RESEARCH ARTICLE – VÝZKUMNÝ ČLÁNEK

Raw materials for Neolithic ground tools from the extraction fields at Bílý Kámen Hill, Central Bohemia

Suroviny neolitických broušených nástrojů z těžebních polí na Bílém kameni ve středních Čechách

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The assemblage of ground tools and their fragments from the site of Bílý Kámen Hill near the town of Sázava (Czech Republic, Central Bohemia) is one of the largest chronologically uniform collections in Central Europe. Based on the dominant representation of bored axe-hammers, we date it to the late phase of the Stroked Pottery culture (SBK; 5100/5000–4500/4400 cal BC). Their connection to the extraction of local marble and the production of prestigious bracelets raises many questions. The material composition of the assemblage could be the key to understanding the origin of the artefacts. In this article, we examined 912 samples using optical and electron microscopy methods. This points to the dominant representation of amphibole-rich Jizera Mountains-type metabasites. Other rocks are represented only in small quantities and raw materials of local origin are probably missing in the assemblage. It is thus comparable to assemblages from contemporaneous settlement sites, although we do not yet know of stable occupation in the vicinity of the site, nor do we even anticipate its existence.

Neolithic – Stroked Pottery culture – ground tools – petrography – Jizera Mountains-type metabasites

Soubor broušených nástrojů a jejich fragmentů z lokality Bílý kámen u města Sázavy (střední Čechy) představuje jednu z největších chronologicky jednotných kolekcí ve střední Evropě. Na základě dominantního zastoupení vrtaných sekeromlatů ji řadíme do mladší fáze kultury s vypíchanou keramikou (SBK; 5100/5000–4500/4400 cal BC). Souvislost kolekce s těžbou místních mramorů a výrobou prestižních náramků vyvolává řadu otázek. Klíčem k porozumění původu artefaktů může být surovinové složení souboru. V tomto příspěvku jsme zkoumali celkem 912 vzorků metodami optické i elektronové mikroskopie. Výsledky ukazují na dominantní zastoupení metabazitů typu Jizerské hory. Ostatní horniny jsou zastoupeny jen v malém množství a suroviny lokálního původu v souboru pravděpodobně chybí. Soubor je tak srovnatelný se soudobými sídlištními lokalitami, přestože stabilní osídlení v okolí lokality dosud neznáme a ani ho tam nepředpokládáme.

neolit – kultura s vypíchanou keramikou – broušené nástroje – petrografie – metabazit typu Jizerské hory

Introduction

The study of the extraction and especially the distribution of stone raw materials is one of the basic pillars for learning about the intercultural relationships between prehistoric human communities. This is certainly true for the Central European Neolithic, both for its early stage represented by the Linear Pottery culture (LBK; 5500/5400–5100/5000 cal BC), and the later stage represented by smaller cultural units stemming from the LBK tradition. In Bohemia, this is the Stroked Pottery culture (SBK, 5100/5000–4500/4400 BC). Also belonging to this later period is a remarkable assemblage of ground industry from the Bílý Kámen Hill near the town of Sázava (Central Bohemia; *Fig. 1*).

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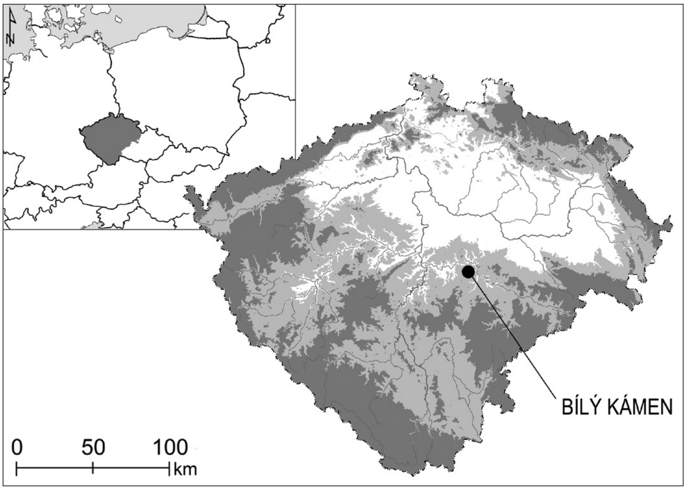

Fig. 1. Bílý Kámen. Localisation of the site.

According to the original published hypothesis, the marble from Bilý Kámen should be the main source of raw material for the production of drilled and polished bracelets (*Zápotocká 1984*). These marble bracelets were a significant and widespread phenomenon of the Middle Neolithic period. They can be found in both the Stroked Pottery culture and the contemporary Rössen culture areas (*Zápotocká 1984*; *Burgert – Přichystal 2022*). Neolithic workshops with evidence of marble processing in the wider Sázava region and, last but not least, extensive mining relics right on top of Bílý Kámen should have indicated this fact.

In recent years, we have focused on the research of extraction relics and the petrography of the marble (*Burgert et al. 2020*). The most important finding is the fact that Bílý Kámen is not the main source of raw material for the production of marble bracelets. According to our findings, the main source was located about 10 km further south in the vicinity of Český Šternberk (*Burgert – Přichystal 2022*). At the same time, it seems likely that the bracelets from the Rössen culture had a completely different source of raw material, which was not located in the Bohemian Massif (*Ehling et al. 2020*).

Still, the assemblage of ground stone tools from Bílý Kámen represents the largest chronologically uniform collection of finished tools and their fragments in Bohemia and probably in the whole of Central Europe. A typological and chronological analysis of this assemblage has already been published (*Burgert et al. 2020*). The mentioned study also discusses the connection between the assemblage of ground industry and the prehistoric marble extraction that also took place at the site, despite this was not the primary source for bracelet production. The connection with mining is already given by the occurrence of tools at the extraction fields, which were located completely outside the settlement context. However, only a very small number of specimens in the collection bear traces of use in stoneworking. This contradiction has not yet been reliably explained. Moreover, the tools were likely intentionally fragmented and the non-standard way of treatment is evidenced by their accumulation in a single space-limited place.

The question of what raw materials the tools are made of and where their origin lies has played an important role since the find was originally made. In the case of a predomi-

Fig. 2. Typical fragments of artefacts from the Bílý Kámen assemblage. All artefacts are made of metabasite from the Jizera Mountains (photo by L. Vojtěchovský).

nance of local raw materials, we can assume that the set has a rather utilitarian character being created for the needs of mining. Otherwise, we will be able to trace the approximate origin of the community that used the site. Although an attempt was recently made at a separate analysis (*Šreinová et al. 2018*), the issue has not yet been reliably resolved. The main reason is the fragmentation of the assemblage and the absence of relevant geochemical and petrographic analyses. The aim of this article is a complete material determination of the entire assemblage and the placement of the results into the context of our current knowledge of the raw material spectrum of the ground stone industry of the Stroked Pottery culture.

Acquisition and typochronology of assemblage

The unusual assemblage of ground tools is now held mainly in the collections of two museums: the Kutná Hora Museum (452 specimens) and the National Museum in Prague (446 specimens). Another 10 specimens are now deposited in the National Lithotheque of Stone Raw Materials in Brno. Four specimens from Bílý Kámen also belong to the estate of Slavomil Vencl (held today at the Institute of Archaeology in Prague). A small part of the original assemblage was also allegedly handed over to the Mining Department at the National Technical Museum in Prague (*Žebera 1986*, 12), but is not currently found in the collections of this institution. As such, we had a total of 912 specimens with an aggregate weight of 72.7 kg (i.e. all of the material we were able to collect from the former study) available for our petrographic analysis (*Fig. 2*).

The assemblage was acquired in the late 1930s/early 1940s (specifically 1937, 1939 and 1940) during an archaeological excavation at the Bílý Kámen site. The excavation was

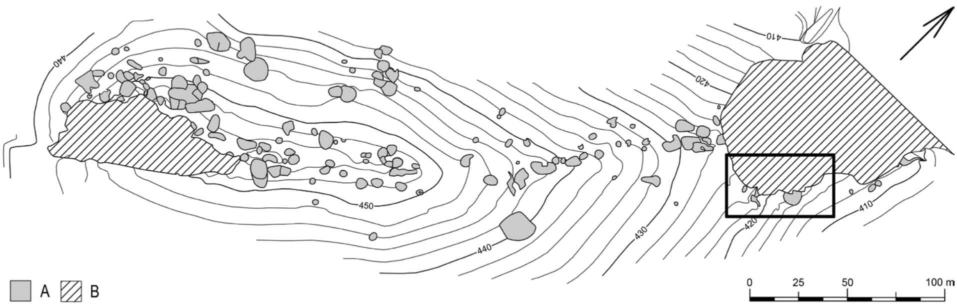

Fig. 3. Bílý Kámen. Plan of mining field at the 'Na Sedlišti' location. A – mining relics, B – large quarries from the 20th century. The small frame shows the probable location of the find of the concentration of ground industry (adapted from *Burgert et al. 2020*, Fig. 8).

headed by geologist Karel Žebera (1911–1986) at the northeastern top part of the 'Na Sedlišti' location (*Fig. 3*). While the precise location of the find can no longer be determined today, it was situated in the upper part of the wall of the marble quarry active at the time of excavation. It was in all likelihood a concentration in a single place, perhaps on the bottom of a prehistoric extraction pit. Today we can only assume the location of the find, it cannot be reconstructed exactly (*Fig. 4*). Nevertheless, the entire assemblage of ground industry is very likely connected with the prehistoric extraction of marble.

Probably in the year 1936, employees of the marble quarry were the first to draw attention to the occurrence of fragments of prehistoric tools. In the report from the first excavation season, we learn of the find of a 'Neolithic layer' preserved between medieval mining shafts and the medieval backfill (*Žebera 1939*, fig. 5). A more precise description is missing from the subsequent two excavation seasons. We do know, however, that Žebera continued the digs because the quarry was still expanding towards the area of the previous excavation. Only a handful of finds are recorded from the final season (1940). Therefore, it is probable that in 1939 he focused on the same situation as in 1937 and this excavation was finished in 1940.

