Der Anschnitt, Beih. 34, S. 285–301, 2017, DOI https://doi.org/10.46586/DBM139

Martin Straßburger

Development of specific mining technological aspects from the Early to the Late Middle Ages

ABSTRACT: *Mining operations and the archaeological record resulting from them are analyzed with regard to their chronological development from the Early to the Late Middle Ages. The exploitation of mineral resources is a transformation process based on knowledge of geology, mineralogy, the according application of laws of physics as well as chemistry. Prospecting, exploitation and processing are the three underlying sub-processes involved, followed by primary and secondary metallurgy. They form the basic structure of a chaîne d'opératoire. Technology, technique, tools and execution of the mining operations are differentiated as four core areas and discussed.*

KEYWORDS: MINING OPERATIONS, TECHNOLOGY, TECHNIQUE, MINING TOOLS, CHAÎNE D'OPÉRATOIRE, HABITUS, SPECIALZATION, KNOWLEDGE

Introduction

Mining operations and the archaeological record resulting from them can be analyzed with regard to their chronological development. This is done in this contribution for the time from the Early to the Late Middle Ages with regard to deep mining in ore deposits.[1] The exploitation of alluvial and eluvial deposits is left out although it is another highly interesting topic. Furthermore, ventilation and surveying were omitted as the existing data provides too few information about trends in developments so far.
Generally speaking, the exploitation of mineral resources is a transformation process based on knowledge of geology, mineralogy, the according application of laws of physics as well as chemistry. Prospecting, exploitation and processing are the three underlying sub-processes involved, followed by primary and secondary metallurgy. They form the basic structure of a chaîne d'opératoire, a conventionalized, learnt succession of technical operations closely tied in with social patterns of behaviour.
Four core areas can be differentiated: technology, technique, tools and execution of the mining operations. Specific traditions in terms of context as well as a habitus can be recognized and as such a stable structure within which the miners were working and acting in a dynamic process. Several developments in mining technological aspects are detectable which can be analyzed.

Development of mineral deposits

The exact process during the Middle Ages is mostly unknown. There is only a story of monks prospecting for iron and copper after a flood by Gregory of Tours (+ 594) in his history of the Franks. From the 16th century onward, there are extensive descriptions of mining in textbooks.

Generally, the development of deposits is carried out in two phases which frequently merge. In the course of prospecting, first of all unknown objects are searched for (Wilke, 1974, p.6). After that, a recognized deposit is intensively examined to assess and plan working it.

During the High and Late Middle Ages, outcrops were one means of orientation. This can be observed on the plateau of the Argentario near Trento and at Ramsbeck in the Sauerland. For prospecting lead ore veins in elevated landscapes formed by glaciers in Wales, the technique of hushing was used in the 12th and 13th centuries (see Timberlake, 2004, p.75).

Especially in mountainous regions the upper part of a deposit was prepared for winning by adits driven from the valley bottom (Hafer, 1950, pp.24; cf. also Wagenbreth, Wächtler, Becke et al., 1990, p.41 and Dornbusch and Pötsch, 1962, p.90). From these ore and rock could be hauled to the surface relatively easy without special hoisting device. Furthermore, adits caught the water entering above their level, which was discharging by itself (Wagenbreth, Wächtler, Becke et al., 1990, p.41; Dornbusch and Pötsch, 1962, p.90). One example for an adit serving the development of a deposit is the high medieval Venetian adit at Ramsbeck. Other features show that driving was carried out in fault or vein zones like in the late medieval and early modern adits in the Schauinsland near Freiburg. By this, the loss of ore veins could be avoided. But an influence of the geological-tectonical situation on the techno-economical process was also possible, especially where the vein was dislocated and development had to start afresh. This is indicated by abrupt changes in direction and hooks in plans of the driving (Fig. 1).

Driving and winning techniques

By the winning techniques the deposit or country rock are mined and workings of all kind in the deposit itself or in the country rock are created (Fritzsche, 1949, p.148). The tools for the works are generally the same and it is exclusively about winning techniques by hand. In the following, mainly wedge, pick, gad and hammer work as well as fire setting are considered.

Wedges were pointed and applied in harder rock (Agricola, 1556 (1994), p.120; cf. Tizzoni, 1997, p.275 fig. 2: Mining of the 12th/13th century in Lombardy with finds of wedges and identical tool marks to those in the Birkenberg, in the Schauinsland (Fig. 2) and in the mine “Segen Gottes” at Haslach; cf. also finds from Brandes-en-Oisan in Bailly-Maître and Dupraz, 1994, p.66 fig. 38). The hammers used in medieval mining were amongst other things made of wood. Depending on the space, they could only be handled with one hand (see Weisgerber, 1996, pp.2-18). Adits and levels driven in wedge work are to a large extent oval and had a maximum height of 1-1, 2 m.

Pick work alone could only be employed on the whole working face in softer or weathered rocks (Hoff-

Fig. 1. Plan of the late medieval Gegentrum III-adit of the Schauinsland mine near Freiburg (map: M. Straßburger).

Fig. 2. View into a segment of the late medieval Gegentrum III-adit of the Schauinsland mine (photo: M. Straßburger).

mann, 1830, p.4; Ržiha, 1867, p.10; Veith, 1871, pp.220f.; cf. also Simonin c. 1868, p.426 ,fig. 134; Straßburger, 2002, pp.79-80). Until the 19th century picks of different sizes existed, the smallest resembling a hammer (cf. Morgans, 1871, p.79). Finds of medieval picks are rare and in most cases can only be roughly dated, like one from a spoil heap in the Vosges Mountains. Other examples come from Massa Marittima and Serbia. Going by these examples, the head of the tools had a length of c. 11, 3 cm and a width of c. 2, 5 cm at their back. A 13th century pick from the Bliesenbach mine weighs more than 1 kg. The handle was 1-1, 3 cm thick. Meanwhile, there is also one find from the high medieval mining in Dippoldiswalde. Apart from that, mainly depictions are available like that on a gravestone in the church San Francesca in Massa Marittima, on the town seals of Sulzburg, Todtnau and Bythom or in the windows of the Minster in Freiburg. The seal of Todtnau even shows a miner with a tanged pick and two stalkless pick heads on a strap. These depictions conform to the picks, with which Nappian and Neucke are fitted out. For early modern times entirely different forms can be observed. The most common is depicted in De Re Metallica.

Gad and hammer work was applied for several centuries. Identical basic forms of the tool and working techniques in the several mining districts can be discovered in each case. Tool marks in the walls are curved grooves with the section of a notch (cf. Straßburger, 2002, pp.75-79).

Fig. 3. Fireset working in the Canopa of Busa del Pomar (photo: M. Straßburger).

In Saxony and the Czech Republic gads are detectable since the 13th century. These are basically tanged wedges. Although gads of various sizes are already known for medieval times, it remains unclear if they were used for different works. Only since early modern times this differentiation of gads is traceable, especially due to the written sources, describing and depicting gads for different purposes (see Agricola, 1994, pp.120-122; Schwazer Bergbuch, Cod. Vindobonensis 10.852, fol. 143 and 143v; cf. also tool finds from the mine “Caroline” at Freiamt-Sexau north of Freiburg).

A first mentioning in written sources can be found in the book of document of Goslar from the time around 1320 (Faller, 1967, pp.24). Depictions of this working technique are found on seals like those of Nagybánya and Felsöbánya, both from the year 1347. On the one from Felsöbánya pick work is shown in addition. According to the state of research so far concerning tool finds and features of tool marks, it can be stated that gad and hammer work was introduced at different times in the mining districts. Furthermore, during the Late Middle Ages a dominance of pick and wedge work has still to be anticipated.

Firesetting was an effective, but slow technique (Barnatt and Worthington, 2006, p.5). It was mainly used in hard rocks, especially when following thinner veins. It did not serve the winning of the ore itself, which in most cases was softer and could be hewn, picked or broken out. A disadvantage consisted in the compulsory sufficient ventilation, necessary to ensure the air supply for the fires and the smoke outlet. Another problem was that this technique could not be applied in wet mines.

