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Stone Tools from Prehistoric Mining Sites in North Tyrol, Austria: Typology – Terminology – Material Properties

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Keywords
Prehistoric copper mining, stone tools, typology, terminology, ore beneficiation

Abstract

Mining archaeological field prospections and excavations conducted by the Research Center HiMAT at the University of Innsbruck yielded proof of extensive copper ore mining from the late Middle Bronze Age to the Early Iron Age (1300 - 700 BC) in the mining regions of Kitzbühel-Jochberg and Schwaz-Brixlegg in Northern Tyrol. This paper deals with stone tools collected at prehistoric mining sites and focusses on their typology, material properties and the problem of terminology. Petrographic analyses show a conscious selection of special stone materials for different applications. Typically, hard and tough metamorphic rocks collected from river gravel banks or glacial deposits of alpine valleys were used as raw materials for tool production. In general, well-rounded pebbles and boulders of amphibolite, garnet-amphibolite and eclogite were the preferred rock type used for percussion tools. According to the archaeological evidence, such stone tools were mostly used in the ore beneficiation process (crushing, to some extend also grinding) and have only rarely been found in connection with underground mining activities. For further beneficiation processes (grinding), other properties of the stone material such as abrasive capacity were required. In this context, boulders of orthogneiss/gneiss were the favoured rock material for netherstones (anvil stones and lower grindstones) and upper grindstones. The investigation of hafting modifications visible on stone tools shows that several hafting methods can be discussed, and that cords from plant fibres as well as straps of animal skin/leather could have been used for this purpose. Analysis of traces of wear provide information on the former function of the stone tools as well as on their practical application.

Introduction

This study was conducted within the framework of the Research Center HiMAT (the History of Mining Activities in the Tyrol and adjacent areas - impact on environment and human societies) at the University of Innsbruck. It is based on the investigation of stone tools collected during mining archaeological prospections and excavations carried out in the context of the project "Prehistoric copper production in the Eastern and Central Alps - technical, social and economic dynamics in space and time", funded by the Austrian Science Fund FWF[1]. During the Bronze Age and the Early Iron Age the mining districts of Schwaz-Brixlegg and Kitzbühel-Jochberg were of great economic importance for the copper supply not only of the Eastern Alpine region but also of the wider parts of Central Europe to the north. The mining district of Schwaz-Brixlegg is located in the Lower Inn Valley between the two eponymous towns of Schwaz in the west and Brixlegg in the east, whereas the district of Kitzbühel-Jochberg is located in the very east of the province of North Tyrol, near the border to the province of Salzburg. While in the Schwaz-Brixlegg mining district primarly fahlore was mined for the copper production, chalcopyrite was the predominant raw material in the well-known Mitterberg area in Salzburg as well as in the Kitzbühel-Jochberg mining district (Stöllner, 2009, pp.54-56).

In order to better understand the processes of ore extraction and beneficiation, the supposedly simple technological complex, such as those of the stone tools used, must be thoroughly investigated. It can be assumed that not only the type of ore mined had an influence on the form and function of the stone tools used, but also the kind of rock (gangue) in which the ore occurs. For example, it can be assumed that different tools were used for

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mining fahlore, which is mainly found in the “Schwazer Dolomit”, than for chalcopyrite, which is found in schist rock. While in the hard dolomite the fire-setting method was used for mining (Goldenberg and Rieser, 2004, p.39), in the weaker schist bronze socketed picks were used (Stöllner, et. al., 2016, p.78). In both cases, however, the same stone tool forms were used for the beneficiation of the ore, including mallets, hammerstones, anvil stones and grindstones.

Studies on stone tools from the area under consideration have so far only appeared as by-products of mining archaeological investigations (Goldenberg, 2013; 2014; Klaunzer, et. al., 2009; Staudt, Goldenberg and Scherer-Windisch, 2017; Staudt, et. al., 2019a). Since a systematic and holistic study of these artefacts from North Tyrolean prehistoric mining districts has not been carried out so far, this work aims at compiling all observed features as well as at thus-based categorisation and interpretation. Existing regional typologies (Rieser, 2000, pp.85-88; Rieser and Schrattenthaler, 2002, pp.69–70; 2004, p.81) are included and discussed, as are relevant mineralogical and petrographical aspects.

For this study, a total of 251 stone tools have been investigated, whereby almost all of them were categorized, photographed and drawn by the authors, who also obtained statistical data for later analyses. 158 pieces originate from systematic excavations and can thus be stratigraphically assigned, while 93 pieces represent stray finds. 79 % (199 pieces) of the stone tool assemblage originate from the Schwaz-Brixlegg mining district, 15 % (37 pieces) from the Kitzbühel/Jochberg district and 6 % (15 pieces) from various other sites in North Tyrol.

Most of the stone tools from the Schwaz-Brixlegg area originate from ore processing sites (115 pieces), while 43 pieces come from smelting sites and 25 pieces from underground mines (Table 1). However, 16 tools from the Schwaz-Brixlegg mining district could not be assigned to a specific find context (stray finds). It should be noted, however, that the differentiation between actual mining and processing sites can often be problematic, as the extracted material was often separated directly at the entrance of a pit/underground mine. Regarding the Schwaz-Brixlegg processing sites (Staudt, et al., 2018b; 2019a), those from the plateau at the Blutskopf (44 pieces) and the Weißer Schrofen (66 pieces) were the ones that yielded the largest number of stone tools, while among the processing sites in Jochberg (Staudt, et al., 2020; 2022), the site at the Schusterkogel was represented with 18 pieces and the Wild-Hochalm with 16 pieces. While no new smelting sites were excavated in the Kitzbühel area, a smelting site with a total of 43 stone tools was discovered with the Rotholz site (Staudt, et al., 2017;

Table 1: Different tool classes and their corresponding distribution according to finding sites and areas. Sites marked in yellow represent underground mining areas, red sites represent mining/ore processing areas and blue sites represent smelting sites.

Mining district	Location	Cat. A: Tools with hafting modifications (mallets)	Cat. B: Hand-held tools (hammer-stones)	Cat. C: Netherstones (anvil stones, lower grind-stones)	Cat. D: Tools with hafting modifications (Eastern Alpine upper grindstones)	Cat. E: Abraders and polishers	Multi-purpose tools	Unclas-sificable	**Total**
Schwaz-Brixlegg	Bauernzeche*	4	2	1		1		10	**18**
	Blutskopf Gut Wetter Bau*	1	1						**2**
	Blutskopf Plateau**	6	5	1				32	**44**
	Gratlspitz**	1	1					3	**5**
	Grattenbergl		1	1				1	**3**
	Moossschrofen*							5	**5**
	Rotholz***	2	2	8	1	1		29	**43**
	Weißer Schrofen**	18	5					43	**66**
	Other	5	1	1				6	**13**
Kitzbühel-Jochberg	Wild-Hochalm**		2	3	6		5		**16**
	Schlaberstatt**		2				1		**3**
	Schusterkogel**		5	3	2		3	5	**18**
Other		4	4	1		1	2	3	**15**
Total		**41**	**31**	**19**	**9**	**3**	**11**	**137**	**251**

*= underground mining area; **= mining/ore processing area; ***= smelting sites

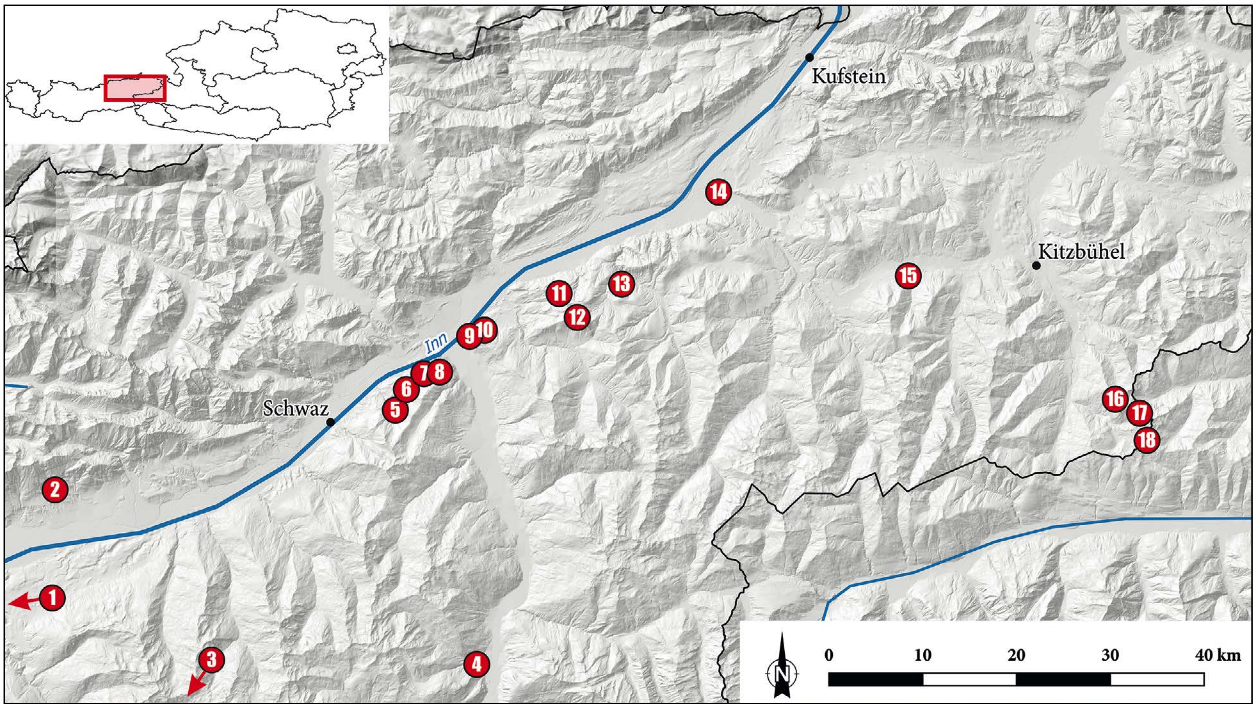


Figure 1. Find locations of the artefacts presented in this work: 1: Rotenstein (Serfaus); 2: Kiechlberg (Thaur); 3: Knappenkuchl (Navis); 4: Kleinschwendberg (Schwendau); **Schwaz-Brixlegg district**: 5: Blutskopf; 6: Obertroi; 7: Rotholz; 8: Schrofen; 9: Kleinkogel; 10: Bauernzeche; 11: Moosschrofen; 12: Gratlspitz; 13: Mauken; 14: Grattenbergl; **Kitzbühel-Jochberg district**: 15: Götschen (Brixen im Thale); 16: Wild-Hochalm; 17: Schusterkogel; 18: Schlaberstatt. Graphics: R. Lamprecht.

2018a; 2019) in Schwaz-Brixlegg. Underground excavations could only be investigated in the Schwaz-Brixlegg area, whereby the very large mining site at the Bauernzeche (Staudt, et al., 2019a) yielded a total of only 18 stone tools, while little or no stone tools were found at other underground excavations.

