Chapter 7
Methods of Mining Archaeology (Montanarchäologie)

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Introduction

Mining archaeology is a multidisciplinary approach to understanding people's roles and relations to raw materials, especially with respect to the social and economic consequences of their exploitation. It has become a specialized field within archaeology, and therefore, it may be justified to outline the methodological framework of this field. Mining archaeology has traditionally been seen as a study of the mining technologies used in the past, but only rarely has it engaged with the socio-economic and cultural aspects of these practices (Weisgerber 1989/1990; Pfaffenberger 1992; Steuer and Zimmermann 1993; Knapp et al. 1998; Stöllner 2003; Topping and Lynott 2005). Critical to the advancement of this field has been the realisation that mining archaeology is the study of systems used to describe long-term historical processes that have been influenced by other technologies, innovations and raw materials equally. If one looks, nowadays, at projects focussing on ancient mines, one must always engage with various other subjects including trade, settlement patterns and socio-economic systems such as class and its relation to the exploitation and distribution of resources. It is, therefore, a logical consequence not to speak about mining archaeology on its own but to use terms like the archaeology of raw materials, Montanarchäologie (montan-archaeology) and economic archaeology (e.g. Clarke 1953; Zimmermann 2000)[1].

[1] The German term "Montan"(based on the Latin "res montanarum") does not translate well into the English language, but I have suggested introducing the loan-word "Montan" as a term for a kind of "raw material archaeology" whose main focus is on the entire chain of mineral resource production practices and its socio-economic consequences (e.g. Stöllner 2008b, pp. 149).

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B. W. Roberts, C. P. Thornton (eds.), *Archaeometallurgy in Global Perspective,* DOI 10.1007/978-1-4614-9017-3_7,

If one accepts the broadening of the terminology, then one has to engage with three levels of consideration. First, what is the relation between archaeology of mining and the various technological approaches that were used throughout history to extract raw materials? Second, if archaeologists want to reconstruct the ancient economy, then mining must be considered as just one part of an entire production chain, including processing, trade and usage of raw materials. Third, the broadened field of "Montanarchäologie" must deal with all aspects of the production process, which must take into account the ideological, social and spatial spheres of human behaviour (Stöllner 2008a, 2008b). The level on which we choose to explore ancient mining has consequences for the methods used.

Methodological Issues: Basic Concepts and Problems

Acquiring raw materials was, in all societies, a costly and time-consuming (but nonetheless essential) task. This process nowadays has shifted to a global level and its consequences are not as apparent for each individual. However, in the past, the level of spatial and societal interactions between people and communities was the most important; as such interactions were responsible for the dissemination of societal knowledge, techniques and of new materials and products. Thus, the regional and chronological context of ancient mining is critical, as hunter–gatherer groups of the African Iron Age had very different mining processes than urbanized Bronze Age miners of Central China.

Over the years, several special research areas of mining archaeology have been outlined and investigated more precisely. These research areas provide a theoretical framework with which one can approach the different questions that are always part of resource management.

The Importance of the Chaîne Opératoire

There is no doubt that functionality is a basic prerequisite for understanding ancient mining, but there are also ideological, cultural and social reasons why people behave in particular ways. For this reason, the French archaeologist Claude Leroi-Gourhan developed the idea of the *chaîne opératoire* or "chain of operations" for any productive practice (Leroi-Gourhan 1964). Essentially, this means that we must study each step of a particular productive process and look for social and cultural influence within each step. For example, the mining of sulphidic copper ores involves the extraction, the preprocessing (beneficiation and/or roasting) and the smelting of such ores (e.g. Eibner 1993; Herdits 1993). Given a specific level of technological experience, one can propose a several-step process that one may describe within a *chaîne opératoire*. This proposed model logically depends upon the complexity of the process for how interdisciplinary the network has to be developed. That is, the more complex process chains must incorporate multiple materials (e.g. stone tools,

Table 7.1 Various major levels to describe a mining region within a historical, economic and a social process

Natural landscape	Quality, sustainability and accessibility of raw materials
	Ecological preconditions of the natural landscape (favourable settling conditions; favourable conditions for subsistence economies)
	Traffic precondition especially for long distance trade
Cultural landscape	Regional economic balance with subsistence economy (e.g. stress factors in landscapes)
	Importance of the hinterland (size, structure of settlement) regional traffic lines and their improvement
	"Social abilities" (technological knowledge handed over; local tribal and political organisation)
Mode of production	Reconstructing the technological process (chaîne operatoire)
	Degree of specialization
	Interaction and labour division
Duration of time	Longue durée in specialized landscapes (imprinting phases in mining regions)
	1. Initial or inventing phase
	2. Phase of stabilisation or consolidation (radiation)
	3. "Industrial" phase
Society (ethnic, social and cultural tradition)	Tradition of labour
	Social control of winning and distribution
	Integration of different social and ethnic groups (children, women, foreigners etc.)
Trading modes	Dependency on trade (spatial standard/scale of trade; importance in regard to the economic scale)
	Organisation of trade (technical and logistical; social: exchange and symbiosis with other groups)
	Trading level (e.g. long-distance trade, trade by stages, ports of trade)
Historical processes	Changes in supply and demand structure (by crises, epidemics or wars, etc.)
	Changing of ritual and fashion demands
	Technical Innovations
	Processes of colonization

copper ore, water, timber and charcoal production), which requires researchers from different methodological disciplines (e.g. archaeobotanists; mineralogists and metallurgists) (general e.g. Ottaway 1994; Hauptmann 2007a). The advantage of working with process chains is that archaeologists, metallurgists and mining historians are able to model resource and working patterns in more predictable ways, and then look for the influence of social and cultural factors on past behaviours.

