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Reviewed Article:

Life of a Stone Axe. Chaîne opératoire of Neolithic Polished Stone Tools Based on an Archaeological Experiment. A view at the second life of polished tools from Czechia

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The aim of the project described in this article was to reproduce the life of polished stone tools from their manufacture, use and use after repair or as a new tool. The data resulted from eight years of detailed documented and time-demanding experiments (just drilling alone presents more than 2500 hours of work). Some of the results created a new view of the polished stone tools' chaîne opératoire. In the Czech environment it especially concerns so called workshops on Neolithic settlements. Furthermore, the data from the experiments are compared to traces of manufacture and use on the original artifacts from Bohemia and Moravia.



Currently it is important to bridge between practice and theory, between 'living history' and measured archaeological experiment, between the importance of gaining skill and exact analysis. All are needed. In our too fast lives under the pressure of

ALL FIGURES REFERENCED IN THIS ARTICLE CAN BE FOUND IN THE APPENDICES BELOW.

Introduction – so called workshops and depots configuration

On the territory of the Czech Republic, polished stone tools are found within the context of Neolithic settlements, as single finds, in graves or in hoards. Only graves and hoards represent closed assemblages and provide more information about the 'life' of polished stone tools. The pieces deposited in graves are usually shorter; we can presume they were shortened during their use. So-called 'manufacturing hoards' prevailed among the hoards (Vencl, 1975). The

lack of time, we tend to sacrifice some of the research components.

artifacts are not finalised and carry traces of manufacturing. Their lengths suggest to us the sizes of the original artifacts.

Within the published finds of polished stone tools in Bohemia and Moravia, there are some exceptional assemblages (hoard Praha – Ruzyně, hoard no.1 from Mšeno) (See Figure 1). From the experimental point of view, the find from Praha – Ruzyně does not seem to be a workshop assemblage (Bařtová, *et al.*, 2011) but a gradual collection from production of shoe-last adzes (probably by cutting and polishing) from one piece and at the same time storage of axes damaged during work (longitudinal flake chipped of the tool). The hoard was deposited in the wall of a storage pit and could represent a workshop where damaged tools were repaired.

Additionally, the find of multiple Neolithic polished stone tools from Mšeno is also exceptional. It was placed below the floor of a house and contains undamaged tools that could represent a single person's equipment (Lička, 1981, pp.615-616). A number of other hoards contain unfinished tools, material in a rough shape for future tools and rough-outs (Vencl, 1975).

Apart from the stated closed assemblages, there are numerous open assemblages, sometimes described as workshops. Within Czech archaeology, the interpretation of workshops went in two different ways (Burgert, 2019, pp.197-198). Either it used the number of stone objects within archaeological features (quantitative approach) or assessed the objects qualitatively. This created unsolvable contradictions. S. Vencl (1975, pp.16 and 18) already started to differentiate workshop type of finds from settlement waste, but at the same time he supposed? existence of artifacts broken during manufacture. He first placed the initial shaping of rough-outs close to the source of the material but drilling could, according to him, destroy rough-outs (Vencl, 1975, pp.63 and 67). Within the hoards he differentiated between roughly worked large shapes and partially prepared tools from settlements (Vencl, 1975, pp.55,56 and 64).

We would like to rule out the **quantitative direction** of thinking about the so-called workshops because it does not allow the differentiation of manufacturing settlements. Polished stone tool remains appear on all settlements (Vencl, 1975, p.18) and are dispersed. Suggestion of their concentration (See Figure 2) might better correspond with the distance of the area with waste from concrete pits, where the remains could be preserved as archaeological evidence. We prefer a **qualitative approach** based on the categorisation of finds.

Intuitively, finds of rough-outs, fragments or cores have been identified as workshops since the first half of the 20th century (Burgert, 2019, pp.197-198). We can consider the depiction of stone artifacts from Hustřřany in Bienenbergov's publication from 1779 (Kalferst, 2007, p.77) as the first evidence of workshops in Eastern Bohemia. It presents the typical inventory of a so-called workshop: rough-outs and waste, cores and hammerstones. Also considered as parts of workshop assemblages are cores and rough-outs (řřřda, 2007, p.76), as well as flakes, cut-offs, hammerstones and polishing stones (řřřda, 2004, pp. 167-172) or reamers (Vencl, 1960, p.41). Often there are also polished stone tools, broken either during manufacture or the finishing process (Davidov, *et al.*, 2004, p.195). S. Vencl (1960, pp.31 and 40) considered hammerstones (a tool of an unknown function, created by polishing of damaged ends of original shoe-last adzes, axes and hammer ends of hammeraxes) and sandstone polishers as evidence of manufacturing of stone tools on every settlement. The idea of workshops in the lowlands was supported by the isolated finds of large blocks of material of up to 12 kg mass (Vencl, 1975, p.67). It seemed that the raw material was worked on the settlements. This thinking was altered by the find of the sources of metabasite type Jizersk hory (řřrein, *et al.*, 2002; Přichystal, 2002). It showed that knapping of the material took place mostly, if not fully, immediately in Jizersk hory at the sources (řřřda, *et al.*, 2012; 2013; 2014). At the same time, it was obvious that the source of metabasite was outside the Neolithic settlement area and therefore it was necessary to transport the material or rough-outs to Eastern Bohemia, where there is a concentration of so-called workshops (Vencl, 1975) covering more than 100 km; and finally, the discovery of the material source validated the experimental manufacture from metabasite, which we started before 2002 (Tich, 2000, pp.110, Figure 13d).

A model was created (Tich, 2021, Figure 6), which respects not only finds of material blocks and primary debitage carried out also in secondary workshops (Bartık, *et al.*, 2015, p.52, model B) but also finds of rough-outs on consumer settlements (Bartık, *et al.*, 2015, p.52, model C). The stated model took into consideration our experiments with stone polishing, cutting and drilling.

Methodology

For the above-mentioned reason, we compare the results of our long-term experiments from recent years with archaeological finds. The single categories of so-called workshops we also compare with the content of polished stone tool hoards. While various assemblages from settlements do not always contain all categories, in the case of hoards it is possible to categorise them as closed assemblages. Though we also see differences in the hoard contents. Information on hoards was gained from well-published finds (Vencl, 1975; Lička, 1981; Bařtová, *et al.*, 2011), information on settlement finds was gained from study of the finds of the so-called old collection from Eastern Bohemia Museum in Hradec Krlov, supplemented by selected finds from the National Museum in Prague and some in detail published finds from settlements in Bohemia (Davidov, *et al.*, 2004; Bařtová, *et al.*, 2011).

The results of our archaeological experiments were compared to the polished stones from the museum depository and this fed back into the setup of following experiments. The experiments were preceded by an extensive phase of gaining experience with the replicas to help us achieve relevant results. In chosen cases, the characteristics of original finds and replicas were compared microscopically (Department of Archaeology, Philosophical Faculty Hradec Krlov). Unfortunately, because of erosion of the original artifacts, this was not always possible. As a result, the research was mostly based on macroscopic comparison. To ascertain the strength of the material, one sample was measured in Central Laboratory Předměřice nad Labem of The Technical and Test Institute for Construction Prague.

We would like to highlight the following:

1. Manufacturing of authentic replicas is very time consuming. Destruction of some artifacts during the experiments is necessary and therefore is very expensive.
2. In case of microscopic observation there is a concern that replicas might contain traces of a modern tool. During our experiments, the groove traces were created using natural abrasives (its existence on originals was published for example by Vencel (1975, p.64)) on a rough grindstone. They are, therefore, authentic.
3. Gaining large number of replicas is time consuming. This is necessary for results comparison.
4. It is desirable that more experimenters take part as they present different approaches to both manufacturing and tool use. Characteristics of the key material (metabasite Jizerské hory) are not homogenous thanks to variation in the material. At the same time, only the highest quality of the material ascertains successful result of an experiment.
5. Differentiating between large (length from approximately 30 cm) and small (around 20 cm in length) tools is fundamental both in replication and interpretation of the original artifacts. It plays an important role in assessing the technologies used (knapping, cutting, drilling, polishing) and tool use (axes, adzes, hammerstones). Manufacturing and use of smaller tools is easier and does not tell us anything about the characteristics of the rarer large tools.

There are many studies concerning *chaîne opératoire* (for example Gosselain, 1992; Grace, 1997; Soressi and Geneste, 2011; Coupaye, 2009). The issue is sometimes described as operational sequence (Bar-Yosef and Van Peer, 2009). When we talk here about the 'life' of polished stone tools from their manufacturing to their 'death', we also consider their 'second life' in the shape of further use after destruction of the original artifact.

Critique of *chaîne opératoire* (for example Monnier and Missal, 2014) highlights the danger of subjectivism connected to personal experience. We attempted to minimise this possible weakness of *chaîne opératoire* by involving a larger number of experimenters, gaining experience and proficiency and identification of as many marks on the original finds as possible (unfortunately polishing covers previous traces, even in the second life of the artifact).

We think it necessary to assess the *chaîne opératoire* specifically to a technology. We believe that in the 'life of polished stone tools' we are not attempting to read Neolithic people's intentions; We are only identifying single phases of the material/tools changes on the basis of comparison of original remains with their replicas created by archaeological experiment. Even though basic techniques (polishing, drilling) are obvious on each artifact, evidence of other technologies can be rare (cutting covered by polishing, knapping before and after polishing). This evidence is fundamental, with its help we support the results of archaeological experiment. Moreover, since we are concerned with combined techniques (knapping, cutting, drilling, polishing), we cannot follow them on one artifact as is possible with knapped tools.

Polished stone tools in Eastern Bohemia

In Eastern Bohemia there is a unique opportunity to study *chaîne opératoire* of polished stone tools. There are available finds from the 'old collection' in Hradec Králové. Eastern Bohemia is an area of a concentration of hoards and so-called workshops (Vencel, 1975). At the same time, this area was covered by extensive archaeological excavations preceding the building of motorways D 11 and D 35 (See Figure 3). These excavations though did not register presence of hoards and 'workshops'. They uncovered only common settlement waste. Eastern Bohemia is also unique for the occurrence of high quality sandstone, which was used in manufacturing. In the immediate vicinity of these sources near the modern village of Skála there is one unusually-placed Neolithic type roundel (See Figure 3). The dating of the roundel is so far uncertain (it contains La Tene finds) but the name of the village suggests that the sandstone outcrops must have been visible in the Middle Ages. At this source of sandstone, the roundel may have been a place of gathering (Tichý, 2021).

Important hoards unfortunately originate from earlier excavations (Vencel, 1975), and today it is difficult to assess their content. Only fragments of the original finds are preserved, these are part of the 'old collection'. Despite that, the collection can be used for studying technology and wear of polished stone tools and their sizes. Part of the collection (222 pieces) was assessed in detail, specifically artifacts with holes. These seemed to be the easiest to 'read' for assessing the orientation of the tool handle. All tools were analysed for traces of manufacture or use (See Figure 10). There were only 54 complete tools, the biggest group of 24 belong contained tools 10 – 15 cm long. Furthermore, there were tools in the length of 0-5 cm (2), 5-10 cm (11), 15-20 cm (9), 20-25 cm (2) and longer than 25 cm (6). We do not know the original contexts of the 'old collection' artifacts, but as with traditional findings of Neolithic in Bohemia, they likely originated from settlements. This is supported by the fact that the 19th and early 20th century finders paid attention primarily to larger pieces.

The following characteristics were important for the replica manufacturing: the most common distance of the hole from the sides of the artifact is approximately 18/17 mm, the most common diameter of the hole is between 20 and 23 mm, the most common holes are 3-4 cm deep (54 pieces), the most common angle of the blade is 80°, the most common angle of the cutting edge is 30°.

From the point of view of tool use and its 'death', the direction of the breakages is important. Vertical breakages were observed on 18 pieces, oblique on 37 pieces while horizontal ones were the most common – 85 pieces. Longitudinal (planar) breakages were found on only 20 pieces. Fragmentation of artifacts relates to the direction of material (metabasite Jizerské hory) foliation, which is most often at a right angle to the breakage (right angle foliation 125 pieces, oblique 13 pieces, parallel 10 pieces, on the remaining 74 pieces it was undeterminable).

Description and assessment of the experiments within the context of polished stone tools finds

Knapping and chipping stone rough-outs

For metabasite in Jizerské hory we gained material for our experiments from historical and recent stone piles created by field clearing. Today it is difficult to find suitable material for making replicas, especially of large tools. The basis of the work is a hammerstone (See Figure 4:1). Holding a hammerstone in hand as a mallet proved effective. With regards to the strength of the material, hammerstones made from metabasite proved successful. Though even they often did not sustain massive hits. Broken hammerstones correspond with archaeological finds (Šída, *et al.*, 2012; 2013; 2014). It is therefore not possible to identify their original mass and design. In the quarries there are exceptionally rare original finds (See Figure 12:1). Although we successfully replicated the creation of a rough-out (See Figure 4:5a), the fragments from the Neolithic quarries were even bigger. They had to be created by large hammerstones with greater mass and even larger pieces of material.

During the surface survey it was occasionally possible to find rejects. It is important that it is possible to identify two size groups: smaller ones around 20 cm and longer, broken ones. Though it is not possible to determine the original length, it must have been at least 30 cm. It is obvious that smaller rough-outs were manufactured directly in the mountains and that for at least part of the production, they did not transport of large blocks of material to the lowland settlements. That is an economic approach whereby transport of unnecessary mass of material does not take place. This possibility was already admitted by S. Vencl (1975), before the discovery of the metabasite quarries in Jizerské hory.

A fundamental finding of the experiment is the differentiation in the workability of the different types of metabasite (Tichý, *et al.*, 2021c). Not every type can be used for knapping the rough-outs. Hard metabasite types can be split only into slabs. Further attempt at working it would lead only to breaking the material into unusable pieces. It is difficult to determine the moment when the knapping is still possible. The manufacturer attempts to remove as much of the superfluous material as possible, as it is difficult to remove it following grinding. It is possible, though, that attempts at knapping an unsuitable type of metabasite still took place after transport of the prepared material to the settlement. That would explain the finds of smaller pieces of the especially hard metabasite types.

In any case, knapping, while demanding much strength, is the least time demanding technique used in working metabasite type Jizerské hory. Even difficult to work shapes were possible to create by safe pecking. This method was stated already by S. Vencl (1975).

