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Bronze Age Mining in Hallstatt. A New Picture of Everyday Life in the Salt Mines and Beyond

Hans Reschreiter
Kerstin Kowarik

Abstract
The first evidence for underground salt mining in Hallstatt dates to the Bronze Age. In its dimensions, the Bronze Age mining phase rivals the later and better known Iron Age mining. Although both mining communities were confronted with the same challenges, the mining technology and structure, as well as resource management, differ greatly. Bronze Age salt mining was characterised by the use of large shafts, which could reach enormous proportions. The extraction and transport of salt from the mines were aided by uniquely customised techniques. These special developments were used exclusively in Hallstatt – there have been no observations of technology transfers with contemporaneous copper mining communities or other groups. In order to enable an overview of the manifold aspects of Bronze Age salt production, an annotated picture of everyday life in that epoch was created.

Keywords
Mining, technology transfer, reconstruction, picture of everyday life, resource management, Bronze Age, Hallstatt, Upper Austria.

Zusammenfassung – *Der bronzezeitliche Bergbau in Hallstatt. Neue Lebensbilder zum Salzbergwerk*

Untertägiger Salzbergbau kann in Hallstatt erstmals ab der mittleren Bronzezeit nachgewiesen werden. Dieser Bergbau dürfte ähnliche Dimensionen erreicht haben wie der spätere, besser bekannte Bergbau der älteren Eisenzeit. Obwohl beide Bergbaue im selben Revier arbeiteten und mit denselben Herausforderungen konfrontiert waren, fanden die Bergleute der Bronzezeit ganz eigene Lösungen, um Steinsalz aus der Tiefe zu holen. Diese unterschieden sich auch grundlegend von jenen des benachbarten Kupfererzbergbaus. Der Hallstätter Bergbau der Bronzezeit ist charakterisiert durch einen ausgeprägten Schachtbau, welcher riesige Dimensionen erreichte. Für die Gewinnung und Förderung des Salzes wurden maßgeschneiderte Techniken und Geräte entwickelt. Diese Spezialentwicklungen kamen ausschließlich in Hallstatt zum Einsatz – Technologietransfer mit den Kupfererzbergleuten oder anderen Gruppen kann nicht beobachtet werden. Auch das Ressourcenmanagement, die Organisation und die Anforderungen an die Betriebsmittel unterscheiden den bronzezeitlichen Salzbergbau von zeitgleichen Kupferproduktionen und dem nachfolgenden Betrieb der älteren Eisenzeit. Um den Salzbergbau der Bronzezeit in seiner Vielfältigkeit übersichtlich darzustellen, wurde ein kommentiertes Lebensbild erstellt.

Schlüsselbegriffe
Bergbau, Technologietransfer, Rekonstruktion, Lebensbild, Ressourcenmanagement, Bronzezeit, Hallstatt, Oberösterreich.

1. Preface: Bronze Age Mining in Hallstatt

Since 1960 the Natural History Museum Vienna has been systematically researching the prehistoric salt mines of Hallstatt. Extensive underground Bronze Age and Early Iron Age mining sites have been detected and investigated.[1] Currently 18 Bronze Age sites are known within the Hallstatt salt mountain.[2] On the surface, several sites evidence large-scale meat production during the Bronze Age.[3]

Although large parts of the prehistoric salt mining areas were already assigned a Bronze Age date in 1975,[4] Bronze Age mining still stands in the shadow of the Iron Age mining phase – which is not surprising, considering the long history of research on the Iron Age mining phase and the excitement generated by the wealth of the Iron Age cemetery. However, analysis of the underground sites clearly shows that Bronze Age mining was at the very least comparable in size and extent to its Iron Age counterpart.

In recent decades, various aspects of Bronze Age salt mining were published.[5] The present paper sets out a synopsis of these findings and brings together current knowledge of mining technology, organisation, and structure to form a holistic picture of prehistoric salt mining in Hallstatt. In

1 Barth 1982. – Barth 1986. – Reschreiter, Kowarik 2008a.

2 Schauberger 1960, 12 find-spots, annotations by F. E. Barth, 6 find-spots.

3 Pucher et al. 2013.

4 Barth, Felber, Schauberger 1975. – Stadler 1999.

5 E.g. Barth 1967. – Barth 1986. – Barth 1987–1988. – Barth 1992b. – Barth 1993–1994. – Reschreiter 2005. – Reschreiter, Totschnig, Grabner 2010. – Grabner et al. 2015. – Kowarik 2016.

order to highlight the uniqueness of the Bronze Age Hallstatt economy, this paper will provide a comparative study of contemporaneous copper mining, other salt production sites, as well as the Iron Age salt production at Hallstatt. In order to present the 'underground world' with its many facets as vividly as possible, the now established format of a 'busy picture' of everyday life (*Lebensbild*) is chosen.[6]

1.1. Haselgebirge and Heidengebirge

Mining took place in Hallstatt in the type of rock known as 'Haselgebirge'. Haselgebirge is a mixture of different types of rock, the main components of which are salt, clay, and anhydrite.[7] It is a softer, plastic rock and for that reason constantly in motion. Within the Haselgebirge core, seams up to 17 m wide made of almost pure rock salt exist. The rock pressure from the mountain closes open cavities. For this reason, there is, with one single exception, no prehistoric mine which remains open. Further characteristics of the deposits are the large salt-free top layer and the steep incline.[8] These are the ways in which Hallstatt is fundamentally different from the prehistoric Alpine copper mines. There, the ore sticks right out of the surface rock, the thickness of the seams reaches only decimetres, and the rock is usually so stable that mines built over 3000 years ago can still be entered today.[9]

As, over time, the pressure from the mountain re-closes any cavity, all materials left behind are enclosed in the mountain. Especially in the Bronze Age, but also in the Iron Age, miners left everything they did not need in the mining galleries: burnt torches, broken tools, out-of-order equipment, used ropes and much more. The leftovers of production, mixed with salt and waste rock form thick layers of mine waste – the so called 'Heidengebirge' – and can reach a thickness of several metres. Due to the salt, all organic materials left in the mines have been preserved in a near perfect condition.[10]

Conservation of organic material is a precondition to understanding the material culture of prehistoric societies, as over 90 % of tools, equipment, clothing, household items, transport devices, etc. were made of organic materials.[11] The best conditions for the preservation of organic material are found in salt, ice, underwater, and sometimes in moors and in tree-coffins. Only at three sites worldwide do we encounter the near perfect preservation of organic objects in salt – in Hallstatt, Hallein/Dürrnberg[12] and Chehrābād[13] in north-west Iran.

Organic objects providing important archaeological information have been found in deserts, moors, and tree coffins. These most often belong to funerary contexts and thus represent the result of very specific cultural transformation processes, giving us a very selective picture. Archaeological discoveries in ice have mostly been limited to isolated finds[14] lacking in contextual information – with, of course, the notable exception of the Iceman. Finds from bogs and wetland areas are better suited to help us understand everyday life in prehistoric times; that (among other reasons) is why certain areas surrounding the Alps were recently put on the UNESCO world heritage list. Thousands of objects made of wood, bast, and tree bark illustrate the great variety of material culture used by prehistoric societies. The wealth of finds and the variety of objects discovered in bog and wetland areas does not, however, cover all categories of organic materials. For example, objects made of materials such as wool, leather, fur, feathers, skin, horn, sinew, bladder, intestine, and other organs are not preserved in water. That these materials were used in prehistory is known from finds discovered in ice, in Nordic tree-coffins, and in desert areas.

The only find sites with perfect conservation conditions for all classes of materials, outside of funerary contexts, are the salt mines. They therefore offer the possibility to research and reconstruct the worlds of prehistoric life and work with a unique analytical resolution available nowhere else.

In recent decades it has been possible to excavate thousands of pieces of equipment, tools, textiles, production devices, and mine timbers out of the often metre-high layers of mine production waste at Hallstatt. Hallstatt is therefore the richest find-site in Europe for objects made of organic material.[15]

In addition, the salt mines of Hallstatt include materials from both the Bronze Age and the Early Iron Age – and therefore allow two metal-age epochs to be compared on the basis of their organic material cultures. This is especially noteworthy due to the fact that, apart from the salt mines, there are almost no larger archaeological finds coming from

6 Reschreiter, Pany-Kucera, Gröbner 2013. – In art these types of images are referred to as *Wimmelbilder* ('teeming pictures'). They go back to Hieronymus Bosch and Pieter Brueghel the Elder.

7 Schauberger 1986. – Unterberger 2009, 99.

8 Unterberger 2009, 87.

9 O'Brien 1996, 12 and Fig. 4. – Goldenberg et al. 2011. – Goldenberg 2015, 153.

10 Tintner et al. 2016.

11 Reschreiter 2015a, 83.

12 Stöllner 2002.

13 Aali, Stöllner 2015.

14 E.g. Hafner 2015. – Steiner, Marzoli, Oeggl 2016.

15 Reschreiter et al. 2014, 356.

Fig. 1. Busy picture of everyday Bronze Age life at the Hallstatt mines, made in 2006 (Drawing: D. Gröbner, H. Reschreiter, NHM Vienna).

the Early and Late Iron Age where organic material has been preserved.

2. Illustrations of Everyday Life in Hallstatt

Drawn or painted images portraying detailed reconstructions of prehistoric mining activity are used regularly to present the many and varied aspects of the prehistoric Hallstatt mining world.[16] This tradition dates back to Friedrich Morton, who depicted the state of research by means of a diorama for the Hallstatt museum.[17] Forty years later, in 2002, Wolfgang Lobisser built a diorama for the newly opened publicly accessible portion of the mine, and in 2003 Klaus Löcker produced the first drawings (*Lebensbilder*) of the prehistoric salt mines for a lecture in Cardona, Spain. In 2006 more of these pictures were created for the illustration of the overview work 'Kingdom of Salt. 7000 Years of Hallstatt'.[18] Since then these illustrations of everyday scenes have become a fundamental tool and are used as a central element both in published literature and during lectures on the latest developments in research (Fig. 1).[19]

Illustrations of prehistoric everyday life are understood to be drawn from scientific models and are mostly used to present the latest state-of-the-art research on the Hallstatt mines, as well as to complement discussions. They are not conceived as purely popular illustrations for children's or popular science books, and not only intended to raise a smile.[20]

It is necessary to append the basis for the illustrations to them in writing, in order to explain and enable better understanding of them. This necessity has often been noted.[21]

Just as scientific models are refined and changed as research progresses, new knowledge about prehistoric salt production in Hallstatt led to revisions in the images of

16 Reschreiter, Pany-Kucera, Gröbner 2013.

17 Morton 1959, 66.

18 Kern et al. 2008.

19 E.g. Reschreiter, Grömer, Totschnig 2009.

20 Rouff 2002. – Reschreiter, Pany-Kucera, Gröbner 2013, 34–35.

21 E.g. Kühberger 2008, 59.

everyday life in the salt mine. Recent results of experiments and computer-based simulations concerning the working process were incorporated into the new versions. This article will introduce the latest version of the illustrations of Bronze Age mining.

Illustrations of everyday life-scenes in prehistoric Hallstatt fulfil many functions within our research and public education processes.[22] They offer a simple introduction to Hallstatt mining archaeology, which is in many ways fundamentally different from other types of archaeological investigations. They have also proven to be a perfect starting place for interdisciplinary work. With the help of these illustrations, academics from other disciplines can be quickly brought up-to-date on the most recent models of early life and can be integrated into the research process.

Images of everyday life also fulfil another, important function: just like computer-based modelling approaches, they force us to think all the way through our mental models of prehistoric work processes and to systematically analyse the database of our arguments.[23]

2.1. The Layout of the New Illustration

In order to enable a quick understanding of the changes that have taken place in the current state of salt mine research, the layout and basic elements of the illustrations created in 2006 were kept the same, just as was done for the update in the illustration of the Early Iron Age salt mine. The extremely detailed execution of the illustration was deliberately kept, although that form is nowadays often replaced by a more schematic type of drawing.[24] The picture was again created step-by-step, together with the artist Dominic Gröbner. The goal of the new illustration is both to present the most recent results of research and to encourage discussion about them (Fig. 2).

The guiding principle of the new illustration was to represent only objects that are evidenced through our excavations. The only place where this line had to be crossed was in the representation of the miners' clothing. The pieces of textiles found in the Bronze Age mines do not give us enough information to reconstruct the outfits worn by Hallstatt miners, so well-preserved clothing from the Nordic Bronze Age was used instead.

3. The Bronze Age Mines

The majority of the Early Iron Age sites give a rather uniform impression. The spectrum of finds is nearly identical and the objects are very similar to one another. This group of sites is known as the 'Eastern group' (*Ostgruppe*).[25] The Bronze Age sites show more variety, although they were at least partially contemporaneous.[26] One group of shafts – the 'Northern group' (*Nordgruppe*) – is characterised by the spatial proximity of the areas as well as the similarity of the excavated objects.[27] Large numbers of finds and significant findings have come out of the Grünerwerk.[28] The 1882 report of a collapsed shaft in the Appoldwerk also belongs to this group.[29] In contrast, the Bronze Age mining gallery located in the Christian von Tuschwerk area (*Christian von Tuschwerk, Alter Grubenoffen*) shows distinct differences.[30] It is also the area with the highest density of finds. All three areas have in common the element of an enormous central shaft connecting the mining gallery either with the surface or the next gallery above or below, whereas in the Early Iron Age narrow slanted tunnels connected the mining galleries to the surface.[31] Bronze Age mining was specialised in the production of small-sized chips of salt rock. The extraction, sorting, and transport of this material structured the entire work process – in contrast to Iron Age mining, which focused on the extraction of large tablets of rock salt and left small piece salt, even of the purest quality, in the mine.[32]

As the Bronze Age sites show marked differences it is difficult to combine them to form one single illustration. It is, however, necessary to bring together the finds and findings from the various sites, because no single site has delivered enough data by itself to enable the illustration of a reconstruction scenario. The consolidation of this information (Fig. 3) requires that some finds and reconstructed work processes need to be discussed in detail.

3.1. The Shafts

All Bronze Age mines discovered in Hallstatt up until now are formed around central shafts of large dimensions. That makes them very different from the Iron Age mines, which were accessed through narrow, slanted tunnels inclined at c. 45°.[33]

22 Reschreiter, Pany-Kucera, Gröbner 2013, 34.

23 Kowarik, Reschreiter, Wurzer 2017.

24 Kühberger 2008, 54. – Grömer, Kern 2018.

25 Schauberger 1960.

26 Stadler 1999.

27 Schauberger 1960.

28 Barth 1986. – Barth, Neubauer in prep.

29 Barth, Neubauer 1991.

30 Barth 1993–1994.

31 Barth 1982. – Reschreiter, Kowarik 2008a.

32 Barth 1976b.

33 Barth 1984. – Reschreiter 2005.

Fig. 2. Busy picture of everyday Bronze Age life at the Hallstatt mines, made in 2015 (Drawing: D. Gröbner, H. Reschreiter, NHM Vienna).

All three Bronze Age shafts are of exceptional dimensions. Shafts from prehistoric mines are usually dug round and with a minimal circumference.[34] In Hallstatt to date only shafts with rectangular or square cross-section are known. The shaft evidenced at the Grünerwerk is rectangular and measures 23 × 7 m.[35] The foot of the shaft at the Appoldwerk site can be estimated from the maps drawn in 1882 as being over 7 m in diameter (Fig. 4).[36]

The shafts at the Christian von Tuschwerk area have not yet been fully excavated, but, based on our current understanding, a rectangular cross-section with side lengths of at least 10 m can be reconstructed.

In order to introduce this basic characteristic of Bronze Age mining in Hallstatt (shaft structures) to a wider audience, a mining gallery with two shafts is shown in the illustration of the Bronze Age mine (Fig. 3/1). In the picture, the mining gallery is entered from above through a shaft and a further shaft leads down to the next mining gallery below.

