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Prehistoric Copper Mining Between Hohe Salve and Hahnenkamm: First Results of Mining Archaeological Surveys in the Brixental and the Grattenbergl/Kirchbichl (North Tyrol, Austria)

Roman Lamprecht, Julia Haas and Gerald Hiebel

Keywords

Prehistoric copper mining, mining archaeology, geomagnetic survey, North Tyrol, Bronze Age, Iron Age

Abstract

The Brixental was an important connecting area between the Bronze and Iron Age copper mining districts of Schwaz-Brixlegg in the west and Kitzbühel-Jochberg in the east. For this reason, the mining landscape of the Brixental, which has been little researched to date, was investigated for potential prehistoric copper mines. Through literature research and the study of geodata (DEM, orthophotos) prior to the surveys carried out in 2023, a total of six core areas were defined, which were investigated for the presence of mining archaeological features and finds. During the survey, all relevant features like mining heaps *(Bergbauhalden*), depressions formed by open-cast mines or collapsed adits/"mining pits" *(Pingen*) and underground mines (*untertägige Abbaue*) were documented and samples were collected for radiocarbon dating. In this way, it was possible to provide evidence of prehistoric mining at three sites based on the artefacts discovered (stone tools, pottery, slag, etc.), while in the case of Götschen near Brixen im Thale it was possible to obtain radiocarbon dating for Early to Middle Bronze Age mining. In addition, various samples provided evidence of widespread mining activities in the Late Middle Ages and Early Modern Age. In these periods the Brunnalm in Kirchberg in Tirol was particularly important. Located at the western entrance to the Brixental, Grattenbergl in Kirchbichl was investigated using geophysical methods (geomagnetic measurements), revealing evidence of metallurgical activities (smelting furnace and/or roasting bed) during the Hallstatt period. It can therefore be concluded that copper mining was carried out in the Brixental that was similar to the well-known mining areas (Kitzbühel-Jochberg, Schwaz-Brixlegg) in the vicinity and that traces of it have been preserved to the present day.

Introduction

As part of the project "Information Integration for Prehistoric Mining Archaeology"[1] at the HiMAT Research Centre at the University of Innsbruck, surveys for mining archaeological remains in the Brixental were carried out during three weeks in 2023. The aim of these investigations was to examine the prehistoric mining landscape, which is now known internationally as a world-famous skiing region, but has so far been little explored archaeologically. The Brixental is an approximately 30 km long south-eastern side valley of the Tyrolean Lower Inn Valley, which branches off near Wörgl and joins the Leuken Valley near Kitzbühel and consists of the municipalities of Itter, Hopfgarten im Brixental, Westendorf, Brixen im Thale and Kirchberg in Tirol (Figure 1)[2]. Based on the very prominent location of Grattenbergl (Figure 1,1) at the western entrance of the Brixental, it can be assumed that this was an important strategic position, as the route into the Brixental - and thus to the rich ore deposits in the Kitzbühel and Brixental area - could be controlled (Tomedi, 1998, p.41). However, as Grattenbergl has been poorly researched to date, it was decided to investigate this site using geophysical methods. The most important copper deposits in the Brixental are found around Hohe Salve (1.828 m a.s.l), which is a landmark visible from far away. The westernmost prehistoric site, Itter-Kraftalm (Figure 1,2), is located on the north-western slope of Hohe Salve, while the newly discovered – supposedly historical mines – at

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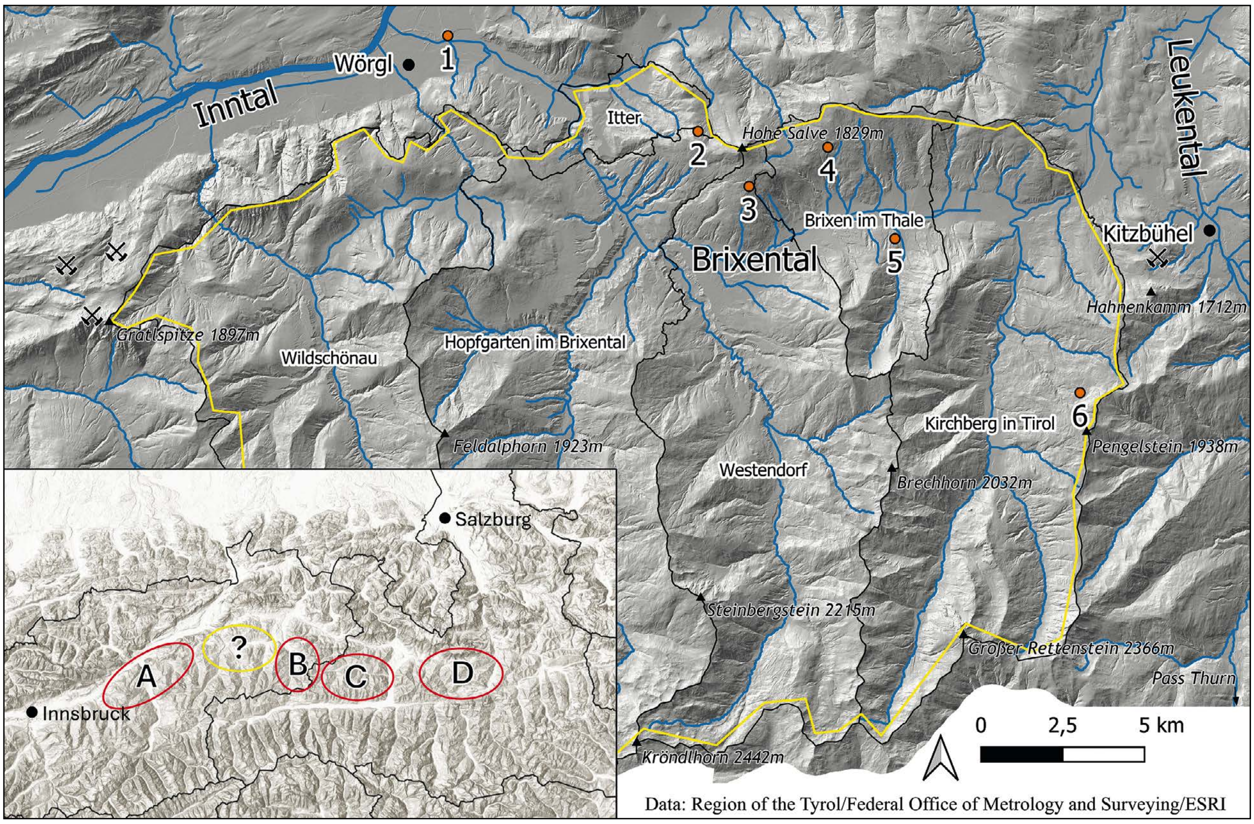


Figure 1. Topographic map of the "core-areas" of the 2023 mining survey in the Brixental: 1: Kirchbichl-Grattenbergl, 2: Itter-Kraftalm, 3: Westendorf-Jordanwiese, 4: Brixen im Thale-Niedingerwiese, 5: Brixen im Thale-Götschen, 6: Kirchberg in Tirol-Brunnalm. Bottom left: Map of the research area (yellow circle) and well-known prehistoric mining districts in the Tyrol and Salzburg (red circles): A: Schwaz-Brixlegg, B: Kitzbühel-Jochberg, C: Glemmtal/Viehhofen, D: Mitterberg. Map: R. Lamprecht.

Westendorf-Jordanwiese (Figure 1,3) are located further south. To the east there are further (presumably) prehistoric mines at Niedingerwiese (Ottneralm). Probably the best-known prehistoric mining area in the entire region is located south of Brixen im Thale near the Zöpfl homestead in the Götschen area (Figure 1,5). The easternmost site explored during the survey is located at Brunnalm in Kirchberg in Tirol (Figure 1,6), where extensive mining operations were carried out in historical times.

It is remarkable that not a single Bronze Age settlement is known from the entire Brixental valley. From the vicinity of the Brixental, prehistoric settlements are known from Bacherbirg in Aurach near Kitzbühel (Krauß, 2001, 2002, 2003, 2004, 2005) and Grattenbergl in Kichbichl. Nevertheless, a single Late Bronze Age necropolis is known in the entire valley with the Westendorf site (Merhart, 1931). Another Late Bronze Age cemetery has been found at Kitzbühel-Lebenberg at the beginning of the Brixental (Eibner and Pittioni, 1974; Scheiber, 2011). There are however numerous prehistoric stray finds known from the entire Brixental, testifying to the extensive prehistoric occupation of this region (Zemmer-Plank, 1968).

State of research - previous investigations into prehistoric mining in the Brixental

While the adjacent mining regions such as Kitzbühel-Jochberg (Much, 1879; 1902; Preuschen and Pittioni, 1939; Pittioni, 1943; 1968; Klaunzer, 2008; Koch Waldner, 2017; 2019) and Schwaz-Brixlegg (Goldenberg, 1998; 2013; 2015; Rieser and Schrattenthaler, 1998/99; Goldenberg and Rieser, 2004; Staudt, et. al., 2019a) have been researched for quite some time, the Brixental is poorly researched[3]. With the exception of the Götschen site site (Preuschen and Pittioni, 1954) south of Brixen im Thale, not a single prehistoric mining site was known in the entire valley. Heinz Neuninger, Ernst Preuschen and Richard Pittioni were able to provide evidence of prehistoric mining at Götschen in the 1960s and 1970s (Neuninger, Preuschen and Pittioni, 1970). In 1992, R. Krauss and P. Gstrein conducted an excavation at Götschen (Gstrein, 2013, p.42), however, the finds and features were not published, while later investigations (Staudt and Goldenberg, 2018; Lamprecht, 2019, Tabl.43) were also able to prove prehistoric mining. Nevertheless, a new inspection of

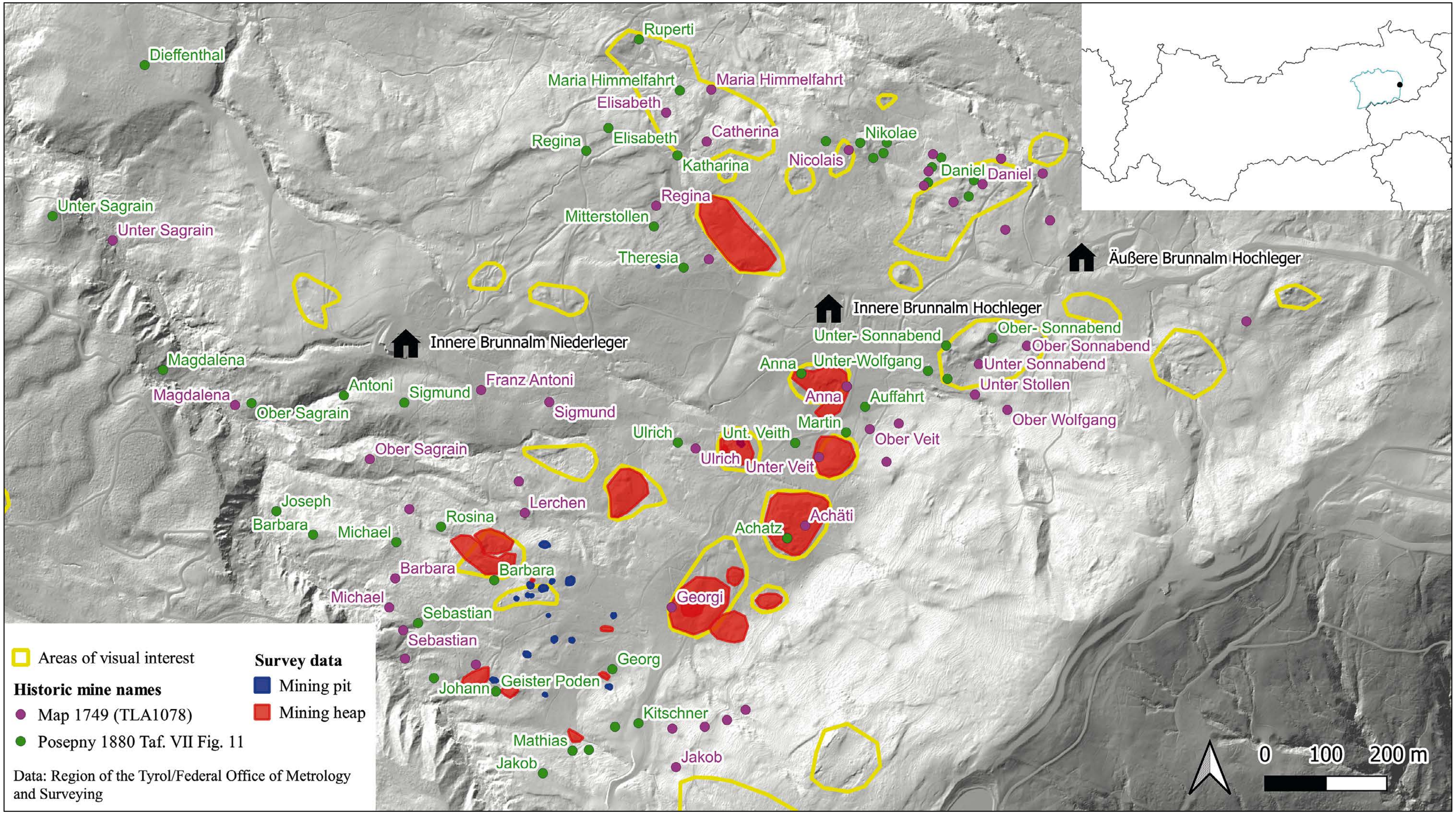


Figure 2. Map of historical mine names and the discovered features of the survey from 2023 in the area Brunnalm (Kirchberg in Tirol). During the survey, only the central area of the map was examined. Map: R. Lamprecht.

the site was necessary to gather samples for radiocarbon dating and to clarify the state of preservation of the site.

The situation is quite different at Niedingerwiese site (occasionally referred to as Ottneralm or Traholzrevier) to the east of Hohe Salve. Although prehistoric mining has long been suspected in this area (Pošepný, 1880, p.372; Isser von Gaudententhurn, 1888, p.242; Srbik, 1929, pp.160-161), no archaeological investigation has thus far proven its existence.

By far the most widespread research area was Brunnalm north-west of Jufenkamm west of Kitzbühel which is primarily known as a historic mining area. Its peak activity was probably between 1500 and 1580 AD, when fahlore, pyrite and chalcopyrite, cinnabar and quartz were mined (Pošepný, 1880, pp.374-380; Isser von Gaudententhurn, 1888, p.213). A map by P. P. Zwicknagel from 1792 shows as many as 40 mines (Pošepný, 1880, p.375; Tabl.VII, Fig.11), while another map from 1749 shows 47 mines in the Brunnalm area (unknown author, 1749). In some cases, these two historical maps could be used to locate and chronologically categorise terrain features (depressions formed by mining/"mining pits", mining heaps, etc.), which is why it was possible for the first time to assign some of the mining features on Brunnalm to a specific historical mine name (Figure 2). The main focus of the survey was on the area south of Innere Brunnalm, where evidence of prehistoric mining (stone tools, ore processing layers etc.) were discovered in 2011 (Albrecht, Schrattenthaler and Rieser, 2012).

The last core area of the 2023 survey was Kraftalm in Itter west of Hohe Salve. There are several presumably prehistoric mining structures in the immediate vicinity of the new *Alm*[4] built in 2020. Apart from a brief mention of large fire-set mines by Peter Gstrein (Gstrein, 2013), these mines were completely unknown in the literature and consequently not investigated. The collection of prehistoric artefacts related to mining activities (stone tools, ceramics, slags etc.) by the mining researcher Hanspeter Schrattenthaler provided new insights into these structures and indicates extensive prehistoric mining in this area.

