. Aali

kind of protective hand cream (Pollard et al., 2008, p. 148). Based on the clothing remains, it is likely that Saltman 5 also wore trousers and a tunic with a braided belt in *kumihimo* technique (Grömer et al., 2020), like Saltmen 3 and 4. The age of the bone suggests a fully-grown adult to mature male of about 40 years. Genetic analyses confirm the male sex. Tapeworm (*Taenia*) was detected as an intestinal parasite in the palaeofaeces samples collected from the abdominal and hip areas of Saltman 5 (Nezamabadi et al., 2013a, 2013b). Two specimens of stable nitrogen δ^{15}N and carbon δ^{13}C isotopes provided evidence of two different 'nutrient landscapes'. While the data from the hair (which suggests the recent past of the deceased) fits into the regional spectrum of the Tehran/Qazvin Plain, the skin measurement tends to point to a Central Asian signature. This inference is strengthened by the identification of another intestinal parasite, this time probably of animal rather human origin, in an Achaemenid soil sample from the vicinity of the Saltman 5 findspot: *Oxyuris equi*, also known from Iron Age equids in Central Asia (Nezamabadi & LeBailly 2015, pp. 120–124).

Saltman 4 became an icon of the excavations in Chehrābād and is certainly one of the best researched mummy finds at the salt mountain. This is due first to his excellent preservation (Fig. 37). The mummy was found lying on its stomach, supported by its hands, in a layer of debris from the accident of 400 BC (Aali, 2005, 2022, pp. 55–57; Vatandoust & Hadian Dehkordi, 2005; Aali et al., 2012a; Öhrström et al., 2016; Aali & Stöllner, 2020). The mummy is fully dressed in woollen trousers, a tunic, leather shoes and a cape made of fur (Grömer, 2020; Ruß-Popa, 2020). It is a juvenile of about 15 years, as revealed by the bone age and dental status. Saltman 4 is about 170–175 cm tall, with reddish-brown, short-cropped hair and no beard. Silver earrings were found on his right and left ears; two clay pots with paste-like content, and a knife, were found on his body (Fig. 38).

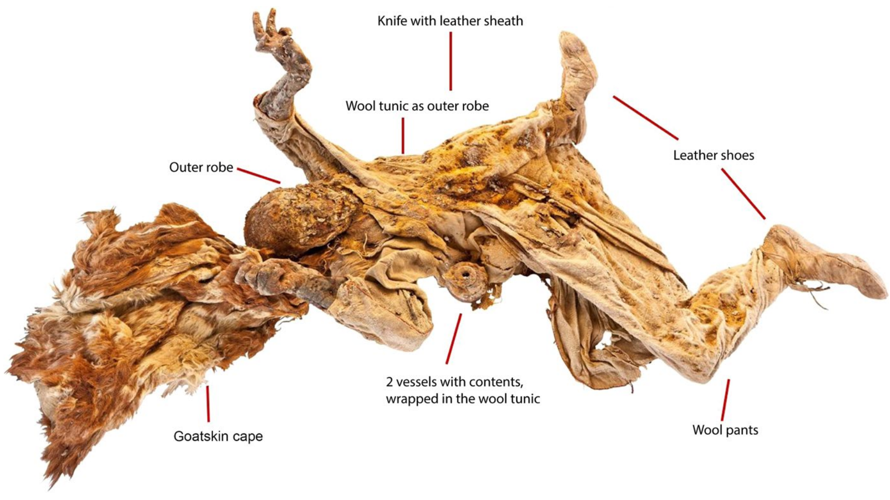


Fig. 37 Saltman 4 and his most important equipment. Photo: K. Stange, AVTention Marienheide; Graphic: Th. Stöllner

Fig. 38 Equipment of Saltman 4. Top: iron knife in leather sheath; bottom right: one of the two small vessels for liquid or paste; bottom left, precious metal left earring. Photo: Th. Stöllner

Computed tomography (CT) scans showed signs of a massive trauma, with a compressed thorax and multiple fractures, including rib fractures (Öhrström et al., 2016) (Fig. 39). These injuries were lethal. The force of the impact most likely burst the internal organs and death must have occurred very quickly. The facial skull was also crushed.

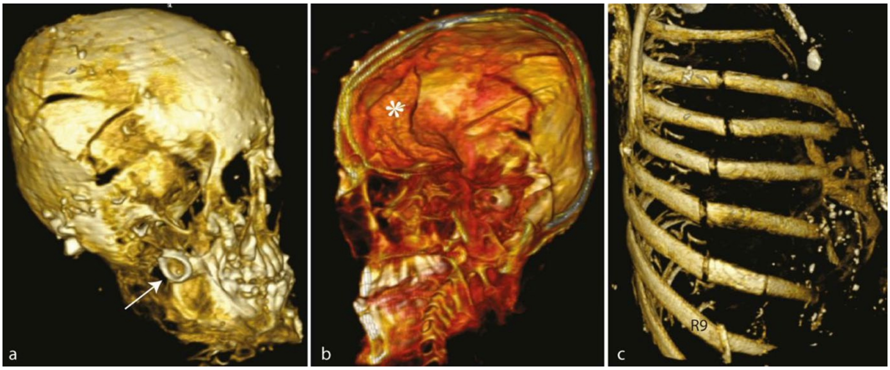


Fig. 39 Radiological investigation of skull and thorax of Saltman 4 show heavy traumata and bone fractures. Radiology/figure: L. Öhrström/F. Rühli

The nitrogen $\delta^{15}N$ and carbon $\delta^{13}C$ isotope findings (Fig. 35) are particularly significant. The results suggest that Saltman 4 is a stranger to the area, displaying a relatively recent non-local diet (Ramaroli et al., 2010, pp. 350–351). Saltman 4 apparently arrived at the Douzlākh as a juvenile male. His short-cropped hair, well-preserved fingernails, the pristine appearance of his work clothes, and above all his hardly worn shoes (in comparison to Mummy 3) suggest the possibility that he arrived in Douzlākh shortly before the catastrophe that ended his life, perhaps as an apprentice. Whether he was sent to work as a *rabbap* (a labourer under corveé obligation within the Persian Empire) or as a *puhu* (a servant or slave) (see Klíma, 1977; Dandamayev, 1988) at the Douzlākh is unclear. Achaemenid labourers were by no means without rights; *bandaka* (bondsmen) had to perform specific services in the Achaemenid and Sassanid empires, but these services were strictly delimited (also Dandamayev, 1988). That is, as *bandaka*, all men had to perform an imposed service as royal subjects. This is of particular interest for the organisation of work at the Douzlākh. It is conceivable that Saltmen 3, 4 and 5 were sent (or imported) from Central Asia to work at the salt mountain. At least two of the Sassanid miners may also have come from further afield. This raises questions concerning how the mining enterprise was embedded in the regional environment and what logistical conditions were initially present.

Talkherud: A Changing Salt-Mining Landscape

In addition to the results on the origin of the worker groups, on-site data on subsistence structure, meat supply and agricultural products consumed indicate a variety of interconnections between the rural hinterland and the salt mine. This is less clear during the Achaemenid period, during which supplies did not necessarily come from the surrounding area (stable isotope data are still pending here). Conversely, the embedding of Sassanid and more recent mining in a rural environment characterised by horticulture and irrigation farming is even clearer (Boenke et al., 2020; Mashkour et al., 2020; see also above). These findings also lead to the question of how mining contributed to the integration of the wider salt landscape (Stöllner & Aali, 2020). Thus, it is striking that settlements in the older mining periods tend to be found at some distance from Douzlākh (Fig. 1). The older ancient settlements are located in the valleys of the Mehrābād, Rezābād and Chehrābād rivers, rather than at the headwaters of the rivers, while they seem to advance into the area surrounding Douzlākh at the latest in the Middle Islamic period. This could be related to an intensification of irrigation farming with fresh water from the upper valley heads, as the surface and near-surface groundwater around the salt mountain is saline and undrinkable. Since then, as geoarchaeological investigations prove, the now incipient agriculture has contributed to a progressive backfilling of the valleys (see Geology of the Deposit and the Filling of the Valleys Around the Douzlākh section).