Stone cutting

type of cut	length of cut (mm)	depth of cut (mm)	width of cut (mm)	total length (mm)	total width (mm)	total height (mm)	weight (g)	box	photo
across hole	132	3,5	13/6,5	135	55	45	949	22 504-2171-divide	14-18
doublesided 1	100	22	–	135	55	45	949	22 504-2171-divide	15-21
doublesidedý 2	62	11	–	135	55	45	949	22 504-2171-divide	15-21
? doublesided 1	75	8	–	84	52	31	213	2900-2919	43-45
? doublesided 2	60	6	–	84	52	31	213	2900-2919	43-45
on side	81	8,5	7 ?	84,5	40	14	73	2650-2669	61-64
across hole	39,5	2	3,5	129	64	49	603	2680-2689	78-79
on side	188	22	–	250	75	55	1,794 kg	2690-2699	81-86
along each other1	57,5	1,2	3,5/4,5	184	59	31,5	551	2740-2759	115-117
along each other 2	89	0,5	3/3,1	184	59	31,5	551	2740-2759	115-117
onside?	55	16	–	76	44	20	113	2530-2549	159-163
on side	42	14	–	56	53	26	104	2550-2579	171-173
on roughout	143	19	15 ?	170	54	29	472	2390-2391	251-258
on side	49	19	–	70	53,5	34,5	172	2430-2459	280-287
on side?	46,5	6	–	57	62	14	57	2460-2479	290
on side?	68	19	–	96	31,5	19	114	2460-2479	297-300
on front	87	3	4	52	48	32	387	2260-2269	356-361
on side	286	26	15 ?	374	86	74	4,53 kg	VIII.	47-52

on roughout	143	2/3,5/3	4/5,2/6	246	102	40	1,86 kg	2320-2329	375-382
on side	305	19	10 ?	338	50	76	2,42 kg	VIII.	53-56
in side	200	14	-	338	50	76	2,42 kg	VIII.	53-56
on back	71	11	10 ?	338	50	76	2,42 kg	VIII.	53-56
on side	111	21	-	112	47	24	216		1 až 3
on side	47	11	max 7	57	50	24	110		11 až 16
on side	21	8	max 7	57	50	24	110		11 až 16
on side	38	19,5	max 10	60	57	31	185		17 až 25
on side	54	13	-	95	52	46	396		31 až 35
left side	132	11,5	-	113	52	18	140		40 až 45

TABLE 1. EVIDENCE OF CUTTING METABASITE JIZERSKÉ HORY FROM THE FINDS OF MUSEUM OF EASTERN BOHEMIA IN HRADEC KRÁLOVÉ

Pieces of metabasite that cannot be knapped can be cut (See Table 1). S. Vencl (1975) describes rarely preserved pieces of materials with pecked grooves aiming to divide the material into slabs. Such slabs might not be effectively worked by knapping or chipping. Our experiments showed (Tichý, *et al.*, 2021a) that knapped artifacts still contain too many protrusions which would take an extremely long time to remove. That applies especially to large artifacts. On the other hand, cutting is a very effective technique (See Table 2). The reason is the achievement of flat sides which are easier to straighten on a flat grinding stone.

used material	date of experiment	max. depth of cut (mm)	cut aver./hour (mm)	max. width of cut (mm)	max. length of cut (mm)	time of cutting (h)	abrasive material (g)	quantity of used abrasive material (g)	saw	total number of saws	note
01a_ amphibolite	7. 4. - 11. 4. 2020	11	1,4	14	272	7 h	4 (K)	-	pí	-	
01b_ amphibolite	12. 4. - 16. 4. 2020	7	1,2	14,5	269	5 h 25'	4 (K)	-	pa, pí	-	pí - sandstone
02a_ amphibolite	16. 4. - 18. 4. 2020	12	1,67	16	312	8 h	4 (K)	-	pa, pí	7	pa - flint
02b_ amphibolite	18. 4. - 21. 4. 2020	14	1,19	16	306	8 h 45'	4 (K)	-	pa, pí	-	ko - bone
01_ metabasite	1. 5. - 16. 5. 2020	11	2,2*	15	221	4 h 30'	4 (K)	-	pí	-	result influenced by the starting value
02a_ metabasite	17. 5. - 29. 11. 2020	19	0,8	18,5	195	23 h	3 (K), 4 (K)	-	pí	21	
02b_ metabasit	5. 12. 2020 - 26. 4. 2021	13	1,04	15	198	14 h	not sifted (K, C)	257	pí, ko	13	
03a_ metabasite	22. 4. - 25. 8. 2021	15,2	0,52	16	283	30 h	not sifted C	-	pí, mb	78	metabasite saw
03b_ metabasite	27. 4. - 24. 9. 2021	11	0,85	14	229	13 h	not sifted C	517	pí	18	ruzyně
04_ metabasite	2. 5. - 22. 8. 2021	25,5	0,68	21	207	49 h	not sifted (C), ash	1959	pí	73	
05_ metabasite	15. 7. - 12. 8. 2021	14,5	0,95	18	145	37 h	not sifted C	1340	pí	61	with polishing 23
		153,2			total:	199 h 40'				271	

TABLE 2. OVERVIEW OF EXPERIMENTS WITH CUTTING METABASITE JIZERSKÉ HORY

The cutting method could have been simple. During our experiments (Tichý, *et al.*, 2021a) archaeologically documented sandstone saws proved effective. It would be also possible to use other materials (Stolz, 2016). Complicated hafting, which was presumed in the past (Vencl, 1960), was not necessary. What was needed though, was to use flakes of the correct shape (See Table 3). Preparation of such flakes depended on sufficiency of material. It is possible to imagine sandstone outcrops or even splitting of discarded grinding stones on settlements.

date	saw number	number of abrasive sides	time (min.)	cut depth (mm)	cut length (mm)	saw material	note
05-12-20	1	1	60	0,0	23,0	sandstone Kocbeře	
05-12-20	2	1	35		23,0	sandstone Kocbeře	
05-12-20	3	1	85		23,0	sandstone Kocbeře	
10-12-20	4	2	83		23,0	sandstone Kocbeře	
11-12-20	5	1	40		23,0	sandstone Kocbeře	
19-01-21	6	2	90		23,0	sandstone Kocbeře	
26-01-21	7	1	90		23,0	sandstone Kocbeře	
07-02-21	8	2	70		23,0	sandstone Kocbeře	
08-02-21	9	1	50		23,0	sandstone Kocbeře	
15-02-21	10	1	10		23,0	sandstone Kocbeře	
15-02-21	11	1	50		23,0	sandstone Kocbeře	
25-04-20	12	1	120		23,0	bone	did not work
26-04-20	13	1	60	12,0	23,0	sandstone Kocbeře	
total	13	16	843	12,0			total time with sandstone saws 623 min.

TABLE 3. CONSUMPTION USAGE OF SAW WHILE CUTTING EXPERIMENTALLY

The Praha – Ruzyně hoard (Bařtová, *et al.*, 2011) allow an exceptional insight into this technique. Among others, it contained two finalised shoe-last adzes and two shoe-last adze rough-outs. The rough-outs were cut on both sides (See Figure 1). This? documents repeated cutting from the same slab of metabasite. The second rough-out was cut on an already polished side (See Figure 1), before the rest of the surface was polished. One of the finished tools has on the profile obliqueness corresponding to the angle of a cut on the first artifact. If these four artifacts were not directly cut from one slab, they surely document a common method of shoe-last adze production.

Although evidence of metabasite cutting represents only a small part of manufacturing traces in the museum depositories (Tichý, *et al.*, 2021a), we can presume that much of the traces of cutting were overlaid by grinding of the artifact (See Figure 4:3). It is often presented by miniscule traces on the finished artifacts (See Figure 4:2). Even though cutting is similarly time demanding as other techniques (see below), it is very effective, especially in the case of large artifacts (Tichý, *et al.*, 2021a),

Stone grinding / polishing

Stone polishing seems to be a clear and easy technique. The tools are markedly polished and there are sandstone grinding stones available in the archaeological record. The grinding stone are usually small, often worn from many sides. If a rough-out was not worked by cutting but only by polishing, it was necessary to grind away considerable protrusions of the very hard stone. Our experiments show (See Table 4) that it is very time consuming ((Tichý, *et al.*, 2021a), (artifact on Figure 4:5a changes into 4:5b). We attempted to increase the effectiveness of polishing in two ways. Scattering of abrasive materials did not work very well, and demanded preparation of the abrasives. On the other hand, pecking of the worn smoothed grinder with a metabasite hammerstone proved affective. The roughened surface allowed for faster removal of material (See Figure 4:6).

polished material	date of experiment	time of grinding (h)	weight (g)	total wastage (g)	wastage (g) aver./hour
01_metabasite	25. 3. - 29. 4. 2020	33 h	774 - 655	119	3,3
02_amphibolite	29. 4. - 14. 5. 2020	13 h 15'	503 - 362	141	9,2
03_amphibolite	14. 5. - 11. 6. 2010	22 h 45'	2088 - 1659	429	18,6
04_amphibolite	27. 5. - 17. 6. 2020	13 h 45'	1557 - 1234	323	23,6
05_gabbro	12. 6. - 14. 6. 2020	6 h	1440 - 1319	121	20,2
06_metabasite	20. 6. - 18. 11. 2020	15 h	1508 - 1365	143	9,5

07_marlstone	04-07-20	3 h	833 - 507	326	108,7
08_metabasite*	20. 6. - 26. 10. 2020	5 h	2955 - 2353	602	140,4
09_basalt	25. 9. 2020 - 11. 5. 2021	21 h	1759 - 1058	701	31,9
10_metabasite	3. 11. 2020 - ongoing	10 h	1238 - 1037	201	18,3
11_metabasite	3. 11. 2020 - 30. 9. 2021	28 h	1985 - 1374	611	22,8
12_metabasite	7. 5. - 7. 12. 2020	7 h	770 - 570	200	28,6
13_metabasite	22. 7. - 13. 8. 2020	27 h	3505 - 2905	600	18,4
14_metabasite	09-12-20	1 h	34 - 27	7	7
15_metabasite	9. 2. - 21. 2. 2021	5 h 15'	1028 - 847	181	30,2
16_metabasite	23. 2. - 28. 3. 2021	21 h	1427 - 1089	338	16,6
17_basalt	26-03-21	2 h	953 - 916	37	18,5
18_granite	06-04-21	1 h	1358 - 1322	36	36
19_limestone	07-04-21	45'	958 - 899	59	78,7
20_flint	20. 4. - 29. 4. 2021	7 h	477 - 440	37	5,3
21_metabasite	20. 5. - 30. 7. 2021	8 h	2023 - 1810	213	26,6
22_metabasite	1. 7. - 30. 9. 2021	105 h	2310 - 1420	890	8,4
23a_metabasite	11. 7. - 10. 8. 2021	20 h	1895 - 1636	259	13
23b_metabasite	17. 8. - 20. 10. 2021	54 h	1264-822	442	8
24_travertine	5. 8. - 23. 8. 2021	1 h 50'	320 - 116	204	111,2
25_limestone (Býčí skála)	7. 9. - 9. 9. 2021	5 h 20'	1484 - 679	679	113,2
26_basalt (Ralsko)	9. 9. - 24. 9. 2021	14 h 35'	1266 - 760	506	38,9
27_calcite marble	04-10-21	2h 40'	875 - 418	457	152,3
28_basalt (Ralsko)	15. 11. 2021 - ongoing	5 h	1624 - 1388	236	47,2
29_calcite marble	5. 10. - 8.11. 2021	16h 50'	4072 - 930	3142	175,2
	total:	476 h		12kg 240g	

*strongly weathered

TABLE 4. OVERVIEW OF EXPERIMENTS WITH GRINDING METABASITE JIZERSKÉ HORY: WITH CONCURRENT WEIGHING WE MEASURED AVERAGE LOSS OF VARIOUS ROCKS PER HOUR. THE TABLE SHOWS DIFFERENCES BETWEEN DIFFERENT MATERIALS, EVEN IF IT IS THE SAME ROCK. THE DIFFERENCES CAN BE ATTRIBUTED TO DIFFERENT COMPOSITION OF EACH PIECE OF ROCK, THAT ALSO REFLECTS IN THE SIZE AND SHAPE OF A CONCRETE PIECE. SMALLER SHAPES WITH REGULAR FEATURES SEEMS TO BE EASIER TO WORK.

Polished artifacts can be divided into finished shapes and rough-outs. Rough-outs use to be covered by small facets (Vencl, 1975) (See Figure 12:2). During our experiments it showed that the faceted pieces can be further polished only on a flat grinding surface. This applies especially for rough-outs of large tools, which need large grinding stones. Large grinders are preserved only exceptionally. Our experiments made it necessary to differentiate between two types of grinders. Among the aforementioned irregular shapes found on settlements, we assume it was necessary to use large grinding surfaces found either outside settlements (rock outcrops or large sandstone boulders) or large grinders transported to settlements. Their existence is documented by rare finds of flat grinders near sandstone outcrops (Burgert 2022, Tichý, *et al.*, 2021a) (See Figure 5D), already mentioned finds of faceted rough-outs, but also finds of large cuts of stone which could have been worked only on a flat grinder. It is important to mention that shaping with the help of facets also appears on smaller tools (See Figure 4:4), it does not need to be connected to the production of new tools. The existence of large flat grinders can be evidenced by smaller products. Fragments of sandstone on settlements are sometimes covered by grooves (See Figure 4:7). These may originate from repairs of smaller damaged artifacts. These fragments do not need to represent primary manufacturing.