In the Schwaz-Brixlegg area (Figure 1, 5–13), first evidence of small scale copper metallurgy and possibly copper extraction from local fahlore-group minerals is known from the Neolithic period (Bartelheim, 2002; Huijsmans, Krauß and Stibich, 2004; Huijsmans and Krauß, 1993; 1998; 2006; Huijsmans and Krauß, 2015; Tomedi, Töchterle and Staudt, 2013). Three main phases of fahlore mining can be identified for the Early Bronze Age (phase 1, 22nd to 19th century BC), the Late Bronze Age and the Early Iron Age (phase 2, 12th to 7th century BC) as well as Late Medieval and Early Modern times (phase 3, 15th and 16th century AD). While in the prehistoric phases 1 and 2 mining was entirely focused on copper production, the focus shifted to silver extraction during the youngest phase 3 (Goldenberg, 2013, p.89). In contrast to the fahlore district in the Lower Inn Valley, chalcopyrite deposits dominated the mining district of Kitzbühel-Jochberg. In this district, prehistoric copper production was flourishing at the end of the Middle Bronze Age/beginning of the Late Bronze Age (14th/13th century BC) with the well-known mining hotspot of Kelchalm, presented in detail by Ernst Preuschen and Richard Pittioni (Preuschen and Pittioni, 1939; 1954; Pittioni, 1943). These mines were again exploited in the Early Modern Age (16th century AD and in the 19th/20th century AD). It is only in recent years that further extensive prehistoric mining areas have been discovered in Jochberg by archaeological prospections, whereby a large number of stone tools was found (Figure 1, 16–18) (Staudt, et. al., 2020; 2022).

The history of the research of stone tools from mining contexts in the Eastern Alps

One of the first descriptions of cobble stone artefacts from the Eastern Alps was presented by Matthäus Much, who already recognized them as mining tools in the 19th century AD (Much, 1879, p.CXLVII). His studies included finds from the famous prehistoric mining sites at the Mitterberg near Bischofshofen and the Kelchalm at Aurach in the Kitzbühel mining district (Much, 1895, 1902). At the beginning of the 20th century, several stone tools from the Mitterberg district and other areas of the province of Salzburg were presented by Georg Kyrle and Olivier Klose (1918), followed by the investigations by Karl Zschocke and Ernst Preuschen (1932). Unfortunately, due to the extent of their work and the extremely broad material basis, stone tools were described in an unspecific way. Later Preuschen and Pittioni maintained

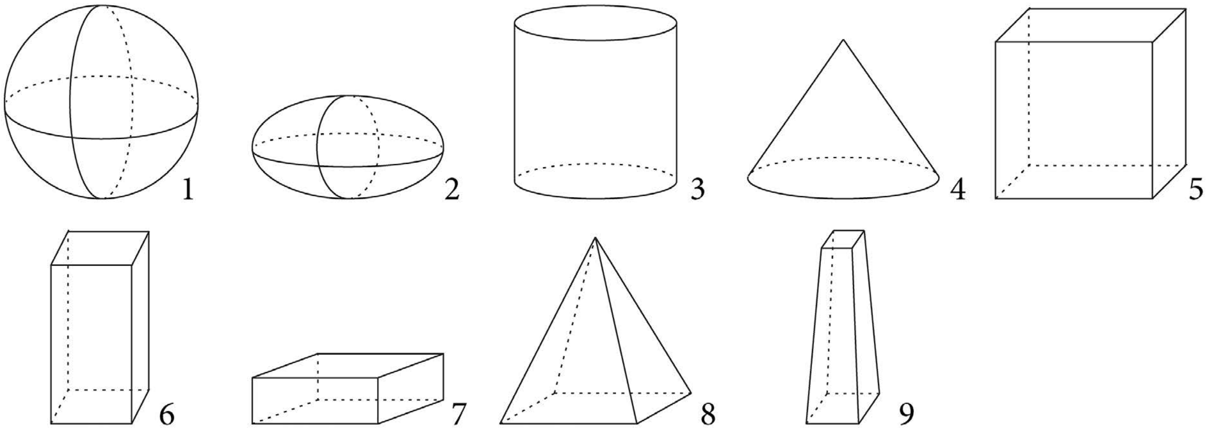


Figure 2. Basic geometric shapes that can be used to describe stone mining tools: 1: Sphere; 2: Ellipsoid; 3: Cylinder; 4: Cone; 5: Cube; 6: Cuboid; 7: Platy cuboid; 8: Pyramid; 9: Wedge. Graphics: R. Lamprecht.

an intensive and very productive collaboration, which is demonstrated, amongst many others, by their works on the Kelchalm (Pittioni, 1943; Preuschen and Pittioni, 1939; 1954; 1955). Now stone tools represented an integral part of their archaeological finds and were included into the discussion. The first attempts of categorisation focussed on dividing the tools into three categories: upper grindstones ("Läufer"), netherstones ("Unterlagsplatten") and hammerstones ("Klopfsteine") (Preuschen and Pittioni, 1954, p.80). Research on the Mitterberg was later expanded by Clemens Eibner (Eibner, 1972; 1974) and more recently by Thomas Stöllner (Stöllner, et. al., 2009; Stöllner, 2015).

Systematic archaeological research in the prehistoric mining districts at Schwaz-Brixlegg began only in the 1990ies. Before, initial works in the field of geology (Gstrein, 1978; 1981; Pirkl, 1961; Vohryzka, 1968) and historical research (Isser von Gaudententhurm, 1905; Srbik, 1929) addressed the possibility of prehistoric mining, but had not yet explicitly proven it. The research activities of the 1990ies could confirm for the first time a fundamental evidence of prehistoric fahlore mining in the Schwaz-Brixlegg mining district (Goldenberg, 1998; Goldenberg and Rieser, 2004; Rieser, 2000; Rieser and Schrattenthaler, 1998/99; 2002; 2004).

Typology and terminology of stone tools from mining contexts

Stone tools were used in many aspects of mining. It can be assumed that stone tools were mainly used in ore processing for separation (mallets, hammerstones and anvil stones) and ore grinding (lower and upper grindstones) (Eibner, 1982, p.403, Fig.2). Hafted tools like mallets could be used for crushing extraction or for loosening rock slabs which remained on the extraction surface as a result of the fire-setting process (Goldenberg, 2013, p.101; Rieser and Schrattenthaler, 2002, p.108). In addition, hammerstones could be used for the crushing extraction, even though they are probably less efficient than hafted types. For the first coarse ore separation, both above-mentioned categories of equipment could be used, whereby a netherstone (anvil stone) was additionally required for this purpose. After the coarse separation, a finer separation could take place. This was done with various grinding stones and corresponding upper grindstones (Eastern Alpine upper grindstones; Eibner, 1982, pp.402-404). For the maintenance of stone tools, pecking stones were used, which can hardly be distinguished from hammerstones, and for the repair of metal tools, abraders and polishers were used.

Terminological problems have so far rarely been addressed when working on stone tool assemblages from mining contexts. Usually, the authors for the district under consideration propose individual typologies and terminologies. Although common terms such as "grooved" or "notched hammerstone" or "mallet" are generally used for a specific type of tool, these terms are not appropriate for an exact typological characterisation.

For the Mitterberg area, the function-oriented typology and the associated terminology presented by Alexander Maass is relevant (Stöllner, et. al., 2012, pp.125-128), although a systematic classification had already been established earlier (Gale, 1991; Gale and Ottaway, 1990). In a similar manner, Rieser and Schrattenthaler proposed a typology of stone tools from the Schwaz-Brixlegg area (first published in Rieser and Schrattenthaler, 1998/99, p.153). They distinguished five categories of tools, based on their hafting modifications on the one hand and their intended purpose on the other. This categorisation must be questioned, however, because the mixture of two dif-

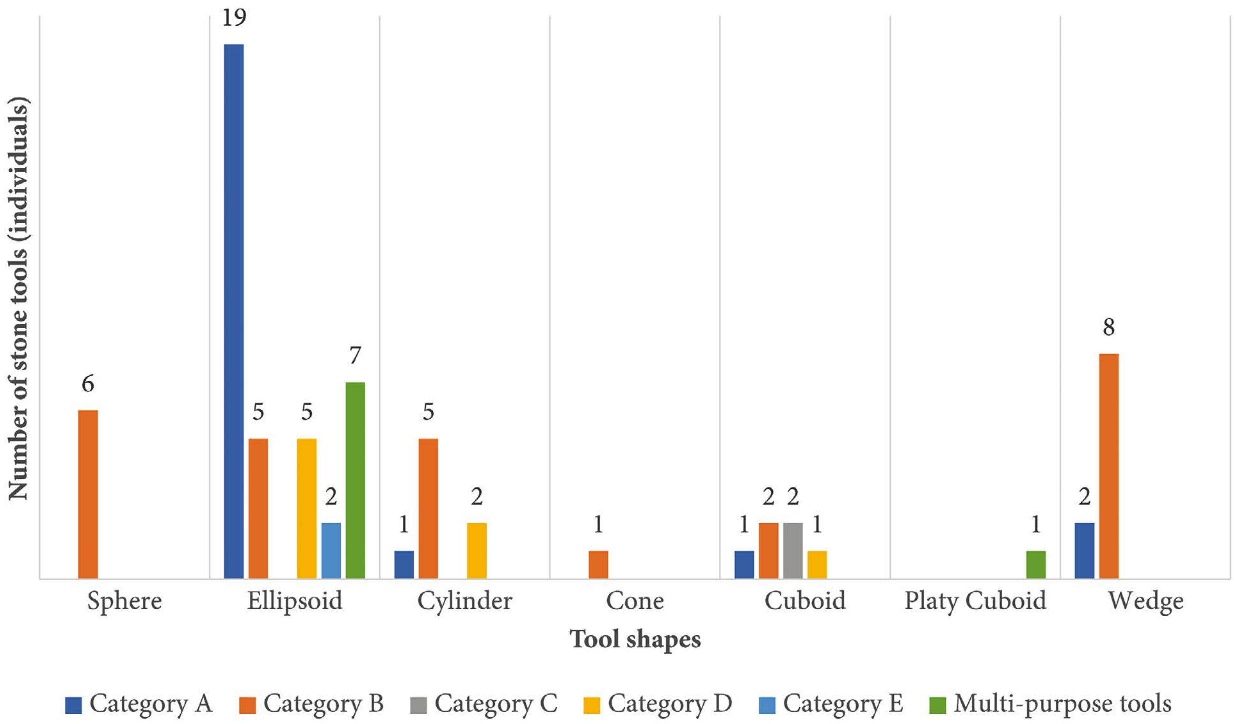


Figure 3. Categories of stone tools in relation to the basic geometric shapes. For this statistic, only "individuals" (>50 % preserved) have been used. Graphics: R. Lamprecht.

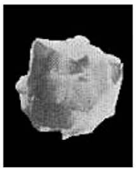
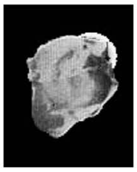
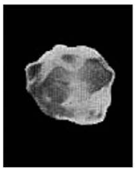
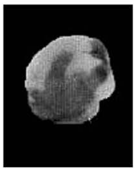
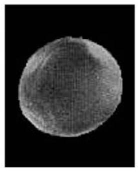
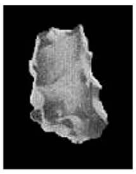
ferent approaches creates inconsistency of nomenclature. Both approaches must therefore not be mixed up, as is the case here.

In contrast to the German language, the English language allows for simplifying the terminology of stone tools, as can be seen in general works on prehistoric mining in the British Isles (Pickin, 1990). However, even in English terminologies are not free of confusion, and Simon Timberlake rightly states that surprisingly there is no standardization so far of the functional analysis and terminology of stone tools (Timberlake and Craddock, 2013, p.39). As a conclusion, Timberlake suggests calling all such tools "cobble stone mining tools", which seems likely the best way to describe them[2].