Answering these questions requires a continuation of the well-focused research which began in 2005 with the survey and identification of ancient sites around the mine, and which has continued with the addition in 2010 and 2011 of field-walks and further systematic approaches (Aali & Stöllner, 2015, pp. 19–26). As a result, a site-list of 18 sites, from prehistory to the Islamic period, was achieved (see Supplementary Information, List 1). In 2021, adding to the eight previous seasons of excavations at Chehrābād (Douzlākh) salt mine from 2004 onwards (Aali, 2022), a study of the ancient sites south of the salt mine was initiated. Five important ancient sites in this area were surveyed systematically (in A Supply Post for Douzlākh? Excavation and Magnetics at Tappeh Kūzehchi and Other Rural Settlements and Their Chronology: Surveys and Sherd-Scatter sections), in addition to small scale excavations at one of the sites (in A Supply Post for Douzlākh? Excavation and Magnetics at Tappeh Kūzehchi section). The sites were selected for their possible chronological connections to the operation periods of Douzlākh salt mine, in order to understand the rural connections of the salt-mining operations (Zifar, 2021).

A Supply Post for Douzlākh? Excavation and Magnetics at Tappeh Kūzehchi

Location and Surveys 2020–2022

One of the 18 recorded sites, known as Tappeh Kūzehchi, was selected and proposed for the first step in further studies and small-scale excavations (36° 52′ 58.77″ longitude and 47° 48′ 07.54″ latitude (zone S38, Northing: 4085559, Easting: 749729. Highest point: 1452 m above sea level; Zanjān Roud district, Ghani Beyglou rural district l, Zanjān Province) (Fig. 40).

On the basis of a number of diagnostic potsherds found during the 2016 survey, Kūzehchi has been dated to the Iron Age III–Achaemenid periods, and it is suggested that excavations at the site have the potential to contribute significantly to our understanding of the archaeology of Achaemenid/Iron Age III periods in Zanjān province and the Douzlākh salt mine area in particular. Although several artefacts from Douzlākh have absolute dates for the Achaemenid period, the number of finds from the Achaemenid period is smaller than from the Sasanian period, which increases the need for a study at Tappeh Kūzehchi. Here we present the results of excavations at Tappeh Kūzehchi in September and October of 2020, and the results of geophysical surveys in 2021, which offer the first indication of a possible connection between the site and the neighbouring salt mine. The mound is comparatively

Fig. 40 General view of Tappeh Kūzehchi from northeast; aerial photo: I. Mostafapour/H. Zifar

small, with an almost flat top, covering less than 1 ha and standing c. 12 m above the height of the surrounding ground, with a gradual slope from south to north. The mound consists of a natural rocky basement and is covered by archaeological strata of different thicknesses. The site, however, is surrounded on three sides to the north, west and south by the apple orchards of the nearby village (Fig. 40).

The Biyouk Chay river flows south to north and is the main and closest source of water, running about 200 m east of the site in a shallow valley. Biyouk Chay passes through an intermountain valley, passing close to Qezelje village and finally reaching the river Chehrābād, which is one of the tributaries of the Qezel Ouzan river. The salt mine at Douzlākh is about 5 km away and can be seen from the top of the site.

Altogether five grids of 0.1 ha were measured during the magnetic survey (for methodology see Other Rural Settlements and Their Chronology: Surveys and Sherd-Scatter section). The greyscale picture shows some noteworthy anomalies that could be interpreted as archaeological structures, including two fortified edges and two settlement pits (Fig. 41). Two black anomalies show high temperatures (> 47nT), which is usually an indication of burned material such as charcoal or mud brick fragments. Two dipoles (black-white anomalies) may show potential pyrotechnical installations. In the southwest, there is an S-shaped dipole structure, again with high temperature values (> 100nT), which may indicate a roasting bed or a similar installation that might be associated with high temperature activities, such as (s)

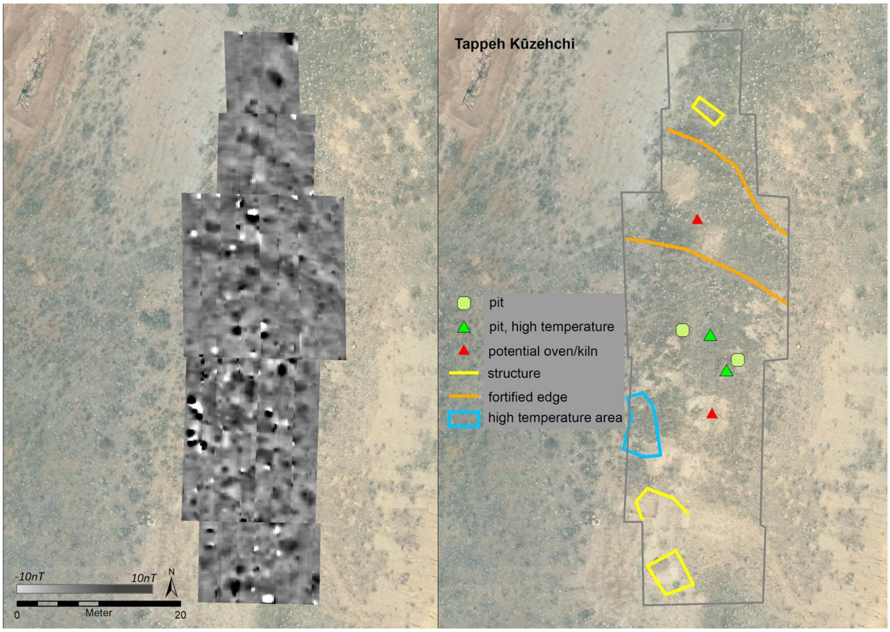


Fig. 41 Tappeh Kūzehchi. (Left) greyscale picture of magnetometer measurements; (Right) interpretation. Photo/Graphic: B. Sikorski/H. Zifar

melting. The linear, rectangular and square structures may in most cases be interpreted as house and wall remains, depending on settlement structures (Fig. 41).

Excavations in 2020

Based on a number of diagnostic sherds, which were found during a survey carried out in 2016, Kūzehchi was dated preliminarily to the Achaemenid period. Excavations were predominantly focused on providing an absolute chronology of the site itself. Initially, two trenches were opened in the highest part of the mound. However, since the archaeological layers here were not very deep, a third and fourth trench were opened in the southern and northern part of the mound respectively. Excavations revealed two major occupation phases. The earlier phase had been dug into the natural cobble-boulder layer of the mound and was characterised by pyrotechnical installations and ash layers. The later phase consists of stone architecture and some notable small finds. An exception is trench 4, which only revealed one occupational phase of stone architecture.

The early phase in trench 1 revealed a round pyrotechnical installation with a rectangular mud brick column at its center and a small channel dug into its round outer part; the entire structure was filled with ash but no evidence of (metal) production was discovered inside the installation. However, a very few fragments of fused material were found in the layers above. This is noteworthy since a pit grave (male individual) had been cut into the floor of the pyrotechnical installation that was filled with three different layers. It therefore seems possible that the fused material was removed from its original location during the embedding of the grave into the earlier layers and that the fragments were excavated in a secondary context. Only one fragment is magnetic and may relate to metal activities; future analysis is required to provide more details of a connection between the installation and the fused material. The burial and its associated layers, however, are suggested to mark an intermediate phase, but this was not confirmed within the remaining trenches (Fig. 42). Noteworthy is a west–east running plastered stone wall that was connected to the bottom of the pyrotechnical installation.

The early phase in trench 2 revealed several pits of unknown function, ash layers, a fireplace and a large pyrotechnical installation (Fig. 43, 1–2).