Research history of Grattenbergl in Kirchbichl

First finds were discovered on Grattenbergl in the first half of the 19th century; however, they were originally thought to be the remains of a Roman settlement. Further finds came to light in 1813 during the construction of ramparts (von Mersi, von Pfaundler and Röggel, 1834, pp.267-268; Wörgler Antiquitätenverein, 1842, p.2583). On the southern side of the Brixentaler Ache, a large Iron Age necropolis was uncovered on Egerndorfer Feld in the 19th century and subsequently explored by various archaeological excavations. In total, over 700 cremation graves were uncovered (Egg, 2016, p.270). Archaeological research of the immediate surroundings - and thus also of Grattenbergl - experienced an enormous boost because of the excavations at Egerndorfer Feld. In 1911, Franz von Wieser reported traces of a ring wall on Grattenbergl, but also noted that there were still remains of the fortifications from 1809 (Tyrolean Rebellion) in the same area (Wieser, 1911, p.4). However, it is no longer possible to reconstruct the location of these fortifications, as they are no longer visible. It is also still unclear to what extent Grattenbergl was affected by the military actions of 1809. All we know is that Austrian soldiers were stationed there for some time (Prem, 1909; Mertelseder and Schemfil, 2007, p.100).

The first archaeological excavations on Grattenbergl were carried out in two campaigns between 1975 and 1978 by the Archaeological Department of the Tyrolean State Museum Ferdinandeum (Liselotte Zemmer-Plank). On the south side of the hilltop, a 74 m long excavation trench was opened[5], in which settlement phases between the Bronze Age and the Latène period were identified (Egg, 1976, p.343; 1979, p.167; Zemmer-Plank, 1990, p.96, nt.117). Unfortunately, the excavations had to be stopped and the results have remained unpublished to this day, meaning that an important prehistoric find complex has been inaccessible for the scientific community. The mining researcher Robert Krauß carried out another excavation on the eastern side of Grattenbergl in 1995, the results of which also remain unpublished (Sölder, 2014, p.19, 29). Since then, no more archaeological investigations have been carried out. Nevertheless, there have been reports of stray finds from Grattenbergl (Merhart, 1934, p.103; Gleirscher, 1986; Zanesco, 1994). One of the most substantial find complexes is probably the one recovered by Hans Appler, Alexander Altenburger and Josef Zeisler, which includes 50 kg of pottery fragments. Chronologically, the finds could be assigned to the Hallstatt C and D phases (Appler, Altenburger and Zeisler, 1997, pp.12-13, 51-54). In addition, various metal artefacts (Appler, 2010, pp.76-81), *tuyères* (Töchterle, et al., 2013, p.6; Tomedi, Töchterle and Staudt, 2013, p.62, 64, Fig.10) and stone tools (Lamprecht and Haas, 2022) were discovered, which allow us to conclude that metallurgical activities were carried out at the site. Unfortunately, Grattenbergl is a popular target for illegal metal detectorists and illegal diggers, which is why many finds can be considered to be lost.

Mineralogy of relevant ore deposits

The Brixental is located in the greywacke zone and the Northern Calcareous Alps as well as in the areas bordering Salzburg in the Silvretta-Seckau Nappe System (Kreuss, 2008). As in the case of the Hohe Salve, the copper deposits are found within the Schwaz Dolomites, the Wildschönau Schists and the Banked Dolomites (Kreuss, 2008) or in the case of Brunnalm in Kirchberg in Tyrol within a mixture of Banked Dolomites and Sandstone, Siltstone and Claystone (Heinisch, et al., 2003). Interestingly, the Brixental has also chalcopyrite ores in addition to the fahlore known from the Schwaz-Brixlegg district. While fahlore and chalcopyrite are prominent at the Götschen site, fahlore dominates at Brunnalm and in the Traholz district (=Niedingerwiese) (Vohryzka, 1968, pp.17-24; Neuninger, Preuschen and Pittioni, 1970, pp.22-23; Vavtar, 1977) as well as Itter-Kraftalm and Westendorf-Jordanwiese.

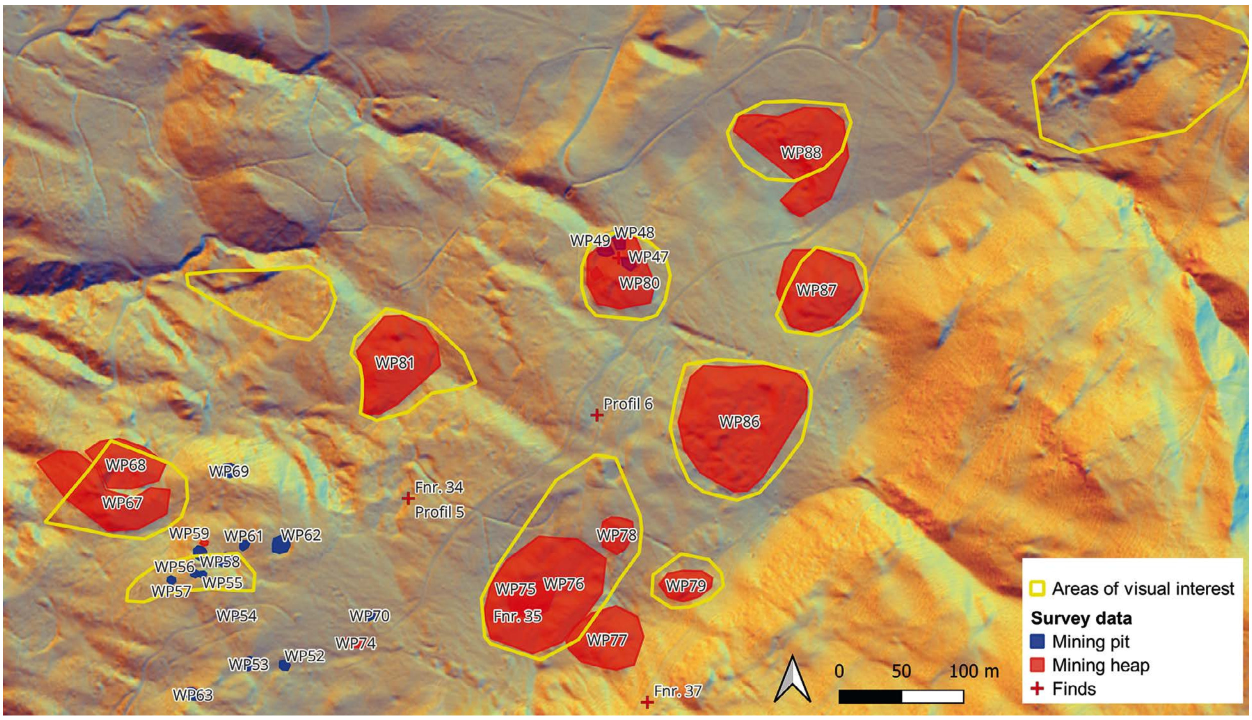
Methods of surveying

Field survey

Prior to the archaeolgical fieldwork, extensive research was carried out over a period of several weeks. The evaluation of geodata (aerial photographs, terrain models, geological maps) was important in this context, as mining structures can be identified based on suspicious terrain features such as artificial fills (mining heaps) and places where material was extracted (depressions formed by open-cast mining, underground mines, etc.). Such suspicious terrain structures can be identified in the digital terrain models based on previous experiences gathered during field surveys undertaken in the historic and prehistoric mining districts in the Lower Inn Valley. The analysis of a hillshade model[6] according to visual criteria like artificial elevations and depressions described above was particularly useful in this step (Figure 3). In addition, elevation contour lines (distance 0.50 m) were created to be able to identify possible mining structures more easily. As a result, it was possible to define a total of 121 areas of visual interest for the entire project area, which could then be specifically visited during the subsequent field surveys. The written sources on mining in the Brixental provided several other potential sites where mining could not necessarily be detected during the surveys. A further source for defining areas of interest is the Interactive Raw Material Information System (IRIS)[7], which lists mineral deposits throughout Austria. In this case, the copper deposits in the study area were of particular interest.

To have all relevant geodata available in the field, a standard tablet (Android) and various smartphones with

Figure 3. Areas of visual interest based on the DEM (yellow areas) connected with survey data (depressions formed by open-cast mines or collapsed adits/"mining pits": blue, mining heaps: red, finds: red cross). The mining traces in this area showed to be related to intense mining activities in the Early Modern Age (15th - 18th century AD). Core region "Brunnalm" in Kirchberg in Tirol. Geodata: Region of the Tyrol/Federal Office of Metrology and Surveying. Map: R. Lamprecht.



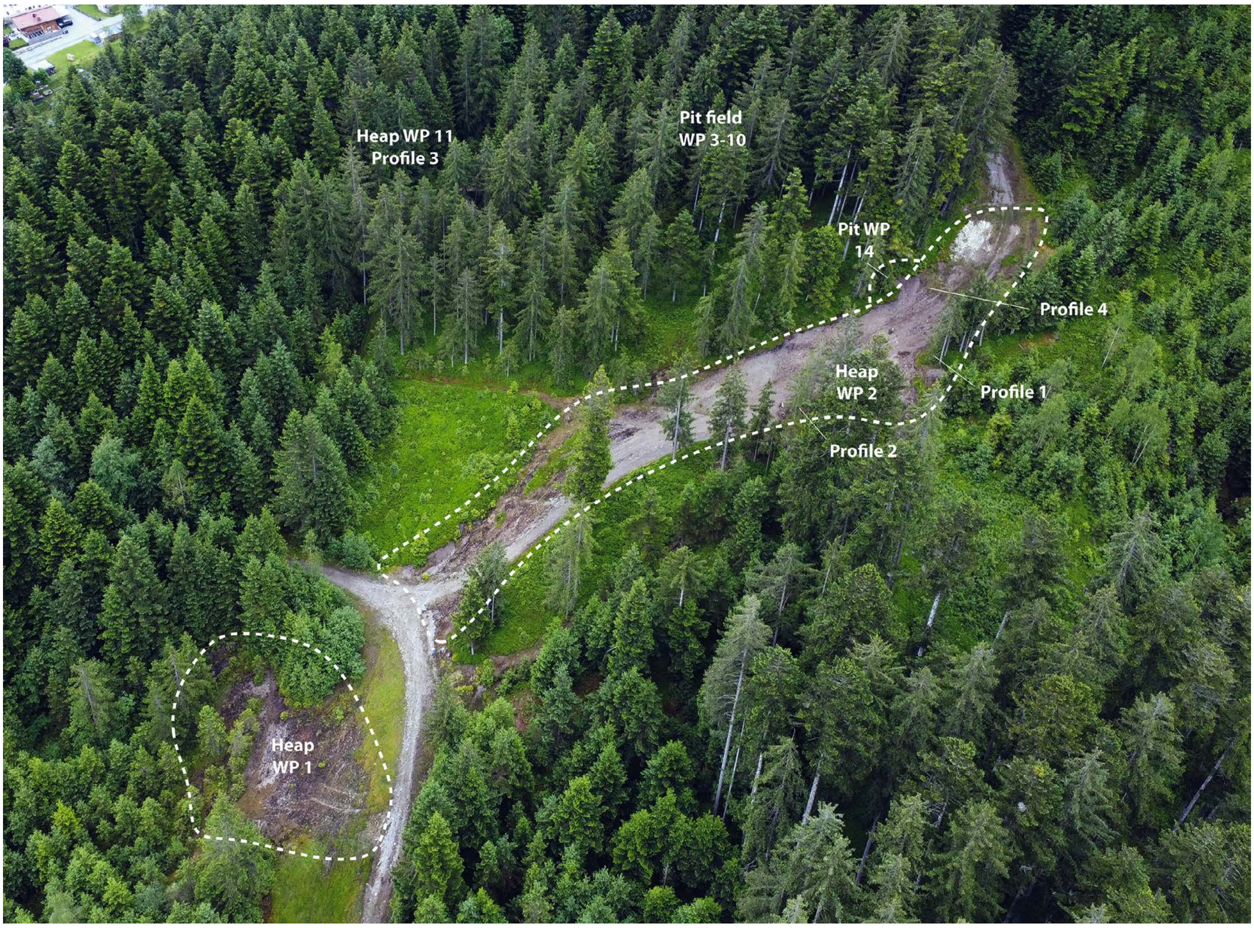


Figure 4. Drone image of the prehistoric mining area at Götschen near Brixen im Thale. Photo: R. Lamprecht.

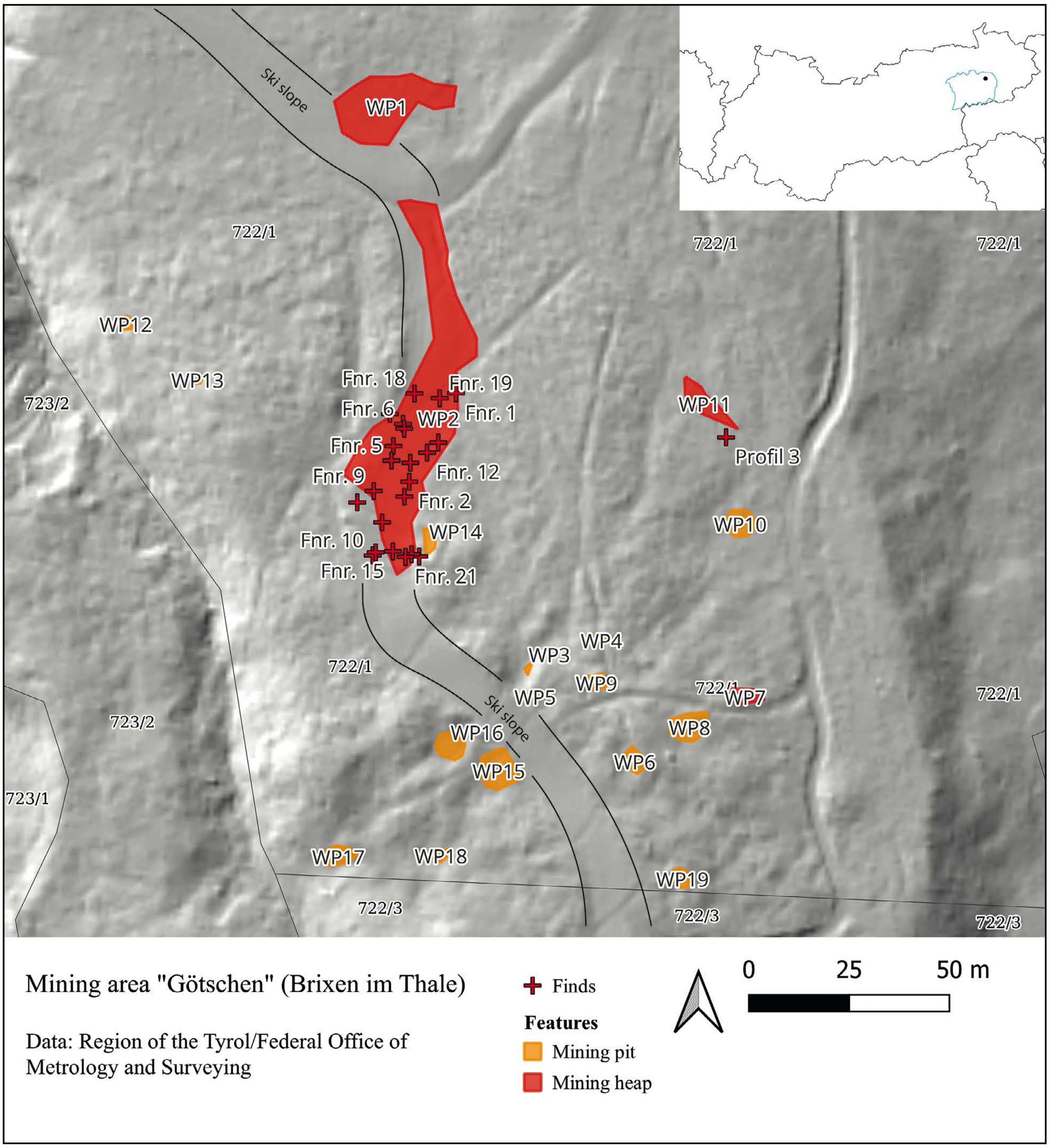
the portable QGIS application Qfield[8] and Locus Map[9] were used. These devices were subsequently used to map the finds and structures using GPS. All discovered finds and features were measured, photographed and described using a dedicated recording sheet. Each feature relevant to mining archaeology was described as waypoint (WP). In this way, 109 features were discovered. The most common features were depressions formed by mining (open-cast mines or collapsed adits; N=53), mining heaps (N=35), collapsed mine entries (N=5) and open adits (N=4). In four cases, fire-set mines were found, which are indicators for prehistoric mining activities. Structural features not related to mining activities, such as mounds, ditches and buildings, were documented in one case each, while natural rock crevices were discovered five times. It became clear that the in-depth analysis of terrain models and other available geodata were essential in making the archaeological fieldwork as effective as possible. The documentation of the discovered finds and structures using the mobile QField application proved to be a useful tool. This methodology ultimately led to the discovery of several previously unknown mining areas.

