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At the Dawn of Early Extractivism: Firesetting and Herding as practices of Early Mining Communities between Europe, Eurasia and West Asia

Thomas Stöllner, with a contribution of Erich Pucher

Abstract: The presentation aims at the dissemination of knowledge stocks within mining communities between Europe, West Asia and Central Asia between the 4th and 2nd millennium BC. Within this vast space, remarkable technical similarities in subsistence practices and ore extraction can be observed. They include ore extraction by means of firesetting, the extraction of ores with the help of special tool-sets and the subsequent ore dressing before the mines, as well as the regular transport of ore concentrates to settlements nearer or further away, where the ores were further smelted and cast into shape with the help of crucibles. These techniques required the appropriation of montane resource-scapes through more or less permanent, but mostly seasonal practices and a way of life equally tied to this rather extensive and mobile strategy at certain times during the year. It can be assumed that the management of grazing zones and animal herds had to adapt to these conditions in a specialised way and that other agricultural strategies were added in phases, when greater continuity in the year-round care of the fields was possible in the settlements. Climatic and subsistence conditions in the montane resource areas thus played an important basic prerequisite for the adaptation of technical practices in ore mining and further processing. Just as the basic geological conditions favoured the spread of certain techniques. The article compares some intensively studied ore mining sites (Georgia, Kazakhstan, Iran, Austria) of this period and sheds light on similarities, but also differences in a time before the development of first economized and extractivistic metal ore mining, which took place between the 3rd and 2nd millennium BC in different places in Eurasia and West Asia.

Keywords: Early Metal Age, Bronze Age, mining, firesetting, husbandry and pastoralism, food-supply, commercialisation

Résumé : L'exposé vise à montrer la diffusion des connaissances au sein des communautés minières entre l'Europe, l'Asie occidentale et l'Asie centrale entre le IVe et le IIe millénaire avant notre ère. Au sein de cet immense espace, on observe des similitudes techniques remarquables dans les pratiques de subsistance et l'extraction du minerai. Elles comprennent l'extraction du minerai à l'aide de l'abattage par le feu et de maillets en pierre et le traitement ultérieur du minerai devant les mines, ainsi que le transport régulier des concentrés de minerai vers des villages plus ou moins éloignés, où il était fondu et mis en forme à l'aide de creusets. Ces techniques nécessitaient l'appropriation des espaces de ressources montagnards par des pratiques plus ou moins permanentes, mais le plus souvent saisonnières, et un mode de vie également lié à cette stratégie plutôt extensive et mobile à certaines périodes de l'année. On peut supposer que la gestion des zones de pâturage et des troupeaux de bétail a dû s'adapter de manière spécialisée à ces conditions et que d'autres stratégies agricoles ont dû être adoptées lors de certaines phases, lorsque les habitats permettaient une plus grande constance dans l'entretien des champs au cours d'une année. Les conditions climatiques et les conditions de subsistance dans les espaces de ressources montagnards ont donc joué un rôle important dans l'adaptation des pratiques techniques d'extraction du minerai. De même, les conditions géologiques de base ont favorisé la diffusion de certaines techniques. L'article compare certains sites d'extraction de minerais (Géorgie, Kazakhstan, Iran, Autriche) de cette période ayant fait l'objet de recherches approfondies et met en lumière les similitudes, mais aussi les différences à une époque précédant le développement de la première extraction de minerais métalliques économisée et extractiviste, qui a eu lieu entre le IIIe et le IIe millénaire avant notre ère dans différents endroits d'Eurasie et d'Asie de l'Ouest.

Mots clés : Premier âge des Métaux, âge du Bronze, exploitation minière, abattage par le feu, élevage et pastoralisme, approvisionnement en nourriture, commercialisation

INTRODUCTION AND RESEARCH QUESTIONS

The spread of metallurgy since the invention of metallurgical pyrotechnics in the 5th millennium BC can be described as a spread of technical but also social practice bundles (generally Roberts et al., 2009; Hansen, 2013). Metal as a social innovation probably included further economic, social and technical innovations associated with the extraction of metal ores in mainly mountainous regions (Stöllner, 2023a). In addition to the more permanent use of ecological marginal zones, developments from the 4th millennium BC onwards also led to the permanent expansion of mining regions. Ultimately, all of this points to a variety of knowledge complexes and innovation bundles that were absorbed, adapted and finally made into stable subsistence practices and their interrelation with social communities. Within this process, two sets of practices seem to be of central importance: the technique of setting fires and the development of distinct herding practices as an important source of meat and dairy products. Both practices depend on the climatic and subsistence conditions in the mountainous resource areas (wood, grassland) and thus played an important role in the adaptation of technical practices in ore mining. They provide the background to the question of what were the enabling and limiting factors when mining turned into a commercialised enterprise that also generated dependencies in various respects (food and supply regimes and ecological potentials). Even more, one could ask whether this period witnessed an 'economisation' of practices towards capacity-based mining (in the sense of an early extractivism).

The practice of firesetting is associated with a specific set of technical practices, including the subsequent processing of ore in front of the mines, as well as the regular transport of ore concentrates to settlements near or far, where the ore was further smelted and shaped using crucibles (e.g. Weisgerber and Willies, 2000; Strahm and Hauptmann, 2009; O'Brien 2015, p. 195–243; Hauptmann, 2020). Its oldest evidence is known for ore extraction at the end of the 6th and the beginning of the 5th millennium BC in the Middle Balkans and the Vinča culture (Jovanović, 1982; Radivojevic and Roberts, 2021). It is interesting to note that this technique, as well as the use of other techniques, such as the use of stone hammers and antlers, was initially used in the mining of jasper and green pigments in the 5th and 4th millennia BC (Schmid, 1999). It was not until the 4th millennium B.C. that the technique became the standard method over a wide area along the Tethyan Eurasian mountain belt and finally in the area of tin ore mining (from the 3rd millennium BC; Stöllner 2023a, p. 41–42; see here fig. 1). The connection with a deposit area with specific geological conditions of

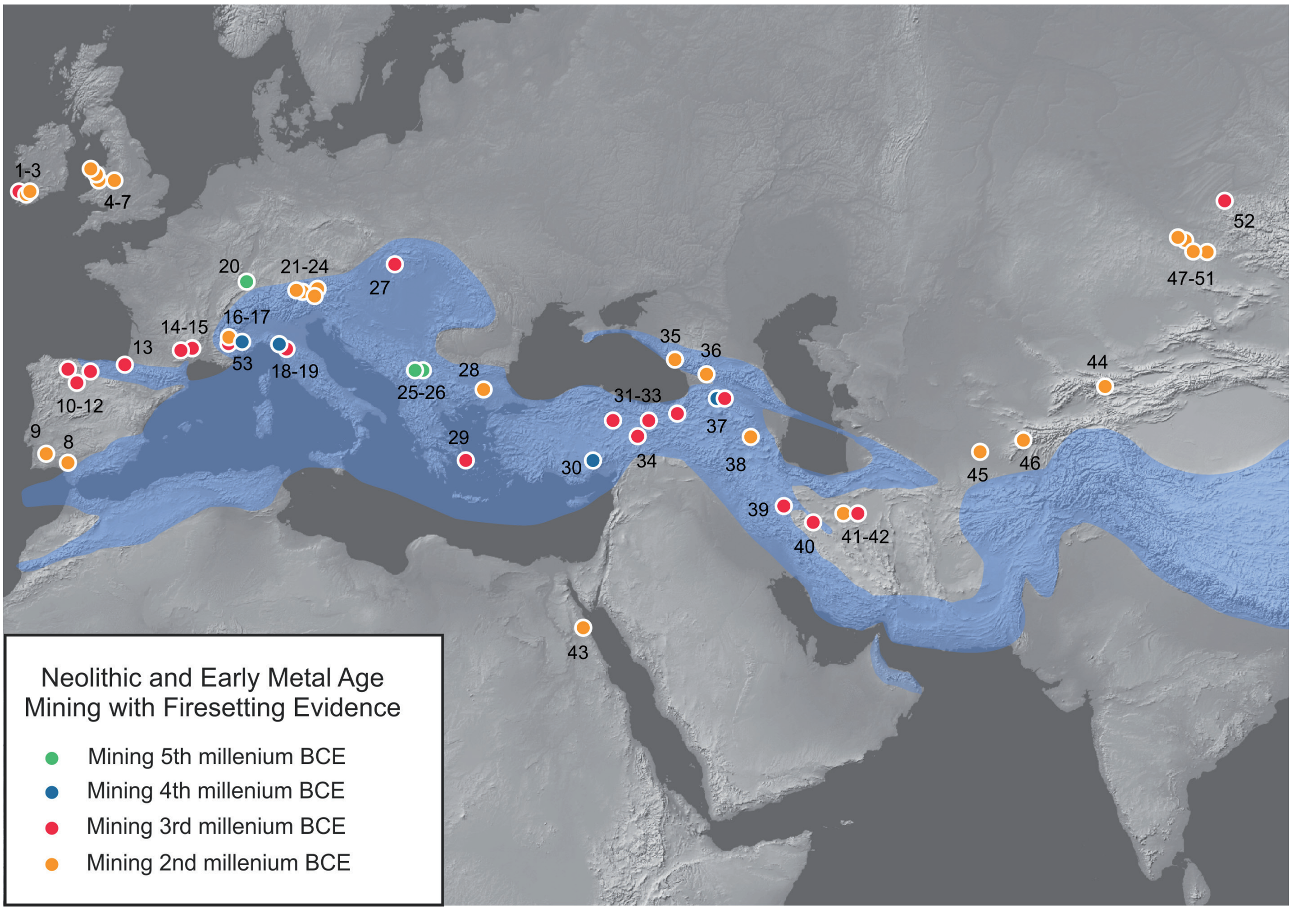

Fig. 1 – Firesetting in prehistoric mining (5th till 2nd millennium BC) and the TEMB-girdle (blue): 1: Ross Island; 2: Mount Gabriel; 3: Derrycarhoon; 4: Parys Mountain; 5: Great Orme; 6: Cwmystwyth; 7: Alderley Edge; 8: Chinflon; 9: Mocissos; 10: El Aramo; 11: El Milagro; 12: La Profunda; 13: Causiat; 14: Cabrière; 15: Bouco-Peyrol; 16: Saint-Vérant; 17: Les Rousses; 18: Libiola; 19: Monte Loreto; 20: Kleinkems; 21: Schwaz; 22: Brixlegg; 23: St. Veit; 24: Mitterberg; 25: Rudna glava; 26: Jarmovac; 27: Špania Dolina; 28: Adatepe; 29: Siphnos; 30: Kestel; 31: Gümuşhane; 32: Kozlu; 33: Murgul; 34: Zeytindağ/Keban; 35: Bashkazara; 36: Saarkasch; 37: Sakdrisi; 38: Mazrayeh; 39: Shakin; 40: Veshnaveh; 41: Kuh-e Zar, Anaru; 42: Kuh-e Baba Ahmad; 43: Jebel Zeit; 44: Aktaš; 45: Karnab; 46: Mushiston; 47: Karagoin; 48: Askaraly; 49: Kalai Topkan; 50: Urunchaj; 51: Čerdojak; 52: Vladimirovka; Altai (Map: DBM/RUB, Th. Stöllner).

hydrothermal deposit formations (veins and mass deposits), especially complex ores with quartz-rich, intergrown ores, indicates a connection with the application of the process (summary: Hauptmann, 2020). In addition, these more northerly and less arid regions (compared to the more southerly areas, for example) had better access to locally available fuels, which made the more extensive use of the techniques possible in the first place. The mining areas of the southern Levant (Egypt's Eastern Desert, Sinai, Wadi Arabah and Fenan), for example, have yielded little evidence of fire setting, suggesting ecologically unfavourable conditions for the use of the technique.

Firesetting and pastoralism as practice bundles therefore required the appropriation of mountain resource spaces through more or less permanent living and subsistence practices. This question became even more debated after A. Sherratt introduced 'secondary products' such as milk, cheese or wool as an important aspect of earlier prehistoric societies more than 40 years ago (Sherratt, 1981; 1983; critically: Vosteen, 1996; Craig et al., 2005).