A typochronological analysis of the entire assemblage was recently performed (*Burgert et al. 2020*, 353–356). Just under half of the finds (442 specimens) could be typologically classified into basic categories, with the vast majority being fragments, in exceptional cases completely preserved bored axe-hammers (407 specimens). Fragments and completely preserved flat axes (25 specimens) are represented only in small numbers. Two finds could be fragments of hoof-shaped wedges, but this determination is uncertain. One perforated macehead was identified. One of the key problems is determining from how many original tools the assemblage of fragments actually comes, but due to the heavy fragmentation, we can only guess. A certain guide could be the total weight of the assemblage, which could correspond to finds ranging from several dozen up to the low hundreds.

Regional geological context

The studied area is located near the contact zone of three large units of the Bohemian Massif: the Moldanubian Region (Moldanubicum), the Kutná Hora Unit of the Kutná Hora –

Fig. 4. Bílý Kámen. Photo of current state of terrain relics (spring 2023). A – mining pit; B – mining pit disturbed by the wall of a modern quarry at the location of the probable find of the ground tool assemblage (photo by P. Burgert).

Svratka Region, and the Central Bohemian Region (Bohemicum). Moreover, a large granitoid body of the Central Bohemian Pluton intruded here and affected the surrounding rocks by contact metamorphosis. This complicated situation led to the classification of some subunits either in the Kutná Hora Crystalline or in the Moldanubicum. This in particular concerns the Šternberk–Čáslav Variegated Group, in which Bílý Kámen with a body of calcite marble and evidence of its prehistoric extraction is situated, as well as a large number of amphibolite intercalations in its broad surrounding area, which K. Žebera regarded as source material for the ground tools found on Bílý Kámen. This unit was previously classified in the Kutná Hora Crystalline (*Mísař et al. 1983*), but the prevailing opinion in the 1990s was that it is a diverse group belonging to the Moldanubicum (*Kachlík 1999*). The classification was based on the rock composition of the Šternberk–Čáslav Variegated Group and on the identification of the Micaschist Zone in its tectonic overburden. In other places of the Bohemian Massif, the Micaschist Zone is also considered retrogradely metamorphosed Moldanubian rocks.

Here we venture a brief super-regional note. At the end of the 20th century, the search for key sources of metabasites for the production of Neolithic ground tools in the territory of the Czech lands was based mainly on the conclusions of the study by *Vencl* (*1975*) pointing to the conspicuous concentration of hoards of metabasite tools and their semi-finished products in northeast Bohemia. It was already clear at that time that this source of raw material could not be located south of northeast Bohemia, i.e. in the area of the Kutná Hora Crystalline Unit or the Moldanubian Region, which are more metamorphosed. Based on a microscopic study of thin sections, *Štelcl* and *Malina* (*1975*, 190–191) also observed that the origin of amphibole greenschists (metabasites according to recent classification) at Moravian Neolithic settlements could not be from the Sázava River region, as assumed for Bohemia by *Žebera* (*1955*, 41).

The Šternberk–Čáslav Variegated Group extends from Bílý Kámen south of the town of Sázava through Rataje, Český Šternberk to Čáslav. As such, Bílý Kámen represents its westernmost part, which was heavily influenced by the intrusion of the Central Bohemian Pluton, which is evidenced by up to 2 m thick veins of pegmatitic granite penetrating the marble. The marble body, including the granite veins, is tectonically affected in some places (crushed, limonised, contains elongated positions of chloritic or sericitic matter), the result of the northern continuation of the faults demarcating the Blanice Graben to the east.

The group consists of biotite-sillimanite paragneisses with numerous bodies of amphibolites (*Fig. 5*), mainly dolomite marbles in the vicinity of Český Šternberk, muscovite quartzitic gneisses to quartzites; erlans are rare. From our perspective, important amphibolites were petrographically analysed by *Ondřej* (*1922*) and *Koutek* (*1933*), and geochemically by *Kachlík* (*1999*).

Amphibolites are represented by numerous locations in gneiss, mica-schist, and marble with a highly fluctuating thickness from decimetre layers to bodies hundreds of metres thick. Highly instructive outcrops are between Poříčko and Český Šternberk. These amphibolites are regarded by J. Koutek as orthoamphibolites formed by the recrystallisation of gabbros, diorites, and, to a lesser extent, pyroxenites. At other areas west of Ledečko, he supposes paraamphibolites, i.e. metamorphosed alternating layers of basic pyroclastics and carbonates. *Kachlík* (*1999*) determines schistose amphibolites in section containing yellowish-green or less bluish-green predominantly Mg-amphibole, less frequently tschermakite and pargasitic amphibole. The amphibole content fluctuates in the 40–65 % range. Plagioclases have an oligoclase to andesine composition, and accessory minerals are represented by ilmenite and titanite, often grouped in chain-like aggregates. More acidic types of amphibolites from Český Šternberk may contain an admixture of quartz. Retrograde metamorphosis is manifested by the presence of chlorite with anomalous blue-red interference colours; biotite and carbonate are also present. Massive coarse-grained gabbro-amphibolites have relics of isotropic and porphyritic structures and higher contents of plagioclase. The composition of amphiboles is more varied. They are richer in Ca and Fe;

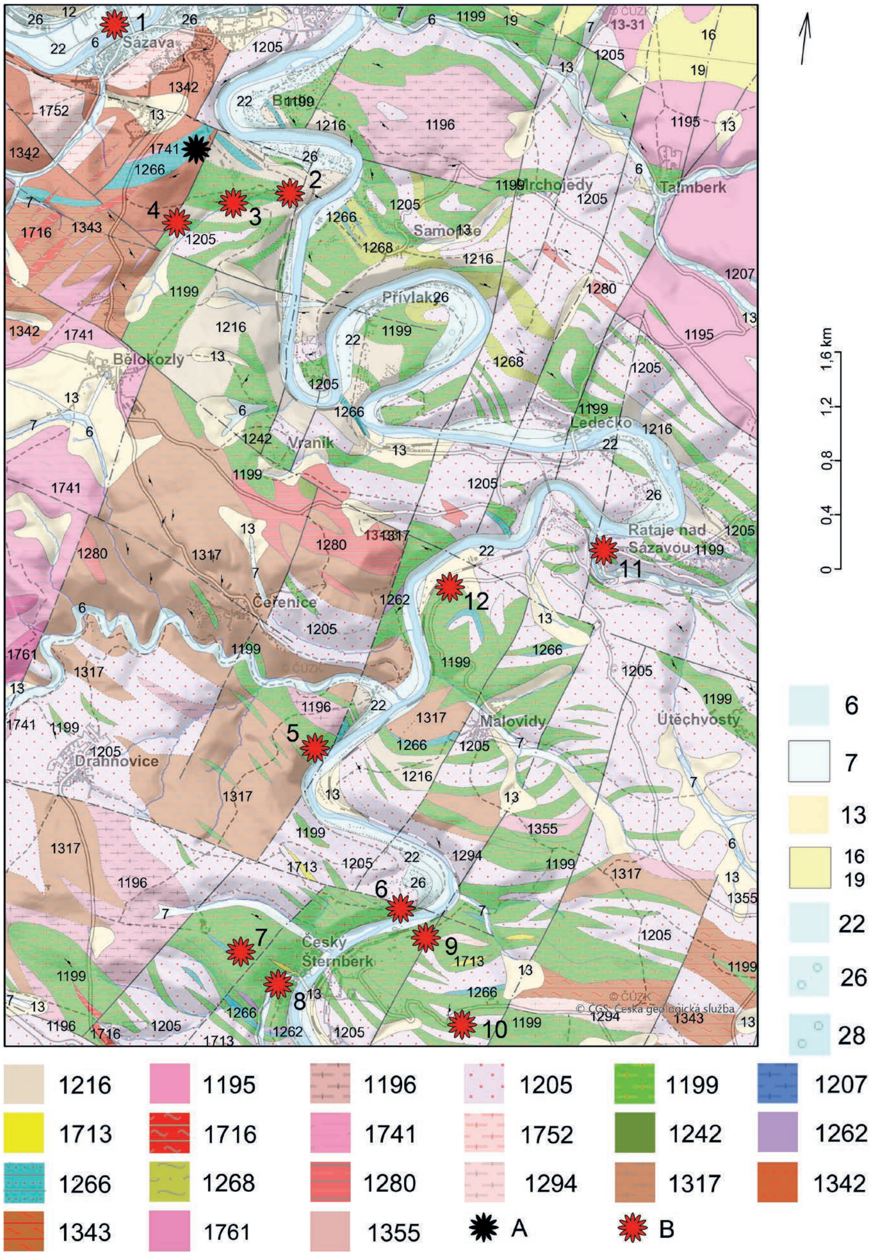

Fig. 5. Geological map of the Sázava River region studied in detail. A – Bílý Kámen, B – analysed amphibolite outcrops (adapted according to www.geology.cz, Geoscience maps, Geological Map of the CR 1 : 50 000). *Legend*. Quaternary: 6 – alluvial sediment; 7 – polygenetic sediment; 13 – loamy sediment with rock debris; 16, 19 – loess and loess loam; 22, 26, 28 – sand, gravel; Carboniferous – Permian (Central Bohemian Pluton): 1713 – aplite, pegmatite, aplopegmatite with tourmaline; 1716 – vein granite; 1741 – fine-grained two mica to biotite granite; 1752 – granite (Kšely unit); 1761 – granite to quartz diorite (Benešov type). Proterozoic to Paleozoic, Kutná Hora Crystalline Uni, Moldanubicum: 1195 – two-mica migmatite to orthogneiss; 1196 – biotite-muscovite orthogneiss; 1205 – two-mica schist; 1216 – two-mica gneiss to biotite paragneiss with amphibole; 1199 – amphibolite; 1207 – erlan, marble; 1242 – serpentinite; 1262 – erlan; 1266 – calcite and dolomite marbles; 1268 – quartzite, paragneiss; 1280 – orthogneiss to metagranite; 1294 – orthogneiss; 1317 – migmatite; 1342, 1343, 1355 – paragneiss.