The height of the shafts, i.e. the distance between the mining gallery and the surface or to the next mining gallery, is currently unknown. The findings at the Appoldwerk indicate a very high shaft. The evidence for this lies in the incredibly large pile of mine timber that was excavated at the site, and which represents the remains of the wooden constructions (staircases and platforms) installed in the shaft.[37] At the Christian von Tuschwerk site, the shaft timbers cover a large surface area of over 1 m. These timbers are, however, only three layers deep (Fig. 5). For this reason we assume that the shaft was not very high, and estimate that the next

34 Weisgerber 1990, 6–7.

35 Reschreiter, Kowarik 2008b, 53.

36 Barth, Neubauer 1991.

37 Barth, Neubauer 1991.

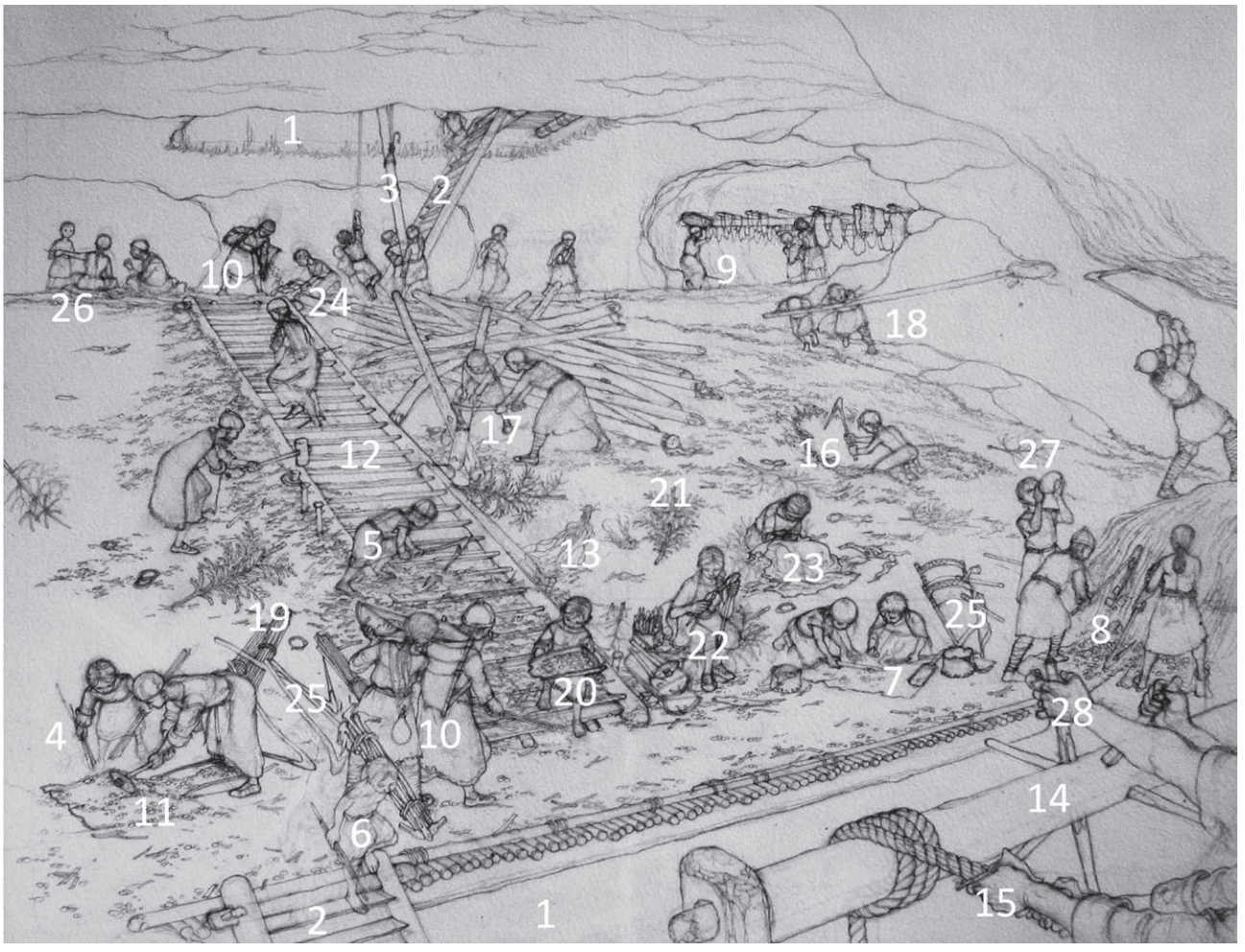

Fig. 3. Preliminary sketch for the busy picture of everyday Bronze Age life at the Hallstatt mines. A detailed discussion of the numbers is provided in the text (Drawing: D. Gröbner, H. Reschreiter, NHM Vienna).

mining gallery was located only a few metres above the one we are currently excavating. Our findings also indicate that the next shaft leading downwards is off-set from the one inside the Christian von Tuschwerk area.[38]

The shafts served many purposes: entering and exiting the mine (see section 3.2), transport (see 4.2) and ventilation (see 4.5.2). All three functions have been portrayed in the busy picture.

3.1.1. Moving About in the Shafts

The large piles of broken mine timber encountered at the Appoldwerk and the Christian von Tuschwerk areas are interpreted as the collapsed remains of the wooden constructions inside the shafts. Large numbers of pieces of staircases were located within this shaft debris. As a result, we can say that these shafts were not only used for ventilation, but definitely served to enter and exit the mines and to move between the different mining galleries. In the illustration, someone is descending the stairs down into the shaft (Fig. 3/2) and the boy in the foreground is busy getting ready to equip the miners in the gallery below with a bundle of pick-handles (Fig. 3/6). Constructions aiding access and transport through mining shafts date back to the Neolithic.[39]

The large number of timbers found indicates that the constructions in the shaft required a large amount of wood. Exactly how the timbers were built in cannot yet be reconstructed. The most plausible explanation would seem to be that platforms were built in at regular intervals in the shafts. It can be assumed that shaft structures only took up a small part of the shaft's cross-section, because the shafts also

38 See illustration in Kern et al. 2008, 52.

39 Weisgerber 1990, 9.

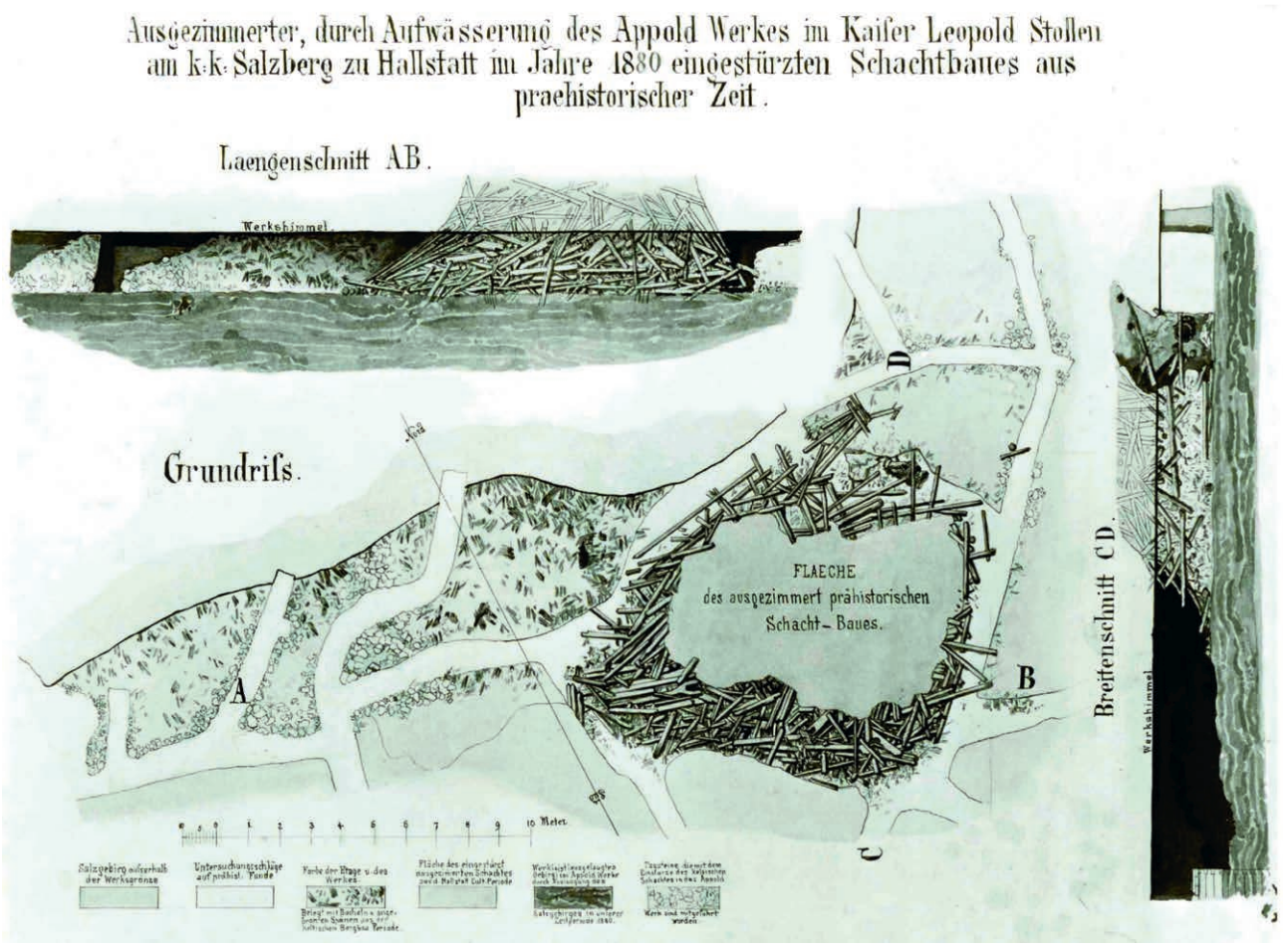

Fig. 4. Findings at the Appoldwerk site in 1880. The collapsed shaft reinforcements were excavated over a large area (Watercolour: Hallstatt Museum).

served to transport materials of large dimensions (see 4.2) and to ventilate the mine.

In the narrow, slanted tunnels of the Early Iron Age logs braced between the tunnels' side walls served as stepping boards.[40]

3.2. Size and Geometry of Mining Galleries

According to Gerd Weisgerber, the only existing forms of movement within prehistoric mines were belly-crawling, crawling on all fours, and bent-over walking as well as more or less upright walking.[41] This assessment does not hold true for the Bronze Age mines in Hallstatt. All mining galleries that were excavated are enormous. They are so large that the waste layers inside the mines sometimes reach over 5 m in height. And even over these, the Bronze Age miners might still have walked upright.

While the Iron Age mines consist of horizontal mining galleries with lengths of up to 200 m and heights of over 20 m, the Bronze Age mines were constructed around shafts.[42] At the Grünerwerk site, a number of inclined finger-shaped mining galleries were excavated that led from the central shaft to the richer veins of salt. At the Christian von Tuschwerk site, nearly horizontal galleries connected by vertical shafts were excavated.[43] These galleries could be up to 25 m wide and over 50 m long. One of these galleries is portrayed in the illustration.

But it was not only the galleries themselves that were enormous. The large dimensions of many of the mine timbers and staircase elements found inside the mine evidence considerable shaft sizes, as well as large openings at the surface and into the mine – allowing for the transport of logs of 8 m in length through these openings. By comparison,

40 Reschreiter 2005, 28.

41 Weisgerber 1990, 5.

42 Barth 1990.

43 Reschreiter, Kowarik 2008b, 52.

the central shaft at the modern salt mine in Hallstatt can only accommodate a maximum timber length of 6 m and measures 3 × 4 m.

Normally, even in these large mining galleries, it was not necessary to put in support structures due to the special geological situation within the Haselgebirge rock formation. For this reason, the mining gallery in the illustration is shown without supporting timber structures.

The geometry of the Hallstatt mines is fundamentally different from the contemporaneous copper mines in nearby Salzburg. There, narrow veins of ore were mined to a great depth, so that narrow slits, only as wide as the vein of ore, were formed in the mountain. However, the veins, and consequently also the slits, sometimes reached a height of 30 m.[44]

In Hallstatt the salt deposit at the Christian von Tuschwerk site is so rich that its extraction could be structured according to the needs of the miners.[45] The mine almost looks as though it were conceived on a drawing-board. The bottom of the mine is almost horizontal, consists of pure salt, and the find spots above and below the excavation site indicate that further horizontal mining galleries exist there, separated from the currently excavated mining gallery through a layer of rock only a few metres thick.[46] At the Mitterberg copper mine site, Peter Thomas also assumes that the ore was mined following a master plan.[47]

3.3. Social Structure – Considering the Iron Age Evidence

In the case of the Early Iron Age, sufficient evidence supports the reconstruction of the social structure. Through a synopsis of finds from the mines and anthropological analysis of skeletons from the cemetery, the social structure and the integration of children, women and men in the work process as well as the division of labour according to age and gender can be reconstructed.[48] For the Bronze Age, however, neither cemetery nor settlement sites are known and the finds from the mine cannot be easily sorted into age groups; the size of the mining community and the work load carried by each age and gender group cannot be reconstructed or can only be insufficiently reconstructed. For these reasons, a reconstruction analogous to the Early Iron Age was chosen for the new Bronze Age mine 'life scene'.

Fig. 5. Various views of fractured mine timbers at the Christian von Tuschwerk area (Photo: D. Brandner, NHM Vienna).

Considering the size of the Early Iron Age mining galleries, the location and the size of the cemetery, it must be assumed that miners lived close to the mines, up in the Salzberg Valley, and that they lived there throughout the entire year. For the Bronze Age we also assume that the work was not

44 Stöllner 2015, 178. – Thomas 2018, 39–50.

45 Unterberger 2009, 90.

46 Kowarik, Reschreiter, Wurzer 2015, 152.

47 Thomas 2018, 371–396.

48 Pany-Kucera, Reschreiter, Kern 2010. – Reschreiter, Pany-Kucera, Gröbner 2013.

seasonal. One indication in favour of a continuous presence in the valley is the proof of winter residency, which has been established by the fact that 90 % of the wood used in the mines was felled between October and April.[49]

On the basis of the size of the cemetery, Frank Nikulka assumes that during the Early Iron Age, Hallstatt was one of the largest societies in central Europe.[50] Marks of wear on the skeletons found at Hallstatt show that at least all individuals from inhumation burials (just over 50 % of those buried in a grave) worked in salt production.[51] The mining galleries of the Bronze Age are comparable in dimension to those of the Iron Age. On this basis it is reasonable to assume that the society of miners living on the salt mountain in the Bronze Age was one of quite considerable size.

3.3.1. Children and Teenagers in the Mine

While the size of shoes[52] and caps[53] in finds from the Early Iron Age shows that babies, children and young adults were present in the mines, no such conclusions can be reached based on the Bronze Age finds. The only exception is the case of a conical hat found in the Grünerwerk.[54] The hat has a circumference of 53 cm and would therefore fit a young person of c. 11 to 13 years of age (Fig. 6).[55] According to this find, there is at least one proof for the presence of young adults in the mine.[56] However, for the Bronze Age it is unclear how often young adults and possibly also children participated in mine work. The cap only establishes that they were present.

Data from the Iron Age show that 100 % of the skeletons of children found from this epoch have marks of wear on the spine, so it seems that child labour in the mine was no exception but rather the norm.[57] At present no such data for the Bronze Age exists.

Fig. 6. Conical hat from the Grünerwerk (Photo: A. Rausch, NHM Vienna).

Due to the lack of a cemetery, it is also not possible to make statements about the social structure of the mining community at that time. Without funeral provisions and well-preserved skeletons it is not possible to establish whether those who received rich funerals had worked intensively since their childhood, as was the case in the Iron Age.

3.3.2. Representation of Children in the Illustration of the Bronze Age

The data for the Early Iron Age and the recent intensively led debate on the demographic structure of prehistoric societies resulted in a representation of children and young adults in the new illustration of Bronze Age life. In the new picture, children and young adults are shown performing routine tasks.[58] Intensive child labour is intentionally shown. Children were integrated in routine work and the tasks they completed might have included taking care of lighting tapers (Fig. 3/4) cleaning the staircase (Fig. 3/5), the transport of equipment (Fig. 3/6) and sorting broken rock salt (Fig. 3/7).