Fire setting was extensively used in the Carolingian-Ottonian silver ore mines of Melle in France and also in the high medieval mines on the plateau of the Monte Calisio near Trento (Fig. 3) and at Ramsbeck. Similar features are known from the Derbyshire Peak District which mainly date to early modern and modern times. In the iron ore mining of the Forest of Dean this technique was still used in the 18th century. Even younger examples

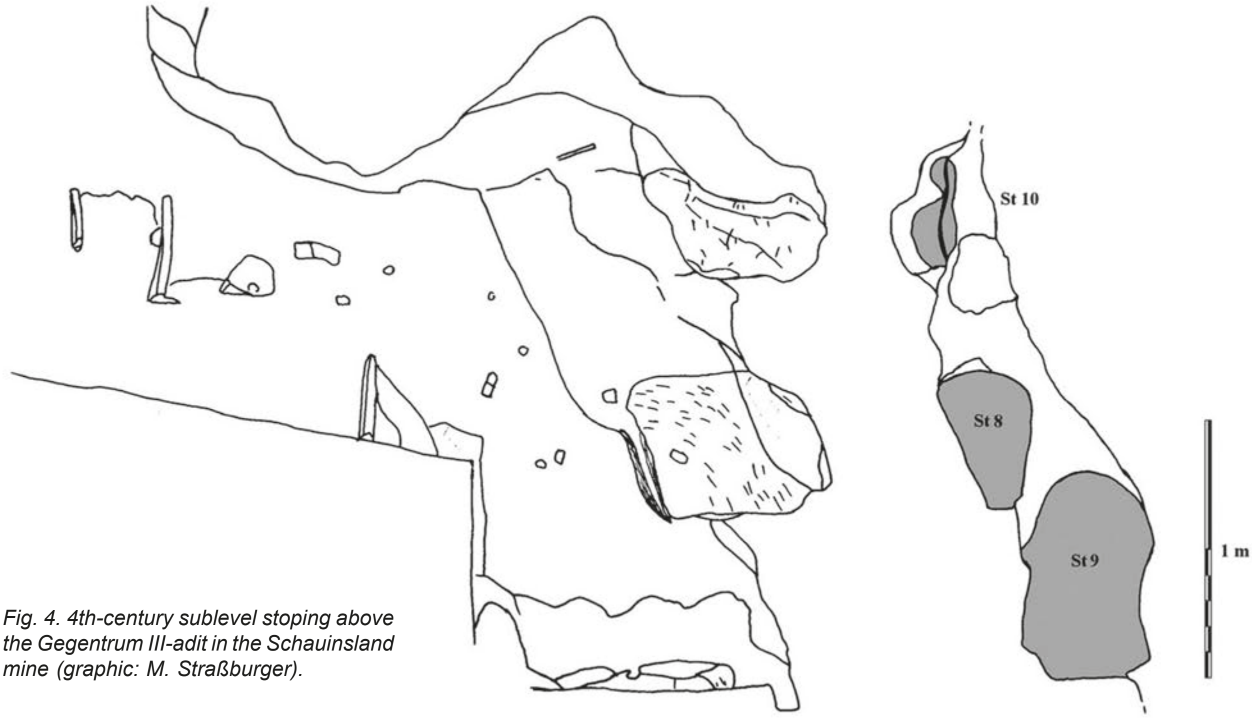

Fig. 4. 4th-century sublevel stoping above the Gegentrum III-adit in the Schauinsland mine (graphic: M. Straßburger).

are amongst others features in Saxony and in the Rammelsberg at Goslar. the best known historical and detailed description of fire setting is that by Georg Agricola (1994, p.89). But according to the existing archaeological and historical data a decrease since the Late Middle Ages begins to show in general.

Working techniques

The term "working technique" describes the geometric aspects during the systematic creation of mine workings in the deposit and the geomechanical treatment of the excavation during winning taking into account the adaptation of the particular method to concrete geological and technical conditions (Krause, 1986, p.4; cf. Bayer, n.d., p.87). The basics of the techniques have formed in long historical processes and developed in various different ways, influenced by regional specifics and diverse conditions.

Sublevel stoping

Medieval workings in steep dipping veins partly consist of levels arranged "moniliform" one above another and separated from each other by small horizontal pillars, which were hewn away during the proceeding winning. This is a form of sublevel stoping (Krause, 1986, pp.49-51.), which has been recorded in the Black Forest in the Schauinsland (Fig. 4), in the Teufelsgrund in the Münstertal (Fig. 5) and in remains in the mine "Segen Gottes" at Haslach and is also known from mines in Saxony (information on examples in the Freiberger district was kindly provided by Stephan Adlung, Freiberg). Features of this kind are already known from Roman gold mines in Romania (cf. Wollmann, 1976, p.183 as well as fig. 3 and 4; idem, 1999a, p.129, fig. 19b. Cetatea Mare.; idem, 1999b, p.25, p.27 Gauri and Coranda Verde as well as text on p.27.).

By advancing the sublevels steep dipping, thin to strong deposits of any extension were divided into horizontal sections convenient for working (Krause, 1986, p.49). The driving always started from a central development working, orientated on the existing conditions of the deposit. So far, mainly the variation with horizontal pillars between the levels has been recorded. These were hewn away in a second phase of the winning process. Sublevel stopes were designed for the winning of the entire deposit and could be adapted to all conditions in steep inclinations (Krause, 1986, p.51).

Overhand stoping

Overhand stoping is suitable for working medium inclined and steep dipping deposits. After the discovery of the vein, the deposit was developed ascending starting from a ground level. The in situ ore in the ceiling of the working was won stepwise up to a higher upper level (Krause, 1986, p.12 and p.41; Bayer, n.d., p.88; Oppel, 1769, pp.45f.; Hoffmann, 1830, pp.71-72; cf. Straßburger, 2002, p.65). On the step-like diagonal several workspaces were manned, which made a higher concentration of work for winning possible (Bayer, n.d., p.89; cf. also Bersch, 1898, p.229). With the advancing drift wall the ceiling of the ground level was secured by boxing. By this

Fig. 5. 15th-century sublevel stoping in the Teufelsgrund mine in the Münstertal south of Freiburg (graphics and poto: M. Straßburger).

a platform for the stope filling was created (Hoffmann, 1830, pp.71-72; cf. also Bayer, n.d., p.89). When the thickness of the vein was small the gangue and the country rock were directly backfilled and served the hewers as base (Bayer, n.d., p.89). In low height the excavation was left open, but in larger ones backfill was brought in following the winning, in order to reach the ceiling again (Bayer, n.d., p.89; cf. also Bersch, 1898, p.229).

One disadvantage of overhand stoping was the loss of ore in the packing during winning (Köhler, 1897, p.239). Based on the evidence so far, it has been established in its typical occurrence since early modern times.

Underhand stoping

Underhand stoping is the inversion of overhand stoping. Its first appearance cannot be dated precisely. By early modern times at the latest, it developed its classical form. With this technique the deposit was located in the floor and extracted in dipping direction (Krause, 1986, p.43; cf. Oppel, 1769, pp.44-45; Köhler, 1898, pp.105-106). Working proceeded in short, stepped, horizontal walls and started with the sinking. The chamber resulting from this above the bench stayed open or was backfilled.

The application of underhand stoping was of advantage especially if a ore vein of small extent did not reach down to a lower level and its development by overhand stoping would have been too complicated and costly. Apart from this, the accumulating problems of this type of stope with ventilation, drainage and haulage as well as difficulties in securing and concerning the mechanization of all operations in the working restricted the use (Krause, 1986, p.43).

Hand filling

For winning loose materials or such with little cohesion, the so-called hand filling with shovel, scraper and trough was used.

For the 12th/13th century scrapers made of wood are known, e.g. from Dippoldiswalde. Iron scrapers with narrow blades and close-fitting shaft hole of the 13th/14th century have been retrieved in Bliesenbach and Altenberg-Müsen (cf. also depictions in the Stone Book by Alfons the Wise in Weisgerber, 1998a, p.186, fig. 169). In contrast to these early modern ones are larger dimensioned, as finds from the mine "Caroline" (Fig. 6) at Freiamt-Sexau north of Freiburg and from the Richelsdorfer Gebirge show (Sippel, 1999). Georg Agricola describes their use for scraping material together which then was loaded with a shovel into "vessels" (Agricola, 1994, p.122).

The excavated material could be pulled in troughs like shown on the Kuttenberg Kanzionale. In a mine at Niederpöbel (Saxony) a trough dating to the 13th century was found (see Hemker, 2013, p.31). Apart from this, mainly early modern and modern finds are known so far. The reason probably is that only few medieval mines have been examined until now.

From the Altenberg at Müsen a one-piece shovel is preserved. A contemporary depiction can be found in the Stone Book by Alfons the Wise (cf. Weisgerber, 1998a, p.186, fig. 170). Two-piece shovels are known from Dippoldiswalde, Bliesenbach and an iron ore mine at Sémur in Auxerre (on Bliesenbach and Sémur see Weisgerber, 1996, p.8 and fig. 16). This type also occurs in other contexts in metal, metalsmiths and in print art. It is shown in context of the building of a charcoal burner in the "Guild collar" of the silversmiths of Ghent dating to the end of the 15th or beginning of the 16th century (Dorchy, 2013, p.282 and p.281, fig. 2) and with a pointed, iron cladded blade in the Theuerdank from 1517 used for draining a ditch in the course of a siege (Bavarian State Library Munich, Sign. Rar. 325 a, Holzschnitt 94; cf. Burgkmair and Füssel, 2003). Archaeological finds and depictions seem to indicate that this shovel type was built differently according to the purpose. Based on those from the tin placers in Cornwall, it can be assumed that shovels without iron

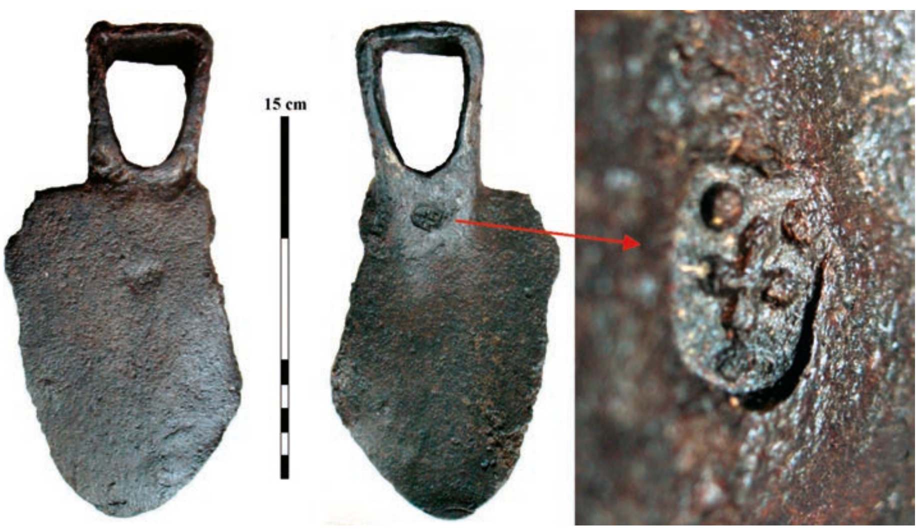

Fig. 6. Scraper from around 1520 found in the mine "Caroline" near Freiamt-Sexau (photos: M. Straßburger).

cladding were probably employed for clearing flumes or gulleys. Similar constructions of paddles can be found in the modern brewing trade (cf. Siuts, 1988, p.209 tab. 118).