Fe-tschermakitic amphiboles are more common. Actinolitic amphibole and actinolite also occur. Poikiloblastic intergrowths of amphibole and plagioclase are more common.

Dolomitic marbles near Český Šternberk in the Na Stříbrné location have been already analysed (*Burgert et al. 2020*). These contained pure Ag–Pb–Zn ores in such quantities that they were previously mined here. Among other things, these marbles are considered to have been the main raw material for the production of Neolithic marble bracelets.

Other rocks in the region also include smaller amount of serpentinites: the body west of Ledečko, small serpentinites near Vraník and Poříčko, and especially the body near Otryby with a continuation near Vranice (*Koutek 1933*). Graphitic quartzites and graphites near Soběšín are also mentioned. In terms of igneous rocks, deposits of biotitic granite in mica-schist, aplites in amphibolites, and possibly coarse-grained pegmatites are reported. During our investigation of the Bílý Kámen extraction pit in 2019, we identified a 1.5-metre-thick vein of aplitic granite in the marble following the direction of 190°, i.e. similar to the Kouřim fault. From the area of Chuchelník Mill, *Koutek* (*1933*) reports a vein of syenite porphyry (according to today's classification of porphyritic microsyenite).

Methodology

All fragments of ground tools were observed under a stereo microscope and their magnetic susceptibility was measured using a handheld ZH Instruments SM-30 magnetic susceptibility meter. Attention was paid primarily to the predominant metabasites. Based on the occurrence of needle-like structure, it was possible to single out a group corresponding to Jizera Mountain-type metabasites. Another identified group was composed of classic amphibolites of the Moldanubian type. The last and smallest group was made up of the other rocks.

Several petrographic sections were prepared from each of these groups. They were subsequently analysed under an Olympus polarising microscope and electron microprobe analyser CAMECA SX100 at the Joint Laboratory of Electron Microscopy and Analysis of the Department of Geological Sciences at the Faculty of Science, Masaryk University and the Czech Geological Survey. The conditions of the WDX measurements were set for accelerating voltage of 15 kV, beam current of 10–20 nA, and beam diameter of 1–5 µm. Natural minerals and synthetic phases were used as standards. The crystal-chemical formulas of feldspars were calculated on basis of 8 oxygens, amphiboles on basis of 23 anions including (OH+F+Cl) and 15 cations and classified according to *Leake et al.* (*1997*), 4 oxygens and 3 cations (magnetite), 3 oxygens (ilmenite), 8 cations (apatite), 3 cations (titanite) and 18 anions including (OH+F+Cl) = 8 (chlorite). Stechiometric calculations and charts were carried out using FormCalc, Formula, and Triplot software.

Results of mineralogical and petrographic analysis

Amphibole-rich Jizera Mountains-type metabasites

On a fresh section, these rocks are macroscopically dark greenish-grey, often massive, sometimes with a hint of foliation. The patinated surface of the artefacts is up to a light

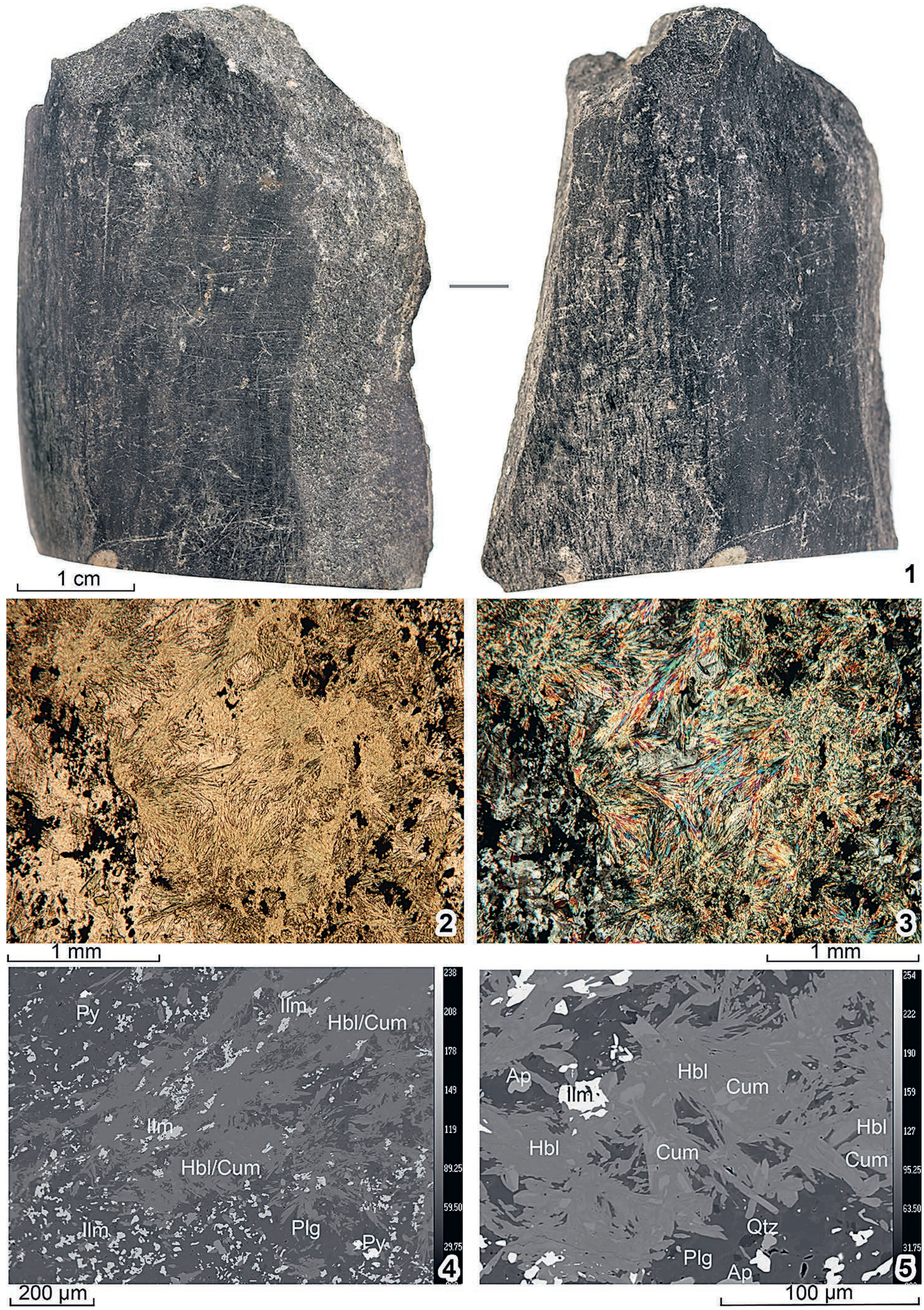

Fig. 6. Jizera Mountains metabasite used for axe hammer Sázava 1870. 1 – photo of the sample; 2 – thin section in plane-polarized light; 3 – thin section with crossed polars; 4 and 5 – back-scattered images of individual minerals using microprobe. Abbreviations of minerals (*Whitney – Evans 2010*): Ilm – ilmenite, Hbl – hornblende, Cum – cummingtonite, Plg – plagioclase, Py – pyrite, Qtz – quartz, Ap – apatite, Chl – chlorite, Leuk – leucoxene, Mag – magnetite, Amp – amphibole, Ttn – titanite, Epi – epidote, Bt – biotite.