M. Pearce speaks here of a metallurgy-pastoralism nexus (Pearce, 2025), but perhaps it is more appropriate to generalise it to a mining-metal-pastoralism nexus. The link in the appropriation of a mountainous landscape has already been demonstrated years ago by M. Pearce and R. Maggi (2005) in relation to the Ligurian Apennines. Other examples have since been discussed (Antipina and Morales, 2006; Berthon et al., 2021; Stöllner et al., 2022). In another context, I have called this a miner-herder strategy, which is linked to specific practices and can also lead to a certain tradition of action in specific landscape and climatic settings (Stöllner, 2023b). But also the vision of a (larger) meat supply, either in processed parts or in live animals, is discussed (Wijngaarden-Bakker, 2004; O'Brien, 2015, p. 264–265), as well as their reuse, mainly as working tools, as in the Great Orme (James, 2008; 2011). In many cases, however, the actual link to pastoral practices in the agricultural hinterland remains to be understood in order to understand the involvement of the mining communities themselves. The mobility patterns of domesticated animals, discussed later in this article, may provide a possible answer to this question.

For earlier periods, however, it remains to be seen whether the increasing appropriation and reorganisation of mountain areas actually led to a close economic symbiosis between herders and miners, or whether this was characterised more by coexistence (as has been suggested for the Kargaly mining complex in the southern Urals: Antipina and Morales, 2006). In the Alpine Arc, the development of hard cheese production may have become a similarly important aspect in later parts of prehistory. This required not only innovations in rennet management, but also a constant supply of table salt. Although current research in the Central Alpine Arc has only been able to establish a definite link between hard cheese production and alpine pastoralism in the Iron Age (Reitmaier, 2020), the production of fresh cheese (with a limited shelf life) and wool may have occurred even earlier.

The conspicuous linkage of the technique to certain ecological zones suggests that the spread of the technique occurred through the transfer of knowledge along similar ecological and economic lines. The central question may therefore be whether this spread (e.g. from south-eastern Europe to the west, east and south-east) took place through mobile mining groups passing on their knowledge of how to establish and adapt the technology to other communities related by metal consumption. But how was the division of labour organised within the mining groups? This certainly depended on the scale of production that was intended and that was to be achieved. A small labour force could certainly practise a different division of labour within kinship groups than larger enterprises. The gradual increase in the use of metal and raw materials probably changed the traditional strategies of direct access to other, more permanent strategies of managing ore deposits and subsistence conditions (as can be seen in large mining operations such as Mitterberg [Stöllner, 2015; Pernicka et al., 2016] or the Great Orme [Dutton et al., 1994; Williams and Le Carlier de Veslud, 2019]).

In the following, I will examine several intensively analysed ore mining sites from the 4th to 2nd millennium BC in Georgia, Kazakhstan, Iran and Austria, which the Bochum teams have been able to investigate for more than two decades. In particular, the question of the significance of different conditions for the connectivity of the montane deposits will be investigated. The question is whether certain technical and subsistence patterns can be compared in different ecological zones (Caucasus, Iranian highlands, Eurasian steppe zone, Alps). What kind of miner-herder practices can be observed? In contrast to the diffusion of metallurgy, the focus is more on the appropriation of peripheral environments and the application of knowledge practices in such ecologies.

FIRESETTING AS A TECHNICAL PRINCIPLE IN EARLY METAL AGE

Physical and chemical preconditions

Fire setting is not equally effective in all rocks because it relies on heat-induced expansion along the crystal lattice axes of certain minerals such as quartz, feldspar, calcite or iron carbonate (for physical requirements see Weisgerber and Willies, 2000, p. 135). This mineral association is common in igneous, sedimentary and metamorphic rock sequences. Quartz in particular has a high expansion behaviour, which is why quartz-rich rock sequences are particularly suitable for the application of this technology. The temperatures achievable in an open fire are typically between 600 and 800°C. Depending on the mineralogical composition, these temperatures have different effects: the heat capacity and density of the rock, together with the water chemically bound in the rock, determine the explosive effect of the heat applied to the rock: Sinock

(1984, p. 49–50) gives coefficients of thermal expansion for some important minerals. As already mentioned, quartz has the best expansion behaviour (4.42 at 800°C), followed by microcline, orthoclase and plagioclase. Not only do the minerals differ in their expansion behaviour, but also in their critical fracture temperature. Whereas basalt fractures at around 550°C, quartzite, granite and granodiorite fracture at temperatures between 200 and 300°C.

Ore-bearing rock formations are rarely so homogeneous that the effects of a fire can be accurately predicted. Other parameters must also be taken into account. The fuel available (in addition to logs, charcoal or brushwood can be used) must be considered, as must the influence of air currents (especially underground). The interaction of these and other parameters is crucial to the success of the technology. This is clearly demonstrated by the experience of various firesetting experiments (see below).

The early use of fire: basic techniques and evidence from the oldest metal ore mining

In addition to the use of fire itself, the technology is always associated with certain technical aids that are time-bound (Weisgerber and Willies, 2000). Within the prehistoric periods, an interaction with stone hammering can in principle be observed. There are also other components, such as certain bone and antler tools, which can vary in time and space. However, archaeological observations show that there are differences depending on the rock and the type of mineralisation. These can easily be understood as local adaptations from a basic repertoire of technical possibilities and experience. While the prehistoric firesetting technique developed from the 5th millennium BC onwards was mainly based on the interplay with stone hammering, metal tools (bronze, iron) were increasingly used to work the surfaces set on fire.

In this way, fire setting could be used as the main driving technique or in a supporting role. Bjørn Ivar Berg (1992, p. 55–76) therefore divides the driving work into three steps: hammering with fire setting, fire setting with hammering, or just fire setting.

The use of fire setting has to be implemented with varying degrees of efficiency in the driving work: the effect of the fire is more effective on the roof and walls than on the floor, making shaft sinking more difficult. On the other hand, sideways sinking at ground level is not a problem, provided that the working area is well ventilated. Under good ventilation conditions, sinking a vertical shaft is not too difficult and, in the case of this installation, could certainly be combined with lateral widening work, including the use of fire. However, the initial driving of a level area from a certain depth was always associated with ventilation difficulties, which is why laterally widened so-called tumble mines (for the term, see Weisgerber, 1989) were often preferred in early mining. Chimneys and ventilation shafts are also known. This principle can be clearly seen in the mines of Veshnaveh or Schwaz-Brixlegg (see Goldenberg and Rieser, 2004, p. 41, figs. 5–6; Stöllner et al., 2011a, p. 599).

The lighting of the fire was an important moment: not only did the sudden appearance of dangerous fumes have to be taken into account, but the direction of the fire also had to be supported. The construction of the woodpile was certainly of paramount importance, but in addition the fire could be steered in a certain direction by means of firesetting platforms or covers (stone slabs, 'muffles') (Gätzschmann, 1846, p. 697, p. 706; Weisgerber and Willies, 2000). In early modern mining there were detailed regulations on the development of flue gases (Agricola 1556, Book 6, p. 185; Weisgerber and Willies, 2000, p. 141).

The early use of fire: its manifestations in prehistoric copper, tin and gold mining

As mentioned at the beginning, the use of fire is one of the oldest and most important extraction techniques in ancient mining. Without being able to describe all the phenomena in detail, some examples of research carried out by the Deutsches Bergbau-Museum in Bochum in recent years will be discussed: They illustrate the application of the technology in various ore districts. In the Veshnaveh copper deposit (3rd/2nd millennium BC), driving was used throughout; since highly enriched copper ore nests in stratiform enrichment zones usually extend horizontally in basalt and andesite rocks, the advance was laid out to follow the rich ore parts (fig. 2, 1-3). Niches and linear drifts were driven up to 30 metres into the rock. In very rich ore zones, the drift was extended laterally. However, these were mostly driven adits, which in turn were laterally extended (Stöllner et al., 2011a, p. 598–600). One particular example is Mine 21 at Chale Ghar, where a panel with so-called exfoliation plates was discovered at the end of the adit.

These were probably left at the end of the last mining operation. Fire-set stopes developed differently in deposits with vein-like and subvertical ore bodies. Good examples are the tin mines of the Andronovo Culture in Central Asia: excavations at the mines of Karnab and Mushiston (Uzbekistan, Tajikistan) between 1997 and 2000, as well as the mines of Askaraly (Eastern Kazakhstan), have provided very good evidence for this technology (Stöllner et al., 2011b; Garner, 2014) (fig. 2, 8-11). At Askaraly, the highly enriched cassiterite veins and ore strings were mined in an enrichment zone. The individual firesetting domes became very high: this also necessitated the construction of firesetting platforms, as demonstrated in the fully investigated mine workings of Askaraly II, Western Mine (Stöllner et al., 2011b, p. 242–244). Such platforms have been documented by P. Pétrequin for the production of adze blades by the Yeleme in New Guinea: simple wooden scaffolds are leaned against the steep quarry wall and a fire is lit on them (Pétrequin and Pétrequin, 1993; Pétrequin et al., 2008). The wooden platform burns down with the fire before the

Fig. 2 – Firesetting traces in Bronze Age mines in West Asia and Eurasia. 1-3: Veshnaveh, Qom Province, Iran (Chale Ghar mine 21, Lagh-e Morad, mine 1); 4-7: Sakdrisi, Bolnisi district, Georgia (mines 1/2 north extension; mine 1/1; mine 1/2 north-extension, hammering traces; mine 2, southern drive mit Firesetting debris; 8-11: Askaraly II, Özkemen oblast, Kazakhstan, East mine 1, west drive with refilling, East mine 1, west drive lowest flour, West mine east lowest drive with burned wooden stage, West mine, east lowest drive wirth Firesetting debris, refilled; (photos: DBM/RUB, Th. Stöllner, J. Garner [9]).

desired piece of rock can be broken (fig. 2, 10). The granite dug mine at Askaraly is in many ways similar to the mines at Karnab, which were investigated in the 1990s as part of a large collaborative project (Pre-Islamic Tin Mining in Central Asia, 1995-1999; Garner, 2014). The mines were excavated to a depth of 17 m (pit 6/1: Garner, 2014, p. 95–98); similar depths were also reached in the Mushiston mine, while the Askaraly II mine stopped at a depth of almost 10 m. The almost shaft-like descents that could be reached by mining are interesting: examples of this type can be found at Askaraly II, West Mine (Stöllner et al., 2011b), at Karnab, Mine 6/1 (Garner 2014, p. 95–98), and in Georgia, Sakdrisi, Mine 1/1 (Stöllner et al., 2014).

A close analysis of the driving direction shows that the extractions were not aligned, but that very steep advances were made in short alternation in opposite directions. This is evidenced by short, flat steps that descend like stairs. This is particularly evident in mine 1/1 of the Sakdrisi gold mine: the steeply sloping part of the mine reached a depth of over 11 metres and could only be worked steeply upwards (fig. 2, 4-7). The use of firesetting allowed the Sakdrisi miners to reach depths of almost 30 m from the surface in extremely hard rock. The haematite-gold ore is embedded in a quartz-rich vein and silicified host rock of dacite and rhyolite: This required a great deal of hammering, as is clear from the thousands of hammer fragments found in the mining area (Stöllner et al., 2014; Tamazashvili, 2024).

The processing equipment found in Early Metal Age mines also follows a certain pattern, albeit with many variations. The tool most often found in connection with the use of firesetting is the stone hammer. At Karnab, the limestone used there (quartz-rich shell limestone: Garner, 2014) was only effective on the quarried granite in combination with firesetting: metamorphic rocks such as amphibolite, lamprophyre (Veshnaveh; Stöllner et al., 2011a) or andesitic rocks, porphyrites and granodiorites (Sakdrisi) were often used (Stöllner et al., 2014; Tamazashvili, 2024): As a rule, a certain section of rock types predominates. This is impressively demonstrated in Sakdrisi: the rock types found in Sakdrisi can be found as river pebbles in the nearby Mashavera River. However, it was found that the 100 formally suitable rocks collected did not match the spectrum of rocks found in the hammers found in the quarry. In particular, dense andesitic-basaltic rocks appeared to have been deliberately selected, followed apparently by granodiorites, which were collected a little more frequently.

The question of the method of hafting is more difficult because it has been demonstrated less frequently. Without going into all the evidence in detail, it should be noted that there is evidence of knotted hafting from Central Asia to Ireland, as discovered in the 19th century at Mitterberg in Salzburg (see, among others, Thomas 2018; for the example from Askaraly, cf. Stöllner et al., 2011b; fig. 3,7609). Thanks to the excellent excavation observations at Copa Hill (Timberlake, 2003a), there is also evidence for the so-called Chuquicamata shafting, a type that has proved particularly effective in experiments (Craddock, 1992; Timberlake and Craddock, 2005; Timberlake, 2017). In this case, the mallet is held in place by tied willow or hazel rods or hazel sticks. These are bent into a U-shape over a notch or shaft groove and the shaft is tied with rawhide.

