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Long-term Salt Mining in Chehrābād: Resilient Strategies in Accessing Mineral Resources at the Iranian Highlands

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Resilient strategies in approaching resource-scapes at the Iranian Highlands: an introduction

Mining certainly was a pull factor for prehistoric populations and therefore has implications for archaeologists' discussions of mobility, migration and trade. Mining attracted people relocating in search of quick success and fortune, and also attracted "investors", triggering the development of new sorts of social organisation. As this is commonplace, it allows for an investigation of the factors that influenced societal strategies and practices under specific conditions caused by environmental aspects and natural resource yield. Such an approach enables a specific perspective on single resource-scapes. In defining such scapes, resilient strategies and general societal and economic embedding are of central importance.[1]

The highland communities of the Iranian plateau faced hazardous circumstances that bound them to certain strategies to secure their subsistence and their vision of their lifescapes. Wind, a shortage of water and restricted access to arable land were the most important factors (Makki 2017). Mountains and fresh water oases became therefore important subsistence spaces. The abundance of mineral deposits (Momenzadeh 2004) contrasted with the remoteness of the arid and mountainous landscape that made surviving difficult for larger groups of mining people. Grasping the full potential of the mineral deposits, with their wealth of metals, semi-precious stones and salt, required strategies and particularly investments from organisations to enable large-scale operations. This way of administratively organising enterprises was different to other more traditional mining practices that combined pastoral activities with collecting, sporadic and seasonal mining operations. Husbandry systems were an important backbone of the first dwellers in the late 7th millennium (Mashkour et al. 1999; Mashkour 2003). The importance of goat and sheep herds is easily seen in prehistoric iconography and decorations on pottery from the earliest periods onwards (Young and Fazeli 2013). One could argue that the small-scale mining operations driven by miner-herders were more resilient against all sorts of threats such as climatic changes, shortages of food, the depletion of deposits, or changes in consumer demands. Their resilience was simply based on a small-scale, long-term strategy related to social practice in using these resources. A good example are acquisition modes,

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1 The term "resource-scape" is used in accordance with the discussion and definitions of Tim Ingold (2000) and refers to aspects of daily routines and practices and a spatial concept. The concept of resource-scape in the sense of mining landscapes still has to be discussed on the basis of typical routines shaping these manmade environments.

conveyed through axe quarrying or ochre mining in pre-modern societies (e.g. Sagona 1993; Pétrequin et al. 2000; Pétrequin and Pétrequin 2006; general discussion: Stöllner 2017). In such cases, there was often a close relation between production and consumption as well as narratives and social practices that interwove both. Did this support the development of long-lasting acquisition practices that could also withstand large-scale economic, ecological and social changes? Regarding the Eastern Alps Bronze Age communities, there is a strong argument to be made that the exploitation of copper stabilised the dwellings and supplies of the Inner-Alpine communities and enabled more long-lasting developments (e.g. Stöllner 2019). Within permanent mining concepts, an exploitation of long duration enables a discussion of different stages, starting at the inventing stage, followed by the consolidation and development of an intensive "industrial" stage. The archaeological sources are more easily interpreted, simply because there is permanent infrastructure involved. Long-term development also facilitates a discussion of re-organisation stages and therefore a long-lasting adaptive cycle (Gunderson and Holling 2002; for mining communities: Stöllner 2015, 70–71). This would be an indication of a sort of resilience that enabled communities involved in resource acquisition to benefit from a long-lasting economic strategy (in this direction: Bradtmöller et al. 2017; generally various articles in Faulseit 2015). However, this raises an important question: were such strategies more sustainable for the societies involved than were small-scale seasonal and sporadic access modes?

Pastoral and state-driven strategies at the Iranian Highlands

Previous research results suggest that resource management systems developed in a distinct manner at the Iranian Highlands. This includes special technical solutions and principal production and consumption modes. Similar to metallurgy (Helwing 2013; Pigott 1999), mining technology also had distinct features at the Iranian Highlands (Stöllner 2004). One could mention the fact that the traditional exploitation mode of following the lode galleries did not change during the later antique periods, when particularly in the Greek and Roman worlds horizontal galleries had already been established as the basic principle of mining layouts. This certainly had to do with the abundant near-surface mineral resources and the low water table that allowed mining at deep levels (e.g. Nakhlak: Stöllner et al. 2004). Regarding structural modes, pastoral winning modes were the most stable and long-lasting. One could question whether this changed when the first stable mining settlements or guarding fortresses were founded nearby important mineral deposits (e.g. Hallier 1972; 1973; Nikzad et al. 2018). The basic reason for relying on pastoral subsistence strategies was simply the aridity and remoteness of some of the mineral deposits. This can be observed especially in the frame of the Central Plateau, but even in more fertile and semi-arid mining districts, it is clear that the regional agro- or horticultural systems also determined the exploiting strategies (see below comparison of Veshnāveh and Douzlākh evidence; **Fig. 1**).

Looking in more detail at current results, it is likely that early copper ore and silver ore exploitation was connected with oasis-based settlements, especially at the Central Plateau. This is clear when looking at the early metallurgical centres from the late 5th millennium toward the 2nd millennium onwards (e.g. Helwing 2013). While this is easily confirmed by the evidence of metallurgy, this is more difficult to prove regarding ore production. The Veshnāveh copper ore-mining district strongly supports this assumption, as the mines themselves were operated by herder-miners during the early 2nd millennium BCE (Nezafati and Stöllner 2018; Stöllner et al. 2011). At the moment this assumption can be made only indirectly on the basis of

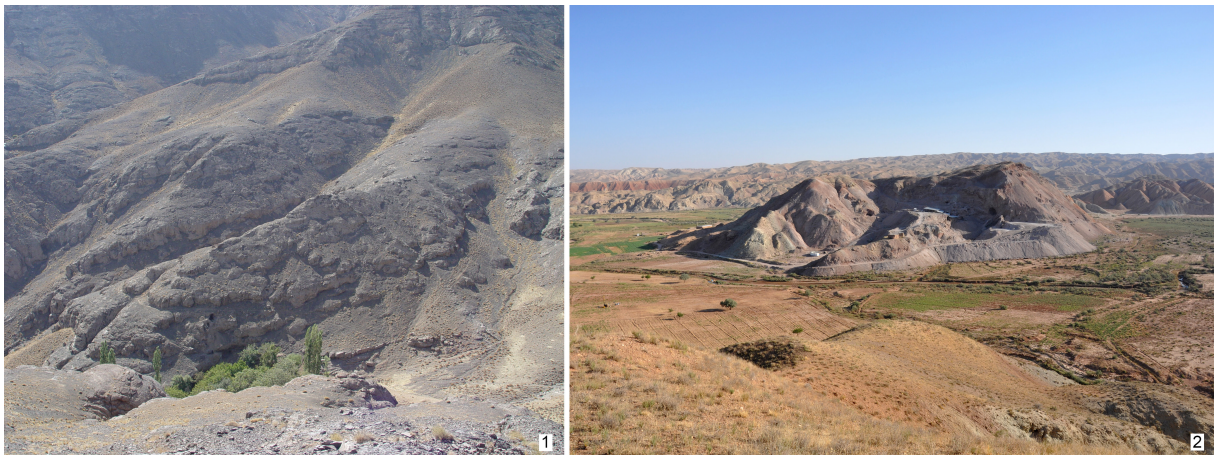

Fig. 1. The mining area of Chale Ghar (Veshnāveh) in the Kuhestan-e Qom, prov. of Qom [1] and of the Salt-mountain of Douzlākh near Chehrādād, prov. of Zanjān [2]. Photos: DBM/ICHHTO/RUB, K. Roustaei [1], S. Saedi [2].