Haulage underground

The term "haulage" describes first of all the process of transporting the mined ore from the point of winning to processing or smelting (Köhler, 1897, p.300; cf. Straßburger, 2002, p.89). Besides this it also comprises all facilities, constructions and provisions serving the movement of mineral raw material, waste rock, materials and persons as well as the operation of these constructions itself (Bischoff, Bramann, Dürrer et al., 1988, p.134).

Haulage in horizontal excavations and workings

Rich ores were carried either in containers (sacks, baskets) or without them (Veith, 1971, p.195). The sacks in the depictions of the windows in the Minster of Freiburg could be a hint to rich ores. Sacks are also mentioned in the mining law by Johann of Üsenberg (General Landesarchiv Karlsruhe 103/13, oldest copy of the Üsenberger Bergordnung). It remains to be examined if there is a context of change from sacks to kibbles as containers for haulage with the transition from rich to primary ores. Baskets are known from the high medieval mining in Dippoldiswalde and from early modern workings in the Freiberg district (see Adlung, 2011, p.71).

For towing or dragging haulage mostly troughs were used, like those found in the mine "Bliesenbach" in the Bergische Land or at Niederpöbel and which are shown in the Kuttenberg Kanzional (cf. Hemker, 2013, p.31). Interesting are the finds of wooden sledges in the late medieval mining of Kopaonik (Bogosavljević and Vuković, 1993, p.414 and p.416, fig. 7).

Ores and waste rock were partly dumped in steep inclined wooden chutes or even gullies hewn in rock, in which they slid to a lower point due to their own weight (Ržiha, 1867, p.251; cf. also Agricola, 1994, p.127). Wooden chutes are known from the high medieval mining in Dippoldiswalde and were in use well into modern time.

So far, it is not clear when wheel transport first came up. The "karrowegus" mentioned in context with an adit in the mining law of Trento (1208– 1215) cannot be assigned explicitly to haulage (cf. Ludwig, Schmidtchen, 1997, p.50). Considering small underground sections mostly encountered in the area of the Argentario wheel transport would have been difficult if not impossible. But there are also drivings showing profiles and sizes reminding of Roman works in which this kind of haulage would have been possible. These were introduced in Europe during the 13th century (Binding and Nussbaum, 1978, p.93, fig. Z 27 and following). Since the 16th century parts of so called "Hundtslaufe" or tub tracks occur among the archaeological features.

Fig. 7. Early medieval shaft timbering from the Hainberg at Neuburg on the Danube (photo: M. Straßburger with kind permission of the Bayerische Verwaltung der staatlichen Schlösser, Gärten und Seen).

Shaft winding

Whereever possible shafts were sunk in the ore vein during the Middle Ages, making possible faster sinking and simultaneously prospecting (cf. Straßburger, 2002, pp.91-92). Depending on the vein shape this resulted in shafts not going down vertical or with varying angles so that the hoisting vessels were running on the footwall and the ropes rubbed against the hanging wall or benches formed. In order to reduce the friction or even strikes of the vessels on the footwall, this was lined with wood. This has been recorded in the high medieval mining of Dippoldiswalde (Scholz, 2012, p.35).

For the Altenberg at Müsen shaft depths of 70 or 90 m are assumed (Dahm, Lobbedey and Weisgerber, 1998, p.30 and p.226) and in the Bohemian silver ore mining depths of 120-150 m are estimated for the time at the end of the 13th century. A similar measure may have been reached on the Treppenhauer with 90 m. Mining in the Rammelsberg at Goslar reached up to 160 m below surface around the year 1300 (Bartels, 1996, p.240; id., 1997, p.45; Alper, 2004, p.355).

Baskets as container for hoisting are known at least since the 12th century. In article 4 of the "Oberharzer mining law" so called "kerve" as obviously important property of the Silvanes are mentioned (Alper, 2004, p.357; Gottschalk, 1999, p.114, fig. 16). The depiction of a wattled basket can be seen in the Dieselmuot-window in the Minster of Freiburg and the Kuttenberg Kanzional shows several of these. According to Georg Agricola their capacity was the same or even larger than the one of kibbles or tons because they were lighter (Agricola, 1994, p.125). Approximately contemporary to the Kuttenberg Kanzional kibbles or tons constructed of staves seem to have been used in some districts as e.g. finds from the shaft in the Donnerloch at Steinbach (Haut-Rhin) indicate which have dendrochronologically been dated to the end of the 1470s (Bohly, 2008, p.96).

For hoisting the output knob and crank winches were installed (cf. Weisgerber, 1981b, pp.165-166). Winches with iron cranks are known from at least about 1400 and were taken up slowly . If larger forces were needed knob winches were still used. Since early modern times there has been an increased number of depictions showing crank winches. The earliest depiction in a mining context can be found at Ulrich Rülein of Calw from 1505.

Meanwhile, several archaeological features of winches have been discovered, dating from the end of the High Middle Ages to modern times, e.g. in Saxony (Dippoldiswalde), in Donnerloch at Steinbach (Haut-Rhin; Bohly, 2008), in the Black Forest (Caroline at Freiamt-Sexau, Schauinsland, Steinbronnen in the Münstertal (dated c. 1528–1530: see Herbener, 2012, pp.246-250, Segen Gottes at Haslach-Schnellingen) and in the Vosges Mountains (Himmlischhör on the Neuenberg at Sainte-Marie-aux-Mines: Ancel, 1992, p.503 no. 5.54; idem, 1992d, p.504, no. 5.55-5.57), Wurtzelbaum adit and Haus von Sachsen in the Neuenberg, shaft in the mine “Glückauf” (Ancel and Fluck. 1988, pp.92f., fig. 63).

The possible strain of long, free hanging hoisting ropes was of special significance for mining. This results from the particular carrying capacity and the own weight of the rope. Leonardo da Vinci (1452–1519) noticed that the latter acted directly proportional to the rope length. An increase of this with greater hoisting depth meant a reduced carrying weight because the rope holds less effective weight due to its growing own weight with greater length (Ludwig and Schmidtchen, 1997, pp.223-224; from Herbert Maschat according to Codex Madrid II). One consequence was the sinking of broken shafts like those recorded in the high medieval mining of Dippoldiswalde and particularly in early modern mining.

Mine support

If the bearing capacity of a rock is exceeded by the creation of a mine working, securing measures are necessary. Their tasks are to keep open the working and to protect the workforce (Ržiha, 1867, p.630; Reuther, 1989, pp.362ff.). This means first of all that the openings are not rounded or curved more than necessary (Köhler, 1897, p.474). Furthermore support also refers to the backfilling of chambers hewn out, with waste rock, safety and barren pillars. If these means are not sufficient, the actual support has to be carried out with wood, dry stone walls or other constructions. The effort depended on the expected effects resulting from rock pressure.

Support in horizontal excavations

Wooden support was installed in adits and galleries when stability was missing or reduced (cf. Straßburger, Tegel, 2009, pp.183-184). In general prop and hitch timbering as well as framing are distinguished. Frames are support units consisting of props and cap (Ržiha, 1867, p.633). The purpose of framing is to hold the poly-directional rock pressure. Therefore the timbers have to support and interlock each other. Until around 1500 tenon joints and toothing can be observed as usual connection of the timber elements. Examples are Altenberg-Müsen (13th/14th century), Essen-Rüttenscheid (14th century), Schleiz (14th century), Kopaonik (14th/15th century; Bogosavljević and Vuković, 1993, p.414 and p.415, fig. 5) and Sontra (end of 15th century). This construction of framing with mortised planks or square timbers is still described by Georg Agricola (1994, p.93). Contrary to that the Schwazer (Codex Vindobonensis 10.852, around 1561) and Lebertaler Bergbuch (c. 1556) depict a more massive framing made of strong square timbers. The halving of cap and props seems to emerge at the beginning of the 16th century. With this the construction type used until modern times was developed.