As in the Iron Age, children are shown holding and maintaining the lighting tapers, as there have been no holders

49 Grabner et al. 2015, 299.

50 Nikulka 2016, 246 and Tab. 18.

51 Pany-Kucera, Reschreiter 2014, 173.

52 Barth 1992a.

53 Reschreiter, Pany-Kucera, Gröbner 2013, 56.

54 Barth 1986, 29.

55 Oster 1961, 465.

56 Experiments in carrying loads with reconstructions of carrying sacks have shown that the length of the sack's carrying strap must match the length of the carrier's back. If it does not, the carrying sack will either hang crooked on the person's back or the whole load will rest on the wooden stick at the side, which is only there to help balance the sack. It was hoped that by measuring the length of the strap, one could make a statement, through indirect evidence, about the use of the sacks by Bronze Age young persons or children. However, there is little variation among the five carrying sacks; both the length of the carrying strap and the distance from the lower end of the strap to the place the wooden stick is attached vary very little and are quite similar to the copy made by Lobisser, which can be used with ease by an adult.

57 Pany-Kucera, Reschreiter, Kern 2010, 49.

58 E.g. Röder 2010. – Röder, de Jong, Alt 2012. – Röder 2014.

found for the lighting tapers from the Bronze Age, which is why it is assumed that someone had to maintain and carry them.[59] Recent experiments in burning replica tapers/taper bundles conducted in conjunction with the excavation have also made it clear that it was necessary to manipulate them constantly to ensure that they burnt evenly.

3.3.3. Roles of Men, Women and Children in the Illustrations

In the first version of the Bronze Age illustration, almost exclusively male miners were drawn, as befits common stereotypes for prehistoric life. In the new versions (Bronze Age and Iron Age), an attempt was made to overcome these stereotypes[60] and to portray women in 'active' roles – in contrast to the usual trend.[61]

In a similar vein, approximately the same number of women and men are shown working. In addition, 50 % of the people shown in the picture are children and young adults, similar to how Brigitte Röder represented them.[62]

According to documents from modern mines and from cultural anthropology, it is common for whole nuclear families to work together in mines, but they do not form one working group. Instead, the groups of workers are formed according to age and gender.[63]

4. Working Procedure

Working processes in the Bronze Age mines were set up for excavating and transporting small chips of salt rock. The procedure included all the necessary steps, from breaking the salt out of the mountain to sorting it and transporting it, to carrying out the necessary measures to maintain an infrastructure, to guaranteeing security, to maintaining equipment and satisfying the basic elemental needs of the workers, like eating and relieving themselves.

In the illustration of the Iron Age, cooking, food and other daily activities are shown in the foreground, while the mining of salt tablets and their transport are in the background. The reason for this division is that many finds that give us a good impression of life in the mine were preserved in the waste layers from the Iron Age. However, because broken equipment was either intensively recycled or used as fuel for heat, there are some steps in the work process for which no hard evidence exists.[64] The composition of the Bronze Age waste layers is distinctly different. In these layers, thousands of pieces of equipment and tools from the mining of salt and from its transport have been preserved, but there are almost no remains evidencing the daily life of the miners (see 5.2). That is why, in the illustration of Bronze Age mining, salt mining work is shown in the foreground and daily life in the background.

4.1. Extraction and Processing

4.1.1. Extraction

In the case of the Early Iron Age, the details of rock salt extraction techniques are well understood, due to the existence of pick marks in the Stügerwerk,[65] two specimens of salt tablets,[66] and the findings from other sites (Kernverwässerungswerk, Kilbwerk). Salt tablets up to 150 cm wide were broken out of the rock with picks and brought up to the surface, while the smaller fragments that were broken off during the picking process were left behind in the mine. The tool that was used, a short-handled bronze flanged pick, was shown to be effective in mining experiments from 1973 and 1974.[67]

The situation for the Bronze Age is very different. Pick marks evidencing the extraction technique were not discovered until 2016 at the Christian von Tuschwerk find-spot. Their detailed interpretation is still under discussion. It is clearly apparent that salt extraction was focused on small piece salt. This is proven because of the transport equipment used (see 4.2) and further sustained by the fact that the mine waste consists almost exclusively of burnt-out tapers, waste rock (mostly clay and gypsum) and broken equipment. Among these are hundreds of fragments of broken pick handles.[68] Bronze Age picks differ in many basic aspects from their Iron Age successors, as well as from those used in the copper mines (see 6.3.2, 6.3.3). By contrast, the mine waste from the Early Iron Age shows a high content of small piece salt, which was not brought to the surface, but simply left behind.

Since the exact procedure for use of the mining tools has not yet been explained (see 6.3.2), more than one variation of the tools' use has been included in the illustration (Fig. 3/8).

59 Pany-Kucera, Reschreiter, Kern 2010, 56–57.

60 Röder 2002.

61 Mehling 2002, 89. – Kowarik, Leskovar 2015.

62 Röder 2010, 2.

63 Regarding the nuclear family and age as a social category, see also Röder 2010, 13, 19.

64 Reschreiter, Grömer, Totschnig 2009, 318.

65 Barth 1982.

66 Barth 1976b.

67 Barth 1976a. – Reschreiter 2017.

68 Kowarik, Reschreiter, Wurzer 2017, 176.

4.1.2. Processing and Sorting

During the mining of ore-containing rock, the extraction of rock is followed by its processing. The processing consists of purifying the ore from its matrix and any country rock. Processing can include mechanical (pounding, cobbing, sieving, sorting) and chemical techniques and is done to increase the amount of ore present compared to waste rock. Afterwards, the ore is processed by means of smelting.

By contrast, during salt rock mining in the Early Iron Age, the processing step was left out and the salt tablets were brought to the surface without further purification.[69] The same is thought to be true for Bronze Age and Iron Age salt rock mining in Transylvania and the South Ukraine.[70]

However, for the Bronze Age salt mining in Hallstatt, evidence for an underground processing step exists. The absence of small salt chips in the waste layers and the presence of waste rock like gypsum and clay there lead to the conclusion that the broken salt rock was sorted directly in the mining galleries. A possible tool for the job could have been long, lancet-shaped hardwood tools, of which many were found in the waste layers.[71] In the illustration there are two children shown on a wool blanket, sorting small pieces of mined rock with these wooden tools (Fig. 3/7).[72] Lancet-shaped pieces of wood similar to those found in Hallstatt can also be found in the Mitterberg Bronze Age copper mines, which have been associated with transport of ore by Thomas.[73]

Beside the children a wooden bucket is displayed, in which the broken-off tips of bronze picks have been sorted out and collected. In the mining waste layers of the Early Iron Age there are many broken pick tips and broken off flanges from the bronze picks, whereas in the Bronze Age these pieces could not even be detected through wet sieving.[74] We conclude that this is a further indication that the sorting process of the Bronze Age was so exact that even the smallest pieces of precious bronze were sorted out.

One interpretation of the function of the wool blankets (see also 4.2.2) is, that they were employed to avoid mixing the broken salt chips with charcoal pieces from the mine waste. The blankets might have been used as a floor cover during the picking and sorting processes (Fig. 3/7 and 3/8). An alternative way to keep the mined salt clean, not pictured in the illustration, is that the area being mined was kept very clean, so that the miners could cut out the rock and sort it without the use of blankets. One example of this kind of process can be found today in a salt mine in Yemen.[75] The waste layers in Douzlakh, Cherabad/Iran can also be interpreted in this way.[76] In this scenario any mining waste would have been discarded into parts of the mine which were no longer in use.

4.2. Transport

The next step in the mining procedure after mineral processing is its transport to the surface. By 'transport' every form of material movement in the mine is to be understood. This encompasses the movement of mineral raw material that has been extracted, of waste rock, or of equipment and tools. Transport represents a fundamental process in any type of mining. According to Weisgerber, in a shaft, materials can be transported hand-to-hand, by carrying, or with ropes; in mining galleries, carrying or dragging are possible means of transport.[77] In the case of the Bronze Age mine in Hallstatt, carrying transport in the mining gallery is evidenced by the carrying sacks. Rope transport is documented for the mine shafts. Miner's troughs, that were dragged on the ground, as in copper mining, have not yet been found at Hallstatt.[78]

4.2.1. Carrying

Various ways of carrying loads have been established through finds in the Early Iron Age mines at Hallstatt.[79] The wear marks on the skeletons of children from these sites could only have been caused by carrying heavy loads directly on the head or with the help of a forehead strap. The women's skeletons, on the other hand, show wear marks indicating one-sided carrying on one shoulder. Since the burial ground of the Bronze Age society in Hallstatt has not yet been discovered, we cannot reach conclusions about the transport of mining materials through indirect evidence as we do for the Iron Age.

Highly specialised carrying sacks are the only currently known evidence of transport in the Bronze Age mine. Since other forms of transport cannot be excluded, they were included in the illustration of the mine. Salt-cured meat is transported on a person's head to the drying cabinet

69 Barth 1976b.

70 Synopsis: Harding, Kavruk 2011. – Harding 2013, 63–64. – Harding, Kavruk 2013.

71 Grabner et al. 2015, 302.

72 Reschreiter 2013, 24.

73 Thomas 2018, 288–295.

74 Reschreiter, Kowarik 2008d, 87.

75 Marsnjak 2009.

76 Aali, Stöllner 2015 and Fig. 42.

77 Weisgerber 1990, 9–10.

78 Synopsis: Thomas 2018, 167–169.

79 Pany-Kucera, Reschreiter, Kern 2010, 56–58. – Reschreiter, Pany-Kucera, Gröbner 2013, 29–30.

Fig. 7. The position of the steps in the staircase proved correct in a test (Photo: H. Reschreiter, NHM Vienna).

(Fig. 3/9). The young boy in the foreground and the carrier in the background carry a bundle of new pick handles (Fig. 3/6) and meat on their shoulders.

Carrying Sacks

The transport of salt through the mining gallery is portrayed in the illustration as being performed with carrying sacks made of cowhide (Fig. 3/10), the icons of Bronze Age research in Hallstatt.[80] Two specimens each of carrying sacks come from the Appoldwerk and Grünerwerk areas, and one from the Landsteinerkehr site – however, up to now, none have been recovered from the Christian von Tuschwerk site.

Shovel, Filling Trough, and Scraper

In the Bronze Age two types of tools were used to move broken and sorted salt into transport containers: shovels and the combination of filling trough and scraper. Shovels made of maple wood were found at the Grünerwerk and are associated there with the carrying sacks.[81]

At the Christian von Tuschwerk site shovels do not occur. Instead numerous scrapers and filling troughs were excavated, which served as tools for collecting and scooping small piece salt (Fig. 3/11). Currently no evidence exists for the use of carrying sacks at this site. It is therefore unclear whether carrying sacks or other devices were used to transport the salt to the central shaft. In the illustration of the Bronze Age mines both techniques are depicted.

In Hallstatt, shovels and scrapers were not used in the Iron Age mines. The large amounts of broken small piece salt were scooped with shards from broken wooden vessels into sacks made of goat or sheep hide.[82] By contrast, a large quantity of Iron Age shovels was excavated at the Dürrnberg.[83]

The transport of salt to and between the shafts occurred in part over staircases (Fig. 7; see 6.3.2., 'Notched Log Ladders and Staircases'). In the illustration, stairways are shown in both shafts (Fig. 3/2) and also connecting the two shafts for the purpose of transporting materials and salt (Fig. 3/12).

4.2.2. Transport with Ropes

Material transport through the shaft was executed by means of ropes (Fig. 3/3). The ropes were probably not only used for the transport of salt to the surface, but also to deliver equipment and supplies to underground mining galleries. The transport through the shafts was carried out using massive lime bast ropes. To date, the use of ropes has been established by the finds of an extremely tattered and worn rope and single strands of bast ropes in the Christian von Tuschwerk site.[84] In the illustration of the mine, a discarded rope is shown lying on the ground to allude to heavy use of the ropes and their subsequent replacement (Fig. 3/13).

Rope transport is a technique evidenced since the Neolithic.[85] What is, however, unusual about the ropes found in Hallstatt is their dimensions. With a diameter of 4 cm, they are the thickest known ropes from central European prehistory. Through many experiments and knowledge exchange with West African rope manufacturers, information about the carrying capacity, manufacture and wear on the ropes was collected.[86] According to that information, a 4 cm-diameter rope allows for a carrying capacity of over 1000 kg. Such a capacity was not required for the transport of salt, but most certainly for the transport of mine timber into the mining galleries, e.g. to bring the 8 m-long staircase stringers down into the mine. The analysis of the work traces on the logs shows that the wood was worked in a fresh state. That means that one staircase side could have easily weighed over 300 kg.

The vertical distance over which loads had to be hoisted was probably, at least at the Christian von Tuschwerk site,

80 Barth 1992b.

81 Barth 1986, 24. – Grabner et al. 2014, 150.

82 Reschreiter, Grömer, Totschnig 2009, 310–311.

83 Stöllner 1999, 143, 151, 163, 166. – Stöllner 2002. – Boenke 2014, 88.

84 Löcker, Reschreiter 2005.

85 Weisgerber 1990, 8.

86 Van der Stege et al. 2012. – Reschreiter, Hein, Palm 2015.

not very high. The pile of wood which resulted when the shaft supports collapsed has a diameter of about 15 m, but is only about 50–80 cm high, from which it can be concluded that only two to three platforms were built in. It has therefore been assumed that the shaft reached a height of c. 10 m before it opened into the next mining gallery. The discovery of offset, shorter shafts at the Christian von Tuschwerk site suggests that it was necessary to shift loads carried on ropes from shaft to shaft. Taking into account the considerable weight of the rope itself (1.4 kg per metre when wet), it seems that limiting the vertical distance to be overcome must have been of great value.

The details of the transport with ropes are not yet understood in detail. Ropes can be used hanging freely without guide rafters or pulleys, as examples from wells in West Africa show. The heavy weight of the rope itself and the large weight of the loads to be transported make such a scenario seem unlikely. Experiments in the salt mines have demonstrated that guide rafters that do not turn engender very high losses in pulling ability due to friction. Even if the rope and the polished guide rafter are greased, it takes 80–90 kg of effort to hoist a 50 kg load. Still no pulleys have been found at Hallstatt or at any other site in central Europe.

Since the Hallstatt miners developed many specialised construction techniques to meet demands in their working routine (see 6.3) that differed fundamentally from the solutions used in other mines, it could also be that when it came to lifting technology, they went their own way. However, although material transport is central to the working process of every mine, for Hallstatt, the requisite finds are still lacking. Some of these might be concealed in the group of objects whose function has not yet been explained. For the illustration of the Bronze Age, information from the finds in the Mitterberg copper mines was used in the illustration. At least two finds of simple winches have been made there.[87] Winches reduce the losses due to friction and make it possible to hoist larger loads. The winch in the foreground of the illustration is similar in style to those found at Mitterberg (Fig. 3/14).

The leather palm protectors which were found in great numbers at the Christian von Tuschwerk site are also shown as being connected to the transport of loads with ropes. The marks of wear on them could have come from braking the rope action (Fig. 3/15).

The finds from Iron Age mines lack evidence of the use of ropes for transport; to date only one indication of it exists, which dates from the 19th century.[88] The wear marks on the skeletons of Iron Age women, children and young adults show that the majority of transport during the Iron Age was achieved by carrying the loads.

Wool Blankets, Wool Sacks

An appropriate transport container is necessary in order to transport material with ropes.[89] Finds of prehistoric transport baskets and bags are not very common, however they do exist.[90] For Hallstatt it seems that a specific type of wool cloth was used. At the Christian von Tuschwerk site, over 60 very coarse and dense wool textiles with heavily lined edges were discovered. They have been associated with transport devices on the grounds of their construction, which is fundamentally different from that of other textiles, and on the basis of a report dated to 1886 out of the Appoldwerk. At that site, two carrying sacks stacked one in the other were discovered and inside the upper carrying sack a coarse wool blanket of 100 × 140 cm was found.[91] Many of the wool cloth fragments are so small that the original form cannot be reconstructed. Due to the lack of seams it must be assumed that these were transport cloths rather than sacks.[92] Experiments have shown that up to 50 kg of salt can be rolled up and attached to a rope in blankets the size of the one found at the Appoldwerk site.

In the first diorama of the Bronze Age mine, complete cowhides, based on finds from the mines, were interpreted as transport containers. But analysis of the wear marks on the straps have now demonstrated this hypothesis to be invalid. The cowhides fulfil another function in the working process (see 4.5.3, 'Animal Hide Processing in the Mine').