the archaeological evidence of Veshnaveh mining, as no high-altitude settlements were evident at the mining district. More importantly, there is no known metallurgical evidence, indicating that the ores were smelted at other areas where sufficient fuel could be provided. Another indirect piece of evidence is available through provenance studies of ores beneficiated and smelted at sites such as Tappeh Sialk, Arisman or Qoli Darvish/Jamkaran (Nezafati and Stöllner 2018). The mixture of ores and the variability of possible ore provenances (according to their geochemical composition) indicate ore supply from far-distant areas, in the case of Arisman even from distances of about 500 km (e.g. the Nakhlak silver source: Pernicka et al. 2011; Stöllner et al. 2004; for the Sialk case: Nezafati et al. 2008). This indicates very specific and wide-spanning networks during the older prehistoric periods. This raises the question of how metallurgical centres such as Arisman and Sialk could have managed ore delivery by including pastoral herders' and miners' networks. Permanency in exploiting specific mineral resources was probably based on long-lasting transfer of knowledge that bound such groups to specially selected tracks, grazing grounds and mineral resources (such as in the mountainous pasture grounds in the Kuhestan-e Qom, where Veshnāveh is situated: Nezafati and Stöllner 2018; **Fig. 1.1**).

The first results gained from a systematic investigation of the Veshnāveh Bronze Age mines' archaeozoological record provide insight into this traditional miner-herder subsistence and acquiring pattern (Doll 2012/2013). The composition of the domestic herds correlates with the husbandry pattern known from the Iranian Highlands. This certainly applies to cattle and the high portion of caprines, while the evidence of pigs and chickens is surprising (**Fig. 2**). Doll identifies the osteological features as part of kitchen refuse. The bones are broken into small fragments and show cut marks and traces of burning. There is no evidence of complete carcasses. This is the case for sheep/goat, and is even clearer for adult cattle, where the bones showed regular cut marks. Cattle certainly were slaughtered, processed and consumed in the vicinity of the mining area. The majority of the cattle were adult individuals similar to the age-pattern of some equids, often horses but also donkeys. They seemingly accompanied larger mixed herds driven to the mountains. Equids were usually not consumed as the lack of cut marks indicates, but were rather deployed for carrying loads, provisions, persons and the ore yield down to the flatter parts of the plateau where the settlements might have been situated. This might indicate that some animals such as pigs, cattle and chickens were taken as provisions to the mines. This

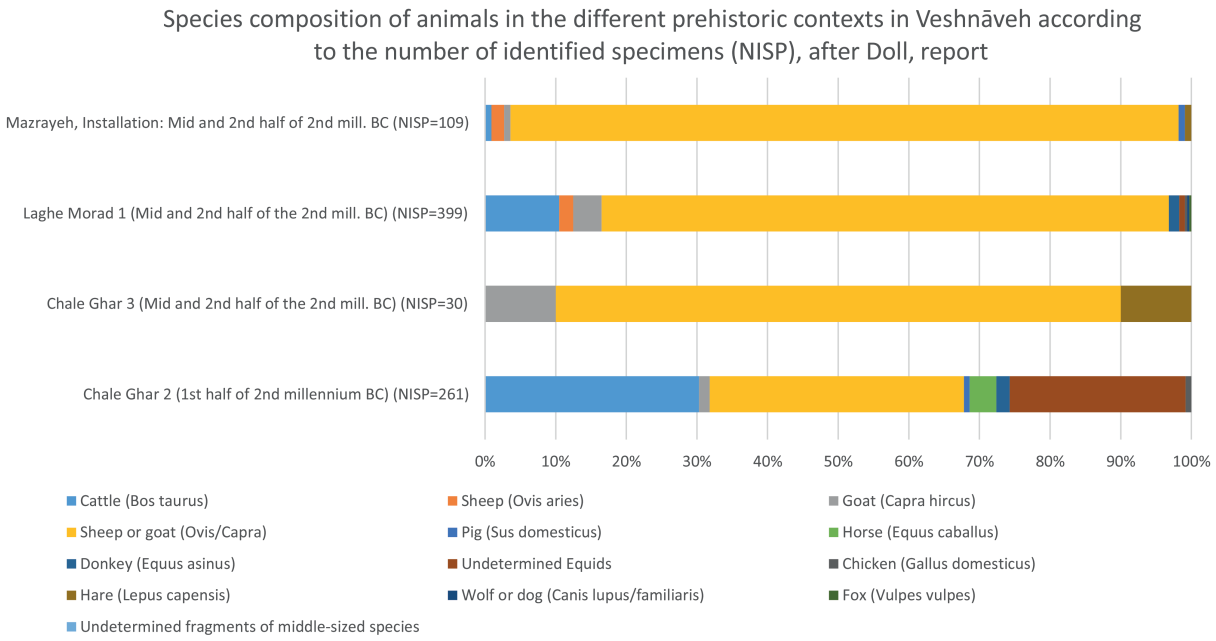

Fig. 2. Species composition in the different prehistoric mining contexts in Veshnāveh according to the number of identified specimens (NISP) in the frame archaeozoological investigation, after Doll 2012/2013. Chart: DBM/RUB, T. Stöllner.