In addition to the wide variety of hammers used in the mines described, other types of bone tools were also used (fig. 3). In addition to antler picks, such as those found at Sakdrisi, scrapers made from ox ribs and scrapers made from ox shoulder blades are common. They are known from all the sites described above, but ultimately from

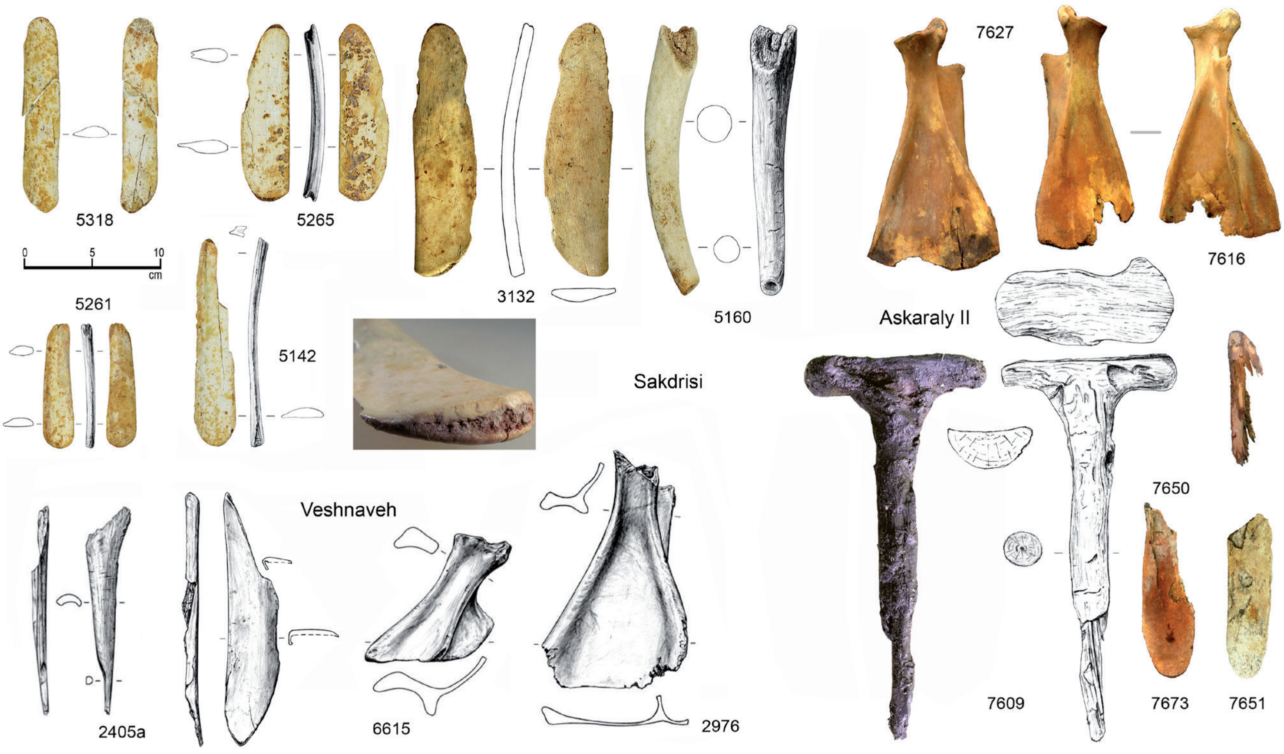

Fig. 3 – Bone tools from Bronze Age mining in Sakdrisi /Georgia, Veshnaveh/Iran, Askaraly II/Kazakhstan, antler, bone chisel, rib scrapers, shoulder blade scrapers, wooden handle (photos/drawings: Th. Rabsilber, K. Tamazashvili, J. Garner, Th. Stöllner).

all early metalworking sites, such as the Early to Middle Bronze Age examples in Wales and the Peak District (The Great Orme-Copa Hill, Cwmystwyth, Ecton, Derbyshire hire, Great Orme near Llandudno: Timberlake, 2003a; 2003b; unclear at Great Orme: Dutton et al., 1994; generally O'Brien, 2015).

Hammerstones and ore mills have often been found together. Particularly characteristic are 'dimple stones' with numerous cup-shaped depressions, which can be used effectively with stone hammers the size of a child's fist. Smaller and also widespread are small palm-sized underlays, often with a central depression (e.g. Garner, 2014). The case of Sakdrisi, in particular, has shown how diverse this working tool could be developed if the processing had to differentiate in detail (e.g. between gold-rich and gold-poor sands).

The wood needed for firesetting has been analysed in some cases: So far there is no evidence for the use of charcoal in the older prehistoric periods: in general, the natural supply of wood depends on the forests used, as shown by various archaeobotanical studies of ash and charcoal layers in early metal mining areas (fig. 4). In Sakdrisi, local oak was generally used as a heat-retaining wood (W. Schoch, in: Stöllner et al., 2021). In contrast, 10% consisted of a variety of brushwood, which was probably burned in the fire. In the tin mines of Askaraly in eastern Kazakhstan, on the other hand, juniper and conifer brushwood (*Juniperus*, *Abies* sp.) were used as brushwood, while poplar and birch were used as heat-retaining logs (det. W. Schoch, Stöllner et al., 2011b). This pattern of fuelwood use differs significantly from that found in the contemporary settlement and from the practice of cremation in the cemetery (fig. 5). In contrast, the

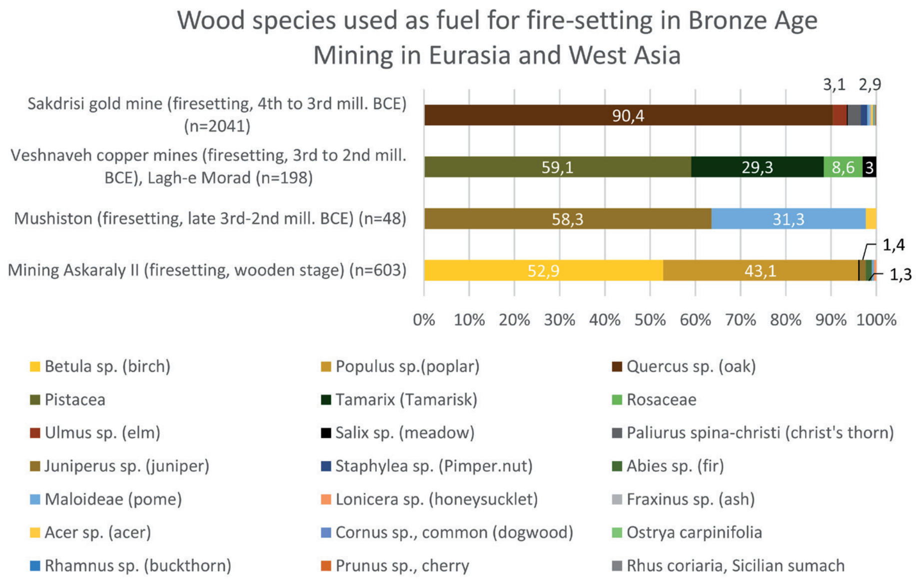

Fig. 4 – Wood-species used for Firesetting from Bronze Age mines in West Asia and Eurasia (data W. Schoch, Birmenstorf; R. Pasternak, Kiel).

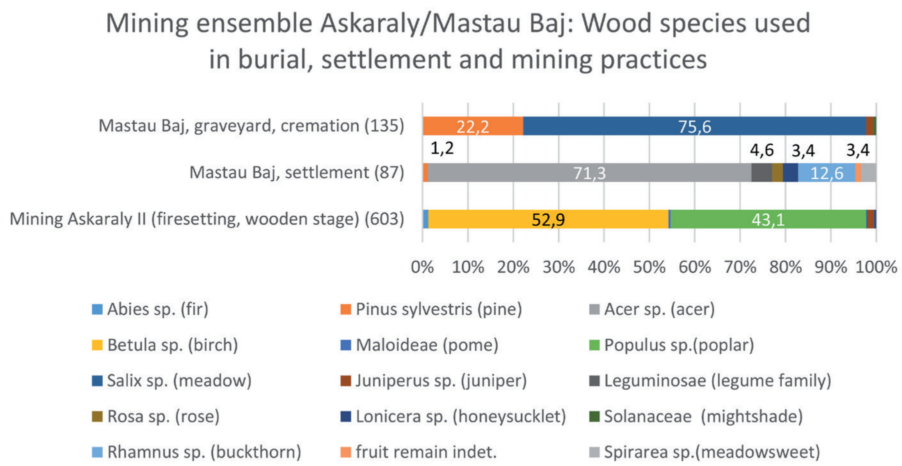

Fig. 5 – Wood consumption pattern of the Bronze Age mining community of Askaraly II/Mastau Baj in East Kazakhstan (data W. Schoch, Birmenstorf)..

very dry climate has affected the tree population in the copper mines of Veshnaveh: however, charcoal analyses have shown that in the 2nd millennium a combination of heartwood (pistachio) and tamarisk brushwood was used. R. Pasternak also assumes a denser forest cover than today, reduced probably due to intensive grazing since then rather than mining (R. Pasternak, in: Stöllner, et al. 2011; see here fig. 4). In the sparsely vegetated steppe around Karnab, wormwood shrubs seemed to be the only useful woody plants, but their suitability was demonstrated in a firesetting experiment (Garner, 2014).

Bronze Age mining in the Eastern Alps, where spruce and fir have been found (Zschocke and Preuschen, 1932; Rieser and Schrattenthaler, 1998–99, p. 175), whereas in the British Isles oak and beech heartwood were preferred (O'Brien, 1994, p. 166; O'Brien, 2004). It is unfortunate that we lack a modern investigation of the firesetting techniques proposed by Zschocke and Preuschen (1932) for the Mitterberg type of East Alpine deep mining. This is different for the copper ore mining in the carbonates of the Schwaz-Brixlegg district, where detailed modern observations are available (Pichler et al., 2013; Staudt et al., 2019). It is striking that, despite the wide variety of wood available, a combination of heat-bearing heartwood and heat-sparking brushwood was often chosen. This also proved to be a practical combination in the burning experiments.

Fire setting experiments of Bronze Age Mining

There is already a wide range of fire setting experiments to understand their use in prehistoric and historic mining (Rieser and Schrattenthaler, 1989/99; O'Brien, 1994; Schmid, 1999; Timberlake and Craddock, 2005; Py and Ancel, 2006; Timberlake, 2007 and 2017; Stöllner et al., 2012). Most of these experiments were based on historical accounts or archaeological observations of mining sites. This is different from the experiments of P. and A.-M. Pétrequin, which were designed on the basis of ethnographic observations in Papua (Pétrequin et al., 2008). E. Schmid in Kleinkems, who was one of the first to conduct experiments in 1952, tested water dousing (Schmid, 1999). Later experiments by Rieser and Schrattenthaler (1998/99), Timberlake and Craddock (2005), and Timberlake, Stöllner and Craddock (Stöllner et al., 2012; Timberlake, 2017) showed that this is not absolutely necessary. In the hard limestone of Kleinkems, however, it has proved helpful, as it did in the extraction of lapis in Badakhshan (Weisgerber, 2004, p. 133). It helps to cool the stone quickly, but does not increase the amount of stone.

The experiments conducted to date have also provided insights into the ratio of wood used to rock produced (the so-called wood-rock extract ratio), which ranged from 1:0.8 to 1:2.3 in the Welsh experiments and as low as 1:0.27 at Mount Gabriel, Ireland (O'Brien, 1994). In the Sakdrisi experiment, the ratio was strongly influenced by the amount of iron ore and weathered cracks, but generally an average of 1:0.7 was observed (Timberlake, 2017; here table 1 and fig. 6). Overall, smaller fires were shown to be more efficient. It was found to be important to stack stem wood (log-thick branches or logs) on the outside and brushwood on the inside. Stones were used to weight down the pile, making it easier to direct the fire in one direction. When stones were used, they proved to be very effective, especially in the parts that were exposed to the fire. However, in the parts that were not thermally treated, this efficiency decreased significantly.