Support in workings

The amount of wood needed and the construction type of support in workings mainly depended on the winning technology and rock conditions. Props stood vertical as pillar against the rock pressure between the hanging wall and the footwall (Straßburger and Tegel, 2009, p.177). Inclination, mining method and condition of the hanging wall decided whether a rigid or flexible support was inserted (Fritzsche, 1942, t. 2, p.15). In steep inclination support with low flexibility was used in most cases because in general the drawdown of the hanging wall was only little. Apart from the strutting slabs props are used in steep inclination also to hold horizontal pillars, ceiling or backfill. The props are covered with boards to create a platform. Examples are found in Dippoldiswalde for the 12th/13th century, in workings of the 14th century in the Schauinsland mine and in the mine “Teufelsgrund” in the Münstertal dating to the 15th century. They are working surfaces on which backfill was packed or even fire was set. The latter obviously was the case in the mine “Teufelsgrund” where charcoal was lying on a platform which probably originated from a fire for reinforcing air circulation. To make the support more flexible the props were sharpened. With this the sap wood was removed from pinewood.

Support in shafts

In shafts wood was used for support and installations of any kind (cf. Straßburger and Tegel, 2009, p.185). The timbering of the shaft support had to be especially resistant as repair works were difficult (Fritzsche, 1942, t. 2, p.17). Already from the 7th century examples are known in unconsolidated rock in Bavaria (Fig. 7). Their construction is similar to those of contemporary wells (fig. 267; Frei, 1966, p.43; Eckstein, 1974, pp.28-41). Features of the 12th/13th century have been recorded in Dippoldiswalde (cf. Hemker and Lentzsch, 2012, p.278), in the Bergische Land (Drozdzewski, Juch and Heckman, 2012, pp.162-164) and in the Altenberg at Müsen (Weisgerber, 1998a, pp.189-193). The timbers of the frames were mortised with each other. In the Black Forest no medieval shaft timbering in situ has been found so far. Only the prop holes are preserved allowing a partial reconstruction. Therefore, it is unclear if the style of the timbering was similar to that at Altenberg-Müsen (13th/14th century) or at Kopaonik (14th/15th century; Bogosavljević and Vuković, 1993, p.414 and p.415, fig. 5). A shaft support in the Donnerloch at Steinbach (Haut-Rhin) from the end of the 1470s (Bohly, 2008, pp.94-95) still shows the same connections of long pieces and cap pieces. The frames rested each on two crossbars. The shaft walls were lined with wooden boards. In the mine "Caroline" at Freiamt-Sexau two shafts were dendrochronologically dated to the 16th century (Straßburger and Tegel, 2009, p.185). The set support is very similar to the arrangement of the timbers from Donnerloch at Steinbach. In the time after 1500 an extensive change to a massive support in underground workings seems to become apparent which resulted in an increased demand for wood.

Mine drainage

In mining the term "drainage" comprises all facilities, constructions and provisions keeping the workings free of water, like drainage adits, flumes, launders as well as grooves in the walls and storage basins (Agricola, 1994, pp.142-171; Proempeler, Hobrecker, Epping and Ritter, 1957, p.189; cf. Straßburger, 2002, p.92).

The driving of adits with a slight gradient into the mountain enabling water to flow out itself was the simplest though quite costly possibility to keep mines free of water (Wagenbreth, Wächtler, Becke et al., 1990, p.55; cf. Straßburger, 2002, p.94). A drainage adit is already mentioned in the mining law of Trento. One of these was recorded in Canopa delle Acque. Another example is the Venetian adit at Ramsbeck (Fig. 8 and 9). These mine workings were in use and kept open for long durations.

According to today's comprehension a flume is a groove in the floor of a level by which the mine waters are discharged to the surface or the shaft sump (Bischoff, Bramann, Dürrer et al., 1988, p.382). They could be elaborated as a hewn, lined with semi-monocoque channel or a paved race. In the main levels they are mostly found on the left wall, rarely in the middle or on the right (Proempeler, Hobrecker, Epping and Ritter, 1957, p.201). If the channels were in the middle, they had to be covered like in the Venetian adit at Ramsbeck (12th/13th century). Medieval wooden sluices have been recorded in Dippoldiswalde and Bollschweil-St. Ulrich. Water was also diverted with sluices from the walls of adits. These consisted of two hollow, tightly jointed tree stems.

Grooves were hewn in the walls of mine workings (Gequäle or Gequelle) leading water for example off shaft areas into the channel of levels branching off to prevent it from flowing into workings below (cf. Straßburger 2002, p. 96). This method was already applied in medieval mines among other things to keep the places dry for firesetting like in Canopa Doss del Cuz (Trentino). An increasing number of such grooves can be observed since early modern times.

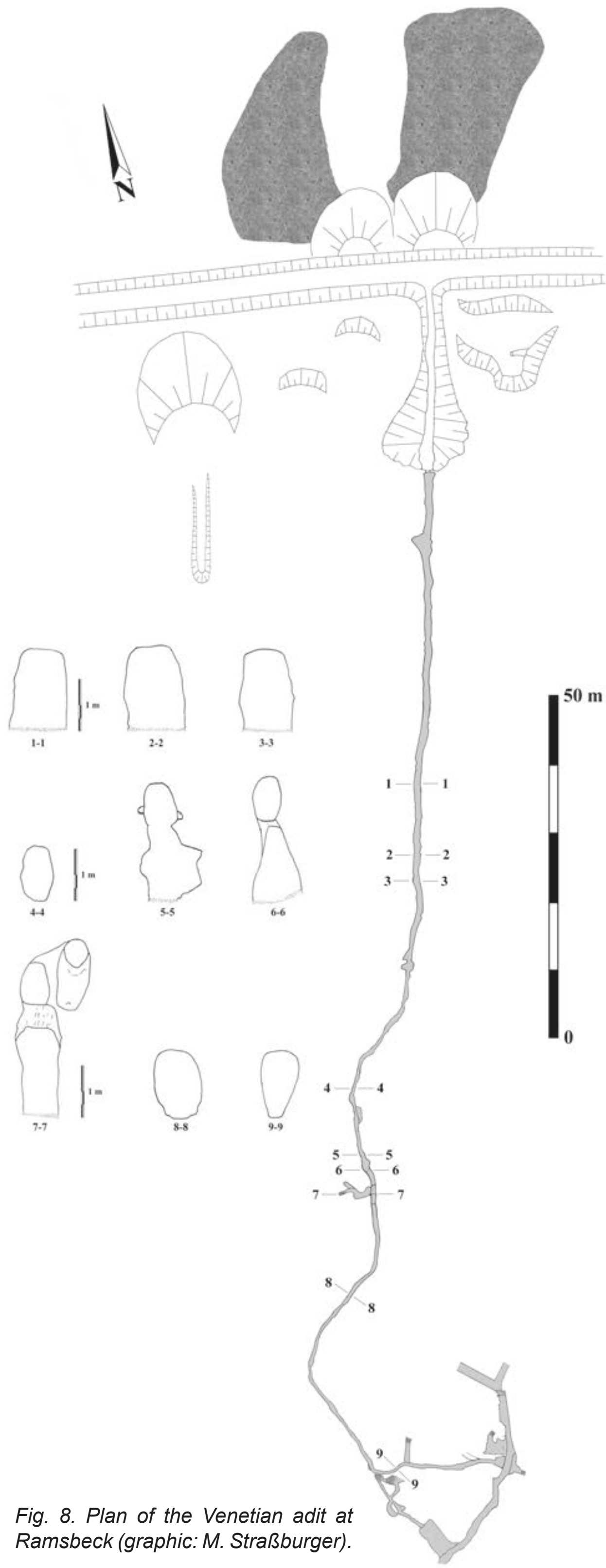

Fig. 8. Plan of the Venetian adit at Ramsbeck (graphic: M. Straßburger).

Storage basins hewn out of the rock are known from the high medieval mining in the Trentino (Fig. 10) and of Dippoldiswalde (Fig. 11). Supposedly to the end of the

Fig. 9. *View into the Venetian adit at section No. 8 in figure 8 (photo: M. Straßburger).*

Fig. 10. Basin in a high medieval working in Canopa Doss del Cuz, Trentino (photo: M. Straßburger).

Fig. 11. Basin in a high medieval level in Dippoldiswalde (photo: M. Straßburger).

14th and beginning of the 15th century a water box with an appliance for regulating the water outflow in the mine "Teufelsgrund" in the Münstertal can be dated (Herbener, 2012, pp.264f.).

Mechanical installations for pumping had to be built when the inflow of water increased. The operation of water driven pumps was sophisticated and expensive. Positive proof of such installations exists for Jihlava on March 29th, 1315 in a confirmation of agreements between different persons and Henricus Rothermel by Johann of Luxemburg as king of Bohemia (cf. Haasis-Berner, 2001, pp.53-54; cf. idem, 2008, p.43; cf. Kraschewski, 2012, p.284). The aim was to drain the Altenberg at Jihlava. A document from Kremnica dating from July 14th, 1331 deals with the building of two water wheels for draining the mines (Kraschewski, 2012, p.284). In the Rammelsberg the Feuergezäher vault was created probably around 1360 (Slotta, 1983, p.55), which housed a wheel of 6 m diameter (Balck, 1999, p.93 and p.215). On June 15th,1351 bishop Frederic of Bamberg and Hans the Rothermel contracted the building of a mechanical pump, to drain the mines on the Goldberg at St. Leonhard (Haasis-Berner, 2001, p.55; cf. Kraschewski, 2012, p.284).