Geomagnetic measurements

As part of the project, geophysical surveys were carried out on the well-known prehistoric settlement on Grattenbergl. An attempt was made to investigate the eastern side of Grattenbergl, as surface finds (stone tools, slag, *tuyère* fragments, etc.) have been collected there in the past that could indicate local metallurgy. Due to the nature of the terrain, four survey areas were defined. In addition to the geomagnetic measurement, stray finds from occasional surveys (Lamprecht and Haas, 2022) were also included in this study. For the geomagnetic survey, a hand-held 5-channel fluxgate gradiometer from Sensys (sensor distance: 0.50 m) was used for the magnetic surface investigation of small and medium-sized areas for ferromagnetic objects, interference fields and signatures.

The measuring device used for the geomagnetics, a MAGNETO® MXPDA from SENSYS, is a hand-held 5-channel fluxgate gradiometer (sensor distance: 0.50 m) for the magnetic surface examination of small and medium-sized areas to detect ferromagnetic objects, interference fields and signals. The sensors used are vertical differential magnetometers with a measuring range of ±8,000 nT. As the resulting measuring data was influenced by numerous ferromagnetic interferences, a threshold of ±30 nT was used for the interpretation. The georeferencing of the hand-staked measuring areas was done by measuring the corners of each area using a differential GNSS system[109]. Due to the limited topography of Grattenbergl, it was not possible to establish a large measuring area (area 1: approximately 17 x 17 m), making interpretation of the measurement results difficult. The measured data was processed with the SENSYS DLMGPS® (version 4.01) and MAGNETO-ARCH® (version 1.00) software, generated as a digital greyscale image and archaeologically interpreted in a Geographic Information System (QGIS). All work was carried out and evaluated in accordance with the current standards of the Austrian Federal Monuments Office[11]. The results were then analysed and discussed with fellow scientists from the department of Archaeologies from the Leopold-Franzens University of Innsbruck.

Figure 5. Plan of the mining structures at Götschen in Brixen im Thale. Plan: R. Lamprecht.



Discovered mining features in the Brixental

Brixen im Thale - Götschen

The best-known prehistoric mines in the entire Brixental are located in the Götschen area, north of Zöpfl farm on the south side of the village of Brixen im Thale. So far, no mapping of the mining features has been published, therefore a new inspection of the site was necessary. Also, the preservation of the site was unclear, as a ski slope from Kandleralm ("Variante 16a Götschen-Abfahrt") was constructed between 1963 and 1965 (Feichtner and Posch, 1988, p.366). The ski slope cuts through parts of the former ore extraction area and the corresponding mining heaps on a large scale. These areas can still be seen today as unvegetated areas, with the largest mining heap (WP2) being exposed over a length of almost 100 meters. The Götschen site is divided into a southern part, where an area with depressions formed by opencast mining is located, and a northern part, where large mining heaps can be found. A total of 14 depressions (WP3-6, 8-10, 12-19) and four mining heaps (WP1, 2, 7, 11) were discovered (Figure 4). The lowest of these heaps (WP1) is in the far north of the site and based on its characteristics, is most likely to be interpreted as an ore beneficiation site (Figure 5). To clarify the features of WP2, small test pits and profiles were created at three locations. An additional test pit (profile 3) was opened

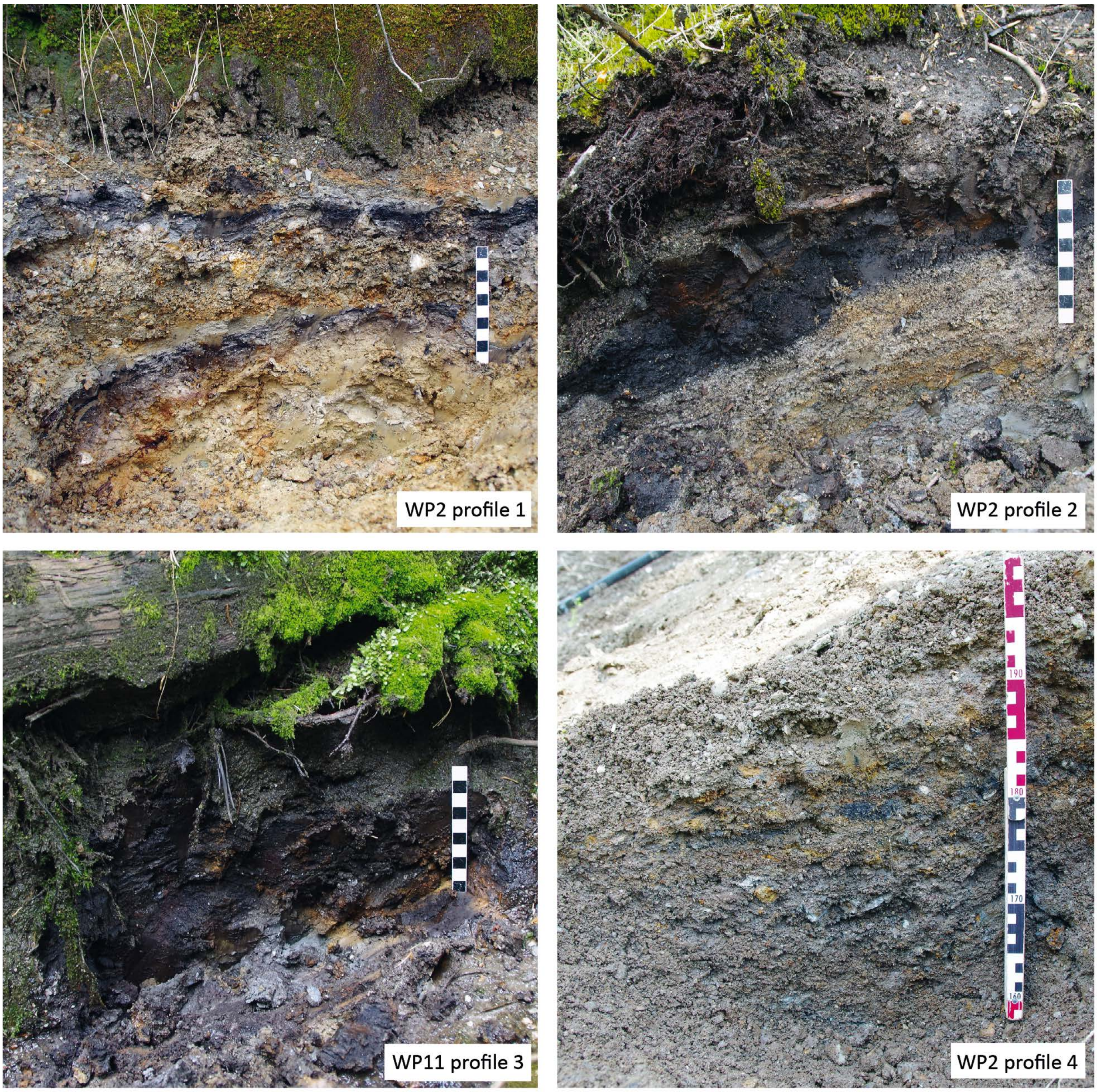


Figure 6. Profile sections of mining heap WP2 and 11 at Götschen in Brixen im Thale. Profile 4 shows characteristic ore beneficiation layers consisting of small ore and charcoal particles. Photos: R. Lamprecht.

at mining heap WP11. All profiles showed charcoal layers of different thicknesses (Figure 6). Ore processing layers were mainly found in profile 4, where also larger charcoal fragments (BX21) and a ceramic fragment were discovered.

A large number of stone tools, fahlore and pottery fragments were found on the surface in the entire upper area of mining heap WP2. To the east of the large mining heap WP2 there is another heap, WP11. In this area, charcoal layers were also discovered (profile 3, Figure 6). The corresponding mines ("mining pits") are located to the south of the mining heaps and appear as mostly circular depressions of 2 to 9 m in diameter and a depth of up to 4 m (WP3). The former ore extraction area is heavily overgrown and covered by a forest, only the water-filled depression WP16 is clearly visible.

Itter - Kraftalm

In the immediate vicinity of Kraftalm in Itter (Figure 7), several fire-set mines (WP102, 105-107) and corresponding mining heaps (WP103 and 104) are located at the foot of a steep cliff. In addition to smaller fire settings (e.g. WP105) there were also larger underground mines (WP102). The fire-set mine WP102 is divided into a smaller mine in the east and a larger structure in the west. The eastern mine is 3.6 m long, on average 1.5 m wide and 2.3 m high and currently contains a statue of Virgin Mary (Figure 8, left). The western mine (Figure 8, right), on the other hand, is 10 m deep, 1.2 m wide and 1.7 m high. In the centre of the mine, a shaft branches off downwards, which is filled with large amounts of rubbish (broken dishes, glass, metal, etc.) and can still be recognized as such 7 m down. This means that the original depth of the mine remains unclear. However, it is striking that the entire mine was made by fire-setting. In some areas traces of historic mining phases could be seen in form of scaffolding foundations and sporadic marks from mallet and gad. Mining heap WP103, located below WP102, is rich in fahlore and bones coloured green (BX41) by copper minerals. Most likely this structure belongs to the mines located above.

A little further to the southeast, several mining structures can be found below a road bend. In addition to the extensive opencast mine WP37, there are several smaller partially fire-set mines in the immediate vicinity (WP38, 40, 41 and 108) as well as an associated mining heap (WP39). The opencast mine WP37 has an extension of 20 (W-E) by 25 (N-S) m and is up to 15 m deep (Figure 9). As the mine consists of many fire-set domes, it is very likely that it was created in prehistoric times. More recent (probably Late Medieval/Early Modern Age) phases of mining are indicated by the presence of drillholes for blasting (Figure 10, no. 3), wedge pockets (Figure 10, no. 4), scaffolding foundations (Figure 10, no. 6) and marks from mallet and gad. However, these traces do not indicate large-scale mining activities in historic times, so explaining the good preservation of the site. As no datable material could be collected from the surface, the authors decided to carry out a small test excavation (SuS 1) in the entrance area of the mine. In an area measuring 30 x 30 cm, waste material was found over the entire depth of the pit. At a depth of about 60 cm, the floor of the fire-set dome was reached. At a depth of about 50 cm, unglazed pottery, animal bones (BX27) and charcoal (BX26) were discovered.

To the west, WP37 is bordered by various fire-set mines (WP38 and 108), in both mines traces of a younger mining phase (drillholes) were discovered. A little further downhill, a collapsed mine (WP40) and a fire-set adit (WP41) can be found. WP41 consists of several fire-set domes in the entrance area and continues in the form of a 35 m deep adit, which was made using the fire-setting technique on its entire length. It is possible that the fire-set domes in the entrance area represent the oldest phase of the mine, which was subsequently extended to its final length. Among the above-mentioned features, mining heap WP39 is located, which is rich in fahlore. Due to the steepness of the terrain, a mixing and/or overlapping of prehistoric and younger mining heaps can be assumed.

Brixen im Thale - Niedingerwiese

The area is composed of a prominent hilltop, surrounded by numerous depressions (WP27, 29, 30) and mining heaps (WP28, 31), and a southern area containing depressions (WP22, 24) and mining heaps (WP23, 25). An extensive mining site (WP32) can be found on the plateau to the north of the hill, which is characterized by several very large depressions (Figure 11). The largest mining heaps (WP23 and 25) are located about 150 m south of the hilltop and probably belong to the depressions (= ore extraction sites) WP22 and 24 (Figure 12). The depressions are therefore probably the remains of collapsed mine entrances. Both mining heaps are now exposed in several places by the roadway, which means that a lot of fahlore can be found on the surface. A little further uphill, another mining heap (WP28) is opened up by the roadway, on which a lot of charcoal and pottery was found in addition to fahlore. According to Hanspeter Schrattenthaler, who has repeatedly visited the site in the past, a large part of the charcoal originates from a small hill that used to be located west of the re-

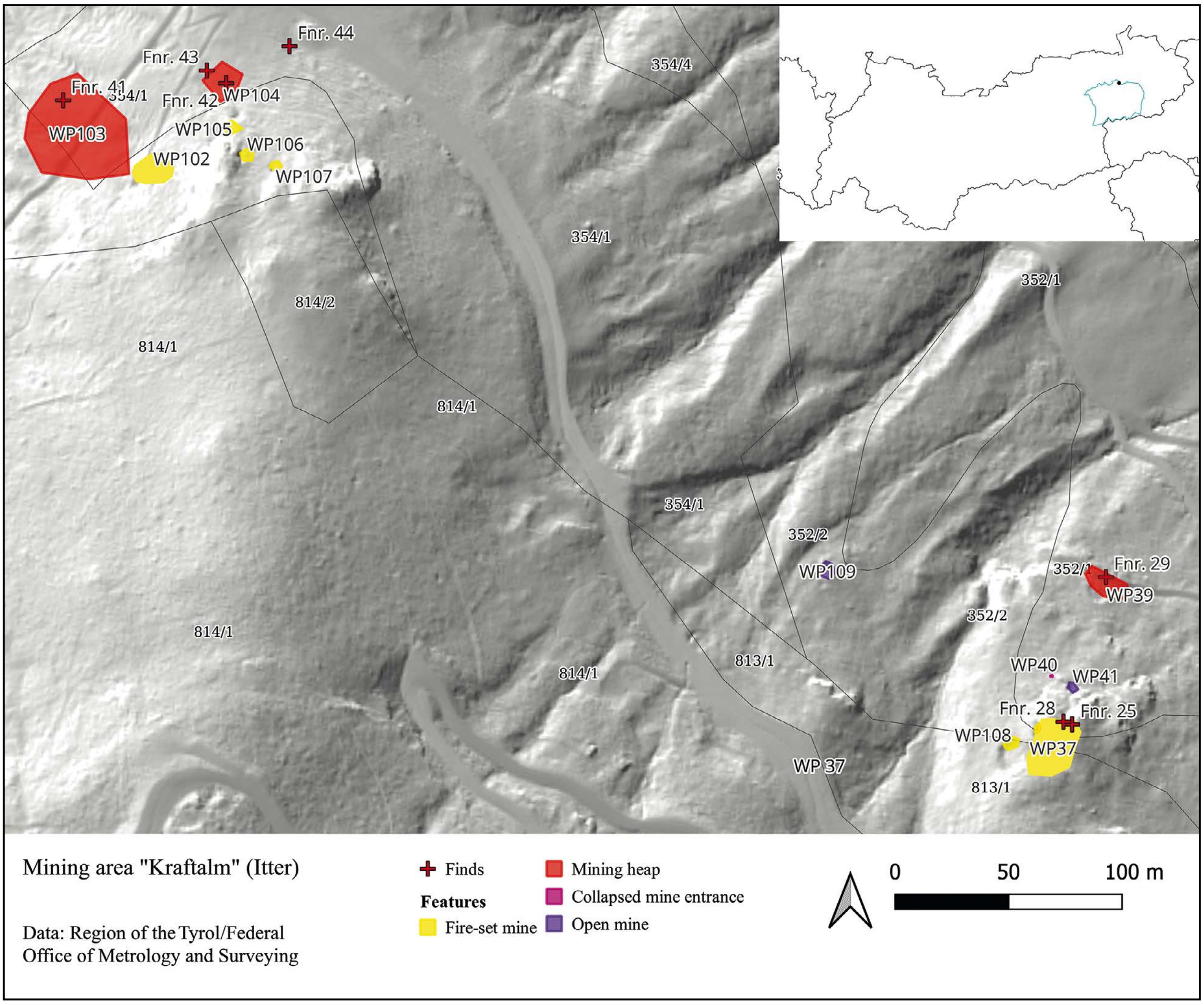


Figure 7. Plan of the mining structures at Kraftalm in Itter. Map: R. Lamprecht.