One of the pits was filled with boulders, cobbles and several ground stones; the installation showed ten small circular holes and one large oval hole, all of which were filled with ash. Several slag fragments were discovered in the filling of the installation. The fragments vary considerably in size but are all magnetic. This may be a result of metallic iron inclusions—now visible as orange (iron) rust on the surface—or magnetite, which forms during (strongly) reduced conditions. Macroscopic observations further revealed that many fragments have convex outer surfaces in cross-section and, therefore, could derive from small and relatively thin slag cakes. A few fragments show a slightly concave indent on their ‘top’, covered with rust. The latter may have derived from the residual imprint of the iron-rich material that has formed above. Further inclusions are small pebbles and charcoal. Only one fragment was preliminarily identified as technical ceramic. The characteristics described may indicate their origin as broken-up smithing slag. Whether the above-described

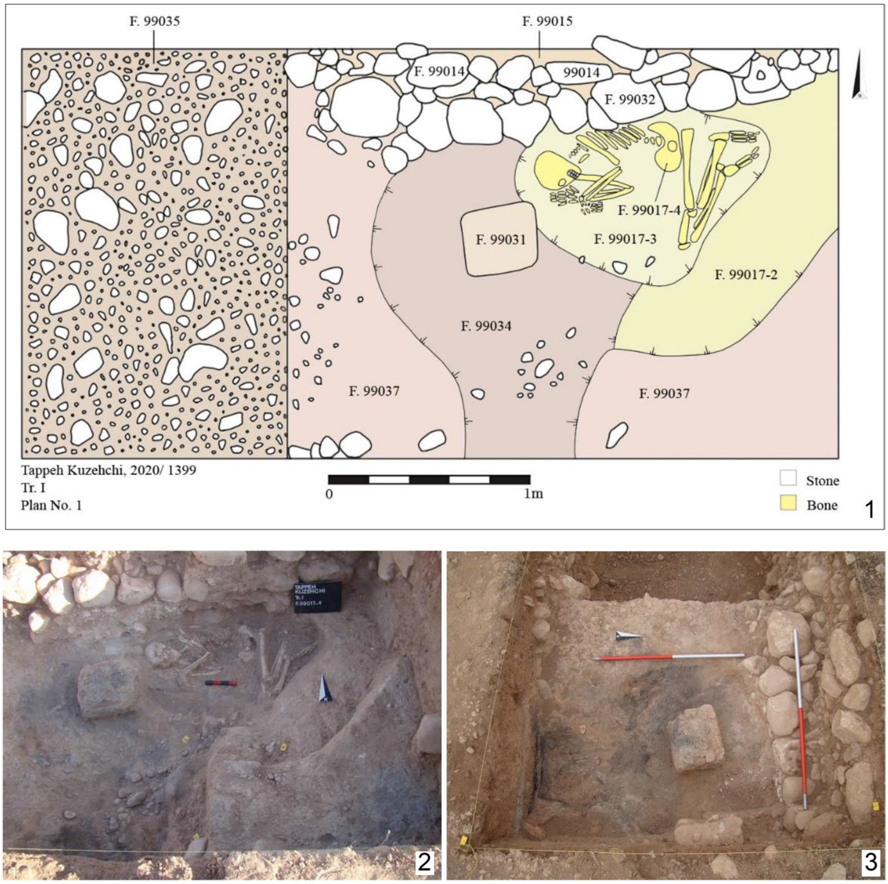


Fig. 42 Tappeh Kūzehchi. **1** plan and **2**, **3** photos of stratigraphic sequence of thermal structure and burial in Trench I. Photo/Graphic: Iman Mostafapour

associated installation can be related to smithing activities requires further examination. Alternatively, the slags may have been deposited in a secondary context and a smithy may have existed in unexcavated areas nearby. Some fragments showed elevated copper and, in a few cases, also elevated arsenic levels during (pXRF) surface analysis. This may indicate that contemporaneous copper processing took place at Kūzehchi, and the slag was therefore contaminated with those elements (see also below, trench 3).

The early phase in trench 3 evidenced a pit filled with boulders, two ash layers, one of which extended across the entire trench, an in situ jar, which was embedded in the natural cobblestone layer, and two fireplaces (Fig. 43, 3–4). Noteworthy are several slag fragments that were discovered within the latter pyrotechnical installations. Like the slag found in trench 2, several of the fragments have a convex outer surface in cross-section, which hints at an origin as small slag cakes. Further, most of the finds are magnetic and show rusty areas that link the slag to iron forging.

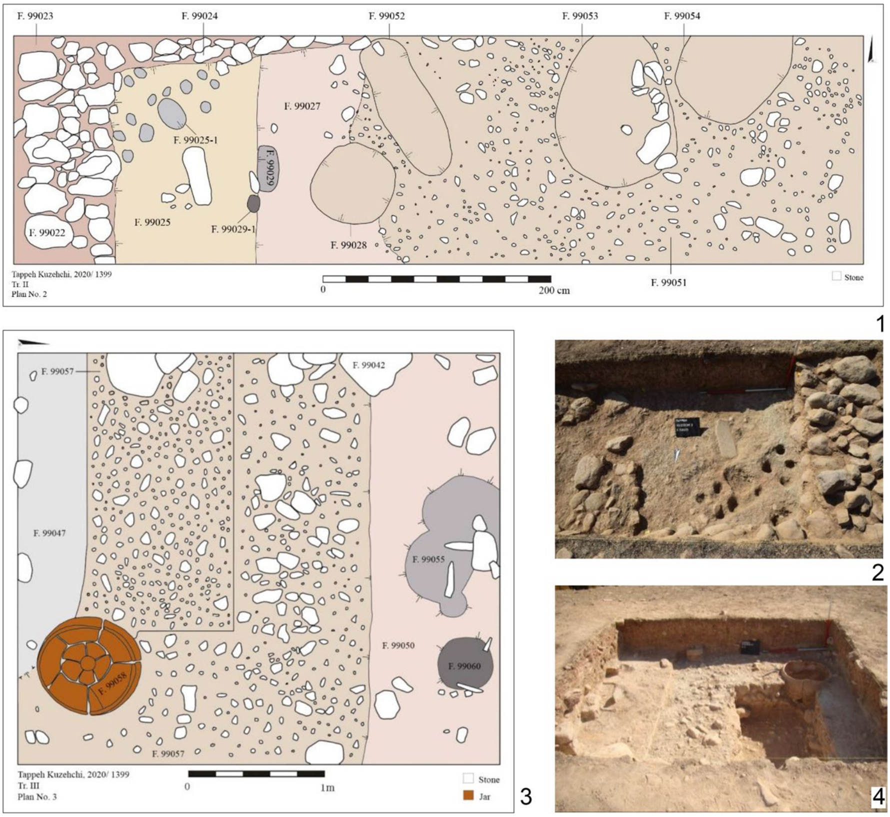


Fig. 43 Tappeh Kūzehchi. **1**, **2** stratigraphic sequence of thermal structure, stone walls and pits in Trench II; **3** stratigraphic sequence of thermal structures and in situ jar in Trench III; and **4** the end of excavation in Trench III. Photo/Graphic: Iman Mostafapour

However, two fragments can be linked to copper-based metal working, one of which is a technical ceramic. The latter supports the idea that copper-based materials were worked at the site in addition to iron.

The later phase of the site is characterised by stone architecture and various small finds. In trench 1, two stone walls made of cobbles and boulders and fixed with clay mortar seem to have been connected to each other and may have originally formed an enclosed space (Fig. 42). Similarly, in trenches 2 and 3, two stone walls—made from the same materials and built perpendicular to each other—were excavated in each trench (Fig. 43). Additionally, a mud brick platform was found close to the intersection of the two walls in trench 3. A noteworthy find within the later phase of trench 3 was a large jar, which was broken and appears not to have been discovered in situ; a second jar, found in situ, derived from the trench's earlier phase.

The material culture of (the excavated part of) the site consists of potsherds, animal bones, pivots, ground stones, pounding stones, slag (see above), whorls, a single bead and some clinkers. Some of the artefacts discovered indicate activity in craft workshops. Tappeh Kūzehchi diagnostic ceramics (225 pieces) are divided into four general groups of brown (59.5%, of which 80% are light brown), buff (33.5%), grey (6.6%) and red (0.4%) wares. Regarding manufacturing technology, there is not much variation among the sherds. The ceramic assemblage from Kūzehchi shares common manufacturing characteristics, namely technique, temper and firing temperature. All the pottery is wheel-made and has received sufficient firing. Only 26% of the sherds have a smooth polish in comparisons to 35.5% with a wet-hand polish; 36.5% have a slip and only 19% have a wash. Most of the pottery (96.4%) is tempered with fine sand, while a small amount (3.6%) is additionally tempered with a combination of mineral and organic materials. The majority of diagnostic ceramics (89%) are plain. Only 21% of sherds are decorated; of these, 64.5% are painted (all the decorations are in brown and reddish brown). The other decorations involve appliquéd (29%) and incised (6.5%) designs. Potsherds, according to preliminary comparisons, belong to the Achaemenid period. It is interesting to note that the pottery discovered at Tappeh Kūzehchi bears strong similarities to the pottery from the Achaemenid layers from Douzlākh (fabric wares are currently under study by K. Franke and A. Aali).