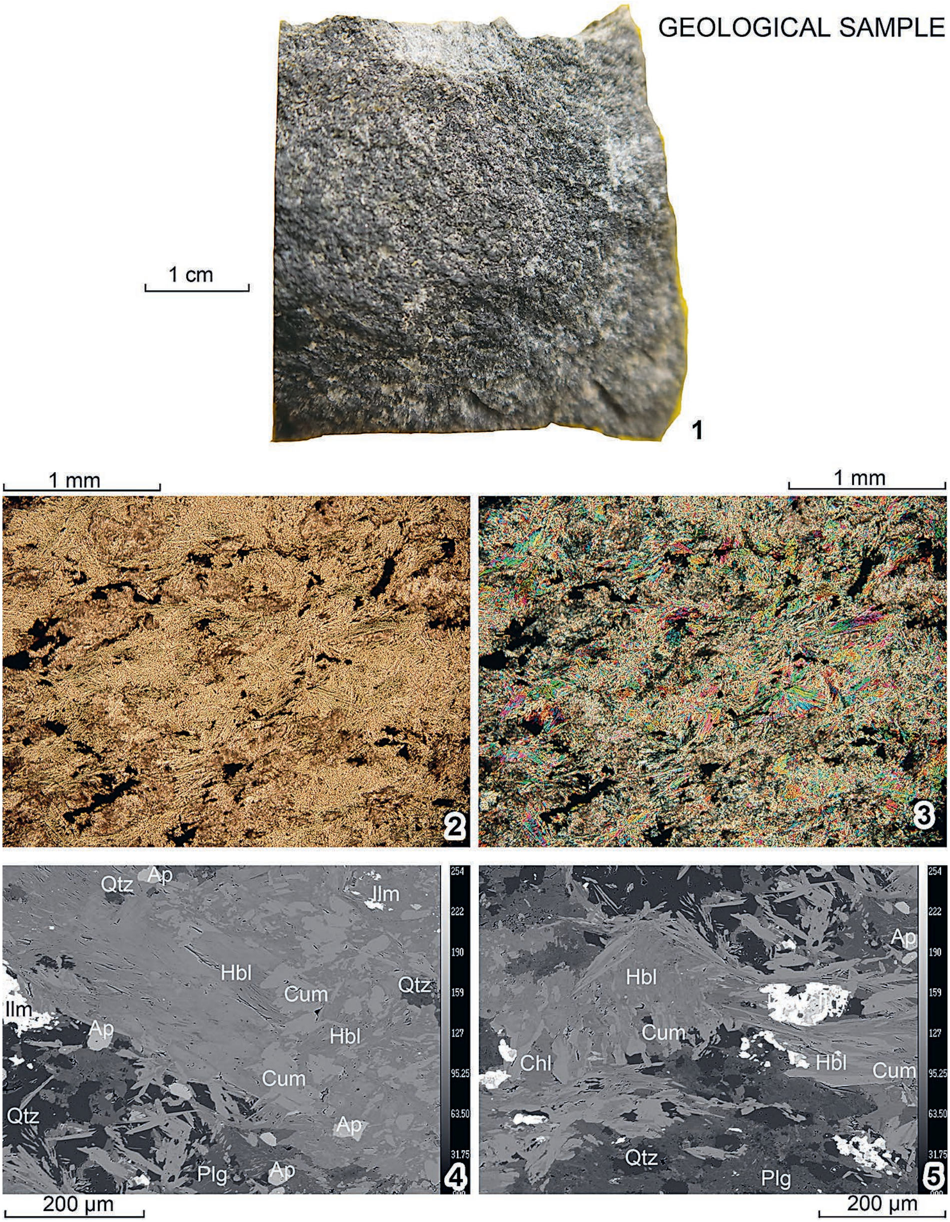

Fig. 7. Comparative raw material: metabasite from the prehistoric quarry at Velké Hamry, Jizera Mountains. 1 – photo of the sample; for 2–5 see caption for the *Fig. 6*.

greenish-grey, usually with a band structure in which thinner dark-green streaks to bands up to 0.5 mm thick alternate with lighter bands up to 2–3 mm thick (*Fig. 6*; *7*). We divided the metabasites from Bílý Kámen into three varieties on a working basis: a) predominant metabasites with dark green schliers (elongated thin lenses) or bands; b) metabasites with small porphyry phenocrysts of whitish feldspars; c) massive dark green nephritic metabasites with a predominance of fibrous amphiboles.

Under a stereo microscope, sheaf-like aggregates of needle-like amphiboles are clearly visible, especially in light bands. Small accumulations of pyrite, sometimes completely changed to limonite, were observed from opaque minerals. The magnetic susceptibility of specimens having a corresponding thickness of around 4–5 cm was predominantly in the range of 0.5–1.05 × 10^{-3} SI. Small chips were also measured for approximation purposes and naturally had lower values. Fragments of axe-hammers from these metabasites with magnetic susceptibility up to 4.5 × 10^{-3} SI occur exceptionally. The density established for several artefacts was in the range of 2.99–3.06 g/cm^3, which corresponds to the average density established for 10 samples from sources in the Jizera Mountains (2.97 ± 0,06 g/cm^3).

Polished petrographic sections were made from fragments of bored axe-hammers that K. Žebera marked Sázava 1295, 1362, 1452, 1470, 1866, 1870, and NM 87903, NM 87942, NM 555239. According to observations under a stereo microscope, they correspond to metabasites of the Jizera Mountain type.

Accumulations of radial aggregates of needle-like amphiboles are easy to identify in a section examined by a polarising microscope (*Fig. 6: 1 and 2*). According to microprobe analyses, the needle-like amphiboles often have a zonal structure, with cores corresponding in the diagram after *Leake et al.* (*1997*) to magnesio-hornblende or actinolite, whereas the peripheral parts are composed of cummingtonite (*Fig. 6: 4 and 5*). We can display the position of the analysed amphibole diagram according to *Leake et al*. (*1997*) (*Fig. 8*). *Šreinová et al.* (*2018*) describe the same observations for amphiboles of metabasites from Bílý Kámen. Small allotriomorphic feldspars are without twin lamellae and their composition is mostly in the range of labradorite-bytownite. Samples with andesine also appear (*Fig. 9*). For the sake of comparison, the diagrams include our analyses of metabasites from prehistoric extraction fields in the Jizera Mountains, which show absolute agreement between the material of axe-hammers from Bílý Kámen and material from the Jizera Mountains.

Ore minerals are represented mainly by ilmenite, substantially less by magnetite, and rarely by pyrite (size up to 0.5 mm), which can form clusters with pyrrhotite or sphalerite. Apatite and quartz grains are accessory minerals.

Metabasites rich in amphiboles make up 80 % of the assemblage. Their portion reaches 86 % if we include 35 pieces which, mostly due to their small dimensions, can only generally be classified as metabasite. All their features, including microprobe analyses of individual minerals, correspond well to metabasites from the Jizera Mountains. As such, our conclusion refutes the hypothesis of *Žebera* (*1939*; *1940*; *1955*; *1986*) that the tools were made from local amphibolites and that there are most likely prehistoric amphibolite quarries somewhere in the vicinity of Bílý Kámen. The predominance of metabasite from the Jizera Mountains in part of the assemblage of ground tools from Bílý Kámen held at the National Museum in Prague was also identified by other authors (*Šreinová et al. 2018*). However, they refer to the raw material with a presumed Jizera Mountain origin as amphibole hornfels, and according to them, the representation of this raw material in the collection from the National Museum is not as significant, reaching only 44 %. Our research also indicates that the collection from the National Museum is somewhat more diverse in terms of raw material compared to the assemblage held in Kutná Hora.

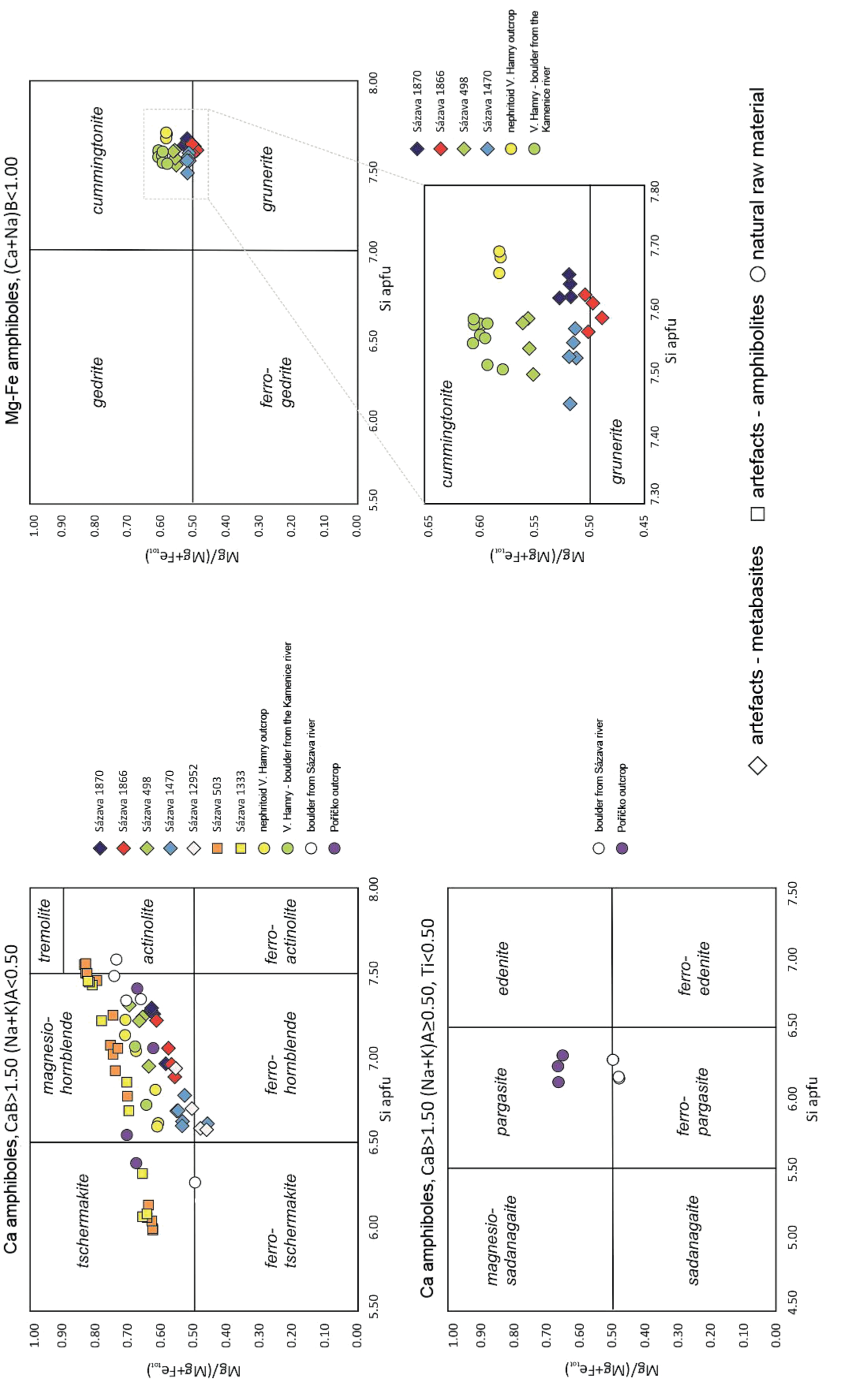

Fig. 8. Chemical analyses of amphiboles on microprobe from metabasites and amphibolite artefacts and from comparative natural sources in diagram after *Leake et al. 1997*.