No transport sacks have been found at the Mitterberg copper mines. Thomas explains this fact by the conservation conditions there, which are poor for wool and leather/hide. He however assumes that transport sacks were used as part of the chain of transport there.[93]

87 Thomas 2018, 301–306.

88 Barth 1970–2019, 'Fundstelle Josef Ritschnerwerk', citing the chronic from Engleitner 1813: "Im Josef Ritschnerwerk soll im Jahre 1768 bei der Wersäuberung ein abwärts führender alter Bau mit schräg gelegten Bäumen belegt, vom Werkshimmel abwärts gegen die Werkssohle aufgeschlossen sein, in welcher ein starker Riem daran eine Rinke von Zink befestigt war, so muthmaßlich eine alte Kern Aufzugsgrube gewesen ist. Der Umfang davon, ein starkes Klafter betragend, war voll von Gschütt und Tagerde."

89 Weisgerber 1990, 10.

90 Stöllner, Weisgerber 2004.

91 Grömer, Rösel-Mautendorfer, Reschreiter 2013, 122.

92 Grömer, Rösel-Mautendorfer, Reschreiter 2013, 122.

93 Thomas 2018, 420–423.

Thick, rough work textiles such as those found at the Bronze Age sites are not present in the spectrum of finds from the Early Iron Age sites. However, Iron Age workplace demands were very similar to those of the Bronze Age. As evidenced by the enormous waste layers, large amounts of salt chips were moved, but completely different containers were chosen for the task; large numbers of goat- and sheepskin sacks were used for transport.[94] Sacks of this type are not known from the Bronze Age salt mines.

4.3. Prospecting

Very often, mineral deposits are not so rich that mining can be carried out indiscriminately. Prospecting is necessary to find new areas worthy of extraction. For this purpose, small tunnels are dug to investigate the deposits. Prospecting tunnels have been established to have existed in the copper mines.[95] The comparatively large number of small prehistoric tunnels which were found in Hallstatt at the Kübeck site indicates intense prospection activity. At the Christian von Tuschwerk site, one tunnel with a width of roughly 1 m was dug from the large mining gallery, through the mine waste layers and into the depths. It is not certain that this tunnel served the purpose of prospecting; however, due to the unusual nature of this find, it was put into the illustration of the mine in order to encourage discussion about it (Fig. 3/16).

4.4. Mine Construction and Maintenance by Means of Mine Timbers

The most important raw material at the Hallstatt salt mines was wood. The majority of tools and equipment were completely or at least partially made of wood, as well as mine timbers to build the platforms in the shafts, the staircases, and supports for the mine entrances (which were tunnelled through the relatively soft overhead rock).

In the centre of the illustration of the Bronze Age mine, a pile of mine timbers which are being prepared for use is depicted (Fig. 3/17). Mine timbers were not used to support the large mining galleries; instead, they were mainly built into the shafts, as platforms and stairs to allow people to move through the shafts. Large amounts of mine timber were used for these wooden structures.[96] The shaft debris from both the Appoldwerk and the Christian von Tuschwerk areas consists of hundreds of logs and pieces of roughly hewn construction wood.

In the mining galleries neither protective nor support elements were needed due to the static qualities of rock salt. Bronze Age mining is similar in this way to Early Iron Age mining. Almost no mine timbers were found in the mining galleries of the Early Iron Age, despite their considerable size. The same is true for all tunnels connecting the mining galleries within the rock salt deposit. Neither show traces of wooden support structures.

For the sediments covering the rock salt deposit the situation is entirely different. Any slanted tunnel or shaft dug through these soft sediments to the surface needed to be heavily timbered as no cavity would have remained open for more than a short time.[97] This is clearly documented through one preserved Iron Age tunnel.[98] However, no timbered Bronze Age tunnel has yet been found.

The continual mountain pressure causes the reclosing of any cavity inside the salt mountain. Although this is a slow process, and therefore supporting and propping inside the mines and shafts is unnecessary, it is an inexorable one, which necessitates regular maintenance activity (see 4.4.3). If tunnels or shafts are fitted with platforms, staircases and other wooden constructions, the pressure on them increases over time until they finally collapse. For this reason, tunnels and shafts needed to be regularly re-enlarged and the wooden constructions replaced. Such regular maintenance activities lead to a greater demand for wood. Dendrochronological analysis of shaft timbers indicates that the wooden structures in the shafts had to be continuously repaired.

Bronze Age ore mining also made use of mine timbers, but mostly for another reason. The country rock in this case was most often stable enough on its own; only seldom did it need to be supported. However, very often platforms were built in the tunnels.[99] In both Hallstatt and Mitterberg, boards were created through the tangential and radial splitting of logs, but the boards were used for different purposes: in Hallstatt, split log boards were used almost exclusively for the construction of wooden staircases. Split log boards were seldom used as mine timbers. In the Mitterberg region, by contrast, radial split boards[100] and tangentially split boards[101] were regularly used as mine timbers – even more often than logs.[102] In Dürrnberg, many boards and split planks were also discovered alongside logs.[103]

94 Barth 1995, 82. – Reschreiter, Grömer, Totschnig 2009, 311.
95 Thomas 2018, 414–420.
96 Grabner et al. 2015.
97 Unterberger 2009, 89.
98 Barth 1984.
99 Thomas 2018, 256–259.
100 Thomas 2018, 66–77.
101 Thomas 2018, 77–87.
102 Thomas 2018, 130–134.
103 Boenke 2014, 55–65.

4.4.1. Wood Chips

Wood chips are the largest group of finds in the Bronze Age mines, along with burnt tapers. They show that many mine timbers were shaped in the mine itself. The analysis of the hatchet marks on wood pieces and wood chips demonstrates that it was mainly fresh wood direct from the forest that was processed inside the mine.

The form of the wood chips and the cuts on the remains of large logs indicate that the timbers needed for shaft structures were delivered to the mines already cut to the appropriate length, plus a little bit of extra length. They were then worked to fit more precisely at the construction site inside the mine. At that point, the end of the tree trunk, which was often shredded during transport, was cut off.[104]

Similarly, in the Mitterberg mining region the timbers had to be cut to measure, so that they fit exactly.[105] Chopping blocks for wood-cutting were found at the Mitterberg site; however, they have not been found at Hallstatt.[106]

In the Iron Age mines at Hallstatt, wood chips are rare. This is not surprising, as there were no structures built into the mining galleries. At the Dürrnberg site, wood chips are also an underrepresented find group.[107]

4.4.2. Transport of Mining Timbers

In the numerous Circum-Alpine wetland sites, many thousands of pieces of wood used for construction have been found. Surprisingly, only seldom has evidence of the transport of tree trunks from the forest to the construction sites been found. The situation at Hallstatt and Hallein is very different: here the fundamentals of the Bronze Age and Iron Age transport of wood could be retraced.[108] A very special hauling technique could be shown to have been used at Hallstatt. The details of this technique were investigated jointly with children through a school project known as a 'Sparkling Science Project'.[109]

4.4.3. Crowbars – Maintenance

The salt mountain is, as has been noted, malleable and constantly in motion. Mountain pressure continually squeezes open cavities in mines closed. These deformations lead to the formation of cracks and to breakage in the Haselgebirge rock (see 1.1).[110] To prevent loose plates of rock (rock salt and country rock) breaking out from the roof or walls of the mine, the mine must be constantly inspected and maintained (see also 4.4).[111]

One tool used to achieve this purpose is found regularly in the mine waste layers: ash-wood crowbars, 3 m long with a wedge-shaped working end. In the illustration of the Bronze Age mine, two miners are shown removing a loose stone plate (Fig. 3/18). Finds as well as the structure of the mine waste evidence regular maintenance activities. To date, no finds of large rock salt pieces that could be associated with plates breaking from side walls or ceiling could be found in the waste layers.

Although finds of such maintenance tools are lacking for the Iron Age, we have indications for their use. Without regular maintenance work stone plates (rock salt and country rock) would have unavoidably broken from the walls and ceiling. But even in the waste layers in enormous mining galleries, no evidence of such occurrences could be discovered. It is also apparent from the skeletons in the burial ground that the Iron Age miners had 'their' mountain and working processes under control, since the excavated skeletons do not show signs of multiple fractures or lost limbs. The mines were most likely safe in both the Bronze Age and the Iron Age.

Crowbars have also come into discussion for the copper ore mine in the Mitterberg region.[112] They were also used in the Iron Age mine at the Dürrnberg site.[113]

4.5. 'Basics': Lighting, Ventilation, Maintenance of Working Materials

4.5.1. Lighting Tapers

Lighting tapers were the only source of light in the Bronze Age mines. Although during the Iron Age large fires were set down inside the mines in addition to the use of tapers, there is no evidence of larger fires for the Bronze Age.[114]

The tapers from the Iron Age sites are quite uniform. They are made of firewood, are split radially out of the tree trunk, and have a long, rectangular shape.[115] At the Bronze Age Grünerwerk site, only tapers which are square in shape (5 × 5 mm) have been found. At the Bronze Age Christian von Tuschwerk site, there are square-shaped, rectangular-shaped and also mixed forms of tapers. Large numbers

104 Totschnig 2013.
105 Thomas 2018, 88–103.
106 Thomas 2018, 117–119.
107 Boenke 2014, 105.
108 Lobisser 2005. – Totschnig 2013.
109 Rudorfer, Reschreiter 2014, 51.
110 Unterberger 2009, 90.
111 Fellner 1999, 187.
112 Thomas 2018, 184.
113 Stöllner 2002, 125, 234 and Pl. 70, No. A63.
114 Barth 1995, 81.
115 Grabner et al. 2015, 300.

of so-called torch-rings were excavated at the Grünerwerk and Tuschwerk sites.[116] It is thought that they were used as a safety device for the transport of tapers. In the illustration of the mine, there are many 1 m-long bundles of tapers, held together with these rings (Fig. 3/19).

In the earlier busy picture of the Bronze Age mine (Fig. 1), the tapers are being burnt one at a time. However, experiments have shown that fir tapers do not burn well by themselves. When they are bundled together and moved continuously, they emit an even light. In the new illustration of Bronze Age life at the mines, children are therefore shown tending bundles of lighting tapers (Fig. 3/4).[117] Miners are also drawn with bundles of tapers: a Bronze Age characteristic was to hold the bundle with the teeth (Fig. 3/18). At both the Hallstatt and the Mitterberg regions evidence of this has been found in the form of tooth marks on the tapers.[118] The consumption of tapers was very high. According to calculations, over 2600 tapers were required for mining one cubic metre of salt.[119] Raw materials for the tapers were taken only from straight-grained, branch-free wood.[120] Firewood continued to be used at Hallstatt in the Iron Age mine. At the Dürrnberg site near Hallein, firewood was also favoured.[121]

4.5.2. Ventilation

A sufficient supply of fresh air is fundamental to the success of mining. At the depths reached at Hallstatt, natural ventilation cannot provide a sufficient supply of fresh air.[122] The ventilation must have worked, as shown by the depths reached (over 140 m) and by the millions of burnt tapers. If the oxygen level in the air dropped below 16 %, they would not have burnt anymore.[123] Therefore, it must be assumed that artificial ventilation was used. There are several variants imaginable. Fresh air can be brought into the mine through air shafts, fans made of parts of trees or through thermal ventilation. Air shafts or twin shafts function by having one shaft parallel to another, one of which brings in fresh air while the other lets the oxygen-poor air out of the mine.[124] The concept of a ventilation shaft has been known since the Neolithic period and was also put to use in Bronze Age copper mines.[125] No shafts have been proven to have been used as ventilation shafts at Hallstatt, but at the Grünerwerk and Appoldwerk areas two parallel shafts exist that theoretically could have been connected with cross-cuts and so served as a ventilation system.

Thomas infers that the ventilation at the copper mines in the Mitterberg region was very astutely managed. He sees evidence in the finds of ventilation shafts that were covered up in order to maintain ideal ventilation conditions.[126]

According to the current state of affairs at the Hallstatt excavations, it must be assumed that the central shaft was also used for ventilation. In the illustration of the Bronze Age mine, several forms of ventilation have been included. This includes thermal ventilation by way of fire and baskets of coals as well as fanning. Thermal ventilation functions on the principle of warm air rising: the oxygen-poor mine air is warmed and rises on its own up out to the surface. The stream of air coming out then automatically pulls fresh air down into the opening of the mine. This form of ventilation is still used today in modern coal mines,[127] and has been described systematically by Weisgerber.[128] It is assumed that thermal ventilation was also used in the Early Iron Age at Hallstatt. There is very good evidence for large fires in the Iron Age mines. It is clear that they were used for cooking, light and also probably served to keep the ventilation going.[129]

For the Bronze Age we only have a few indications of large fires in contrast to large amounts of charred pieces of wood that were found in the Iron Age mines. However, there is still a fire drawn at the foot of the shaft in the illustration. Since the Bronze Age mining process is thought to have been divided into clearly defined activity zones (see 5.2), it is conceivable that the places where fires were burnt have not yet been discovered.

According to Johann Unterberger it is not always necessary to have a large fire in order to create sufficient mine ventilation.[130] Among the finds from the Christian von Tuschwerk site there are many filling troughs that have been burnt on the inner surface. It is entirely conceivable that old filling troughs were used as containers for embers. In the illustration, a boy is shown in the front middle section carrying a fresh load of embers into the mine in order to keep the air circulation going (Fig. 3/20). The container holding the embers creates a warm stream of air going upwards in the middle of the shaft, while the fresh air can descend along the cold walls of the shaft. The larger the cross-section of

116 Reschreiter, Kowarik 2008d, 58.
117 Reschreiter, Pany-Kucera, Gröbner 2013, 29.
118 Barth 1987–1988, 44. – Thomas 2018, 145–157.
119 Kowarik, Reschreiter, Wurzer 2017, 176.
120 Grabner et al. 2015, 301.
121 Boenke 2014, 74.
122 Weisgerber 1990, 12.
123 Unterberger 2009, 93.
124 Weisgerber 1990, 13.
125 Thomas 2018, 371–396.
126 Thomas 2018, 371–396.
127 Jicinsky 1901, 94.
128 Weisgerber 1990, 12.
129 Barth 1995, 81.
130 Unterberger 2009, 92–93.

the shaft, the less both airstreams intermix or interfere with each other. If the shaft is not sufficiently large, so-called airstream splitters must be built into the shaft that prevent the two air streams from mixing and bringing the ventilation to a halt. In the illustration there are some young pine or fir trees next to the container of embers (Fig. 3/21). These are common among the finds at the Christian von Tuschwerk site and could have been used as fans to keep the air circulation going. A term used to describe this fanning process is the German word *fochen*, which miners use to describe the artificial circulation of air into or out of the mine. Fir branches with needles still on them have also been discovered at the Grünerwerk site and have been associated with ventilation.[131]

4.5.3. Maintenance of Work Materials

Mines are not just centres of production, they are also large centres of consumption. The equipment and tools used for underground work get worn out fast and have to be replaced or repaired often. The high number of broken pick handles, filling troughs and scrapers in the waste layers bear witness to this fact.[132]

Sharpening of Picks

One kind of work which must be done again and again in the mine is the sharpening of the miners' tools (*Gezäh* in German).[133] Our mining experiments show that the tip of a bronze pick can be used for up to an hour before it becomes dull and must be exchanged. That is the reason why the changing of pick tips is shown in the illustration. In the middle of the picture there is a wooden bucket with substitutes and someone is in the middle of exchanging the tip of his pick (Fig. 3/22).

Such buckets were frequently discovered at the Christian von Tuschwerk site and also at the Grünerwerk site.[134] They often have the marks of pick tips on the inner floor of the bucket, which is why they have been singled out as transport containers for pick tips. We assume that the dull tips were brought to the surface after every shift, in order to be sharpened and readied for their next use. No evidence has been found of transport containers for pick tips from the Iron Age.

Whetstones were found in the Iron Age mine, but it has not yet been demonstrated that they could have been used for pick tips.[135] In the burial ground, many graves contained high quality whetstones – however, those found in the mine are of relatively soft material, which indicates that they were used for some other purpose. Broken pick handles were exchanged down in the mine during the Iron Age, exactly as in the Bronze Age.