Drilling of hafting hole

During late Neolithic there was massive expansion of stone tool drilling (Vencl, 1960). This technique is currently among the least known. We, therefore, included in our extensive experiments with drilling metabasite type Jizerské hory and other rocks. At the beginning we were looking for suitable material to make the drill. While in the Neolithic hollow drill was prevalent, we tried also a full drill. Then it was necessary to study two types of drilling – two directional and one directional (Tichý, 2018; 2019; 2020; Tichý, *et al.*, 2021b; 2022b). During more than one hundred tests, we used at first drills made from horn, antler and bone (69 holes), elder (25), wood (5) and reed (8) and later, also from copper and iron. We drilled different types of rock used in Czechia in the Neolithic and Aeneolithic (Přichystal, 2013) (most were chosen and determined by professor Antonín Přichystal). This created a database allowing for extensive comparison of characteristics of types of rocks (apart from the above mentioned we published here also our latest experiments with drilling – see Table 5). Some holes which were unfinished during our experiments suggest that certain rocks cannot be drilled (flint, jade, spilite), which corresponds with archaeological finds.

	material	average drilling speed	max. drill hole depth	average drill reduction	total drill reduction	total number of drills	time of drilling		stone thickness	abrasive material	mass of weight	způsob vrtání /drilling method 1/unidirectional 2 bidirectional	type of drill	notes	
		mm/h	mm	mm/h	mm		h	min.	mm		g				
87	metabasite	0,76	33,1	9,10	395,0	7	42	0	35,0	4K,4+3K,4+3H,N4	290	2	hollow, deer bone	adapted drill, drilling under water	15 12
88	limestone	2,31	73,0	7,4	260,0	6	34	30	75,0	4K,4H,4+3H,4+3K	290/460	2	hollow, elder, diameter 40/28 mm	adapted drill, dry drilling	12 3.
97A	marlstone	9,36	9,0	1,4	7,0	1	5	0	50,0	4+3H	290	2	full, wood, diameter 15 mm	adapted drill	4. 7.
97B	marlstone	2,21	19,0	1,13	17,0	2	15	0	30,0	4+3H,4+3K	290/460/730	2	full, wood, diameter 15 mm	adapted drill	9. 18
97C	marlstone	12,13	21,4	6,66	20,0	1	2	45	35,0	4+3K	350	2	full, elder, diameter 21 mm	adapted drill	20 21
98A	marlstone	11,56	35,0	8,16	49,0	4	5	15	65,0	4+3K,4+3H	350	2	hollow, elder, diameter 37 mm	adapted drill, drilling under water	22 24
99A	marlstone	5,85	39,3	12,61	164,0	8	11	30	76,0	4+3H,4+3K,4K,4H	350	2	hollow, elder, diameter 37 mm	adapted drill, dry drilling	27 8.
99B	marlstone	9,42	66,0	10,57	74,0	3	7	0	66,0	4+3H,4+3K	290	2	hollow, deer bone	adapted drill, dry drilling	27 3.!
99C	marlstone	13,2	66,0	14,6	63,0	4	2	40	66,0	4H,4+3H	290	2	hollow, deer bone	adapted drill, drilling under water	4. 5.!
100	metabasite	0,93	49,0	14,23	726,0	14	46	30	49,0	4K,4H	300	2	hollow, deer bone, diameter 15 mm	adapted drill, drilling under water	14 16
104	metabasite	1,2	30,0	13,96	349,0	8	24	0	31,0	4K,4+3K,4+3H,4+3N,4N	290	2	hollow, deer bone, diameter 13 mm	adapted drill, drilling under water, hard	8. 26
108	metabasite Želešice	1,21	41,2	16,97	577,0	8	33	45	42,0	4K,4+3H,4+3N,4H	290	2	hollow, deer bone	adapted drill, both wet and dry drilling	6. 5.!
112	metabasite	2,5	5,0	7,5	15,0	1	2	0	-	-	300	2	hollow, deer bone	adapted drill overlapping circles	28 28
113	metabasite Želešice	0,56	13,6	6,83	164,0	3	23	30	-	4K	300	2	hollow, deer bone	adapted drill, drilling under water, cut	29 27
114	metabasite	0,8	30,4	10,52	400,0	7	37	45	45,0	4K,4KŽ,4H	300	2	hollow, deer bone	adapted drill, drilling under water, for cutting	28 28
115	metabasite	0,6	12,6	4,61	97,0	2	20	30	76,0	4H,4H+3K	300	2	hollow, beef bone, diameter 20 mm	adapted drill, drilling under	17 10

3369 - hole 1	40,0	11,7	5,0	14,4	11,7	23,6
3369 - hole 2		9,4	3,6	16,0	9,4	22,7
2445	21,0	12,8		7,0	12,8	13,7
average	21,0	11,7	6,2	16,6	11,7	26,7

TABLE 6. EVIDENCE OF DRILLING METABASITE METABASITE JIZERSKÉ HORY FROM THE FINDS OF MUSEUM OF EASTERN BOHEMIA IN HRADEC KRÁLOVÉ.

One direction and two direction drill is, for us, an unknown construction. We followed the principle that the two-directional drill was fixed at two points and one-directional only in the bottom point. Based on preserved manufacturing traces (See Figure 4:8), it seems that the evidence supports the two-directional drill. A two-directional drill reaches higher frequency of revolutions, although the maximum frequency was not needed for optimal performance. In order to optimise drill performance, you needed to be able to feel how it is operating. Performance also depended on frequency and amount of added abrasives, that swirl bellow the water surface held in contact between drill and the drilled rock. The performance of the drilled did not correlate with maximum load. To give you an idea we will describe here a typical experimental drilling on the example of experiment number 135 (See Table 7). With the two-directional drill, the mass of the weight pressing the drill was around 300 g (plus the weight of the wooden shoulder). Based on observation of original unfinished holes, it is possible to recognise several phases of drilling (See Figure 5). The first phase is a shallow cut after a rotation of the drill, only a few millimetres deep. It has a 'U' shape. Some Neolithic drilling finished in this phase. We can confirm that it is a critical point, after the first hour of drilling when the drill cuts in a few millimetres, in the next hours its performance slows down to minimum. The 'U'shape holds at most to the depth of 1 cm. Deeper it changes into wide 'V'. At a depth of about 3 cm it changes into a sharp 'V'. The bone drill becomes translucent and its performance improve. The end of the drill is very thin which corresponds with original artifacts.

date	hole depth (mm)	drill length (mm)	abrasive material number	time of drilling (h)	weight	drill number	drilled in an hour (mm)	drill loss (mm)	notes
3.9.	4	57 do 45	K4	1	300g	1	4	12	drill number 1, length 57 mm
4.9.	4,4	37	K4	1	300g	1	0,4	8	
5.9.	5	31	K4	1	300g	1	0,6	6	
6.9.	5,7	24	K4+3	1	300g	1	0,7	7	end of drill
7.9.	6,4	110 do 99	K4+3	1	300g	2	0,7	11	drill number 2, length 110 mm
7.9.	7,1	89	K4+3	1	300g	2	0,7	10	
8.9.	7,8	78	K4+3	1	300g	2	0,7	11	
9.9.	8,6	66	K4+3	1	300g	2	0,8	12	
10.9.	9,6	54	K4+3	1	300g	2	1	12	
13.9.	10,2	45	K4+3	1	300g	2	0,6	9	
14.9.	11	34	K4+3	1	300g	2	0,8	11	end of drill
15.9.	11,4	110 do 103	K4+3	1	300g	3	0,4	7	drill number 3, length 110 mm
16.9.	12,4	93	K4+3	1	300g	3	1	10	
17.9.	13,2	84	K4+3	1	300g	3	0,8	9	
18.9.	14	75	K4+3	1	300g	3	0,8	11	
19.9.	14,8	62	K4+3	1	300g	3	0,8	13	
20.9.	15,8	49	K4+3	1	300g	3	1	13	
21.9.	16,6	36	K4+3	1	300g	3	0,8	13	
22.9.	17,2	29	K4+3	45min	300g	3	0,6	7	end of drill
22.9.	17,4	112 do 108	K4+3	15min	300g	4	0,2	4	drill number 4, length 112 mm
24.9.	18	98	K4+3	1	300g	4	0,6	10	
25.9.	19	90	K4+3	1	300g	4	1	8	
28.9.	19,4	81	K4+3	1	300g	4	0,4	9	
29.9.	20,4	69	K4+3	1	300g	4	1	12	
30.9.	21,2	58	K4+3	1	300g	4	0,8	11	
1.10.	22	48	K4+3	1	300g	4	0,8	10	
2.10.	22,8	38	K4+3	1	300g	4	0,8	10	
3.10.	23	33	K4+3	20min	300g	4	0,2	5	end of drill
3.10.	23,6	82 do 72	K4+3	40min	300g	5	0,6	10	drill number 5, length 82 mm
5.10.	24,4	49	K4+3	1	300g	5	0,8	23	

6.10.	25	36	K4+3	45min	300g	5	0,6	13	end of drill
6.10.	26,2	107 do 88	K4+3	1h 15 min	300g	6	1,2	19	drill number 6, length 107 mm
7.10.	27,6	65	K4+3	1	300g	6	1,4	23	
8.10.	28,6	50	K4+3	1	300g	6	1	15	
9.10.	29	45	K4+3	20min	300g	6	0,4	5	end of drill
9.10.	29,4	109 do 105	K4+3	40min	300g	7	0,4	4	drill number 7, length 109 mm
10.10.	30,4	93	K4+3	1	300g	7	1	12	
11.10.	31,4	77	K4+3	1	300g	7	1	16	
12.10.	32,1	63	K4+3	1	300g	7	1	14	
12.10.	32,4	63	K4+3	1	300g	7	1	14	
13.10.	33	54	K4	1	300	7	0,6	9	
14.10.	33,4	44	K4+3	45min	300	7	0,4	10	end of drill
14.10.	33,8	112 do 110	K4+3	15min	300	8	0,4	2	drill number 8, length 112 mm
16.10.	34	100	K4+3	1	300	8	0,2	10	vein
17.10.	35	89	K4+3	1	300	8	1	11	
18.10.	36	78	K4+3	1	300	8	1	11	
19.10.	36,4	68	K4+3	1	300	8	0,4	10	
20.10.	37,2	56	K4+3	1	300	8	0,8	12	end of drill
21.10.	38	112 do 97	K4+3	1	300	9	0,8	15	drill number 9, length 112 mm
22.10.	39	79	K4+3	1	300	9	1	18	
23.10.	40	57	K4+3	1	300	9	1	22	
23.10.	40,6	52	K4+3	15min	300	9	0,6	5	end of drill
23.10.	41	113 do 101	K4+3	30min	300	10	0,4	12	drill number 10, length 113 mm
24.10.	42,6	77	K4+3	1	300	10	1,6	24	
24.10.	43	71	K4+3	15min	300	10	0,4	6	
24.10.	43,6	59	K4+3	30min	300	10	0,6	12	end of drill
26.10.	44,2	112 do 98	K4+3	1	300	11	0,6	14	drill number 11, length 112 mm
27.10.	45,4	85	K4+3	1	300	11	1,2	13	
28.10.	x	75	K4+3	1	300	11	x	10	

TABLE 7. DETAILED RECORDING OF EXPERIMENT 135 – TYPICAL COURSE OF DRILLING. METABASITE_S = 40 MM

From the finds we do not know about a phase when the drill cut through and it was not possible to stop the escape of water held around the drill. When the drill was close getting through the stone, the core used to be knocked out. Knocking out of the core left a thin flake on its bottom end (See Figure 10:5b). These sharp edges of the lower thinner end of the hole were probably polished by a sandstone as we do not find this edge on the original finds.

Use of polished tools

Hafting of finished tools is mostly divided according to presence or absence of a hole. The hole determines the use of an inserted handle. We were also testing a possible use of a conical handle fastened like a pickaxe, which does not contradict the wider end of the hole pointing away from the handle. It also corresponds to some archaeologically documented fastenings (Tichý and Panáček, 2024). There are also archaeological examples of fastening of undrilled axes (Vencl, 1960) but not of shoe-last adzes. During our experiments, we identified advantages of tools with holes. Their fastening does not reach over the sides of the tool and allows for better control of the hit and higher effectiveness of use (Tichý and Panáček, 2024).

The most numerous assemblages of polished stone replicas in our experiments were used to work wood digging out a 3m long section of a log boat in 2022 (Tichý, *et al.*, 2022a), cutting down trees in the woods in March 2023 and spring 2024 (See Figure 6:1). A massive shoe-last axe was under strain for the longest (about 300 hours), during digging out the 3m long section of a log boat in winter of 1997/98. During the experiments only some of the replicas were damaged (See Figure 6:5). Mostly this referred? to tools made from basalt or amphibolite (Tichý, 2023). In case of metabasite tools, only thinner blades were damaged (possibly used incorrectly for rough work while cutting down trees). Other damage was caused by defects in the material or a chip along the length of the tool, starting at the blade. The damage corresponded to damage known from Neolithic settlements. These are very well documented in the hoard from Praha - Ruzyně (See Figure 12: 9). Drilled tools from metabasite type Jizerské hory have not been broken during our experiments so far. We, therefore, carried out a strength test on a drilled

axe of medium size (24 cm) (See Figure 6:4). The axe broke at the hole only under strain of 34.5 kN (approximately 3.45 tonne) (Levinský and Fiala, 2025). If we disregard the thin metabasite tools (thin flat axes), the massive tools (mostly based on a wedge shape) are very resilient.

From Neolithic settlements in Czechia there is documented large damage to the cutting edge of the tools. So far we have not been able to replicate it during our woodworking experiments. We decided to experiment with working limestone/marble with drilled tools from metabasite type Jizerské hory. It is one of documented activities where axes were used on materials harder than wood. (See Figure 6:2). Their use is presumed to be in working marble on Sázava site during the late stages of stroke-ornamented ware culture (Burgert, *et al.*, 2020). From there, there is also known use of drilled axes with badly damaged blade, very rarely found elsewhere, and also with rounded ends of the tool. During the experiment with three drilled axes for six hours, authentic planar breakages (See Figure 6:3) were created, similar to finds from settlements, but the damaged blades did not have traces of rounding known from the original artifacts from Sázava. That would correspond with more delicate stonework such as pecking.