The rock material and the preparation of the stone tools were also studied in detail, especially in the Brit-

	Fireset 1/2011	**Fireset 2/2011**	**Fireset 3/2011**	**Fireset 4/2013**	**Fireset 5/2013**	**Fireset 6/2013**	**Fireset 7/2013**	**Fireset 8/2013**	**Fireset 9/2013**	**Fireset 10/2013**	**Fireset 11/2013**
Wood (kg)	214	48	84	174	49	77	50	89	49	50	20
Wood sp.	oak	oak	oak	oak	oak	oak	oak	oak	oak	oak	oak
Wood size(m)	0.8-1.1	0.5-0.8	branch	0.3-0.8	branch	0.8	0.5	0.5–0.8	0.5	0.5	branch
Duration (min)	240	150	210	135	165	270	120	180	150	150	205
Firing time	180	120	180	105	135	240	60	150	120	120	175
Hammering time	60	30	30	30	30	30	30	30	30	30	30
Max temp. (ºC)		796	500	577	746	762	746	666	826	472	577
Water douse (kg)	Y	N	N	Y	N	Y	N	Y	N	N	N
Exfol rock (kg)	78,09	14,7	12.2	4.3	2	5.6		3.26	0.66	6.3	0.3
Pick rock (kg)	35		6,8	9.4	7.7	7.5		22	6.6	5.1	1.4
Hammer rock (kg)	65,7		26	34.5	24.1	15.75		16	2.9	6.6	7.8
Hammer and pick rock (kg)		86,5					69				
Site	vein A-B, face	vein A	underg round	vein B	vein B	vein B	vein C	Vein A-B, face	Feature 10135 Mine B2-3	NW rift, mine A	vein B
Mining time (hrs.)	1	0,5		1.5	1	1		1		0.5	0.5
TOTAL rock (kg)	186	101	45	48	34	29	69	40	10	18	10
Ratio wood: rock	**1: 0.87**	**1: 2.1**	**1: 0.54**	**1: 0.28**	**1: 0.69**	**1: 0.38**	**1: 1.38**	**1: 0.45**	**1: 0.2**	**1: 0.36**	**1: 0.5**

Table 1 – Experimental firesetting and mining experiments at Sakdrisi Mine (2011 and 2013).

Fig. 6 – Firesetting experiments in Sakdrisi 2011 and 2013. 1: preparing the hammer-stone tools with Chuqui-hafting; 2: underground fire-set with dense smoke; 3–4: hammer- and antler-work after the fire-set; 5–7: experimental tools with Mitterberg-, Chuqui-afting, antler-pick; 8: fire-set experiment with the tool-set used and driving cavity; 9: beneficiation experiment with ores and experimental tools (mallet, crushers and grinders); 10: beneficiation tools found in Sakdrisi, dimples-stones, grinding-plates, ginders and small anvils (photos: DBM/RUB, Klaus Stange, AVtention [1-7], T. Rabsilber [10], Th. Stöllner [8-9]).

ish experiments. This revealed the importance of the choice of stone used: the type of stone and its toughness must have been chosen empirically. For the mines at Cmwystwyth in mid-Wales, Timberlake suggests that beach pebbles were used because they would have been exposed to the selection pressure of the surf. It would therefore have been easier to recognise which pebbles were suitable for extraction. The preparation of the notches and stone hammers, i.e. the making of the necessary notches and grooves, could usually be done quickly: after a series of experiments, B. Craddock in particular was able to develop an efficient method for making notches of the Chuquicamata type (the Chuqui shafting). During a series of experiments in Sakdrisi, B. Craddock made various hammers with different possible hafting types to test their efficiency in hammering work (Stöllner, et al. 2012; Timberlake, 2017). The manufactured tools were to be made according to the knotted branch haft (Mitterberg type) and the so-called Chuqui haft (fig. 6, 1): both types were to be tested in direct comparison. For the Chuqui shafts, fresh hazelnut sticks were used, which had to be moistened, twisted at the bend and beaten open to allow optimal placement and fixation on the stone. Untreated, moistened raw goatskin was used to fix the handle of the hammer, which consists of two hazel rods. In addition, a glue made from boiled pig's ears was applied to the raw hide bindings for reinforcement. For the Mitterberg hafting, the rawhide binding was placed over the centre of the stone, which lay flat. An attempt was also made to match the stone to the contact surface of the knobbed hafting. The heaviest hammer weighed approximately 4 kg, while the lighter smaller hammers weighed between 0.5 and 1 kg. While the Chuqui hafting was more suitable for heavy hammers and proved effective for striking from below (underhand stopping), the Mitterberg hafting was best for smaller hammers and direct blows from above (fig. 6). Like a celt, it could also be used on the sole and ridge.

The Sakdrisi experiments also helped to understand the econometric parameters of free gold extraction at Sakdrisi (the so-called Paravani calculation). Firstly, in terms of the operational effort to extract gold from a deposit like Sakdrisi (according to the old enrichment in the veins), but secondly to understand the societal impact that the extraction once had (Stöllner et al., 2014; Stöllner et al., 2021). Reconstruction has allowed us to understand the work load and possible size of the work-groups, but also how continuous the exploitation may have been (year-round or seasonal).

INTERWOVEN MINING COMMUNITIES BETWEEN EURASIA AND WEST ASIA

If we look at the spread of mining practices and techniques as a whole, then it becomes clear that the attachment to certain ecological zones, whether they were arid or humid, may have been associated with certain adaptations in subsistence. Let me now analyse the examples of successful application of both the practice-bundle 'firesetting' and 'herding' in different geographical and deposit zones.

The southern Caucasus and the Dzedzvebi-Sakdrisi complex

We start with the South Caucasus in the 4th and early 3rd millennium BC: here, the extraction and further social embedding of gold production in the Sakdrisi and Dzedzvebi complex can be regarded as one of the best-studied examples of this period (Gambashidze and Stöllner, 2016; Stöllner et al., 2014; 2021; 2023: see here fig 7). Begun in 2004 by a Georgian-German team, the work has since been continued in nearly 14 campaigns and has focused on numerous aspects of gold and copper extraction, ore processing, and their economic and social embeddedness. A further look at Late Chalcolithic-Early Bronze Age developments in the wider Transcaucasian environment makes it clear that the Sakdrisi-Dzedzvebi process emerged during a phase of social and economic consolidation of the Kura-Araxes societies (Stöllner, 2021). This, in turn, was based on an earlier, Chalcolithic phase of extensive resource exploitation of the montane areas between the Kura and Araxes rivers, leading to an

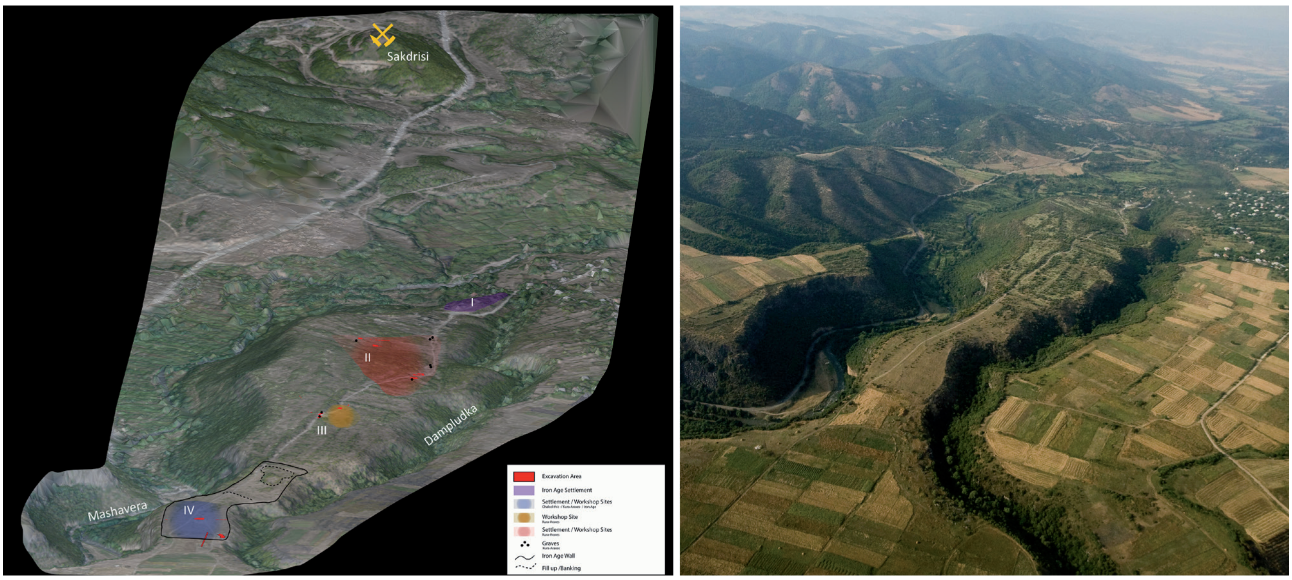

Fig. 7 – Left: The settlement plateau of Balichi-Dzedzvebi and its archaeological sites on the northern hilltop (I, Iron Age), northern slope (Dzedzvebi, area II, Early Bronze Age), on the northern part of the central plateau (Dzedzvebi, area III, Early Bronze Age) and on the southern plateau (Dzedzvebi, area IV, Chalcolithic, Early Bronze Age and Iron Age). Right: aerial photograph of the plateau (left: (plan processing/3D visualisation: DBM/RUB/GNM, A. Hornschuch/F. Klein; right: RUB/DBM, Th. Stöllner).

initial appropriation of metals and high pastures (Stöllner, 2024).

Recent results of studies on the mobility of domestic animals (Berthon et al. 2021; R. Bérthon and A. Vautrin in: Stöllner et al. 2023, p. 111–116; A. Vautrin in: Stöllner and Gambashidze 2024, p. 568–569; Vautrin 2024) show that pastoralism was initially oriented towards high-altitude summer pastures (figs. 8 and 9). With this seasonal mobility, mineral resources such as copper ores, but especially obsidian, were also appropriated and used more systematically (e.g. based on data from Dzedzvebi: Stöllner et al., 2023). In the Kura-Araxes communities, however, access changed again in the second half of the 4th millennium, as settlement landscapes and upland pastures were now used more intensively and permanently (generally Stöllner, 2021). There were now more permanent settlements at higher altitudes, and the mobility patterns of livestock also changed.

The corresponding results from the settlement phases of the Chalcolithic and Early Bronze Age settlement of Dzedzvebi clearly show this intensification, stabilisation, but also professionalisation of agropastoral practices (N. Boenke, in: Stöllner et al., 2023, esp. p. 106–111). Between the gold mines of Sakdrisi and the artisan settlement of Dzedzvebi, a permanent production process developed, which was accompanied by more stable subsistence conditions, probably due to a larger population living in the area for a longer time. The study of pottery finds also indicates that these groups came to the Mashavera valley from different parts of the Kura valley, possibly also via the Armenian plateau, to participate in the production process (Otchvani et al., 2021).

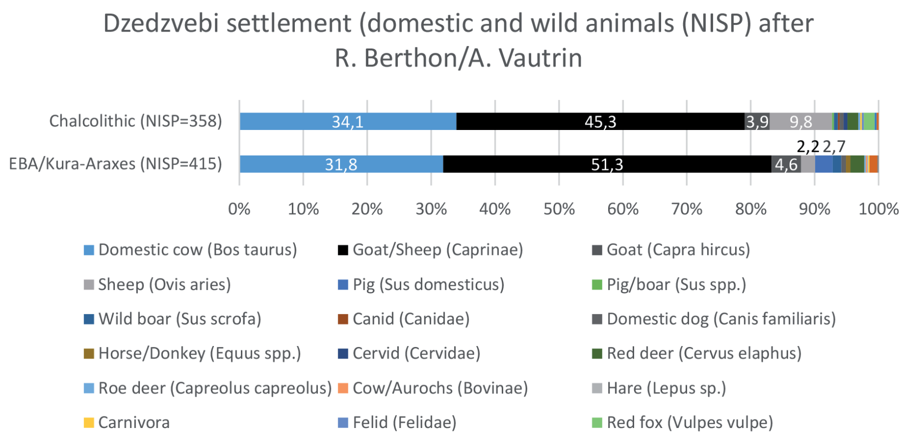

Fig. 8 – Relative representation of domestic mammals from Chalcolithic and EBA levels at Dzedzvebi (in % of the domestic mammals NISP) (draft/data: MNHN, A. Vautrin, R. Berthon).