The Importance of the Natural (Landscape) and the Geological Preconditions (Table 7.1)

Determining the quality and the sustainability of a mineral deposit, as well as the accessibility and actual content of the deposit, was essential for early societies (general e.g. Stöllner 2003, p. 421; Strahm and Hauptmann 2009, pp. 121) to make decisions about the mining technologies to be used and to what extent. This very general statement forms the background for discussing the beginning and end of a long-term production process. What has rarely been considered are the short-term effects of small bonanza-type deposits (e.g. a "gold rush"), or how the irregularities within ore deposits may cause unpredictable situations. In other words, to what extent do varying deposits affect the blossoming or the collapse of a *chaîne opératoire* ? In certain case studies from historical periods, researchers have traced back such collapse situations to complex socio-economic situations (e.g. the cost increase associated with deeper and more laborious mining) (e.g. Harz: Bartels 1997), rather than more obvious geological reasons (e.g. the vein is "mined out"). However, we must remember that the geographical preconditions (e.g. relations to agricultural zones, the climate and vegetation— for instance, in relation to fuel resources; Engel and Frey 1996; Hillebrecht 1999) are also determining factors. For example, traditional mining in steppe zones can clearly be differentiated from those in arid or desert areas or from high mountain ranges. To what extent mining groups in these regions were restricted by food or water supplies is reasoned by assessing landscape conditions, but also their general subsistence pattern (e.g. herders vs. farmers: Cribb 1991; Alizadeh 2004). As long as raw material acquisition remained on a small tribal or familial level, resource exploitation was at least as successful as in specialized mining communities, due to the more limited geographical and subsistence restrictions.

Cultural Landscapes, the Longue-Durée and Societal and Trading Patterns (Table 7.1)

There are several cultural factors that influence the productive sphere of a society. For example, in my own research I have tried to distinguish between natural landscapes and culturally reorganised landscapes (Stöllner 2008a; 2008b). Many regions of the world were cultivated very early on and the exploitation of raw materials was a major part of their success as farmers. As mentioned above, landscape conditions influence not only the techniques of extraction but also the *long durée* of mining processes (e.g. Braudel 1977; for mining: Stöllner 2010, esp. 297–301). Social complexity could grow slowly and sustainably in cultural landscapes over centuries on the basis of local tribal and social organisational patterns, as has been shown for salt-producing communities in the Alps (Bergier 1989; Kern et al. 2009), for amber "fishing" in the Baltic Sea, for Cypriot copper (Ganzelewski and Slotta 1996) or for the lapis lazuli mines of Afghanistan (Kuhlke 1976).

What should not be underestimated is the influence of socio-cultural traditions on the manner of production, trade and division of labour within communities. For example, given that mining was a practice generally associated with men, only particular social values decided whether children and women were included and, if so, in which part of the process. Of course, there are also examples of women carrying out resource exploitation without men. For instance, red ochre, used as make-up and body paint, could have been mined by those who wore it, such as the women of the Himba in Namibia (Pickford et al. 1998). In addition, the inclusion or

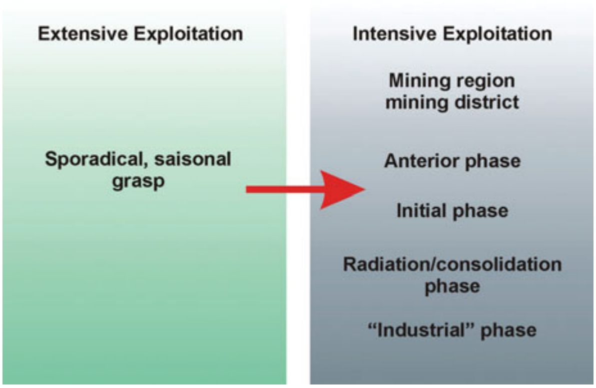

Fig. 7.1 Production modes and their relation to imprinting processes (intensive exploitation). (After Stöllner 2008a, p. 77, Fig. 5)

exclusion of foreigners was culturally determined, as their inclusion inevitably led to a gradual disintegration of traditional working patterns in that particular society.

Another factor that is directly related to production processes is the structure of markets and trade. Basic mechanisms of supply and demand were dependent upon trading networks whose efficiency had a direct influence on the success of an extracting process over time. The geographical location was often responsible for structuring markets, as the traffic routes and the mechanisms of trade determined the degree to which particular resources could be exploited.

Spatial Organisation

Exploitation activities are always linked with the landscape and geographical setting, but they are also dependent upon the economic and societal demands. Therefore, it is not surprising that by studying the spatial organisation of mining enterprises, one can also come to understand the social and ecological impacts. It is useful here to make a division between different spatial structures that also reflect different modes of production—i.e. between extensive, impermanent winning modes and more intensive, deposit - and site-based exploitations (Stöllner 2003, pp. 430–433; Stöllner 2008a) (Fig. 7.1). Extensive mining is normally associated with small-scale expeditions and can still be found in some traditional societies today. Such exploitations often left nearly invisible traces and were often obliterated by later and more intensive periods of winning. But this does not mean that a sporadic or seasonally based operation is a "simpler" mode of production or related to less advanced traditional societies. Oftentimes, such small-scale operations were also a consequence of the geographical setting, such as when deposits are situated in hostile landscapes that only allow an impermanent and seasonal access.

What can be described archaeologically is a core part of functional interrelation that we may call an "*ensemble*" (Stöllner 2003, pp. 429–430). An ensemble is defined by the relationship between two elements of a characteristic workflow, such as a smelting site and a mine, or a smelting site and a metal workshop. Within an extensive,

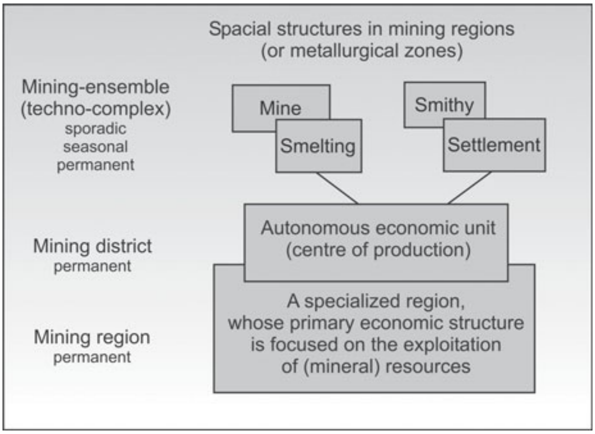

Fig. 7.2 Scheme of spatial structures of early mining enterprises and their interconnection in a functional mode. (After Stöllner 2008b, p. 169, Fig. 31)

sporadic mining enterprise, an "ensemble" may not be linked topographically—the mineral source and its first stage of processing could lie a great distance apart. Analysing such chain links by interdisciplinary approaches allows a reconstruction of functionality, and thus the embedding of the mining into either an isolated or a more complex economic cycle.