Tool shape and weight

An appropriate way of describing a tool's shape is by comparing it to certain geometric shapes. For our pur-

Figure 4. Roundness scale for sedimentary particles based on Powers (1953) (doi: https://doi.org/10.1306/D4269567-2B26-11D7-8648000102C1865D; modified by R. Lamprecht).

hohe Sphärizität	high sphericity						
niedrige Sphärizität	low sphericity						
Powers 1953		very angular	angular	sub-angular	sub-rounded	rounded	well-rounded
Translation ***Übersetzung***		*sehr kantig*	*kantig*	*wenig kantig*	*wenig gerundet*	*gerundet*	*gut gerundet*

pose, nine defined geometric shapes are considered, one of which is of particular importance for describing stone tools: the ellipsoid shape (Figure 2, 2). Hand-held smoothing and polishing stones (category E), which were usually made of ellipsoidal pebbles or fist-sized rocks, are among the smallest tools used in prehistoric mining contexts. Similar shapes were preferred for hammerstones (category B), despite the fact that almost spherical geometries occur only with hammerstones that were heavily worn on all sides (Hahn, 1991, p.296, Fig.91). Ellipsoid shapes again predominate among the mallets (category A).

Apart of suitable material properties such as the hardness and toughness of the selected rock, the density/specific weight of the rock material was an important factor especially for crushing purposes. It is remarkable that the side where the haft met the stone is usually the flattest part of the mallet, which is surely not coincidental[3]. Furthermore, upper grindstones (category D) were mainly made from larger ellipsoid and cylindrical cobbles. Weight, size and hardness of the rock material were of prime importance as well as the shape for hafting and a flat surface for the grinding process. Most likely, cobbles with at least one flat surface were chosen for the production of upper grindstones (category D), in order to save effort while preparing the surface needed for the grinding process by pecking. As for the netherstones (category C), shape may have played a minor role, but again flat working surfaces were of importance, which is why cuboid shapes were well-suited for this purpose.

In general, it can be observed that for some categories (especially category B) raw material in any shape was used for the production of stone tools (Figure 3).

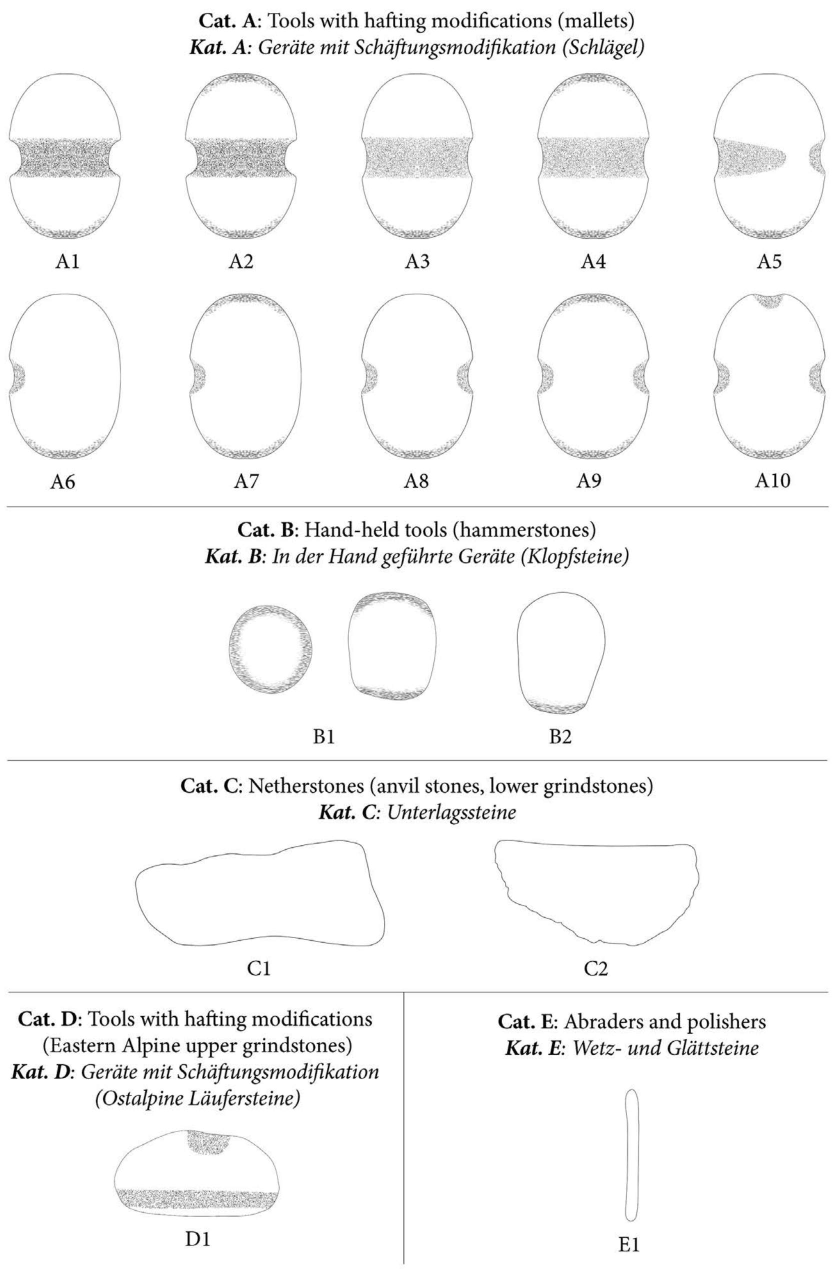


Figure 5. Classification and typology scheme for the material presented. Graphics: R. Lamprecht.

The selection of material is therefore more related to the intended use and the rock properties than to the physical form of the cobble. However, for category A and C specific shapes were preferred. Regarding tool weights, it could be noted that more attention was paid to the selection of raw material than to a uniform weight within different tool categories, which also means that no size and weight groupings were evident.

To describe the roundness of a tool, an adapted version of the scale by Maurice Cary Powers (1953, p.118) was used (Figure 4). Alternatively, the Krumbein scale (Krumbein, 1941) can also be used as suggested by Timberlake and Craddock (2013, p.59). The Krumbein scale, however, seems to be less useful because it only includes the degree of rounding and does not distinguish between initial shapes of cobbles with low and high sphericity.

Classification

Existing classifications offer a large degree of diversification, regardless of the language in which they are used. Problems with appropriate translations may contribute to a certain degree of confusion. The first basic classifications go back to the beginning of prehistoric mining research in the eastern alps in the 19th century, whereby it was already assumed that stone tools were mainly used for ore beneficiation (Much, 1879, p.XXV). In the following, existing classifications will be discussed, and a new classification will be presented[4]. As mentioned earlier, it is likely that the mallets, hammerstones, netherstones and Eastern Alpine upper grindstones can be attributed to the various steps of ore beneficiation, while abraders and polishers can be attributed to tool maintenance. Based on these functional associations, an initial general categorisation is proposed, deliberately choosing terms that are as neutral as possible in order to avoid unnecessary confusion (Figure 5). In the following, the term "individual" refers to an artefact which is preserved to more than 50 % of its original volume, because smaller fragments can only occasionally be assigned to a specific category or even a type.

Category A: Tools with hafting modifications - mallets

This functional group includes percussion tools that have been prepared in any way for hafting, which are therefore commonly referred to as mallets. The hafting modifications occur as pecked notches or grooves (Figures 6 and 7), occasionally combining both, as has been shown already in earlier work on stone tools from the Schwaz-Brixlegg mining district (Rieser, 2000, p.88). So far, no correlation has been found between the type of hafting modification and the used raw material, while there is a definite connection between the choice of raw

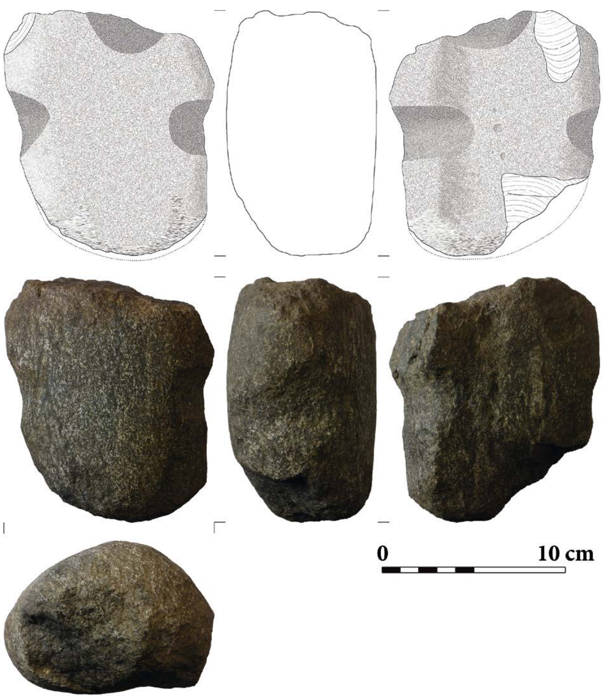


Figure 6. A notched mallet of amphibolite (Kat. Nr. 100/WS24_16) with impact fractures on one end. Drawings and photos: R. Lamprecht.

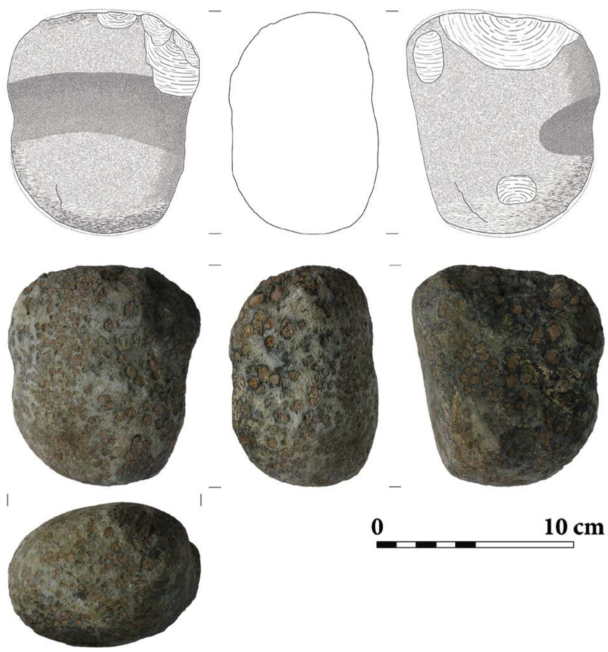


Figure 7. A grooved mallet of eclogite (Kat. Nr. 20/BK20_16) with impact fractures and flake scars on both ends. Drawings and photos: R. Lamprecht.

