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VIDAN B. DIMIĆ; Institute of Archaeology, Belgrade, Serbia

HAMMERING THE PAST: THE EXPERIMENTAL (RE)CONSTRUCTION AND USAGE OF PREHISTORIC MINING HAMMERSTONES FROM THE PRLJUŠA–MALI ŠTURAC SITE, RUDNIK MOUNTAIN

e-mail: v.dimic@ai.ac.rs

Abstract – The locality of Prljuša–Mali Šturac on Rudnik Mountain is one of the richest prehistoric mining sites in Europe, taking into account the number of recorded, collected and analysed mining hammerstones. The reasonably estimated number of these tools of 2,000 and more clearly depicts the intensity of prehistoric mining activities at this locality as well as the conspicuousness of the mining potential which this mountain possessed. During the archaeological research conducted so far, 688 hammerstones have been collected and analysed (of which 478 are from recent excavation campaigns), thus producing results based on which hypotheses were made regarding their manufacture and use. Consequently, in the summer of 2017, an experimental (re)construction was undertaken on three basic types of these tools, as a complementary segment to a set of functional and typological analyses. The goal of the experimental research was to enable and gather as much as possible data that would serve as a comparative filter for testing previously set hypotheses and research questions related to the manufacture and usage modes of this category of mining tools. The mining hammerstones made for the purpose of this experiment proved to be extensively efficient in practice. The obtained results enabled a more complete understanding of the prehistoric mining technology on this site, but also raised some new questions.

Key words – Prljuša–Mali Šturac, copper mining technology, experimental (re)construction, mining hammerstones, production and use

INTRODUCTION AND ARCHAEOLOGICAL BACKGROUND

The Rudnik Mountain is famous for its richness of the ore malachite (carbonate copper ore) *inter alia*, whose deposits have been recognised and exploited from prehistory to the present day. Archaeological remains and written sources clearly indicate traces of mining activities during the Roman and especially the medieval period when the mountain represented a significant mining centre.[1] Explorations of this site conducted in the 1980s provided initial data on prehistoric mining activities on Rudnik.[2]

The site of Prljuša is located on a very steep slope of Mali Šturac, the lowest peak of Rudnik Mountain in Central Serbia, near the town of Gornji Milanovac. The site is ellipsoidal, and covers a surface of 2.5 ha,

[1] Јовановић П. 2007.

[2] Jovanović B. 1988.

The explorations at Mali Šturac have been conducted thanks to financial support of the Ministry of Culture and Information of the Republic of Serbia. This paper represents an integral part of research on the project: *Archaeology of Serbia – cultural identity, integration factors, technological processes and the role of the Central Balkans in the development of European prehistory* (No. 177020), financed by the Ministry of Education, Science and Technological Development. I would like to express my gratitude to Dragana Antonović for valuable suggestions during this research.

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ranging from 882 m ASL at the bottom to 994,41 m ASL at the top of the slope (Fig. 1a–b).[3] It was discovered in 1980 and subsequently explored to a lesser extent from 1981 to 1989.[4] The research was renewed in 2011 and the coordinator of the field excavations, which have been continually performed to the present day, is the Archaeological Institute of Belgrade in cooperation with the *Museum of Rudnik* and *Takovo* Region in