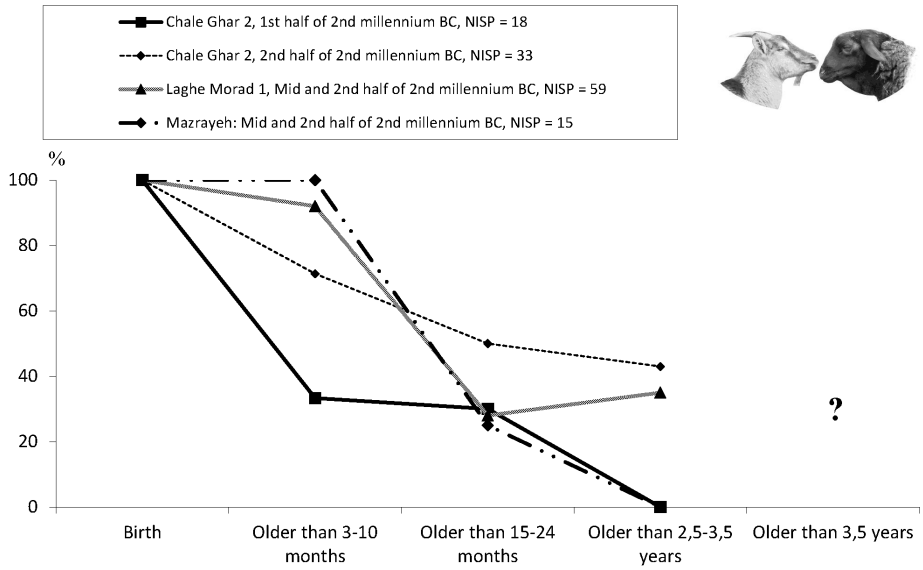

Fig. 3. Age profile of the bones of the small ruminants of different prehistoric mining contexts in Veshnāveh according to epiphyseal fusion stages. The shapes of the curves illustrate the shares of the bones with fused epiphyses in each age class showing the share of animals that survived the specific age class. After Doll 2012/2013, Fig. 21.

was possibly also the case for the caprines, although their situation may have been more diverse; they accounted for the largest portion of the herds, and could easily be kept nearby, grazing and moving to surrounding pastures. It can therefore be asked whether the age pattern (**Fig. 3**) reflects the whole herd or only those that were consumed during the mining period (it is not necessarily clear that this period was spring/summer. Even summer/autumn would be possible). The sheep/goat documented in and in front of the mines had reached their 2nd or 3rd year, which indicates that they were originally bred for meat and wool production. However, there are differences in the record: the site of Chale Ghar shows a larger portion of very young animals, which could suggest that mining activities took place in late spring and summer.

It is most interesting to explore the mobility patterns of sheep and goats with respect to resource-rich altitudes nearer to or further from metallurgical centres, an attempt not yet made on the basis of isotope research (Sr-/O-isotopes). Such an intensive overlap of subsistence and exploitation strategies might have been typical for the Iranian Highlands for a long time. It may also have been fundamental for the Early Iron Age, for instance in the Luristan area, where the exploitation of tin was important to meet the social requirements of shiny bronze items typical to that zone (mines at Deh Hosein: Nezafati et al. 2009).

Whether the miner-herders' tradition was still the dominant acquisition strategy during the younger periods at the Iranian Highlands is a question that can be asked: a first rough overview of what is known from various mining districts generally indicates a rise in mining activities during the 1st millennia BCE and CE. It is only an assumption that mining became a controlled activity that had to supply Achaemenid centres with basic goods such as salt, stones and metals. At the moment only the salt mine of Chehrābād has been sufficiently investigated for that period (see below). This mining complex has delivered some first results that indicate a directional and controlled organisation: there is proof of foreign labour force, standardised equipment and controlled supply of consumables. However, it is still unclear whether the surrounding rural landscapes followed a clear institutional organisation that enabled this. The development of irrigation systems to enable stable settlements in the region has already been identified as one of the most important factors of this fundamental turning point.

From the Achaemenid period onwards, it is likely that the semi-stable miner-herder strategies were combined with institutional mining organisations, but these relations remain poorly investigated. When looking at younger institutional landscapes of mining, there is ample evidence for the Sassanian and Early Islamic period: mining sites were often accompanied by mining settlements and military fortifications. It is debateable whether this already occurred during the Parthian period – answering this would require further detailed fieldwork. Examples are abundant along the mineral resource landscapes of the Urumieh-Dokhtar belt from the northwest to the southeast (e.g. the mining districts of Khosf, Qaleh Zari, the Holabad-district near Natanz, the Nakhlak district: Hallier 1972; 1973; Nikzad et al. 2018; Stöllner 2004). The rural settlement ground of the Talkherud salt-mining landscape demonstrates this change: rural settlement occurred only at a later stage in the area surrounding the salt mine (**Fig. 4**) and indicates systematic landscape management which required pastoral and horticultural organisation. One could even assume that the mining activities enabled continuous and sustainable settling in a rather unfavourable landscape with restricted water resources.

One of the overall reasons for the dramatic increase in institutional mining landscapes during the Parthian and Sassanian periods in the Iranian Highlands could be the gradual