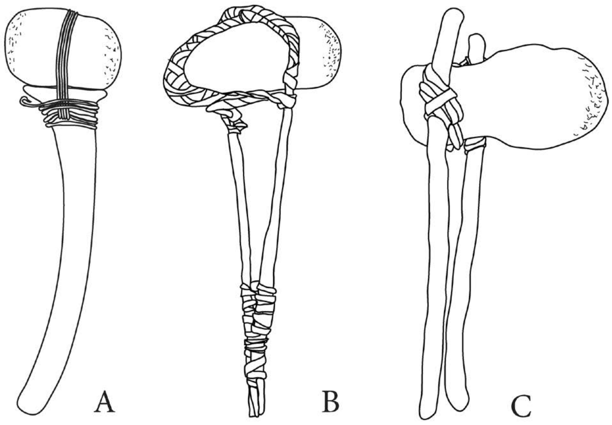


Figure 8. The three modes of hafting and their archaeological equivalents: A: Mitterberg (Austria)/Mt. Gabriel (Ireland), B: Mount Gabriel (Ireland)/Chuquicamata (Chile) and C: Thebes (Egypt). Drawings: A, C: J. Haas. B: Redrawn by J. Haas after an illustration from Craddock (1995, p.45, Fig.2.15).

material and the field of application. 32 % of the investigated tools of this category show notches, while only 20 % have a groove. A further 13 % of artefacts represent a mixed type, while the remaining 35 % could not be assigned to any specific type. Furthermore, grooved mallets can be divided into two different main types with a shallow and a deep groove. A smooth transition between notches and grooves as well as between shallow and deep grooves may make it difficult to assign them to one of the mentioned types. The occurrence of impact fractures (percussion marks) was also included in the typology. If a tool was only used on one end, it was distinguished from a tool with marks on both ends. As a result, ten different types of mallets have been defined in this paper. It should be noted that with the increasing number of new finds also new types may be identified and added to this category. Largely, the shape of the cobbles is uniform, and mainly rounded to well-rounded pebbles with low sphericity (Figure 4) were used. An average reconstructed weight of about 2 kg was recorded for the 24 individuals of this category. The minimum weight is slightly less than 1 kg, whereas the maximum weight is 4.2 kg. This means that category A shows a considerable range of individual weights.

Hafting reconstructions (mallets)

Basically, there are three types of hafting methods that can be considered for mallets (Figure 8): Mode A) attaching the stone on a piece of wood or a branch[5]; mode B) securing the mallet with a sling made of a bent branch, and mode C) two wooden sticks fastened to the stone with leather bands. In the first case, the mallet is prevented from sliding by straps made of organic material such as animal skin, leather, or ligament strings. Two preserved hafts from the Mitterberg (Thomas, 2018, p.355) and one from Mt. Gabriel in Ireland (O'Brien, 1994, p.146, Fig.69, p.633) provide us with evidence of mode A hafts. Additionally, there is evidence of mode B hafts from Mount Gabriel (O'Brien, 1994, p.152, Pl.45) and Cwmystwyth in Central Wales (Timberlake, 2003, pp.72–73, 79, Fig.79). Comparable hafts are also known from the Bronze Age tin mining districts of Kazakhstan (Thomas, 2018, p.355), whereas mode B hafts are mostly reconstructed on the basis of artefacts from the well-known "Copper Man" from Chuquicamata/Chile (Craddock, 1995, p.44, Fig.2.14). Ancient stone working and mining industry in Egypt provides us with some evidence of the third hafting method (mode C), which is only rarely taken into consideration when discussing stone tool finds from the European continent. This haft consists of two wooden sticks, which are fastened to the stone with a leather band. Mallets were used in prehistoric gold mining in Egypt (Klemm and Klemm, 2013, p.6, Fig.1.4). Furthermore, stone mallets were used to quarry and shape stone, which is also shown in depictions (Wild, 1966, Pl. CLXXIII). An original hafted mallet was found at the temple of Mekitre (Meketre) in Thebes, dated to the beginning of the 20th century BC (Arnold, 1991, pp.260-261, Tab.6.2, Fig.6.14)[6].

Functional interpretation of mallets

The functional interpretation of mallets will be briefly discussed in the following, since a clear assignment to a working process cannot be made without any doubt. From an eastern alpine research history point of view, the use of mallets for ore processing is most commonly assumed due to their find context (Eibner, 1979, p.159; Much, 1895, p.258; Stöllner, et. al., 2012, p.127; Thomas, 2018, p.361). At the Mitterberg in Salzburg, mallets were rarely found underground, which suggests that they were not used for underground mining but probably for ore processing above ground (Thomas, 2018, p.357). In addition, mining with bronze picks has been proven both for the Mitterberg and for Kitzbühel-Jochberg (Stöllner, et. al., 2016, p.78; Staudt, et. al., 2020; 2022). In the British Isles, however, there is evidence for the use of mallets for underground mining, as can be seen, for example, at the sites of Copa Hill (Timberlake and Craddock, 2003, pp.88–92), Alderley Edge (Timberlake, 2005a) and Mt. Gabriel (O'Brien, 1994, pp.117–121). In the case of Copa Hill (Timberlake and Craddock, 2003, pp.90–91) and Alderley Edge (Timberlake, 2005a, p.71) one can assume a diverse field of applications for mode B-hafted mallets involving underground work. For the Middle Bronze Age, there is also evidence for the use of bronze picks at the Great Orme mines in Llandudno, Wales (Jowett, 2017).

The most significant argument against the primary use of the mallets in underground mining in the Schwaz-Brixlegg district is the distribution of finds. Only in a few cases mallets could be found in underground mining areas and smelting sites, whereas on processing sites considerably more mallets were discovered (Table 1). Nevertheless, recent research has shown that bronze picks similar to Mitterberg and Kitzbühel were used at the "Weißer Schrofen" site in the Schwaz-Brixlegg district (Goldenberg, Staudt and Grutsch, 2019, p.162; Staudt, et. al., 2019a, pp.135-137). However, it must be noted that only one fragment of a bronze pick was found so far. This suggests that underground mining was done using other tools and techniques like fire-setting, for which mallets can be taken under consideration.

Experiments have shown that such hafted mallets produce good results in post-fire-setting work (Timberlake, 2005b, pp.190–192; Timberlake, 2015, p.161). It could also be shown that for the production of mallets, it was often not necessary to groove or notch cobbles which already had a well-suited shape for hafting (Timberlake, 2015, p.161). Experiments in the Sakdrisi gold mine (Georgia) have shown that both mining and processing using mallets is quite efficient (Timberlake, 2015, pp.153-155; Craddock, Stöllner and Timberlake, 2016, p.55). Even if more experiments on fire-setting in the Schwazer Dolomit are necessary, promising results could already be achieved with the use of mallets (mode A) after fire-setting in first tests (Rieser and Schrattenthaler, 2002, p.109).

In the end, it cannot be fully determined whether mallets were regularly used for underground mining. Even if the distribution of finds speaks against the primary use of mallets for underground work in the Schwaz-Brixlegg mining district, their use in loosening rock after fire-setting is quite likely (Goldenberg, 2013, p.101). One must rather suppose a versatile field of application for mallets, which includes underground work as well as ore processing and many other kinds of work.

Figure 9. Cylindrical hammerstone (Kat. Nr. 16/BK17-5_16) with impact surfaces on both ends. Drawings and photos: R. Lamprecht.

Category B: Hand-held tools - hammerstones

Hammerstones are percussion implements, which are used in a hand-held way and can therefore be distinguished from the hafted mallets. They can be distinguished from "geofacts" or "eoliths" (randomly created without human influence) by the occurrence of at least one surface with impact fractures, which may show flake scars (Hahn, 1991, p.296). Due to the often only slight difference in appearance between artefact and geofact, it can be assumed that stone tool artefacts are occasionally not recognized as such (Fiedler, 2012). The poor state of research on cobblestone tools is probably partly due to this phenomenon.

Among the 27 investigated individuals of this category, the average weight is approximately 1 kg, the smallest specimen weighing 0.25 kg and the largest more than 3 kg. Cylindrical and spherical hammerstones are usually smaller and have more impact surfaces as those with other shapes. Due to the loss of material over time, heavily used tools (Figure 9) tend to lose weight, which can result in weights as low as 0.25 kg. The range of shapes includes cobbles with high and low sphericity, but all individuals are rounded or well-rounded in their initial shape. The vast majority of this group, similar to tools classified as category A, originate from ore processing heaps in the immediate vicinity of the mines. Unhafted tools are rarely associated with underground mining, as can be concluded for the mining districts in North Tyrol. Most likely, finely intergrown ore was processed with

Figure 10. Lower grindstone (Kat. Nr. 152/WH8_17) with intentionally roughened surface. Photos: R. Lamprecht.

these devices in order to separate the ore-rich material from the host rock/gangue. Ore-bearing rock that had previously been coarsely crushed with hafted tools (category A) was further broken down in the next step, using hammerstones and netherstones (category C).

Hammerstones are among the oldest tools invented by humankind, some even dating as far back as to the Palaeolithic, when simple river pebbles were used to prepare food and to grind mineral resources (Schulte-Dornberg, 2012, p.518).

Category C: Netherstones - anvil stones, lower grindstones

Category C includes tools that were placed on the ground and served as a base for different kinds of use. As a generic expression, the term "netherstone" was chosen, as sug-

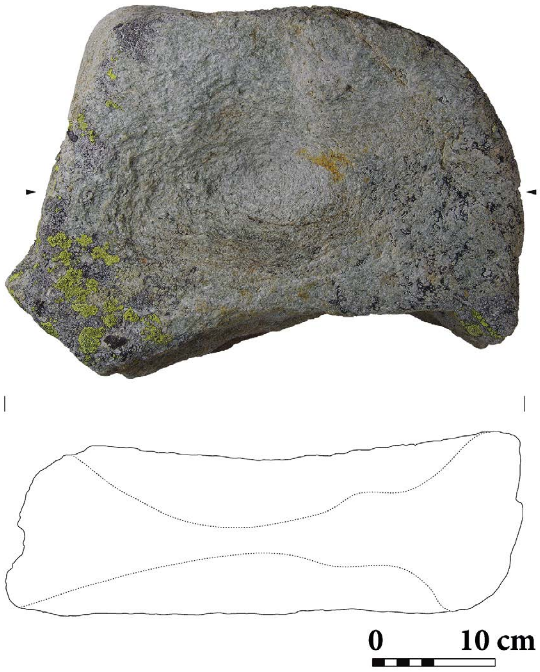


Figure 11. A gneiss netherstone (Kat. Nr. 138/SK106_18) for pounding with wear marks on both sides. Drawing and photo: R. Lamprecht.

gested by Jenny L. Adams (Adams, 2014, pp.148–150). The terms "anvil stone" and "lower grindstone" were subsequently chosen as subcategories, whereby lower grindstones can usually be identified as such by their smooth grinding surfaces and anvil stones by depressions created by pounding.

While the combination of hammerstones and anvil stones is known to have been used since the Lower Palaeolithic, the use of grindstones increased from the Upper Palaeolithic onwards. After the appearance of agriculture in the Neolithic, grindstones occurred on a regular basis (Peacock, 2013, p.16). It has been observed that grinding surfaces were sometimes intentionally roughened to increase their efficiency (Figure 10). All devices of this group were employed in a passive way. Netherstones (anvil stones) for pounding (Figure 11) were used for the first processing steps, whereby the ore concentration was constantly increased by continuous separation (Goldenberg, 2013, p.103). Further processing was done either with hand-held upper grindstones (not proven so far in the investigated area) or by using the technologically more advanced hafted upper grindstones (category D). In order to make the grinding process more efficient, both the upper grindstones and the netherstones were provided with "line-roughening" ("Strichrauung") (Klose, 1918, p.23; Kyrle, 1918, p.47). This modification usually followed the longitudinal axis of the netherstones, whereas the upper grindstones were given a different orientation of roughening. Particularly well-preserved line-roughenings are known from the tools of the Bronze Age mining activity at Vetriolo-Levico Terme (Trentino/Italy) (Preuschen, 1962; 1973). The predecessors of modern mills, the so-called Olynthus mills, also show a large number of different roughening patterns (Frankel, 2003, p.9, Fig.7). To prevent the ground material from being lost, the netherstone was placed on an organic base. Materials such as leather, rawhide, tightly woven textiles or wickerwork were used for this purpose. Most of the devices, some of which were very large, tended to be made of flat rock materials. The degree of rounding is not of great importance and, due to the difficulty of reconstructing the former overall size, weight estimations are difficult to achieve. As one would expect, tools of this kind are usually found at ore processing heaps.