Hammerstones for pecking

Rounding of the ends of tools is commonly represented on the settlement during the whole of Czech Neolithic on so-called hammerstones. One of the authors tested long term usage of the common size of hammerstones (673g, 318g, 399g and 373g weight) with pecking metabasite (Tichý, 2021) (See Figure 9B). The result of these experiments was a rougher ware (See Figure 7:16). Our new experiments showed (See Table 8) that more authentic fine surface is created while pecking sandstone grinders (See Figure 4:6) or querns (See Figure 6:6). on shorter ends of the hammerstone, which are typical for the finds from lowland settlements.

date	side A smaller (min.)	side B bigger (min.)	weight (g)	round mallet
14-02-25	10	5	312	sandstone
03-03-25	20			sandstone
04-03-25	20			sandstone
05-03-25	10			sandstone
06-03-25	10			sandstone
11-03-25	10			sandstone
12-03-25	15			sandstone
13-03-25	15			sandstone
18-03-25	5			sandstone
19-03-25	20			sandstone
20-03-25	15			sandstone
27-03-25	10		308	sandstone
total	160	5		

TABLE 8. WORK STRESS OF TWO EXPERIMENTAL HAMMERSTONES 32 AND 33

Common presence of hammerstones (See Figure 7) with a small working area suggests that this tool had a particular function. We presume that it concerns pecking of grinders and querns rather than working metabasite. While hammerstone used to work stone needs a rounded surface, hammerstone for pecking has a clear edge on the edge of the original surface and the new working surface. We, therefore, presume a hypothesis about the 'life' of a hammerstone (See Figure 7:17). When the tool was broken in two (See Figure 6:4), its sharp edge was used without adaptation for pecking. After the edge was worn, the other side could be used. On a large hammerstone there was no sharpening of the tool but an oblique area was created along the whole circumference (See Figure 7:15). A circumference edge could still be used for pecking. If this tool got damaged by harder hits, it created further sharp edge. If the hits were lighter, the whole surface started resembling a polished surface (Fi. 7: 1-13).

To assess their authenticity some of the original artifacts from the Neolithic settlement Obědovice were analysed microscopically (See Figure 8) with the use of digital microscope VHX-6000 and profilometer VR-5000 3D.

The following samples were chosen:

- Experimental hammerstone from metabasite Jizerské hory for pecking sandstone (See Figure 8.2)
- Experimental hammerstone from metabasite Jizerské hory for crushing quartz (See Figure 8.3)
- Experimental hammerstone from quartz for crushing quartz (See Figure 8:4)
- Experimental hammerstone from metabasite Jizerské hory with a hole for pecking sandstone (See Figure 8:5)
- Experimental hammerstone from metabasite Jizerské hory for pecking sandstone (B) and with a polished surface (A) (See Figure 8:6)
- Original hammerstone from metabasite Jizerské hory (See Figure 8:7)
- Original circular hammerstone from metabasite Jizerské hory (See Figure 8:8)
- Original hammerstone from metabasite Jizerské hory (See Figure 8.9)
- Blase of an original flat axe from metabasite Jizerské hory (See Figure 8:10)

- Original cut off area of a metabasite Jizerské hory (See Figure 8:11)
- Experimental hammerstone from metabasite Jizerské hory for pecking, for working metabasite Jizerské hory (See Figure 8:12)

The aim was to compare replicas used for pecking a sandstone grinder (for example Figure 8:2), and crushing quartz (See Figure 8:4) with original artifacts (See Figure 8:7) from an unknown site, a circular hammerstone (See Figure 8:8), typical hammerstone with small working surfaces (See Figure 8:9), a complete small flat axe (See Figure 8:10) and an evidence of cutting (See Figure 8:11). All artifacts are from metabasite Jizerské hory, only one hammerstone was from quartz (See Figure 8:4). One of the hammerstones used for pecking (Fig, 8:6) was partially polished to allow for comparison of a surface created through pecking and surface created by polishing. One of the hammerstones used for pecking was given a hole and was used with a wooden handle (See Figure 8:5) so the traces of pecking were all in one direction. The aim was to compare work ware on hammerstones with axe blade modification (See Figure 8:10) and traces of stone cutting (See Figure 8:11). On the replicas there are clearly visible traces of pecking but the surface of the Neolithic tools from Obědovice are much eroded in the direction of the material foliation (See Figure 8:11). The modification of the axe (See Figure 8:10) gives us information about fine polishing of the blade. We interpret the surface of the round hammerstone (See Figure 8:8) as a tool for rough work (working stone?). Traces of pecking on a replica of a hammerstone can be well differentiated from the polished surface (See Figure 8: 6 A, B). Crushing quartz created a different type of surface, it was medium rough. (See Figure 11:6). A distinct macroscopic comparison between traces created by working metabasite with a metabasite hammerstone (See Figure 8: 1 right, 8:12) and traces of quartz crushing (See Figure (8.1 left and middle).

Use of damaged pieces and the question of so called workshops

We think that our experiments also contributed to the knowledge of tool fragmentation on Neolithic settlements and to explanation of the term 'workshop'. The archaeological record from settlements is well characterised by the 'old collection'(See Figure 10). While longitudinal breakages happen during the working hits, transverse breakages happen at first on thinner tools and much later on more robust tools. With regards to the measured strength of metabasite as a material, we presume that breakage of many artifacts was caused by an excessive hit (See Figure 10:1). This claim is supported by similar damage (breakage within the hole) on the Aeneolithic battle axes, which do not have a working blade. Apart from hammerstones for pecking (See Figure 10:2) fragments of broken tools were used for manufacturing of smaller tools. These could be created by re-grinding or drilling a new hole (See Figure 10:3), or by knapping the damaged shape (See Figure 10:4), which would create a secondary rough-out, that would then be polished. Primary manufacturing was restricted to cutting (See Figure 10:5a) and drilling (See Figure 10:5b-d). Not all drilling had to be primary (drilling of an unpolished rough-out). Many cores had polished bottoms which could be evidence of re-drilling of an earlier finished tool. Secondary drilling is documented by repeated drilling of the same artifact (See Figure 6:4, 10:3, 12:10).

Though flakes strongly suggest manufacturing, many of them have one side polished (Tichý and Drnovský, 2007; Tichý, *et al.*, 2008). Meaning they were prepared from a finished tool. Impression of manufacturing could be given by unknapped rough-outs (See Figure 10:6), which could have been brought in this shape from a quarry in Jizerské hory. Polishing stones are too small to be used in manufacturing (See Figure 10:7). Also damaged tools are not evidence of manufacturing.

With regards to the complicated history of the 'old collection', it surely does not contain the whole scale of artifacts (for example small fragments which were not attractive for the finders). We can analyse a characteristic 'workshop' from the find in Hněvčev, which was obtained by systematic and repeated field survey. Its alternative assessment (F. 9) corresponds with the above. Most artifacts have traces of earlier polishing (See Figure 9: 1, 10, 16). Therefore these are either broken (See Figure 9: 1, 10, 16) or repaired tools (See Figure 9:15). Drilling, according to the findings of cores (See Figure 9:3) took place on settlements but there are often new holes made in old tools fragments. Smaller pieces of transported material (See Figure 9: 6-9) could be found on settlements but material for manufacturing large tools is not known from settlements.

The content of 'workshops' on Neolithic settlements has never been defined in detail. We are attempting here to name all its components according to partial references by S. Vencl (1975). We include results of our experiments and take into consideration contents of published hoards from Czechia. Thus we are attempting to create a model for further assessment. The presence of 'workshops' on settlements is represented by:

1. Fragments of polished tools; these are fragments of finished polished tools (See Figure 10:1). They are not evidence of primary manufacturing.
2. Flakes: flakes are important evidence of manufacturing on settlements (See Figure 10:5e). Though it is necessary to see if they have traces of earlier polishing (Tichý and Drnovský, 2007; Tichý, Drnovský and Šída, 2008), because then they could be evidence of reworking of an already existing tool. Small flakes often avoid detection. If they are available, it is necessary to assess their size. Small fragments are evidence of repairs of smaller tools, not manufacturing. The situation is complicated by the reworking of a massive polished tool (Tichý and Zítka 2022) creating many flakes without traces of earlier polishing (See Figure 6:9), Despite that we do not need to doubt that reworking of broken or damaged tools did happen on settlements. It is not primary manufacturing.
3. Broken and modified artifacts: These could be a broken, long-term used tool. In some cases, its surface does not have traces of polishing, because it was knapped into a rough-out of a new tool, often of different function (See Figure 10:4) or smaller size (See Figure 10:4a). It is not primary manufacturing.
4. Secondary modified polished tools: details called to their previous 'life'. For example, the repeated polishing of one of the flat axes in the Praha – Ruzyně hoard (there are two others unrepaired) (See Figure 10:3a). Another example is a presence of an earlier hole on the tool

from the 'old collection' (See Figure 10:3b). This example is also a probable change of the artifact function. It does not represent primary manufacturing.

5. Damaged tools; Concerns recognisable, nearly complete artifact. Unusually the cutting edge is damaged (See Figure 6:8). Not primary manufacturing.
6. Broken holes and cores: drilling of polished tools very probably happened only in settlements as is shown by cores found there (See Figure 10:5b). We explain it by the time demands of drilling. We can differentiate between primary drilling of an unpolished rough-out (See Figure 10:5c) and later drilling, e.g. drilling of an already polished tool (See Figure 10:3, 10:5d). Drilling of rough-outs therefore represents primary manufacturing, secondary or repeated drilling represents repairs or repurposing.
7. Cutting. Cutting is documented by traces of cutting on unfinished artifacts (See Figure 4:2) or cut offs (See Figure 10:5a). On settlements these are usually represented by smaller waste. The piece on Figure 10:5a documents this. It was cut previously (the cut is straight but the edge of the cut is rounded). According to our experiments cutting demands large number of sandstone saws. One of the possibilities is their manufacturing outside settlements and primary cutting taking place similarly to rough grindings at the sources of sandstone. Long cuts (30 and more cm) we know on rough-outs from hoards (outside settlements?). Evidence of cutting on settlements (as in Praha – Ruzyně) correspond more with production of small artifacts (length 20 cm). We count cutting with regards to the above uncertainty as possible evidence of primary manufacturing.
8. Unpolished rough-outs: knapped roughouts could have been brought to the settlement. From the quarries in Jizerské hory we know two sizes of knapped rough-outs. Larger, more than 30 cm long, and smaller about 20 cm long (See Figure 12:1). The size of the finds on settlements corresponds with the smaller ones. With regards to characteristics of metabasite Jizerské hory (Tichý, *et al.*, 2021c), this might be a case of risks of transferring raw material over large distances only to find a serious defect at the settlement. Even successful manufacturing of rough-outs presumes large amount of waste (Tichý, *et al.*, 2021c). For this reasons we do not presume manufacturing of rough-outs by knapping on settlements.
9. Grinders: to make large polished tools there is a need for adequately large grinder. To create facets there is a necessity for a straight surface. Grinders on settlements are small with convex or a planoconvex side (See Figure 10:7). Exceptions are known near sandstone outcrops (Burgert, 2022). we presume primary grinding near the source of sandstone. According to current evidence grinding/ polishing on settlements represents repairs of damaged tools. That would also be supported by the presence of fine-grain sandstone (for sharpening?).
10. Hammerstones; hammerstones (See Figure 10:2) are known from settlements in large numbers. Experimentally, we have so far managed to differentiate between hammerstones for pecking (See Figure 7:14 and 15) and for splitting metabasite (Fif. 7:16). The majority of hammerstones on settlements were used for pecking. we do not consider hammerstones as a proof of primary manufacturing.

Discussion

Currently it is important to bridge between practice and theory, between 'living history' and measured archaeological experiment, between the importance of gaining skill and exact analysis. All are needed. In our too fast lives under the pressure of lack of time, we tend to sacrifice some of the research components. The traditional contradiction 'theory – practice' is now joined by 'fast – time consuming'. It is obvious how research such as the study of time-consuming manufacturing of polished stone tools can be disregarded. There might be distrust of the results because of our skill or subjective experience. We acknowledge that the modern experimenter could be a weak link in an archaeological experiment (Dvořáková, 2024) and counteract it with extensive experiments carried out by a group of experimenters on the same topic. Also intuition should not be dismissed as irrational. Intuition of an experienced practitioner can be presented as a complex of knowledge, experience and skill. Deliberated and aimed application of skill is a component of artifact analysis.

It allows us to see archaeological evidence in new ways. For example:

1. We do not see the Praha – Ruzyně hoard as manufacturing only (Bařtová, *et al.*, 2011), it also has a component of tool repair (See Figure 1). It is important evidence of this practice on Neolithic settlements, where finds of 'second life' artifacts prevail.
2. Settlement finds of flakes polished on one side (Tichý and Drnovský, 2007) also document artifact modification.
3. Some artifacts from Neolithic settlements are rough-outs knapped from an earlier tool (for example Burgert, 2022, here Figure 12:12 at the top). They are rare because many of them would be finished (polished).
4. Re-drilled axes are known from depositories of the National Museum Prague, Archaeological Institute of Czech Academy of Science in Kutná Hora and Museum of Eastern Bohemia in Hradec Králové (See Figure 10:3b). It might seem that the tool did not change its function as it is still an axe but according to our experience (Tichý and Panáček, 2024) shortening the tool changes its characteristics. For example, there would be change in performance.
5. Re-drilled axes also could have changed their function, for example when the tool loses its cutting edge (See Figure 10:3)
6. It would be necessary to be more careful in proclaiming deliberate destruction of polished tools on Neolithic settlements (for example Figure 0:4a; Burgert, 2019, p.196). Our experiments proved their durability. At the same time we found out that there are ways of using them that can destroy them (working stone, wrong use of the tool, slip of a hit). Here it is important that the traces of damage on replicas and original artifacts correspond.

Conclusion

Our long-term experiments with manufacturing and use of polished stone tools often brought completely new information on the technique of (1) drilling with a hollow drill, (2) use of hammerstones for pecking of grinders and querns, (3) grinding large artifacts on a large and flat grinder, and more frequent use of (4) stone cutting, which decreases the time needed for polishing.. Based on a qualitative analysis, results of our experiments (See Figure 11) and their comparison with original artifacts, we created a model of a stone axe's life (See Figure 12). We attempted to differentiate between primary manufacturing and artifacts damaged by use.

The results of our research based on archaeological experiments (1 – 4) contributed to a qualitative assessment of the term 'workshop'. 'Workshop' does not seem to us as a space localised just within a settlement context. Manufacturing starts in the quarries from where the knapped rough-outs are transported closer to settlements. Hypothetically, we presume the existence of polishing (presented by faceted unfinished rough-outs) outside settlements. Drilling and cutting surely took place on settlements, as these are the only places we with finds of cores. We see importance in differentiation between small and large polished stone tools. Two categories can be distinguished already in Jizerské hory quarries – smaller - about 20 cm - and longer - of more than 30 cm length. Similar division can be observed in other materials quarries, for example of silicates in Jablines (Demoule, 2004). Remains from the settlements correspond mostly with tools damaged or destroyed by use. It is, therefore, waste and not evidence of primary manufacturing. In settlements there is evidence of repairs and modification of broken tools to new, smaller ones. Often they change their original function (for example an axe into a mallet). Small fragments served without further modification as hammerstones for pecking of flat grinders and querns. Though these were not hammerstones for working metabasite.