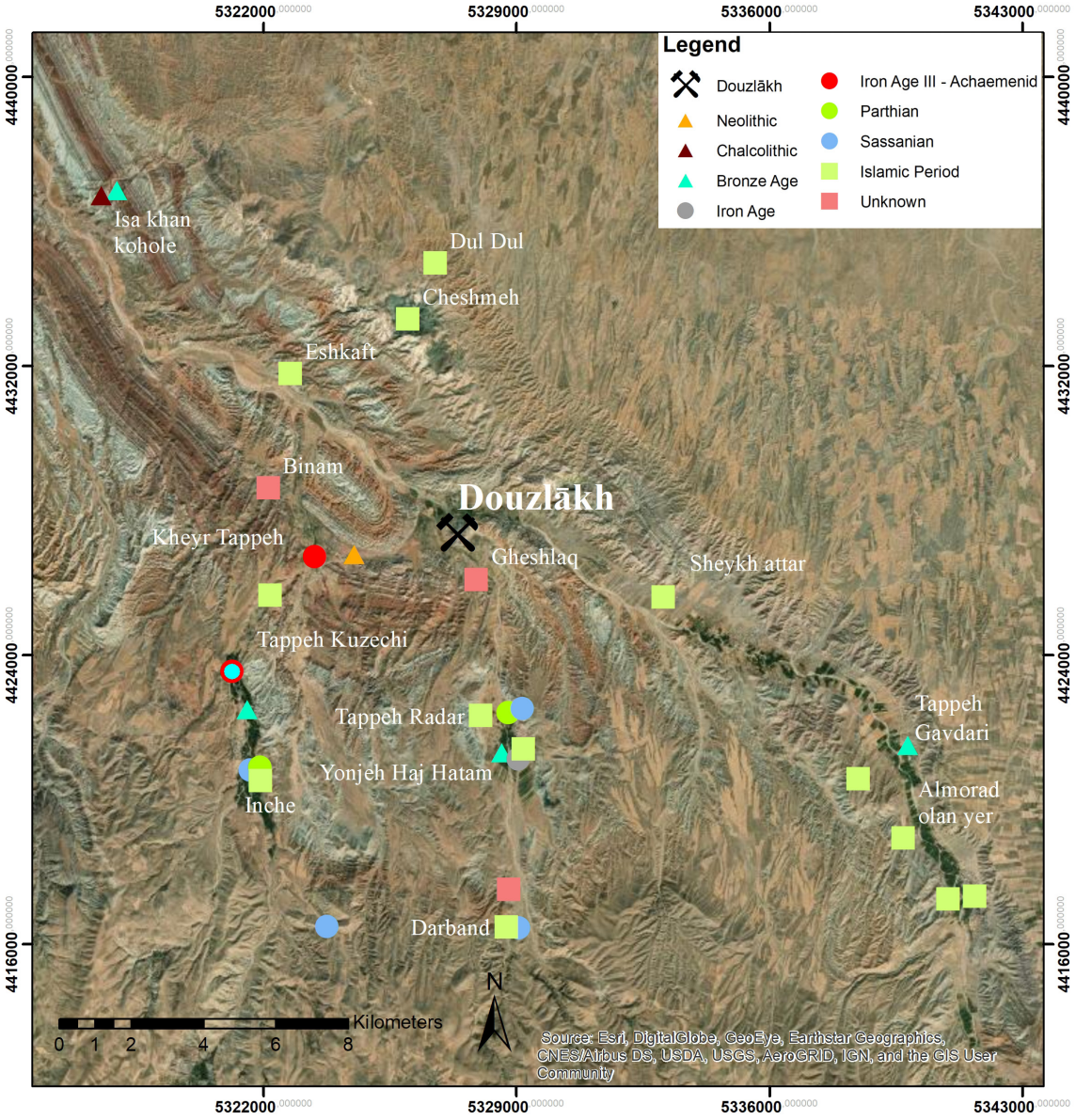

Fig. 4. Archaeological sites and settlements in the hinterland of Douzlākh salt mine in the Talkherud basin in Zanjān province. Data: DBM/ICHHTO/RUB, mapping: N. Schimerl.

monetisation of economic and political practice brought about by the directional economic strategies of state institutions. The royal foundation of cities, coinage and possibly also important mining enterprises were controlled to some extent by the state (Göbl 1971; Gyselen 1989; 1990). We still have very limited information about single mining enterprises that would allow insight to procedural steps and interconnections between production and consumption (as we do for Imperial Roman mining; e.g. Domergue 2008). Despite those political developments, it is unclear whether such an organisational pattern remained stable after the Arabian conquest or throughout the Middle Islamic period. Examples such as Nakhlak indicate continuous silver mining activities in the Early Islamic period (Stöllner et al. 2004), but the question of continuity often remains unanswered. Whether such activities were still controlled by central

authorities or whether the traditional miner-herder-strategies were again applied is an open question, despite the fact that there are general mappings and records of Persian and Arabian geographers (Al-Muqaddasi, Ibn Hawqal and Hudud al'Alam: Allan 1979). Nothing is said regarding how those mining enterprises were operated and whether they were controlled by central authorities. Nevertheless, it is quite likely that many of the mining activities reported by the medieval geographers had their origins in the older Parthian and Sassanian period. As detailed economic texts about the mining processes are sparse or undiscovered, our knowledge is based mainly on archaeological sources.

The salt mine of Chehrābād: pattern of subsistence and operation periods of long-lasting exploitation

The protohistoric mine of Chehrābād has been known since the first occasional findings of mummified human carcasses in 1993; systematic research started after two rescue excavations carried out by ICHHTO Zanjan in 2004 and 2005, when five other mummies (or "Saltmen") were found and investigated. These findings induced further research and in 2009 the International Chehrābād Saltmummy & Saltmine Exploration Project was founded (Aali 2005; Aali et al. 2012a; 2012b; Aali and Stöllner 2015). During several field campaigns and further laboratory and indoor research, thorough and condensed research results were achieved that allow a better understanding of mining activities as social and economic practices of highland dwellers. The most amazing aspect is the longevity of the activities, which stretched from the middle of the 1st millennium BCE to the end of the 20th century (**Fig. 5**). This provides insight into the economic activities of highland communities over a long diachronic period, and also enables a comparison and discussion of these long-lasting activities in terms of traditions and resistance. The key argument is certainly single operation periods, as they suggest which kinds of activities and organisational structures are to be expected. It is noteworthy that these operation periods are temporally linked to the major phases of extensive state control of the Central Plateau during the Achaemenid, Sassanid, Seljuq/Ilkhanid, Safavid, Qadshar and Pahlevi periods. This generally indicates some sort of connection to state organisation of labour, trade and distribution networks. Despite those rather external factors of organisation, it is an important question how people who relied on rural latency in subsistence and agricultural strategies interfered with these kinds of governmental demands. The Douzlākh salt mountain was certainly also of regional importance to meet the demand for salt for food and animal husbandry. Its small-scale yield was definitely restricted in times of centralised exploitation by foreign miner groups. The larger-scale mining also enabled the flourishing and development of the surrounding valleys, seen in the continuous increase in settlements in the vicinity. Such foreign investments may have influenced the regional traditions of extensive landscape use and forced people to establish permanent settlements and horticultural planting with elements of an irrigation system. As fresh water sources were only occasionally accessible in the surroundings of the salt mountain and downstream in the Talkherud river system, fresh water conducts from the upper part of the surrounding valleys were required (Aali and Stöllner 2015, 16–18; new observations by courtesy of E. Draganits and R. Khoshraftar, Chehrābād project). These came into use at the earliest during the Achaemenid period, but most likely later during the late Parthian and Sassanian periods. This resulted in a continuous transformation from a rather remote and uninhabitable landscape to a cultivated rural one. It can be assumed that this transformation enabled increasing endurance in larger-scale exploitation of the salt mountain, mitigating volatility in salt demand, trading networks and political organisation.