Absolute Dating and Conclusions

With the aim of establishing an absolute chronology for Kūzehchi, several ^{14}C samples were taken for analysis, the results of which are shown in Fig. 44 (supplementary list 1). Except for two samples that failed due to insufficient collagen content, all analysed samples date to the Achaemenid era; samples derive from all three different phases evident at Tappeh Kūzehchi. Here, the early phase was identified only within trenches 1, 2 and 3, while the late phase was evident in all four trenches. An intermediate phase was solely evident in trench 1.

Prior to recent investigations, archaeological knowledge about the Achaemenid period in the Talkherud area was mainly limited to the salt mine itself. Despite the

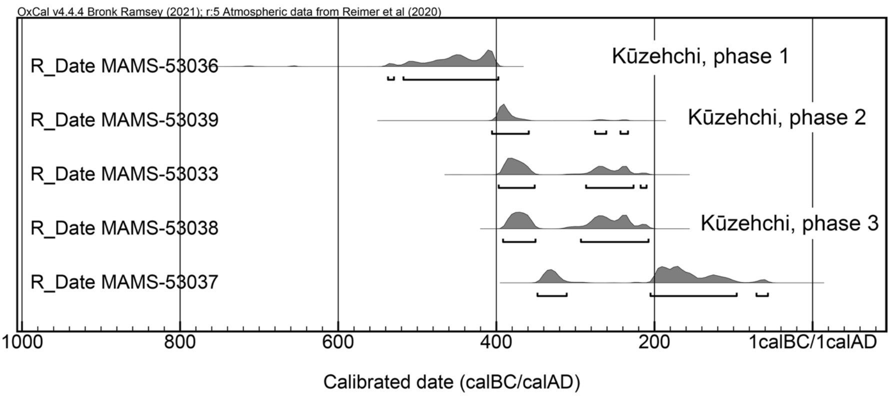


Fig. 44 Tappeh Kūzehchi, AMS ^{14}C dates according to the stratigraphic sequence. Photo/Graphic, after OxCal, Version 4.3

relative thinness of cultural deposits (about 1 m) Tappeh Kūzehchi contains important information about the Achaemenid period. The pyrotechnical installations, the slag, and the ground and pounding stones discovered at earlier levels indicate that Tappeh Kūzehchi may have functioned as a workshop during the early phase at the site. This phase is contemporary with Achaemenid mining activities at the Douzlākh salt mine. What is dubiously called an intermediate phase is a simple burial with no grave goods. The late phase probably represents the remains of a poor occupation horizon, with stone architecture that shares common features, such as stone arrangements, size and type of stones, orientation of the walls, and the formation of rectangular spaces. No plasters were recognised during the excavations, with the exception of a single plastered wall that had been attached to the pyrotechnical installation in trench 1. Further, no traces of roofs or ceilings, or their collapsed remnants, were found during the excavations. The middle, and especially the late phases, are clearly younger than the mining activities at Douzlākh. They evidence the transformation of the site from a workshop to a (rural) settlement after the collapse of the Achaemenid salt mine.

On the basis of all the evidence obtained, it can be cautiously assumed that Tappeh Kūzehchi is a supply post for the Chehrābād Salt Mine during the early phase; this may include basic provisions, but more importantly the supply of metal artefacts. Metallurgical waste material hints at implement or tool production at the site, and no evidence of primary smelting was found. However, further excavations and archaeometric analysis will have to confirm these hypotheses.

Other Rural Settlements and Their Chronology: Surveys and Sherd-Scatter

Methodology of Intensive Site Survey 2021

Five sites were selected for further intensive field survey, with the intention of establishing a chronological connection between the mine and the rural settlement, and secondly, gaining an understanding of architectural remains and economic activities. One of the sites which is not contemporaneous to the salt mining (Tappeh Haj Hattam) will be presented elsewhere (PhD study of H. Zifar). It was decided to carry out magnetometer surveys and random surface collection of diagnostic sherds to attain a more systematic insight into the above-mentioned research questions. During the 2021 survey, a grid system was set up for every ancient site, and each surface find was registered using a total station.

For the magnetometer measurements, one fluxgate gradiometer with a 5-channel system (Sensys) was used. The measurements were performed within a measuring quadrant (grid) of max. 20×20 m. The probe registers the vertical component of the magnetic field with an accuracy of 1 nT (nanotesla), a line spacing of 0.5 and a sampling (measuring point distance) of 10 per metre. For visualisation, each measurement point was converted into a pixel. The resulting magnetogram, or greyscale picture, provides the basis for the archaeological interpretation. Finally, the obtained data was entered into the GIS system ArcGIS (Esri) and linked with other information from the survey: the sherd-scatter mapping, the aerial photographs and satellite pictures, all of which was then processed into different maps. The results from the older, second millennium BC sites at Tappeh Haj Hattam (including a possibly related graveyard) are not reported in this article but will be part of the PhD study of H. Zifar.

Zarin Tappeh

This site is situated north of the village of Chehrābād on a high and natural hill on the western bank of the river Chehrābād. The elevation of the hill in relation to the riverbed is about 12 m (Fig. 45).

The hill is about 90 m in length and c. 80 m in width. It has a steep slope in all directions, except for the east, where a relatively gentle slope stretches towards the village. Several pits were dug at this site during illegal excavations, and traces of ashes, and mudbricks, are visible here. This hampers the magnetic survey. Only the upper part of the hill shows cultural material and sherd scatter, while no traces are visible on the lower slopes. Zarin Tappeh is about 4 km away from the Douzlākh salt mine. More importantly, Zarin Tappeh is located in the same valley as Tappeh Haj Hatam. This valley leads to the salt mine in the north and thus connects the upper Chehrābād valley area as a potential agricultural area with the mine.

Alongside the illegally-dug pits where ashy material and charcoal appear in large quantities, the magnetometer survey shows a dipolar anomaly as a high-temperature area with values up to 62 nT. South of this feature, a further dipole structure, c. 1 m

Fig. 45 Zarin Tappeh, view from the southeast. Photo: H. Zifar

in diameter and with elevated nT values of up to 39 nT is visible, providing more evidence of a possible oven/kiln/furnace site. Two further pits show elevated values up to 34 nT and evidence the presence of burnt material. This indicates a high temperature area at the crest of the hill, possibly a workshop area. Findings at the site, such as slag, support this assumption. On the area below the plateau, an additional grid was investigated. A kind of 'sediment channel' is visible, but its function remains obscure (Fig. 46).

Based on its pottery (Fig. 47, Table 3), Zarin Tappeh most likely belongs to the Sasanian period. The bulk of Sasanian pottery derives from the upper part of the site, but a few pottery fragments from the Islamic period were found near the village houses at the bottom of the valley. As shown in Table 4, the surface potsherds of Zarin Tappeh are comparable to the Sasanian sites of Ghaleh Yazdgerd in Kermanshah (Keall & Keall, 1981), Hajiabad of Fars (Azarnoush, 1994), Takht-e Soleiman in Azarbaijan Province (Schnyder, 1975) and Turang Tappeh in northeastern Iran (Lecomte, 1987).