The determination of such economic systems leads mining archaeologists to the idea of "mining districts". A "district" should be understood as locally concentrated, intensive exploitation of a deposit: Generally, one could understand them as large and permanent production units. Often they are parts of an even larger unit, the so-called "mining region" ("Montanlandschaften") that assembles different production and functional units on the larger scale of a landscape (Fig. 7.2). In such cases, there are certain preconditions that have enabled a regionally stable and long-lasting development. Such stability is often the result of a combination of various positive social, economic and geographical circumstances. After decades of research, such landscape systems are much better understood, yet still there are only a few examples such as the Harz ore deposits (copper/lead-silver) studied by German Harz-Archaeology (e.g. Seegers-Glocke 1999; Bartels et al. 2007; Alper 2008); the Cypriot copper mines studied by Bernard Knapp and colleagues (Given and Knapp 2003); the Fenan copper mines studied by Andreas Hauptmann, Gerd Weisgerber, the team of Graeme Barker as well as Thomas Levy's work during last 15 years (Hauptmann 2007a; Barker et al. 2008; Levy et al. 2002; Levy 2009) or the Eastern Alpine Salt Mines (Kern et al. 2009; Stöllner 2010). In these few examples, the integration of archaeological, interdisciplinary and historical data has allowed a decent reconstruction of a broad economic history for the region.

Temporal Development—Stratification in Time—Adaptive Cycles

The temporal development of a mining operation, especially within economic zones dependent upon such exploitations, is considered to be an important approximation for describing complex economic interrelations more generally. In reference to the landscape being used and exploited, we may call this an "imprinting" process. Such a process usually lasts for several centuries (if not longer) and can be understood as a transformative process by which a landscape is changed into a zone with a special social and economic role. This stratification can be described within a four-phased concept:

- An *initial or inventing phase* (*invention phase*) sees the introduction of a new concept (new technology, new strategies of exploiting) into a district of a deposit or into a landscape. It occasionally superseded the *anterior phase* of part-time exploitation.
- A *phase of stabilisation or consolidation* (*radiation phase*) leads to the first successful exploitations and to the formation of successful working units (regional diffusion). Such activities have a notable influence on the local society and environment. For example, successful exploitations can result not only in a major improvement in living conditions, in the emergence of new professions and in the development of social hierarchies, but also in the degradation of landscape and the local environment. In the regional context, initial and consolidation stages are often difficult to distinguish, as is the case in Feinan's Early Bronze Age copper production. On a regional or even interregional scale, this extension (consolidation) was often the basis for the general "industrial" stage (e.g. in Feinan during the Early Bronze Age; in the Alps during the Late Bronze Age: in this way discussed by Stöllner 2008a, esp. 80–86).
- An *industrial phase* (*establishing phase, innovation phase*) is characterized by an abundant growth in exploitation in a regional context, in combination with considerable effects upon society and the natural environment as well as cultural landscapes. The expression "industry" is not used in connection with "industrialisation" but means a manner of frequent and standardized mass exploitation.
- This simplified schema for the development of exploitative practices in a region can be concluded by a phase of *collapse and reorganisation*. An industrial phase often imbues also the reasons for a following collapse of an economic or ecological system either by greedy over-exploitation or by over-expenditure of technological or economic resources. Besides internal reasons for a collapse, there are also external ones that must be considered, such as the changing of demand, the influence of historical events or the general economic crises that affect also the production sphere. Often multiple reasons led to a crisis and scenarios of disasters are usually reconstructed in great haste. Archaeology compounds its problems in detecting historical coincidences either because of the incorrect synchronisation of events or through the inability to securely identify the cause and effect adequately.

Such adaptive cycles (from invention to collapse) are frequently used in sociology and history to describe long-term processes in society or economy. If we adopt, for instance, the adaptive cycles that have been again discussed in recent years (Kondratiev 1984; Holling et al. 2002), we are able to model a cyclical system of occasional usage of deposits according to preconditions such as demand, trade or

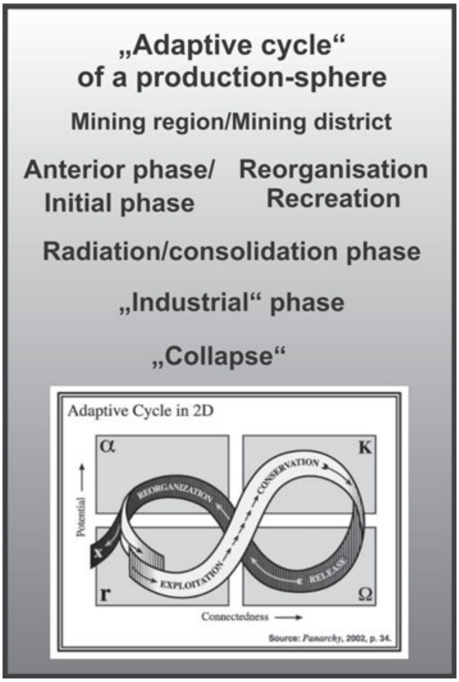

Fig. 7.3 Scheme of procession steps within a production sphere as an adaptive cycle system. (After Holling et al. 2002, p. 34; Stöllner 2010, p. 77, Fig. 5)

general technological ability (Fig. 7.3). In the light of empirical data, we have to stress that a cyclical economic development is not self-evident. Indeed, we often observe that after the collapse of an exploitation system, no phase of reorganisation has followed simply because the collapse did not allow any renewed rise.

The Importance of Econometrics:

One of the problems of economic archaeology is to present reliable data with concern to production intensity and economic profit. This basically is reasoned in the structure of our data sets, but partly also reasoned in research strategies that generally have not developed methods of this kind. It is undoubtedly of high value if production cycles and the up and down of the market may be understood in their full complexity. Econometric questions and methods, therefore, need to be developed according to specific research layouts and production cycles.