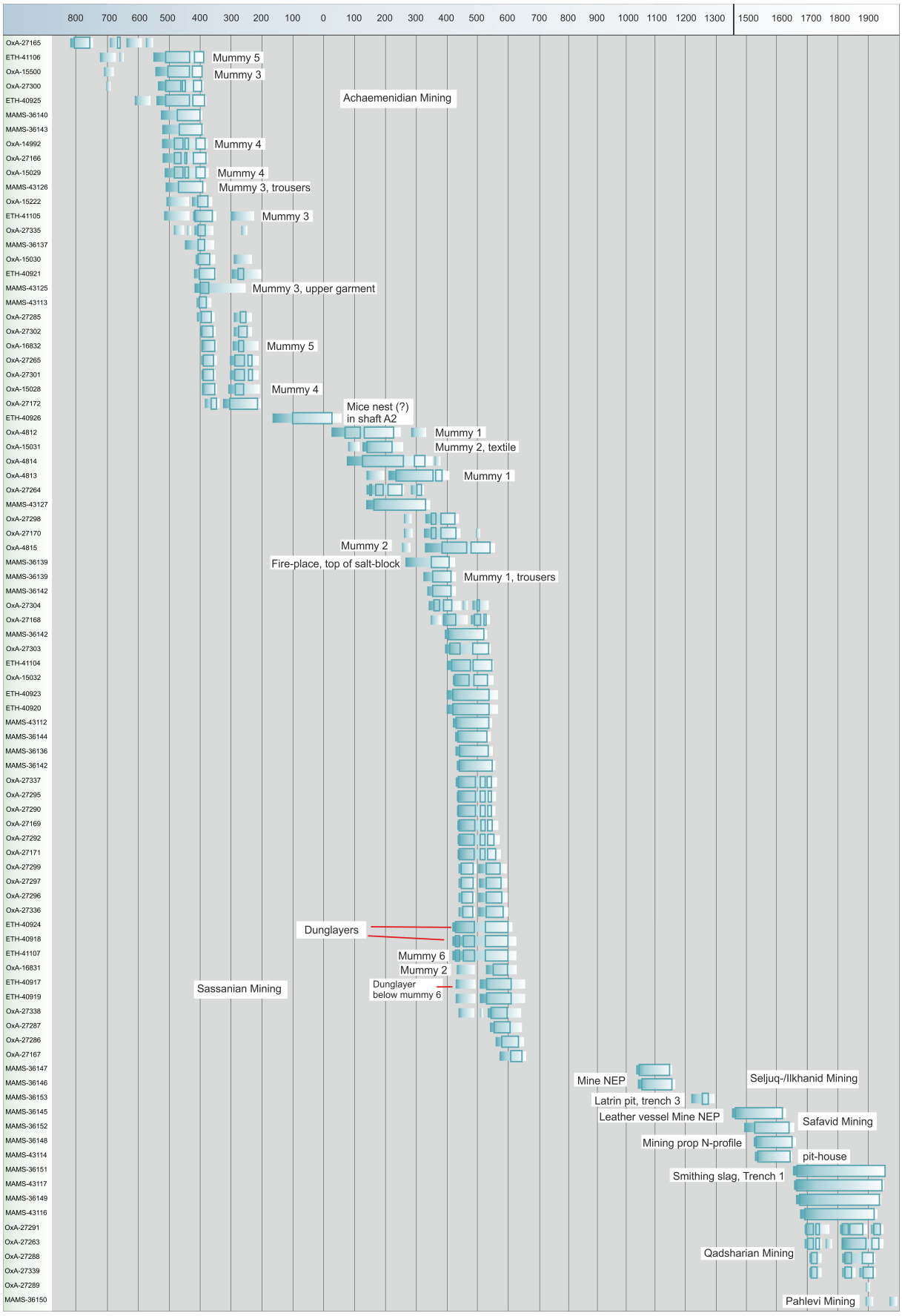

Fig. 5. AMS-^{14}C-dating of findings from the Douzlākh salt mine, current stage of the art (1σ/2σ-standard deviation). Data: DBM/ICHHTO/RUB, chart: T. Stöllner.

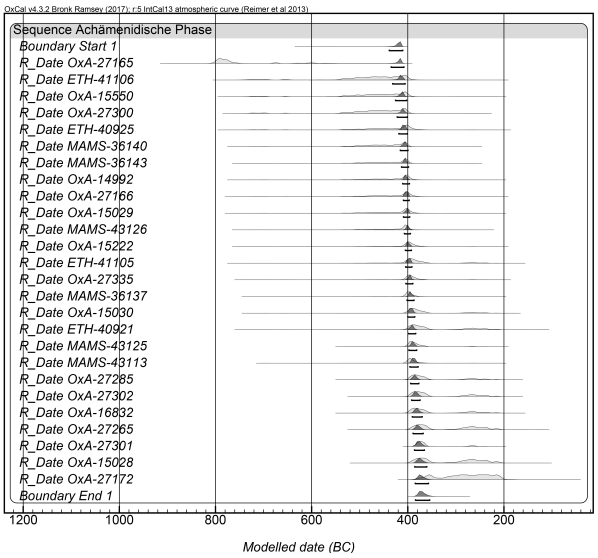

Fig. 6. Chehrābād, Bayesian modelling of 26 AMS-¹⁴C-dates from the Achaemenid period, after OxCal, Version 4.3.

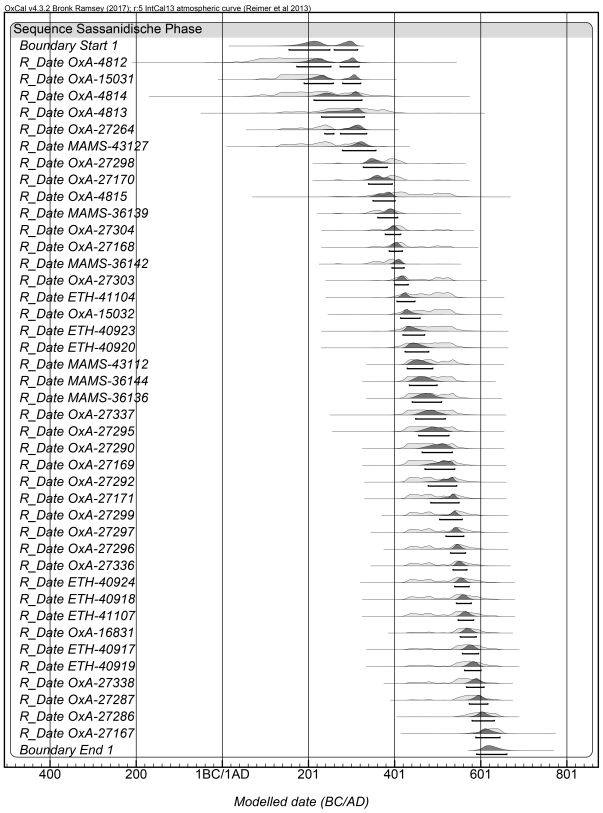

Fig. 7. Chehrābād, Bayesian modelling of 42 AMS-¹⁴C-dates from the Sassanian period, after OxCal, Version 4.3.

The operation periods

Nearly 90 AMS-¹⁴C-dates have already been operated in the Oxford, Zurich and Mannheim laboratories (**Figs. 5**, **6**, **7**, **8**). Because of their overall consistency, these data allow for further modelling. Bayesian modelling is used to better understand operation periods in order to tighten statistical overlapping, particularly as it can be assumed that the operating time span was continuous (the continuously deposited stratigraphic sequence can also prove this).