Reza-ābād-South

This ancient site is located 10 km southwest of the salt mine of Douzlākh and 6 km south of Tappeh Kūzehchi; it was discovered during a field walk in 2014. The site is in a rather montane environment and thus sits at a higher elevation than other ancient sites in the Talkherud catchment zone of Douzlākh. This

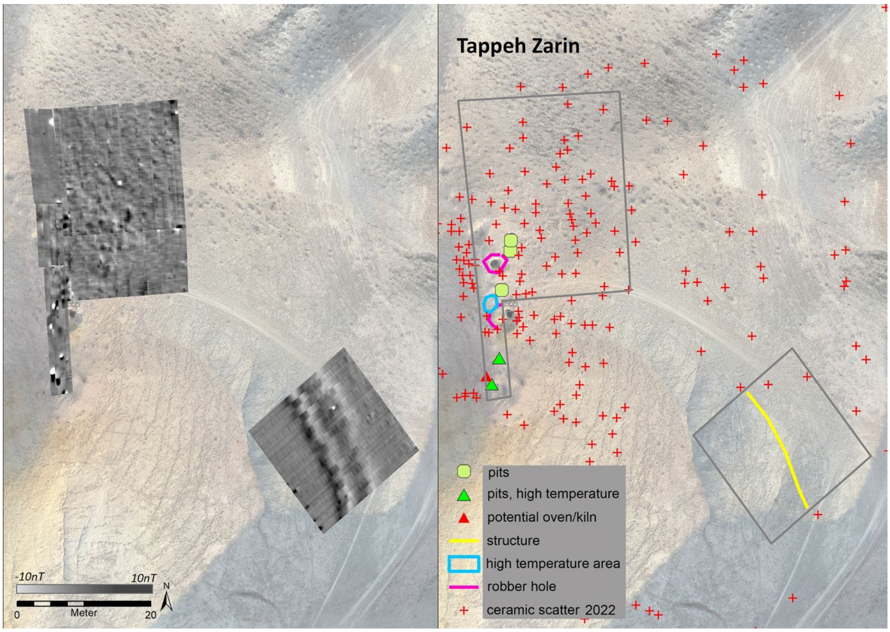


Fig. 46 Zarin Tappeh. (Left) greyscale picture of magnetometer measurements; (Right) interpretation and sherd scatter. Photo/Graphic: B. Sikorski/H. Zifar

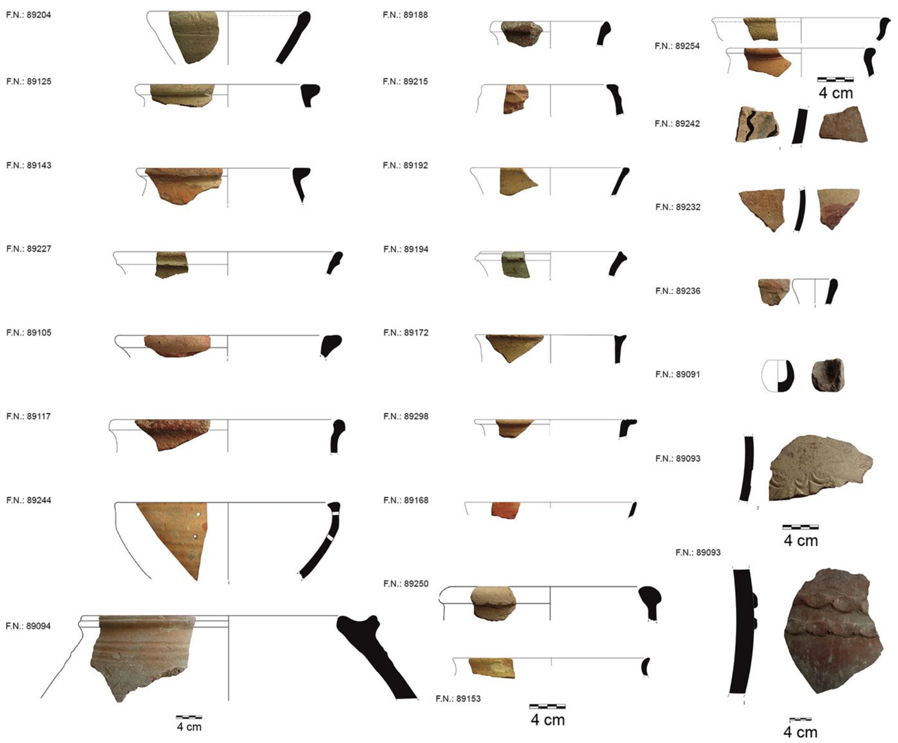


Fig. 47 Zarin Tappeh: selection of diagnostic sherds. Scale: 4 cm. Graphic: Photo/Graphic: H. Zifar

Table 3 Zarin Tappeh pottery comparison

Sherds	Parallels
Figure 9 R.N. 98,254–2	Lecomte, 1987, p. 57, No. 5; Keall & Keall, 1981, Fig. 13, No. 27
Figure 9 R.N. 98,254–1	Schnyder, 1975, Fig. 84, No. 7
Figure 9 R.N. 89,188	Keall & Keall, 1981, Fig. 17, No. 7
Figure 9 R.N. 227	Keall & Keall, 1981, Fig. 15, No. 8
Figure 9 R.N. 89,250	Lecomte, 1987, pl. 57, No. 3
Figure 9 R.N. 89,194	Azarnoush, 1994, Fig. 171 k; Kiani, 1982, Fig. 4-2

outstanding feature may determine a possible interpretation of the site. The site has a length of 150 m and a width of 85 m. There is an oval protrusion approximately 2 m higher than the surrounding agricultural lands in its northern and eastern parts. In the same area, there are two illegally excavated pits (Fig. 48).

Table 4 Reza-ābād-South pottery comparison

Sherds	Parallels
Figure 15 R.N. 89,382	Aali, 2020, 89, RN: 80056-2
Figure 15 R.N. 89,348	Aali, 2020, 91, RN: 80080-2; Aali and Stöllner, 2015, 88, Fig. 86-13; Muscarella, 1973, Fig. 15-8; Dyson, 1999, Fig. 4(d)
Figure 15 R.N. 89,360	Aali, 2020, 108, RN: 80115-1
Figure 15 R.N. 89,382	Aali, 2020, 89, RN: 80056-2; Aali, 2020: 117, RN: 80224-3
Figure 15 R.N. 89,383	Aali and Stöllner, 2015, 88, Fig. 86-8; Muscarella, 1973, Fig. 16-5; Goff, 1985, Fig. 2 (24)
Figure 15 R.N. 89,389	Aali, 2020, 119, RN: 80030-7

Fig. 48 Reza-ābād-South, view from southeast. Photo: H. Zifar

Altogether, 16 grids with a total of 0.6 ha were measured during the magnetometer survey. The site is littered with small dugouts up to 2 m deep. The greyscale picture shows some notable anomalies that are potentially archaeological structures, including six pits with high nT values up to 32 nT. As in Kūzehchi, they provide evidence of burned material. Two potential supra-structured edges were located in the middle of the measured area. The linear, rectangular and square structures may be remains of houses and walls and are comparable to the settlement structure at Tappeh Kūzehchi. Several hectares of the site require further examination (Fig. 49).

After this thorough study, the ceramic finds from this site appear to resemble Achaemenid pottery (Fig. 50). Importantly, there are similarities with the pottery from Tappeh Kūzehchi and the Douzlākh salt mine, indicating a contemporaneous occupation of the site.

Tappeh Sheikh Attar

Tappeh Sheikh Attar is located on the eastern riverbank of the Mehrābād river valley and 5 km southeast of Douzlākh. Unfortunately, illegal excavations have resulted in a large number of pits, which makes it difficult to work with magnetometers. The site consists of two tall ridges, the northeastern one being the highest. Architectural remains are visible within the pits between these two protrusions. The road from Mehrābād village to Ebrahimābād passes through the south of the site. Surface finds include pottery, stone tools and slag. Most of the finds were unearthed during the illegal digging. The pottery shows great variety in shape and decoration. A comparison with pottery from neighbouring regions reveals that sherds from different cultural periods of the Islamic era are present within the Tappeh Sheikh Attar collection (Fig. 51). Most of the glazed pottery has incised decoration, known as *sgraffiato*, under the glaze. Some of this represents a local type of sgraffiato known as

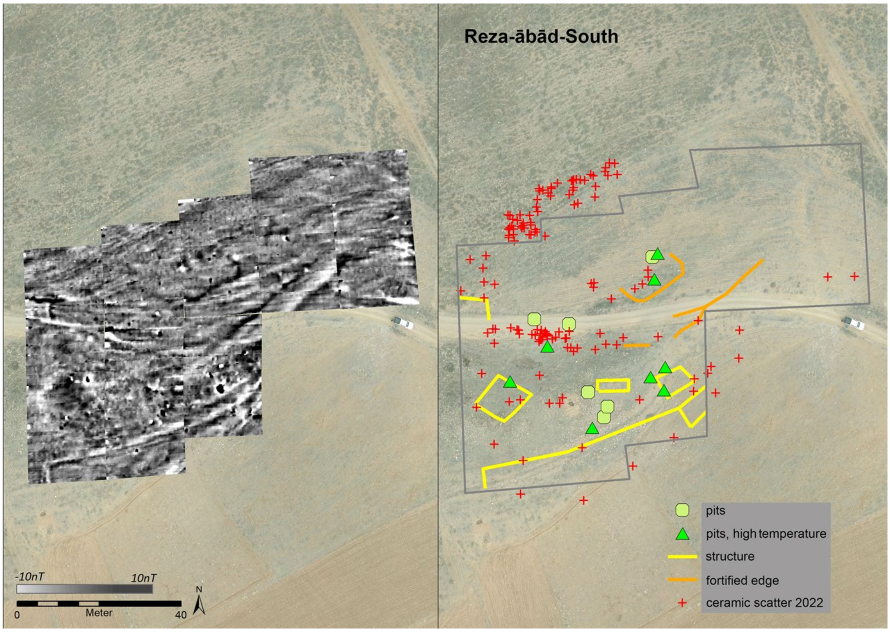


Fig. 49 Reza-ābād-South. (Left) greyscale picture of magnetometer measurements; (Right) interpretation and sherd scatter. Photo/Graphic: B. Sikorski/H. Zifar