Animal Hide Processing in the Mine

In the illustration of the mine, a woman is shown who is cutting an animal hide (Fig. 3/23). The origin of this scene is the find of two cowhides in the material from the Christian von Tuschwerk site. Further, in recent years some pieces of animal hide were found in waste layers, which can be understood to be the leftovers from hide cutting. Originally the large cowhide was thought to have been used as a carrying sack and was represented that way in a diorama. However, due to the find of the strips of animal hide in the waste, it now seems clear that this hide was in fact the raw material for the creation of hide objects such as leather palm protectors. No model has yet been developed to explain why animal hides were processed in the mine itself, or why pieces weren't cut up on the surface and finished there, then brought down into the mine.

In the Iron Age mine there have not yet been any finds indicating that animal hides or skins were processed down in the mine. However, the repair of goatskin sacks probably took place underground and was included in the illustration of the mine.[136]

4.6. Additional Industry: Pork Meat

During the Bronze Age, a second economic branch rose to importance alongside the production of salt: meat processing and conservation. Every year, hundreds of pig carcasses were salted in log basins.[137] Thousands of animal bones and the remains of 4 × 4 m basins show the scale of this meat production facility. There are several arguments as to why the meat processing industry grew strong in the Salzberg Valley: it was probably simpler to bring the pigs to Hallstatt than to bring the salt to the pigs; and the mine was the perfect place to smoke and cure meat. In the illustration of the Bronze Age mine, miners are shown hanging salted meat up on drying racks to cure, although there have been no specific finds to support this assumption (Fig. 3/9). Along with pork meat, large fish filets have been drawn in. The conservation of freshwater fish with salt has been thematised in this way; this practice is continued today in places like Lake Iseo in Italy.

131 Barth 1987–1988, 40.

132 Kowarik, Reschreiter, Wurzer 2017, 176.

133 Weisgerber 1989.

134 Grabner et al. 2015, 302.

135 Barth 1972, 40.

136 Reschreiter, Pany-Kucera, Gröbner 2013, 30.

137 Pucher et al. 2013.

5. Organisation

5.1. Division of Labour

Age- and gender-specific divisions of labour can be reconstructed very well for the Early Iron Age.[138] In the Bronze Age mining process, the construction of the carrying sacks gives us hints as to the way work proceeded. There are almost no marks of wear on the underside of the side-supports, which shows that once the sacks were filled, they were not set down. From this evidence the conclusion can be drawn that at least three persons were involved in the working process. One person picked up the salt with a filling trough and scraper (Fig. 3/11) and filled it into the carrying sack, which was being held on a second person's back (Fig. 3/10). The carrier then transported the carrying sack to the filling place at the shaft, where the salt was emptied into wool blankets or wool sacks. The third person was necessary to hold the blanket or sack during filling so that all went well (Fig. 3/24 and Fig. 8). Following the emptying process, the next load could be picked up. Since, at both the Appoldwerk site and the Grünerwerk site, carrying sacks were found together in pairs, it must be assumed that at least two carriers were used in the transport process.[139] This continuous process is portrayed in the illustration of the mine.

Computer simulations and excavation and carrying experiments have shown that this transport was very efficient and that large amounts of salt could be brought to the shaft in this way, while the extraction of salt with the pick was very time-intensive.[140]

In order to employ both carriers in a continuous fashion, it would have been necessary to have many more than 17 miners working with picks, as was shown in the first variation of the illustration of the mine. We conclude that in the Bronze Age mining process there was no strict division of labour such as took place in the Iron Age. It is conceivable that all the miners worked together to break out a large amount of salt, and then worked together to transport it. An attempt was made to portray this alternating process in the illustration of the Bronze Age mine. On the right side of the picture, the salt is being excavated while the carrying sack lies on the floor unused (Fig. 3/25). On the left side, the picks are left on the ground and the filling trough, scrapers, and carrying sacks are being used (Fig. 3/25).

Fig. 8. Reconstruction of a carrying sack during a test (Photo: D. Brandner, NHM Vienna).

5.2. Activity Zones

The waste layers from the Iron Age give the impression that there were no clearly divided activity zones in the mine. The spectrum of finds is quite similar at almost every find-spot. So far, the only place where an area for a specific activity has been found (as at the Dürrnberg site) is at the Kernverwässerungswerk, where a conspicuous pile of paleofaeces was located.[141] The absence of recognisable activity zones could have been caused by the need to move large quantities of mine waste, or due to smaller excavation surfaces. Neither of these possibilities can be excluded.[142]

However, the nearly even distribution of all different categories of finds in both the pits of the excavation rooms as well as in the connecting tunnels supports the idea that living and working went hand in hand in the Iron Age mine and were not spatially separated, as is shown in the illustration of the mine.

In the Iron Age mine waste layers there is evidence not only for mining work through things like broken tools, but also for the fulfilment of the miners' basic needs – like eating, wearing clothes, and relieving themselves. The large quantities of leftover food, cooking tools, food supplies, textiles, hides and leather as well as paleofaeces make it possible to reconstruct the life of the miners in some detail.

In Europe, little information about prehistoric eating habits is available. Within the Iron Age mine waste layer, however, there are so many remains of life at the time that the cooking of specific recipes, their ingredients and even the way in which they were eaten could be reconstructed – a

138 Pany-Kucera, Reschreiter, Kern 2010. – Reschreiter, Pany-Kucera, Gröbner 2013.

139 Barth, Neubauer 1991.

140 Kowarik, Reschreiter, Wurzer 2015, 153. – Reschreiter et al. 2018b, 63.

141 Stöllner et al. 2003.

142 Reschreiter, Pany-Kucera, Gröbner 2013, 33. – Reschreiter et al. 2014, 356.

singular occurrence. The fragments of enormous cooking pots and the size of the cooking spoons from the Early Iron Age lead to the conclusion that large shared kitchens were created 100 m underground.[143] It seems that a great number of portions were cooked. Many analyses and experiments have led to conclusions about exactly what was cooked as well as the fact that it took many hours to cook it.[144] The finished stew, which is known as '*Ritschert*', has been found in Hallein and Hallstatt and was filled into small, wooden, round-rimmed bowls from big cone-necked cooking pots with wooden ladles.[145] Incrusted food remains occur regularly on the large number of excavated wooden vessels.

Since no eating utensils have been discovered, we must assume that the stew was eaten without the help of tools. The exact method of eating the stew – whether it was prepared very fluid and drunk directly out of the bowl, or was made into a thicker mash and then brought to the mouth via the fingers, or whether possibly the bowl could have been held directly to the mouth and the stew pushed in with the fingers, or if another technique was used – has not yet been explained.

Due to the fact that the ceramic and wood inventory uncovered at the mine fits into the spectrum of finds from other sites from the same time period, we must assume that in Hallstatt the eating habits were not specific to the miners but were similar to the usual techniques used by inhabitants of the Early Iron Age. According to that model, 2500 years ago solid food was eaten without utensils, directly with the fingers.[146]

Apart from the extensive finds in cooking implements and tableware, there were also hundreds of paleofaeces found in the waste layers of the Iron Age mine. On the basis of the fact that paleofaeces were indiscriminately distributed in all of the Iron Age waste layers, we must assume that there were no special places set aside for their disposal. That is the reason why a man is shown relieving himself in public in the illustration of the mine.[147]

The composition of the Bronze Age mine waste layers is fundamentally different from those from the Iron Age. To date, no remains of cooking utensils or ceramic pieces in any form have been found. The same can be said of the finds at the Mitterberg site.[148] The situation is similar for abandoned hide, skin and leather goods. During the Iron Age, pieces of personal equipment such as caps made of animal fur and shoes were mixed into the mine waste layers in great numbers and were found mixed in with equipment, the many carrying sacks and other remains. In the Bronze Age mine waste, there are personal protection devices made of leather, hide and fur (leather palm and finger protectors) and many technical textiles (see 4.2.2, 'Wool Blankets, Wool Sacks'). To date there have been finds of one cap and one shoe (that unfortunately disappeared after World War II) discovered.[149] It appears that in the Early Iron Age, shoes and caps were considered disposable and were left along with the transport sacks in the waste layers. However, in the Bronze Age, shoes and caps were not just left behind as the palm protectors were, but were treated differently.

It is not just cooking utensils and pieces of clothing that are lacking from the Bronze Age. After 30 years of excavation, only seven pieces of paleofaeces have been unearthed. In Mitterberg paleofaeces are also lacking. It seems as though only equipment and tools directly associated with the breaking out and transport of salt can be found in the waste layers of the Bronze Age. However, it is not assumed that the workers left the mine to eat, drink, and go to the toilet in the Bronze Age. Instead, it is thought that the areas in which salt was mined and transported were strictly divided from those areas where the miners ate, drank, and relieved themselves. In the illustration of the mine, a child is portrayed being sent to go to the toilet (Fig. 3/26).

Due to the small area of archaeological excavation it is quite possible that the area in which the Bronze Age workers lived has not yet been discovered.[150] Thomas also argues intensively that at the Mitterberg site, the ensembles of finds are representative of a similar situation.[151]

To date, it cannot be explained why the miners of the Bronze Age treated their waste so differently from their successors during the Iron Age, or why the division of the activity zones was so fundamentally different.

There are also basic needs that left no trace behind in either the Bronze Age or the Iron Age waste layers. For example, there are no definite traces of the presence of carrying vessels for the transport of fluids or for drinking. In the Iron Age waste layers there are countless fragments of goat and sheep hides, and some of them are so carefully processed and sewn that they seem similar to African water skins.

143 Barth 1995.

144 Barth 1999. – Bertieri 2009.

145 Boenke 2014, 151.

146 Reschreiter 2015a, 84.

147 Reschreiter, Pany-Kucera, Gröbner 2013, 34.

148 Thomas 2018, 368–369.

149 Barth 1986, 30. – Reschreiter, Kowarik 2008d, 59.

150 Reschreiter 2013, 25.

151 Thomas 2018, 404–410.

However, proof that some skin sacks were used to transport fluids has not yet been found. There have been no finds of goat or sheep hides from the Bronze Age mine; however, some fragments of animal bladders were found. They would serve well as fluid containers as they are flexible and watertight. However, here, too, direct evidence is lacking. In order to address the theme of drinking and the transport of fluids, a few miners were drawn in the illustration with animal bladders hanging on their belts, or are shown drinking from bladders (Fig. 3/27).

Apart from drinking, there is also no evidence to show that miners slept overnight in the mine – nothing from either the Bronze Age or the Iron Age. There is a total lack of finds on the topic of sleep for the Bronze Age – it is not known how miners slept, what they slept on, or what they slept under. It would seem appealing to sleep inside the mine in the winter, which, at 8°C, would be warmer than outside. However, for the Iron Age mine there is one finding which excludes the notion that children or babies might have slept for weeks in the mine: their skeletons show no signs of rickets, which would have appeared had they stayed out of the light for weeks at a time.

5.3. Working Conditions

5.3.1. Work Safety: Leather Palm Protectors

Hallstatt has an exceptional position when it comes to work safety. There is no other Iron Age site which shows evidence of protective safety measures, which is not really very surprising. Objects made of leather or hide are most often found within tree-coffins, in the ice of Siberian graves, in the desert and on bodies found in the bogs. However, work gloves or finger protectors were apparently not necessary for the afterlife or the honour of the dead, because they are not to be found in the graves of Taklimakan or from Tuva or in the Danish National Museum collection.

In the Bronze Age mines, different variants of workers' protection have been proved to exist. These have also been included in the illustration of the mine. In the picture there are different kinds of leather palm protectors and finger protectors.[152] The man with the winch guides the transport rope with the help of a leather palm protector (Fig. 3/15), while the other operates the winch with the help of finger protectors (Fig. 3/28).

Finger protectors have also been found in the Iron Age mine; however, leather palm protectors have not been discovered. The animal hide caps have also often been mentioned in connection with work safety, because they were made of thick sheepskin and both warmed the head and protected it from injuries. According to depictions from situlae, these caps were very common headwear for men in the Early Iron Age and were widely distributed throughout Europe. They have only been preserved in salt. Shoes from Hallstatt in the Early Iron Age can be understood not just as pieces of clothing, but also as part of workers' safety equipment. Based on the size of the shoes and their wear marks,[153] these shoes were worn by those workers who transported loads through the mines over notched log ladders and stepping boards in the slanted tunnels.[154] Shoes with wear marks in the areas of the heels and under the balls of the feet, as is seen in the case of standing while hacking with a pick in the mining gallery or from walking on even ground are seldom seen in Hallstatt. By contrast, at the Dürrnberg site, those kinds of marks are quite common.[155]

To date there have been no known finds related to work safety in hide or leather from the Alpine Bronze Age copper mines, due to the minimal chance of their being conserved under the conditions in the mine there.

5.3.2. Health of the Miners

The new illustration of Bronze Age life shows only healthy, well-fed miners. No parasitological studies could be conducted on the Bronze Age paleofaeces due to their limited occurrence. That is the reason why no one is portrayed suffering from whipworm or roundworm[156] and bending over in pain from belly cramps, as in the illustration of the Iron Age mine.[157] However, new studies of the health conditions of the Iron Age miners force us to rethink this picture of an idyllic prehistoric world.[158]

According to these studies, almost all Hallstatt miners suffered from chronic sinus and nasal infections, also maxillary sinusitis infections spreading from the teeth were observed.[159] It is argued that such massive infections were triggered or at least promoted by the working conditions in the mine.

Conditions similar to those in the Iron Age mine would have existed in the Bronze Age mine: a high exposure to smoky air near the surface due to the lighting tapers, very

152 Reschreiter, Kowarik 2008c, 75. – Posel 2018.

153 Barth 1992a.

154 Reschreiter, Pany-Kucera, Gröbner 2013, 30.

155 Stöllner 1999, Pls. 5, 19, 21, 24. – Stöllner 2002, Pls. 129, 137, 143.

156 Hörweg et al. 2008.

157 Reschreiter, Pany-Kucera, Gröbner 2013, 34.

158 Pany-Kucera et al. 2018.

159 Pany-Kucera et al. 2018, 989.

high humidity in combination with a relatively low temperature of 8°C and a strong draught.[160] For that reason it seems clear that those illnesses which can be identified from the Iron Age skeletons would also have affected the Bronze Age miners. In the next update to the illustrations of life in the mine, miners with runny noses and swollen skin in the area of the upper and lower jaw will be portrayed, in the same vein as Irmgard Bauer.[161]

6. Structure

6.1. Monopoly

Bronze Age mining in Hallstatt is likely to have had a quasi-monopoly position. No other salt producers are known to have existed within hundreds of kilometres.[162] It can be assumed that Hallstatt salt was transported over long distances and in all directions. The nearest 'competitors' on the salt market can be found in central Germany, Poland, Transylvania, Italy and eastern France.[163]

Hallstatt is therefore the only Bronze Age salt mine in Europe. Likewise, apart from Transylvania and South Ukraine, it is the sole supplier of rock salt. Despite this quasi-monopoly position, instead of applying the technologies used in the nearby copper mines, Hallstatt miners went their own way (see 6.3.4).

In the Early Iron Age, the situation changed fundamentally. From 650 BC onwards, the large salt mine of Dürrnberg was operated in the direct vicinity of Hallstatt. In addition, two producers of evaporated salt could now be found in the Eastern Alps, namely Unken near Lofer and Halltal near Hall in Tirol. However, this new situation on the 'salt market' did not lead to any technology transfer; instead, each mining operation continued to do its own thing. Even at the two salt works of Unken and Halltal, completely different briquetage vessels were used.[164]

6.2. Resources

6.2.1. Specific Requirements for Tools and Equipment

Thousands of tools and pieces of equipment have been preserved in the Hallstatt mines – many more than at other archaeological sites in Europe. The large quantity of mining tools allows researchers to determine the range of variation of the items and hence to make statements about requirement profiles which had to be met by the tools' makers. Bronze Age pick handles, for example, show that the tree species, quality and shape had to meet specific requirements and that only minor deviations were tolerated.[165] Both handles made of beech and those made of oak met these requirements. Since, due to climatic conditions, oaks only have a marginal presence in the Inner Salzkammergut, a reliable and intensive supply of these resources can be assumed.[166] Apparently, raw materials available nearby – including but not limited to beeches – were not always preferred, as is assumed for Dürrnberg.[167] The permanent import of resources implies a sustainable network.[168]

The axil (e.g. the angle between the upper surface of a branch and the stem from which it grows), which also determines the picks' working angle, is 60.6° on average in the Dürrnberg mine.[169] This coincides well with the means measured at the Iron Age sites of Hallstatt.[170] In the Arthurstollen mine near St. Johann in Pongau, the values are significantly higher, namely between 63° and 90°.[171] While the growth angles of the hafts in Hallstatt coincide extremely well with those in Hallein, there are large differences in other areas. In Hallein, pick handles showing large knots or branch bases and broken at these natural weak points were found repeatedly. Hallstatt material finds lack such items. It seems that raw materials were more carefully selected at Hallstatt.