The Achaemenid sequence consists of 26 dates, most falling between the second half of the 5th century and the early 4th century BCE (**Fig. 6**). Although there is one date from the 8th and 7th century BCE (OxA-27165), there is an argument to be made for not expanding the operation time to an older period. The date derives from a wooden handle discovered during the rescue excavations in 2004/2005, the stratigraphic context of which is not exactly fixed. It is a piece of deciduous wood. Therefore, it would be unsurprising if an older handle had been used. As the piece was made of an indeterminable deciduous wood, it is not unlikely that it was old wood. Aside from this piece, an operation period of only a few decades between the second half of the 5th and the 4th millennium is probable. The Achaemenid mine was abandoned after a mining catastrophe that cost three miners their lives. This catastrophe can be temporally modelled between 405 and 380 BCE, as pointed out by various authors (Aali et al. 2012a; Pollard et al. 2008).

The Sassanian dates range over a longer time span: there is a clear stratigraphic sequence, particularly in trenches A and C, that corresponds with a chronological sequence of ¹⁴C-dates between the 2nd/3rd century CE and the 5th/6th century CE (Aali and Stöllner 2015). 41 dates range over a time span of more than 300 years (**Fig. 7**). Bayesian modelling curtails the range to the beginning/middle of the 3rd century until the beginning of the 7th century. The beginning of the Sassanian

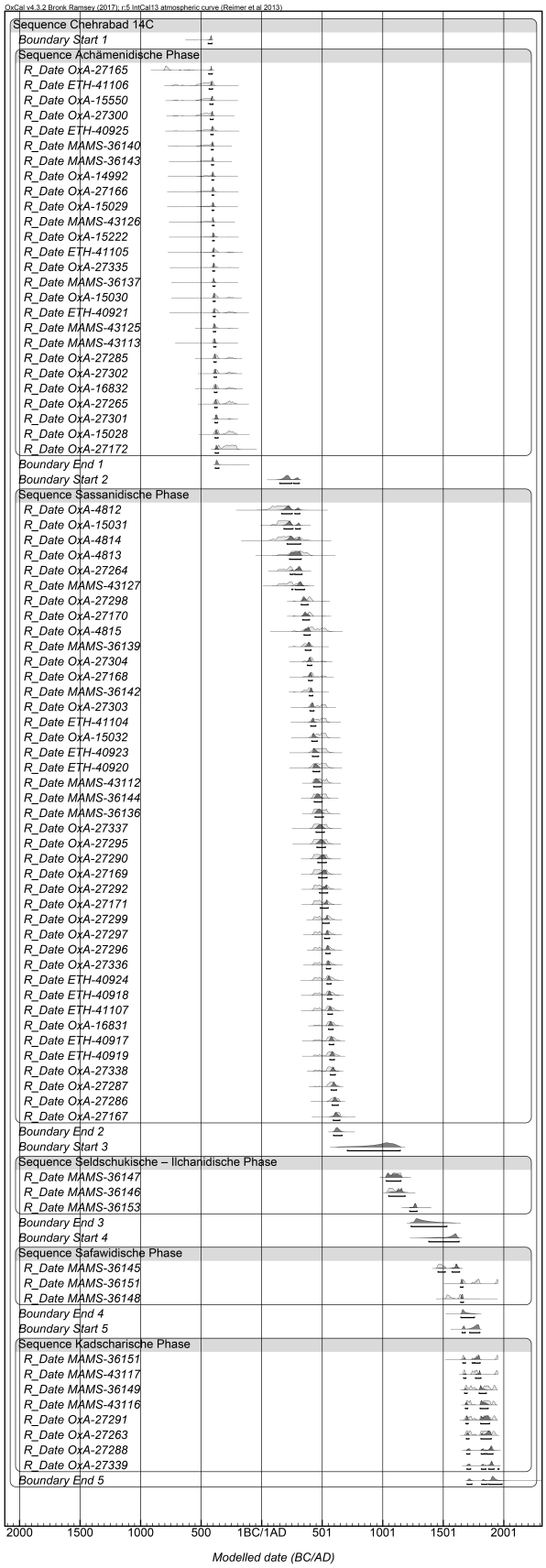

Fig. 8. Chehrābād, Bayesian modelling of all the relevant AMS-^{14}C-dates from the mine, after OxCal, Version 4.3.

operation period can be stratigraphically defined: some fireplaces were settled on top of the Achaemenid debris and indicate first activities in still open mine galleries around the 3rd century (MAMS-36139). Rather unclear is the situation with the mummy Saltman 1 and some accompanying artefacts that date slightly older; as these artefacts were not found in a regular excavation, their exact location is unknown (OxA-4812, 4813, 4814, OxA-15031). These dates range roughly between the 1st and 3rd century CE and correspond with a layer dating that was received from layer 31000, a layer that is noted at the lowest part of the Sassanian layers, even older than the above-mentioned fireplace (OxA-27264). The conclusion is that this mining phase began slightly earlier, possibly during the 2nd century or the beginning of the 3rd century CE. As a next step, there is an indication that large parts of the mine were cleaned and debris re-dumped roughly around the 4th and 5th century (e.g. layer feature 30000).[2] There is no reason to conclude discontinuity in mining operations. The latest Sassanian activity dates from the 5th to the early 7th century, with evidence of another catastrophe (mummies 2 and 6).

The younger periods are documented by far fewer dates, which does not allow certainty about exact operation periods. There are three dates from the Seljuq and Ilkhanid period, which may indicate mining between the 11th and 13th century CE (**Fig. 8**). Four dates from the Safavid period show a better concurrence (**Fig. 8**). They originate from two settlement features and two mining layers and are therefore more indicative of an operation period. Bayesian modelling suggests a mining period that spanned from the end of the 15th century to the 17th century CE, perhaps 150 to 200 years. Considering eight younger Qadsharian dates, it is likely that there was

2 The layer number was used in 2010 and 2011, but was assigned to the layers 31052+31053 in 2016.

no hiatus from the younger mining period (**Fig. 8**). This is also supported by the fact that the stratigraphic sequence of the large north profile shows seemingly continuous overlying strata between the Safavid and the Qadsharian times. This indicates a much longer continuous mining operation between the late 15th century and the early 20th century.

The logistic/subsistence pattern

The level of organisation and subsistence of the mine and the miners is certainly important in understanding the way that these societies coped with difficult circumstances regarding labour force, daily goods and production means. Catastrophes had an even greater impact and seriously disrupted the production process. The overall demand for salt likely also influenced the fortunes of the production process.