In settlements mostly knapping of damaged polished stone tools into smaller secondary rough-outs took place. These sites have traces of the original polishing, similarly to flakes created by secondary knapping. This is up-cycling already damaged pieces where making the tool smaller often changed its function (for example, a flat axe into a chisel). So far in settlements there has not been discovered any evidence of large tool manufacturing by grinding and cutting. We know long cuts (30 cm) from hoards, which have so far been found outside settlements. Shorter ones (20 cm) are documented from the exceptional settlement hoard from Praha – Ruzyně. This hoard is not just a hoard with evidence of manufacturing of small tools, but it also contains tools with damaged cutting edge. The grinders for settlements are too small and missing the flat surface necessary for polishing with the help of facets. Many have grooves corresponding with polishing smaller stone tools.

The impression of settlement workshops that concentrate all steps of manufacturing is created the presence of broken holes, supposedly broken during manufacturing. That is the only non-forceful manufacturing technique. Breakage of holes during drilling is not realistic. All necessary techniques are time consuming; the only fast technique is knapping. Knapping took place directly in quarries, so the material did not need to be transported with unnecessary waste. That? does not decrease importance of knapping which was used again on settlements for modification of damaged tools.

The impression of manufacturing on settlements is stronger on those closer to sources of metabasite. There is a need for qualitative analysis which would divide artifact remains into the stated categories (See Figure 9 and 10). The phenomenon of so-called workshops and secondary use of broken metabasite tools is an indication of Neolithic behaviour. The material remained attractive even after the original tool was damaged. In Bohemia it is possible that the following culture with stroked ware recycled remains of Linear Pottery Culture metabasite tools and contributed to significant reduction of stone tools as an archaeological source. Similar behaviour could have continued into the Aeneolithic.

Acknowledgement

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Attachment(s)

[Appendix 1 - Figure 1](#) (1.51 MB)

[Appendix 2 - Figure 2](#) (1 MB)

[Appendix 3 - Figure 3](#) (2.6 MB)

[Appendix 4 - Figure 4](#) (2.39 MB)

[Appendix 5 - Figure 5](#) (6.54 MB)

[Appendix 6 - Figure 6](#) (2.59 MB)

[Appendix 7 - Figure 7](#) (2.57 MB)


[Appendix 8 - Figure 8](#) (5.46 MB)

[Appendix 9 - Figure 9](#) (2.79 MB)

[Appendix 10 - Figure 10](#) (2.34 MB)

[Appendix 11 - Figure 11](#) (5.48 MB)

[Appendix 12 - Figure 12](#) (1.96 MB)

 **Keywords** [stone working](#)
[stone](#)
[tools](#)

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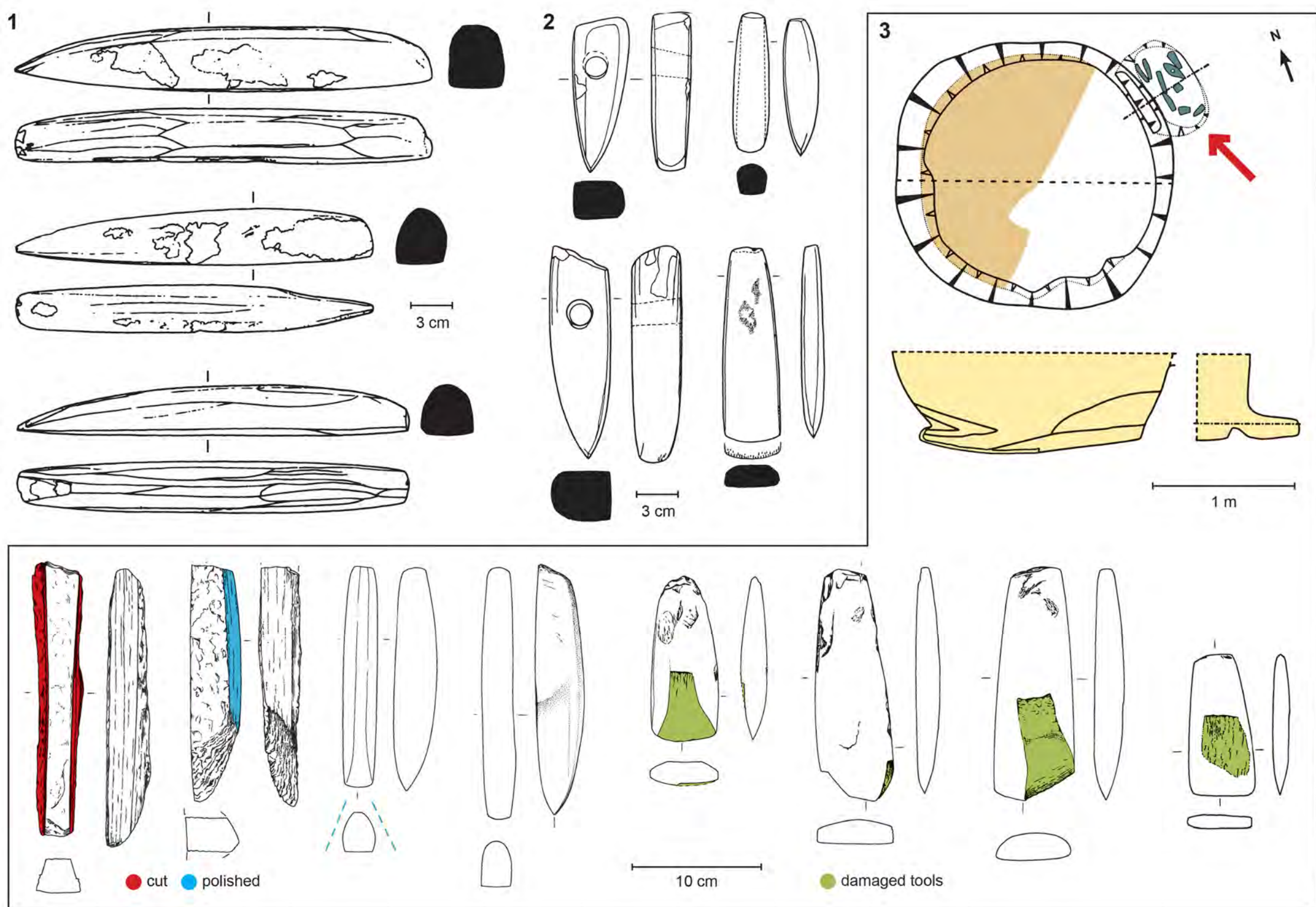


Fig1. Important hoards of stone tools in Bohemia:

1 part of the manufacturing hoard from Vitiněves with facets of unfinished artifacts (other hoards of this type from Chudonice, Jeřice, Křinec, Lovosice)

2 Mšeno: under a floor of a Neolithic house there were functional tools of various sizes and types

3 Praha – Ruzyně: in a side of a storage pit there was probably stored a piece of material, from which people cut of pieces to make shoe-last adzes. At the same time there were axes with damaged cutting edge. Some of them seemed to be already repaired. It is difficult to differentiate them from primarily manufactured tools.

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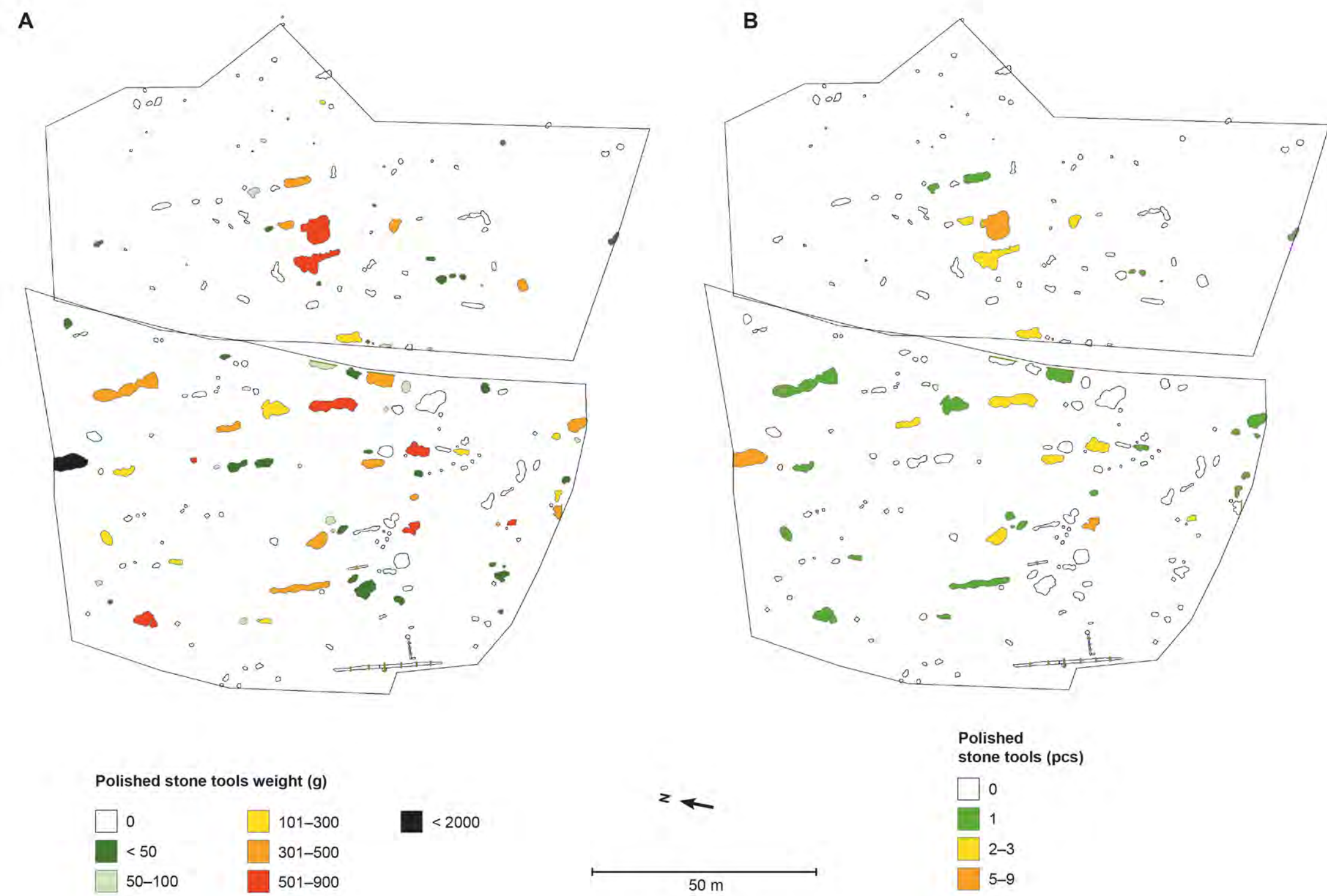
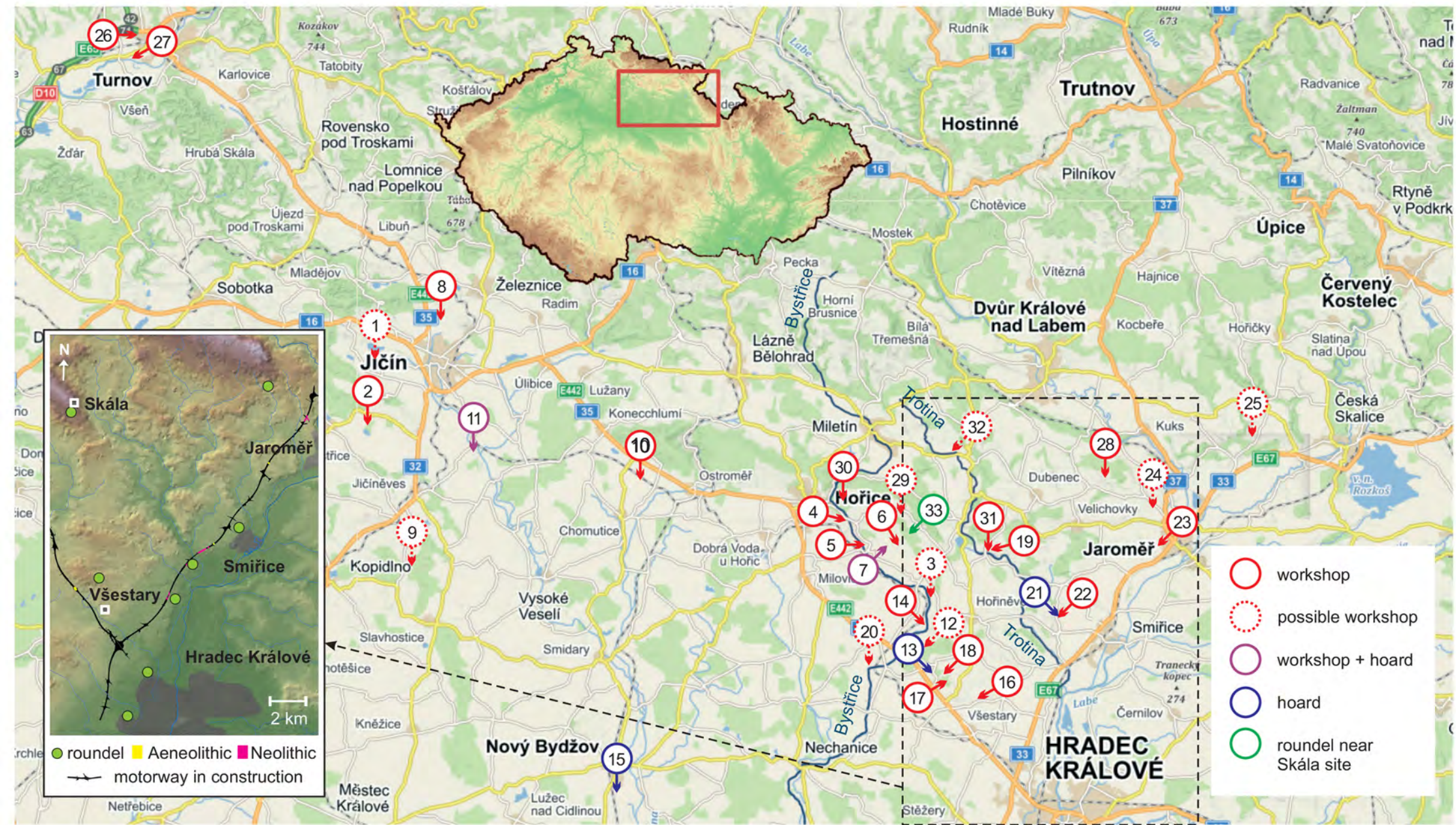