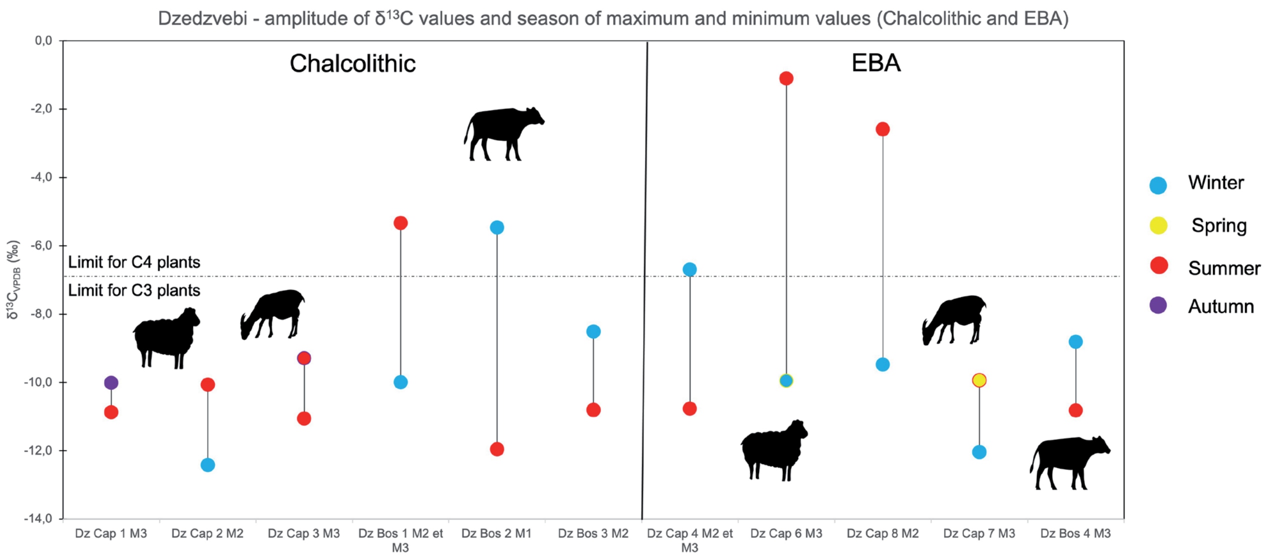

Fig. 9 – Amplitude of δ13C values during Chalcolithic and EBA. The colors designate the season for which the minimum/maximum of δ13C is reached (blue = winter, yellow = spring, red = summer, purple = autumn, when mixt colours = late season / early season, ex: red/purple = late summer-early autumn). The season was determined according to the δ18O value of the sample (draft/data: MNHN, A. Vautrin).

The process of gold production itself, which was clearly described, and by means of experiments and time calculations of the operation chain (based on the archaeological record) (Paravani calculation: Stöllner et al. 2021), clearly showed that different groups could have carried out the mining and processing. A small group of miners was probably able to extract enough gold in a few days to produce socially representative items such as golden earrings. It is likely that this type of mining was carried out in collaboration with the local population and local knowledge holders in order to exploit the rich gold deposit. The structures of the settlement show that larger groups may have stayed in Dzedzvebi at different times (of the year?; Stöllner et al., 2023, p. 121–124).

The high degree of ritualisation of gold mining reveals a multitude of negotiation processes (Stöllner et al., 2023, p. 127–128). Here, an interwoven resource landscape could develop that was effective for at least 500 years. The example of Dzedzvebi and Sakdrisi thus shows that the local connection between the settlement plateau and the mining zone led to the development of an intermediate resource landscape, which gradually became more stable in terms of location, but also enabled the integration of mobile groups through pastoralism and social practices around the gold-extraction and gold consumption.

Drought and mountains: The beginning of metal ore mining at the Central Iranian Plateau

The second example leads us to the Iranian plateau, and in particular its western part, a zone that experienced a strong dry phase and desiccation, especially in the middle Holocene (after more favourable conditions in the 6th and 5th millennia; Kehl et al., 2023; Rafiei-Alavi et al., 2023). The first metallisation of the plateau communities in the early 4th millennium probably led to a specialisation of metallurgical practices in the larger settlements (e.g. Helwing 2013; 2021). These were mostly located in water-rich areas, which may have been due to the climatic conditions of this zone. The intensification of copper and silver production at sites such as Arisman (Vatandoust et al., 2011, p. 11–530; Nezafati et al., 2021) and Sialk (Nezafati and Pernicka, 2005; 2012), which is particularly evident in the later 4th millennium, shows that the question of fuel resources already had a significant impact on the metal resource landscape at this time (fig. 10). The diverse ore supplies from a larger deposit area (Kahak, Baqoroq/Nakhlak, etc.) alone make this likely (e.g. E. Pernicka, K. Adam, M. Böhme, Z. Hezarkhani, N. Nezafati, M. Schreiner, B. Winterhöller, M. Momenzadeh, R. Vatandoost, in: Vatandoust et al., 2011, p. 675–679,

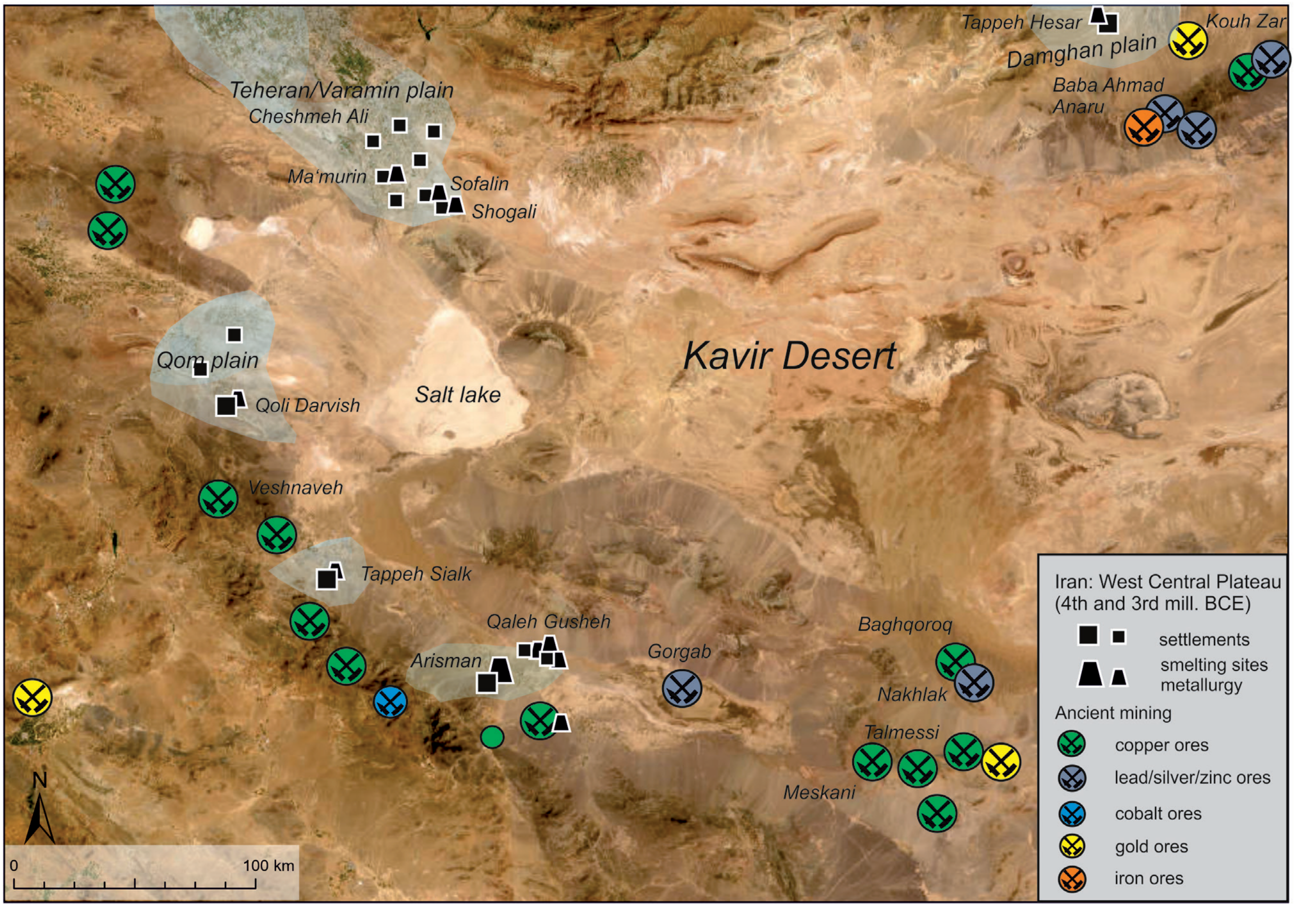

Fig. 10 – West Central Iran: Ore deposits, mining and metallurgical sites of the 4th to later 3rd millennium (after Vatandoust et al., 2011; Helwing, 2021; Fazeli-Nashli et al., 2013; draft DBM/RUB, Th, Stöllner).

figs. 45–46; for Nakhlak: Stöllner et al., 2004). This suggests sporadic and seasonal exploitation of the rich deposits in the surrounding area of west-central Iran (fig. 10). Unfortunately, hardly any mining from this period has been investigated. Currently, only the Veshnaveh deposit has been sufficiently investigated to provide answers about the character of ore exploitation (Stöllner et al., 2011; Nezafati and Stöllner, 2018; Stöllner et al., 2025).

In the Veshnaveh copper district, the earliest phase of near-surface ore mining can still be linked to the end of the Sialk IV period and the period just after. This is a period that is characterised by an extreme scarcity of evidence for settlement sites on the Western Central Plateau; recently, new sites have been discovered in the vicinity of Veshnaveh (near Fordu at the site of Yousef Khan: Sołtysiak et al., 2019; in general: Fazeli Nashli et al., 2022). This may indicate that mining at Veshnaveh was also active during this period. Most of the ^{14}C data from the mining come from a later period after the 4.2 event (fig. 11). The dating sequences and characteristics of the

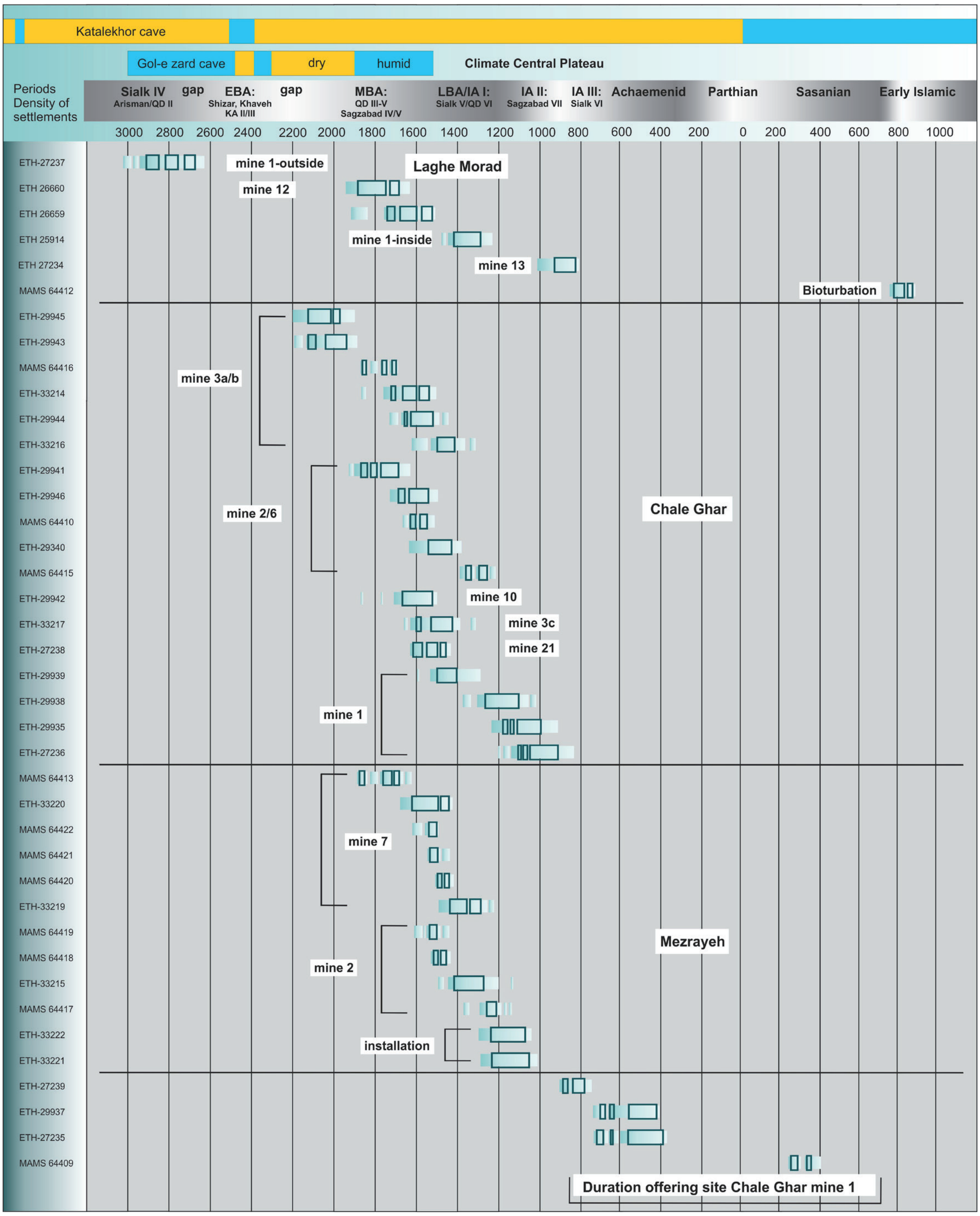

Fig. 11 – Veshnaveh, AMS-^{14}C-dates of mining and ritual activities in Veshnaveh and the climatic and settlement history of the Iranian Central Plateau (draft Th. Stöllner; climate and settlement data after Kehl et al. 2023; Rafiei-Alavi et al. 2023); calibration OxCal v4.4.4 Bronk Ramsey (2021).