There are some areas of interest that provide further insights. The basic question is how stably the miners could be provisioned by the surrounding rural communities, which was of the highest importance if the miners did not come from the surrounding hinterland, but from abroad. Let us start with the miners, as the salt mummies from this site enable deeper insight. Research on their provenance had been carried out regarding regional and inter-regional mobility and their origin (Pollard et al. 2008; Ramaroli et al. 2010). Preliminary analysis of collagen $\delta^{13}C$ and $\delta^{15}N$ of the salt-preserved bodies, aiming at both the reconstruction of palaeodiet and provenance analysis, revealed significant inter-individual differences that suggested different places of origin (Bocherens et al. 2000; 2006; Ramaroli et al. 2010). Looking at these data, especially from the Achaemenid mining group, Saltmen mummies 3, 4 and 5 indicate two different nourishment regimes (according to the hair and skin samples and their nitrogen $\delta^{15}N$ and carbon $\delta^{13}C$ levels; **Fig. 9**). Saltman 4 can be characterised as a complete outsider, while the other Achaemenid miners (mummies 3 and 5) also indicate nutrition from non-local food sources (fish). There is also the evidence of the helminth species, the horse pinworm (*Oxyuris equi*), which indicates connections to Central Asia, where it seems to have originated; it was found in a soil sample at mummy 5 (Nezamabadi et al.

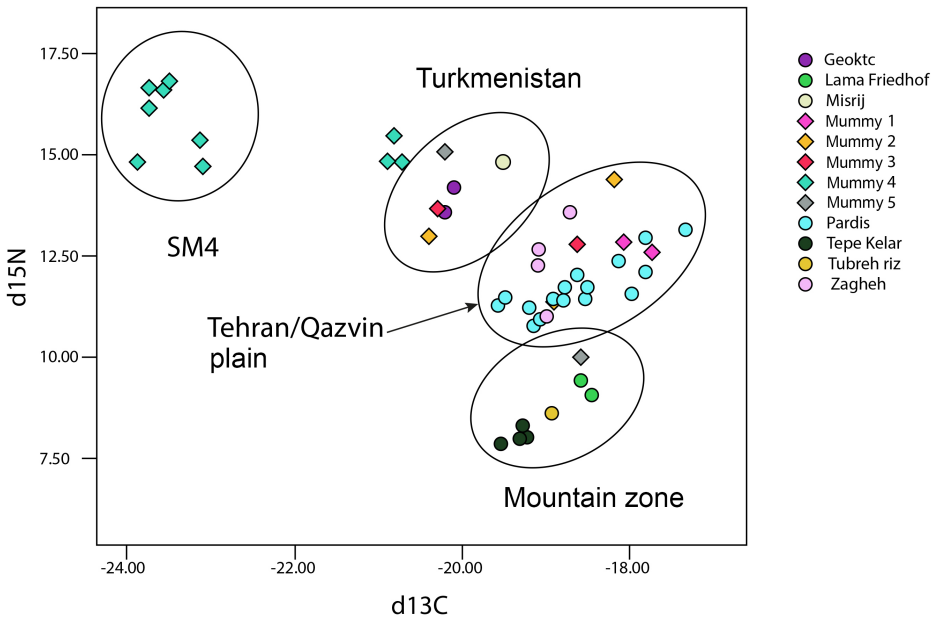

Fig. 9. Nitrogen $\delta^{15}N$ and $\delta^{13}C$-isotope levels of mummy parts of Douzlākh salt mine (Chehrābād) in comparison to human and animal bones from prehistoric and antique contexts from the Northwestern Central Plateau and from Turkmenistan. Chart: DBM/RUB after Bocherens et al. 2000; 2006; Ramaroli et al. 2010.

2013). Saltman 4 shows two different ranges of non-local values, which may suggest that he stayed at the Douzlākh salt mine over a certain time span. Saltman 3 and Saltman 5 have different values from their hair, which fits local data, and their skin, which suggests a foreign provenance. A probable explanation is that a displacement had already occurred some time ago during their lives. A similar pattern of isotope data was also observed for Saltman 2, an adult man who died during the older part of the Sassanian operation period. Only Saltman 1, the late Parthian to early Sassanian individual, seems to have had a local background (Vatandoust and Hadian Dehkordi 2005). The genome data underline the likelihood of workmen migration as a common circumstance of Achaemenid and Sassanid salt production. Mummy 6 has a rare mt haplogroup (U2e) which is currently uncommon in Iran and the Middle East, but more common in Estonia, Russia, Slovakia and the Caucasus (5–10%) (Warinner and Rühli in Aali and Stöllner 2015, 96).

Apart from workmen mobility, there is also the question of supply and whether these logistics were organised as a long-distance supply system or by the hinterland communities. Considering the Achaemenid macrobotanical record, there is a strong argument for stored food supplies, including different grain species such as barley. Fruits such as apricots and peaches were possibly transported in a dried state. In general, the lack of fresh vegetables and fruit is indicative of the Achaemenid period, while the Sassanid and Islamic operation periods produced a far larger number of fruits (nuts as well as grapes, melons and hawthorn), legumes, oil-plants and a broader variety of grains, such as bread wheat, wheat, barley, einkorn, emmer and durum wheat (Boenke in Aali and Stöllner 2015, 63–66). Freshly picked cottons seeds that possibly stuck to the clothes of the miners prove that there were gardens and irrigated fields nearby. We can therefore assume that the rural communities of the hinterland played a major role in mining, particularly from the Sassanian period onwards. This coincides with the lack of Achaemenid settlements in the direct surroundings, while we find younger sites from the Sassanian times upstream in the Talkherud river system (**Fig. 4**). Settlements in the site's vicinity only date to the Middle Islamic period or later.

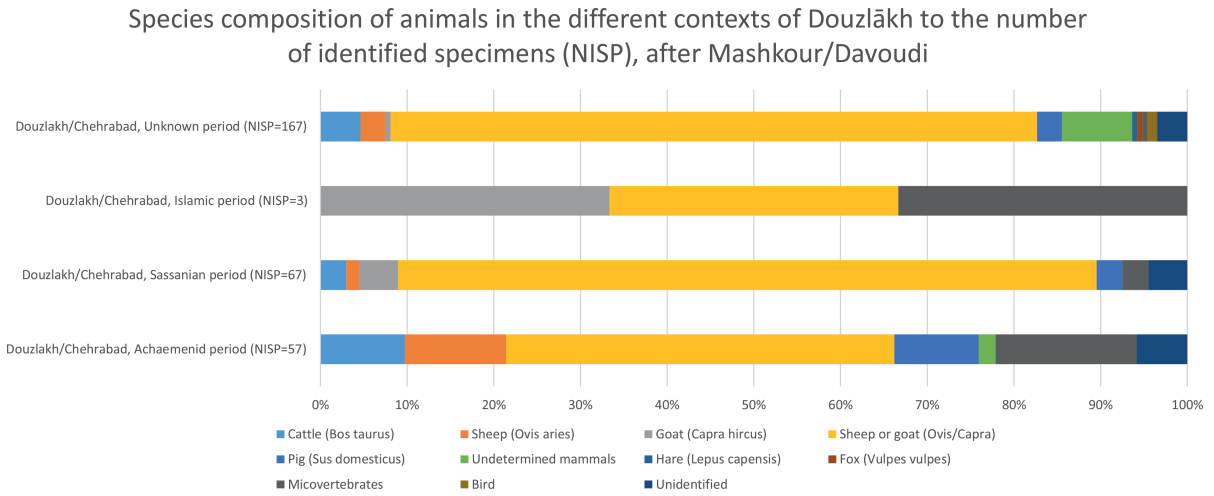

Fig. 10. Species composition in the different prehistoric mining contexts in Douzlākh salt mine according to the number of identified specimens (NISP) in the frame of archaeozoological investigations, after M. Mashkour/H. Davoudi, data till the 2016 excavation. Chart: DBM/RUB, T. Stöllner.