Fig 2. Distribution of polished stone tools in archaeological features of the Neolithic settlement Obědovice, season 1999 (author Aneta Brožková)

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- | | | | | |
|----------------------------|-------------------------------|---------------------|---------------------------------|-----------------------------------|
| 1 Březina workshop ? | 8 Kbelnice workshop | 15 Chudonice hoard | 22 Rodov workshop | 29 Boháňka Za stodolou workshop ? |
| 2 Bukvice workshop | 9 Labouň workshop ? | 16 Chlum workshop | 23 Dolní Dolce workshop | 30 Doubrava workshop |
| 3 Cerekvice workshop ? | 10 Sobčice workshop | 17 Lípa workshop | 24 Horní Dolce workshop ? | 31 Jeřičky workshop |
| 4 Doubrava workshop | 11 Vítíněves workshop + hoard | 18 Lípa hoard | 25 Chvalkovice-Sebuč workshop ? | 32 Bílé Poličany workshop ? |
| 5 Jeřice workshop | 12 Čistěves workshop ? | 19 Lužany workshop | 26 Ohrazenice workshop | 33 Třebovětice roundel |
| 6 Jeřice Blatečka workshop | 13 Čistěves hoard | 20 Mžany workshop ? | 27 Nudvojovice workshop | |
| 7 Jeřice workshop + hoard | 14 Hněvčevy workshop | 21 Rodov hoard | 28 Litíč-Nová Amerika workshop | |

Fig 3. Map by R. Tichý, based on Kalferst (2007)

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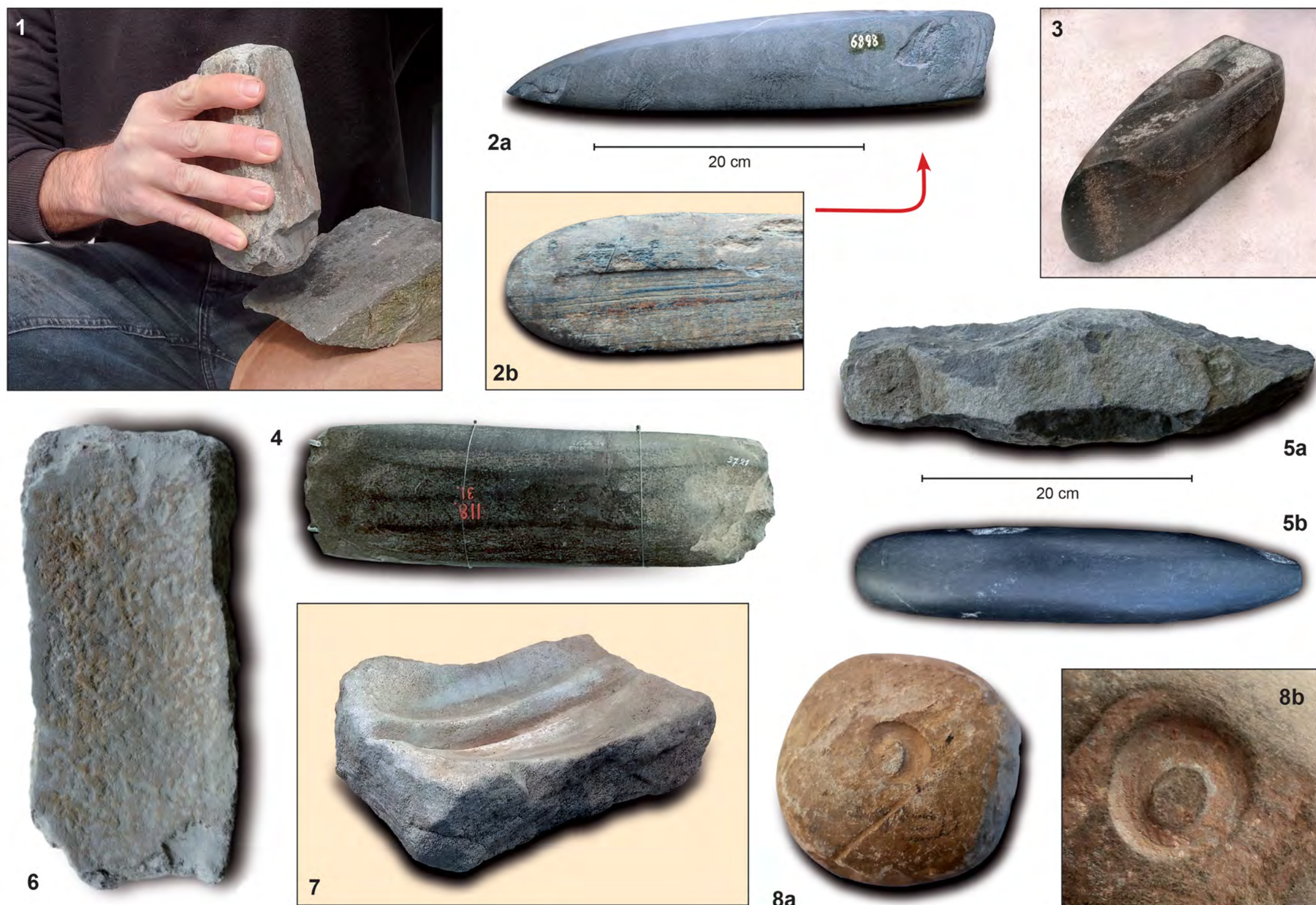


Fig 4. Chaîne opératoire of polished stone tools – combination of originals and replicas

- 1 localisation of strain on the edges of a hammerstone while knapping metabasite (1.5 kg)
- 2 traces of cutting used to make a large axes and covered by subsequent grinding
- 3 remains of cutting on the edge of a tool replica
- 4 exceptionally preserved faceting on a small Neolithic axe
- 5 rough-out of a large axe with a large volume of metabasite to be grinded off (a) and finished replica (b), time of grinding 104 hours
- 6 grinder after pecking renews its effectivity – the flat surface is needed to grind large axes
- 7 grinder with traces of grinding small axes without effort to keep flat surface needed for creating facets
- 8 During initial drilling there is sometimes created a lens centre documenting use of a two-directional drill

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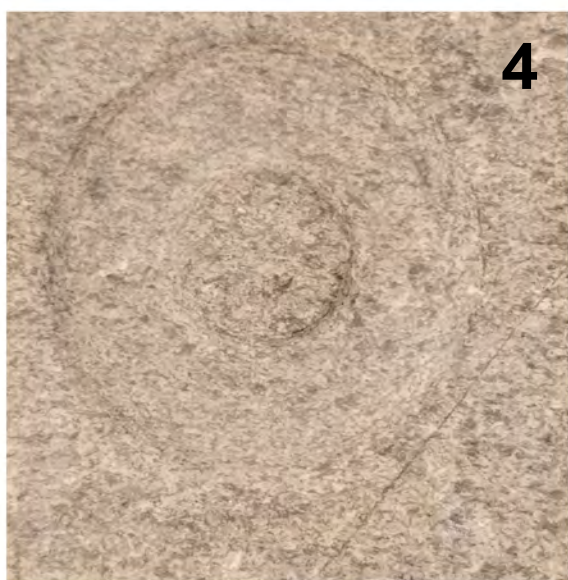


Fig 5. Comparing work traces of experimental drilling with original artifacts
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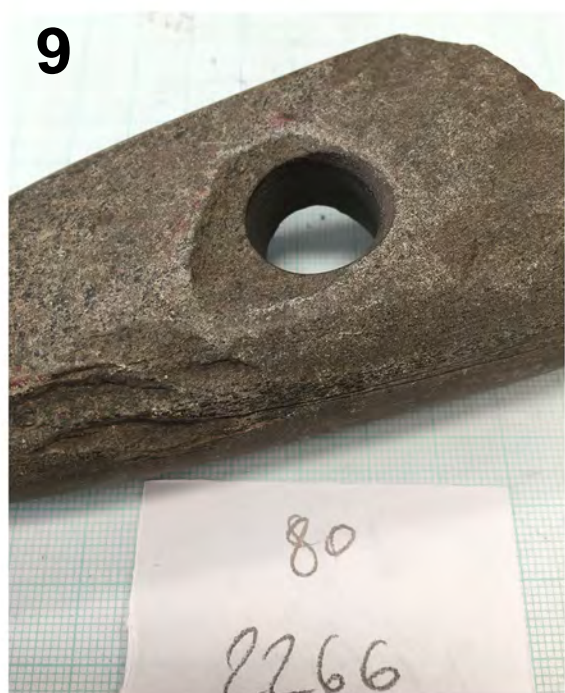
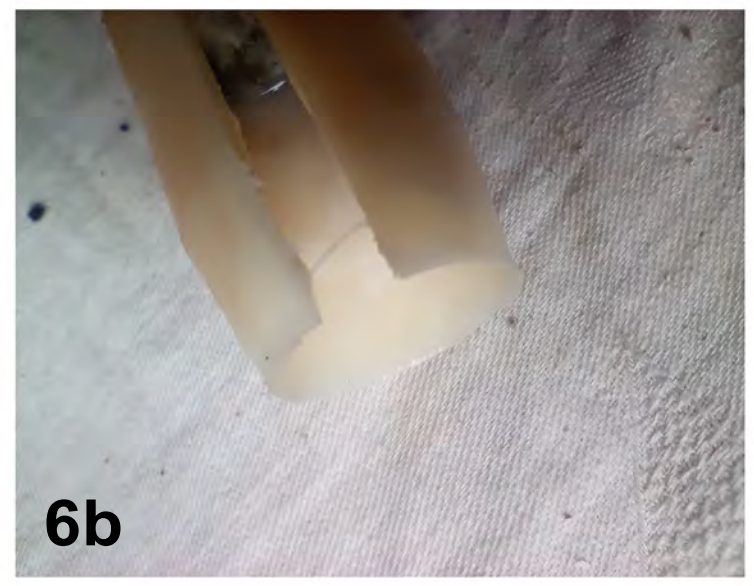


Fig 5. Comparing work traces of experimental drilling with original artifacts
Unless stated otherwise photos R. Tichý, for the pdfs: Image prepared by M. Zielinska from photos by R. Tichý



Fig 6. Comparable assemblages of polished stone tools - originals, replica production and use

- 1 work stress of stone axe replicas when cutting down trees, very demanding steep cuts
- 2 work stress of stone axes when working marble
- 3 different deformation of the cutting edge created by strong hits on the stone
- 4 In the Research institute of materials Předměřice nad Labem the axe was broken by force of 3.4 tonne
- 5 Damage to cutting edges of axes while cutting trees
- 6 Pecking of querns with a hammerstone from metabasite
- 7 Re-knapping of a damaged axe, 'old collection'
- 8 Rough-out knapped from a round stone, Neolithic settlement Obědovice
- 9 Experiment of P. Zítka and R. Tichý with repairs of a damaged cutting edge; on the right flakes with one polished side, left – even with repair there is a large amount of unpolished flakes

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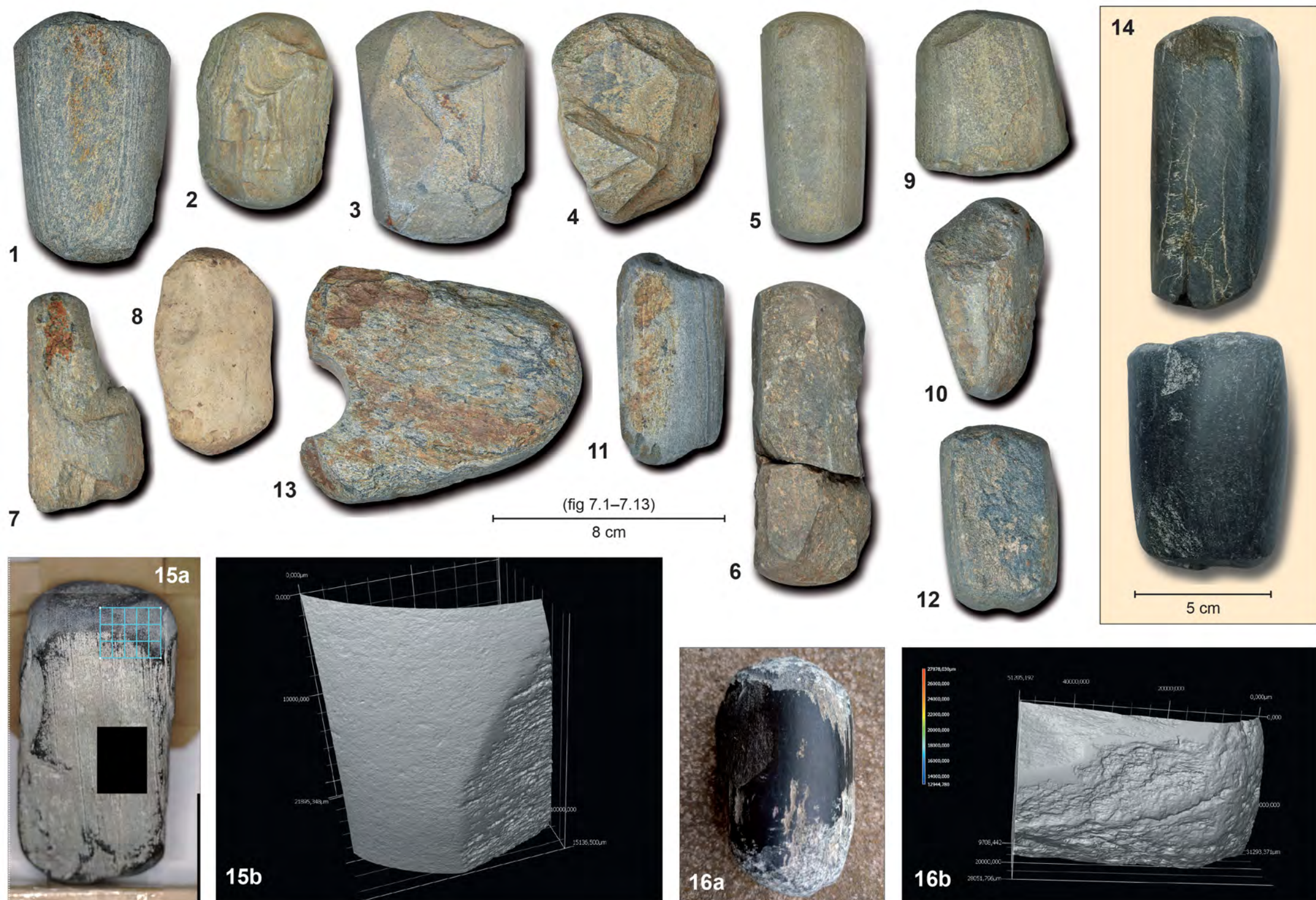