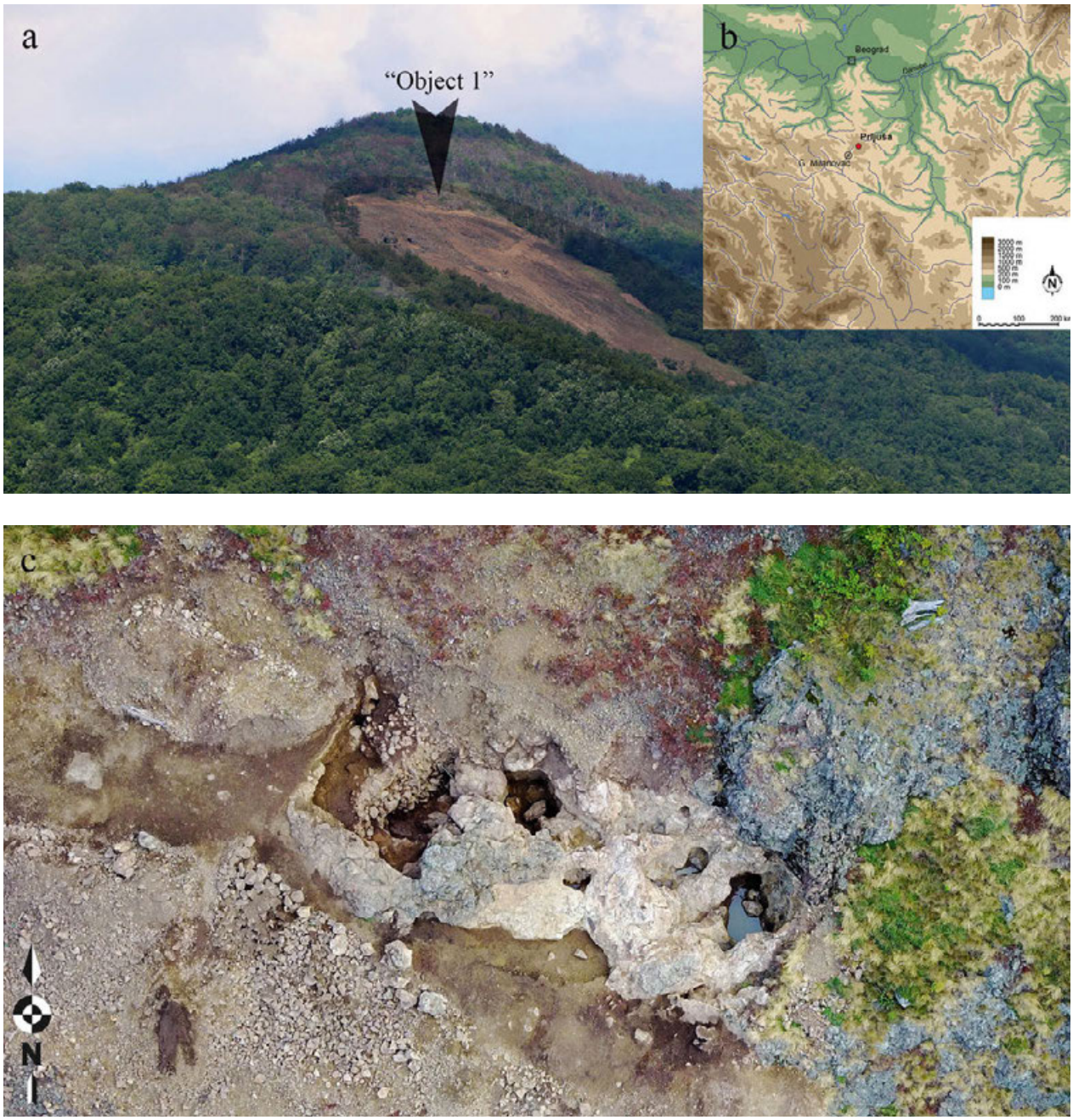

Fig. 1. a) Lower peak of Rudnik mountain – Mali Šturac with the slope of Prljuša, where remains of copper ore exploitation were found; b) geographic position of the site on the map of Serbia; c) orthophotography of the investigated segment of Object 1 on the top of the slope of Prljuša (Project documentation)

Сл. 1. а) нижи врх Рудника – Мали Штурац са падином названом Прљуша, на којој су пронађени остаци експлоатације бакарне руде; b) географска позиција локалитета на карти Србије; с) ортофотографија истраженог дела Објекта 1 на врху падине Прљуше (пројектна документација)

Gornji Milanovac, with the project „*Prospection of Mali Šturac, research of prehistoric mining*" headed by D. Antonović, PhD.[5] Recent site explorations uncovered numerous material remains that testify to the exploitation of malachite during the Eneolithic as well as later through the Bronze Age.[6] Over 15 objects (mining shafts) were discovered, which constitute the structure of this site, of which, during new excavations, Shafts 4 and 6 were systematically explored, while the impressive Object 1[7] (Fig. 1c), which represents the best-investigated unit to date, and a genuine example of the combined surface and underground exploitation of copper ore at the site, is still being explored.[8]

The method of ore exploitation at this site is closely linked to the geological basis of Prljuša, or more precisely, the volcanic activities that produced diatreme and the formation of very hard sedimentary (various types of sandstone), contact-metamorphic (hornfels and scarn) and igneous rocks such as: quartzlatite, latite, dacite etc. through which the ore penetrated and deposited.[9] At some locations mineralisation of malachite formed at the surface (Shafts 4, 5 and 6), while bigger ore deposits were deeper in the bedrock (Object 1 and Objects 10–15). Such a situation influenced the application of both surface and underground exploitation of the copper ore at Prljuša. The mining technology itself, whose roots go much deeper into prehistory, when the exploitation of flint and other rocks suitable for making stone tools was carried out, was advanced and applied to metallic raw materials. Surface mineralisation of malachite was clearly visible to prehistoric miners with its intensive green colour, hence the exploitation started from there. The use of fire to first weaken the rocks and then the crushing with hammerstones was a wide-spread practice in prehistoric mining technology and, as such, was also used in the case of Prljuša.[10] Traces of burning in the form of soot were recorded in almost every explored shaft, on vertical walls and preserved parts of ceilings. In order to follow the ore vein, the rock was broken with hammerstones of various sizes, which represented the basic set of tools. We can assume the use of other tools such as wooden stakes, wedges, shovels, antler tools[11] etc such as the tools preserved in prehistoric mines in Great Britain etc. However, in Prljuša, these tools were not preserved due to the low Ph value of the soil and the decomposition process. Traces of mining activities and ore extraction are clearly visible in the mineralisation zones in each of the explored mining shafts. The quantity of mining hammerstones which were discovered at the site is very impressive, more than 700 and it is estimated that over 2,000 of these tools are scattered over the site surface. The discovered hammerstones were found in all excavation layers, and were of different sizes, shapes and degrees of wear.[12] The mining hammerstones from Prljuša, their possible appearance as a complete tool, method of use and functionality represents the main research focus of this paper. Based on the analysis of the hammerstones[13], the very structure of the mining shafts at Prljuša and the traces of work on their walls and ceilings, a reconstruction of the mining technology using a set of mining hammerstones was carried out.