The pattern of domestic animals involved at the mine of Chehrābād is also indicative. Only a small number of domestic animals are evidenced during the Achaemenid period (Mashkour in Aali and Stöllner 2015, 112–17; **Fig. 10**). Cattle and pig bones indicate the delivery of food consumables during that period, rather than husbandry near the mine. The situation is different in the younger Sassanian operation period, when ovicaprids again held a dominant position in the domestic animal record. There is still uncertainty regarding the correct interpretation of these differences, but it seems plausible to understand the higher proportion of rather immobile and meat-providing animals during the Achaemenid period as a result of centrally organised food delivery to the mines, particularly considering the lack of contemporary settlements in the area.

What is still lacking with the biogene materials from Chehrābād is a systematic investigation of stable $\delta^{18}O$-isotopes of sheep and goats (bones, fur and wool) in order to understand the pastoral economy around the mines, especially during the Sassanian period. It is clear that donkeys played a major role in transporting the salt (Askari et al. 2018) and that goat and sheep herds were kept in the area, possibly roaming the landscape and bypassing the mine, where some of them were exchanged to provide meat and fur for the mine. From Pahlavi texts we know about daily workloads being rewarded traditionally by meat parts. Therefore, it could be assumed that the distribution of meat parts was a way to remunerate the workers in the mine (Macuch 1990). This could explain the increase in sheep and goat meat as provision for the miners in comparison to the Achaemenid period. The higher proportion of cattle and pig indicates that the herds, including some sheep and goats, were kept nearby the mine, with the miners.

Discussion

The Chehrābād mine and the older Bronze Age evidence from Veshnāveh suggest that traditional extensive exploitation modes, including seasonal access to the deposit, were often accompanied by food provisions delivered from afar, and by domestic animals that came with the miners. Sheep and goats were the most numerous, with the miners using pastures surrounding the mines for their flocks to graze. This afforded rather small groups of miners some sort of stable provisions while working away from their settlements in the mountains, even more if they preferred a semi-nomadic or nomadic way of life. The situation was similar during the Iron Ages, especially during the Achaemenid period. From the latter, we have the textual sources of fatigue duties, the so called *bandaka*, by which workmen (*rabbap*) could be sent to other parts of the empire (Klima 1977). These groups of workers might have organised their provisions similarly to how miner-herder communities traditionally did it. Domestic animals and possibly other supplies were taken to the mines. As deep mining required a higher level of constant supply (tool handles, iron picks, lamp oil, ropes, baskets, textiles and more), we have to assume that there was a generally higher level of organisation. A similar directional background probably explains the foreign origin of many of the workers. It is nonetheless noteworthy that the salt mining of Chehrābād flourished and was active in times when centralised state control is assumed to have been in place (Achaemenid, Sassanian, Seljuq-Ilkhanid and Safavid-Qadshar period). This state-controlled organisation might have been favourable when coping with serious problems. When after some decades the Achaemenid salt mine of Chehrābād collapsed, it brought mining in general to an end. This was not so during the younger phases: in the obviously longer-lasting Sassanian exploitation, there were two mine collapses. Even for the younger event, it

is doubtful that it led to the end of all activities. The remains of the dead (mummy 2 and 6) were re-dumped during younger activities; therefore, a complete breakdown is unlikely. The end of the mining activity in that period is instead likely related to the Arab conquest at the beginning of the 7th century, when changes in economic and trading patterns have to be assumed (Spuler 1952). What seems clearly connected with the longer-lasting mining operation is an already developed hinterland with gardens and most likely an irrigation system that allowed settling around the Douzlākh, especially from the Middle Islamic period onwards. Therefore, we would expect the Sassanian or Middle-Islamic rural landscape and its mining site to have formed a better strategy to withstand serious breakdowns in production and the loss of experienced workers. Would we qualify this as stronger resilience to the dangers and variable fortunes of the mining process? By applying the adaptive cycle concept to the salt mining history of the Talkherud basin, one certainly could argue that the reorganisation of the mining became possible through the evolution of an agrarian hinterland, most likely during the Parthian/Sassanian period. This had a major impact on the abilities of the communities involved to handle major problems and catastrophes. When looking at the examples of the Central Plateau in more detail, we learn that traditional miner-herder communities were able to react quickly, as raw material exploitation was certainly only one part of their economic activities. We may ask how resilient miner-herder traditions were influenced by institutional demands in stable and large raw material deliveries, and how this altered their raw material networks. The Achaemenid fatigue duties, the *bandaka*, remained possibly in the old concepts of seasonal access to mineral resources, but was replaced by far-distance modes of transferring goods and workers. This led to less flexibility in coping with sudden problems. At Chehrābād the problems of providing provisions for larger-scale exploitation were only solved when a regional rural hinterland was established. The strategies of subsistence and patterns of mobility as part of complex social organisations were established in connection with the mining, enabling the latter to withstand serious problems in production, supply and trading.

Conclusions

How we appraise the resilience of different exploitation modes to withstanding environmental changes and economic stress, provoked either by sudden catastrophe or by long-lasting transformation, depends on how the communities were embedded in their social, economic and environmental surroundings. If the mining was appropriate to societal demand for a raw material and if this also applied to the level of subsistence activities in the landscapes involved, we see long-lasting effectiveness of concepts. The miner-herder strategy certainly evolved since the older prehistoric periods and was still active in historical periods within nomadic groups. Braudel's concept of a long-lasting *géohistoire* (e.g. Braudel 1972; 1977) can be applied here, as the regional Talkherud salt mining history bears the aspect of continuing societal, political and economic development from the Sassanian period onwards. The attempt of state organisations to increase stability and production probably altered the traditional concepts. When exploitation reached a larger scale, the concepts had to be directional and had to involve rural communities as well. This produced higher vulnerability if exploitation groups had to be provisioned in fringe areas (mountains and arid zones), and if such groups faced serious problems. For instance, after the Achaemenid catastrophe in Chehrābād, the mine and the salt production were lost for a longer time span. Its organisational concept was not resilient enough to restart the exploitation after a short while.

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