Figure 8. Fire-set mine WP102 at Kraftalm in Itter. Photos: R. Lamprecht.

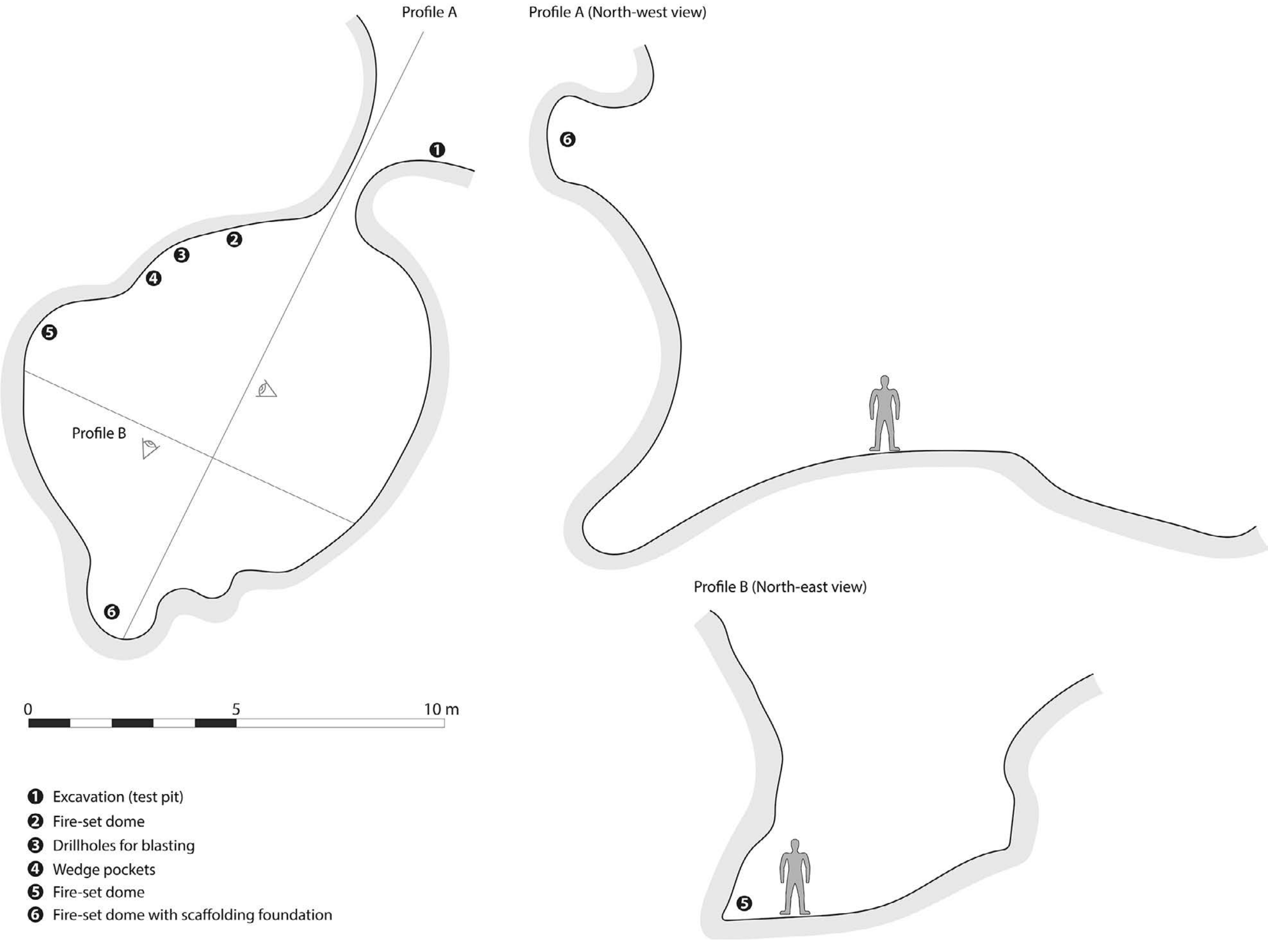


Figure 9. Top view (left) and profiles (right) of the WP37 open-cast mine at Kraftalm in Itter. Map: R. Lamprecht.

cent roadway and was spread over a large area during land consolidation. Analysis of aerial photographs show that there were major disturbances in the area between 2004 and 2012, whereby the forest cover was reduced and the road was enlarged. An Eastern Alpine upper grindstone found by Alexander Albrecht, which is best known from the prehistoric mining areas of Mitterberg and Kitzbühel-Jochberg, was discovered in this area. On the hilltop itself there are some smaller depressions (WP27, 29 and 30) and a small mining heap (WP31). By far the largest depression (WP32) can be found on the flat area north of the hilltop extending 50 m W-E and 40 m N-S and a maximum depth of up to 6 m. Unfortunately, due to the recent use of the area as animal pasture, no large-scale soil exposures are currently visible, which is why the chronological context must remain unclear for the time being. However, a prehistoric origin of these features seems plausible.

Kirchberg in Tirol - Brunnalm

By far the largest number of mining traces could be discovered on Brunnalm in Kirchberg in Tirol, even if none of the structures found can be assigned to a prehistoric period. However, the area was intensively researched during the 2023 survey as there is evidence of prehistoric mining (Albrecht, Schrattenthaler and Rieser, 2012). Since the discovery of the possibly prehistoric finds and features in 2011, massive changes to the terrain have taken place due to the construction of a ski slope and a lift. Despite repeated consultation with the 2011 survey team, it was no longer possible to locate the site of 2011. However, in the immediate vicinity a total of 22 depressions (WP47, 48, 51-58, 60-63, 65, 69-71, 73, 83-85), 20 mining heaps, some of them very large (WP49, 50, 59, 64, 66-68, 72, 74-82, 86-88) and a building (WP46) were discovered during the 2023 survey (Figure 13).

The objective was not only to localize possible prehistoric mining, but also to cover as much of the large area of Brunnalm as possible. While overgrown mining heaps are very common in the entire Brunnalm area, depressions formed by collapsed adits were found more frequently in the flat terrain in the south. For this reason, the focus was on the area south of the Hochleger ("upper pasture") of Innere Brunnalm (Figure 14). As the mining

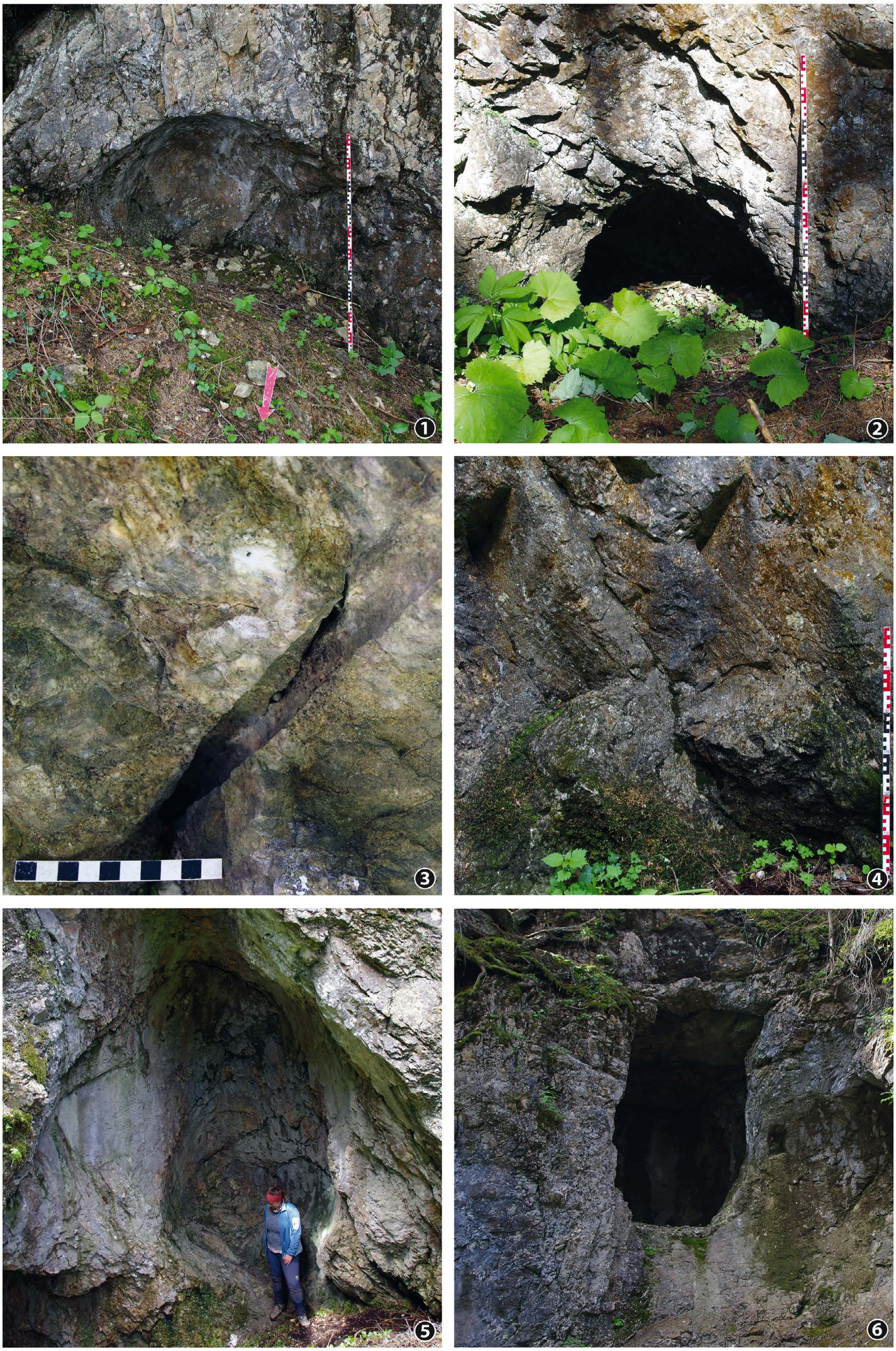


Figure 10. Details of open-cast mine WP37 at Kraftalm in Itter. 1: Fire-set dome in the area of the excavation test pit, 2: Fire-set dome, 3: Drillhole for blasting, 4: Wedge pockets, 5: Large fire setting in the rearmost area, 6: Fire setting and scaffolding foundation. Photos: R. Lamprecht.

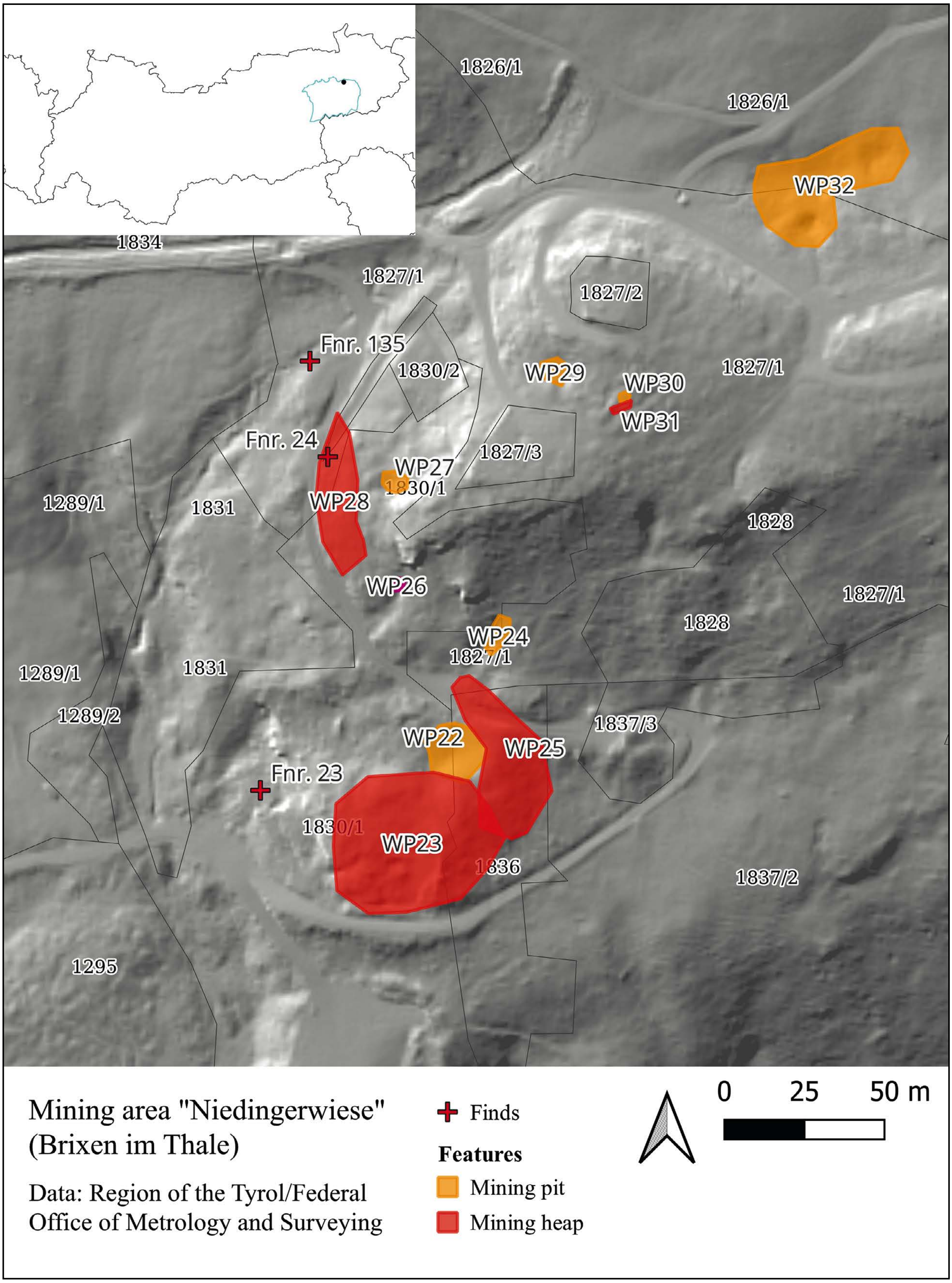


Figure 11. Plan of the mining structures at Niedingerwiese in Brixen im Thale. Map: R. Lamprecht.

Figure 12. Drone image of the mining features at Niedingerwiese in Brixen im Thale. Photo: R. Lamprecht.

heaps were all heavily overgrown, however, little datable find material was discovered (with the exception of the Late Medieval/Early Modern Age Passau-type pottery). In two places, stratigraphic layers could be documented. While one of these profiles (profile 6) showed the natural soil structure, profile 5 revealed a charcoal-bearing layer of up to 15 cm thickness over a length of several meters (Figure 15). From this layer, sample BX34 was used for radiocarbon dating. Although there were no datable finds within the dark layer, ore remains (iron-rich spots) were visible. Although the layer resembles prehistoric ore processing layers, as could also be observed at Götschen near Brixen im Thale, the dating of these samples provided insights of a Late Medieval/Early Modern Age mining period (see chapter "Results").