Details of the technical composition of these constructions during the 13th and 14th centuries are largely absent in the archaeological features so far. According to the current state of research they were most probably a so-called "Heinzenkunst", which is regarded as the most effective innovation of late medieval times (Kraschewski, 2012, p.288). A first historical proof of such an installation can be found in the *Liber tertius* by Mariano Taccola, published in 1432 (Stromer, 1984, pp.50-72). Only five years later, the so-called "Radschert" at Todtnauberg is named as "*Bi der oberen radestat*" indicating the existence of a pump (Schlageter, 1989, p.60). These technical installations seem to have experienced a wide distribution and improvements not before early modern times.

Technological interpretation and assessment

Mining operations and the archaeological record resulting from them can be analyzed with regard to their chronological development. The winning of mineral resources termed “mining” is a transformation process based on knowledge of geology, mineralogy, the according application of laws of physics as well as chemistry. It is mainly consisting of the three sub-processes prospecting, winning and processing, followed by primary and secondary metallurgy. They are the basic structure of the chaîne d’opératoire (cf. Leroi-Gourhan, 1943), i.e. a conventionalized, learnt succession of technical operations which are closely interwoven with social relationship patterns (see also Stöllner, 2003, p.418, fig. 1 and pp.419-420). Each described area of this socio-technical system is a case study of its own, even if they are part of the same superior system “mining”.

Four core areas can be differentiated from the different aspects of the chaîne d’opératoire: technology, technique, tools and execution of the mining operations. The activity sequences of winning > processing > smelting > working > distribution > storage/loss > recycling connected to these cannot be altered without negative consequences. Distinctive traditions can be observed resembling the context as well as a habitus and as such a fixed structure, in which miners worked and acted in a dynamic process representing the act of the miners’ work (Zagal-Mach Wolfe, 2013, p.302).

The concept of social habitus, as developed by the French sociologist Pierre Bourdieu is essential for the understanding of social processes, especially regarding the identification of social classes (identity and distinction; Bourdieu, 1987, 2009; Schreg, Zerres, Pantermehl et al., 2013, p.101). Habitus considers social norms as well as individual scope of action. It connects the micro-level of the individual to the macro-level of society but does not provide a specific methodology or a universally valid interpretation (Schreg, Zerres, Pantermehl et al., 2013, p.101).

Technology

A general definition of the term “technology” is difficult to find as it has different meanings depending on the context it is used in (Zagal-Mach Wolfe, 2013, p., 23). In most cases, practical works are accentuated with implicit understanding of the systems of knowledge they are based on. But partly a difference between practical application and knowledge is made. It is a complex network of actions, protagonists and interactions, in which the element of dynamics is an important factor, especially concerning innovations (cf. introduction of chisel and hammer or drilling in driving work) and creativity, like different cuttings in driving work with hammer and chisel (Zagal-Mach Wolfe 2013, pp.15-16). The results of these processes can be recognized in the features and the succession of the material culture. They can partly be explained by the concept of technological decisions.

Mining technology comprises far more than working of ores and smelting or the bare description of tools. Technology as a social process cannot be separated from people, their daily life and human capabilities, their ideologies and believes as well as their ability of disputing complex social, economic and political relationships within mining (Knapp, 1998, p.18; cf. Childs and Killick, 1993).

The miner’s work comprised processes of technology (invention, design, creation, use) as well as knowledge of technology (Zagal-Mach Wolfe, 2013, p.31). These qualified or learnt activities are embedded in the cognitive network of technology and include the ability of imagining the design and form of the result plus the practical realisation. They are structured and executed by skilled individuals. Work as a mental process and mental structure is not preserved and cannot be recorded in this form except for the final result.

Starting point of an analysis of technology and miner’s work is that they are inherent social phenomena (Zagal-Mach Wolfe, 2013, p.18). Dealing with them always means analyzing a complex network. But simultaneously this also means that archaeologists always have only an incomplete insight into all key parts which are important for the network.

Technique

Technique is a basic part of a miner’s work. It is embedded an inseparably in the experience of a person in the act of creation, e.g. of a mine working (Zagal-Mach Wolfe, 2013, p.32). It is closely connected to individual skills, based on the cognitive network of a specific technology and defined by the conducted work. According to this technique is the specific participation of an individual in a community of action. Therefore, a miner is socialized as skilled performer by a learning process. This frequently had the form of an education. Until modern times there is almost no information on this. Only after the foundation of the mining academies and schools during the 18th century education manifests itself clearly. The structure of learning determined the cognitive and motor potential or the limits as well as the allowed extent of creativity to a high degree. All this is given or restricted by the social context of the mining kinsfolk as community of action.

However, technique is specific for the individual (Zagal-Mach Wolfe, 2013, p.32; cf. Parodi, 2010, pp.202-204). Learnt physical activities are constantly modified, changed or perfected individually, determined biologically by constitution and skills. These processes may be barely noticeable, but are sufficient to enable a person to act in a specific way and to perform work. This explains variations in features concerning the driving of horizontal mine workings.

Technology and technique are fixed structures finding their expression in the execution of a task by a skilled individual. While technology concerns the cognitive network of a community and work the act and process of manufacture or creation technique deals with leading the structural process by individuals (Zagal-Mach Wolfe, 2013, p.33). Thus, it can be paraphrased as a specific personal ability or competence, restricted, formed and defined by a given technology, work and social context. It is done by a person in the course of his physical and cognitive capacities. Therefore by the analysis of technique the individual miner can be recorded best.

Mining tools

Until early modern times a differentiation of the forms of mining tools can be observed. From the 16th century onward, some of them did not change over a long period of time. Apart from the form tools together with their marks give information on the applied techniques (Zagal-Mach Wolfe, 2013, p.33).

Technique does not necessarily imply the use of tools. These are incorporated in the process of work and frequently the intrinsic use of an object is an element of technique. If this is used by a skilled individual in the course of the application of technique it can be called “tool”. The application of a tool is not restricted to a specific number of forms of appearances, movements or uses (Zagal-Mach Wolfe, 2013, pp.34-35). It is more the result of the selection among a number of possibilities as well as among forms and materials. Where work is a mental as well as an executed process with individually specified structures, tools also show characteristics differing from those based on a certain intended use. As a consequence of creativity the composition of the tool kit can change, which can be observed on the objects on the basis of modifications or new forms (Zagal-Mach Wolfe, 2013, p.303).

Mining tools are not only connected to technique, the performance of work and the cognitive technological network, but can also communicate identities which are socially determined (Zagal-Mach Wolfe, 2013, p.35). There are examples of miners with picks during the 14tth century as well as with chisel and hammer on seals.

Specialization

Each of the described technological aspects comprises specialized activities within the mining operations, conducted by persons with corresponding apprenticeship and knowledge or experts with implied knowledge using a set of well-developed techniques as well as special tools (Zagal-Mach Wolfe, 2013, p.27).

First of all specialization presupposes, that an according demand exists and that such a surplus is produced that the product can be a commodity, which was the case with metal ores (Zagal-Mach Wolfe, 2013, p.28). But this view focussed on economic aspects bears the risk, that the actual performance is restricted to a collection of a limited number of techniques and tools dictated by economic circumstances. The results would be specific, distinct products, whose form and grade of perfection are interpreted as direct outcome of the economic conditions. With this social analysis are concurrently restricted to a mere calculation of resources and decisions as only economically or probably politically motivated.

Therefore, the definition has to be extended in order to demonstrate the actual complexity, because otherwise not all aspects of miner’s work can be included (Zagal-Mach Wolfe, 2013, p.28). Knowledge is bound to people acting in different social contexts and rolls, like the performance of their work. Regarded that way products cannot be understood as motivated by economic conditions alone. In addition the design is not considered as restricted by a specific, predetermined set of techniques. Instead it is influenced, motivated and formed by a skilled individual.

In the course of production specialization is one of many possibilities of organisation (see Zagal-Mach Wolfe, 2013, p.57-58). It differs from a non-specialized, for example with regard to the time that is spent for the work and in a specific term for the activity and/or person as well as a wage for the work or product of the specialist, like a hewer. In doing so, specialization has to be regarded as versatile. It is characterized by four parameters: context (independent or production is financed by another person), concentration (spatial organization of production), extent and intensity (expenditure of time for the production).

The growing specialization of miner’s work leads by a trend to a differentiation of the profession on a broader basis during early modern times. An overview state of development is given for example in the Schwazer Bergbuch. But different stages of specialization have to be accounted for at any time depending on the level of development in economy, complexity of the labour organization as well as social and political organization.

Invention and innovation

With the idea of a technical solution an invention simultaneously gives an intended possibility of use (action and work function). Therefore it always anticipates a possible purpose. This is based on knowledge, experience and creativity. The latter is the ability to create something completely new, not known before. This process is difficult to track.

Separated from this the term “innovation” has to be regarded, that is the technological-economical successful introduction of an invention and its mass distribution (diffusion). Whether an invention becomes an innovation is decided mainly by economic aspects or even political and military interests. Technological and entrepreneurial activities partly make considerable financial advances necessary. These would only be raised if there was a relevant demand. An example is the introduction and distribution of mechanical water pumps in mining. Individual innovations connect to a process also called "technological progress" in their collectivity.