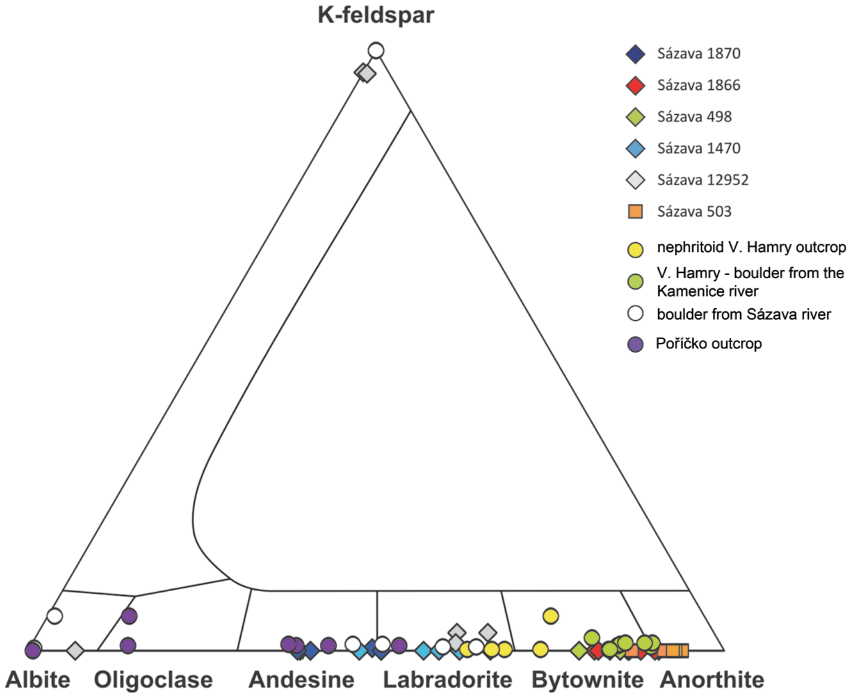

Fig. 9. Comparison of chemical composition of feldspars from metabasite and amphibolite artefacts and from natural sources in triangular classification diagram.

Amphibolites, amphibole and biotite-amphibole gneisses

In this group, we included distinctly granular rocks consisting of amphibole, feldspar, and opaque minerals with a size of up to 2 mm (*Fig. 10*; *11*). Rarely, as the content of light minerals increases, they pass into the category of amphibolic gneiss with the occurrence of biotite up to biotite-amphibole gneiss (though gneiss is represented by only individual pieces). The total representation of these rocks in the studied assemblage is 8 %. Three artefacts labelled by K. Žebera as Sázava 503, 1261, and 1339 were studied under a polarising microscope and on a microprobe. Amphibolite from a natural outcrop near Poříčko and a pebble of amphibolite from the Sázava River collected beneath the bridge in the town of Sázava were used as comparative material. All three amphibolite artefacts have higher magnetic susceptibility (19.1, 8.7 and 20.9 × 10^{-3} SI units), and increased magnetic susceptibility is also characteristic of most other amphibolite axe-hammers. For example, samples P 3131, 3152, 3164, 3170, 3174, 3178, and 3233 fluctuate between 5.71 and 20.0 × 10^{-3} SI units.

However, both analysed local amphibolites have magnetic susceptibility of more than one order of magnitude lower – 0.15 and 0.35 × 10^{-3} SI units. As this striking discrepancy surprised us, we measured the magnetic susceptibility in detail on 15 amphibolite outcrops between Bílý Kámen and Český Šternberk (*Fig. 5*) and found that all amphibolites from larger outcrops and pebbles in the river in this part of the Sázava River region have low values (up to 1 × 10^{-3} SI units). On the other hand, we rarely measured high values on three

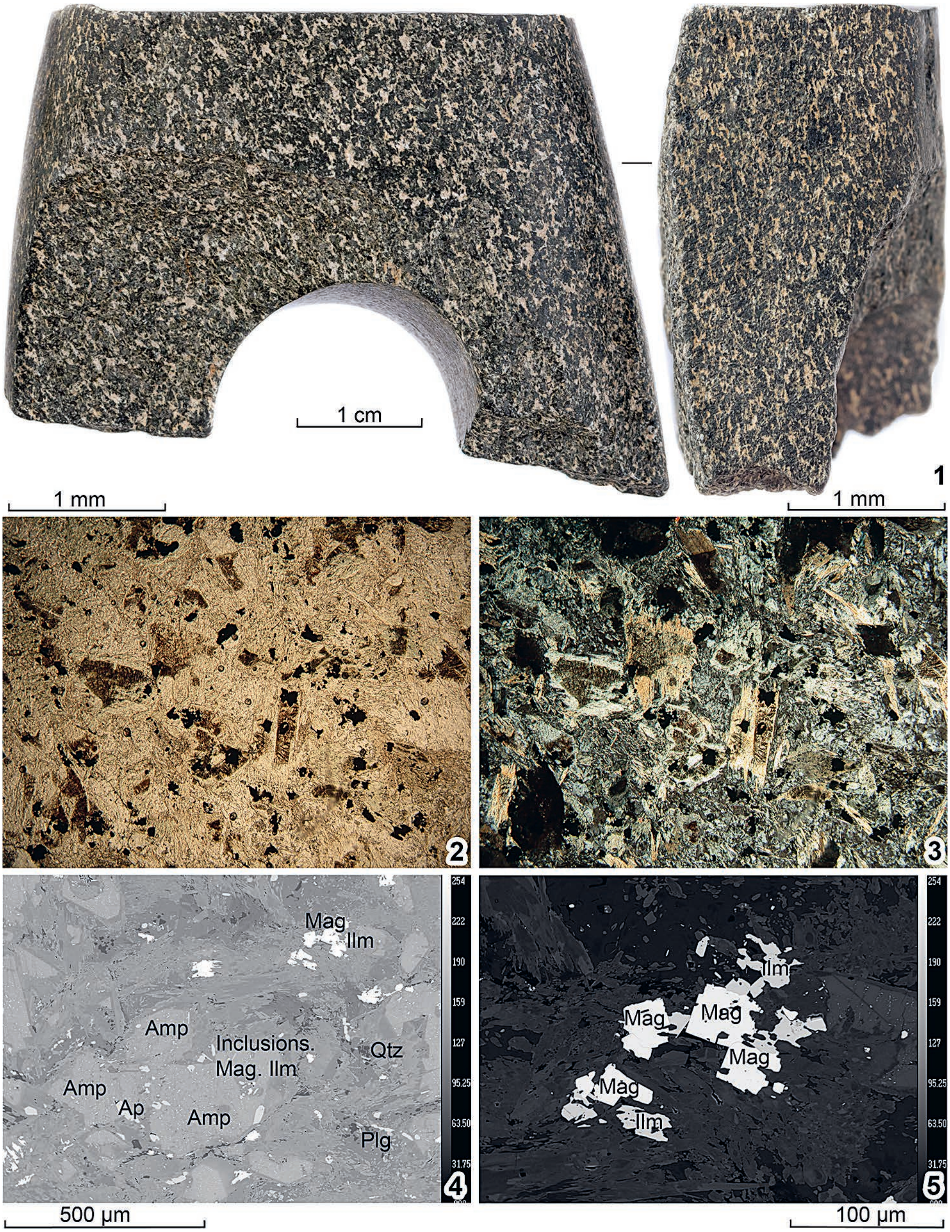

Fig. 10. Amphibolite used for axe hammer Sázava 503. 1 – photo of the artefact; for 2–5 see caption for the *Fig. 6*.

small, crumbled outcrops (south of Sedliště 21–25 × 10^{-3} SI units, at Rataje nad Sázavou 8.59 × 10^{-3} SI units and at Malovidy 4–36 × 10^{-3} SI units).

A comparison of petrographic thin sections under a polarising microscope shows that the amphibolites from natural sources collected between Sázava and Český Šternberk do