Westendorf - Jordanwiese

In addition to the extensive mining operations on the northern slope of Hohe Salve, a previously unknown mining area was discovered on the southern side in the area of Jordanwiese. The mining area is located north of

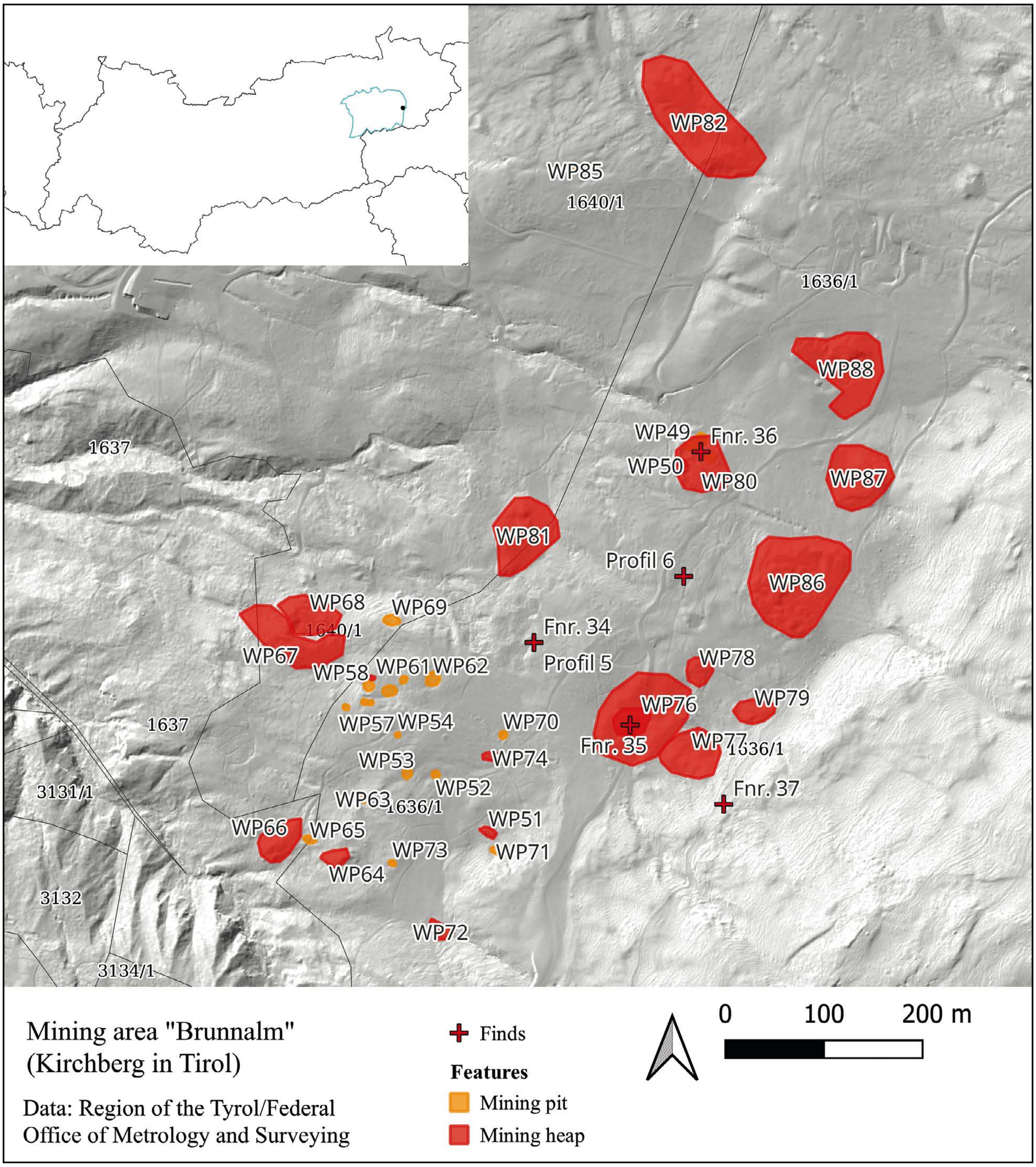


Figure 13. Detailed plan of the mining structures at Brunnalm in Kirchberg in Tirol. Map: R. Lamprecht.

a newly constructed reservoir pond on a small hilltop (Figure 16). The site is divided into the hilltop itself, on which several depressions (WP89 - 91, 98) and a small mining heap (WP92) are located. In addition, two larger mining heaps (WP94 and 95) and depression WP93 can be found down the slope, which are probably the remains of collapsed mines. While the heavily overgrown mining heaps WP94 and 95 could only be recognized as such by the structure of the terrain, remains of fahlore were found not far from depression WP89.

To the east three additional depressions were found, of which WP89 and 91 (Figure 17) were the most obvious. An indication of the chronological classification of the area can be provided by the discovery of an iron mining gad (*Bergeisen*). Therefore, it is highly probable that the mining structures found at Jordanwiese date back to the Late Middle Ages/Early Modern Age. Mines in Moosnergraben (northwest of the hamlet of Moosen in Westendorf) were already mentioned by Max Isser von Gaudententhurn (1888, p.242), which in

Figure 14. Upper picture: survey area (white area) on Brunnalm in Kirchberg in Tirol. Numerous mining heaps can be seen across the entire alpine pasture area. Lower picture: mining structures south of the Innere Brunnalm. Photo: R. Lamprecht. Photos: R. Lamprecht.

the broadest sense could also refer to the mines near Jordanwiese.

Other locations

In addition to the sites already described, there were also other sites that were mentioned in the literature as containing traces of (prehistoric) mining activities or showed anomalies in the digital terrain model, but where no mining sites could be found during the surveys. These include Falkenstein in the Spertental and Ochsalm north of Brunnalm (both Kirchberg in Tirol), Fleidingalm in the Windautal (Westendorf) and Hohe Stoagrubenalm south of Hohe Salve (Hopfgarten im Brixental). Falkenstein is located in the Spertental (Aschau/Kirchberg in Tirol), at around 1300 m above sea level and can be

Figure 15. Both charcoal and ore (rusty spots) were found in profile 5 at Brunnalm. Photo: R. Lamprecht.

Figure 17. Mining feature WP91 at Jordanwiese in Westendorf. In picture: Julia Haas. Photo: R. Lamprecht.

Figure 16. Drone image of the mining area near Jordanwiese in Westendorf. The reservoir pond built in 2013 can be seen in the lower area. Photo: R. Lamprecht.

seen from a distance as a prominent limestone formation. There are several tales surrounding the Falkenstein about a castle built by miners and a buried heathen treasure (Weinold, 1931, p.376; Schipflinger and Traxler, 1995, p.15). For this reason, and in view of the poor find tradition on the hill itself, it was decided to include this area in the survey. Except for a few small-scale quarry sites, no relevant mining structures were discovered. Instead, the remains of a medieval castle complex were discovered, which was probably a ministerial castle of the Counts of Falkenstein (Gwirl, 1999).

In the case of the Ochsalm, only a few natural rock crevices could be found. A similar situation can be observed at Fleidingalm in the Windautal, where apart from an ore sample (probably pyrite) no traces of mining could be discovered.

Geomagnetic survey at Grattenbergl

As previous research mostly focused on the highest part of the hilltop, the survey of 2023 focused mainly on the eastern side (parcel 1355/2), which has been little explored so far. Due to the nature of the terrain, four measuring fields could be defined in this area (Figure 18). Measuring field 1, covering 284 m^2, is located directly above the edge of a former quarry in the south of the hill, while field 2 (700 m^2), 3 (465 m^2) and 4 (320 m^2) are located in the northern part of Grattenbergl, resulting in a total measuring area of almost 1.800 m^2.

Since in many places on Grattenbergl the surface is formed by bedrock and the humus layer is relatively thin, a heterogenous geomagnetic measurement result was to be expected. Disturbances due to external influences were to be expected particularly in the area of a wooden fence that separates two plots of land in a north-south direction. In addition, contamination by metal objects was to be expected over the entire area, as Grattenbergl was directly affected by military operations during the Tyrolean Rebellion of 1809 and the Second World War. Further disturbances can be expected due to modern activities, as Grattenbergl is a popular destination for hikers and is now used as a pasture for horses and cows.

While in measuring area 2, 3 and 4 only a few interesting structures such as glacial gravel deposits and possibly some potential building structures (most likely postholes) could be discovered, the results in measuring area 1 were more promising. Although only very few dipoles (most likely metal objects) and negative anomalies (probably larger stones) were found in measuring area 1 (Figure 18), there were several positive anomalies in the eastern part of the measuring area. However, this is significant because a number of finds (mostly Iron Age pottery, heat-altered pottery, *tuyère* fragments, stone tools) were discovered in this area in the past. It is therefore very likely that the large positive anomalies are archaeological remains, because positive anomalies can be attributed generally to fires or heat-altered material in general. In this case, a prehistoric feature in connection with metallurgical activities like a smelting furnace or a roasting bed would be the most likely scenario. Similar measuring results were obtained in the past, for example at Mauk A (Goldenberg, et al., 2012, p.73) and Rotholz in the Lower Inn Valley (Staudt, et. al., 2019b, p.283, Fig.5) or at Val Faller Plaz in Oberhalbstein (Graubünden, CH) (Della Casa, Naef and Turck, 2016, p.7, Fig.9). At all three locations, prehistoric smelting sites were also discovered during subsequent excavations.

Finds

Ceramics

During the research, 800 ceramic fragments were either found by the research team or lend for documentation by Hanspeter Schrattenthaler. Due to the composition of the ceramic finds, a continuous use of the Grattenbergl is evident. The ceramic assemblage indicates a continuous habitation of the area and an ongoing use of local copper ores from the Early Bronze Age until the Latène period. 720 sherds weighing 3.5 kg were discovered on the surface of Grattenbergl, whereby 102 were diagnostic (14.2 %). While 56 pieces were to be classified as rim pieces, 51 pieces are to be interpreted as fine ware (thinner wall thickness, surface treatment, fine tempering). Most fragments probably originate from bowls with distinguishable zones and forms associated with HaC: three pieces were typical Hallstatt bowls with a tight rim and a short shoulder ending in a round belly (GB110, GB52 and GB79) as also found for example in Bischofshofen-Pestfriedhof (Lippert and Stadler, 2009) or Wörgl-Egerndorfer Feld (Kneußl, 1969; Tomedi, 1998, p.45, Fig.7). Another type of bowl-shaped ceramic has a rounded shape, with a round rim (Figure 19, GB 23, GB25, GB38), which also can be dated to the HaC period, as several examples from southern Bavaria demonstrate (Kossack, 1959). Besides undatable decorations like so called *Fingertupfen* (finger impressions; N=6), typically HaC red, white and black painted ware (N=10) were found. Especially GB53, with its red coloured base and a white line in the core between the rim and its shoulder is typical of HaC.

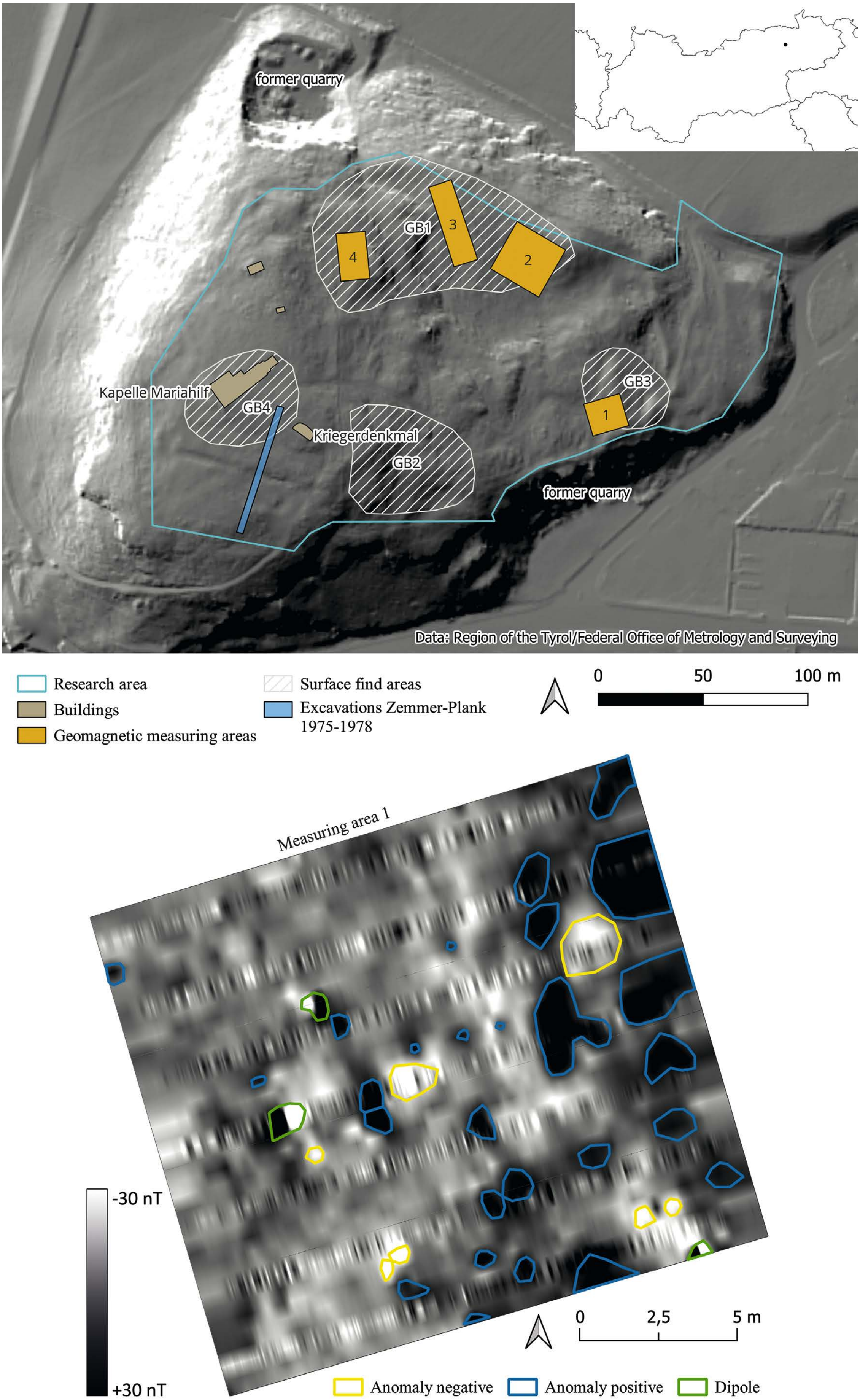


Figure 18. Geomagnetic measuring areas and surface find areas at Grattenbergl in Kirchbichl (upper image). Magnetogram of area 1 (lower image) on Grattenbergl in Kirchbichl. Treshold -30/+30 nT. Map: R. Lamprecht.