Especially in the mining industry these outlined processes are very complex. In most cases it is assumed that no Roman tradition survived in mining (Bartels and Klappauf, 2012, p.193). External influences or transfers from East Asia or the Arab regions remain at first unclear. Although sciences were at a high level during the Middle Ages, in the beginning, relations between them and the technical working environment barely existed (see Troitzsch, 2004, pp.442-443). The artes liberales, taught in the monasteries and universities since the 12th century, did not show any reference to the common sense world during medieval times either. The basic inventions and improvements of the Middle Ages were almost entirely made by practitioners. Regarding their education and derivation the craftsmen were heterogeneous. They progressively took over leading functions and formed the nucleus of the later professional engineers. Only from the 15th/16th century onward a clear change can be observed that had its origin in the Italian renaissance. No brake between Middle Ages and early modern times but a continuous development can be discovered. The Late Middle Ages have got the character of a transition phase or a functional gateway (cf. Kraschewski, 2012, p.316).

The question why and when social and technological change is necessary, acceptable or possible and also when a certain tradition of technology roots in society and forms its social relationships, material considerations and knowledge as well as physics is of basic significance (Zagal-Mach Wolfe, 2013, pp.43-44 and p.52). This does not only concern social change itself, but also those transformations introducing a new object into a society. Hypothetically four conditions can be named for this: import, innovation, copy or combination of technologies and objects from two different societies. Concerning innovation creativity plays a role. The last three distinguish from the first, as they are all based on the local production of the object. Changes including a new item in local production are those which alter traditions and consequently society, too. Transformation of a working method probably also results in different working processes leading to new types of objects or tools. These aspects would e.g. be something to be further investigated concerning the appearance of the stemmed chisel. When introducing new technologies frequently several, qualitatively equivalent but incompatible alternatives existed (Zagal-Mach Wolfe, 2013, p.303; cf. Troitzsch, 1996, p.204). The realization was subject to certain conditions like e.g. competences, controllability, reliability and supply and disposal systems. Amongst others consequences were changes of the human work as well as the conditioning of patterns of action and social relations (Zagal-Mach Wolfe, 2013, p.303).

In most cases archaeological features are the result of already established practices, which restricts the analysis beside a reconstruction to the comparison of material cultures and the bringing out of their differences (Zagal-Mach Wolfe, 2013, p.46). Even slight changes in the working methods probably have their origin in a considerable social transformation. Innovations can be chance by-products of an altered situation and not so much of a planned technological change. Here several possibilities develop and the factors involved in performance and transformation of working traditions as well as the integration of new objects are even more numerous.

The initial factors of such historical turning points are of different origin or show varied structures. Among other things, explanation models are based on alterations in ecological systems, interactions within a society and societies as well as in social groups among each other. With the former evolutionary and systemic approaches are important. The latter is an analysis based on social sciences. But social dynamic was not the only trigger for changes (Zagal-Mach Wolfe, 2013, p.46). The different possibilities of choosing technological solutions were connected to specific characteristics of society, i.e. their environment, own traditions, contacts to foreigners as well as existing courses of action and material culture. Changes can manifest themselves in deviant use of a tool or different organization of production.

Transition forms are difficult to define or are not known (Zagal-Mach Wolfe, 2013, p.48). Tools as archaeological material can be described as material remains of a past production structure and a social association or its social comprehension. To changes in working methods, several phenomena were connected; last but not least conservatism and long-living traditions that can e.g. be observed in the hammer and chisel work during the 18th century. The decision of sticking to old methods instead experimenting with new ones can have several reasons.

Technological knowledge and transfer of knowledge

Social context as well as the learnt knowledge and practical skills rooted in a social and environmental context determine the participation of an individual in a material world (Zagal-Mach Wolfe, 2013, pp.55f.). When participating in a specific social and cultural constellation a so-called "habitus" is transferred, including all thoughts, notions and actions that are compatible with it. To a large extent, these structures appear to be self-evident or remain not reflected by individuals. They act according to conventions and by this represent the normative network of technology.

Therefore knowledge is depending on society, politics or culture. Due to this is to be determined as a social, especially socio-functional phenomenon (Landwehr and Stockhorst, 2004, p.147). Concerning the composition, the structure and the consequent use it has to ask which task certain bodies of knowledge have for the society. It has also to be analyzed which values, norms, categories and meanings it transports and how it produces concepts and purposes itself.

If knowledge is assumed to be socially based, it can be derived that a specific segment of knowledge is not self-evident for a particular point in time (Landwehr and Stockhorst, 2004, p.153, cf. also p.155). This circumstance is demonstrated by the context of power and knowledge. It shows that control was frequently based on a leading role in knowledge and never only on physical power. All information enabling to legitimize, enforce or pass on claims of power within a specific social context are relevant knowledge for ruling in this sense. This also includes the actual knowledge of a matter itself. One crucial question is, who has access or was meant to get it subsequently.

In the written sources an already developed specialization can quite frequently be observed, as shown by the example of the Rotermellin. A document on the leat on the Kandel north of Freiburg names a master Rotermellin, who probably was in charge of the construction (Haasis-Berner, 2008, p.43). In 1315, Johann of Luxembourg, king of Bohemia, acknowledged agreements made by different persons with Henricus Rothermerl on his structuras, which should help to prevent water inrushes into the mines of the Altenberg at Jihlava and at the same time to find a remedy for the frequent water shortage. A Hans Rothermerl, described as "Howly" (miner), was witness for the monastery Baindt in Oberschwaben in 1341. He appears as hydraulic engineer in the Lavanttal in Kärnten in 1350. One year later a treaty between him and bishop Frederic of Bamberg as holder of the mining rights is signed, in which Rothermerl was enrolled to drain the mine. Most probably these were members of a family earning a living with special knowledge on the field of water handling (Haasis-Berner, 2008, p.44). This does not only prove the context of power and knowledge, but also that capital was a further important factor.

In addition the mobility of the "simple" miners has been documented several times in this contexts since the Late Middle Ages. During early modern and modern times there was a further transfer of knowledge or technology by mobility of miners as much asked for specialists, which is evident from written and archaeological sources, especially in Great Britain (Hilberg, 1940, p.131).

Apart from individual-related form, there has been another transfer form of specialist knowledge since the end of the Late Middle Ages, beginning with editions of Vitruv and other treatises on architecture which have already been printed since the second half of the 15th century (Troitzsch, 2004, p.448). Among the books with technical content published in increasing numbers during the 16th century there are several "Kunst- und Probierbüchlein" on metallurgy, dyeing, pottery and other chemical industries addressing scholars and not craftsmen. Among these is the "Ein nützlich Bergbüchlein" by Ulrich Rülein of Calw printed around the year 1500 (Pieper, 1955) which experienced a wide distribution. In 1540 the book "De la pirotechnia" by Vanoccio Biringuccio (1480–1537) who was temporarily in charge of ore mines and foundries was published posthumous. It is a technical instruction for production practice concerning especially founding. Georg Agricola (1494–1555) wrote "De Re metallica libri XII", in which for the first time production processes of mining and smelting were described and illustrated in detail.

Conclusions

The following aspects of mining have been considered in this contribution: prospecting and development of deposits, driving and winning techniques, workings, haulage, support, drainage. Many forms of features and tools as well as techniques occurring in different mining regions were quite long-lasting or conservative, like the timbering. Changes were gradual and started with time delay in mining areas.

In order to explain the long duration and time delay in changes of technology and techniques the habitus concept can be applied. This leads to some postulations reflecting social norms and individual possibilities for acting concerning technology, techniques, tools, specialization (more development in the 16th century which is result of long development during the Middle Ages), technological knowledge (community of practice), invention, innovation and diffusion (creativity; hybrids are difficult to detect).

The examination of changes and their chronology is an important analytical tool. The relation between these two adds up the dynamics of changes (Zagal-Mach Wolfe, 2013, p.49). Several developments in mining technological aspects are detectable which can be analyzed. The process should not be regarded as evolutionary development, e.g. in the sense that simple techniques were replaced by more complex ones. It was demonstrated that several factors played a role before actual innovation developed. Specific traditions in terms of context as well as habitus can be recognized and as such a stable structure within which the miners were working and acting in a dynamic process.

References

1 The following is part of the author's PhD thesis on the archaeology of the Schauinsland mine near Freiburg published in a shortened version in 2015; here cf. full text of the thesis Straßburger, 2014, part I, pp.765ff.

Bibliography

Agricola, G., 1994. Zwölf Bücher vom Berg- und Hüttenwesen. München: DTV GmbH & Co. KG.

Alper, G., 2003. Johanneser Kurhaus: Ein mittelalterlicher Blei-/Silbergewinnungsplatz bei Clausthal-Zellerfeld im Oberharz. *Materialhefte zur Ur- und Frühgeschichte Niedersachsens*, 32. Rahden/Westfalen: Marie Leidorf GmbH.

Ancel, B., 1992. Abbautechniken des 16. Jahrhunderts. In M.M. Grewenig, ed. *Leben im Mittelalter. 30 Jahre Mittelalterarchäologie im Elsaß.* Ausstellung 25. Okt. 1992 –2. Mai 1993 Historisches Museum der Pfalz, Speyer: Historisches Museum der Pfalz, pp.435-442.

Ancel, B. and Fluck, P., 1988. *Une exploitation minière du XVI^{e} s. dans les Vosges. Le filon Saint-Louis du Neuenberg (Haut-Rhin). Caractères et évolution.* Documents d'Archéologie Française, 16. Paris: Editions de la Maison des sciences de l'homme.