Chale Ghar, Laghe Morad and Mezrayeh mining fields show that the pits were mined repeatedly over a period of time. In between, the mines were also used as shelters and campsites. This would also suggest that only small groups of miners worked outside the pits, extracting ore and processing it into concentrates. The use of woody plants (tamarisk and pistachio), especially during the Middle Bronze Age (phases 2 and 3) after the 4.2 climatic event, is important in terms of environmental and subsistence relationships. The archaeobotanical data (especially the charcoal, see above) suggest that the area was more heavily forested than it is today, especially in the stream valleys that drain to the east. However, as the natural fuel potential was not sufficient to produce fuel for the regularly used firesetting technique, this extraction must have been small-scale and gradual.

The analysis of domestic animal mobility by Monika Doll and Hande Özyarkent (figs. 12 and 13) shows that there was regional livestock mobility of caprides, which were reared in the mountainous zone of Kuhestan-e Qom, but were also driven to the summer pastures around the mining site (Doll, 2013; Özyarkent and Stöllner, 2025). The C3/4 ratio, however, indicates that the caprides were grazed in the halophyte area near the Central Plateau plains during the winter. This points to mining-herder communities, some of whom were engaged in (seasonal) mining activities, while others had to engage in animal husbandry (see also Stöllner, 2023b). Donkeys and cattle, on the other

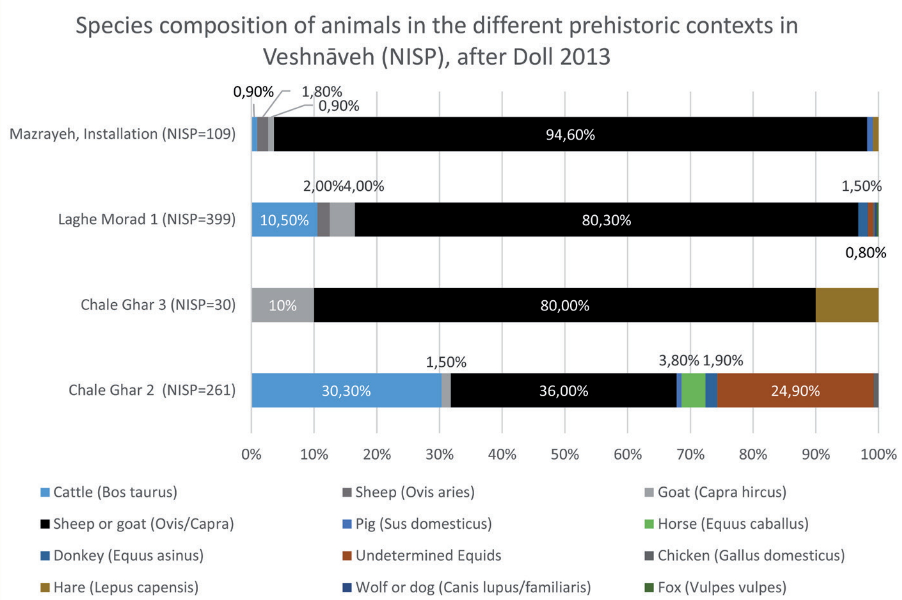

Fig. 12 – Relative representation of domestic mammals from EBA to MBA levels at Veshnaveh (in % of the domestic mammals NISP) (draft/data: DBM, M. Doll).

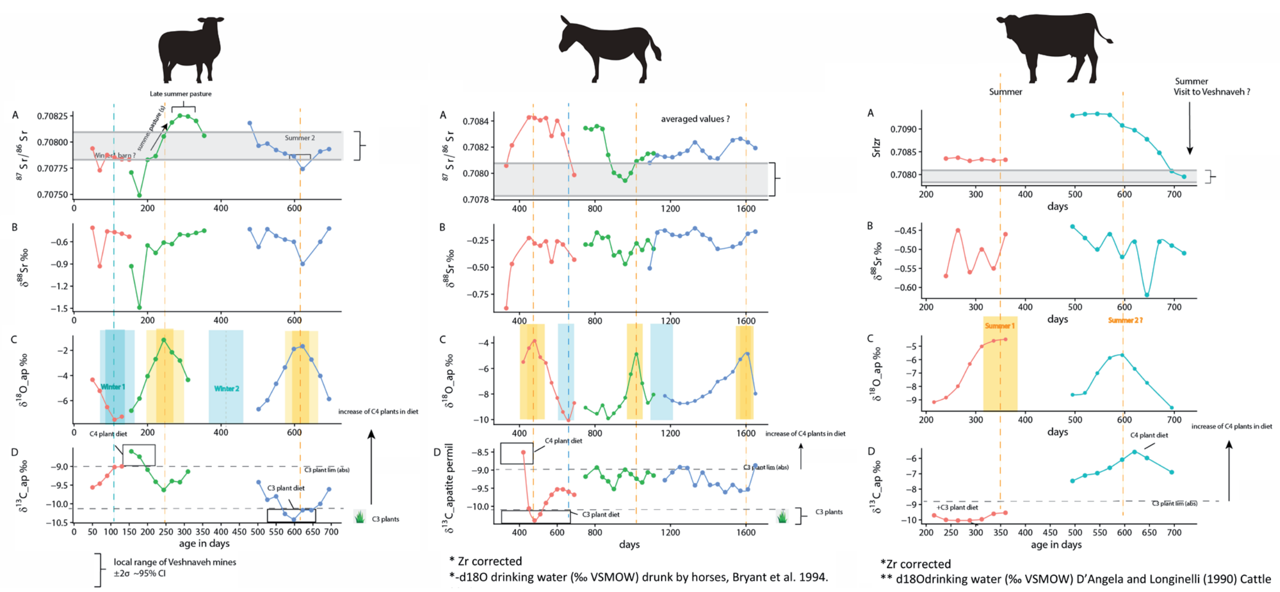

Fig. 13 – Veshnaveh, three domestic animals and indication of their mobility according to $^{87}Sr/^{86}Sr$, $\delta^{18}O$ and $\delta^{13}C$ apatite values; 1. Caprine 2, Molar 1/M2; 2. Donkey 1, Molar 1/2/3; 3. 3. Cow, Molar 2/3, draft: DBM, H. Özyarkent.

hand, were used for transport and to provide meat for the miners, who were probably only temporarily present. All this points to a highly adapted miner-herder economy, suggesting one or more permanent settlements at the end of the access valleys to the mountains. The mining groups probably came from there, and from there the herds were sent to the mountains (consumption of C3 plants) and to the plains to graze C4 plants, probably during the winter, when there was also enough water in the plains. It is also likely that the ore concentrates were transported from there to other metallurgical centres, if they were not further pyroprocessed in their settlement (which we have not yet discovered).

Central Asian herding and mining compounds: Tin mining in the Askaraly region

The importance of pastoral subsistence practices also played a central role in the mobility behaviour of Central Asian Andronovo societies, whose mining and especially metallurgical legacies are known from numerous settlements between the southern Ural foothills and southern and eastern Kazakhstan. One of the best known examples of mining activity based on a steppe economy is the mining area of Kargaly, investigated by an international team led by Evgenij Chernykh, where the mining settlement of Gorny in particular highlighted the great importance of domestic animal subsistence, especially cattle (Antipina, 2004). On a larger scale, the data from Gorny let us argue for extensive cooperation between different communities within a miner-herder complex (e.g. Antipina and Morales, 2006, esp. p. 79–80). The large quantity of animal bones found in numerous features not only indicates the great importance of meat consumption, but also of efficient herding, which in the first half of the 2nd millennium BC was probably much less nomadic and pastoral than previously assumed. The study of metals from the Early and especially the Middle Bronze Age in Central Asia also shows that there were numerous small-scale migrations. Such mobility patterns led to the exchange of metal products over large areas, but not necessarily to large-scale horizontal pastoralism (generally the broad concepts of Chernykh, 2017, p. 90–100; 190–210; on data from the Bochum Kazakhstan Project: Stöllner and Gontscharov, 2021; Stöllner et al., 2022).

Here, the Askaraly mining area, explored by the DBM and Kazakh colleagues between 2004 and 2008, shows the links between mining, settlement and burial activity. In the small mining settlement of Mastau Baj, the repeatedly mined tin ore cassiterite was processed (fig. 14). The Andronovo-Federovka style pottery found in all contexts

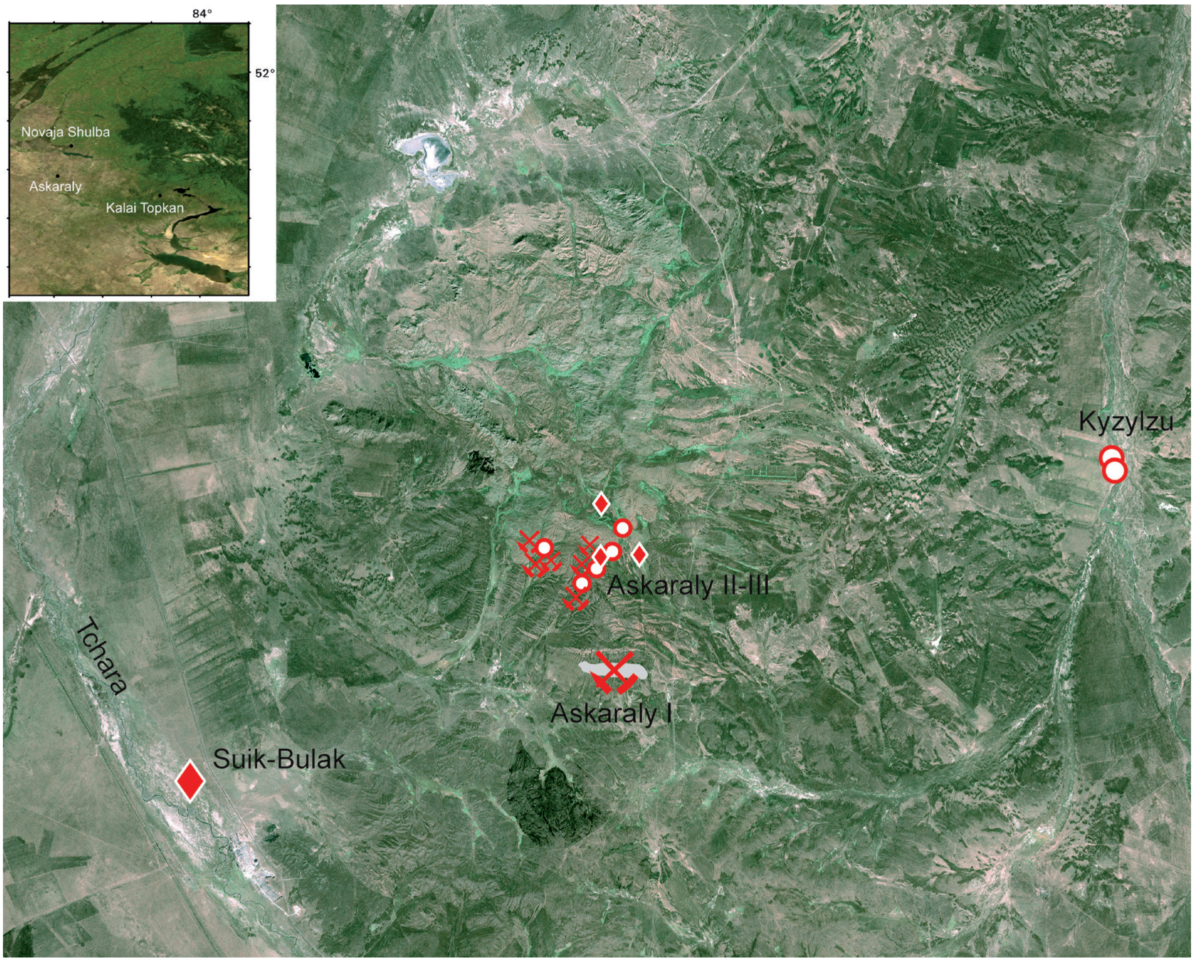

Fig. 14 – East Kazakhstan, Delgebetey (Askaraly)-Mountains, Bronze Age sites in the surroundings of tin-mines (pick/hammer symbols), rhomboids: graves; dots: settlements (mapping: DBM, A. Hornschuch, Th. Stöllner).

suggests that the Askaraly II sites were a contemporary ensemble. Around Askaraly II there were other Bronze Age mining zones (Askaraly I, III-V) (Stöllner et al., 2011b; 2022; Özyarkent and Stöllner, 2025).