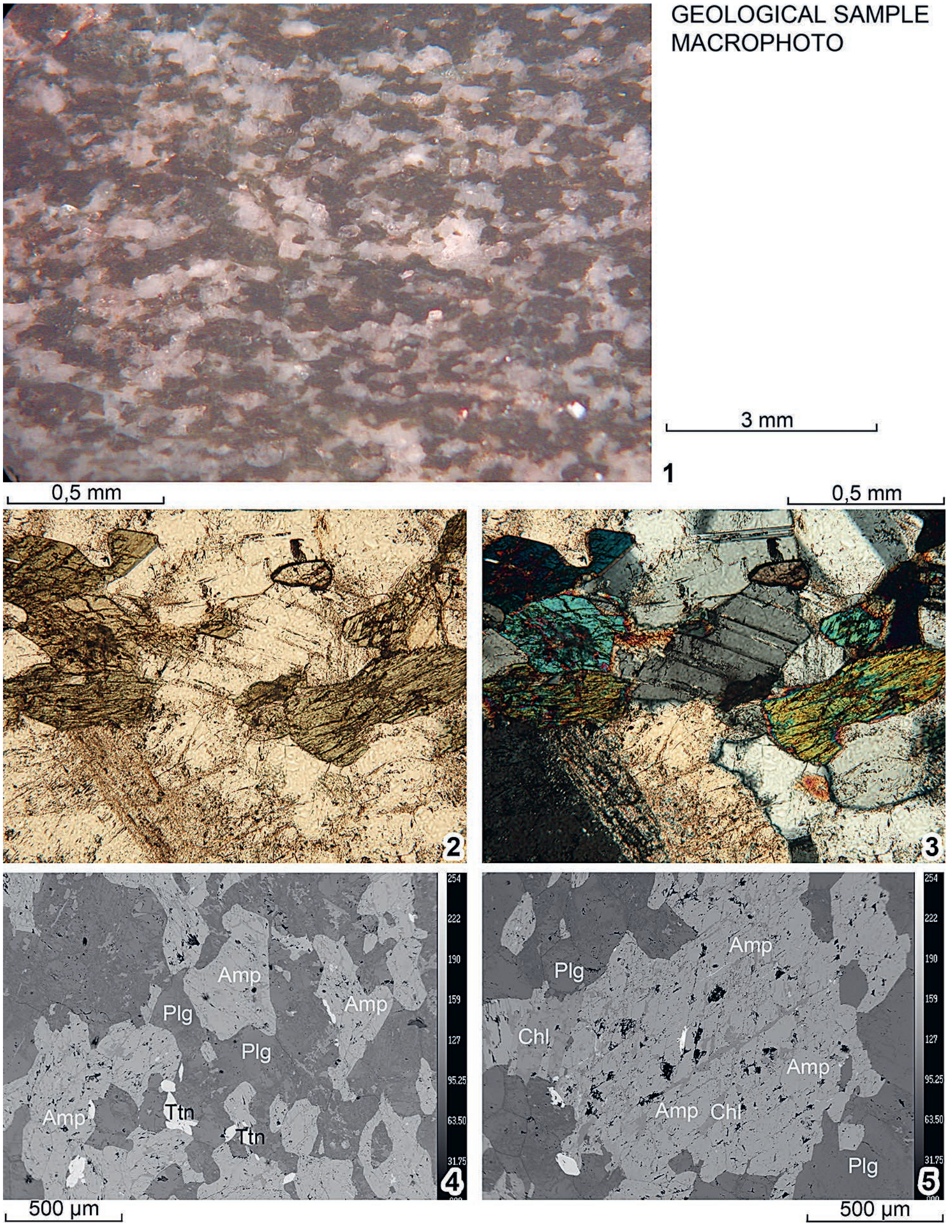

Fig. 11. Amphibolite, raw material, Poříčko, Sázava River region. 1 – photo of the sample; for 2–5 see caption for the *Fig. 6*.

not have the basic rock-forming minerals as strongly transformed as in the amphibolites of artefacts, which also have a higher content of magnetite. Microprobe analyses show that amphiboles from amphibolite artefacts have a wide compositional range from tschermakite to predominant magnesiohornblende and actinolite (*Fig. 8*), which is undoubtedly related to heavy amphibole transformation. We also analyzed the composition of amphibole from natural Sázava sources (pebble, outcrop at Poříčko; *Fig. 8* – white and purple circles are largely outside the line of artefacts /squares/). The detection of pargasite in both natural samples and its absence in the artefacts is significant. The basicity of feldspars in the Sázava 503 amphibolite artefact is very high (bytownite–anorthite), while the comparative natural amphibolites have lower values (*Fig. 9*). Of the ore minerals, large magnetite crystals very often appear in amphibolite artefacts.

Another non-destructive method we employed was the determination of the density of three amphibolite artefacts. An amphibolite rock from the Sázava and amphibolite from the Poříčko outcrop were used for comparing potential raw materials. The amphibolites of axe-hammers had a surprisingly similar density of 3.08–3.11 g/cm^3, while the amphibolites from both natural sources were appreciably lower (2.86–2.87 g/cm^3). Although this is a small assemblage of analysed samples, we identify different values.

In conclusion, it can be stated that the amphibolite artefacts found in the area of the prehistoric marble quarries at Bílý Kámen near Sázava do not primarily correspond to the local sources of amphibolites in this part of the Sázava River region. This makes a certain amount of sense. It is difficult to imagine the production of ground tools from amphibolites directly at their sources. After all, marble from sources in the Sázava River region was also processed in workshops in the Kouřim and Kolín regions, dozens of kilometres away (*Zápotocká 1984*). Similarly, in the case of metabasites from the Jizera Mountains, the final processing did not take place directly at the sources, but in the area of the Bohemian Cretaceous Basin, where there were suitable sources of sandstone for grinding and also stable settlement (*Burgert 2022*).

Magmatic vein rocks

Magmatic vein rocks are represented by nine pieces. Their raw material was identified mainly as porphyritic microdiorite, in fewer cases as diorite (representing less than 1 % of the studied assemblage). As a result of patination, they are usually grey-green on the surface and dark grey-green on a fresh cut (*Fig. 12*). The porphyritic structure formed by phenocrysts of light lath-shaped feldspars and amphiboles is macroscopically distinct. The structure of the basic mass is closest to ophitic. In thin section, the rocks have a simple mineral composition consisting of distinctly pleochroic amphibole (dark green – light yellowish green) that is allotriomorphically limited (*Fig. 12: 2*). Polysynthetically twinned feldspars have a lath-shaped restriction and are frequently zoned. They are only slightly transformed into a mixture of finely flaked minerals (sericite, epidote), usually in the central parts. They enclose acicular elongated apatites, less anhedral quartz or barite. Rare quartz forms allotriomorphic grains between feldspars. Opaque magnetite often has a square or diamond cross-section, and its presence is also confirmed by the high magnetic susceptibility of the rocks ($18–22 \times 10^{-3}$ SI). Grains of skeletal ilmenite and titanite are also present. Small accumulations of chlorite from biotite were also recorded (*Fig. 12: 5*).

It is very difficult to guess the provenance of these rocks, but it can be stated that they do not correspond to the known Moravian sources of diorites and porphyritic microdiorites around the Svratka Valley (today the Brno Reservoir), which were exploited in prehistory and were widely used especially in the Neolithic period (*Přichystal 1988*). The Moravian sources differ by much more transformed feldspars and a lower magnetic susceptibility of

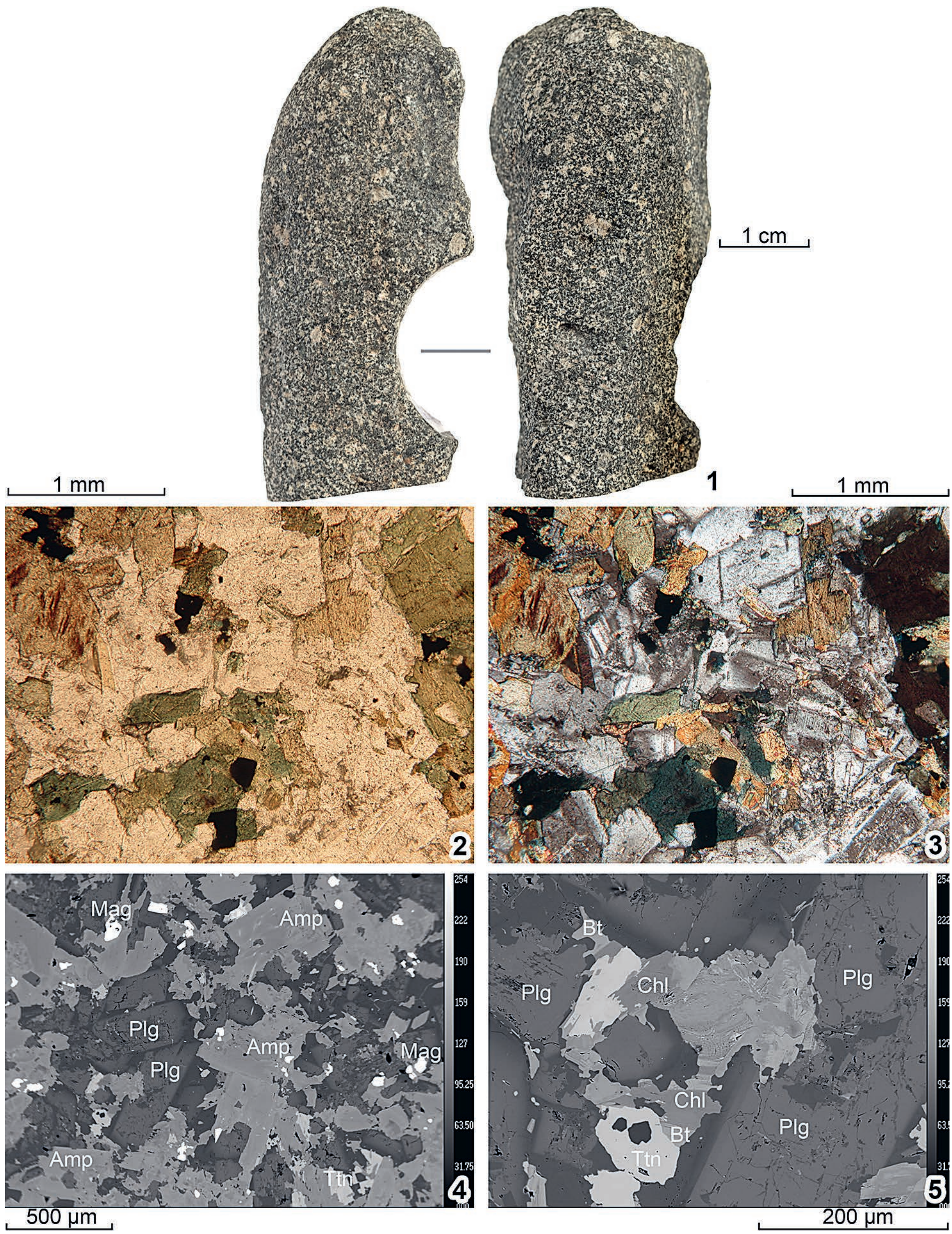

Fig. 12. Porphyritic microdiorite used for axe hammer Sázava 499. 1 – photo of the artefact; for 2–5 see caption for the *Fig. 6*.