Category D: Tools with hafting modifications – Eastern Alpine upper grindstones

So far, devices of this design are known only from the Bronze Age and Iron Age mining areas in the Eastern Alps and may therefore be referred to as "Eastern Al-

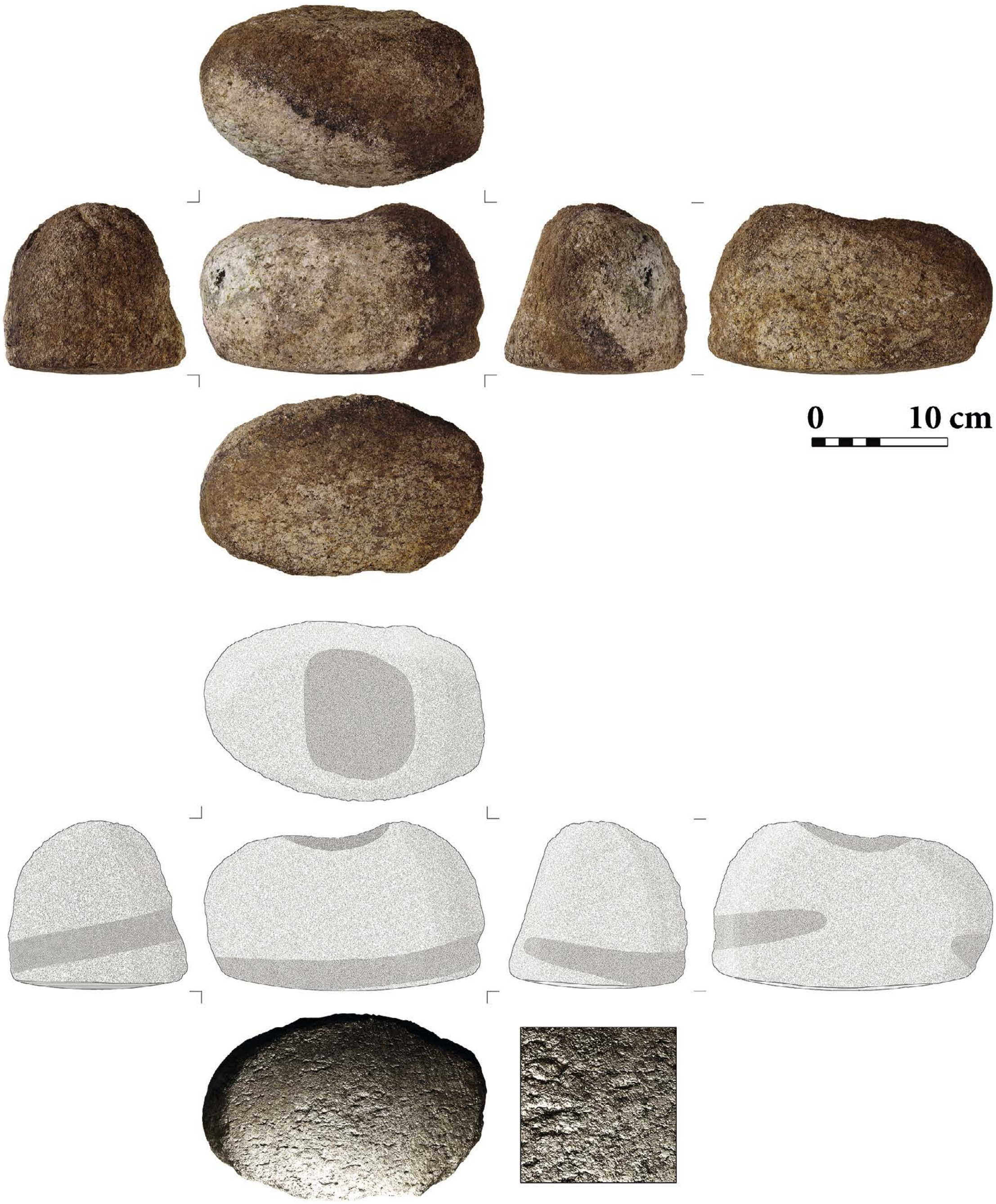


Figure 12. An example of a hafted upper/Eastern Alpine grindstone (Kat. Nr. 160/WH100_18) with a transverse and horizontal groove and a convex grinding surface on the bottom side. Drawings and photos: R. Lamprecht.

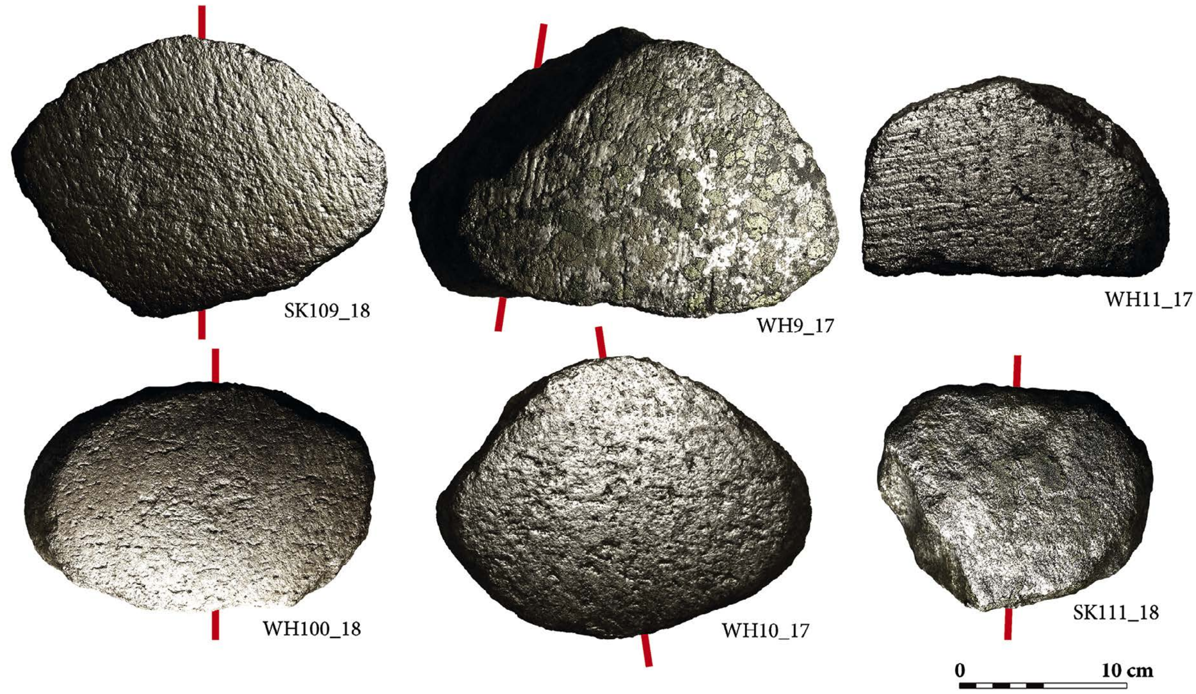


Figure 13. Working surfaces of upper grindstones with linear roughening or “Strichrauung” (top), smooth grinding surfaces (bottom left and centre) and an unused tool (bottom right). The red lines mark the orientation of hafting in relation to the transversal groove on top of the device. Photos: D. Turri and R. Lamprecht.

pine upper grindstones” or “Ostalpine Läufersteine”[7]. Characteristic features of this category are smooth and slightly convex grinding surfaces caused by abrasion as a result of use as well as pecked grooves which generally run horizontally (in the plane of the grinding surface) and transversely (perpendicular to the grinding surface) across the upper grindstones (Figure 12). It is evident that these modifications served hafting purposes. The intentional roughening of the grinding surface is similar to the one described for category C. The random orientation of roughening towards the direction of operation shows, however, that care was always taken not to align the line-roughening of the upper grindstones and the netherstones in the same directions (Figure 13), to obtain a higher efficiency of the grinding process.

Rounded and well-rounded cobbles/boulders were used as raw materials, mostly consisting of gneiss (particularly orthogneiss in the Kitzbühel-Jochberg mining district), the average weight being 5-7 kg. Most of the upper grindstones come from ore processing heaps, only a very small percentage can be assigned to a different context. The most well-known discovery sites are the Mitterberg near Bischofshofen (Eibner, 1993, p.20; Much, 1879, p.XXVII; Stöllner, et. al., 2012, p.128) and the Kelchalm near Aurach (Much, 1895, p.262; Preuschen and Pittioni, 1954, p.80). Recent research has shown, however, that tools of this type can also be found in the area around Viehhofen (Preuschen and Pittioni, 1956; Scherer-Windisch, Brandner and Tiefengraber, 2019; 2020), Jochberg (Lamprecht, 2020, pp.37-38; Staudt, et. al., 2020; 2022), the Brixen Valley (Gstrein, 2013; Neuninger, Preuschen and Pittioni, 1970; Staudt and Goldenberg, 2018) and with isolated specimens in the Schwaz-Brixlegg mining district (Lamprecht, 2020, pp.37-39). Comparable finds of such tools are described also from Vetriolo (Levico Terme) in Trentino. This category of tools, which generally can be attributed to the so-called “younger Eastern Alpine technology” (Eibner, 1993, p.20), were probably developed in the prehistoric chalcopyrite mining districts of Salzburg and North Tyrol. From there, the technique seemed to have spread westwards into the Brixen- and Inn valleys, and eventually as far south as to the Trentino in northern Italy.

Reconstructing operation modes

From the very beginning of mining research in the Eastern Alpine copper districts, the interpretation of the function of upper grindstones was of general consent. Accordingly, the horizontal groove was used to hold a rope or branch in place in order to fasten a wooden crosspiece for hafting (Klose, 1918, p.23; Much, 1895, p.262; Preuschen and Pittioni, 1954, p.80). Alexander Maass was the first to distinguish grooves adapted to pulling and pushing movements (Stöllner, et. al., 2012, p.128, but without further explanations). Although different opinions on the exact way of hafting still prevail, all authors assign the upper grindstones to the mechanical processing of ore. In fact, over 80 % of upper grindstones discussed in this paper originate from ore processing heaps, while the remaining 20 % are to be considered stray finds. Although hafting modifications are widely known among grinding tools, apart from mining contexts this special type of modification first appeared in Alpine regions only at the beginning of the Iron Age. An excellent example are the Olynthus mills and their derivates (Marzoli and Donner, 1994, p.78; Peacock, 2013, pp.38-53). Basically, one can assume two operational modes for such devices: to-and-fro movement and oscillating movement. In the case of unhafted upper grindstones it can be assumed that a single person operated the device, while hafted tools might have been operated by one, two or more people. In an oscillating operation, the haft had to be fixed on one side (Peacock, 2013, p.39; Stöllner, 2019, p.187, Fig.21). The uniform curvature of the netherstones as well as the absence of corresponding abrasion marks make the authors conclude that the assumption of an oscillating movement seems unlikely for the studied artefacts. Much more likely a to-and-fro movement can be assumed (Figure 14). The transversal groove may thus have served to hold a straight piece of wood which was held in place by flexible organic material. Promising experiments have already been conducted in this regard (Lamprecht, 2020).