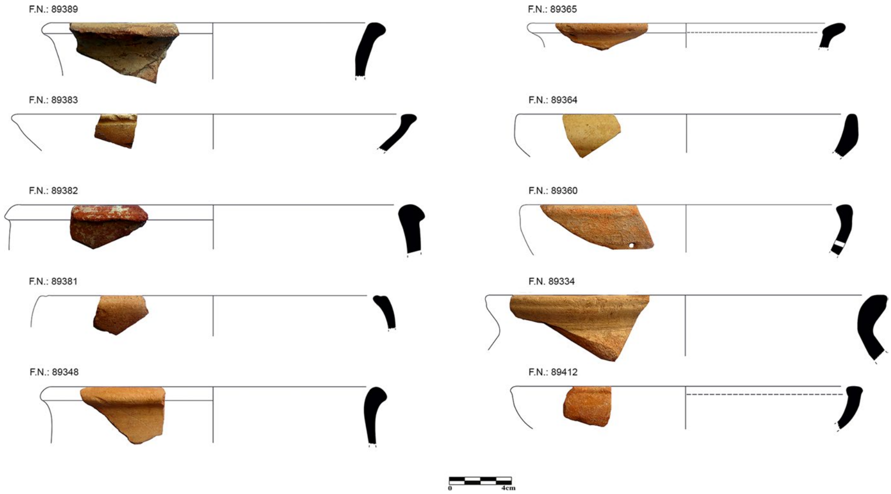


Fig. 50 Reza-ābād-South: selection of diagnostic sherds. Scale: 4 cm. Graphic: H. Zifar

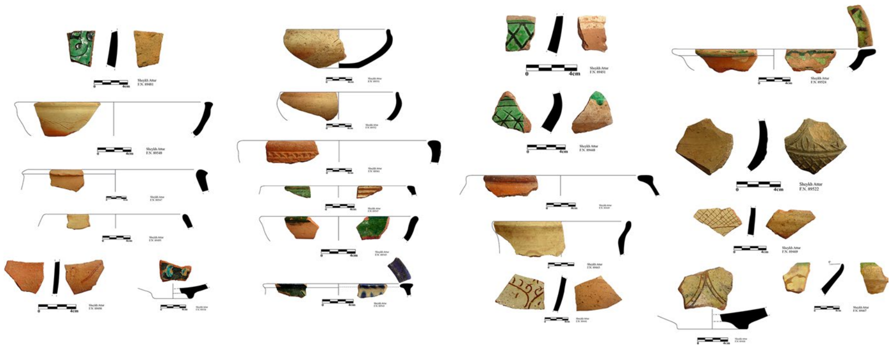


Fig. 51 Tappeh Sheikh Attar: selection of diagnostic sherds. Scale: 4 cm. Graphic: H. Zifar

Garūs style in northwestern and western Iran. Based on this, and due to the presence of sgraffiato and Garūs pottery, the area can be dated to the twelfth–thirteenth centuries AD (sixth–seventh centuries AH in the Islamic system) and is thus contemporary with the Seljuq and Ilkhanid mining periods of Douzlākh.

Pottery from later periods has also been found, such as blue and white glazed pottery from the Safavid period, which extends the date of Tappeh Sheikh Attar to the sixteenth–eighteenth centuries AD (tenth to twelfth centuries AH) (Table 5).

A total of 11 grids were measured via magnetic survey, corresponding to an area of 0.4 ha. The greyscale picture shows some notable anomalies that may represent archaeological structures, including several clearly visible supra-structured features. Right next to them, several black pit structures stand out with increased values of up to 70 nT, which again provide evidence of burnt material. Numerous dipole anomalies show increased values up to 84 nT. The linear, rectangular and square structures

Table 5 Tappeh Sheikh Attar pottery comparison

Sherds	Parallels
Figure 18 R.N. 89522	Wilkinson, 1973, pp. 253–64
Figure 18 R.N. 89524	Reuven, 2020, pp. 405–7
Figure 18 R.N. 89481	Fehérvári, 2000, pp. 86–88; Watson, 2004, pp. 261–62
Figure 18 R.N. 89451	Pope, 1977, pp. 612
Figure 18 R.N. 89448	Watson, 2004, pp. 261–262

are possibly architectural structures of houses and walls that indicate a settlement structure (Fig. 52).

Location and Interconnection of the Talkherud Basin Historical and Islamic Settlements to the Salt Mine of Douzlākh

The five sites studied in the Talkherud basin, along with the historical and cultural layers of the salt mine Douzlākh, cover the entire chronological sequence of

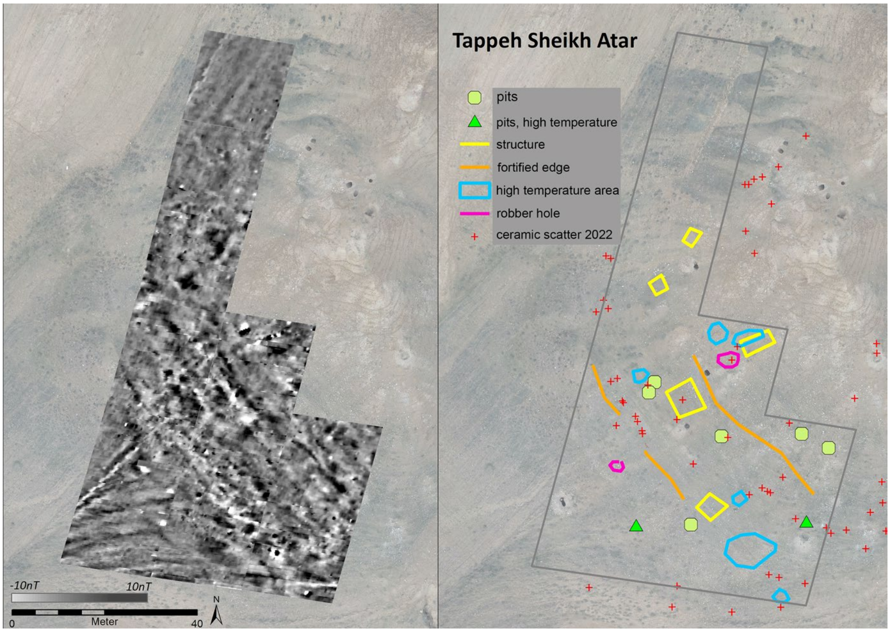


Fig. 52 Tappeh Sheikh Attar. (Left) greyscale picture of magnetometer measurements; (Right) interpretation and sherd scatter. Photo/Graphic: B. Sikorski/H. Zifar

the region: Tappeh Haj Hatam from the second millennium BC (not in this article), Kūzehchi, Reza-ābād South and Zarin Tappeh from the historical periods (Achaemenid and Sassanid), and Tappeh Sheikh Attar from the Islamic period. Most of the ancient dwelling sites in the Talkherud basin are located within the valleys of the southern part of the Talkherud watershed. All three valleys (Reza-ābād, Chehrābād, Mehrābād) flow northwards to a confluence north of the Douzlākh salt deposit. Therefore, it seems likely that most of the settlements were closely related with the salt mine, since they are geographically close. Whilst the two Achaemenid sites of Tappeh Kūzehchi and Reza-ābād South are connected to Douzlākh by the Reza-ābād valley, at walking distances of about 5 km and 10–11 km respectively, the Sassanid and Islamic settlements of Zarin Tappeh and Sheikh Atar are even closer. To reach Zarin Tappeh one must walk upstream along the Chehrābād riverbed for no more than 3 km. Sheikh Atar lies at a walking distance of 4 km upstream along the Mehrābād riverbed. As the sites overlap chronologically with mining operation periods at Douzlākh, a connection seems plausible. In this context, reference must once again be made to Tappeh Kūzehchi, where an Achaemenid workshop site was discovered during archaeological excavations. Here, the early settlement phase, which overlaps with the Achaemenid mining in Douzlākh, is of particular importance. It seems that the community at Tappeh Kūzehchi was engaged in craft activities such as iron smithing and metal processing (cf. 4.1.) that may have supplied the salt mine.