Fig 7. Hammerstones for pecking

1-13 various shapes of hammerstones for pecking, sample, Obědovice, season 1999

14 experimental hammerstones for pecking, by I. Dohnálková

15 experimental hammerstone for pecking, by M. Nikolajevová (microphoto R. Thér)

16 Experimental hammerstone after working metabasite, R. Tichý

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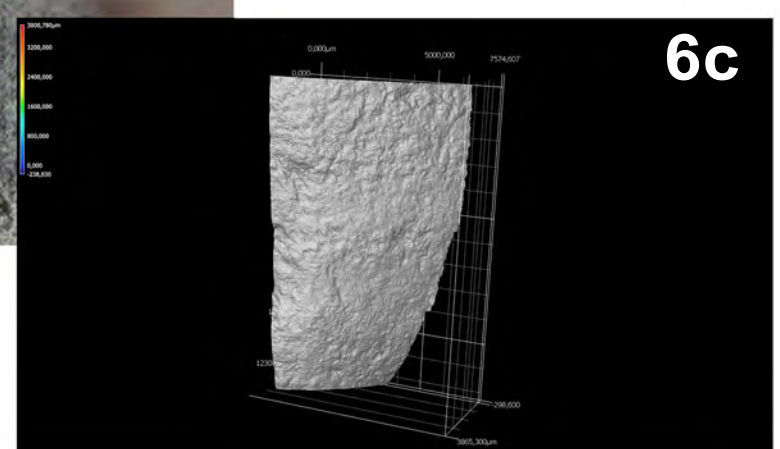
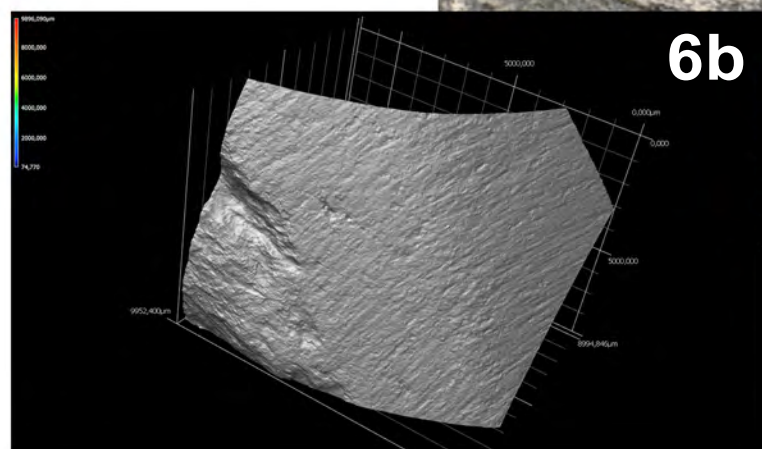
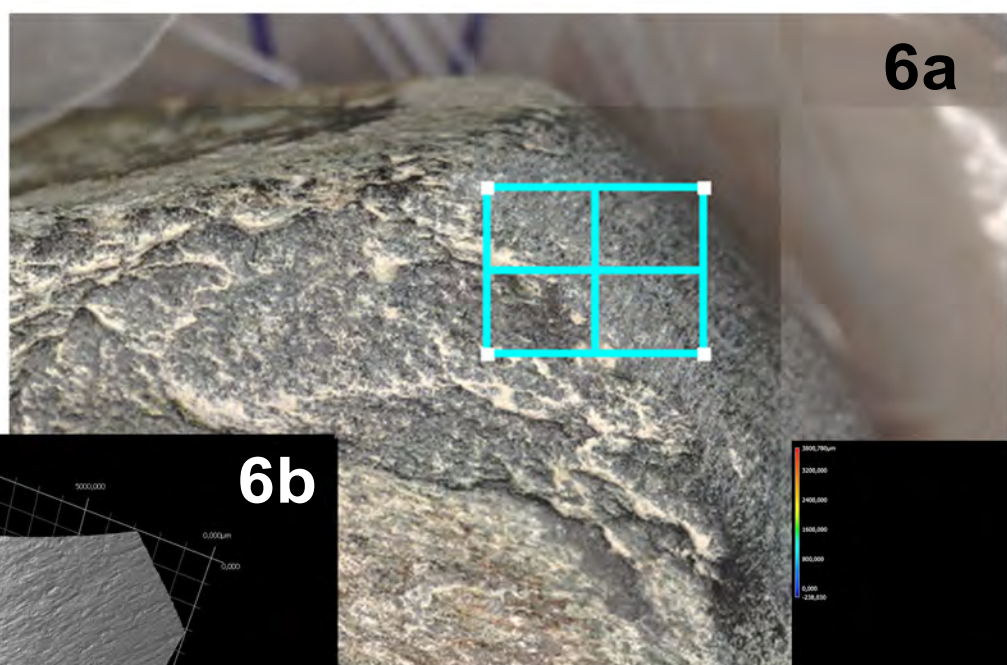
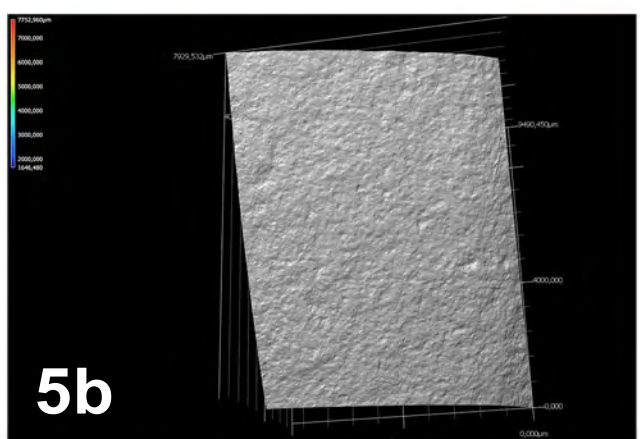
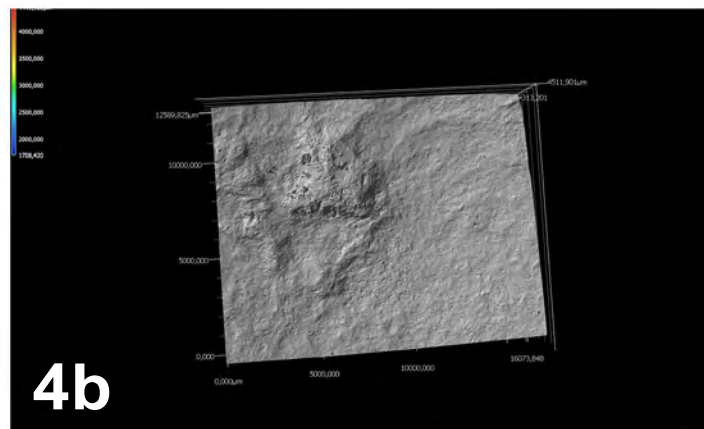
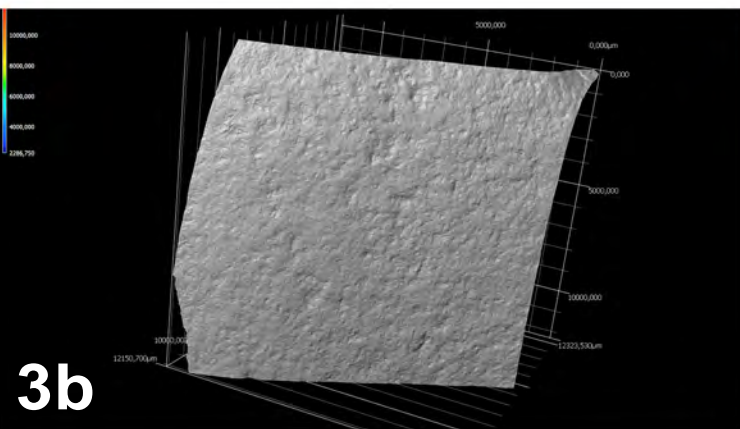
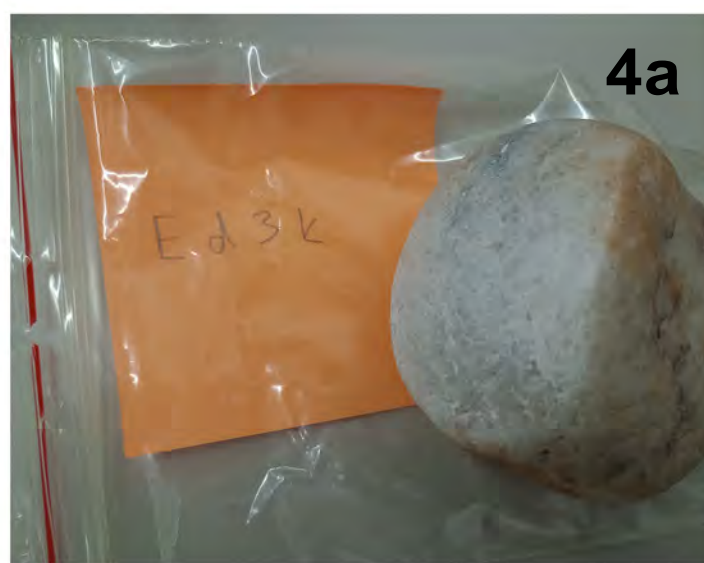
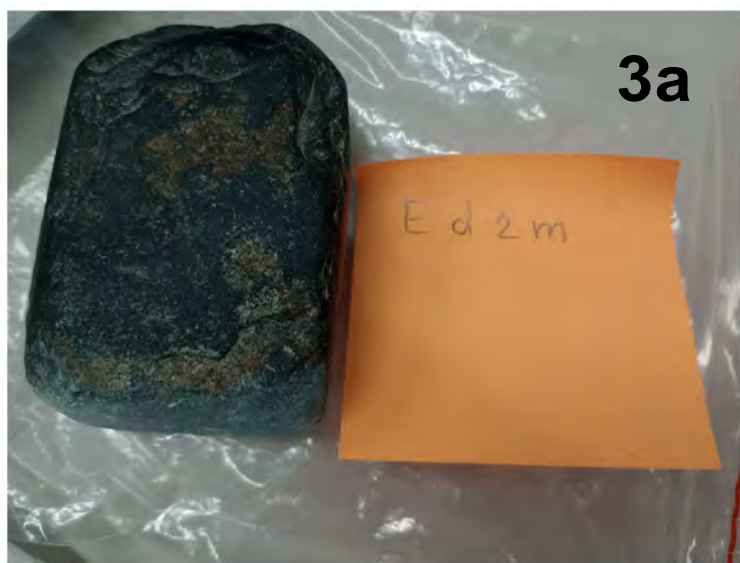
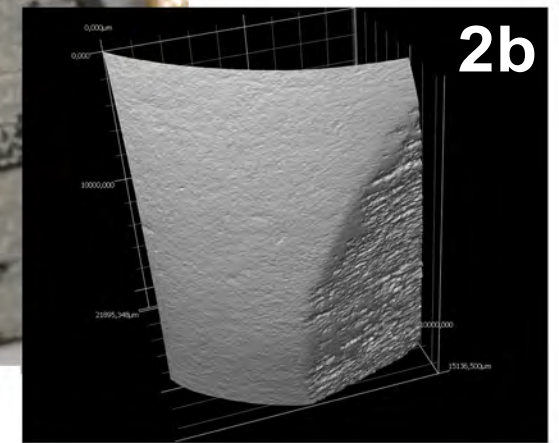
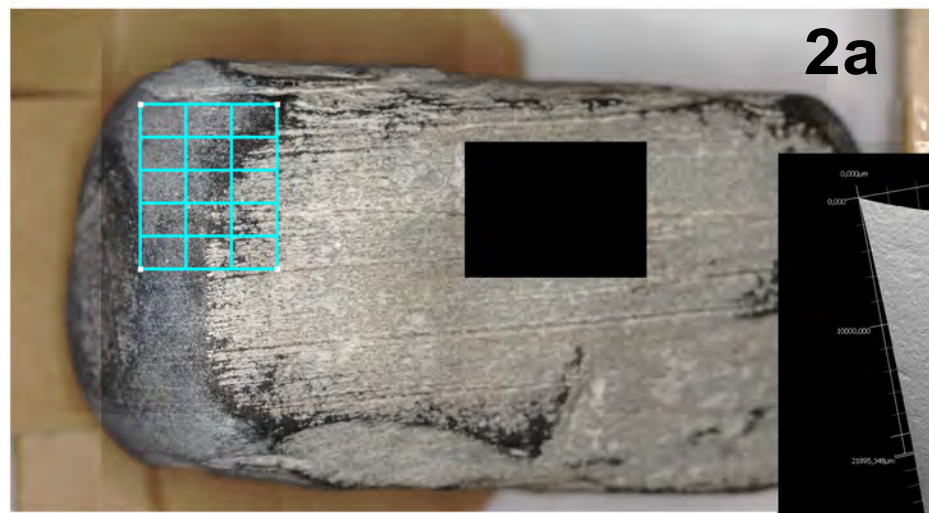