0.7–7 × 10^{-3} SI. *Koutek* (*1933*), who studied the area around Bílý Kámen and Český Šternberk in detail, mentions veins of fine-grained granites, aplites, and pegmatites. We know vein of syenite porphyry only from Chuchelník Mill near Rataje nad Sázavou. According to Koutek, the small bodies of diorite are on the eastern edge of the Central Bohemian

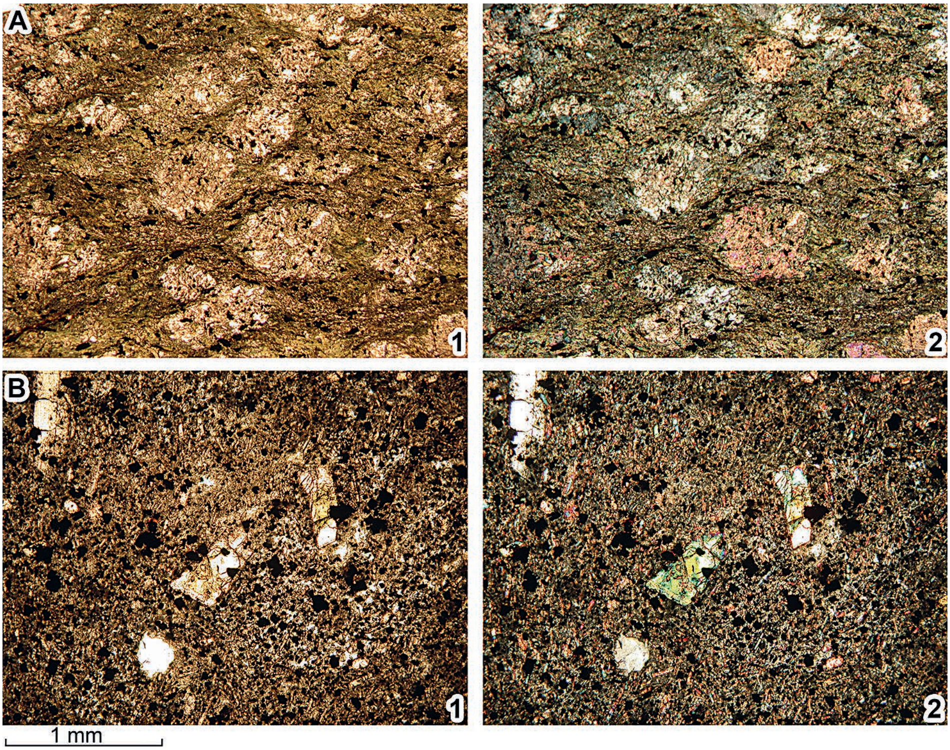

Fig. 13. Artefacts from other igneous rock. A – metagabbro used for axe hammer NM 87936, 1 – thin section in plane-polarized light, 2 – thin section with crossed polars; B – Tertiary basalt used for axe hammer NM 87 830, 1 – thin section in plane-polarized light, 2 – thin section with crossed polars.

Pluton within the Benešov granodiorite. *Šreinová et al.* (*2018*) found two diorite artefacts in the aforementioned Bilý Kámen collection in the National Museum. These authors believe the raw material is of local origin.

Tertiary basaltic rocks

These rocks are represented by 16 pieces, i.e. just less than 2 % of the studied assemblage. They have a strong brownish-light-grey patina on the surface. The basic mass is not well distinguishable even under a stereo microscope, but phenocrysts of ochre-weathered olivine and pyroxene are distinct (*Fig. 13 B/1-2/*). The magnetic susceptibility of these raw materials is relatively high, in the range of 8–20 × 10^{-3} SI units.

The study of a thin section of artefact NM 87830 confirmed the presence of relics of olivine phenocrysts that are heavily corroded by groundmass and pyroxene phenocrysts. Tiny lath-shaped feldspars sometimes form a trachytic texture when they surround some phenocrysts. The groundmass contains some magnetite grains of various sizes; otherwise, it is probably partly disintegrated volcanic glass. Small pyroxene phenocrysts have a fresh appearance.

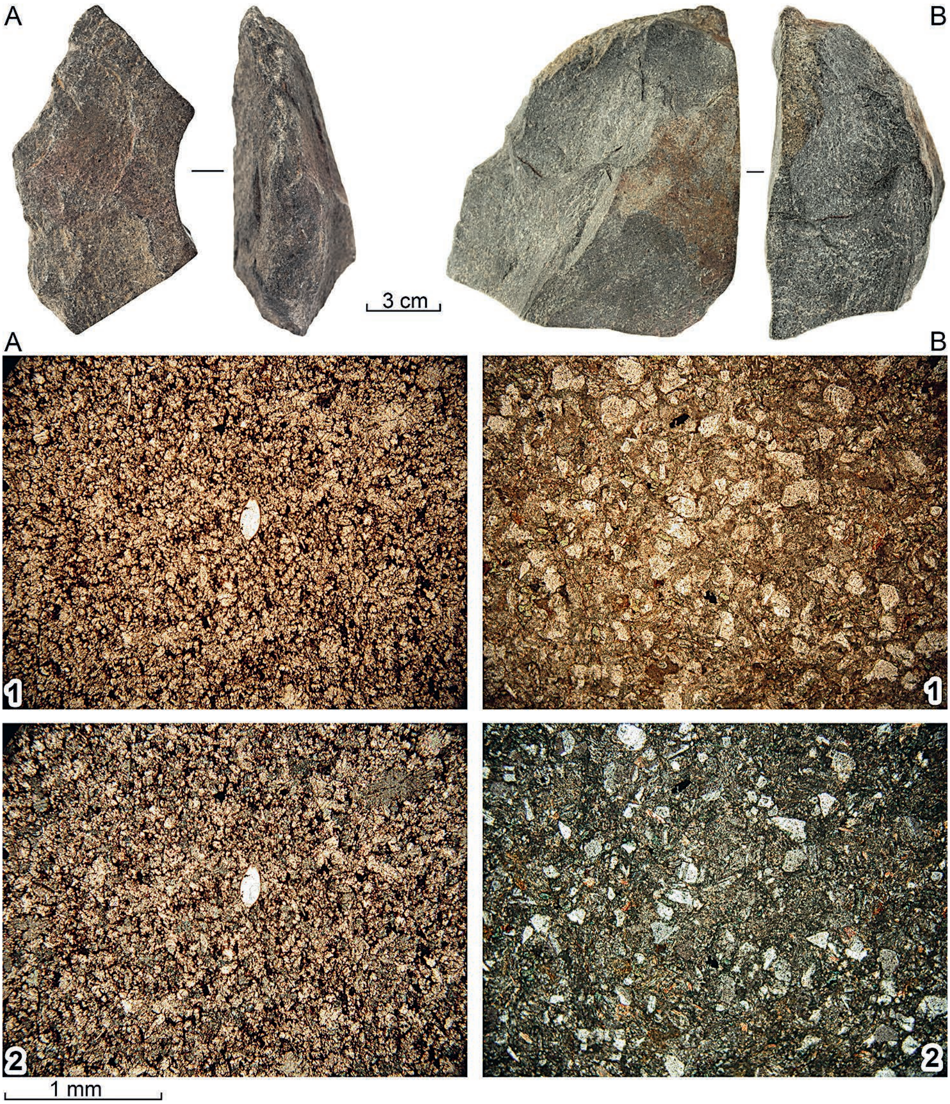

Fig. 14. Artefacts from sediments. A – Devonian limestone used for axe hammer NM 87964, 1 – thin section in plane-polarized light, 2 – thin section with crossed polars; B – Proterozoic crystalloclastic tuff used for artefact NM 87986, 1 – thin section in plane-polarized light, 2 – thin section with crossed polars.

In terms of more detailed classification, the raw materials of the mentioned 16 artefacts can be determined only as Tertiary basaltic rocks, some of which are probably basalts as well. Tertiary alkaline volcanism in Bohemia has a number of specific rocks based on their SiO_2 content, especially in the evidence of nepheline, when basalts can transform into basanites to olivine nephelinites, which cannot be distinguished either macroscopically or under a stereo microscope. Density analysis of artefact NM 88007 produced a value of 3.00 g/cm^{-3}, which broadly corresponds to both olivine basalts and basanites or foidites.

The Bohemian Middle Mountains (České středohoří) is a possible natural source for the considered rocks, besides a number of isolated occurrences between Mladá Boleslav and Jičín; still other smaller sources are located in the territory of Bohemia. The use of local Tertiary volcanic rocks during the period of the Stroked Pottery culture for the production of ground artefacts is evidenced by the collection of macrolithic industry from Mšeno near Mělník. However, their representation at this site is only 2.6 % (*Lička – Šreinová 2022*, graph 12).

Dark Devonian limestone

An unusual raw material, previously unreported from the Bílý Kámen ground tool assemblage, is the black-grey limestone from which the artefact NM87964 was made (*Fig. 14: A: 1–2*). The rock reacts violently with diluted HCl, and a steel needle leaves a white scratch on it. It is clearly a limestone, which was confirmed by a petrographic thin section analysis. Being a soft rock, limestone was used only exceptionally for the production of ground tools, but it is abundantly represented in the raw material spectrum of prehistoric macehead (*Berounská 1987*).

The density of artefact NM87964 is 2.65 g/cm^3, which is roughly consistent with the Silurian and Devonian limestones of the Barrandien. Measurements of 46 samples produced an average value of 2.70 ± 0.1 g/cm^3 (*Eliáš – Uhmann 1968*). Limestones of Cretaceous or Jurassic origin have significantly lower densities (2.44–2.54 g/cm^3). A thin section reveals a large amount of dark organic and clay admixture among the calcite grains. The rock is a limestone of the wackestone type with recrystallized groundmass. Present fossils include crinoids, fragments of crinoid stems, ostracods, and organic-walled microfossils – chitinozoa. According to a consultation with H. Weinerová from the Institute of Geology of the Academy of Sciences of the Czech Republic in Prague and J. Vodička from the Museum of the Bohemian Karst in Beroun, this limestone could probably be stratigraphically placed in the Silurian or lowermost Devonian (*Chlupáč et al. 1992*). We can therefore consider with high probability that it originates in the Barrandian area.