Concerning production intensity, the societal investments and the economic outcome have to be calculated (e.g. for agricultural societies: Kerig 2008). That said, it is still difficult to discuss the scale of ancient labour forces and subsistence strategies. We need to know the exact time span of production, the mean values of production progress and the number of persons involved. Using agent-based modelling seems helpful for narrowing down limiting factors (Holland and Miller 1991; Bloch and

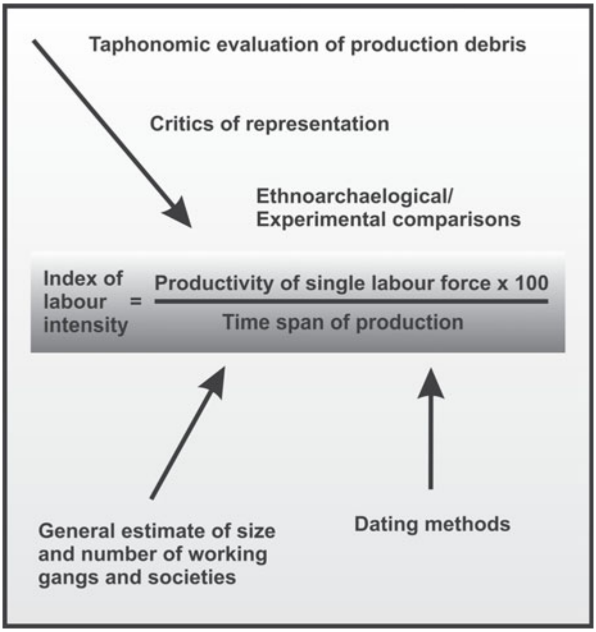

Fig. 7.4 Scheme of parameter to calculate an index of production intensity and different factors that are basic for calculations or influence such calculations. (After Stöllner 2012, p. 436, Fig. 3)

Bonabeau 2002). Such data can only be collected if excavations apply exact taphonomic studies in relation to the qualitative information of the production workflow (e.g. Stöllner 2012, pp. 435–436, Fig. 3). On the basis of such information, a productivity index can be calculated that allows independent comparisons through cultural complexes and periods (Fig. 7.4). Discussing the productivity, technological level and the general cost level, in accordance with the general economic activities (e.g. agriculture, herding and stock-breeding, crafts and trade), allows the estimation of the added value's chain.

As important as those questions may be, there are still considerable empirical biases; the estimation of production outputs can only start with archaeological remains (e.g. for mines, look at the calculations for the Mitterberg-Mines: Zschocke and Preuschen 1932; Stöllner et al. 2011a). Mines are often not accessible any longer, difficult to excavate or entirely destroyed by later exploitation. Slag heaps may be partly destroyed and require survey before any reliable calculations can be made. Indeed, a study of the smelting debris must be considered in the general production chain in case the amount of copper that was produced should be considered in relation to production investments.

Systematics of Montan-Archaeology

The classification of prehistoric and early historical mining methods helps to understand basic factors of operation chains. In this respect, there is less necessity to construct a simple disseminated history of mining for only one period, territory or

Fig. 7.5 Systematics of a basic description of mining and metallurgy in archaeological, historical and archaeometric research—the canon of mining and metallurgy. (After Stöllner 2008b, p. 152, Fig. 6)

Systematics of Mining and Metallurgy

Mining Operations

1. Prospecting
2. Opening the deposit
3. Winning methods
4. Working the deposit (exploitation)
5. Supporting
6. Riding
7. Hauling
8. Draining
9. Ventilation
10. Light
11. Art of surveying mines

Metallurgy and Metal crafts

12. Beneficiation
13. Charcoal burning and forestry
14. Smelting
15. „Refinery“
16. Fabrication
17. Decoration processes (metal crafts)

Economy of Mining

18. Operating, Organization
19. Mining rights
20. Ideology, religion
21. Economy: Theoretical factors

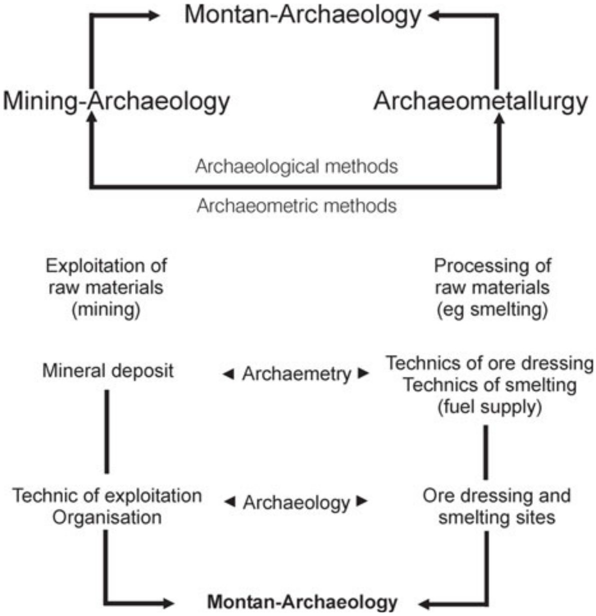

Fig. 7.6 Mining archaeology and archaeometallurgy in definition as it has been used since the 1980s, e.g. at the German Mining Museum Bochum as "montan-archaeology". (After Stöllner 2008b, p. 150, Fig. 4)

district. It is more important to show how the accumulated observations, knowledge and information represent the evidence of production processes like mining, smelting or fabrication. Montan-archaeology offers a specific contribution to historical knowledge, beginning with mining activities, winning of raw materials by mining or quarrying, preparation, handling and/or smelting (Fig. 7.5). It searches for and interprets evidence of activities in the sphere of mineral exploitation and preparation. Thus, montan-archaeology is associated with the peculiarities of particular resources, so that it cannot be fully evaluated by itself. From the early years of mining research, it has usually been left to an interdisciplinary group of scholars working together (Fig. 7.6). Henceforth, montan-archaeology is a methodological field not bound to a particular period or epoch, but interested in special resources and processes on or below the surface.

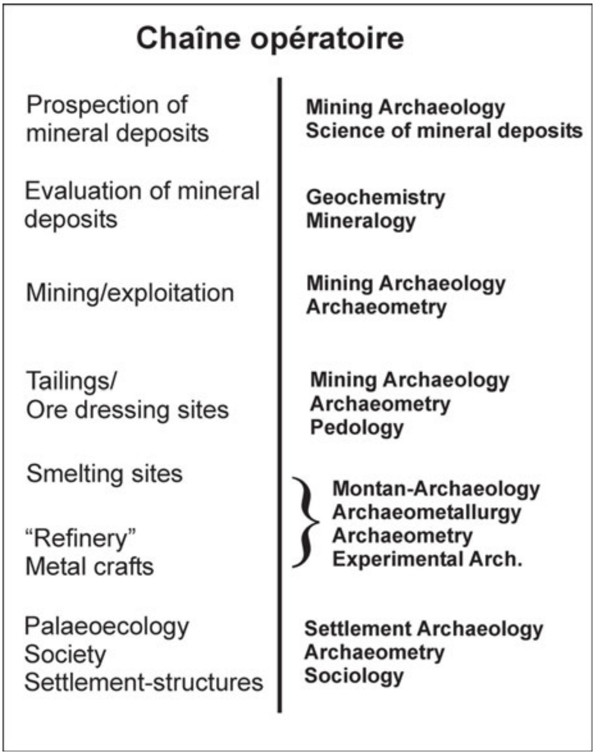

Fig. 7.7 Chaîne opératoire of research in the fields of mining archaeology and archaeometallurgy. (After Stöllner 2008b, p. 151, Fig. 5)