Category E: Abraders and polishers

Abraders are usually defined to be flat plates of various materials showing work surfaces created by usage (Hahn, 1991, p.301). With this type of tool, various organic and mineral materials could be abraded or polished (Gehlen, 2012, p.844). In contrast to netherstones used for abrading and stone dressing, they were usually guided by hand. Pieces assigned to this category were all made from small cobblestones, which are always well-rounded and of low sphericity. The choice of material was of the highest importance. In this respect, Jenny L. Adams' insight into material selection is of great significance: "At the design stage, material selection determines if a tool will abrade, smooth or polish" (Adams, 2014, p.83).

Secondary use and multi-purpose tools

The conclusion that certain devices had several functions at the same time can be drawn from the examination of several objects. Larger tools show traces of secondary use, which can be explained by the recycling of tools that had become unusable for their primary function (broken or strongly reduced devices). Eastern Alpine upper grindstones, for example, were occasionally utilised as anvil stones (category C1) after their primary use. Broken lower grindstones that had become unusable due to breaking were also used for this purpose. It has been observed that in remote mining areas with long transport distances it was particularly important to use stone tools as long as possible and to choose the best available raw material for this purpose (Rieser and Schrattenthaler, 2002, p.74). Overall, only about 4 % of all tools served multiple purposes, while 3 % had secondary uses. The tools presented by Rieser and Schrattenthaler (Rieser, 2000, p.97) showed a much higher degree of re-utilization (18 %). The same can be observed in the Mitterberg area, where 13 % were reused (Gale, 1991, p.144, Tab.1), while a very high degree of reuse of 41 % was documented at Copa Hill (Timberlake and Craddock, 2003, p.88). However, it is difficult to determine whether the secondary use of a tool directly followed the primary use. Therefore, it cannot be ruled out that tools that were no longer useable for their primary purpose were discarded and reused for another purpose at later times. This was particularly common with mallets that had been broken and then were reused as hammerstones. Nevertheless, it is not possible to determine when the reuse took place, since in many prehistoric mining districts in North Tyrol there was intensive mining in the Middle Ages and Early Modern Times, whereby also anvil stones have been used for ore processing.

Experimental research has shown that both underground mining and ore crushing can produce wear marks similar to those found on originals (Timberlake, 2005b, pp.191–192; Timberlake, 2015, p.150; Craddock, Stöllner and Timberlake, 2016, p.53). For this reason, reconstructing the use of a stone tool based on the traces of wear is often problematic.

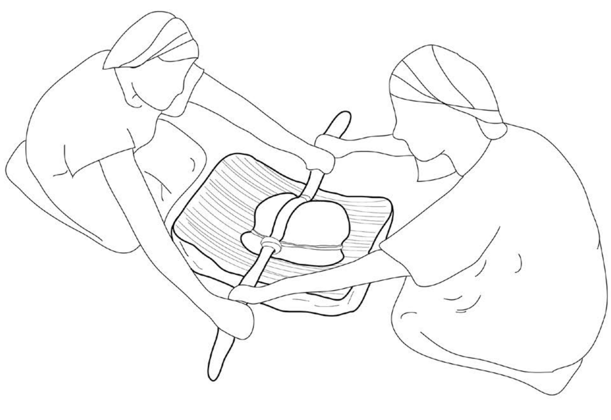


Figure 14. A hafted upper/Eastern Alpine grindstone operated by two people. Drawing: J. Haas.

Use-wear

Each of the different intended uses, which can basically be divided into pounding, grinding and abrading, leaves behind distinct surface marks. The detailed study of these marks can help to better understand the initial function of the tool. To draw comprehensible conclusions it is necessary to refer to comparable data from archaeological material as well as to the results of experimentally obtained data if they meet scientific quality standards.

Breakage and flaking

Severe percussions can cause breaking due to heavy impact stress. Fracturing will then occur along the weakest parts of the stone, particularly material defects and hairline cracks will tend to give way for breakage more easily. This affects especially mallets and hammerstones, although breakage and flaking can be expected for all force-intensive operations. In contrast to breaking, which in most cases leaves a tool unusable, flaking of stone tools may occur during the operation without affecting the function of the device. During the first production phase of cobblestone mining tools, the raw material was most likely roughly shaped, which is indicated by numerous flakes found on the places of manufacture[8]. In general, the same use-wear marks can be expected on non-flint rocks ("Felsgestein") as those left on flint (Gehlen, 2012, p.853). In many cases, the sequence of flaking can be observed (Figure 15). Due to the intensive use of a tool, working surfaces become wider, and stress on the material therefore increases, which considerably raises the probability of flaking and breaking (Gale, 1995, p.122). Fragments of non-flint rocks are generally paid little interest during archaeological excavations, which is why they have rarely been recognised and described as artefacts of archaeological interest. For the material presented in this study, individuals (>50 % preserved) are represented by 79 pieces (31 %), while fragments of stone tools are accountable for 172 pieces (69 %).

Impact scars

Impact scars appear to be the most common signs of wear on all percussion tools and thus occur in all categories except D and E. Occasionally and mainly due to secondary uses, impact scars can also be found within the latter categories. Tools used in an active manner (categories A and B) may display similar use-wear marks as those used in a passive way (category C). The impact scars on "pecking stones" used for the modification and shaping of stone tools during manufacturing can sometimes not be distinguished from the marks left on ore dressing tools. Concentrations of impact scars are referred to so-called impact scar fields ("Schlagnarbenfelder"). Depending on the type of use, active tools may have one, or in the case of double-ended use two or more, scar fields. Netherstones show the same traces of wear, but the mechanical stress gradually deepens depressions on the surface of the device ("Pochmulden"), while active tools develop rounded edges. Different traces of use may also occur during the processing of foodstuffs (Dubreuil, et. al., 2015, p.135), although in general fewer impact scars are to be expected.

Grinding marks

As a result of successive material removal, grinding processes cause a deformation of the used tools (Gehlen, 2012, p.842). Lower grindstones (category C2) show evenly formed depressions, while the working surface of upper grindstones becomes concave, due to the constant abrasive wear. Uneven pressure application will result in

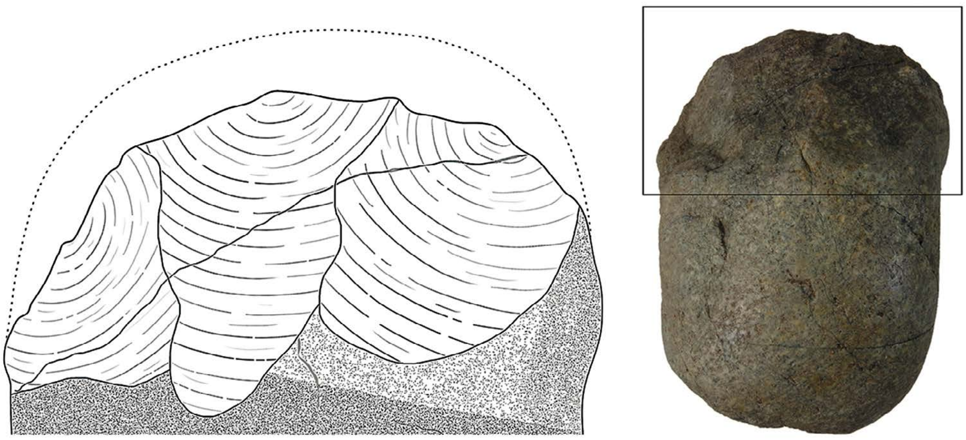


Figure 15. The heavy stress on the material (eclogite) resulted in progressive flaking of one working end of a mallet. Drawing and photo: R. Lamprecht.

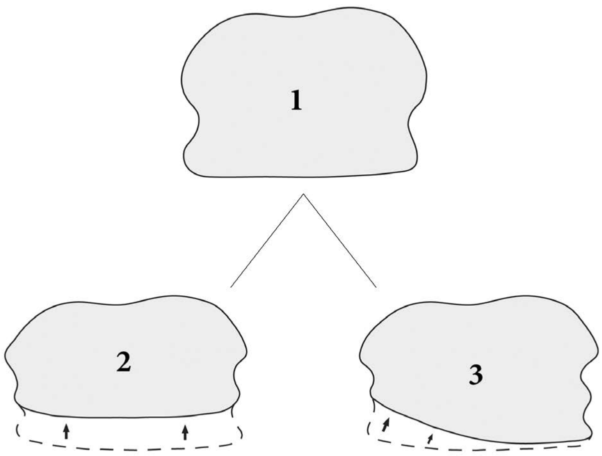


Figure 16. Schematic representation of wear patterns of upper grindstones (category D). 1: Unused tool; 2: Even abrasion; 3: One-sided abrasion as a result of uneven pressure application. Graphics: J. Haas.

one-sided wear of upper grindstones (Figure 16). Also with the upper grindstones care was taken to be able to use the tool as long as possible, which is indicated by multiple horizontal grooves on a single object. In addition, partly worn off horizontal hafting grooves are noticeable on some upper grindstones as a result of extensive use. It can be assumed that the work surfaces of both tools slowly adapted to each other and that the grinding process became progressively more efficient as a result.

The previously described "line-roughening" would have worn off relatively quickly according to the applied mechanical stress. Therefore, smooth grinding surfaces are the result of heavy wear, whereas remaining roughening indicates less stress.

Polishing marks

On a macroscopic level, use-wear features of stone tools used for smoothing and polishing are indicated by slight abrasion of work surfaces, which in some cases became concave as a result.

Besides the use-wear features on polishing stones, Rieser and Schrattenthaler (1998/99, p.174) observed polishes on several mallets at the contact zone between stone and haft. This may happen if the hafted mallet moves slightly, resulting in repeated friction between stone and the wooden shaft. With the investigated material of this study, this effect could not be observed so far.

A stone tool's production and use cycle

Based on the types of rock used, it can be concluded that prehistoric miners knew very well which raw materials were best suited for their respective purposes. Therefore, the best raw materials were selected and collected at spe-

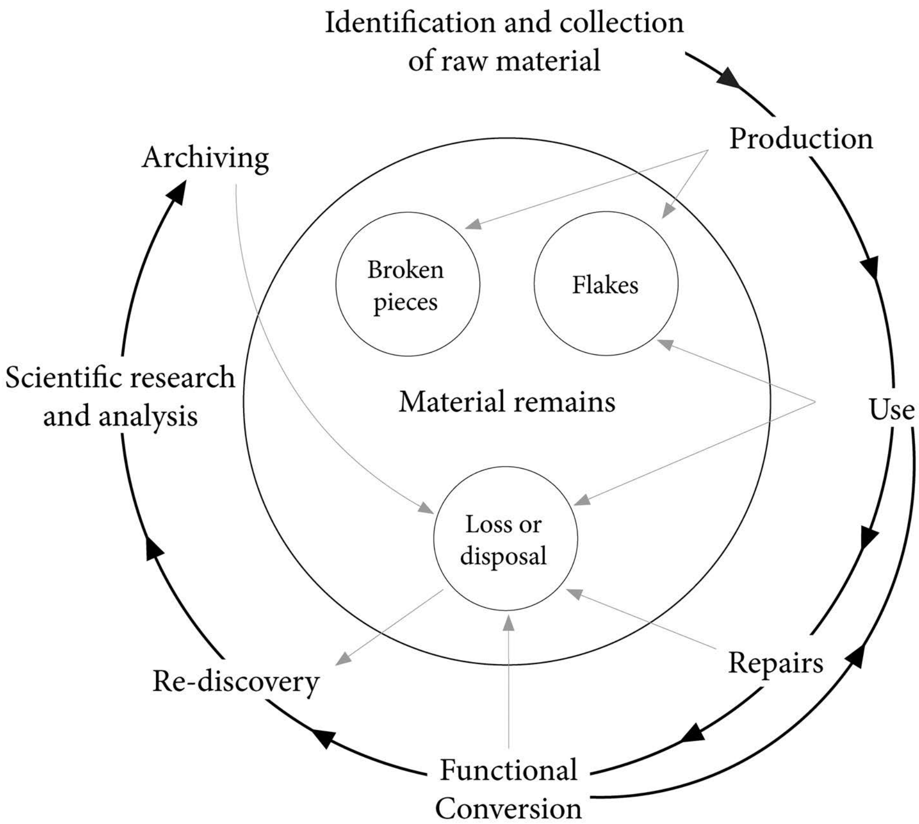


Figure 17. The production and use cycle of a stone tool used in prehistoric mining. Graphics: R. Lamprecht.

cific locations like river gravel bars. In the case of unmodified tool types, the emergence of a stone tool takes place with its first use, whereas hafted tools may undergo modification before use during the hafting process (Figure 17). A rough dressing of cobbles can be achieved by flaking and/or pecking. In addition to the hafting modifications, upper grindstones require the preparation of working surfaces before they can be used. Flakes produced during the use of a device may sometimes be difficult to distinguish from leftovers of the manufacturing process.