Proterozoic crystalloclastic tuff

We included 13 artefacts in this group, all of which come from the collection at the National Museum (*Fig. 14: 4–6*). It is noteworthy that besides local amphibolites, their discoverer, K. Žebera, mentions only '*a single fragment of a spilite tool*' (*Žebera 1986*, 12) in the entire enormous collection from Bílý Kámen.

The rocks included in this group have a macroscopically light greenish-grey colour on a fresh section. The patinated surface is usually light olive-grey (Munsell rock colour chart: 5Y 6/1) without distinguishable components, but there is often a clear indication of bands about 1 cm thick. The rock is hard and a steel needle typically does not make a mark. A clastic structure obscured by newly formed minerals can be distinguished under a stereo microscope. A clear image is provided by the petrographic thin section taken from artefact NM 87986: sharp-edged feldspar clasts of 0.1–0.2 mm size (crystal-clastic structure) dominate, which, together with the basic mass between them, are transformed into the epidote-zoisite group of minerals; accumulations of green chlorite occur in places. This chlorite mostly fills fragments of originally bubbly glassy vulcanite. The rock is essentially identical to the comparative thin section of crystalloclastic tuff from the artefact from the Řivnáč culture site of Hostivice-Palouky (Prague-west district), which was provided to us by J. Zavřel and is stored in the National Lithotheque in Brno.

Other rocks

Only a few pieces in the assemblage were made from other rocks. They were determined mostly only with the help of a stereo microscope and as such their identification is tentative. These are erlan (1 pc), eclogite (1 pc), strongly tectonised metagabbro (2 pc; NM 87936; *Fig. 13A /1–2/*), and serpentinite (2 pcs; NM 87829). The latter is probably a fragment of a macehead (*Burgert et al. 2020*, obr. 5: 12). The raw material is translucent to water green in places; the magnetic susceptibility is close to 60×10^{-3} SI. Dark quartzite with very low magnetic susceptibility was also found (6 pcs), and the use of probably Proterozoic–Palaeozoic metabasalts ('diabase') from the Barrandian (7 pcs) cannot be ruled out.

Discussion

Over the past few years, we have focused our attention on a review investigation of this site, beginning with an archaeological investigation of the mining relics (*Burgert et al. 2020*). We also performed a mineralogical and geochemical analysis of key artefacts (bracelets), and this immediately revealed that the predominant raw material of the bracelets is dolomite marble, i.e. a different raw material than the one present at the Bílý Kámen site (*Přichystal et al. 2019*), a fact simultaneously recognised by yet another team of researchers (*Ehling et al. 2020*). Only several bracelets from calcite marble from the Bílý Kámen site are known. As such, Bílý Kámen with preserved relics of mining is not the main source for the production of bracelets. In terms of chronology, these bracelets belong to the late phase of the Stroked Pottery culture, i.e. to the Rössen culture.

Using field prospecting and geochemical and petrographic analysis of marble sources in the broader region, it was possible to locate the probable main source of raw material for the Neolithic bracelets – the Na Stříbrné site near Český Šternberk situated roughly 10 km south of Bílý Kámen (*Burgert – Přichystal 2022*). Relics of prehistoric extraction have not yet been identified at this location; they were likely destroyed by medieval and, primarily, modern mining.

Returning to Bílý Kámen, an interwar excavation produced a remarkable assemblage of several hundred fragments of ground industry, mainly bored axe-hammers. The chronological classification of the collection correlates with the dating of the marble bracelets. Although the precise localisation of the find in the area is not known, the description suggests that it was discovered on the bottom of one of the mining pits in the SE part of the site (*Fig. 3*), thus raising the possibility of a connection between the find and the extraction of marble. However, the conspicuous concentration in one place along with the enormous fragmentation suggests that the tools were subsequently broken intentionally into the smallest possible pieces, perhaps representing part of ritualised behaviour at the mining site.

One of the keys to the interpretation of the find could be the material composition of the artefacts, which was in the scope of this study. The basic questions were: *1. Does the*

Fig. 15. Split quartz pebble with diameter of 23 cm found at Bílý Kámen during field survey in 2017 (photo by A. Přichystal).

material of the tools differ from those known from common contemporaneous settlements? 2. Are regional materials used to a greater extent in the assemblage?

Our research led to negative answers to both of these questions. The predominant material (80–86 %) is amphibole-rich metabasite from the Jizera Mountains. The second material (amounting to only 10 % of the dominant material) is amphibolite to amphibolite gneiss (8 %). Other raw materials (Tertiary basaltoids, Proterozoic crystalloclastic tuff, dark quartzites, diorites, and porphyritic microdiorites) make up only 1–2 % in each case, or individual pieces (metagabbro, serpentinite, Devonian limestone, eclogite?, erlan?, Proterozoic volcanics?). The raw material composition of the Bílý Kámen assemblage is comparable to the raw material spectrum of ground tools from common Neolithic settlement sites in Bohemia. For example, in an assemblage of 968 pieces in Bylany (LBK and SBK), amphibole-rich metabasites make up 97.7 % (*Velímský 1969*). The representation of amphibolites is 0.8 %, while other rocks represent only individual artefacts. More suitable comparative material is represented by an assemblage of approximately 500 ground tools from the Stroked Pottery culture settlement in Mšeno, where amphibole-rich metabasites from the Jizera Mountains are again the dominant raw material (91.2 %; *Bukovanská – Březinová 1987*; *Lička – Šreinová 2022*, graph 12). Tertiary basaltic volcanics from around the settlement and other rocks appear only occasionally.

Here we dwell briefly on the question of the chronological consistency of the assemblage. Already during the previous typological analysis, we found that some isolated artefacts apparently made their way into the assemblage secondarily. These are several flat axes, the surfaces of which bear traces of having been run over by a plough. Some tools made from basaltic rocks and crystalloclastic tuffs appear typologically younger and are probably Eneolithic (e.g. an axe-hammer from olivine basaltoid labelled NM 555 257). After removing these artefacts whose connection to the assemblage is uncertain, the share of Jizera Mountain metabasites would increase even further.

At the end of this chapter, we focus on the issue of axe-hammers as mining tools. K. Žebera regarded ground artefacts from Bílý Kámen as mining tools for the extraction of marble, comparing them to medieval metal tools used for mining. In general, finds of mining tools from Middle/Late Neolithic extraction sites are rare. They are known most often from the extraction of siliceous rocks (flint, chert), which were obtained from relatively soft chalk or limestone. Antler pickaxes were primarily used for this work. From the vast area of prehistoric mining fields near Jistebsko in the Jizera Mountains, the authors of the research report only five mining tools (*Šída et al. 2014*). These are modified slabs of metabasite, i.e. a material identical to the material being mined. A quartz pickaxe, a massive pickaxe from local metabasite and one globular hammer from Tertiary olivine basalt were described from the same site and from nearby Velké Hamry (*Přichystal 2018*).

During field prospecting at Bílý Kámen in 2017, we found half of a large quartz pebble with a diameter of 23 cm among the mining relics on the surface of the terrain (*Fig. 15*). This rock did not geologically belong at the site and must have been brought there. The find cannot be dated. We believe that this is what mining tools used for the primary Neolithic extraction of marble could have looked like.

It is unlikely that axe-hammers were used at Bílý Kámen for the primary breaking of marble blocks from the mother rock (*Burgert – Přichystal 2021*, 304–310). Parts of hard metabasite tools were probably used for the coarse processing of semi-finished marble bracelets, which were found in one the mining pits during the most recent excavation (*Burgert et al. 2020*, fig. 11). A typological analysis revealed that parts of axe-hammers are not preserved evenly in the assemblage from Bílý Kámen (*Burgert et al. 2020*, fig. 6). The poll parts of tools heavily predominate over cutting edge fragments. One possible explanation could be that damaged axe-hammers were brought to the extraction site, where they were used as working tools for making semi-finished products. The final phase in the ‘life of a tool’ is their intentional maximum fragmentation and ‘burial’ in one of the mining pits. Finds of the polls of bored axe-hammers are also known from other Neolithic mining sites in Bohemia. Several pieces were found at sites of presumed extraction of rhyolite near Malé Žernoseky (*Zápotocký 1969*, 356–359, obr. 38) and one specimen comes from quartzite mines in Tušimice (*Neustupný 1988*), perhaps indicating a similar (or the same) model of behaviour at contemporaneous mining sites.

Conclusion

The aim of our study was to analyse the raw materials of the entire assemblage of ground tools (912 artefacts preserved in the collections of several institutions) found at the end of the 1930s at the Bílý Kámen site near Sázava. Based on the typology of the tools, we date the assemblage to the late phase of the Stroked Pottery culture. In the majority of the cases, these are fragments of bored axe-hammers.

A petrographic analysis demonstrated that the clearly dominant raw material of the artefacts is metabasite from the Jizera Mountains (at least 80 %). Tools from amphibolite make up a small part of the assemblage (up to 8 %). According to our findings, the origin of this material mostly does not correspond to local sources. Other raw materials are represented only sporadically and are also not of regional origin. These are primarily magmatic vein rocks, Tertiary basaltic rocks, Proterozoic crystalloclastic tuffs, and a dark Devonian limestone. We assume the origin of these rocks to the west of the site in the Barrandian area and at its edges. Tertiary basaltoids probably come from isolated occurrences in the

Bohemian Cretaceous Basin and in the Bohemian Middle Mountains. The raw material composition of the entire assemblage is comparable to assemblages of tools found at Bohemian Neolithic settlements. We can therefore consider the previously held opinion that the production and use of ground tools from local amphibolites also took place at the marble mining site as unlikely.

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