Natural sciences, within the sphere of a specific mining archaeology, can contribute to the interpretation and understanding of such remains. This is especially so for ores, furnace remains, technical pottery and slag (Hauptmann 2004, 2007b, 2008). As Fig. 7.7 shows, such research is always a multi- or even interdisciplinary work that combines methods and knowledge from several academic and non-academic fields. The exploitation processes as a whole can be enumerated best into 20 categories, structured around mining, smelting and fabrication activities (Weisgerber 1989/1990, 2003; renewed and added Stöllner 2008a, 2008b). They describe a specific *chaîne opératoire* of such productions. Of these twenty, fifteen are technical, three represent social, economic and political aspects and the two remaining include inter-regional and ideological factors which influence mining and smelting in a wide scale (Fig. 7.5). The systematics model presented here and elsewhere does not comprise all different raw materials but is more focussed on metals. Other raw materials (e.g. salt, ochre, pigments or fossilized wood) had their own preconditions that created specific workflows, but these are beyond the scope of this paper.

Only by using correct terms from several fields of engineering science is it possible to reconcile or absorb the material or even to communicate unequivocally. Terms are comfortably available in handbooks of mining, smelting and quarrying of the nineteenth century and early twentieth century. Because of the modern mining techniques introduced in the twentieth century (e.g. gigantic opencasts, electricity, motors, etc.), the terms of modern mining science often cannot help or even have changed meanings. Regarding what has been said above, it is worth discussing the systematic model of ancient mining and metallurgy. It is a general approach that helps to structure any discussion about prehistoric and ancient raw material exploitation.

Empirical Work and Modelling a Socio-Economic Process

With the methodological issues in mind, the second part of this paper will deal with the empirical work in montan-archaeology that should help to achieve the necessary database. Montan-archaeology, like many applied sciences, is based on specific scientific questions and is—as mentioned—primarily interdisciplinary. Nevertheless, it is an archaeological field and, as a consequence, it finds its methodological basis there. I therefore will restrict myself to describing specific empirical fields.

Disciplines Connected with the Investigation of Early Raw Material and Archaeo-Metallurgical Studies

The investigation of mining and metallurgy requires the integration of methods and knowledge of several related fields. One may call them the methodological canon of montan-archaeology, including several academic fields of mining and metallurgy (Berg- und Hüttenkunde), but also related fields of exploration geology (Lagerstättenkunde) and tectonics and structural geology (Tektonik und Strukturgeologie).

The multiple disciplines that comprise montan-archaeology can be described as the following:

Exploration geology (*Lagerstättenkunde*) is the basic requisite for describing the mineability of a deposit and the possible content of an already exploited deposit (Pohl 2005; Warren 2005). It helps to understand the yield of an ancient mining process. If the mining archaeologist wants to calculate the average ore content of a mine, whose cavity he has already investigated and measured, he has to consult exploration geologists to ascertain the ancient exploration yield.

Mining archaeology (*Bergbauarchäologie*) can be described as the basic archaeological method to survey, excavate and evaluate ancient exploitation areas such as underground mines and quarries.

Archaeometallurgy (*Archäometallurgie*) deals with field investigation of ancient smelting sites and other metallurgical sites and workshops (casting, smithing). It has to consider experimental and ethnoarchaeological approaches as well as specific taphonomic methods to get closer to the specific technical workflows (Ottaway 1994; Hauptmann 2007a, 2007b).

Archaeometry (*Archäometrie*) *of metals* is science based and uses different methods of mineralogy and geochemistry (especially of isotopic chemistry) to answer questions of metallurgical workflows or the provenance of materials (e.g. several articles in Wagner 2007; Begemann et al. 1989).

Mining engineering (*Bergbaukunde*) delivers the basic analogies for ancient technologies applied to specific types of deposits. Technologies themselves adhere to an ancient technical solution and can often be deduced from solutions known in traditional and historical records. Mining engineering provides the basic nomenclature of all types of exploitation processes (Gätzschmann 1846; Hoover 1909; Reuther 2010).

Tectonics and structural geology (*Tektonik und Strukturgeologie*) helps to understand and reconstruct alterations of rock texture by rock mechanics (e.g. pressures, lateral dislocations). This is especially important when discussing the situation underground (e.g. mineability of a deposit) or specific technical solutions (e.g. how to secure an area by timbering).

Mining surveying (*Markscheidewesen*) deals with both the reconstruction of the ancient surveying knowledge and the application of modern technique to the documentation of exploitation sites.

The science of economic ore dressing and metallurgy (*Aufbereitungs- und Hüttenwesen*) is today an academic sub-field in the mining sciences (Montanwissenschaften) that can be explained in analogy to the mining engineering.

Traditional technologies can be reconstructed by historical recipes and by modern ways of evaluating their economic efficiency. Experimental processing or even the interpretation of ancient descriptions (the most famous being those of Plinius the Elder, Theophilus Prespyter, and Agricola) needs the experience and the knowledge of specialists of that field.

There is no doubt that besides the disciplines mentioned, other fields have to be considered for a full reconstruction of old raw material exploitations to be reached. Such fields (e.g. palaeo-environmental reconstruction) certainly belong to any modern archaeological research project and do not need specific discussion here.

Field Methods—Survey

Survey methods constitute a basic component for any archaeological fieldwork but are even more important within montan-archaeology. Mining landscapes are generally too large to excavate extensively. Therefore, surveying methods have to replace in-depth field studies by a sophisticated combination of several methods. For example, if a large slag heap is excavated fully within several months of field work, it is simply too expensive to repeat the same operations at several other slag heaps (e.g. methods as discussed in Ullrich et al. 2007; Stöllner et al. 2011a). Therefore, a combination of surveying and soundings must be practiced, which always have to be tied to further questions about dating and lifespan, about stratigraphy and taphonomic structure of the dumping process (Fig. 7.8).