The scrapers found at Hallstatt, however, exhibit considerable variations in size. For example, both the length and the type of the handles vary. Even the technique of mounting the handle to the blade has several variants.

Likewise, in objects made of animal hides, both strict guidelines and variations can be found. All carrying sacks, for example, although coming from three widely dispersed sites, have almost identical dimensions and designs,[172] while the leather palm protectors differ considerably in shape, size, and design, even when coming from the same site.[173]

In spite of the extremely short service lives of lighting tapers – only a few minutes – and the often observed, apparently wasteful use of them, the quality of the tapers used in Hallstatt is extraordinarily high at almost all sites. Here,

160 Unterberger 2009, 94.
161 Bauer 2002.
162 Reschreiter, Kowarik 2015, 292.
163 Stöllner 2004.
164 Krauss 2003. – Zanesco 2012.
165 Kowarik et al. in press.
166 Barth, Grabner 2003.
167 Boenke 2014, 87.
168 Kalthoff, Cress, Röhl 2016, 28.
169 Boenke 2014, 81.
170 Kowarik et al. in press.
171 Thomas 2018, 157–167.
172 Barth 1992b.
173 Posel 2018.

too, there was obviously a very clear requirement profile to be met,[174] similar to the one in Dürrnberg.[175] Triangular residual pieces, for example, necessarily arising from the manufacture of tapers, are only rarely encountered among the finds. Obviously, these triangular tapers did not meet one of the required criteria and hence were eliminated instead of being used in the mine – even though they would have burnt just as well.

6.2.2. Resource Management

The demand for equipment was enormous in Bronze and Early Iron Age mines.[176] Nevertheless, resource management and the way to handle equipment and old, unusable materials were sometimes fundamentally different between the two eras. While in the Bronze Age, only a few tools were repaired and even functional items were discarded or left behind, in the Early Iron Age, almost all equipment was used intensively and re-used several times.

It seems that, in the Bronze Age, all broken or unusable tools were simply left behind by the miners. There are only very few examples showing that old materials remained in the working process, were recycled or were re-used elsewhere. It can be assumed that some old, worn-out filling troughs were re-used. Some of these are strongly charred on the inside. In the illustration of the mine, such filling troughs were interpreted as containers for transporting hot coals down into the mine, to get ventilation going or to light tapers (Fig. 3/20). Broken pick handles were occasionally reworked into lancet-shaped tools (see 4.1.2; Fig. 3/7).[177] As for the textiles, only one find can undoubtedly be identified as having been 'recycled'. The fabric was torn into strips and tied in knots.[178]

Moreover, in Bronze Age mining, tools that still worked were repeatedly discarded or left behind. For example, several complete scrapers, many lancet-shaped tools that were neither broken nor excessively worn as well as leather palm protectors that appear to have been still usable were found within the mining waste layers. Lighting tapers, burnt down to only half or one-third of their length, were often discarded; while during copper mining, which took place at the same time in the Arthurstollen mine, tapers were on average burnt down to much less than 10 cm of their original length.[179] Repair work can only be observed on less than 1 % of pick handles, some filling troughs and two buckets.[180]

It appears that resources were available in sufficient quantity in all areas, so there was no great need to be economical with them. Particularly for mass-produced objects, it could be demonstrated that, after becoming the property of the user, these objects were regarded as disposable and were also treated as such. When an object is transferred from the producer to the user, a break in the object's history occurs.[181]

In Bronze Age mining, very short object life-cycles can be recorded for almost all object groups; after manufacture, the tools were used, usually until becoming unusable, and were then left behind in mining waste layers. Only a few exceptions from this process can be observed.

For Early Iron Age mining, an entirely different way of handling resources and personal equipment can be reconstructed. Many objects have a very long and exciting history, during which, in some instances, their purpose changed several times, before finally being burnt or being left behind within the mining waste.[182] For example, the way Iron Age mining operations in Hallstatt and Hallein handled lighting tapers is fundamentally different. In the Dürrnberg mine, these tapers were usually burnt down to less than 10 cm of their original length.[183] Likewise, in Iron Age Hallstatt, tapers are significantly shorter than they were in the Bronze Age.

Not a single intact tool or piece of equipment has so far been encountered among the Iron Age finds. It can even be demonstrated that, in stark contrast to the Bronze Age, very intensive recycling took place. Broken pick handles, for example, were not simply discarded, as they were in the previous mining era. Instead, almost 50 % of these handles show traces of intensive re-use as chopping boards.[184]

For several Iron Age wooden vessels, an even more complex usage history can be reconstructed – until they were burnt or left behind as waste. It is assumed that these vessels were originally used in the households up above ground. There, some of them were repaired several times. The signs of wear and tear on them suggest that, even in a fragmented state, the vessels continued to be used as dishes before being used as boards for cracking hazelnuts.[185] As a last step before

174 Kowarik, Reschreiter, Wurzer 2017, 175.
175 Lobisser 2017, 291.
176 Kowarik, Reschreiter, Wurzer 2017, 176.
177 Reschreiter 2013, 25.
178 Grömer, Rösel-Mautendorfer, Reschreiter 2014, 136.
179 Thomas 2018, 147.
180 Reschreiter 2013, 25.
181 Hahn 2005, 43.
182 Kalthoff, Cress, Röhl 2016, 13.
183 Boenke 2014, 70.
184 Reschreiter, Grömer, Totschnig 2009, 315.
185 Reschreiter 2008.

the end of a wooden vessel's life cycle, many vessel fragments continued to be intensively worn or rounded off on the edges. This is considered to indicate that wooden vessel fragments were used to collect salt chips and fill them into hide sacks.[186] In addition, apart from re-using broken or unusable wooden objects as tools or boards, Iron Age people re-used these items as a burning material in underground fireplaces on a large scale.[187] It can also be demonstrated that not only pick handles and wooden vessels, but also textiles were intensively re-used.[188] It is considered probable that textile fragments were not produced due to the wear and tear of working clothes, but were deliberately brought down into the mine as rags for a still unknown activity. Almost all textiles found so far can be regarded as having been recycled.

Recycling and incineration of old materials were sometimes so intense that it has so far been impossible to discover any traces of some steps which must have existed in the mining process. For example, there is not a single clue indicating how large salt tablets were detached and transported by the miners.[189]

In Iron Age Hallstatt, working with old, worn-out materials was not the exception but the rule. For some steps in the mining process, only old materials were used, including, but not limited to, the use of broken pick handles as chopping boards or the collection of salt chips with fragments of wooden vessels. It should be noted that old materials did not serve as replacements for any tools not on hand when needed; instead, secondary use of materials was a standardised approach.[190] While Iron Age mining relied heavily on recycling, with old, worn-out materials as an important resource, Bronze Age miners used special tools for each type of activity.

Decisive gaps in the evidence are not unique to Hallstatt. Likewise, in Dürrnberg, in spite of the existence of salt preservation conditions, it is not yet completely understood how salt chips and broken salt were transported. Although there are a number of shovels, transport containers, whether made of wood, fur, skin, leather or bast, are entirely lacking, with the exception of a transport miner's trough.[191]

In spite of intensive recycling, repair work on equipment can be demonstrated for a few object groups only. Some goat- and sheepskin sacks[192] as well as textiles[193] show several signs of repair work. However, no repair work has so far been observed on Iron Age pick handles in Hallstatt, whereas in Dürrnberg quite a few handles were stabilised by wrapping them with skin or leather straps.[194] The mining waste of Dürnnberg and the Bronze Age mining waste of Hallstatt differ from the Early Iron Age mining waste of Hallstatt in another detail: although the composition of paleofaeces is very similar at both sites[195], suggesting a comparable diet, gnawed bones from the meat components of the stew known as '*Ritschert*' can only be found in Early Iron Age Hallstatt.[196]

Although Iron Age mining seems to have been very economical, some complete fur and leather objects were left behind within the mining waste. For example, several complete caps, a strap construction and finger protectors have been preserved.[197]

It appears that resources were not available in sufficient quantity in almost all areas, so there seems to have been a great need to be economical with them. This is surprising, as one of the wealthiest communities in Europe is likely to have lived in Early Iron Age Hallstatt. It is not yet understood why resource management is so fundamentally different between the Bronze and Iron Age Hallstatt mining operations.

6.3. Special Construction Techniques and Innovations

6.3.1. A 'Mountain Village' at the Cutting Edge

Today, Hallstatt is a mountain village suffering from emigration. It is located on the shores of Lake Hallstatt and its picturesque location attracts tourists. In the Early Iron Age, one of the largest[198] and wealthiest communities in Europe lived in the narrow high valley above the lake, as is evidenced by numerous extraordinary burial gifts.[199] Hallstatt was embedded in a dense and sustainable network, ensuring not only that the miners received an adequate supply of food, clothing and equipment but also the transportation of all the 'luxury goods', later found in graves, to the Salzberg Valley. These trans-Alpine connections started to take shape

186 Reschreiter, Grömer, Totschnig 2009, 311.

187 Reschreiter, Grömer, Totschnig 2009, 316.

188 Grömer, Rösel-Mautendorfer, Reschreiter 2013, 130.

189 Pany-Kucera, Reschreiter, Kern 2010, 55. – Reschreiter, Pany-Kucera, Gröbner 2013, 32.

190 Reschreiter, Grömer, Totschnig 2009, 318.

191 Stöllner 1999, 144.

192 Popa 2008, 104.

193 Rösel-Mautendorfer 2013.

194 Stöllner 2002, Pls. 109, 140, 178, 196.

195 Boenke 2014, 151.

196 Pucher 2010.

197 Barth 1972, Pl. 1. – Popa 2008, 105. – Pany-Kucera, Reschreiter, Kern 2010, 56.

198 Nikulka 2016.

199 E.g. Glunz 1997. – Glunz-Hüsken 2017.

in the Middle Bronze Age and were fully developed in the Early Iron Age.[200] These relationships enabled the creation of a cultural space, part of which has lasted until today.[201] In the Early Iron Age, Hallstatt was far from being a secluded mountain village. Instead, the contacts established over time enabled it to stay at the cutting edge. In the same way as, 2,800 years ago, the people of Hallstatt managed to bring ivory and amber into this Alpine valley, it was a matter of course that they were attired with the finest fabrics of the period, featuring the latest colours.[202]

Mining activities took place on a very large scale in the Bronze Age. It can therefore be assumed that a highly sustainable network was in place in this period, too, supplying the mining community's needs and transporting salt away from the valley. The archaeological landscape around this monopoly operation demonstrates that, from the Middle Bronze Age onwards, routes were well-developed here.[203]

It seems that Bronze Age mining, similar to later mining operations of the Iron Age, was right at the forefront when it came to new trends. For example, not only central Europe's oldest blue-dyed textiles but also one of the earliest tablet woven borders and one of the first zigzag twills were found in the mine.[204]

6.3.2. Unique Techniques and Tools

The textiles found indicate that Bronze Age Hallstatt was at the cutting edge of the technologies available and liaised closely with surrounding communities. Apart from textiles, one would also expect this for mining technologies and mining equipment.

In the Bronze Age, when Hallstatt had its first heyday, there had been a very long tradition of mining in Europe. It can be demonstrated that underground mineral extraction had taken place 16,000 years earlier on Thasos Island.[205] Extensive Neolithic flint mining produced technical solutions for essential requirements for underground mining, the transport of goods and personnel, ventilation, drainage and illumination. Likewise, mining has a long tradition in Hallstatt, as is indicated by the finds of several ancient antler picks.[206] Hence, around 1500 BC, mining technology had been developed over thousands of years and was well known. In the Mitterberg copper mining district, located only a few kilometres away from Hallstatt, a combination of fire-setting and mining with picks was used.

Despite this long mining tradition, well-established technologies and specialised tools available in the immediate vicinity of Hallstatt, it seems that, around 1500 BC, Hallstatt miners decided to develop their own equipment and tools for each of the steps in the mining process, from picking the salt out of the mountain to transporting it. These tools were tailor-made for the Hallstatt salt deposit and differed from everything that had been used before in mining activities or was used elsewhere in the region at that time.

However, the equipment and tools used in Hallstatt not only differ from the mining tools used in the surrounding mines; in fact, they also differ from any wooden tool or utensil known to have been used at the same time in the Alpine area. In circum-Alpine water-saturated sites, thousands of finds made of wood or bast have been preserved. The spectrum of wooden tools used in the Bronze Age is therefore well known. However, no similarities between Hallstatt mining finds and wooden objects from southern Germany, Switzerland and northern Italy have so far been observed.

Might the reason for this completely independent development be found in the specific nature of the deposit? Did the exceptional richness of the deposit enable Hallstatt miners to take a completely different approach than people working in the nearby copper mining districts? It is clear that the shortage of space of any lode was not an issue for Hallstatt. According to Weisgerber, these cramped conditions interfered with – and even determined – the size and shape of the tunnels as well as the manner of material transport.[207] Hallstatt miners had the opportunity to build extensive mining facilities and to optimise equipment and tools without having to consider limitations of space.

Hallstatt's special construction techniques were fully developed as early as in the Middle Bronze Age. It is assumed that these special equipment and tools were invented in Hallstatt itself. It cannot yet be estimated, however, how long it took until this unorthodox path was fully established.

Hallstatt Carrying Sacks

These sacks are most striking when it comes to special construction techniques. They are manufactured from untanned cattle hide and are therefore extremely robust. They are designed in a very special way: they only have one broad carrying strap enabling the entire load (20 l of capacity,

200 Kowarik et al. 2015. – Kowarik et al. 2017.

201 Reschreiter, Kowarik 2017, 440.

202 Grömer et al. 2013. – Hartl et al. 2015.

203 Kowarik et al. 2017, 45.

204 Grömer, Rösel-Mautendorfer, Reschreiter 2014, 131, 136.

205 Koukouli-Chrysanthaki, Weisgerber 1999, 135.

206 Kowarik, Reschreiter 2008, 44.

207 Weisgerber 1989, 195.

corresponding to about 28 kg of salt) to rest on the right shoulder.[208] A wooden stick, attached to the sack and carried on the left shoulder, helps in balancing the sack. When dropping the stick away from one's shoulder, the sack will tilt downwards and will empty itself without an effort. This unique way of functioning is enabled by fixing both ends of the sack's carrying strap to the lower part of the sack. Thanks to their unique construction, Hallstatt carrying sacks are the only carrying system for bulk materials in the world that can be emptied without effort. All other carrying aids, including rucksacks, tubs, carrying bars and baskets carried on one's head or on one shoulder, require an effort that can sometimes be considerable when it comes to emptying the load.