The mobility of the caprids, which regularly moved between different ecological zones (C3/C4 plants), is again interesting. This aspect has been further investigated by M. Doll and H. Özyarkent in her PhD thesis (Doll, 2013; Özyarkent, 2019; Özyarkent and Stöllner, 2025). Nevertheless, most of the sheep, horses and goats moved within the regional framework, probably in the vicinity of the Delgebetej mountain zone (and the associated river valleys where the animals were driven, especially in the summer months; figs. 15 and 16). On the other hand, the cattle studied are striking: they show a very wide mobility to a winter pasture in the south (perhaps beyond the so-called Kazakh threshold). It is reasonable to assume that they were used as pack animals for transporting the tin, as is also assumed for the donkeys at Veshnaveh. Unlike other minerals, tin ore was reduced in the mining settlement. Whether it was then alloyed with copper to form raw bronze or cast into a finished product is unknown.

For the early 1st half of the 2nd millennium, it seems that finished products rather than raw metals were exchanged (see arguments in Stöllner and Gontscharov,

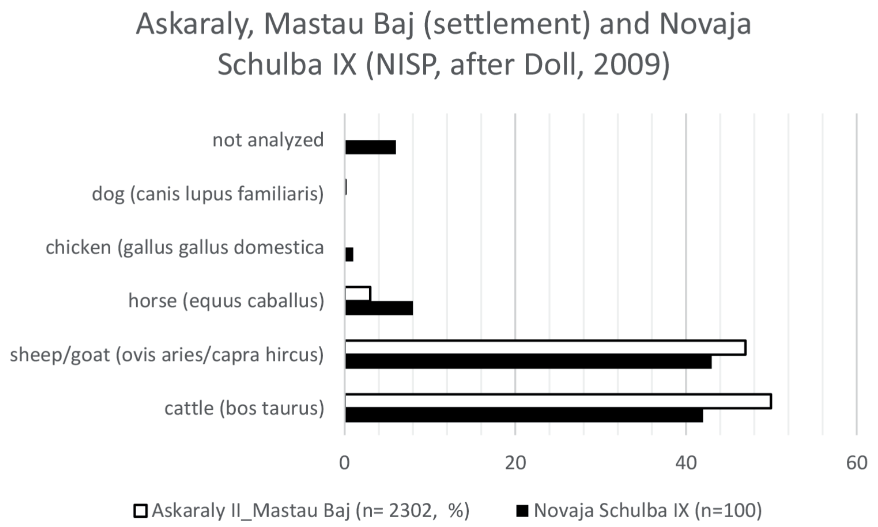

Fig. 15 – Relative representation of domestic mammals from Andronovo levels at Mastau Baj and Novaja Schulba (in % of the domestic mammals NISP) (draft/data: DBM/RUB, M. Doll, Th. Stöllner).

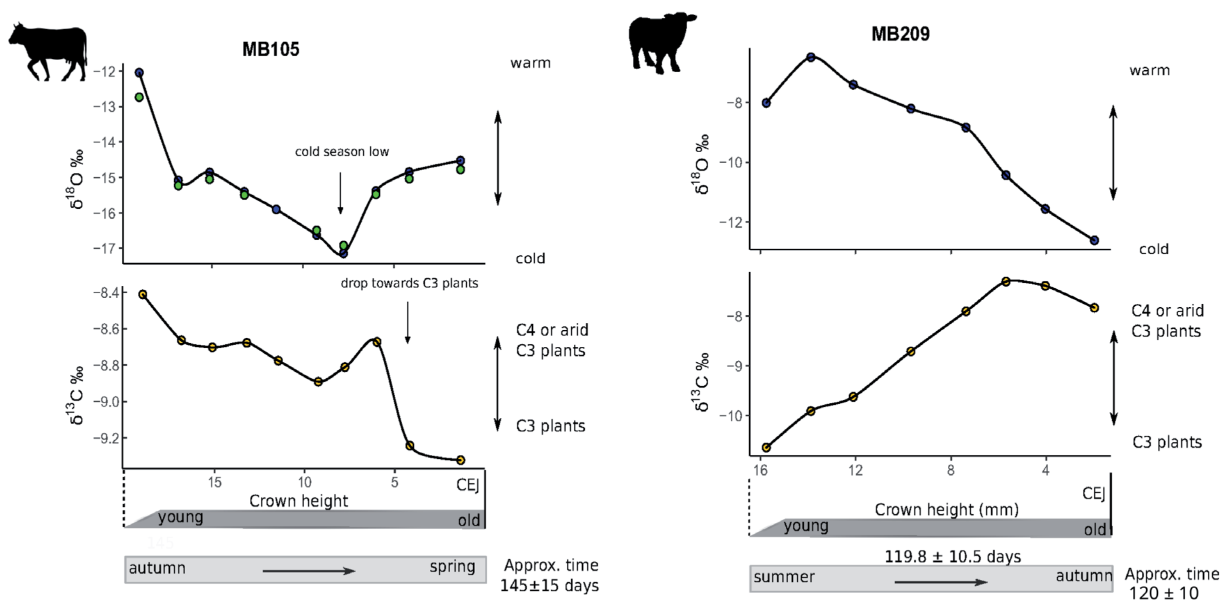

Fig. 16 –Askaraly II, Mastau Baj, Oxygen and Carbon isotope values from the cow sample MB105 (left) and the sheep sample MB209 (right); Oxygen isotope values are calculated to show the meteoric water values using equations water values using equations from D'Angela &Longinelli after Özyarkent, 2019).

2021). Ingots from this period are lacking, while they seem to have become more common in the later 2nd millennium (see also Stöllner et al., 2013; Gontscharov, 2019, p. 82-84). Metal objects, including those made of tin bronze, were used for numerous socially regulated transactions, which would have involved negotiation processes for mining and grazing rights (in general: Frachetti, 2012). A professionalised exchange of tin by the advanced 2nd millennium at the latest was ultimately based on already stabilised networks and mining landscapes since the earlier 2nd millennium BC: many of the metallurgical settlements known from the later Bronze Age already existed in the earlier Andronovo period (e.g. from central and eastern Kazakhstan: Kadyrbaev and Kurmankulov, 1992; Yermolayeva et al., 2024). The exchange of metals, but also their production, seems to have been based on a pastoral economy based on sheep/goats and cattle, organised according to seasonal cycles (see the arguments of Stöllner et al., 2022, p. 121–123).

An early industry evolved? The Alpine Arc and the Mitterberg

A different development of a subsistence-based mining economy is visible in one of the largest Bronze Age mining areas in Eurasia, the Central and Eastern Alpine Arc, where numerous mining communities with a fairly comparable technological concept and also stable subsistence conditions were established in the course of the second millennium (for a summary of the mining regions: Stöllner, 2009). The copper ore districts of the eastern and central Alps were gradually settled from the northern and southern Alpine foothills and then from the main valleys. The Inn and Salzach valleys, especially from the Early Bronze Age communities of southern Bavaria (Straubing culture: Kienlin and Stöllner, 2009; Töchterle, 2015; cf. Stöllner, 2019, p. 14–18). The following copper mining activities seem to have been based on stable supply networks (see already the arguments of Shennan, 1999; for food supply, cf. Pucher, 2009; Schibler et al., 2011; Marti-Grädel et al., 2012; Trebsche and Pucher, 2013). This also allowed the permanent use of alpine backwaters away from the main passage valleys. Our own research, which we have been conducting continuously since 2002 in the Alpine Salzach valley and in particular in the area of the well-known mining district on the Mitterberg (Zschocke and Preuschen, 1932; cf: Stöllner, 2015; Thomas, 2018), I focus mainly on this area (fig. 17).

In comparison with the other mining areas already presented, two aspects are particularly noteworthy for the Eastern Alps and the Mitterberg in particular. Firstly, even the earliest settlement of the later intensively exploited

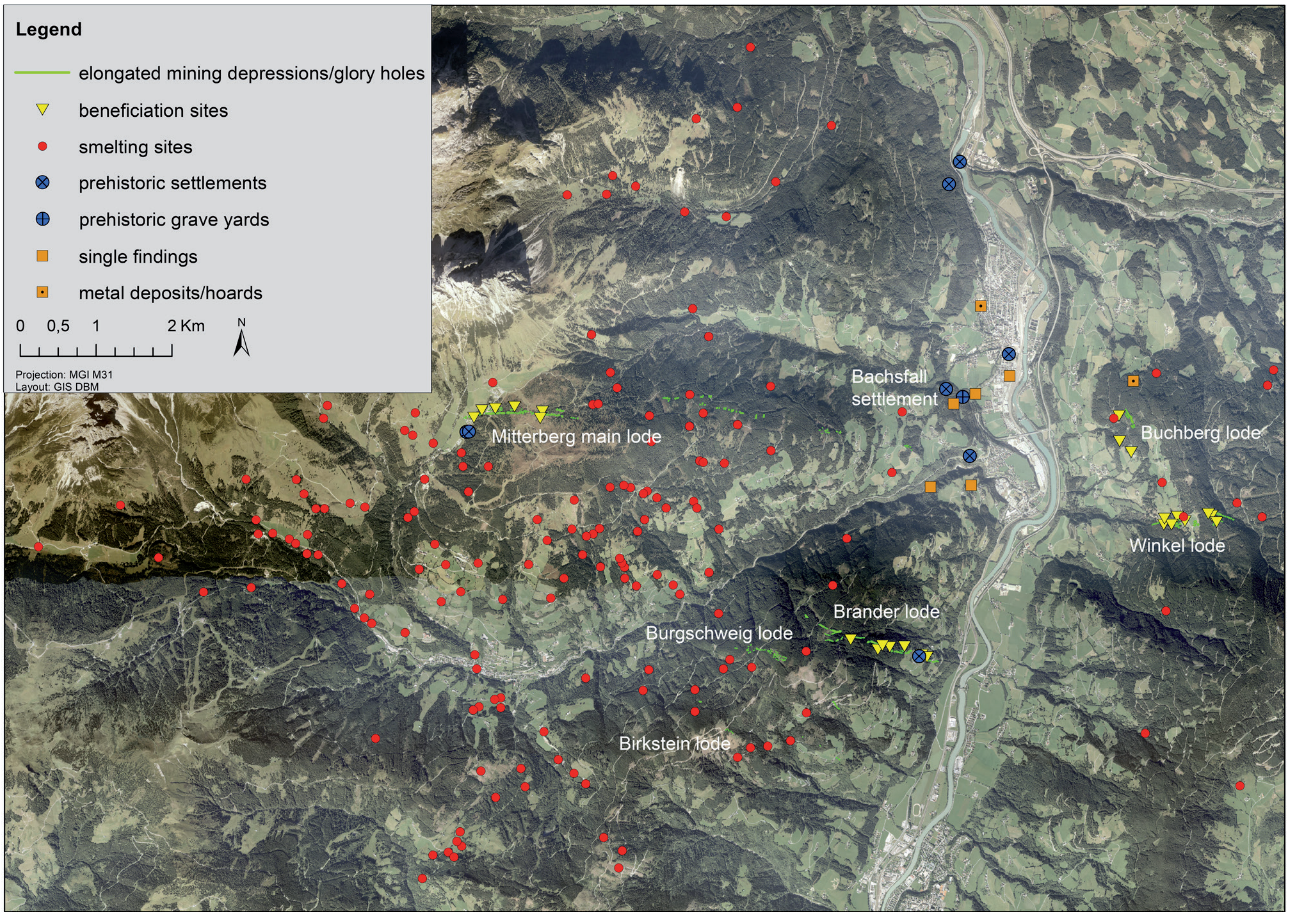

Fig. 17 – Mitterberg mining region, district of St. Johann, Salzburg (Austria), according to archaeological finds and sites (DBM/RUB, A. Hornschuch).

mining region seems to have followed a certain concept of settlement, supply and raw material exploitation. From the very beginning, the structures of the Bronze Age mining landscape in the Salzach-Pongau were subordinated to the needs of copper ore mining and smelting, initially via small village structures, from which the area was developed for mining (e.g. Shennan, 1995; 1999; Kienlin and Stöllner, 2009). In particular, the exploitation of the largest gangue ore deposit in the area around the main vein consisted of numerous contemporary smelting sites (more than 160 associated smelting sites can be identified), infrastructure (houses, mining camps) and evidence for the supply of pork and cooking pots. Such a structure is evidence of a mining community supplied from the valley, which was now even able to mine ore all year round, processing it in early summer and smelting it in autumn. A total of more than 24,000 tonnes of copper could be produced in the district and a total production cycle of more than 800 years could be achieved (Pernicka et al., 2016; Stöllner et al., 2011c). The intensive production required not only forest management (e.g. Breitenlechner, et al. 2014; Pichler et al., 2018), but also, as we assume today, a territorialisation of coniferous wood stocks between smelting and mining operations (on this argument: Stöllner et al., 2011c). Mining techniques also varied considerably, such as the use of firesetting techniques near the surface and wedge cutting with picks in deeper mine parts, which could reach depths of up to 200 metres.