It is self-evident that mining, smelting and further production processes do require a special surveying methodology. Road or river cuts are very helpful especially in fully overgrown landscapes or forests. By following streams, for instance, slag heaps can often be found by following the trail of eroded slags in the stream bed (e.g. F.-A. Linke in: Seegers-Glocke 1999).

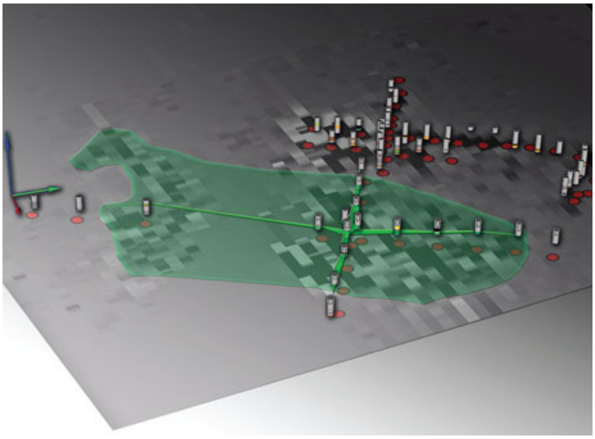

Fig. 7.8 Smelting site SP 14 in the Mitterberg area, Austria. Result of the combined survey in 3D: magnetic survey in combination with drilling survey. In *green*: reconstruction of the slag heap's extension. (After E. Hanning in Stöllner et al. 2011a, Fig. 2)

Detecting mines or interpreting depressions as traces of exploitation is much more difficult if there are no visible traces such as dumps, remnants of tools and so forth. Geophysical methods have the potential to detect mine openings or even to investigate the deposit itself by detecting the filling of mining depressions as well as the depth of the exploited area. In contrast to seismic surveys or geoelectrical tomography, ground-penetrating radar or geo-electric magnetometric survey are not very capable methods for detecting mines (e.g. R. Herd in Stöllner et al. 2009, pp. 124–129). However, geo-magnetic surveying is very useful for detecting smelting sites consisting of slag heaps, furnaces or roasting installations or charcoal pits. Today it counts among the most frequently used surveying methods (J. Fassbinder in: Wagner 2007, pp. 53–73).

A very specific surveying technique is applied to underground mines because of speleological methods of measuring and entering narrow or even dangerous areas. Mapping and describing includes also the third dimension, and the traces of mining work that provide good technological and chronological indications, especially on the basis of the different usage of mining tools (e.g. hammerstones, wedges, metal picks, explosives), are hard to find (Weisgerber 1989/1990). It is the careful observation that enables an experienced eye to carry out a first differentiation and interpretation of an underground mine (Fig. 7.9).

A most helpful and powerful surveying device is the core drilling of tailings, mining depressions or shafts. In recent years, drilling became as important as small sounding investigations. It always has to be accompanied by pedological expertise, but it does deliver most instructive information, not only about soil development but also about the stratigraphy and preservation of the archaeological features.

Field Methods—Excavation:

Excavation must be carried out in a special way in mining archaeology. Excavations underground mean that it is often not possible to work in a horizontal way. Usually

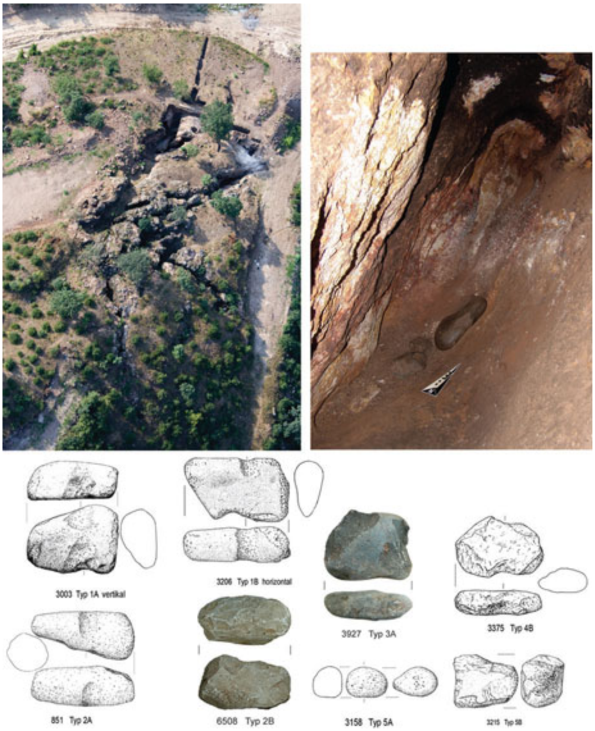

Fig. 7.9 Sakdrissi gold mine, late fourth millenium BC, Georgia. *Top left*: aerial photography of the mining area after cleaning the vegetation and with excavation trenches 2008. *Top right*: underground gallery with hammerstone deposition and fire-setting traces on the ceiling (sooted area). *Bottom*: types of hammerstones for the getter's work. (DBM, Th. Stöllner)

one can proceed only vertically by cutting sections, and through interpretation of these sections and profiles, retrieve the most relevant information about filling layers and mining debris (Fig. 7.10). This is especially true in elongated galleries or mines which are already completely filled or compressed and destroyed (e.g. descriptions of the methodology of underground excavations of the Deutsches Bergbau-Museum Bochum: Stöllner 2002/2003, pp. 24–35; Stöllner et al. 2009; Stöllner et al. 2011b). With respect to taphonomic questions, excavation proceeds along natural layers in order to reconstruct information about layer genesis and filling volume. This is crucial to get sufficient information for the interpretation of a layer either as an occupational level or as debris that emerged through local mineral extraction or that had been dumped from elsewhere. Mining layers generally are as complex as settlement layers and have to be differentiated carefully. Mining techniques are a basic precondition for any underground excavation, including the loading and carrying of material railways and wagons and the use of special advancing techniques such as pneumatic drills (Fig. 7.11). Safety must always be considered first before excavation takes place.