Bailly-Maître, M.-Ch. and Dupraz, J.B.B., 1994. Brandes en Oisan. La mine d'argent des Dauphins (XII-XIVe s.). *Documents d'archéologie en Rhône-Alpes*, 9. Lyon: Ministère de la culture et de la francophonie, Direction régionale des affaires culturelles, Service régional de l'archéologie.

Balck, F., 1999. *Wasserkraftmaschinen für den Bergbau im Harz. Frühneuzeitliche Spuren und deren Bedeutung am Beispiel der Grube Thurm Rosenhof und ausgewählter Anlagen*. Clausthal-Zellerfeld: Papierflieger.

Barnatt, J. and Worthington, T., 2006. Using coal to mine lead: Firesetting at Peak District mines. *Mining History*, 16(2).

Bartels, Ch., 1996. Der Bergbau - im Zentrum das Silber. In U.Lindgren, ed. *Europäische Technik im Mittelalter*. Berlin: Gebr. Mann, pp.235-248.

Bartels, Ch. and Klappauf, L., 2012. Das Mittelalter. Der Aufschwung des Bergbaus unter den karolingischen und ottonischen Herrschern, die mittelalterliche Blüte und der Abschwung bis zur Mitte des 14. Jahrhunderts. In: Ch.Bartels and R. Slotta, eds. *Geschichte des deutschen Bergbaus*, Bd. 1: Der alteuropäische Bergbau. Von den Anfängen bis zur Mitte des 18. Jahrhunderts. Münster: Aschendorff, pp.111-248.

Bayer, M., n.d. *Die Himmelfahrt Fundgrube. Ein Führer durch das Lehr- und Besucherbergwerk der TU Bergakademie Freiberg*. Freiberg: Druckspecht.

Bersch, W., 1898. *Mit Schlägel und Eisen*. Wien, Pest, Leipzig: A. Hartlebens.

Binding, G. and Nussbaum, N., 1978. *Der mittelalterliche Baubetrieb nördlich der Alpen in zeitgenössischen Darstellungen*. Darmstadt: Wissenschaftliche Buchgesellschaft.

Bischoff, W., Bramann, H., Dürrer, F., Moebius, P. G., Quadfasel, H. and Schlüter W., 1988. *Das kleine Bergbaulexikon*. 11th ed. Essen: Verlag Glückauf.

Bogosavljević, D. and Vuković, S., 1993. Archäologische, mineralogische und archäometallurgische Forschungen zur mittelalterlichen Blei-Silbergewinnung in Serbien. In: H. Steuer and U.Zimmermann eds. Montanarchäologie in Europa. Archäologie und Geschichte. *Freiburger Forschungen zu ersten Jahrtausend in Südwestdeutschland*, Bd. 4. Sigmaringen: Jan Thorbecke, pp.409-422.

Bohly, B., 2008. Les vestiges en bois dans la mine médiévale du Donnerloch à Steinbach (Haut-Rhin). In: M.-Ch. Bailly-Maître, C. Jourdain-Annequin, M. Clermont-Joly and St. Jacquemot, eds. *Archéologie et paysage des mines anciennes de la fouille au musée*. Groupes d'Etude des Mines Anciennes. Paris: Édition Picard, pp.89-99.

Bourdieu, P., 1987. *Die feinen Unterschiede. Kritik der gesellschaftlichen Urteilskraft*. Frankfurt a. Main: Suhrkamp.

Bourdieu, P., 2009. *Entwurf einer Theorie der Praxis auf der ethnologischen Grundlage der kabylischen Gesellschaft*. Frankfurt a. Main: Suhrkamp.

Burgkmair, H. und Füssel, St., 2003. *Die Abenteuer des Ritters Theuerdank*. Kolorierter Nachdruck der Gesamtausgabe Nürnberg 1517. Köln, London, Los Angeles, Madrid, Paris, Tokyo: Benedikt Taschen.

Childs, S. T. and Killick, D., 1993. Indigenous African metallurgy: nature and culture. *Annual Review of Anthropology,* 22, pp.317-337.

Dahm, C., Lobbedey, U. and Weisgerber, G. eds., 1998. Der Altenberg. Bergwerk und Siedlung aus dem 13. Jahrhundert im Siegerland, Bd. 1: Die Befunde. *Denkmalpflege und Forschung in Westfalen Lippe*, 34. Bonn: Dr. Rudolf Habelt.

Dorchy, L., 2013. The so-called „guild collar of the master of the silversmiths of Ghent". A unicum dedicated to silver ore mining and processing from the Late Middle Ages. In: R. Smolnik, ed. ArchaeoMontan 2012. Erkunden - Erfassen - Erforschen. Internationale Fachtagung Dippoldiswalde 18. bis 20. Oktober 2012. *Arbeits- und Forschungsberichte zur sächsischen Bodendenkmalpflege*, 26. Dresden: Landesamt für Archäologie Sachsen, pp.279-288.

Dornbusch, G. and Pötsch, H., 1962. Gewinnungsarbeiten. In: G. Leithold, ed. *Taschenbuch für den Bergmann* Bd. III: Tiefbau. Leipzig: VEB Deutscher Verlag für Grundstoffindustrie, pp.89-168.

Drozdzewski, G., Juch, D. and Heckman, H., 2012. Hochmittelalterliches Bleibergwerk in Wülfrath-Rützkausen entdeckt. *25 Jahre Archäologie im Rheinland 1987–2011*, pp.162-164.

Eckstein, M., 1974. Eisenerzbergbau am „Hainberg" bei Neuburg a. d. Donau. *Neuburger Kollektaneenblatt,* 127, pp.28-41.

Faller, J., 1967.Über den Ursprung des Bergleders. *Der Anschnitt*, 19(1), pp.24-26.

Frei, H., 1966. Der frühe Eisenerzabbau im nördlichen Alpenvorland. *Münchener Geographische Hefte*, H. 49. Kallmünz, Regensburg: Verlag Michael Lassleben.

Fritzsche, C. H., 1949. *Lehrbuch der Bergbaukunde*, 2 Bd. Berlin: Springer-Verlag.

Gottschalk, R., 1999. Zur Nutzung des Bleis. *Archäologische Informationen aus Baden-Württemberg*, 41, pp.113-116.

Haasis-Berner, A., 2001. Wasserkünste, Hangkanäle und Staudämme im Mittelalter. *Freiburger Beiträge zur Archäologie und Geschichte des ersten Jahrtausends*, Bd. 5. Rahden: Marie Leidorf.

Haasis-Berner, A., 2008. Zum Wasserbau im Mittelalter. Beispiele aus Südbaden. *Denkmalpflege in Baden-Württemberg*, 37(1), pp.40-44.

Hafer, K., 1950. *Kleine Bergbaukunde des Erzbergbaus*. Halle a.d. Saale: Carl Marhold Verlagsbuchhandlung.

Hemker, Ch., 2013. Dinge, die ein Bergmann braucht. *Archäologie in Deutschland*, 4, pp.30-31.

Hemker, Ch. and Lentzsch, S., 2012. „Holz ist ein Bedürfnis im Bergbau ..." - Holzverwendung in den hochmittelalterlichen Bergwerken von Dippoldiswalde/Sachsen. *Mitteilungen der Deutschen Gesellschaft für Archäologie des Mittelalters und der Neuzeit,* 24, pp.272-282.

Herbener, M.K.M., 2012. *Waldnutzungsinteressen des 18. Jahrhunderts – Fallstudien zum Kloster St. Trudpert im Münstertal (Schwarzwald).* Inaugural-Dissertation zur Erlangung der Doktorwürde der Fakultät für Forst- und Umweltwissenschaften der Albert-Ludwigs-Universität Freiburg i. Brsg. [online]. Available at: <https://www.freidok.uni-freiburg.de/data/8852. URN: urn:nbn:de:bsz:25-opus-88523> [accessed 9January 2014].

Hilberg, F., 1940. Deutsche Bergleute in aller Welt. In: K. Haarmann,J. Hillberg, W. Rattkemper and F. Hilberg. *Bergmännisches Lesebuch*. Essen: Glückauf, pp.128-135.

Hoffmann, C.R., 1830. *Der belehrende Bergmann*. Pirna: August Robert Friese.

Knapp, A.B., 1998. Social approaches to the archaeology and anthropology of mining. In: A. B. Knapp, V. C. Pigott and E. W. Herbert, eds. *Social Approaches to an Industrial Past*. London, New York: Routledge, pp.1-23.

Köhler, G., 1897. *Lehrbuch der Bergbaukunde*. Leipzig: Wilhelm Engelmann.

Kraschewski, H.-J., 2012. Das Spätmittelalter. Die Zeit des Aufbruchs. In: Ch. Bartels and R. Slotta, eds. *Der alteuropäische Bergbau.* Von den Anfängen bis zur Mitte des 18. Jahrhunderts. Münster: Aschendorff, pp.249-316.

Krause, A., 1986. *Zur Klassifikation und Anwendung von Abbauverfahren im Bergbau-Tiefbau unter besonderer Berücksich-*

tigung von Problemen der Gebirgsbeherrschung. Dissertation an der Bergakademie Freiberg zur Erlangung des Grades doctor scientiae technicarum.

Landwehr, A. and Stockhorst, St., 2004. *Einführung in die Europäische Kulturgeschichte*. Paderborn, München, Wien, Zürich: Ferdinand Schöningh.