Regarding the magnetometer surveys, the results from Zarin Tappeh and Reza-ābād-South, as well as Sheikh Atar (indicated by slag finds) are very similar. Since we found no dwelling site with a long chronological sequence in the whole survey area, it seems likely that each site was founded during a particular period, and perhaps also in connection with mining processes in the region. The salt mine at Douzlākh may be of particular importance, but the potential for mines in the region may have played an important role in the formation of these sites in general. A connection to Douzlākh may be especially true for Tappeh Kūzehchi. Here, ^{14}C dates indicate that its foundation is contemporary to the early (and Achaemenid) mining activities at the neighbouring Douzlākh (cf 4.1.3). It seems that the foundation of settlements was primarily motivated not by any agricultural potential of the region (which is generally not high) but rather by the opportunities for salt mining.

Discussion: Three Mining Phases—Three Phases of Landscape Appropriation? Social and Economic Aspects of the Mining Landscape

The salt landscape around the Douzlākh salt mountain cannot be described as particularly favourable for settlement. The available water resources are characterised by high salinity, which makes agricultural use of the valleys and access to drinkable water especially difficult. The three flow systems of the Biyouk Chay (Rezāābad), Chehrābād and Mehrābād, which converge north of Douzlākh to form the Talkherud, supply water from the southern Tertiary basement mountains. Downstream, however, their salinity increases, which places agriculturally favourable zones in the southern parts of the Talkherud watershed (Fig. 1). In addition, the valleys are highly infilled by marl-rich Miocene sediments. These are recognisable within the core drills and the geoelectrical profiles as coarse layers of boulders. This influences the groundwater resources, as the underground aquifers are gradually encroached upon. Conversely, very fine, silty sediments are also noticeable here and indicate irrigation farming. The latter is still practised and leads to fine deposits of wet sediments on shallow arable terraces (Fig. 13). This type of irrigation farming most likely began no later than the late Achaemenid period, but this is not entirely clear, as there are no settlements from this period in the near vicinity of the Douzlākh.

But what archaeological arguments can be made for a relation between the rural sites and the mining? First of all there is the chronological overlap (see Fig. 53) between the salt mining and the settlements. Aside from the spread of prehistoric settlements from the Neolithic and the Chalcolithic, which seem to indicate discontinuous habitation of the region since the fifth–fourth millennium, there are some second millennium settlements (middle to late Bronze Age pottery) that demonstrate a more stable occupation of the southern part of the Talkherud watershed within a framework of rural subsistence activities (Fig. 53, 1). But it should be stressed that none of these settlements reached the older Iron Age periods (e.g. IA I/II), which is a strong argument for discontinuity until the sixth–fifth century BC, when salt mining and contemporaneous occupation of Reza-ābād began (Fig. 53, 2).

The excavations at Tappeh Kūzehchi have shown that a settlement existed within an hour's walk of the operating Douzlākh mine. The various indications of metalworking could speak to a specialised craft that may have been related to the supply of Douzlākh, but the agricultural potential needs to be studied further. Salt production at Douzlākh ended with a mining disaster around 400 BC, perhaps after a comparatively short period of operation. It appears that miners were sent to Douzlākh from afar as part of an institutionally organised *bandaka* (see above, in Salt Mummies and Their Identification: Bioarchaeological Access to the Origin and Life of the Ancient Salt Miners (Interpretation of the New Data); Aali & Stöllner, 2020). This centrally organised enterprise probably involved not only the mining itself, but also the supporting settlements from the very beginning. Two prominent examples from the Achaemenid period are Kūzehchi and Reza-ābād-South. While irrigation at Kūzehchi is supplied by water from the Biyuk Chaj, the farmers at Reza-ābād-South depended on yearly rainfall. The location of Reza-ābād-South possibly opened up the montane hinterland, which was suitable for pastoral uses and held iron deposits. Finds from Douzlākh indicate that supply was focused on cereals—especially barley—as well as cattle and sheep/goats. This type of supply did not necessarily originate from the region itself, but it is possible that the settlements in the valley of Reza-ābād were intended to provide access to further resources from the hinterlands. Nevertheless, it should be noted that these settlements have no immediate precursors, which reinforces the impression of a controlled use of the landscape. It is interesting that the settlement at Tappeh Kūzehchi continues, and with these sites we recognise an increased agrarian use of the salt landscape for the first time. However, it remains unclear whether the comparatively long interruption of salt extraction, until Late Parthian times, is accompanied by a further discontinuity of this settlement in the later Parthian period. None of the younger settlements discovered so

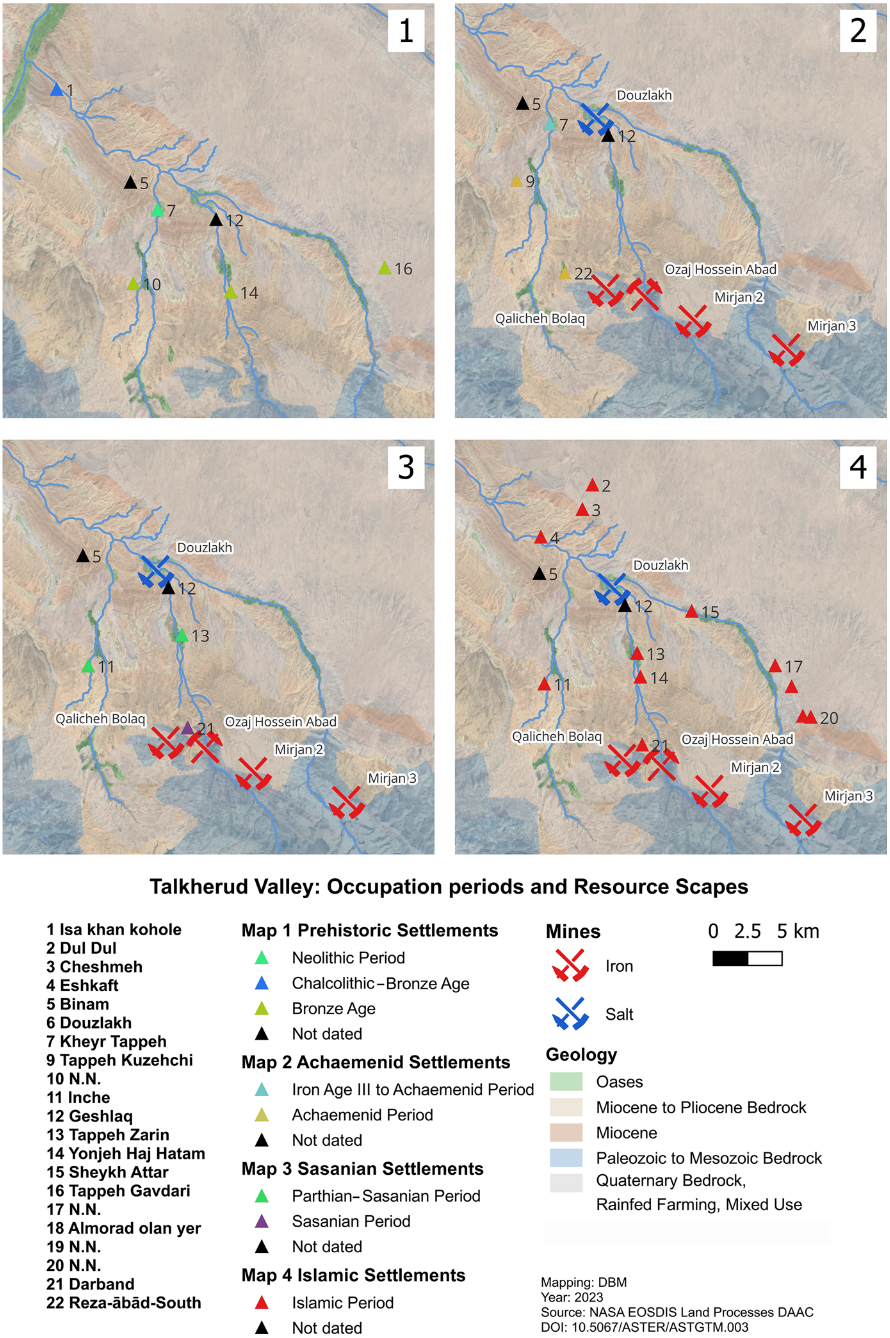


Fig. 53 Prehistoric, Achaemenid, Parthian-to-Sassanid, and Islamic-period settlement pattern compared with the salt mining at Douzlākh, on the basis of simplified geological base map: **1** prehistoric settlements; **2** mines and Iron III/Achaemenid settlements; **3** mines and Parthian/Sasanian settlements; **4** mines and settlements from Islamic periods. Graphic: F. Schapals/Th. Stöllner