By contrast, classical rucksacks with two carrying straps, used in Early Iron Age mining as is corroborated by multiple finds, have so far not been found among the Bronze Age sites in Hallstatt. As they were demonstrably used in the Mitterberg area, carrying bars made of wood would have been easy to use in Hallstatt's large mining galleries, but have not yet been discovered.[209] The fact that carrying sacks were not used in copper mines as part of the chain of transport can be explained by the limited space usually available there.[210]

Large Winged Picks

Miners working in copper mining districts used socketed picks[211] attached to short handles.[212] This mining tool was easy to cast, the blank was simple to post-process and the handle was straightforward to manufacture and adjust.[213] Hallstatt miners, however, did not adopt this seemingly perfect tool, adapting it to their needs; instead, they developed their own solution. They were the first ones to use large winged picks.[214] It was significantly more time-consuming to cast this type of pick and to post-process the blank. Moreover, in attaching the pick, miners were forced to weaken the handle considerably, creating a predetermined breaking point on it.[215] In addition to these serious drawbacks, Hallstatt miners decided to more than double the handle length compared to that of socketed picks, while simultaneously greatly reducing the cross-section of the handle.[216] The finds clearly show that the long handle and the working angle of about 70° were deliberately sought-after characteristics for the picks. Only pick handles that fit this narrow requirement profile were chosen for the work.[217] It can even be proven that pick handles whose natural axils did not match the required angle were bent to achieve the correct angle.[218]

The handle length of 1 m selected by Hallstatt miners makes it very difficult to find trees from which appropriate blanks can be obtained. Nevertheless, the Bronze Age handle variant was used intensively for centuries. Why was the handle designed like this and how was it used? To be able to answer questions like these, researchers working in Hallstatt have relied on experimental archaeology for decades.[219] For the past 50 years, picks have been reconstructed and tested in Hallstatt. For Bronze Age picks, the technique used in the Iron Age, known as 'hammer and pick technology', can be excluded, given that the corresponding marks of wear are lacking on the rear of the haft heads. When performing a direct stroke, however, the picks with their long, thin handles and the 'odd' working angle turn out to be extremely unwieldy and difficult to use, regardless of whether used for the roof, floor or walls of the mine and whether used in a forward-striking or backward-pulling manner. The approach suggested by Pavel Tarasov is a possible solution to this problem. The researcher proposed handling the pick in a similar way to how a short scythe is used (Fig. 9).[220]

The miners might have performed unique swinging motions, coming from their hips and fundamentally differing from traditional stroke motions. If this was true, Bronze Age Hallstatt miners would have redefined stroke motions, making them much more efficient. While these swing motions would be a very good explanation for the handle's extraordinary shape, they cannot be a reason to use cumbersome winged picks instead of modifying socketed picks. There is still no explanation for this phenomenon.

During Early Iron Age mining in Hallstatt, only one very special construction technique was used, namely a winged pick with a 'spring-loaded' hafting.[221] In the Dürrnberg mine, finds show that this special design was not used at

208 Barth 1992b.

209 Thomas 2018, 306–307.

210 Thomas 2018, 167–169.

211 Stöllner, Schwab 2009.

212 Overview: Thomas 2018, 157–167. – Thomas 2018, 225–233.

213 Reschreiter et al. 2018a, 30.

214 Thomas 2014.

215 Reschreiter et al. 2018a, 30.

216 Barth 1967. – Reschreiter 2017, 49.

217 Kowarik et al. in press.

218 Grabner et al. 2015, 302.

219 Reschreiter 2017, 45, 49.

220 Reschreiter 2017, 49. – The short scythe, referred to as a *Kniesense* or *Sichte* in German, is a tool that was frequently used in central Europe, too, during the late Middle Ages and the early modern period.

221 Barth 1967. – Barth 1976a.

Fig. 9. The Hallstatt picks could have been used in a way similar to a scythe (Photo: D. Brandner, NHM Vienna).

all during the same period, although there is strong evidence that this 'hammer and pick technology' was applied to some items.[222] Another striking finding is that the only tree species used for making the handles was beech. Nicole Boenke was able to demonstrate that the range of tree species used was much broader at numerous other sites.[223]

Notched Log Ladders and Staircases

In order to overcome height differences, an ancestor of the ladder, known as a notched log ladder (*Steigbaum* in German), was widely used in prehistoric mines.[224] They can be found in different versions and were also used in the nearby Mitterberg copper mining district.

Hallstatt miners found their own solution here, too. In Bronze Age mining, only staircases were used for transporting materials. It has been possible to fully recover and examine one of these staircases.[225] No comparable staircase designs have been found at other sites, neither in other mines nor at boggy, water-saturated sites. This type of staircase seems to have been used for several centuries in Hallstatt alone. It is assumed that it was also invented here. It is not understood why Hallstatt miners developed an entirely new notched log ladder. Just like the staircases used in Hallstatt, notched log ladders can be placed at different angles. If a notched log ladder is not wide enough, two or more can be put up in parallel to each other.

The exclusive use of staircases to overcome height differences in Bronze Age mines in Hallstatt is remarkable, also because no comparable facilities are known to have been used during later mining efforts in the Early Iron Age; instead, so far, only notched log ladders have been found in the mining galleries.[226] Likewise, Iron Age notched log ladders used in slanted access tunnels were nowhere near the same high quality as Bronze Age staircases. No transport paths have been found so far in the Dürrnberg mine, neither staircases nor notched log ladders.

As different as the three largest Bronze Age sites (Grünerwerk, Appoldwerk and Christian von Tuschwerk) are in some aspects, they are similar in their use of shafts and staircases.[227] Two types of staircases can be observed: staircases that rested on top of waste layers and were fastened with pegs to prevent slippage, and free-standing staircases that were built into the shafts. In the centre of the illustration of the mine, a staircase that rests on the ground is shown. It is thought that this type of construction was designed for transporting heavy or large loads within a mining gallery. The treads are 120 cm wide and were supported in several places by underlying logs. The staircase parts found within shaft debris are, by contrast, mostly from narrower staircases. We interpret this to mean that shaft staircases were mostly used for the entrance and exit of workers, while the transport of loads in the shaft was accomplished with ropes.

Due to the high pressure in the rock at the site of the find, an entire staircase had to be taken apart and removed between 2013 and 2015.[228] A new gallery was created to store the staircase, 35 m below the site, into which an enormous airtight climate-controlled gallery was built for it. The staircase is there as part of the 'Bronze Age Cinema', which is the highlight and end of the tour through the Salzwelten (Hallstatt salt mines).[229]

As part of the relocation of the staircase, each piece was documented in detail. The analysis of the marks of manufacture and wear on the pieces of wood forced a revision of some aspects of the first publication concerning the staircase. It turned out that the treads were not adjustable, as was first assumed, but were built at almost a right angle to the stringers.[230] This means that the steps were not horizontal as in 'usual' staircases, but were unexpectedly slanted upwards.

222 Boenke 2014, 83.

223 Boenke 2014, 85.

224 Weisgerber, Stöllner 2005. – Thomas 2018, 346–351.

225 Reschreiter 2005.

226 Reschreiter 2005, 27.

227 Reschreiter 2005. – Christian Seisenbacher discovered part of a staircase in the 1880 documentation of Appoldwerk, too.

228 Löw, Poppenwimmer, Reschreiter 2016. – See also Stiegen-Blog, Archäologische Forschung Hallstatt, http://hallstatt-forschung.blogspot.co.at/ (last access 3.10.2019).

229 Reschreiter 2015b. – See Salzwelten Hallstatt, https://www.salzwelten.at/ (last access 3.10.2019).

230 Reschreiter 2005.

The advantage of this configuration of treads was shown in an experiment. If, through much use, there is a lot of mud on the steps, the staircase is much safer with these slanted treads; the mud collects on the back side of the treads, where it would have had to be removed regularly. Also, even if the staircase is clean, the danger of slipping and falling over the front step edge when walking down the staircase is reduced. The illustration of the mine portrays how the staircase could be cleaned using a pick. The components of the staircase are marked with signs of strong blows; most likely, the surfaces of the treads and boards received the blows through rough treatment while being cleaned.

The technique used to manufacture the grooves in the stringers – transverse cutting using a bronze axe – is backed up in Hallstatt by multiple finds and can be traced into the modern period.[231] For example, a trunk was discovered in Mitterberg's main tunnel, with recesses showing exactly the same marks as the staircases in Hallstatt do.[232] This item is believed to be a chute.

Transport Equipment and Filling Tools

Likewise, when it came to transporting broken salt, Hallstatt miners went their own way by combining filling troughs and scrapers. In most prehistoric mines, miners relied on the shovel as a filling tool.[233] In the Mitterberg area, for example, a shovel made of spruce has been preserved.[234] Trugs, by contrast, are very rare in prehistoric mines. In the nearby Mitterberg mine, only one trug was identified among the finds,[235] and this one is known to have been used together with spatulas.[236] Trugs and scrapers are ideal for gathering small pieces of debris and decanting them into transport containers.

Replicas of Bronze Age trugs and scrapers have been used for many years during excavation and have proven to be of great value. Although both tools would actually be ideal for any kind of earth, sand or gravel movement, they do not yet form part of the spectrum of wooden tools encountered at water-saturated sites.

Trugs – made of aluminium – and scrapers – made of iron – are still used today in the Hallstatt salt mines, while in the neighbouring Altaussee salt mines these tools were unknown, with the shovel being the single tool of choice.

In Bronze Age Hallstatt, shovels were used in parallel with trugs and scrapers. It is not yet understood why two different filling tools were used at the same time. Both tools have also been found in the Mitterberg area.[237]

What makes these trugs so exciting is not only their intensive use in Hallstatt compared to other European mining areas, but also the raw material selected to manufacture them. Most trugs were made of the bulgy calluses which grow out of fir stumps (wound wood). This growth habit is extremely stable, almost non-splittable, while at the same time being very lightweight.[238] Some trugs were also made of maple. In order to withstand loads, the wall of a maple trug is nearly twice as thick as the wall of a trug made of the callus of a fir stump. For this reason, and since the specific weight of maple is significantly higher, maple trugs were nearly twice as heavy as trugs made of calluses. Interestingly, although a perfect raw material for making all sorts of hollow vessels was available, this material has been encountered very rarely, only at water-saturated sites, and was not used at other sites in such an intensive way as in Hallstatt. Fiavè[239] and Ledro[240] are the only sites where several vessel walls and one vessel wall, respectively, made of calluses from tree stumps have been found. At Arbon-Bleiche, bulgy calluses without further treatment were probably used as beehives (bee gums),[241] whereas, in Hallstatt, they often served as buckets, too.[242] In the Mitterberg area, by contrast, buckets of almost the same dimensions were manufactured using a completely different technique.[243]

Enormous Shafts

The construction of shafts with enormous diameters is another unique trait of the Hallstatt mines. No even roughly comparable dimensions have so far been identified at any other site. In Hallstatt it was possible to construct huge shafts because the shafts were sunk in the salt-rich mountain, and because they were not only used for the movement of persons, salt transport and ventilation, but also for simultaneous salt extraction while they were being dug out.

6.3.3. Reasons for Independent Developments

Whereas for the Bronze Age – thanks to numerous finds preserved in the water-saturated conditions of lake

231 Grabner et al. 2015, 298.
232 Thomas 2018, 336–339.
233 Thomas 2018, 283–288.
234 Thomas 2018, 283–284.
235 Thomas 2018, 295–297.
236 Thomas 2018, 288–295.
237 Thomas 2018, 420–423, discussion.
238 Grabner et al. 2015, 301.
239 Perini 1987.
240 Morton 1962, 377.
241 Leuzinger 2002.
242 Grabner et al. 2015, 301.
243 Thomas 2018, 307–336.

dwellings – researchers have been able to determine, with some accuracy, which archaeological finds from Hallstatt can be attributed to special construction techniques and which finds fit well within the spectrum of tools used during this period, this opportunity to make comparisons does not exist for the Early Iron Age, given that, throughout Europe, almost no archaeological sites with adequately-preserved items made of organic material have so far been found.[244] The only exception are animal hide caps. Since these caps are often depicted on situlae, researchers concluded that they were in line with the period's fashion trends and therefore cannot be regarded as typical 'mine finds'.

Why did Hallstatt miners select or invent their very own variants of transport, extraction and safety measures? Why did they use raw materials that were unusual in those days? Did these special developments – fundamentally different from well-established tools and techniques used at the same time in the nearby copper mines – only arise due to the unique characteristics of this special deposit, or could there have been any other reason behind this independent approach? Some peculiarities of Hallstatt, including carrying sacks as well as filling troughs and scrapers, have very clear benefits and are improvements compared to other tools known to have been used in those days. By contrast, as far as picks and other mining utensils are concerned, we have no idea why Hallstatt miners used them instead of adapting the variants tried and tested in copper mining districts.

6.3.4. No Technology Transfer

Apart from the special developments conceived and implemented here at an extremely high level, Bronze Age mining in Hallstatt is fascinating because these solutions, some of which were perfect, were neither used to create innovation nor used by other mining operations.[245] As for the copper mines located in the Eastern Alps, intensive technology transfer must have taken place between the individual sites; there is no other way to explain the great similarities between the mines scattered from northern Italy to the eastern margin of the Alps. However, no technology transfer between copper miners and Hallstatt salt producers has so far been documented. It seems that technologies did not 'flow' in either direction, or, to be more precise, that no technology or knowledge transfer between salt and copper miners was possible or desired.[246] This is remarkable because an intensive exchange of materials between the mines can be assumed. While Hallstatt miners needed a great deal of copper for their tools, copper miners probably consumed large amounts of salt for preserving their food.

Although it is very likely that close economic ties were forged between salt and copper miners, only one item showing similarities with those found in copper mines has so far been encountered in Hallstatt: the bottom of a bucket, indicating a distant relationship to the bucket bottoms found in the Mitterberg mining district.[247]

Although the staircases, filling troughs, scrapers, and carrying sacks enabled the miners to work extremely efficiently and were used in Hallstatt for many decades or even centuries, it seems as if the knowledge about them lies buried in the depths of the mine.

One question that still has to be answered is why none of the Bronze Age inventions continued to be used in Iron Age mining in Hallstatt, even though the same mineral deposit was used in the Iron Age for ongoing salt extraction. No adoption of techniques or tools used in the Bronze Age by Iron Age miners can be observed. For this reason, it is surprising that some peculiarities specific to Hallstatt – including but not limited to filling troughs, and scrapers, the stew known as *'Ritschert'* and special boxes used for wood chips – are still alive and in use today. The latter clearly indicates that the people living in the region for almost three millennia passed their knowledge on to each next generation, engaging in continuous information transfer from the Iron Age until the present.[248]

7. Gaps in the Evidence

Thanks to Hallstatt's perfect preservation conditions and long-standing research tradition, we are able to describe many aspects of prehistoric mining down to a fine level of detail. In this chapter, we summarise the essential requirements for underground mining processes in order to identify gaps in evidence, and in order to direct research into areas that have so far been ignored, have not yet been recognised, or have not always taken centre stage.[249] This catalogue of requirements is intended to serve as a basic list of everything that can still be expected or still needs to be found, but has not yet been discovered.

In the years 1989 and 1990, Weisgerber wrote his outlines of a systematic science of mining for pre- and early history and Antiquity partly with the intention of creating a tool to find out what kinds of sites we should be looking

244 Reschreiter et al. 2014, 396.

245 Ottaway 2001.

246 Schreiber 2013, 57.

247 Thomas 2018, 307–336.

248 Reschreiter, Kowarik 2017, 440.

249 Reschreiter 2015a, 85.

for and what is still lacking.[250] Weisgerber divided his work into the following sections: prospecting the deposit, making the deposit accessible, mining the deposit, extraction, mine construction, moving personnel, transport of goods, drainage, ventilation, illumination, mine surveying, operational procedures/organisation, mining law, and ideology/religion. Unfortunately, the last four concepts were not explained in detail.

In his comprehensive guide on mining 'Vollständige Anleitung zur Bergbaukunst', Moritz Ferdinand Gaetzschmann – like Weisgerber – focuses not only on technical requirements, but also on framework conditions.[251] For Gaetzschmann, the following conditions had to be met for successful mining: adequate mining crew, various miners' tools, utensils and equipment, together with all the accessories and constructions needed for transport, drainage and ventilation, wages, maintenance, mine construction, the construction of buildings above ground, the purchase of premises, remuneration and taxes, general costs, unforeseen expenses, the construction of roads, bridges and dwellings for workers, officials, warehouses as well as hydraulic constructions.

In 1932, Karl Zschocke and Ernst Preuschen approached Bronze Age copper mining which took place in the Mitterberg mining district by calculating the operating costs of these processes. According to the researchers, the following processes were required for mining by setting fires: gathering and preparing firewood, maintaining a water supply during the day and at night, fireguards, drifting, extraction, trench construction, trench maintenance, transport of mined material to the sorting floors, backfilling, the repair and manufacture of miners' tools and transport containers, etc., preparation of timber and lighting tapers, and much more.[252]

Likewise, Thomas Stöllner repeatedly gives us very detailed information about the organisation and structure of mining operations. Apart from activities taking place in the mine, Stöllner highlights the importance of supply, trade, markets and knowledge transfer.[253] Likewise, Jan Cierny draws our attention to markets as well as economic and political framework conditions.[254]

Thanks to the research done over the last few decades, we have extensive knowledge about the following areas in Hallstatt: gaining access to mineral deposits, mining the deposits, extraction, mining technology, mine construction, moving personnel, ventilation, illumination and organisation.