Tools that have become unusable due to breaking can be identified by hafting modifications or use-wear marks (impact scars, grinding and polishing marks). Tools that have become unusable were just left on site, or they were thrown onto the waste heaps, where many artefacts can still be found today. The wooden haft itself and the materials used for fixation were most likely re-used whenever possible. Near the surface of a waste heap these remains of organic materials are usually completely decomposed by weathering and do not leave any traces. If a stone tool had become unusable by severe wear or breakage, either a repair (if possible) or a conversion of its primary function may have taken place (Figure 17). The secondary use of the stone for another purpose then marks the final phase of the tool's use cycle. Such recycled tools are quite often represented among the inventory of findings.

Mineralogy and material properties

Tools that have been used in an active operational mode are primarily made of high metamorphic rocks with relatively high densities (Figure 18). Amphibolite, garnet amphibolite and eclogite as well as their variations were much preferred as raw materials for active devices (Figure 19). Carbonates and phyllites were only used occasionally, due to unfavourable material properties. Gneisses/orthogneisses were mainly used for passive devices (netherstones), especially local varieties being of importance.

Eclogite, garnet amphibolite and amphibolite

Outcrops of high-grade metamorphic eclogite are usually limited to special rock formations. In case of 3.3 g/cm^3 and even higher values, their extraordinary density in combination with a very tough internal structure are their most striking characteristics (Klaassen, 2005, p.345, Tab.1; Schön, 2011, p.103, Fig.4.3). The most important eclogite outcrops in North Tyrol are located in the Ötz valley at Huben near Längenfeld (Figure 20) (Hammer, 1929, pp.18-20). The outcrops extend over a length of 5.8 km and a width of 2.2 km, with a thickness of several hundred meters. Eclogite occurs in many smaller lenses within a large amphibolite body (Hammer, 1929, p.18). In the rest of Northern Tyrol there are only a few eclogite outcrops, such as those at Ischgl in the Paznaun valley, which are, however, limited to a small area. This also applies to the Swiss part of the Silvretta mountains, where eclogites occur in addition to amphibolites near Zernez, for example (Schweinehage, 2000, pp.31-36). Both lithic materials may have reached the Lower Inn Valley because of erosion processes and

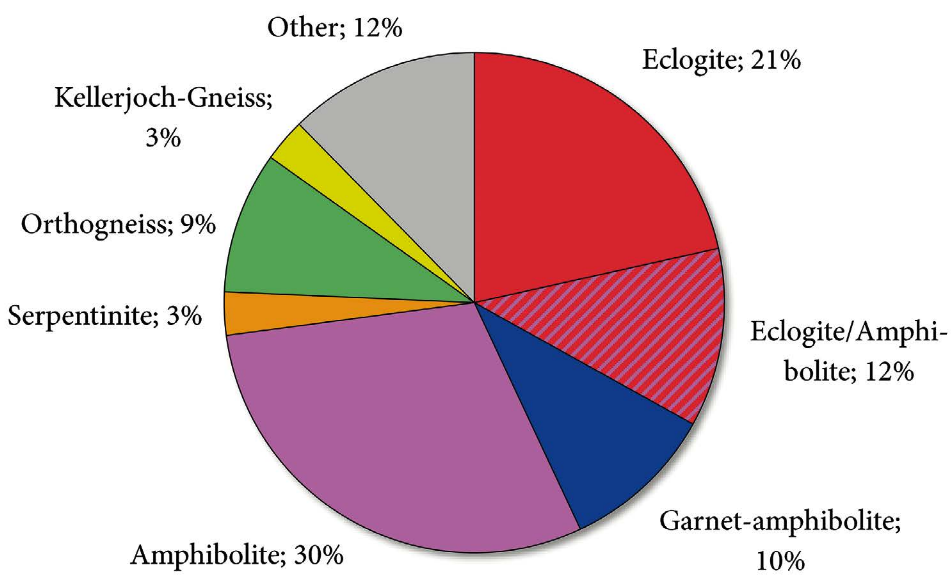


Figure 18. Distribution of material within all tool categories ("individuals" and "non-individuals") for the mining districts of Schwaz-Brixlegg and Kitzbühel. Graphics: R. Lamprecht.

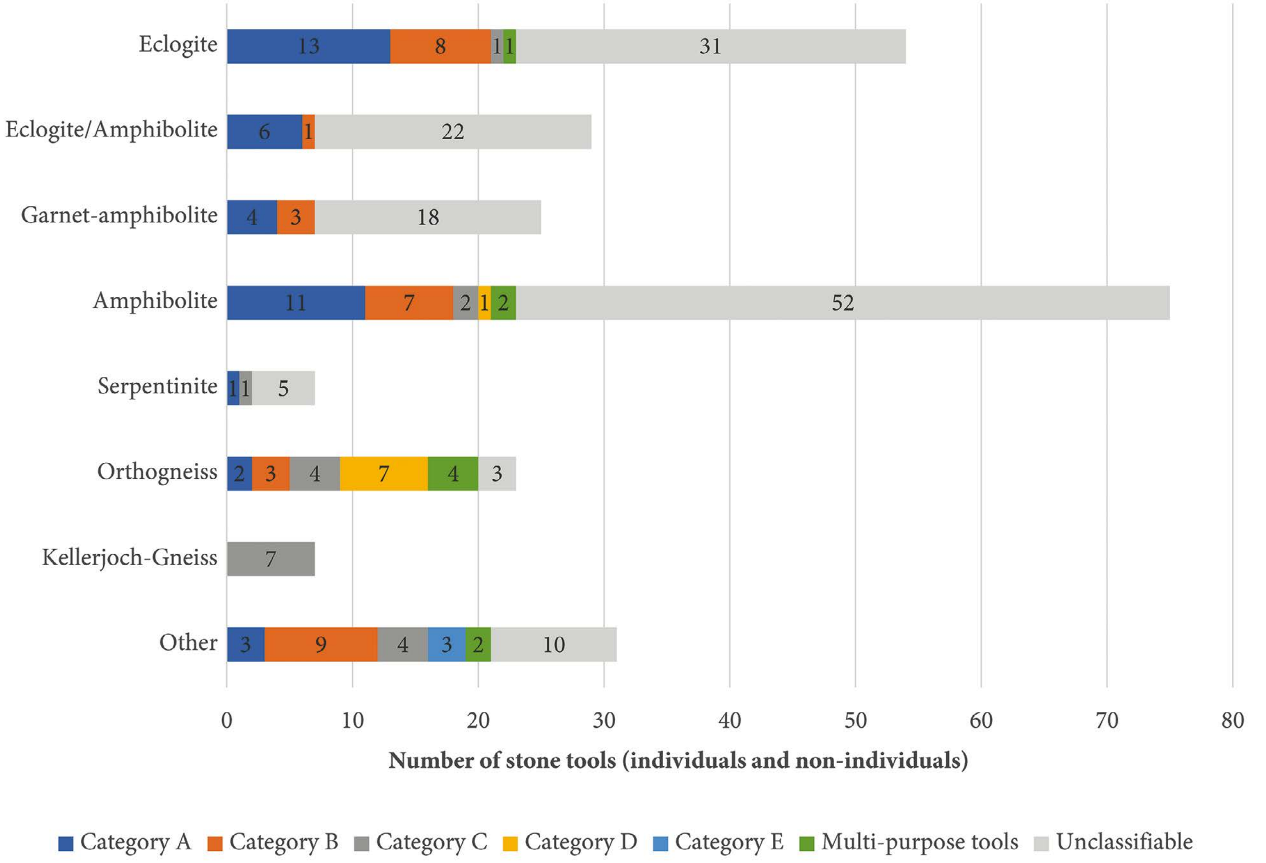


Figure 19. Distribution of rock material within the categories, including both "individuals" and "non-individuals" in this graph. Graphics: R. Lamprecht.

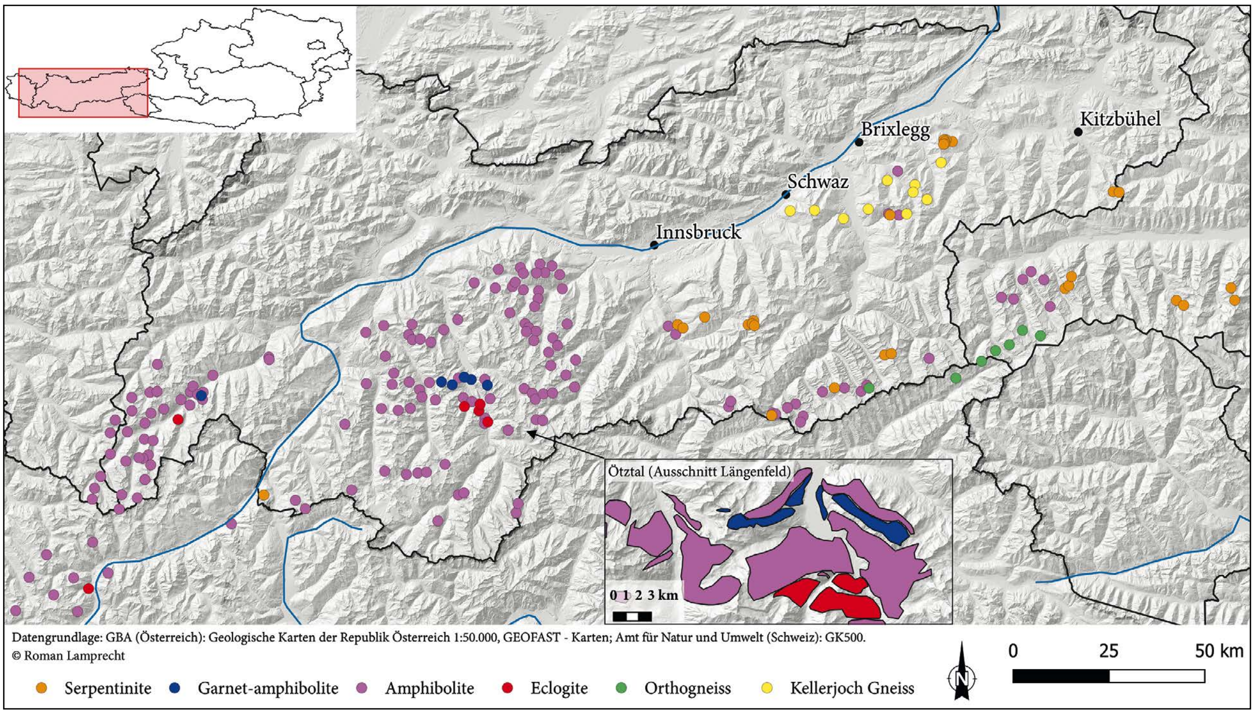


Figure 20. Geological outcrops of relevance regarding cobblestone-mining tools in Graubünden (Switzerland), North Tyrol and Salzburg (both Austria). Graphics: R. Lamprecht.

fluvial and/or glacial transport. Amphibolites appear regularly along the Inn from the Silvretta Complex across the Ötztal-Stubai-complex to the southern parts of the Brenner and the Ziller valley (Klebelsberg, 1935, pp.136-137, 151-152, 218). Garnet amphibolite occurs less frequently, while larger outcrops can be found in the Ötz valley (Hammer, 1929, p.16).