far in the hinterland started before the transition between the Late Parthian and the Early Sasanian period (Fig. 53, 3). This reinforces the impression that the region was not intensively settled when the salt mine was abandoned.

In any case, the on-site data from the excavation at Douzlākh shows that the new mining phase, which began in the second–third century AD, was based on a regional supply system. There are plenty of indicators for cereal production and gardening. Due to the evidence of numerous fruit species (including freshly-consumed) and raw cotton, one can even suggest irrigated fields and horticulture. The nearest places that can be considered for the supply of the mine are now in the upper reaches of the Chehrābād River. Along the riverbank lies Zarin Tappeh, which may have had a similar function to the site of Tappeh Kūzehchi, mentioned above. Stratigraphic excavations carried out in winter 2022/23 demonstrated the chronological sequence from the Late Parthian to the later Sasanian period (Aali, 2023). There is also evidence of smithing activities in a workshop on the upper part of the mound. Pits indicating grain-storage are also present.

It should also be noted that Sassanid sites are now known both in the Reza-ābād valley and in the agricultural area south of Zarin Tappeh. Mining itself also provides clues. Firstly, archaeobotany strongly supports the evidence of gardening and irrigation-based agriculture in the vicinity of the mine, possibly around the fertile areas of Chehrābād village and Zarin Tappeh. The mine itself also underwent some catastrophes, with at least two accidents during the several hundred years of mining at Douzlākh. These by no means led to the end of operations, suggesting that the environment was sufficiently economically resilient to compensate for the loss of production and loss of life. In general, the miners may have come mostly from the region (Saltman 1), but isotope and genetic data taken from Saltmen 2 and 6 point to a foreign origin, at least for the latter. It is therefore probable that the Sassanid mining at Douzlākh was also carried out by a 'state' enterprise, which was now able to draw on significantly improved regional subsistence conditions in the vicinity of the salt mountain. In any case, the finds from Douzlākh show the use of large working groups, which were further supported by pack animals (donkeys) in the removal of salt and debris from the mine (Rossi et al., 2021). Wooden shafts, iron implements and other supplies most likely came from the regional environment. However, it is uncertain whether these undertakings were controlled by regional ruling structures, notably a Parthian–Sassanid elite. Typical Parthian and Sasanian castles, which are unknown from the Talkherud watershed region, are rather known to the south of that region.

No further activities have been documented in the region since the end of the later Sasanian salt mining, some time in the sixth century AD. It is notable that while there are numerous settlements from the Middle Islamic period, there are none from the Early Islamic period. This again would be a strong argument for the interrelation of salt mining and rural hinterland. There is reoccupation of older sites (e.g. Darband and Zarin Tappeh) but not before the Middle Islamic period, when the salt mines show a renewal of mining activity, especially in other parts of the deposit. In contrast to the early Sasanian reopening, none of the galleries were reopened during the Middle Islamic period, reinforcing the impression of discontinuity. In terms of the rural pattern in the hinterland, it is also noteworthy that the Mehrābād valley (the easternmost waterstream of the Talkherud watershed) was now densely settled. Overall, settlement density in the valleys around Douzlākh increased (Fig. 53, 4). The Seljuk–Ilkhanid site of Sheikh Attar may be of importance here, as the extent of the settlement and the overall quality of the ceramic finds indicate a regional center that was closely related to mining. The pottery and slag scatter demonstrate handicraft activities even if they have not so far been further characterised. Related pottery wares have been found at the mine and the Sheikh Attar site, suggesting some connection.

The question of whether the mining was also state-controlled arises in relation to the Middle to Late Islamic mining phase; a detailed investigation of Islamic sites (apart from Sheikh Attar) in the surrounding area is still pending. Whether mining at Douzlākh expanded is still uncertain, but the finds point to certain organisational structures already known in the Sassanid period: subsistence goods may have been transported to Douzlākh, while salt was transported from Douzlākh using donkeys, which may—again—reflect central organisation. By this time, a mining camp had been established at the foot of the salt mountain, possibly for foreign workmen although (to date) no mummy finds have been made. The setting of the more recent Islamic-period mining at Douzlākh is even less clear, and the mine may have become more of a regional supplier. Finds from the large northern profile, however, clearly indicate an intensification of mining from the Safavid period onwards, continuing without interruption until the twentieth century. Again, the supply goods indicate thorough integration with the rural environment, which was continuously occupied during this period.

Conclusions and Summary

The Talkherud salt-mining landscape is an exceptional example of the interaction of local rural communities with potentially institutionally organised resource extraction over a period of 2500 years. The interrupted salt extraction at Douzlākh was—especially in its older operation periods—linked to the rural hinterland, whose occupation seemed to follow the operation periods of the mine. In its early phases, the mine may even have caused the (re)establishment of settlements in the adjacent valleys. Later, the rural occupation also seems to have been discontinuous, being interrupted between individual mining phases, particularly in the Achaemenid and Sassanid periods. Longer settlement sequences only developed from the Middle Islamic period onwards. The question of whether older prehistoric sites, such as those of the Chalcolithic and the late Early and Middle Bronze Age (e.g. Tappeh Haj Hattam) were related to salt extraction remains open. No salt extraction has so far been evidenced. Moreover, until the Sassanid period, settlements appear to have been small and short-lived. In this regard, the results of the excavations at Tappeh Kūzehchi so far are particularly significant, as the settlement endured for some time after the catastrophic collapse of the Douzlākh mine around 400 BC. However, only some of the data outline specific workflows and how supply was organised. Workflows and supply chains became visible through the research on the recovered miner mummies, their equipment, tools and food, but more research is needed. In conclusion, it can be argued that state-organised mining might have become an important stimulus for rural developments within the Talkherud salt landscape until at least the Middle Islamic period. This development was correlated with the founding of rural settlements and an irrigation economy.

Unfortunately, there are few written sources concerning salt-exploitation in northwestern Iran during the timespan considered here, and none for the Achaemenid and Sasanian periods. But the wider context may indicate institutional involvement. At least partial control of salt by the authorities is indicated, in particular, by salt taxation since the Seleucid and the evidence of salt storage since the Sasanian period (Simpson, 2001). In general, the management of institutional landscapes in other areas in the Iranian highlands shows that a centrally organised management of rural settlements was an important feature at least since the Achaemenid period, as mirrored by recent research results from Fars. The network of small farmsteads with storage and production activities documented during the emergency excavations at Tang-e Bolaghi may have related to a supply of the centers in the Morgab plain (Pasagadae) based on irrigation farming (Gondet et al., 2021; Askari Chaverdi & Callieri, 2016). However, the supply organisation for the royal palaces in the Morgab plain (and presumably also for the Marvdasht plain) seems outstanding. The importance of irrigation farming to supply large centers can be seen in numerous later examples, especially since the Sassanid period: the Zāyandeh Rūd near Isfahān, for instance, also continued in this way after the Muslim conquest (Kamalizad, 2016), a concept that can be attested in numerous areas of the highlands (Spooner, 1974). For the first time, the Talkherud settlement landscape and its interaction with the rock salt mine at Douzlākh impressively demonstrate the institutional character of mining in the early historical phases of the Iranian highlands.

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1007/s10963-024-09183-z.

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