The works by Weisgerber, Gaetzschmann, Zschocke and Preuschen, Stöllner and Cierny make it clear that, despite the processes revealed from the items found in Hallstatt and shown in the illustration of the mine, many aspects of salt mining have not yet been adequately considered. Also, the essential requirements for underground mining have not yet been satisfactorily described for Hallstatt. For example, much information is lacking about transport (see 4.2), drainage and mine surveying.

7.1. Drainage

The hydraulic constructions mentioned by Gaetzschmann continue to be a fundamental prerequisite for mining in the Salzberg valley today. Great efforts are made to effectively discharge surface waters, preventing them from infiltrating and damaging the Hallstatt salt mines.

Weisgerber assumes that measures to keep the water away from the underground structure and to discharge it systematically from the mine were not required before Roman times.[255] In any case, however, due to the special topography and geological situation of the Hallstatt region, miners were faced with the problem of surface water infiltration right from the start of mining.[256] It is still completely unknown how the corresponding structural solutions and the discharge of surface waters were organised. Most of the mine water arises in near surface strata, where no prehistoric mine openings are known. We can assume that those responsible for discharging waters or removing infiltrated waters proceeded very carefully and meticulously, given that these waters, would have caused tremendous damage if they had penetrated further into the underground structure of the mine, due to the solubility of this structure. In the Mitterberg area, special buckets made of wood have been linked to this kind of drainage.[257] However, no tool or container whatsoever that could have been linked to drainage has so far been encountered in Hallstatt.

Multiple major disasters, triggered by landslides, can be identified from prehistoric mine openings. Nevertheless, no indications of major amounts of infiltrated surface waters have so far been encountered, except for the Bronze Age site of Grünerwerk. This leads us to believe that, as early as in prehistoric times, people were successful in their attempts to control surface waters.

250 Weisgerber 1989, 190. – Weisgerber 1990.

251 Gaetzschmann 1866, 512–513.

252 Zschocke, Preuschen 1932, 55.

253 Stöllner 2003, 428. – Stöllner 2006. – Stöllner et al. 2016.

254 Cierny 2003.

255 Weisgerber 1990, 11.

256 Unterberger 2009, 89, 91.

257 Thomas 2018, 307–336.

7.2. Surveying the Mine

The mining gallery examined at the Christian von Tuschwerk site seems as if designed on the drawing board, showing almost horizontal floors and separated from the neighbouring mining galleries only by narrow cranches (see 3.2). The low suspension height as well as the sequence of galleries suggest that a very precise knowledge of geology and static conditions existed.[258] Accurate surveying is very helpful for constructing a thoroughly planned mine like this one. Several finds and features indicate that highly-technical, three-dimensional surveying took place in the Mitterberg area.[259] By contrast, no such surveying equipment has so far been identified in Hallstatt.

7.3. Mining Law

In medieval mining, legal certainty is of the utmost importance and hence is discussed extensively in numerous mining textbooks – e.g. in the Mining Book of Schwaz, known as the Schwazer Bergbuch in German. So far, researchers have not fully examined whether any kind of mining law could have existed in the Bronze Age and, if so, how it was interpreted. However, the numerous smelting sites and mining districts which co-exist in the Mitterberg area extremely close to one another suggest that certain laws regulating the use of resources were in place.[260] In Bronze Age Hallstatt, multiple mining operations – some of which used completely different tools and techniques – seem to have been run at the same time.[261] It seems that each of these operations imposed different requirements on its tools and its different suppliers. Likewise, in the Early Iron Age, the large enterprises of Hallstatt and Hallein were run in parallel for several centuries. For a very long time, we have struggled to find out how it was possible for completely diverging producers to co-exist in spite of being so close to each other. Not only did the tools used in Hallstatt and Hallein lack any similarity – the space between the two mining sites was devoid of finds, too. This suggests that the sites were not in direct contact with each other. Were both areas supplying Hallstatt and Hallein and the sales areas distributed between the two enterprises? If so, how was this distribution or segregation regulated?

7.4. Ideology and Religion

In the Eastern Alps, underground miners still pray to their saints, asking them for protection, even today. No tunnel or mine is constructed without a statue or statuette of Saint Barbara, and even for subway tunnels, this patron saint is called upon. Likewise, for prehistoric mining in the Alps, we can assume that miners performed religious acts in order to receive the help of higher beings. Whereas in the Urnfield period, hundreds of kilograms of bronze were buried in the soil in the surroundings of Hallstatt, accounting for the emergence of one of the densest sacrificial or 'deposition' landscapes of Europe, there is not a single piece of evidence of religious acts taking place in the Hallstatt mines. Did the miners perform such acts above ground before descending into the mine so that it is devoid of any depositions, or have we failed to recognise the traces left by these acts in the mine so far? The accumulation of whole bronze objects at the Iron Age site of Josef Ritschnerwerk Sinkwerksebentel, discovered in the late 19th century, is the only find that might be interpreted as a deposition. Unfortunately, no specific information is available for this feature.[262] Stöllner assumes that, in the Mitterberg area, tools were deliberately left behind and deposited in tunnels and galleries.[263]

7.5. Adequate Mining Crew and Knowledge Transfer

Sufficient and adequately trained staff is a fundamental requirement for underground mining operations. To ensure this, a continuous supply of workforce is needed.[264] The demographic structure of the Early Iron Age burial ground as well as the marks of wear visible on skeletons suggest that the new workforce was taken from within the workers' own ranks.

Given that no technology transfer between Hallstatt and other mining operations occurred, it can be assumed that specialists – likely to have been in place in other mines and responsible for spreading technologies from one mine to another – were not required for the existence and survival of Hallstatt.[265] It rather seems that Hallstatt 'managers' trained their staff on their own, sharing their specialised knowledge with members of their own group only. At least in the Iron Age, the presence of very young children in the mine seems to have ensured that the next generation acquired the skills and knowledge for their work as miners from an early age. The continuity of food and technologies observed for the region, lasting from the Early Iron Age until today, suggests that this kind of internal information sharing worked well for millennia.[266]

258 Unterberger 2009, 91.
259 Thomas 2018, 172–184.
260 Stöllner 2015, 183.
261 Stadler 1999, 79.
262 Barth 1970–2019.
263 Stöllner et al. 2006, 105.
264 Cierny 2003.
265 Stöllner 2006, 118.
266 Reschreiter, Kowarik 2017, 440.

The technological differences between Bronze Age Hallstatt mining and copper mining which took place at the same time suggest that in the Bronze Age, Hallstatt 'managers' also trained their staff on their own, passing their knowledge about the deposit and the special requirements of Alpine salt mining on from generation to generation.[267]

7.6. Buildings and Other Above-Ground Infrastructure

Large parts of the Salzberg Valley's surface are now covered with masses of rubble due to ancient landslides which interrupted prehistoric mining activity several times. As for Bronze Age and Early Iron Age features, most of them are buried by several metres of this material and are therefore largely unknown. For this reason, features like those found in the Ramsau Valley at the Dürrnberg Mountain have not yet been encountered at Hallstatt in the Salzberg Valley.[268]

7.6.1. Dwellings and Workshops

No miners' accommodation has been found so far in the Salzberg Valley. According to Nikulka, Hallstatt was one of the largest Iron Age settlements in central Europe.[269] We can therefore assume that a village of considerable size existed on Hallstatt's Salzberg Mountain. However, so far, we have failed to find out where exactly this village was located.

Repairing and replacing equipment and tools are absolutely vital for successful mining.[270] The infrastructure required for this purpose has not yet been discovered in Hallstatt, whereas, in the Ramsau Valley at the Dürrnberg Mountain, workshops for woodworking have been proven to have existed.[271] It is possible that part of the equipment and tools needed was manufactured in Hallstatt, but it cannot be excluded that these resources were delivered to the Salzberg Valley. It seems that only bronze picks had to be manufactured directly on site, given that their tips had to be re-sharpened frequently during a shift.[272] The resulting loss of material might have led to an ongoing demand for new picks – for this reason, we assume that a large casting workshop was run on the Salzberg Mountain. Likewise, for the Karnab tin mines in Uzbekistan – which are only a little older than the Hallstatt salt mines – it can be demonstrated that the stone hammers needed were delivered as blanks, before being completed locally in large numbers.[273]

Lighting tapers were the most important resource in prehistoric Alpine mining and, as such, were consumed in large numbers. Lobisser postulates that a dedicated taper manufactory for the Dürrnberg mine was run in the Ramsau Valley. He argues that residues of lighting taper manufacture were identified among the finds.[274] However, since these residues were burnt and used as lighting tapers, only the use of residues of manufacture in the Ramsau Valley seems to be proven – but not the manufacture of lighting tapers themselves.

7.6.2. Roads, Bridges, Reloading Points, Rest Areas

Based on archaeological site maps, routes leading from and to Hallstatt can be reconstructed very well, both for the Bronze Age and the Early Iron Age.[275]

For the Iron Age, owing to the enormous size of the mining galleries – about 200 m × 20 m – and the short running time of just 100 years, daily production averages of 1000 kg per mining gallery are realistic. Converted to a carrying capacity of 10 kg, e.g., in the case of pack goats, this results in a minimum of 100 goats, leaving the Salzberg Valley every day after having been loaded with salt sacks.[276] Vladimir Salač repeatedly makes us aware of the intensive structures and resources required for long-distance trade.[277]

In addition to the long-range transport of salt away from the valley, we can assume that supply of the miners with equipment also took place on a large scale. Essential components of the underground mining process include not only the movement of persons, transport of goods, and maintaining drainage and ventilation, but also the provision of the right equipment in sufficient quantity. Mining operations can only run smoothly and efficiently with a reliable supply of equipment. Stöllner goes into a high level of detail here, showing which structures might have been established.[278] The Mining Book of Schwaz, dating from the year 1556, clearly shows us that lacking or overpriced equipment can ruin a mining operation.[279]

Apart from mining equipment, the mining community also had to be supplied with food. Evidence from paleofaeces indicates that millet, barley and beans have been reliably available for many centuries.

267 Unterberger 2009.
268 Lobisser 2005.
269 Nikulka 2016, 246 and Tab. 18.
270 Weisgerber 1989, 199.
271 Lobisser 2017, 387–400.
272 Reschreiter et al. 2018b, 63.
273 Garner 2013, 151.
274 Lobisser 2017, 290–291.
275 Kowarik et al. 2017.
276 Bacher in press.
277 Salač 2002. – Salač 2013.
278 Stöllner 2006.
279 Cierny 2003.

Researchers have not yet fully examined which roads, fords, bridges, reloading points, rest areas and other infrastructure were in place or required for the large-scale and long-range transport from and to Hallstatt. Likewise, the quality of these routes and other structures is still unclear – as is the question of who was responsible for maintaining them. The large volumes shown to have been transported, however, suggest that very well-developed structures were in place and that people of these times deployed adequate efforts to maintain this network and to provide the carriers and/or pack animals as well as the rowers of boats with sufficient food.

7.6.3. Warehouses

In the case of an average daily production of 1000 kg, large storage facilities for the salt to be transported away from the valley had to be in place. Researchers have not yet answered the question whether the salt extracted from the mine was handed over for transport directly at the mine site or was brought down to the lake. In any case, warehouses must have existed at or near the places where the salt was handed over.[280]

7.7. 'Unforeseen Expenses'

Mining activities in Hallstatt were interrupted by vast natural disasters (landslides) in the Bronze Age as well as in the Early Iron Age. During the Bronze Age, it was not long after such an event before a new mining operation was started in a nearby district. Even the massive landslide disaster in the Early Iron Age did not lead to the operation being abandoned or to the miners moving to the Dürrnberg mine near Hallein. Instead, people built a new settlement in the swamp area known as 'Dammwiese' and relaunched their operation from there. Apparently, the miners managed to cope with these disasters. They were able to overcome what Gaetzschmann calls 'unforeseen expenses', to consolidate their efforts, relaunch their operation time and again, and to survive through long non-productive periods.[281]

The question of whether such barren spells were bridged by the Hallstatt community itself, or with the help of surrounding regions – whose inhabitants relied on the precious goods from Hallstatt –, or perhaps through good relations with neighbouring regions and/or through other structures cannot yet be answered.

8. Summary

A survey of various characteristics of the Bronze Age mines at Hallstatt reveals even more clearly than has been assumed up to now exactly how independent-minded Hallstatt miners were, not only in the area of mining technology but also in terms of organisation, resource management, tool use and the implementation of equipment, Bronze Age miners operated differently from their contemporaries, the copper miners, and from their successors, the Iron Age miners. The miners of the Bronze Age developed their own solutions for almost all of the challenges associated with underground construction. They invented their own tools, used transport equipment that has no equal for its time anywhere in the world, and wove bast ropes in thicknesses that are not found elsewhere in middle-European archaeology.

Despite large numbers of prehistoric finds within the Hallstatt site, there is no proof for the use of tools or equipment from the nearby copper mines. On the contrary, there is no indication that the Hallstatt miners adopted inventions from other groups of miners or other 'average Joe' workers, although modern experiments with replicas show that such tools would have been very efficient in the Hallstatt context. From that information it has been concluded that no technology transfer took place between the copper and salt mines.

Hallstatt mining technology is also unusual for the time. The proportions of the mining shafts and the size of the mining galleries exceed anything found in the copper mines from that same period. However, it is not the case that the Hallstatt miners developed their own ways of doing things due to isolation; it would be wrong to assume that in the narrow Salzberg Valley they were cut off from the flow of information from elsewhere. Hallstatt was, on the contrary, very much aware of larger trends in both the Bronze and Iron Ages. Prehistoric technological innovations, such as those coming out of textile production, could easily be found there. The economic network in which the mines were embedded must have been very stable and wide-reaching.

The equipment used in the Bronze Age mines was apparently, for the most part, mass-produced. Tools and equipment were distributed generously. If they broke or were worn out, they were discarded. Very seldom are examples of repaired equipment or tools found. The Iron Age production of salt ran completely contrary to this trend. It can be proven that intensive recycling took place in the Iron Age. Certain steps in the work process were even carried out exclusively using recycled materials. Despite the apparently

280 Bacher in press.

281 Gaetzschmann 1866, 512–513.

wasteful usage of work materials during Bronze Age mining, one can recognise a very clear set of purposes for the tools and equipment used, which was narrow and specific, and only tolerated slight deviations.

Bronze Age mining was interrupted by a natural catastrophe. When mining was resumed, it was with a fundamentally different set of techniques and equipment. Even the lighting tapers from this later era are of another shape. We see a completely new structure for the production of salt emerge in the Early Iron Age. Resource management and the methods and habits of waste disposal are different in every way from their Bronze Age predecessors. Likewise, the spatial organisation of salt extraction within mining galleries is different from how it was before. To date, there are no conclusive answers to explain why the differences between Bronze and Iron Age mining processes are so extreme. The wide cleft between the two ages is especially surprising in view of the fact that during both periods, work was done in the same mineral deposits and workers were faced with the same technical challenges. Even though it is possible to portray Bronze Age mining in fine detail in the illustration, and even though a sweeping array of work processes within the mine are understood, a comparison with other, typical examples of underground construction of the time shows that there are many open questions which remain unanswered. Of high importance to future research are the stable supply network surrounding Hallstatt, which both provided for the demands of the mine and served to distribute salt, and the infrastructure for this network as well as its impact on the surrounding landscape. To date we possess only rudimentary knowledge of the structures right near the mine which were so important to its functioning. Part of our knowledge of them can be improved indirectly, through analysis of existing environmental archives. The work presented here can be considered the cornerstone which has been laid, and which will, in the future, assist us not only in gaining a better understanding of the Hallstatt system as a whole, but in closing specific gaps in our knowledge through targeted research.

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Hans Reschreiter
Department of Prehistory
Natural History Museum
Burgring 7
1010 Vienna
Austria
hans.reschreiter@nhm-wien.ac.at
orcid.org/0000-0003-0337-5660

Kerstin Kowarik
Department of Prehistory
Natural History Museum
Burgring 7
1010 Vienna
Austria
kerstin.kowarik@nhm-wien.ac.at
orcid.org/0000-0003-0497-3419