Besides underground excavation, other production sites often require special techniques. For example, iron smithing sites should be wet sieved in order to find even small debris such as magnetite prills and scales of the hammer stroke (general: Jöns 1997; Ganzelewski 2000). The same holds true for small copper slags or grinding debris. Whenever possible, such debris has to be fully recovered, quantified and

Fig. 7.10 Sakdrissi gold mine, late fourth millenium BC, Georgia. Side gallery A3 in depression A, filling with late antique gravel (*top*) and late fourth millenium BC mining debris in the lower part. Example for a vertical strata sequence in a mining gallery. (DBM, Th. Stöllner)

Fig. 7.11 Sakdrissi gold mine, late fourth millenium BC, Georgia. Excavation process with documentation within the mining depression A. (DBM, Th. Stöllner)

qualified. Dry and wet sieving, therefore, is absolutely necessary, not only for archaeobotanical debris or small artefacts. The largeness of sites is usually the main problem which often cannot be solved without the use of machinery. This does make mining archaeology expensive, and means that it is dependent upon the experience and practical knowledge of civil and underground engineering. In this way, mining archaeology is similar to underwater archaeology or the archaeology of wetland sites.

Field Methods—Sampling and Sieving

As mentioned above, sampling and sieving strategies are absolutely necessary and several basic questions must be answered in order to carry out these operations. First, a researcher has to understand the taphonomic value of the archaeological sediment: is it preserved more or less undisturbed? Is it the result of a production process or has it been re-dumped? How far has the material been degraded by soil erosion or other soil processes (e.g. human dumping) above ground? Besides the question of preservation, sieving and sampling has the taphonomic value of revealing *in situ* eco- and artefacts. On the other hand, the sedimentary record tells us about the fractioning of materials during procedural working steps or simply about which kind of rock deposit has been worked. In addition to estimating the quality and composition of the debris, it is also necessary to measure the quantity of the debris (a basic precondition for any econometric calculation) (E. Hanning in: Stöllner et al. 2011a).

Second, a critical estimation of the size of the labour force and any social or cultural effects upon the creation and deposition of the waste material is compulsory. For example, if one compares the different taphonomic structures of Alpine copper and salt mining during the Bronze and Iron Ages, one can see both variables at play. While the Bronze Age mining systems were careful not to dump rubbish within the mines themselves, the opposite is true of the Iron Ages (e.g. Aspöck et al. 2007; Kern et al. 2009; Stöllner et al. 2009). This difference has to do with the organisational patterns of Iron Age large-scale mining (staying underground, large working groups), but also with a different form of cultural behaviour caused by different conceptions of waste management.

Field Methods—Visualization

Surveying is one of the special cases by which mining archaeology especially is distinct from other archaeological fields. This is reasoned especially by the speleological character of underground mines: such archaeological monuments require the documentation of the third dimension because information cannot be visualized only by a projection into a second-dimension depiction (as can be done by a 2.5-dimensional situation in the case of excavations and surfaces). Although architectural three-dimensional displays are more common in archaeology today, it is still too difficult to solve all the problems that have to be faced by an irregular cave-like mine, such as undercutting surfaces and highly exact depiction of surfaces covering all the traces of ancient miners' work. All these efforts are serving essentially as the necessary means to display complex underground excavation and survey work.

Despite all these modern methods, the mapping of mines still depends on conventions that have been developed and standardized since the nineteenth century. Traditional surveying work with compass and a gradiated arc is the basic precondition for any further visualization work but allows no impressions of complex hollow

Fig. 7.12 **a** Traditional mapping underground, Slovakia, Poniky. Medieval to modern times mine. **b** Laser scanning underground, Sakdrissi Gold Mine. (**a** DBM, Th. Stöllner; **b** DBM, Th. Rabsilber)

structures on walls and ceilings (Heller et al. 2002; Steffens 2008) (Figs. 7.12a, b). A mapped documentation of a mine, a quarry or any producing area has to display two kinds of information—the archaeological and the technical. The latter has to follow traditions that are usual in mining surveying, including information of the geological deposit, the extraction technique and the surface of the extraction gallery.

There is a broad spectrum of methods now being included to visualize complex surface and cave-like structures: Besides laser-scanning and photogrammetry, more simple techniques also have to be mastered, especially when working in narrow areas (e.g. by photogrammetry: Arles et al. 2011; by laser-scanning: Schenk and Hanke 2009; general: Grussenmeyer et al. 2010). Highly engineered devices often fail because of the narrow space or other difficulties that are affected by special underground conditions. Whatever the special requirements of documentation are, it depends on a workflow that has to be developed individually. The technical development of soft- and hardware generates rapid progress which generates ongoing technical adoptions: recent research efforts are concentrated on higher detailed and photo-like texturing of surfaces using 3D-information systems.

Laboratory Methods—Written Sources

Historical records are utilized regularly for general information about the technological processes that were carried out at a particular time, but they are seldom exact enough to match the circumstances of an archaeological excavation. Old surveying maps or historical travel accounts are helpful for detecting sources and sites (e.g. the historical record of the mines of Hallstatt, Dürrnberg and Mitterberg: Kern et al. 2009; Stöllner 2002/2003; Zschocke and Preuschen 1932). Historical mining often followed and reopened older exploitations, so such information was often recorded in great detail (Treptow 1907, 1918). Often such older mining traces posed serious dangers to historical mining processes. The "Old Man" (Alter Mann), as such older mining was called, was both feared and respected by the miners, but also noted in historic accounts.

Laboratory Methods—Dating

Providing chronological context for mines is compulsory but often difficult. This is especially true if one considers the complex stratigraphic situation within mines and other production sites (including re-dumping and the relocation of debris). One often has to differentiate between the primary exploitation of the mine, quarry or installation and the secondary filling of such contexts. Usually, working techniques (e.g. working traces on pillars, ceilings and walls) cannot be dated as finely as fillings (on the basis of artefacts or radiometric dates). Rather, one attempts to date an entire technological complex (e.g. fire-setting and hammer tools and bone wedges as a typical tool kit). That said, archaeological artefacts are seldom represented in a producing area's debris.

These problems explain why radiometric methods (e.g. radiocarbon dating: Kromer 2008) and dendrochronology have such a high importance for montan-archaeology. Even then, the exact dating of the operation time is only approximately possible. This is even truer for other radiometric dating methods, such as thermo-luminescence that can be used to date the last heating of feldspars and quartzes (e.g. in slags) (Wagner 2008). The only method which provides a secure and exact dating of operation periods is dendro- (tree ring-) chronology, but only if the wood can be shown to be in a primary context (Pichler et al. 2010a, b).