Fig 8. Micro depictions of work traces on replicas and original artifacts
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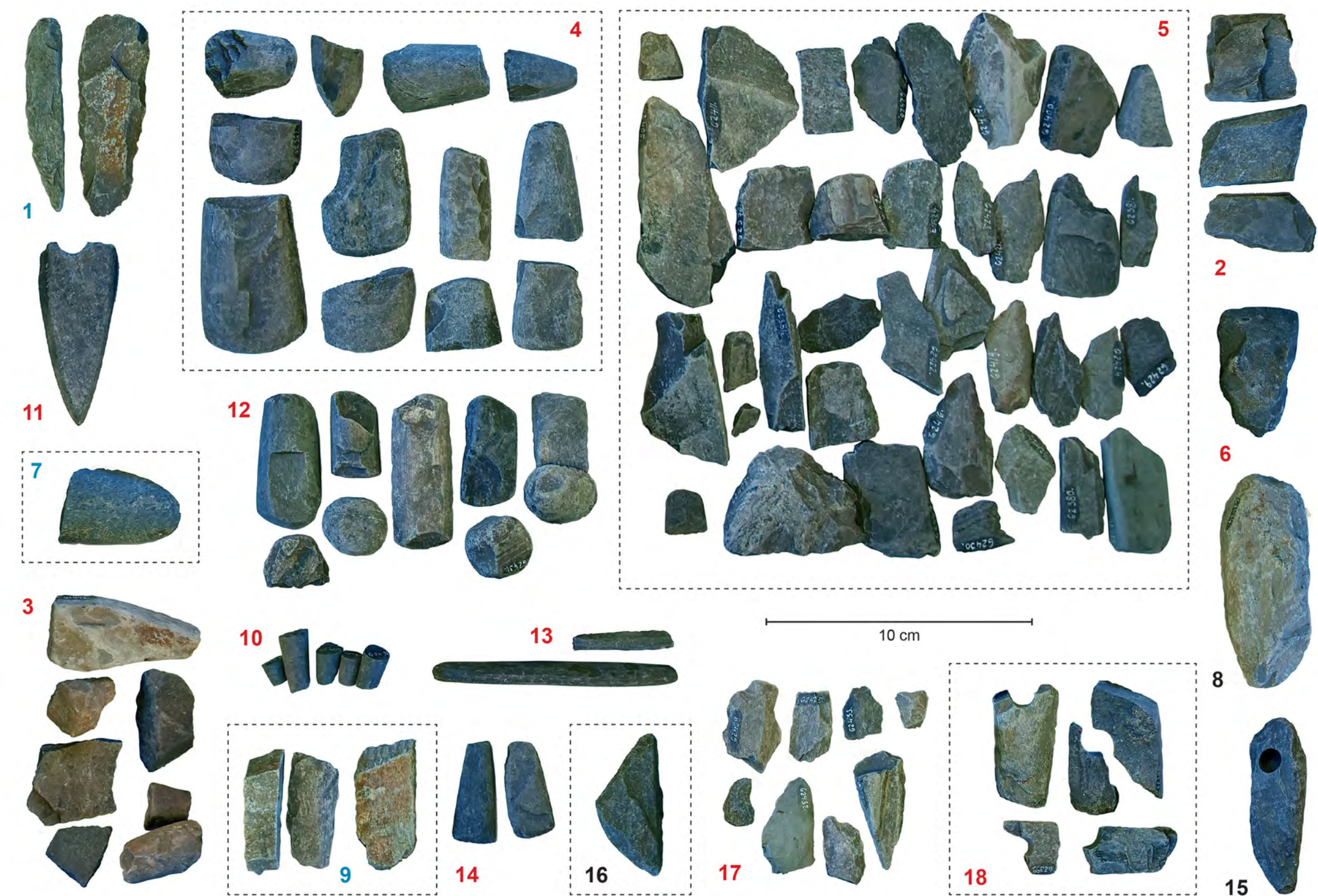


Fig 9. Alternative interpretation of the so called workshop on the example of the Hněvčeves assemblage

- 1 rough-outs cut have been brought to the settlement
- 2 or knapped from large broken tools
- 3 sandstones grinders are too small to make produce large tools
- 4 broken tools which were surely not broken during manufacturing
- 5 flakes and amorphous fragments with polishing on one side are remains of large tools
- 6 polished axe was modified by thinning of the sides by knapping
- 7 round stone and 8 material could have been brought to the settlement as for example hammerstones
- 9 fragments of material unsuitable for knapping could have been created by breaking of the material
- 10 core are evidence of drilling on the spot but they could have been created by secondary drilling
- 11 large fragment of a drilled axe could have been kept as repairable/ reusable
- 12 hammerstones with fine ware of shorter sides were probably used for pecking of grinders and querns
- 13 small wedges and 14 axes could have been made from damaged tools by secondary grinding
- 15 Unfinished drilling of unpolished rough-outs is the only clear evidence of primary drilling on the spot
- 15 cut off from short cutting, we do not know long cuts from settlements, it appears only in hoards
- 17 flakes and amorphous fragments without traces of polishing can be left over from working material, rough-outs or be remains of large polished tools
- 18 remains of drilled tools could have been potentially used as hammerstones

Numbers marked red show evidence of repairs or repeated polishing and create majority of the assemblage, blue numbers could have been brought to the settlement, black numbers represent primary manufacturing on settlement

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Fig 10. Content of the so called workshop on an example of 'old collection'

- 1 fragments broken horizontally and vertically
- 2 hammerstones for pecking
- 3 reduced tools (re-drilled and re-polished), function remains
- 4 knapped fragments of tools – tools with new function
- 5 Manufacturing: a knapping of a rough-out after cutting; b cones; c drilling before polishing; d drilling after polishing; e (added from Obětovice) manufacturing waste
- 6 unpolished rough-outs
- 7 grinders
- 8 damaged tools: a chipped off edge, b battered edge, c across

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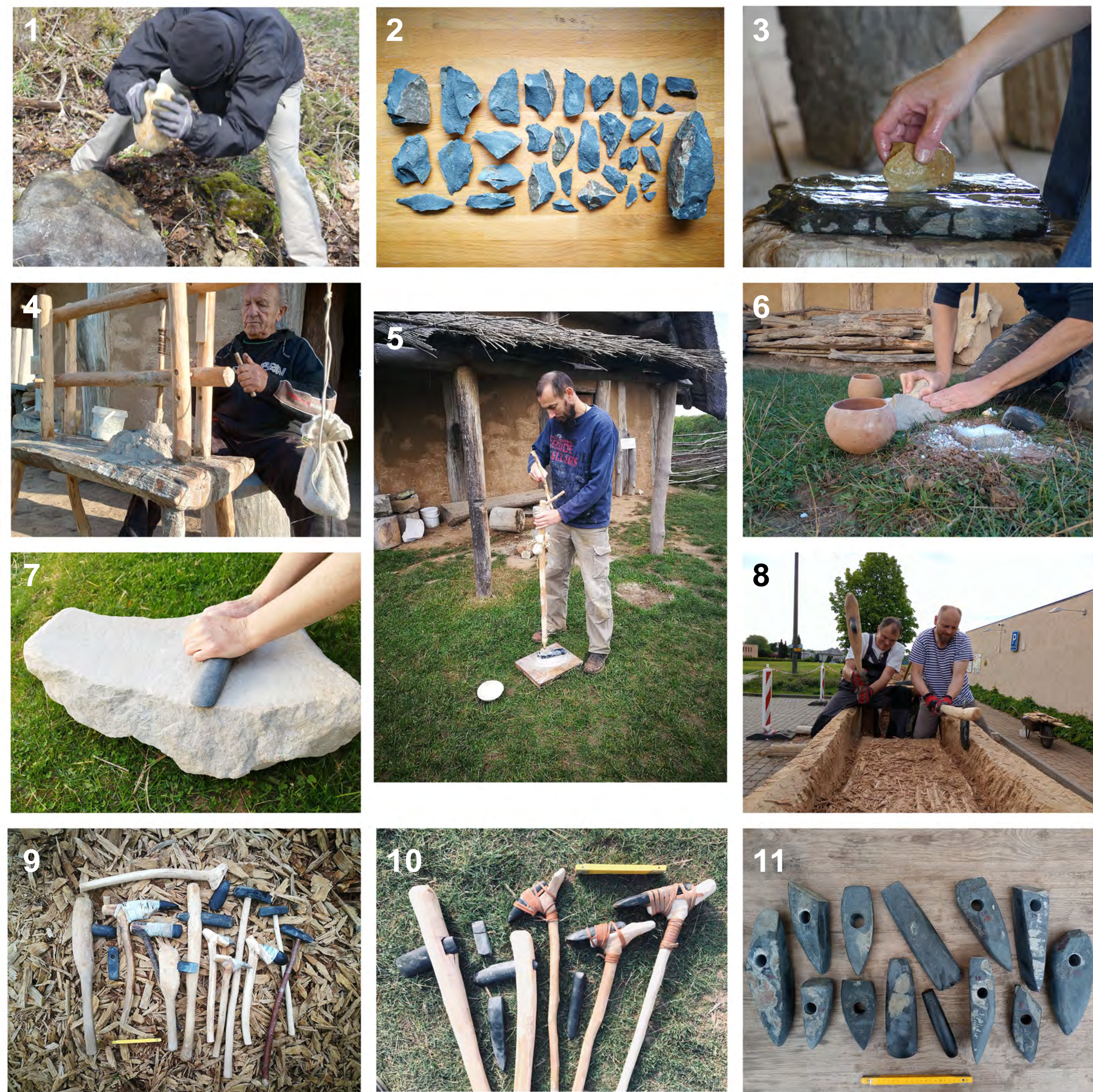


Fig 11. Experiment overview

- 1 knapping of the material with quartz stone
- 2 rough-out from metabasite and manufacturing waste
- 3 cutting of amphibolite with a sandstone saw
- 4 bone drill bit in a two-direction drill
- 5 and one-direction drill
- 6 preparation of abrasive material – crushing quartz
- 7 polishing of metabasite
- 8 digging out a boat, 2022
- 9 axes used to build a boat
- 10 axes used to build a well, 2023
- 11 axes used to cut down trees and split logs, 2024

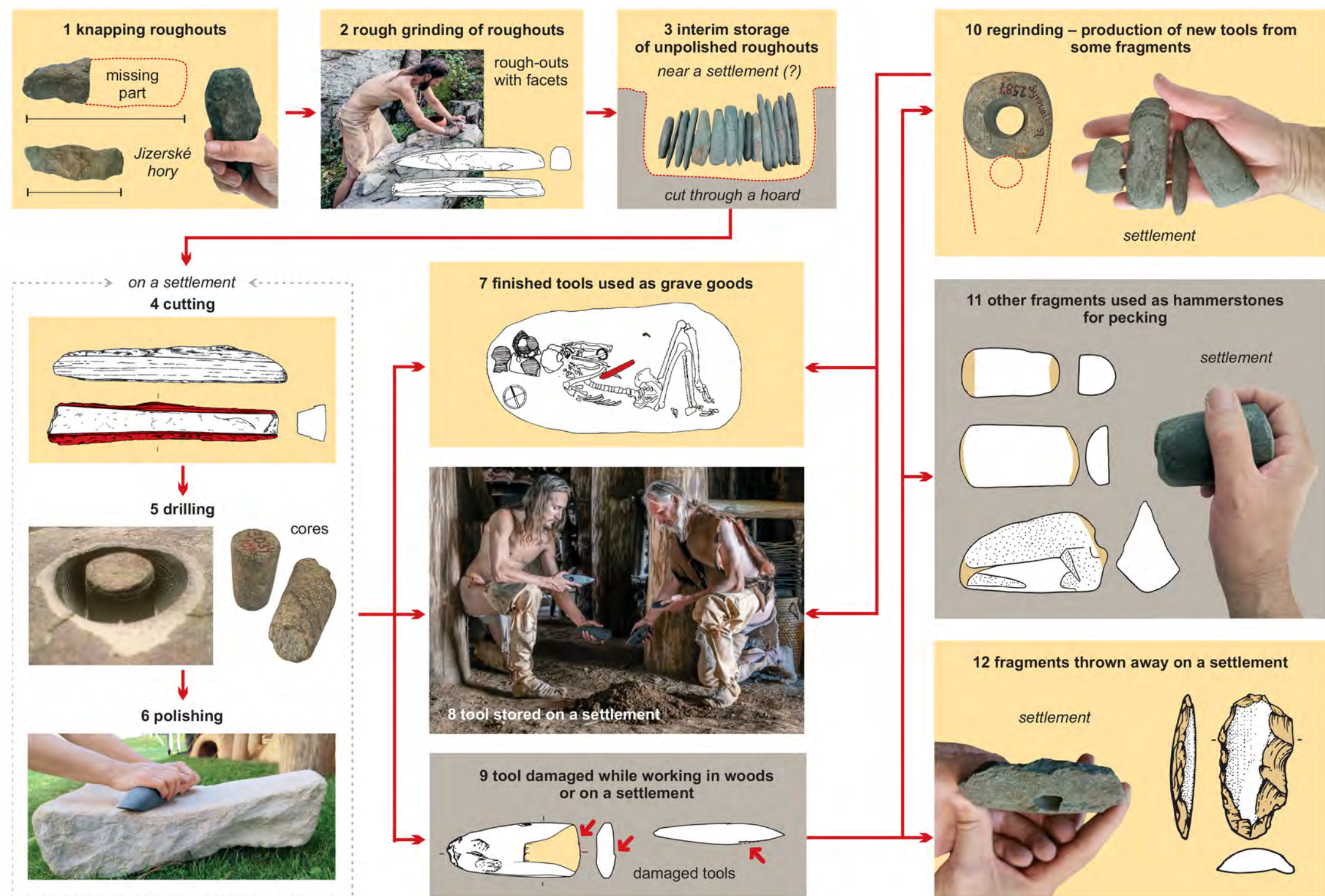


Fig 12. Life of an axes, suggested chaîne opératoire

- 1 knapping roughouts
- 2 rough grinding of roughouts
- 3 interim storage of unpolished roughouts
- 4 cutting
- 5 drilling
- 6 polishing
- 7 finished tools used as grave goods
- 8 tool stored on they settlement
- 9 tool damaged while working in woods or on settlement
- 10 regrinding – production of new tools from some fragments
- 11 other fragments used as hammerstones for pecking
- 12 fragments thrown away on settlement

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