Leroi-Gourhan, A., 1943. *L'Homme et la matière*. Paris: Albin Michel.

Ludwig, K.-H. and Schmidtchen, V., 1997. Metalle und Macht. In: W. König, ed. *Propyläen Technikgeschichte*, 2. Bd.: 1000-1600. Berlin: Ullstein Buchverlage GmbH, Propyläen Verlag.

Morgans, W., 1871. *Manual of Mining Tools*. London: Lockwood & Co.

Oppel, F. W. v., 1769. *Bericht vom Bergbau*. Freiberg: Verlag der Churfürstlich Sächsischen Bergakamie zu Freyberg.

Parodi, O., 2010. Technik als kulturelle Unternehmung. In: G. Banse, A. Grunwald, eds. Technik und Kultur. Bedingungs- und Beeinflussungsverhältnisse. *Karlsruher Studien zu Technik und Kultur*, Bd. 1. Karlsruhe: KIT Scientific Publishing, pp.197-216.

Pieper, W., 1955. Ulrich Rülein von Calw und sein Bergbüchlein. *Freiberger Forschungshefte* D 7, Kultur und Technik. Berlin: Akademie Verlag.

Proempeler, O., Hobrecker, H., Epping, G. and Ritter, H., 1957. *Taschenkalender für Grubenbeamte des Steinkohlenbergbaus*. Düsseldorf: Karl Marklein Verlag.

Reuther, E.-R., 1989. *Lehrbuch der Bergbaukunde mit besonderer Berücksichtigung des Steinkohlenbergbaus*. 11th ed. Essen: Verlag Glückauf GmbH Essen.

Rziha, F., 1867. *Tunnelbaukunst*. Berlin: Verlag von Ernst & Korn.

Schlageter, A., 1989 Die Geschichte von Todtnau und seinen Teilorten. In: A. Schlageter, B. Dörflinger, H. Wittmann, eds. *Todtnau, Stadt und Ferienland im südlichen Hochschwarzwald*. Freiburg: Rombach, pp. 9-11.

Scholz, V., 2012. An Attempt to a descriptive Reconstruction of extractive Mining Technologies during the high Middle Ages at Dippoldiswalde, Saxony. In: J. Silvertant,ed. *Mining and the Development of the Landscape. 7th International Symposium on archaeological Mining History*. Valkenburg aan de Geul, Jihlava: Silvertant Erfgoedprojecten, pp.22-41.

Schreg, R., Zerres, J., Pantermehl, H., Wefers, St., Grunwald, L. and Gronenborn, D., 2013. Habitus – ein soziologisches Konzept in der Archäologie. *Archäologische Informationen,* 36, pp.101-112.

Simonin, L., n.d. *Mines and Miners: Underground Life*. London: William Mackenzie.

Sippel, K., 1999. Der Kupferschieferbergbau im Richelsdorfer Gebirge. Führungsblatt zu spätmittelalterlichen Relikten bei Iba und Nentershausen, Kreis Hersfeld-Rotenburg. *Archäologische Denkmäler in Hessen*, Heft 134. Wiesbaden: Landesamt für Denkmalpflege Hessen.

Siuts, H., 1988. *Bäuerliche und handwerkliche Arbeitsgeräte in Westfalen. Die alten Geräte der Landwirtschaft und des Landhandwerks 1890-1930.* Schriften der Volkskundlichen Kommission für Westfalen, 26. Münster: Verlag.

Slotta, R., 1983. *Technische Denkmäler in der Bundesrepublik Deutschland*, Bd. 4: Der Metallerzbergbau. Bochum: Deutsches Bergbau-Museum Bochum.

Stöllner, Th., 2003. Mining and Economy - A Discussion of Spatial Organisations and Structures of Early Raw Material Exploitation. In: Th. Stöllner, G. Körlin, G. Steffens and J. Cierny,eds. *Man and Mining*. Studies in honour of Gerd Weisgerber on occasion of his 65th birthday. Der Anschnitt, Beih. 16. Bochum: Deutsches Bergbau-Museum Bochum, pp.415-446.

Straßburger, M., 2002. *Archäologie eines Bergwerkes des 17./18. Jahrhunderts am Schauinsland*. Magisterarbeit zur Erlangung der Würde des Magister Artium der Philosophischen Fakultäten der Albert-Ludwigs-Universität zu Freiburg i. Br.

Straßburger, M., 2014. *Montanarchäologie und Wirtschaftsgeschichte des Bergbaus im Schauinsland vom 13. Jahrhundert bis um 1800*, Teil I-III. Inaugural-Dissertation zur Erlangung des Doktorgrades der Philosophie an der Ludwig-Maximilians-Universität München.

Straßburger, M., 2015. *Archäologie und Wirtschaftsgeschichts des Bergbaus im Schauinsland vom späten 13. Jahrhundert bis um 1800*. Universitätsforschungen zur Prähistorischen Archäologie, Bd. 275. Bonn: Dr. Rudolf Habelt.

Straßburger, M. and Tegel, W., 2009. Holznutzung und Bergbau im Schwarzwald in Mittelalter und Neuzeit. *Der Anschnitt*, 61(3), pp.182-192.

Stromer, W. v., 1984. Wassernot und Wasserkünste im Bergbau des Mittelalters und der frühen Neuzeit. In: W. Kroker and E. Westermann, eds. Montanwirtschaft Mittelaltereuropas vom 12. bis 17. Jahrhundert. Stand, Wege und Aufgaben der Forschung. *Der Anschnitt*, Beih. 2. Bochum: Deutsches Bergbau-Museum Bochum, pp.50-72.

Timberlake, S., 2004. Early Leats and Hushing Remains. Suggestions and Disputes of Roman Mining and Prospection for Lead. *Mining History*, 15(4/5), pp.64-76.

Tizzoni, M., 1997. Le miniere di argento medievali in Lombardia: distribuzione geografica e tecniche di scavo. In: L. Brigo and M. Tizzoni, eds. *Il Monte Calisio E L'Argento Nelle Alpi Dall'Antichità Al XVIII Secolo*. Trento: Commune die Civezzano e Fornace, pp.269-279.

Troitzsch, K. G., 1996. Individuelle Einstellungen und kollektives Verhalten. In: G. Küppers,ed. *Chaos und Ordnung. Formen der Selbstorganisation in Natur und Gesellschaft*. Stuttgart: Reclam, pp.200-228.

Troitzsch, U., 2004. Erfinder, Forscher und Projektemacher. Der Aufstieg der praktischen Wissenschaften. In: R. v. Dülmen and S. Rauschenbach, eds. *Macht des Wissens. Die Entstehung der modernen Wissenschaft*. Köln, Weimar, Wien: Böhlau Köln, pp.439-464.

Veith, H., 1871. *Deutsches Bergwörterbuch mit Belegen* (Reprint Vaduz 1986).

Wagenbreth, O.,Wächtler, E., Becke, A., Douffet, H. and Jobst, W., 1990. *Bergbau im Erzgebirge. Technische Denkmale und Geschichte*. Leipzig: VEB Deutscher Verlag für Grundstoffindustrie.

Weisgerber, G., 1981. Mittelalterliche Darstellungen von Kurbelhaspeln in ungewöhnlichem Zusammenhang. *Der Anschnitt*, 33(4), pp.165-166.

Weisgerber, G., 1996. Mittelalterliche Bergbau-Funde aus der Grube Bliesenbach im Oberbergischen Kreis. *Der Anschnitt*, 48(1), pp.2-18.

Weisgerber, G., 1998. Montanarchäologische Untersuchungen auf dem Altenberg – Zum mittelalterlichen Berg- und Hüttenwesen im Siegerland. In: C. Dahm, U. Lobbedey and G. Weisgerber, eds. *Der Altenberg. Bergwerk und Siedlung aus dem 13. Jahrhundert*, Bd. 1: Die Befunde. Denkmalpflege und Forschungen in Westfalen 34. Bonn: Dr. Rudolf Habelt, pp.133-219.

Wilke, A., 1974. Aufsuchen und Erschließen von Erzlagerstätten. In: W. Gocht, ed. *Handbuch der Metallmärkte*. Berlin, Heidelberg, New York: Springer, pp.6-16.

Wollmann, V., 1976. Römischer Bergbau in Alburnus Major (Roşia Montană) in Dakien. *Der Anschnitt*, 28(6), pp.182-191.

Wollmann, V., 1999a. Contribution à la connaissance de la topographie archéologique d'Albvrnvs Maior (Roşia Montană) et à l'histoire des techniques d'exploitation romaines en Dacie. In: B. Cauuet, ed. *L'or dans l'antiquité de la mine à l'objet.* Aquitania Supplément, 9. Bordeaux: Aquitania, pp.117-130.

Wollmann, V., 1999b, Bergbau im römischen Dacien. In: R. Slotta, V. Wollmann and I. Dordea, eds. *Silber und Salz in Siebenbürgen*, Bd. 1. Bochum: Deutsches Bergbau-Museum Bochum, pp.24-34.

Zagal-Mach Wolfe, U. I., 2013. Grasping Technology, Assessing Craft. Developing a Research Method for the Study of Craft-Tradition. *Acta archaeologica Lundensia*, Series 80. Lund: Faculty of Humanities and Theology, Lund University.