Looking at the subsistence conditions of mining, we can assume that the regional subsistence was never sufficient, at least since the establishment of deep mining. In the Salzach Valley, the regional agricultural and pastoral economy was probably only able to provide sufficient subsistence during the late Early Bronze Age in the 18th/17th centuries BC. However, even this can be questioned by reference to purified cereals that may have been transported from the Alpine foothills (Klinglberg: Shennan, 1995). This aspect is clearest in the case of pork in the Mauken valley mining district, which was supplied from the valleys, possibly even from the Alpine foothills (Marti-Grädel et al., 2012; Schibler et al., 2011). For earlier times, one of the best evidences of meat procurement comes from the archaeozoological investigation of the Early to Middle Bronze Age settlement of Bachsfall near Bischofshofen in the Salzach Valley (fig. 18; Pucher, 2009). Meat animals such as cattle and sheep/goats may have been kept in the vicinity of the settlements. Cattle (especially females) were slaughtered after their best reproductive age and after their main use for milk production, indicating a high importance of dairy products in the agricultural zones around. The character of the use of sheep and goats is different. Their main age structure indicates that they were slaughtered in early adulthood, which in turn indicates a selection from local breeds. On the other hand, E. Pucher's study shows that pigs were supplied from abroad: The local pigs were rather large, as has been shown elsewhere in the copper districts. In particular, their age structure (surprisingly dominated by adults, which is not typical of domestic pigs, fig. 19) and the selection of a larger proportion of males indicate that they were supplied to the settlement. E. Pucher concluded that the community at the Bachsfall settlement was not primarily agricultural, but was supplied from an agricultural hinterland (wherever this was).

Later, the Late Bronze age/Hallstatt salt mines probably played an important role in the supply of pigs from abroad. There, pigs were processed into salt-pickled meat

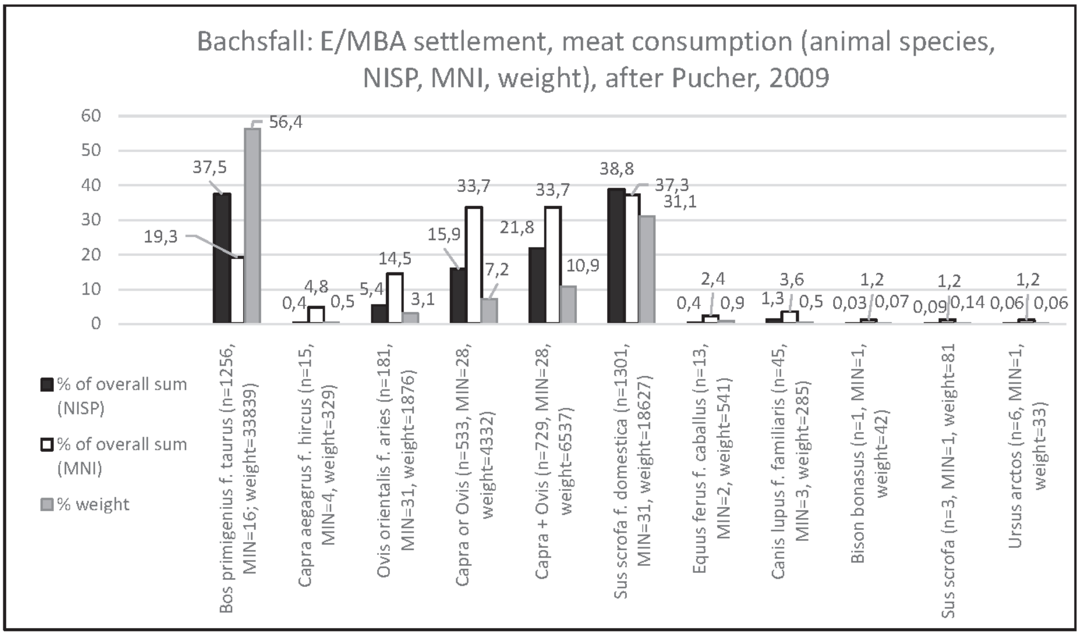

Fig. 18 – Relative representation of domestic mammals from, in % of the domestic mammals NISP, MNI and weight [g] (data: Pucher 2009).

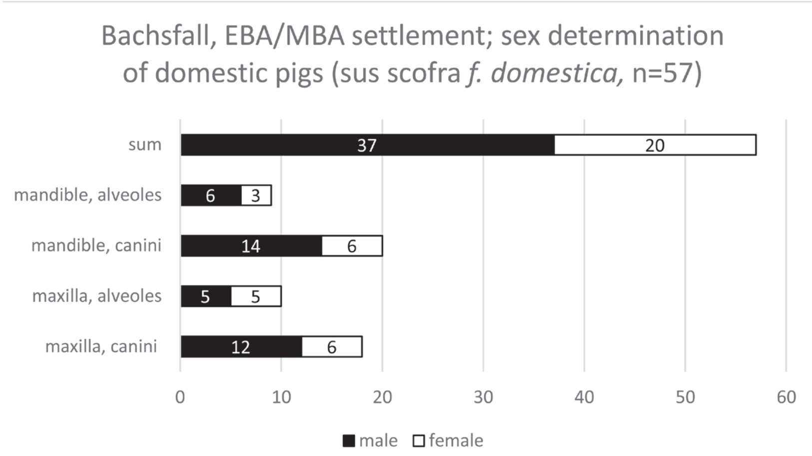

Fig. 19 – Early to Middle Bronze Age levels of Bachsfall settlement, domestic pig according to sex determination of maxillae and mandibulae (data: Pucher 2009).

portions (Pucher et al., 2013). This differs from the earlier evidence from Bachsfall, where pigs were delivered alive or as a whole (there is no evidence for the selection of body parts). This is striking in that a pastoral economy based on sheep and goats never developed in the central areas of the now large-scale mining industry, neither in Kitzbühel (Kelchalm: Amschler, 1937) nor on the Mitterberg (different in Grisons: e.g. Marti-Grädel et al., 2012). The progressive dichotomisation of economic practices is already evident here, which, with the large-scale production of copper, has now entered the realm of commerce and thus of mutual economic dependency.

Copper production not only attracted mining groups and ensured their economic advancement (and thus the valleys between the Inn, Salzach and Enns rivers), but also inevitably led to a now well-established division between subsistence and raw material extraction. This is a process that we have been able to observe in many parts of the ancient world since the second half of the 2nd millennium BC (see Cyprus, Feinan, among others; in general e.g. O'Brien, 2015; Stöllner, 2023a).

CONCLUSIONS

Returning to the questions posed at the beginning of this paper, it is clear that certain practices and a certain form of interwovenness with certain ecological niches emerged within the practice bundles of firesetting and herding within Early Metal Age mining. The close connection to the extraction of raw materials via presumably ritualised access in the form of 'direct access' still seems to have predominated in earlier forms of exploitation (e.g. the arguments in Stöllner, 2023a), but changed from the later 4th millennium BC onwards.

When comparing the examples outlined in this article, it is interesting to first understand the ecological embeddedness of the techniques and practices: in the case of fire setting, technology has not been the limiting factor: The West Asian and Eurasian examples are similar in technical aspects such as hammer and chisel work, ore processing and transport practices. The choice of fuel was more of a limiting factor, as forests were not abundant in the Iranian highlands or steppe zones. This may have forced sporadic or seasonal access by small-scale mining operations. At these zones a highly specialized use of fuel can also be observed, especially in the Askaraly ensemble. It may have been a consequence of this ecological background. This is certainly not the case for the Dzedzvebi-Sakdrisi complex or the Alpine Arc mining communities, which could make extensive use of local oak or spruce/larch and fir forests.

The annual cycles of pastoralism practised by mining communities (not necessarily by the miners themselves) were also influenced by environmental conditions. This is best seen in the regional mobility patterns of livestock. However, the use of cattle as a meat reserve and the donkey as a means of transport is also indicative: livestock played a varied role. While in Veshnaveh the grazing of sheep and goats seems to be linked to mining, the same seems to be true for sheep and cattle in the case of Askaraly. On the other hand, the case of Dzedzvebi already shows a different type of practice: Although herding is still involved, the supply of cattle from deeper parts of the valley seems to indicate organised supply patterns (R. Berthon, A. Vautrin in: Stöllner et al., 2023, p. 111–116). As mining and processing led to the involvement of different Kura-Araxes communities, animals could have been brought in by the groups themselves in the course of seasonal enterprises; such can also be suspected for the Ross Island evidence around the middle of the 3rd mill. BC (Wingaarden-Bakker, 2004). On the Dzedzvebi plateau, several kinship groups appear to have been involved in gold and copper production.

By the 4th millennium at the latest, permanent settlements arose around the mineral deposits, closely linked to pre-existing mobility networks, but also providing the first evidence of planning and more permanent management strategies for resource landscapes. Like Dzedzvebi, but also many other examples (e.g. in Fenan: Wadi Fidan, Khirbet Hamra Ifdan: Levy et al., 2002; for Fenan in general: Hauptmann and Löffler, 2013) show that settlements moved close to the deposit zones as intermediate locations between subsistence practices and raw material extraction. However, the intensity of extraction itself depended on the available fuel resources and the social networks involved, which carried out extraction on a semi-permanent basis. However, the availability of grazing resources may also have been an important factor in the establishment of these semi-permanent mining areas. Pastoralism and, to a limited extent, other agricultural strategies were central to the establishment of these relay settlements, which also became stations for the various groups involved.

The elements presented here are ultimately the prerequisite for the development of stable, but now also more dichotomous social and technical practices of larger groups involved. The example of the 'Mitterberg' mining region (Pongau) allows some observations on the now permanent and large-scale enterprises. Even if the old figures of Zschocke and Preuschen (1932) for the number of people involved in the mining process are somewhat outdated, the number of workers must have been quite large. There is no doubt that permanent and more efficient mining strategies developed. First of all, a complex chain of practice bundles (e.g. the metallurgical chain of deep mining, wet and dry ore dressing, matte and black copper smelting, ingot and finished product casting) could be developed in the Pongau landscape since the 19th and 18th century BC. For reasons of ventilation, it was only possible to set fire to the upper parts of the elongated veins. Smelting and mining had to share forest areas in order to manage the availability of wood, which was used for timbering, ore beneficiation installations (puddles) and as a fuel for smelting and firesetting. The first practices of sustainable timber management are evidenced by a large statistical set of dendrological data (Stöllner et al. 2011b; Breitenlechner et al., 2014; Pichler et al., 2018).

The same applies to food supply (Pucher, 2009): already in the earlier phases, pigs in particular were supplied, as we can also prove a centralised production of cooking pots, which probably went hand in hand with the supply of grain to the mining communities. It is interesting to note that mountain pasturing (as in the central Alps) was not practised to any great extent in the mining landscapes themselves (see also Reitmaier, 2020, fig. 8). The extension of what we could call the Mitterberg process sensu lato (including the principles of the food supply regime: Stöllner, 2019) would therefore focus our perspective on even more complex knowledge bundles that had to be mastered by the inhabitants and copper producers of the Eastern Alps. Such examples open the windows for an economic mining and metallurgy from the late 3rd millennium onwards, which can also be observed step by step in trade and commercial practices. It resembles the principles of an early beginning of extractivistic and commercialiced access modes that 'accelerated' till today.

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Thomas Stöllner
Ruhr-University of Bochum,
Institute of Archaeological Studies,
Pre- and Protohistory
& Deutsches Bergbau-Museum
Bochum, Germany
thomas.stoellner@rub.de
thomas.stoellner@bergbaumuseum.de