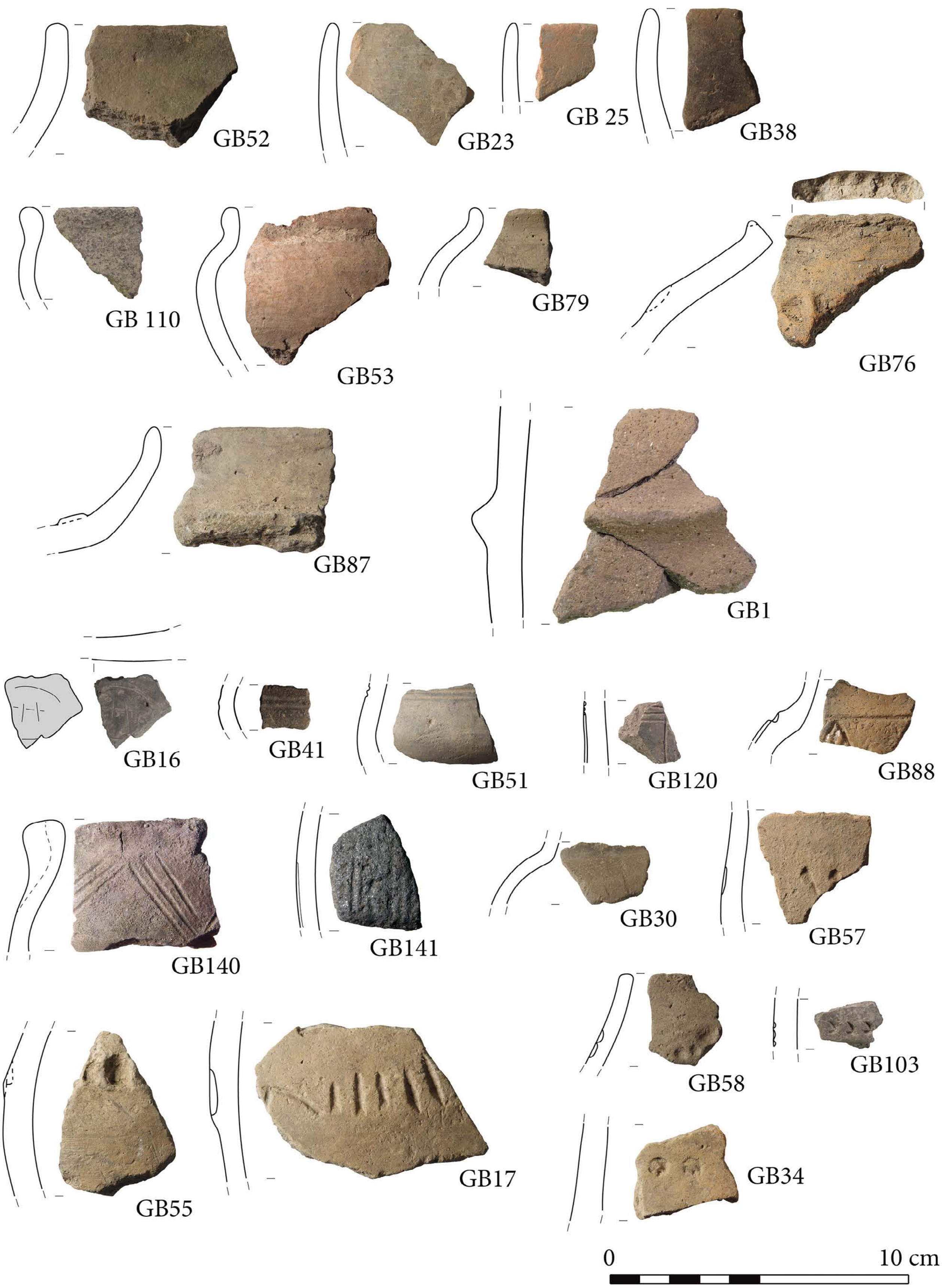


Figure 19. Prehistoric ceramics from Grattenbergl in Kirchbichl. Drawings and photos: J. Haas.

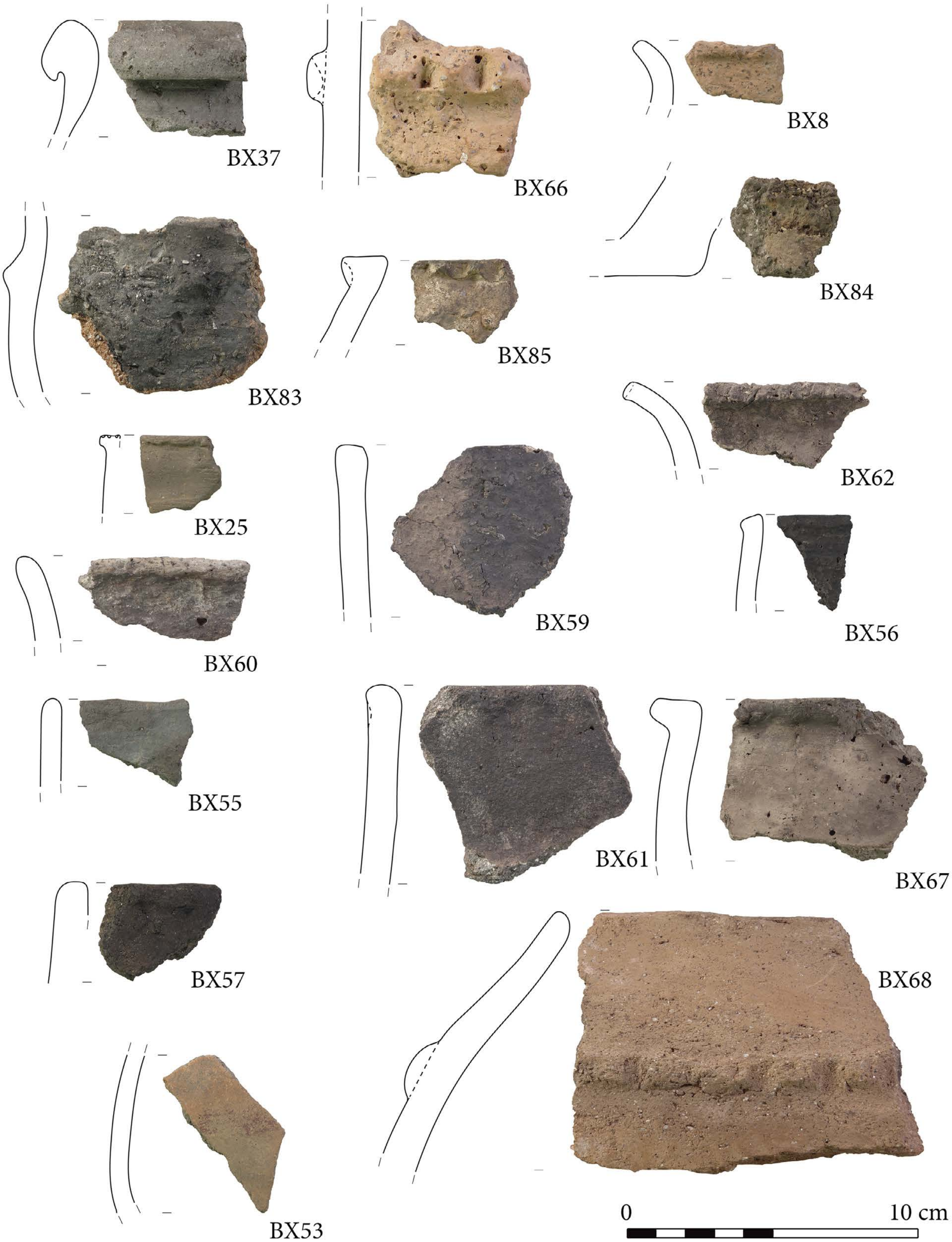


Figure 20. Ceramics from Kirchberg in Tirol-Brunnalm (BX37), Brixen im Thale-Götschen (BX66, BX8, BX83-BX85) and Itter-Kraftalm (BX25, BX53, BX55-BX57, BX59-BX62, BX67, BX68. Drawings and photos: J. Haas.

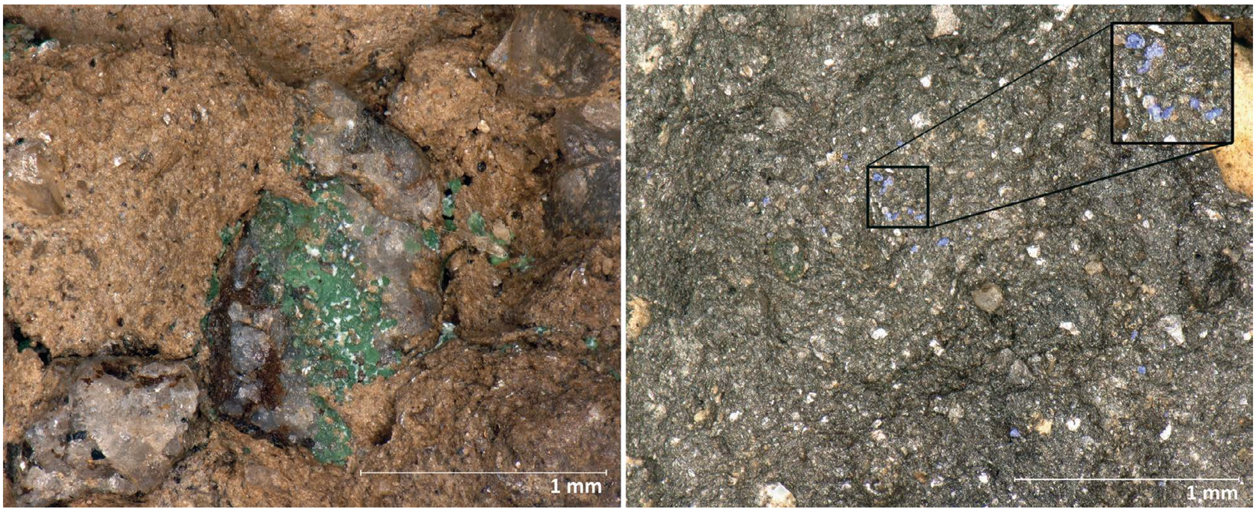


Figure 21. In some ceramic fragments from Götschen-Brixen im Thale, secondary minerals of fahlore were found embedded in the ceramic matrix (temper material). Left: malachite (green), right: azurite (blue). Photomicrographs taken by U. Töchterle and R. Lamprecht using Keyence VHX-6000.

Interestingly, a piece with engravings on the base (potentially an owner's or potter's mark) was found, however, this fragment is too small to identify its form (GB16). Moreover, two stamp-decorated (Figure 19, GB34 and GB103) and ten impressed fragments (Figure 19, GB41, GB51, GB120, GB88, GB30, GB57, GB140, GB55, GB58, GB17) were discovered and consist of either linear horizontal lines, shorter vertical lines, geometrical illustrations or round-shaped impressions. GB88 even shows residues of incrustations in the impressed hatched triangle. Rim decorations like finger impressions (*Fingertupfen*), which were very common in prehistoric times, can also be found on Grattenbergl. Three ceramic fragments might even date to younger periods than Hallstatt times. The two rounded wall fragments of GB41 and GB51 might indicate an Early Latène period, and the graphite(-tempered) ceramic with comb stroke decoration fits even in a Late Latène period (Trebsche, 2010). Generally, the conclusion for a dominant Iron Age settlement on Grattenbergl, especially on the eastern part, can be drawn. However, as the top of the hill has not been under investigation during the research, older traces of human habitation of Grattenbergl cannot be excluded. Identifying older proofs of habitation with the help of ceramics, however, is generally very difficult. For example, finger impressed decoration is long lived and has been identified in the Early Bronze Age or even earlier and was used until the Hallstatt period. Clear markers for earlier periods could only be identified with a greater assemblage of ceramics, radiocarbon dates or archaeological features. However, with the comb stroke decorated fragment, habitation from at least the Hallstatt period can be assumed.

Near Kraftalm in Itter, 40 prehistoric ceramic fragments were documented, of which 20 % (N=16) were diagnostic. Most diagnostic fragments were from the rim of the vessel (N=12), whereby two were tempered with slag. The procedure of tempering ceramics with slag is a typical form of tempering in north Tyrol, Salzburg and East Tyrol, and can be associated with a mining society (Töchterle, 2015, pp.334-337; Tropper, et al., 2019) from the Early Bronze Age until Late Hallstatt times. Other ceramic finds like Fingerprint-decoration (Figure 20, BX68) or a rim with fingernail decoration (Figure 20, BX62), as well as fine ware (Figure 20, BX55, BX56) were identified. As slag tempering and fingerinprint-decoration have such a long-term usage, only the fine ware ceramic with a red coloured line (Figure 20, BX53), limits this specific assemblage to the Hallstatt period. It must be noted, however, that all ceramics from Kraftalm were found in a large area by Hanspeter Schrattenthaler, and therefore no exact context can be given.

Probably the oldest ceramic finds from Brixental originate from Götschen in Brixen im Thale. From the 24 fragments found, five were diagnostic and three were tempered with slag. Further, visible to the eye and documented through a microscope, the ceramics were not only tempered with slag, but also partially with small pieces of fahlore (Figure 21), which has so far not been observed in other ceramic complexes. Copper-containing fine sediment was also found in the pottery from Götschen worked on by Melitta Huijsmans, together with slag, limestone and quartz sand (Huijsmans, 1994, p.156). The presence of secondary minerals (azurite and malachite) in the ceramic matrix suggests a local ceramic production in the circumference of the copper mines. As considered before, dating ceramics in the Alpine region during the Bronze Age has its difficulties due to very limited variability in decoration. However, if various factors like a rough and course surface (Figure 20, BX84), fingerprint decoration on the wall (Figure 20, BX66) fingerprint decoration on the ridge (Figure 20, BX85) or even a beak/"Knubbe" (Figure 20, BX83) can be found, Early/Middle Bronze Age contexts can be assumed.

The youngest ceramic fragment found during the 2023 survey was found at Brunnalm in Kirchberg in Tirol, where one sherd from the Late Middle Ages/Early Modern Age called "Passauer Ware" was found (Figure 20, BX37).

Stone tools

Provenance, distribution of stone tools and find context

In addition to the 22 stone tools from the 2023 survey, 55 pieces from the collections of the mining researchers Hanspeter Schrattenthaler and Alexander Albrecht accounted for most of the finds discussed in this work.[12] The largest stone tool ensemble originates from Götschen near Brixen im Thale and consists of 30 specimens. The second largest complex was found at Kraftalm near Itter (N=26), while Niedingerwiese and Brunnalm (both Kirchberg in Tirol) yielded only 3 and 4 pieces (Table 1). Furthermore, 14 stone tools were discovered at Grattenbergl in Kirchbichl. While in the case of Kraftalm it can be assumed that the ores were mainly mined underground, there is evidence of surface extraction and a corresponding ore processing at Götschen, Niedingerwiese and Brunnalm. In contrast, Grattenbergl can be considered a settlement and/or work site.

Classification and typology

For the classification of the stone tools, the typology of Lamprecht 2022 was applied (Lamprecht, et al., 2022, p.146, Fig.5), which includes 5 tool classes. Therefore, for the Brixental 32 % (N=20) can be classified as hammerstones (Cat. B, Figure 22), while 17 % (N=11) can be classified as Eastern Alpine upper grindstones (Cat. D, Figure 23). 13 % (N=8) can be identified as mallets (Cat. A, Figure 24), a further 3 % (N=2) are netherstones (Cat. C, Figure 25). Another 9 % (N=6) of the tools can be classified as multi-purpose tools (Figure 26), with only one piece (2 %) belonging to the abrader/polisher category (Cat. E, Figure 25). The remaining 24 % (N=15) could not be assigned to any category but were identified as stone tool fragments based on the raw material, which in most cases does not occur naturally in the mining areas.

In the case of Grattenbergl, 9 hammerstones (Cat. B, 64 %; Figure 22), four netherstones (Cat. C, 29 %; Figure 25) and one mallet (Cat. A, 7 %; Figure 24) could be found. Neither Eastern Alpine upper grinding stones (Cat. D), abraders and polishers (Cat. E) nor multi-purpose tools were discovered there. As many different types of cobbles occur naturally on Grattenbergl and the finds presented do not originate from archaeological excavations but rather from surface collections, no unclassifiable stone tools were found. The comparison with adjacent mining districts is useful for statistical evaluation of the stone tool categories. Since a direct comparison of the mining districts is only possible in the case of a standardized typology, the recently published stone tool

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. *= underground mining area; **= mining/ore processing area; ***= settlement/metallurgic area.