Serpentinite

Serpentinite occurs subordinately, appearing more frequently to the east of the Brenner Pass (Reckner Complex, Greywacke Zone). It is therefore more common in the Tux Alps and the southern Ziller valley (Tauern window) as well as in the Wildschönau (Klebelsberg, 1935, p.119), the Brixen valley (Mayr, 1983, p.29) and partly in the Jochberger Achen valley (Figure 20).

Gneiss

The orthogneiss used for grindstones in the Kitzbühel district most likely originated from the Hohe Tauern mountains (Zentralgneise, Tauern window) and crossed the Thurn Pass (el. 1274 m) via glacial transport (Klebelsberg, 1935, p.551; Heinisch, Pestal and Reitner, 2015, p.322). Although outcrops of similar gneisses can be found in the Ziller valley, a regionally occurring variety of gneiss was used for processing equipment in the Schwaz-Brixlegg area, the so called "Kellerjochgneis" or "Schwazer Augengneis", which extends from Schwaz in the west to the Wildschönau in the east (Tropper, et. al., 2016).

Other materials

If no appropriate material could be found in the adjacent area, less ideal material was used. Dolomite, limestone, sandstone, breccia and phyllites were used in exceptional cases. Paragneiss, quartzite, hornblende gneiss, diabas and ultramafitite were also picked up from the Inn gravel bars, although they were rarely in use. All these rocks can be found in the distribution diagram (Figure 18) under the category "Other". Regarding the less-used types of rock, one has to assume that occasionally there happened an unfavourable selection of rock material (Rieser and Schrattenthaler, 2002, p.116). For netherstones, the rock material was of less importance compared to the available size.

Erosion and material transport

Except for the tools made from Kellerjochgneis in the Schwaz-Brixlegg mining district, most of the stone tools were manufactured from non-local material. At the outcrops, large blocks were detached by erosion and subsequently transported down the valley by water or ice and deposited in river sediments and/or glacial moraines (Figure 21). In this way, materials such as amphibolites

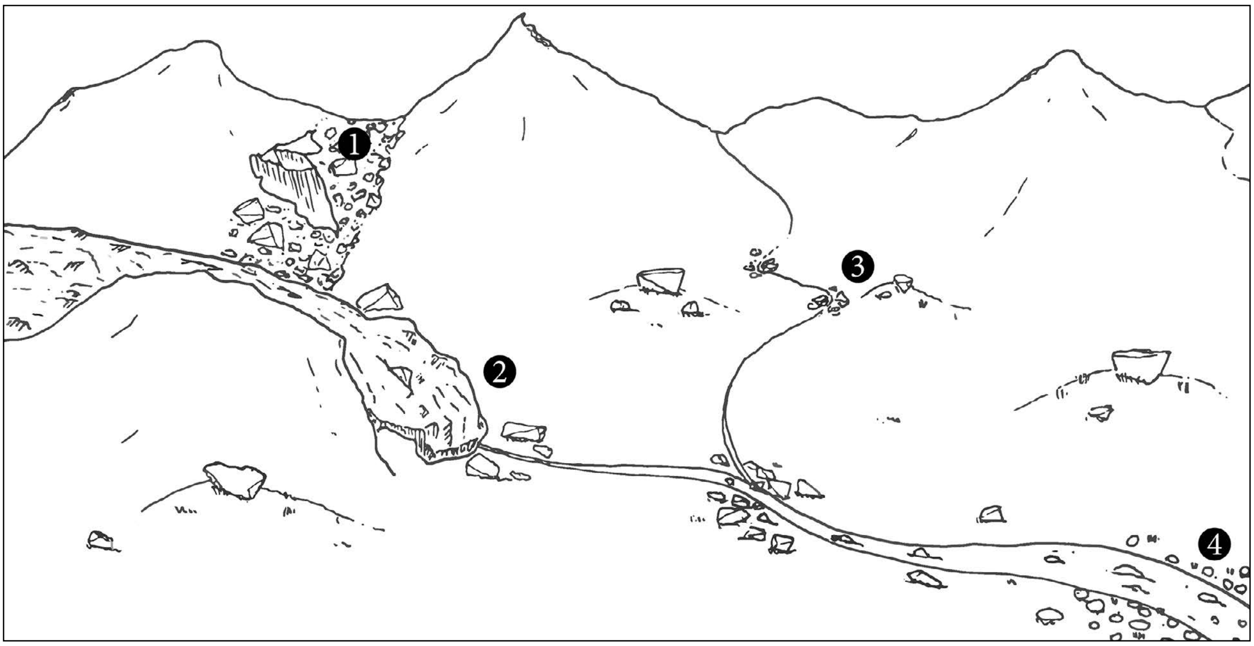


Figure 21. The transport of boulders from the deposit (1) by glacial and fluvial processes (2). Erratic blocks (3) are continuously crushed and rounded by fluvial transport (4). Graphics: J. Haas.

and eclogites, which even came from (far away) Eastern Switzerland, could be collected along the Inn River. With the confluence of the Ötz valley, eclogite cobbles were mixed with those from Switzerland and the Paznaun valley. Due to glacial and fluvial transport, some of these rocks may have travelled over 170 km all the way to the Schwaz-Brixlegg mining district. During this transport, the blocks were constantly reduced in size and rolled off until they achieved their final shape. Distinction between glacial and fluvial rounding is only possible to a limited extent (Zingg, 1935, p.57). Furthermore, the degree of roundness depends on the grain size of the minerals, the material itself and the transport distance (Zingg, 1935, p.86; Domokos, et. al., 2014).

In the end, a large quantity of lithic raw material made it to the "front door" of prehistoric miners, who knew how to use the material in the best possible way. From the Schwaz-Brixlegg mining district, a further 60 km must be taken into account to reach the Kitzbühel-Jochberg mining district. However, some of this distance was no longer covered by natural processes but by human transport.

It seems obvious that material properties were of great importance when selecting a rock for a specific tool. Experience gained over years or even generations of practice could therefore be relied upon. Therefore, particularly dense and tough materials such as eclogites or garnet amphibolites were used for tools that were exposed to high mechanical stress on the one hand. On the other hand, material with an excellent abrasive capacity, such as orthogneisses, was used for all sorts of grinding tools.

The problem of dating stone tools from mining contexts

The dating of stone tools without stratigraphical information in archaeological contexts is very problematic if not impossible, due to the minor changes in tool design over time. Especially "simpler" forms, such as anvil stones, were used for a very long time, even up to the Middle Ages. In contrast to flaked flint tools, dating based on typological classifications is only possible to a limited extent. For this reason, mining tools can usually only be chronologically assigned when their stratigraphic context is known and dated by absolute methods like radiocarbon dating or dendrochronology. This means that stray finds can only be very roughly assigned and that corresponding material from datable archaeological strata is therefore of highest importance. The oldest datable finds from the district of Kitzbühel presented in this paper are from the 13th century BC (Staudt, et. al., 2020; 2022). In contrast, almost all finding sites from the Schwaz-Brixlegg district can be dated to the 12th as far as the 8th century BC (Staudt, et. al., 2018a; 2018b; 2019b). Dozens of anvil stones found at late medieval and early modern sites show that similar tools were also continuously used in later times.

Conclusions

Systematic investigations on mining stone tools are rare and, therefore, still represent a research desideratum. In Northern Tyrol, the research by Rieser and Schrattenthaler (1998/99; 2002; Rieser, 2000) is particularly noteworthy in this context; they mostly dealt with stray finds from the Schwaz-Brixlegg mining area. A large part of the material presented in this study, on the other hand, originates from archaeological excavations and can, therefore, be stratigraphically assigned and subsequently dated by absolute methods like radiocarbon dating or dendrochronology. In the majority of scientific papers on mining stone tools, the troublesome topic of terminology remains almost undiscussed. Therefore, it seemed essential to point out to discrepancies in the published articles and to propose some simplifications. According to Adams' approach (Adams, 2014, p.9), an individual typological scheme was also created for the presented material in this paper. Special care was taken to design the scheme to be as simple and comprehensible as possible and to present the data used as extensively and neutrally as it can be. It could be shown that most of the tools were generally used for ore processing (Table 1), although there is a possibility that mallets were used in underground mining as well. Upper grindstones and anvil stones can be assigned to ore processing activities, while abraders and polishing stones were employed in more universal fields of applications.

For the first time this study presents a detailed classification of "Eastern Alpine upper grindstones" (category D) which turn out to be an important indicator for Bronze Age copper ore mining at least in the area under consideration. It was not only possible to show their spatial distribution but also to discuss possible ways of their usage, varying from oscillating to a to-and-fro movement. This kind of tool highlights not only the high technological standard of specialised mining tools but also the technology transfer among Bronze Age mining communities in the Eastern Alpine region. Unlike the hafting of upper grindstones, that of mallets is quite well studied. Research has been carried out since the beginning of the 20th century, British studies being prominent (Pickin and Timberlake, 1988; Pickin, 1990; O'Brien, 1994; Craddock, 1995; Craddock and Lang, 2003; Timberlake and Craddock, 2013). Nevertheless, by the "Egyptian style hafting" a so far little considered hafting method could also be presented.

During the analysis of raw material, it was possible to point out to relevant rock outcrops through systematic mapping. It became clear that metamorphic rocks such as eclogites or garnet amphibolites only occur regionally. Corresponding specific outcrops can therefore be found in the Silvretta region and especially in the Ötz valley, whereas amphibolites, serpentinites and gneisses are more common and thus cannot be assigned to a specific outcrop.

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Notes

1 Austrian part of a trinational DACH-project, I 1670-G19, 2015 -2018 (Turck, Stöllner and Goldenberg, 2019).

2 Nevertheless, it should be noted that stone mining tools do not necessarily have to be made of cobbles, as has been shown, for example, in the Bronze Age tin mines in Central Asia (Garner, 2013, p.151).

3 Rieser and Schrattenthaler (1998/99, p.174; 2002, p.71) even suggested that sometimes one side was artificially flattened for this reason.

4 First classifications for mallets were presented by John Pickin in 1990, and since then have served as a template for many classifications (Pickin, 1990, p.40, Fig.2).

5 In particular, the transition between branch and trunk can be used for this purpose.

6 Today this piece, bearing the No. MMA 20.3.190, is located in the Metropolitan Museum of Art in New York.

7 Occasionally, such devices are also referred to as "Type Mitterberg" (Stöllner, 2019, p.182), although the area of occurrence extends far beyond.

8 Not many localities of that kind have been identified so far, however the Götschenberg near Bischofshofen could be understood in this respect (Lippert, 1992, p.37).

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