Laboratory Methods—Geographic Information Systems or Global Imaging Systems

Geographic Information Systems or Global Imaging Systems (GIS) was introduced to montan-archaeology in the mid-1990s and has revolutionized the field. Besides basic mapping, GIS allows the implantation of complex data and digital images that,

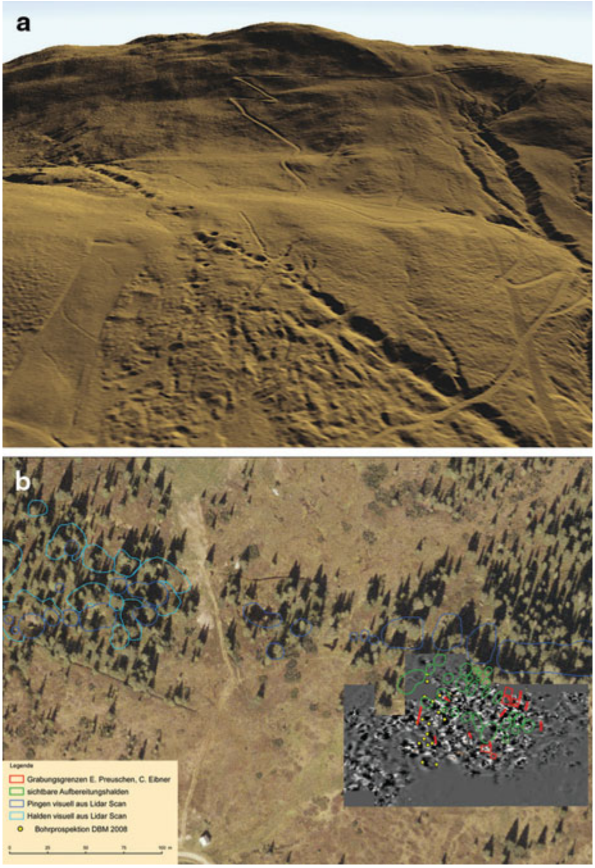

Fig. 7.13 Mitterberg, Austria, Middle to Late Bronze Age mining (seventeenth to ninth century BC). **a** The main-lode mining depression that follows the ancient underground galleries, lidar scan in 3D. **b** GIS mapping of results from lidar survey, magnetic survey, excavation and drillings in the area of the eastern part of the main lode and in the area of a large beneficiation area. (DBM, Annette Hornschuch, P. Thomas)

at higher resolutions, can now automatically detect mining depressions, platforms, tailings or ditches and wall systems. The combination of both GIS and light detection and ranging (LIDAR)-scan systems has proven to be more powerful than other remote-sensing methods (e.g. satellite images or aerial photos), as airborne-laser-scanning provides information even in areas where vegetation and forests cover most of the relevant surface structures (e.g. Devereux et al. 2005) (Figs. 7.13a, b).

Despite great progress in digitizing mining landscapes, everything depends upon the structure of the data being administered in a GIS program. Generally, such systems are only applied usefully to projects that expect a high amount of artefacts (e.g. a complex excavation site) or a landscape that is surveyed and investigated over many years. For example, a mining region with production and settlement sites is ideal for GIS, as questions of territoriality can be investigated either by procedural workflows (e.g. deposit—ores of a special geochemical composition—beneficiation— smelting—final processing) or by morphological and topographical preconditions of the landscape (e.g. traffic, visibility, site-catchment or the analysis of the nearest neighbours). There is a wide range of possible applications that cannot be discussed here in detail (e.g. Hiebel et al. 2010; Hiebel et al. 2012).

Fig. 7.14 Sakdrissi, Georgia—hammerstone kit as prepared by B. Craddock in 2011 used for the fire-set experiment 3/2011 underground (*top*). Exfoliation of wall parts after the fire-set (*bottom left*) and the heavy smoke during the experiment (*bottom right*). (Photos: DBM, K. Stange)

Laboratory Methods—Statistical Approach and Techno-Complexes

A further basic evaluation considers the techno-complexes and their interrelation with other parts of the workflow. It is primarily a qualitative question that secondly has also been accompanied by statistical methods. Timbering and timber use in a mine provides an example (e.g. Cauuet 2000; Thomas 2012). After a first step of differentiating artefacts and working chips, the archaeologist has to consider the representativeness of the sources: are the materials interrelated or is something under- or over-represented? One always has to keep in mind that everything which is used in a production process must have been brought for a specific purpose. Is there a technological progress—i.e. can one detect the individual hand of single craftspeople—or is it possible to reconstruct societal knowledge and work tradition of landscapes? In the Middle Bronze Age mine of Arthurstollen, scholars were able to identify and distinguish the tool marks of wood-working axes on supporting timbers found in the mine (e.g. Thomas 2012, pp. 140–149). These tool marks suggest that only one or two tools were being used, perhaps by a small number of experienced miners. Hammerstones or metal picks often provide a similar window into ancient mining, and it is very informative to combine it with experimental archaeology (Timberlake 2007) (Fig. 7.14). The weight and preparation of these objects have often been standardized according to common knowledge and ideas about how to use them (Pickin 1990).

Therefore, any noted differences embed interesting information about crafting traditions, the adoption of a deposit, as well as the access to resources (e.g. special stone varieties).

Laboratory Methods—Econometric Analysis

Quantitative analyses of mining processes also have to be based upon the technological chain as well as the statistical approach. As before, the taphonomic argument has to be faced: what is representative of a working process? Which various steps of re-dumping are reconstructable in the allotted time? Has the dump been reduced by later reuse? Fieldwork has to face the quantitative questions from the very beginning and during the documenting and sampling processes. There is no other way to get sufficient data. If one wants to calculate the mean value of the use of lighting devices (e.g. oil; wooden tapers), one has to know how many tapers had to be used by a single miner per day. This figure should be then juxtaposed with the debris and layer content in order to understand its value to the archaeological interpretation.

Conclusions

Montan-archaeology is basically an interdisciplinary sub-field of archaeology, which means that full information can be gained only through joint projects and modelling of multiple lines of evidence. There is no other way to work on the complex scientific questions and historical frameworks involved in the social and economic exploitation of resources. Everything depends on the quality of data and the level of argumentation. Often, single mining and production ensembles are well investigated and understood, while the whole mining district or even the region lacks further comprehension. While on the level of a single ensemble it is preferable to deal with single-phase production, diachronic observations allow insight into broader historical processes and into general questions that are linked to raw material production as embedded in societies and settlement history. Montan-archaeology is, therefore, able to describe long-term developments and is but one angle on the societal and economic development of mankind. However, it has to be fed back into the general historical and cultural development in order to be relevant.

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