Mining District	Location	Cat. A: Tools with hafting modifications (mallets)	Cat. B: Hand-held tools (hammerstones)	Cat. C: Netherstones (anvil stones, lower grindstones)	Cat. D: Tools with hafting modifications (Eastern Alpine upper grindstones)	Cat. E: Abraders and polishers	Multi-purpose tools	Unclassifiable	**Total**
Brixental	Brixen im Thale – Götschen**	2	12	2	10		3	1	30
	Itter-Kraftalm*	4	6				2	14	26
	Brixen im Thale – Niedingerwiese**	2			1				3
	Kirchberg in Tirol – Brunnalm**		2			1	1		4
	Kichbichl – Grattenbergl***	1	9	4					14
Total		**9**	**29**	**6**	**11**	**1**	**6**	**15**	**77**

Figure 22. Hand-held "hammerstones" (Cat. B) from Brunnalm (BX100), Kraftalm (BX70 & BX71) and Grattenbergl (GB133). Drawings and photos: R. Lamprecht.

complexes of Schwaz-Brixlegg (Lamprecht, et al., 2022) and Kitzbühel-Jochberg (Staudt, et al., 2024) are particularly relevant in this regard. Therefore, more mallets were discovered in the Brixental than in Kitzbühel-Jochberg, but not nearly as many as in Schwaz-Brixlegg. A remarkably large amount comprises hammerstones and thus surpasses the adjacent districts in terms of quantity. On the other hand, very few netherstones were discovered, which in the case of Jochberg, for example, represents one of the largest groups. There is a comparatively large proportion of Eastern Alpine upper grindstones, mainly due to the Brixen im Thale-Götschen site. Abraders and polishers are relatively rare in the Brixental - as well as in other mining areas - whilst multi-purpose tools are also frequently found. It should be noted, however, that the type of archaeological examination (surface collection, survey, excavation, etc.) is particularly important for the composition of a stone tool complex, as different assemblages can be expected depending on the methodology used. While in the case of archaeological excavations a representative quantity of tools is to be expected, complexes found at archaeological surveys can only be assumed to have limited statistical relevance, as they are primarily superficial collections.

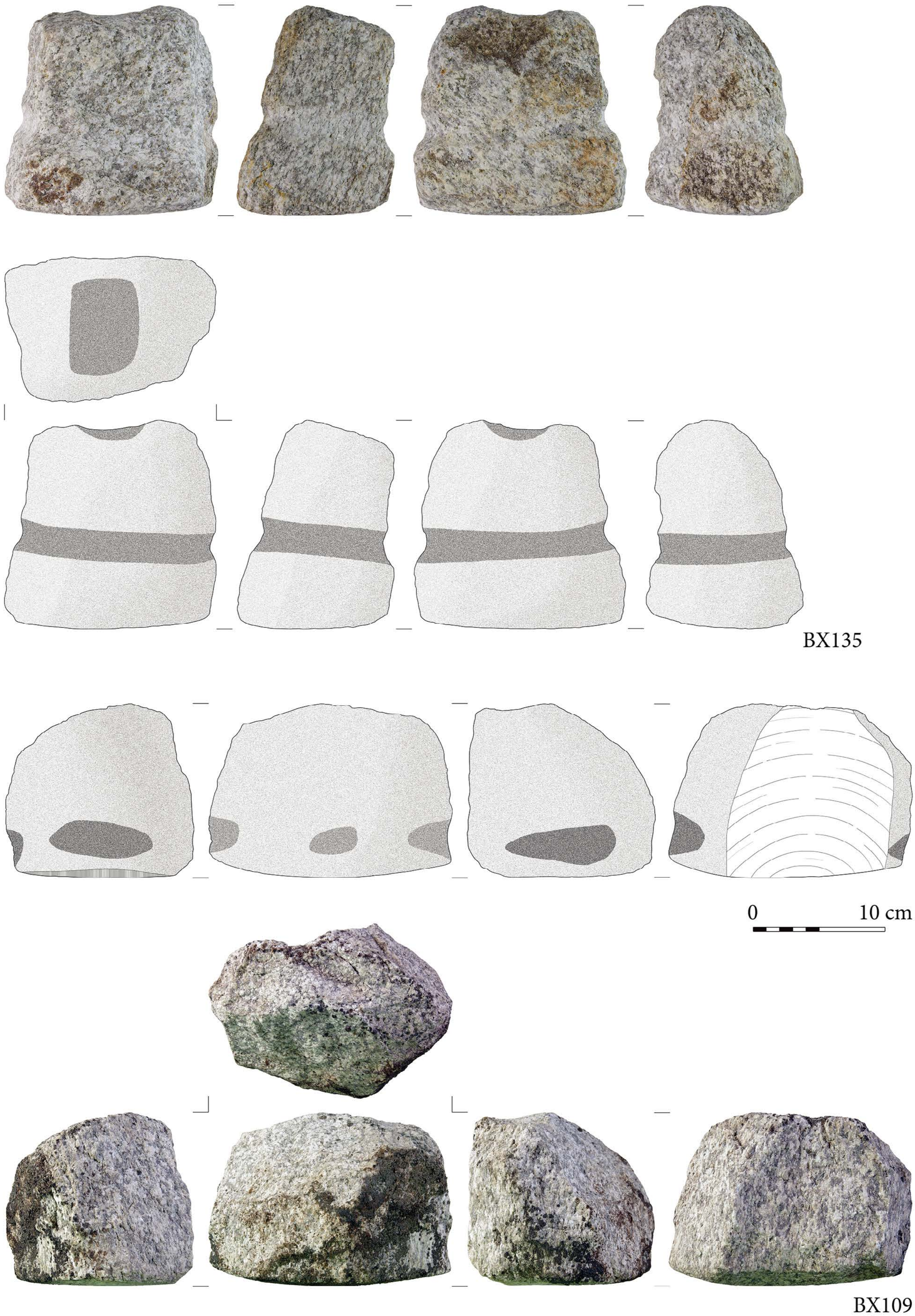


Figure 23. Eastern Alpine upper grindstones (Cat. D) from Niedingerwiese (BX135) and Götschen (BX109). Drawings and photos: R. Lamprecht.

Figure 24. Tools with hafting modifications ("mallets", Cat. A) from Niedingerwiese (BX98), Götschen (BX114), Kraftalm (BX81 & 79) and Grattenbergl (GB139). GB139 was found by Christof Maurer (Kramsach) in 2022. Drawings and photos: R. Lamprecht.

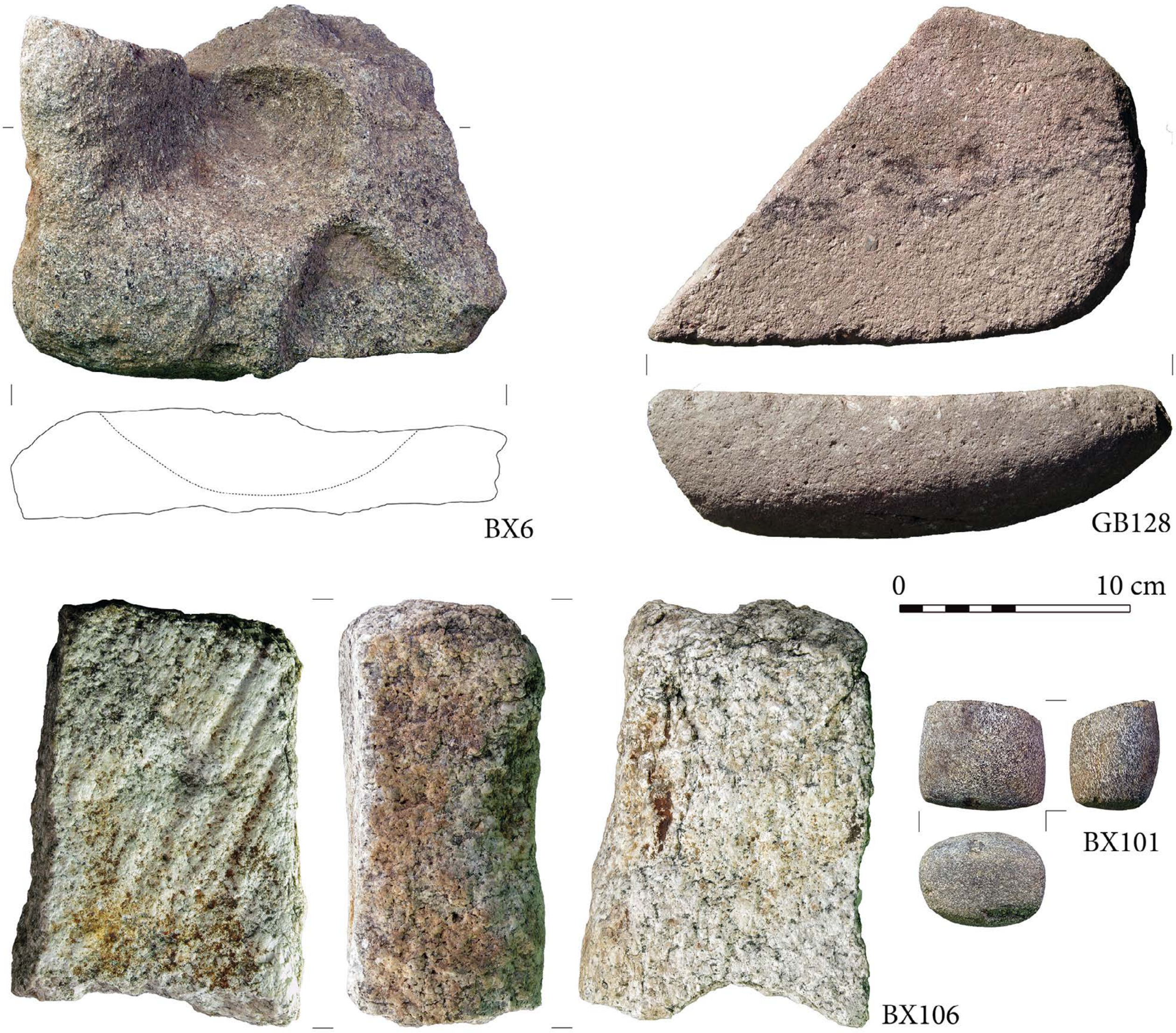


Figure 25. Netherstones (Cat. C) for pounding (BX6) and grinding ore (BX106) from Götschen and lower grindstone from Grattenbergl (GB128). BX101: Abrader/polisher (Cat. E) from Brunnalm. Drawings and photos: R. Lamprecht.

Field of application and use

Mallets (Cat. A) have been hafted in many ways, generally a piece of wood is attached as a handle using plant or animal material (Lamprecht, et al., 2022, pp.147-149). This type of tool is used in a large variety of applications, but in connection with mining probably mainly for ore processing above ground (Thomas, 2018, p.357), but also for loosening rock after fire-setting (Goldenberg, 2013, p.101). Hand-held percussion implements (Cat. B) made of unmodified cobblestones are equally versatile. During the ore-beneficiation process, netherstones (Cat. C) were used for either grinding (lower grindstones) or pounding (anvil stones). Grinding surfaces sometimes show linear striations, while anvil stones are characterized by depressions formed by pounding. Eastern alpine upper grindstones (Cat. D), on the other hand, are a specialized tools that can so far only be found in Eastern Alpine mining districts like Mitterberg, Glemmtal, Kitzbühel-Jochberg, Brixental, Schwaz-Brixlegg and Vetriolo (Lamprecht, 2020, pp.37-39; Lamprecht, et al., 2022, pp.151-153). Tools of this type are characterized by horizontal and transverse grooves used most likely for hafting purposes. These tools were used for fine preparation of the ores before the washing process (Eibner, 1982, pp.402–404). Abraders and polishers (Cat. E) were used for working on organic and mineral materials (Gehlen, 2012, p.844), but also for tool maintenance. They are characterized by worn and polished tool surfaces. One such find from Brunnalm (Figure 25, BX101) shows a very smooth working surface on one side, which is bordered

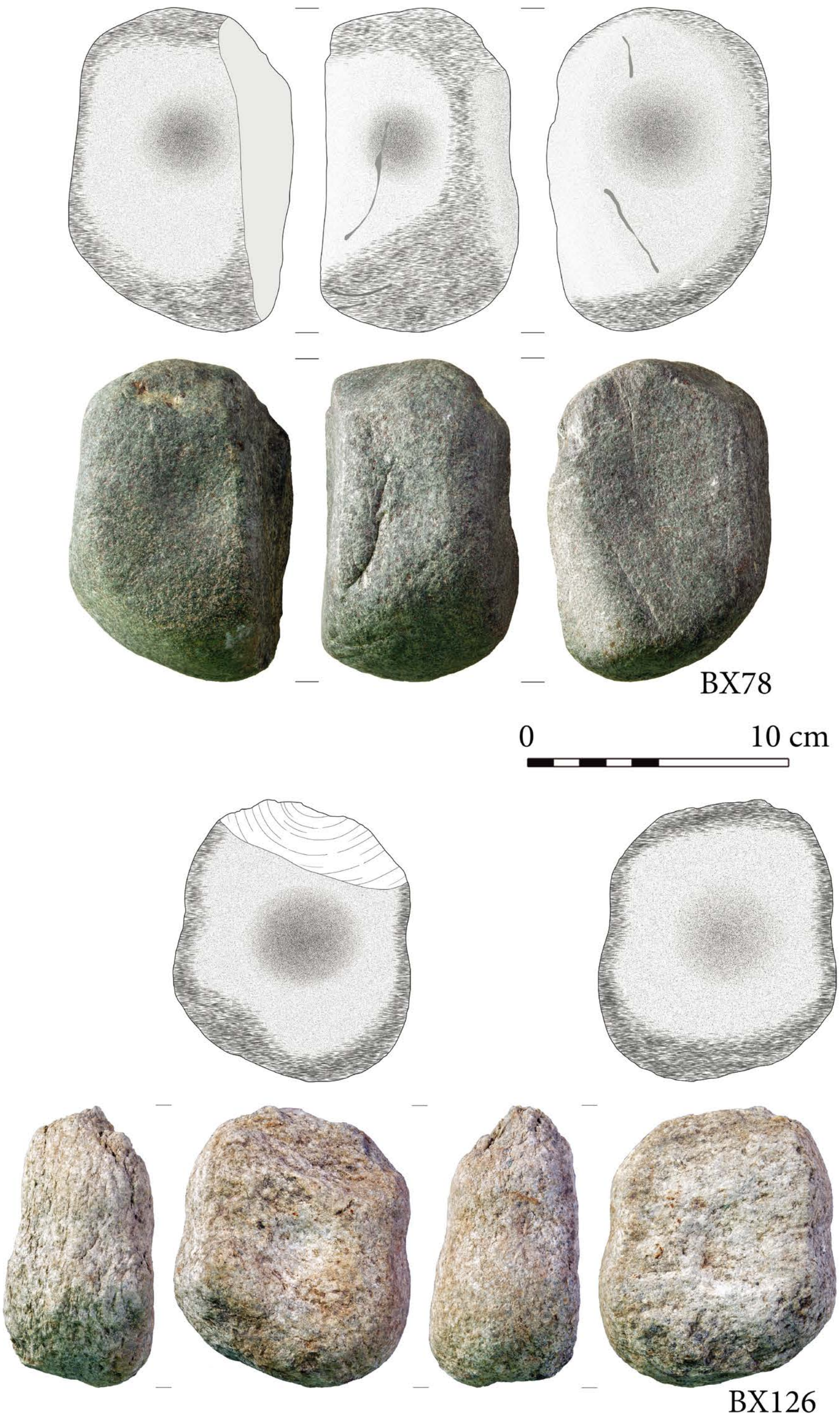


Figure 26. Multi-purpose tools with impact scar fields and depressions caused by ore pounding from Kraftalm (BX78) and Götschen (BX126). Drawings and photos: R. Lamprecht.

by pronounced edges. These use-wear traces are typical for metalworking and can be found, for example, in Late Neolithic/Early Bronze Age finds from Schleswig-Holstein (Freudenberg, 2009). Overall, it can be concluded that, except for the abraders and polishers, different types of tools can be assigned to the various stages of ore processing.

Mineralogy and material properties

The stone tools from the Brixental show a wide range regarding their raw materials (Figure 27). The tools consist of approximately 30 % amphibolite and 30 % eclogite, while various types of gneiss ("Augen-", "Ortho-" and "Paragneiss") account for 16 %. Sandstone (3 %)

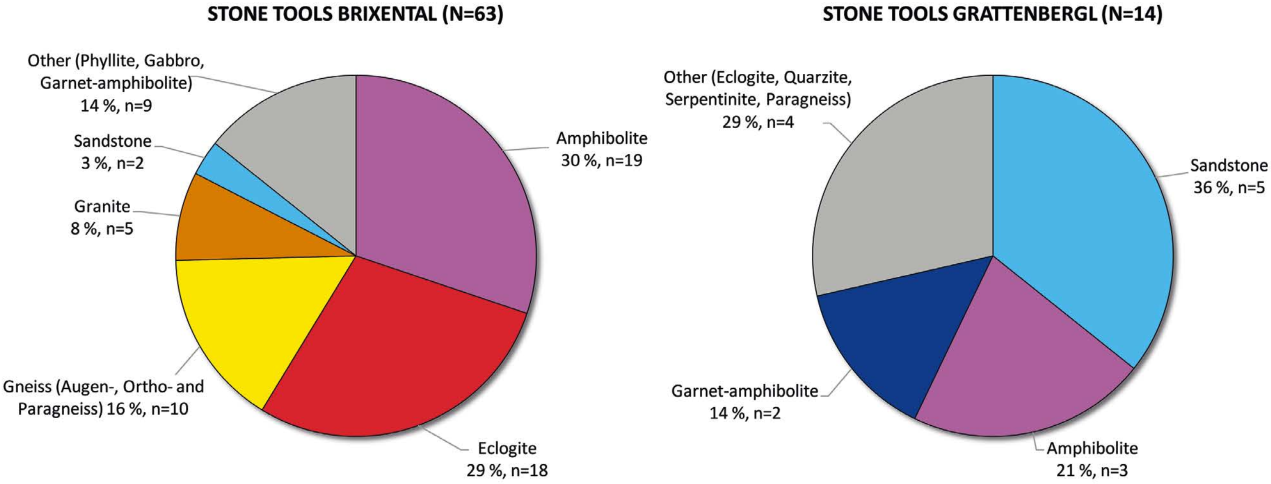


Figure 27. Distribution of material within all tool categories ("individuals" and "non-individuals") for Brixental and Grattenbergl. Graphics: R. Lamprecht.

and other materials (14 %) such as phyllite, gabbro and garnet-amphibolite occur less frequently. In contrast, the distribution of rock types from Grattenbergl shows a completely different picture. Most of the tools at this site (36 %) are made of sandstone, amphibolite accounts for 21 % and garnet amphibolite for 14 %. The remaining 29 % of the devices consist of various materials such as eclogite, quartzite, serpentinite or paragneiss. Active tools consist mostly of high metamorphic rocks like eclogite, garnet-amphibolite and amphibolite rocks with relatively high densities. Sandstone, phyllite and gneiss, on the other hand, were favoured for passive tools like netherstones. While eclogite and amphibolite originate from the Tyrolean Oberland (esp. Ötztal and Paznauntal) and the Lower Engadine in Switzerland (Lamprecht, et al., 2022, pp.156-158), gneiss and granite are found in large parts of the Alpine divide (Zillertal, Hohe Tauern). Sandstones and phyllites can also be found in large parts of the Tyrol.

Therefore, suitable cobbles for stone tool production can be found in the gravel banks of the Inn and some of its southern side streams as well as in post-glacial deposits along the Inn valley. As already mentioned, much of the gneiss used probably originated from the Hohe Tauern mountains and was transported northwards by glaciers (Klebelsberg, 1935, p.551; Heinisch, Pestal and Reitner, 2015, p.322). In the case of the Brixental, ice transfluence of the former Salzach glacier via the saddles in Kelchsau (Hopfgarten im Brixental), Windau (Westendorf) and Spertental (Kirchberg in Tirol) could be determined (Reitner, et al., 2010, p.387). For this reason, raw material for stone tool production can also be found in the Brixental, although there are no natural outcrops. In the case of Grattenbergl, it was observed that many suitable cobblestones and blanks for netherstones could be found directly on site within glacial deposits.

Slags and heat-altered stones

Slags only occurs sporadically in the find material. Two pieces of platy slag (Figure 28, BX49, BX50) originate from Kraftalm in Itter and were discovered by Hanspeter Schrattenthaler during the time of the construction works of the rebuilt alpine pasture. In addition, a slagged stone was found in the immediate vicinity of the hut, which indicates smelting activities on site. Another piece of platy slag was discovered during the geomagnetic measuring on Grattenbergl on the northern slope (Figure 18, find area GB1). Although slags have also been found at Grattenbergl and in the necropolis at Egerndorfer Feld in the past (Zemmer-Plank, 1990, p.96, note 117), analysis of the composition and potential origin of the ores used has yet to be carried out. Similar slags and oven stones were discovered, for example, at the prehistoric smelting sites Mauk A (Goldenberg, et al., 2012; Goldenberg, 2013) and Rotholz (Staudt, et al., 2019b) in the Lower Inn Valley and in Kitzbühel-Jochberg (Goldenberg, 2004; Koch Waldner, 2019; Koch Waldner and Klaunzer, 2015), in all cases relating to Bronze and Iron Age copper smelting.

Metal finds

Various metal objects were discovered during Hanspeter Schrattenthaler's investigations. These include three fragments of bronze tools (Figure 28, BX128-130) found at Götschen, which can best be described as the remains

Figure 28. Bronze tools from Götschen-Brixen im Thale (BX128-131), belt hook (GB35) and platy slag (GB113) from Grattenbergl and platy slag from Kraftalm-Itter (BX49 & 50). Drawings and photos: R. Lamprecht.

of chisels or socketed chisels and were probably used in working metal and/or wood. (Mayer, 1977, pp.217-222, Tabl.86-89).

In addition, one example (Figure 28, BX131) of a bronze pick tip could be found at the Götschen site. Socketed picks and fragments thereof have been found mainly in the regions of the large copper producers in Salzburg, Tyrol, Styria, Upper Austria and Bavaria (Mayer, 1977, pp.226-227; Stöllner and Schwab, 2009; Stöllner, et al., 2016; Goldenberg, Staudt and Grutsch, 2019; Staudt, et. al., 2019a). The shape of this tool features a trapezoidal cross-section and one flat side (Thomas, 2018, p.24). Chronologically, this type of tool can be dated to the Middle to Late Bronze Age (Stöllner and Schwab, 2009, pp.151-159; Thomas, 2018, pp.231-233). In the last few years, several hundred fragments of socketed picks have been discovered during archaeological surveys in the Kitzbühel-Jochberg area (Staudt, et al., 2024, XXI-XXV). In most cases, only the front part of the picks (pick tips) were found, which suggests that the tip deformed during use and then broke off due to metal fatigue.

A fragment of a bronze belt was discovered on the surface in the immediate vicinity of the supposed smelting site on Grattenbergl, on which a triangular belt hook was attached with a single iron rivet (Figure 28, GB35). On the inside, embossed circular decorations were found, some of which were arranged in lines. Due to the non-specific style of the belt plate fragment, a further classification is not possible, yet similar pieces can be attributed to the Hallstatt period (Kilian-Dirlmeier, 1972, Tabl. 15, 154; 47, 422; 50, 531).

Results

In many cases, dating of sites based on typological aspects of the find material is only possible in a very unprecise manner, for example stone tools or finger-impressed pottery appear over large parts of the Bronze and Iron Age. For this reason, the aim was to obtain as much dateable material as possible. For this purpose, existing soil exposures and profiles (drainage trenches) were examined and minimal invasive test pits (30 x 30 cm) were made wherever needed. In some of these small-scale excavations wood, charcoal and bones could be found. Sample BX9 from profile 1 at Götschen dates from the 19th to the beginning of the 17th century BC and can therefore be assigned to the Early Bronze Age (Table 2)[13]. Meanwhile, sample BX21 from profile 4 at the eastern edge of the ski slope at Götschen could be dated to the 15th to 13th century BC and thus to the Middle and the beginning of the Late Bronze Age. The Early Bronze Age date is quite astonishing when one considers that so far, there is only sparse evidence for the mining sites of

Table 2. ^{14}C-dates from the 2023 Brixental survey.

Lab-No	Sample	Location	Waypoint (WP)	C^{14} Age	±	Cal 2 sigma	Sample type
MAMS-65889	BX9	Brixen im Thale – Götschen, profile 1	WP2	3467	17	1880–1697 calBC	Wood
MAMS-65890	BX21	Brixen im Thale –Götschen, profile 4	WP2	3083	17	1414–1288 calBC	Charcoal
MAMS-65891	BX26	Itter – Kraftalm, SuS 1	WP37	571	15	1322–1410 calAD	Charcoal
MAMS-65892	BX27	Itter – Kraftalm, SuS 1	WP37	296	14	1520–1649 calAD	Animal bone
MAMS-65894	BX41	Itter – Kraftalm	WP103	315	14	1510–1641 calAD	Animal bone
MAMS-65893	BX34	Kirchberg in Tirol – Brunnalm, profile 5		353	15	1474–1632 calAD	Charcoal
MAMS-65897	BX104	Kirchberg in Tirol – Brunnalm		310	15	1514–1643 calAD	Animal bone

local copper resources during this period. Indications of Neolithic/Copper Age and/or Early Bronze Age metallurgy have so far only been known for example from Mariahilfbergl near Brixlegg (Bartelheim, et al., 2002, p.66; Huijsmans and Krauss, 2015, pp.95-96), Kiechlberg in Thaur (Töchterle, 2015, pp.155-159) and Buchberg in Wiesing (Martinek, 1996; Martinek and Sydow, 2004; Keil, 2023). A pre-phase of copper production may have already existed between the 5th and 3rd millennia BC in the Lower Inn Valley, the Salzach Valley and Trentino, while the first heyday of Eastern Alpine copper technology finally began in the late 16th century BC (Stöllner, 2015, pp.102-103). This means that with the Götschen site, an Early Bronze Age copper ore extraction/beneficiation site has been found for the first time in Northern Tyrol[14]. In the case of the Early Bronze Age date from Götschen, however, it is still necessary to clarify whether it is an isolated date or if the documented features can be assigned (at least partially) to these times. On the other hand, the Middle Bronze Age date from profile 4 fits very well with the heyday of prehistoric mining in the Kitzbühel-Jochberg area and mining/beneficiation sites such as Kelchalm near Aurach (Koch Waldner, 2019, p.43; Pichler, et al., 2009) and the newly discovered sites in the Jochberg area (Staudt, et al., 2024, XXIX-XXX). Dating the site based on the finds is difficult, as both the stone tools and the pottery are chronologically indistinct. The documented bronze pick tip, on the other hand, can be assigned to a Middle to Late Bronze Age mining phase.

At Itter-Kraftalm, two samples were discovered in test pit 1 (BX26 & BX27). Test-pit 1, which was opened under a (presumably prehistoric) fire-set mining feature WP37 (Figure 10,1), yielded dates in the period between the 14th and 17th centuries AD. Consequently, it is very likely that an initially prehistoric mine was exploited again later. The same can be assumed in the case of a greenish animal bone (BX41) discovered on mining heap WP103 at Itter-Kraftalm located below a presumably prehistoric fire-set mine (WP102), which surprisingly also provided a date of the 16th/17th century AD. Evidence of later periods of exploitation was already indicated by the presence of wedge pockets and drill holes, which are typical signs of Medieval/Modern Age mining, whilst prehistoric mining is evident by the numerous fire-set mines, prehistoric stone tools and pottery sherds.

Although the stone tools indicate prehistoric mining activities, dating of the numerous mining features at Brunnalm is difficult, as both the finds from the 2023 survey and the one done by Albrecht, Schrattenthaler and Rieser in 2011 are chronologically indistinct. These analyses also revealed Late Medieval/Early Modern Age dates ranging from the 15th to the 17th century AD. Thus, as on Brunnalm, extensive mining activities in the Late Middle Ages and Early Modern period are prominent. These mines can be considered the most important in the entire Brixental during these times (Neuhauser, et al., 2022, pp.134-137). Late medieval mining in the Brixental began in the 15th century at the latest, with the last activities probably continuing until the end of the 18th century and has so far been more researched than prehistoric mining[15]. This also means, however, that initially prehistoric mines are likely to be overshadowed by more recent phases of mining. Hence, further investigations by means of archaeological excavations, involving the collection and analysis of stratified samples, are needed to identify older phases of use.

Conclusion

The mining archaeological surveys in the Brixental and at Grattenbergl have closed an important research gap. On the basis of sites like Götschen-Brixen im Thale and Itter-Kraftalm and the mining tools found there (socketed bronze picks and stone tools), the widely discussed technology transfer of the Middle and Late Bronze Age Eastern Alpine mining technology from east to west can be demonstrated once more. In addition, the Early Bronze Age date from Götschen provides evidence of very early mining activities, which have so far not been well documented in Northern Tyrol. Even though the pottery found at Itter-Kraftalm suggests a Hallstatt mining phase, it is important to further investigate this site. In the case of Grattenbergl in Kirchbichl at the western entrance to the Brixental valley, geomagnetic measurements were used to localize a supposed smelting site that was previously only evident on the basis of stray finds (*tuyères*, slags etc.). Overall, the mining landscape of the Brixental fits in very well with the adjacent mining districts of Kitzbühel-Jochberg and Schwaz-Brixlegg and therefore testifies to the high spatial and chronological density of prehistoric mining remains in North Tyrol.

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Notes

1 Funded by the FWF, P31814, project leader: Gerald Hiebel.

2 The investigations initially also included the area of Wildschönau to the west of the Brixental, which could not be investigated further due to limited time. In the Wildschönau, prehistoric mining features could be found around the Gratlspitze. See Staudt, et al., 2019a, pp.120-122.

3 A research overview of the entire Alpine copper mining has been omitted, as the work deliberately concentrates on regional research. However, supra-regional references are made in the evaluation of the geomagnetic survey and in the chapters on the finds.

4 An Alm, Alp, Alpe or Alb refers to the mountain pastures, farm buildings and other infrastructure.

5 It was possible to locate these excavation sections using historical orthophotos from 1976 (Laser- & Luftbildatlas Tirol/Land Tirol-Abteilung Geoinformation). See Figure 18.

6 Data basis: Province of Tyrol, resolution 0.50 m.

7 https://www.geologie.ac.at/services/webapplikationen/iris-interaktives-rohstoffinformationssystem (Accessed: 25 June 2024).

8 https://qfield.org (Accessed: 25 June 2024).

9 Version 3.28.2. https://www.locusmap.app (Accessed: 25 June 2024).

10 STONEX S900A V2 GNSS receiver, EPOSA correction data, RTK position accuracy: ±1 cm.

11 https://www.bda.gv.at/themen/publikationen/standards-leitfaeden-richtlinien/richtlinien-archaeologie-massnahmen.html (Accessed: 19 November 2024).

12 All finds presented in this study were examined and documented by the authors themselves.

13 All samples have been sampled by Curt-Engelhorn-Zentrum Archäometrie gGmbH and calibrated with OxCal 4.4, IntCal 20, Bronk Ramsey (2009).

14 An Early Bronze Age radiocarbon date was obtained at the prehistoric mining area Mauk D in Radfeld (Staudt, 2024, p.245, Fig.105; Staudt and Goldenberg, 2024, p.53, Fig.7). It has not yet been possible to determine whether this is an isolated date, or a more extensive complex can be expected.

15 See for example: Pošepný, 1880, pp.353-379; Srbik, 1929, pp.158-161; Mutschlechner, 1968; Rupert, 1985, p.31; Vavtar, 1988, pp.17-20; Günther, 1999; Graß, 2002, pp.258-261.

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Authors

Roman Lamprecht (Corresponding author)
Leopold-Franzens-University Innsbruck
Department of Archaeologies
Innrain 52a, 6020 Innsbruck, Austria
romanlamp27@gmail.com
ORCID 0000-0001-8633-0964

Julia Haas
Independent researcher
JuliaMariaHaas@hotmail.com
ORCID 0009-0000-6173-767X

Gerald Hiebel
Leopold-Franzens-University Innsbruck
Department of Archaeologies/DiSC
Innrain 52a, 6020 Innsbruck, Austria
Gerald.Hiebel@uibk.ac.at
ORCID 0000-0002-3799-8391