OBJECTIVES

The research of the environment of Prljuša at Mali Šturac, the very structure of the site and its geological basis, as well as the archaeological material collected there during the new research produced a large amount of data that enabled the creation of a general picture of the mining technology at this site.[14] Out of this situation a desire was born to expand this knowledge by examining some particularly specific problems. In this case, a tendency towards the specificum refers to the issue of mining hammerstones, i.e. the operational sequence: from the raw material procurement and tool production to the use, damage and discarding of these tools. Hence, the primary goal of this research was to gather and enable „active" data and information, which was unable to be gained from an insight into „passive"

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[3] Antonović, Dimić 2017.

[4] Jovanović B. 1988, 8–11.

[5] Antonović, Vukadinović 2010; Antonović, Vukadinović 2012a; 2012b; Antonović et al. 2014a; Antonović, Dimić 2017; Antonović 2017; Antonović et al. 2018.

[6] *Cf.* Antonović with further references.

[7] „Object 1" is a label for several mining shafts of different shape, size and depths connected by passages located on the very top of the slope. (For more details *see* Antonović, Dimić 2017; Antonović et al. 2018 with other references).

[8] Antonović, Dimić 2017; Antonović et al. 2018.

[9] Antonović, Dimić 2017.

[10] O'Brien 2013, 443–444; O'Brien 2015, 204; Antonović, Dimić 2017.

[11] Jovanović 1978; Vitezović, Antonović 2017.

[12] *Cf.* Antonović 2013; Antonović, Dimić 2017.

[13] Antonović, Dimić not published (article in process)

[14] Jovanović 1988; Богосављевић 1988; Antonović, Vukadinović 2010; Antonović, Vukadinović 2012a; 2012b; Antonović 2013; Antonović *et al*. 2014a; Antonović, Dimić 2017; Antonović 2017; Antonović et al. 2018.

archaeological material, through the performance of archaeological experiments, which would at least partially complete the knowledge about mining hammerstones from the Prljuša–Mali Šturac site.

MATERIALS AND METHODOLOGICAL FRAMEWORK

Within this paper, a study was carried out consisting of three research steps: archaeological data, experimentation, and analysis and results.

The primary step of gathering more data, with regard to the basic variables of the experiment, was to gain an insight into the archaeological material (mining hammerstones) and their analysis. Additionally, the existing literature has been thoroughly studied, relating both to the explorations of this site as a whole[15], and to the mining hammerstones as a separate element[16]. The literature concerning the exploitation of ores and stone tools from other sites, both in Serbia and worldwide, has also been studied.[17]

During previous archaeological research, over 700 hammerstones were discovered, while 688 of them were analysed. According to the 1981 and 1987 research seasons, 210 hammerstones were collected and analysed (in front of the access to platforms of Shaft 5–45 pieces; in front of Shaft 6–70 pieces), while the rest were discovered on the surface on other parts of the slope.[18] The author of this paper did not have an opportunity to personally investigate the hammerstones from the previous explorations, so the information about them was collected from available literature.[19] During the recent explorations performed from 2011 to 2017, the total number of collected hammerstones exceeded 478.[20] All of these hammerstones (2011–2017) were thoroughly analysed by D. Antonović and the author, and the obtained data served as the basis for creating an experiment.[21]

The functional-typological analyses of the mining hammerstones implied the observation and recording of several elements: petrographic determination,[22] the general shape of the tool and its dimensions (massiveness), traces of use and its intensity, and the observation of supporting morphological elements such as the groove or dent with the aim of securing the best possible attachment or better grip. In this context, the observation of traces of use did not require the use of optical instruments such as a microscope since the traces were clearly visible to the naked eye. When needed, geological magnifying glasses with a magnification of 7× and 20× were used. Classification of the mining hammerstones from Prljuša was not created as before, based on the shape only[23], since it was determined through analysis that a hammerstones in their shape possess extraordinary variability, thus such a classification is not applicable and does not lead to any useful conclusion.[24] Consequently, during the analysis of the mining hammerstones discovered in the 2011–2017 campaigns, a comparison of the aforementioned parameters was performed. Such a study resulted in classification into three basic types[25] (Table 1) (Fig. 2), which were tested by the experiment.

1) ***Hafted hammerstones*** *(type of hammerstone which is attached to a wooden handle).*
2) ***Pendulum type – hammerstones*** *(type of massive hammerstone which is suspended by some kind of rope from a trestle or beam).*
3) ***Hand-held hammerstones*** *(handstones) (for punching, grinding and pulverizing).*

The archaeological experiment was formulated according to Reynolds cyclic system.[26] According to Coles, this experiment could be defined as imitative.[27] The first experiment in this direction was conducted by J. Pickin and S. Timberlake in 1988.[28] Afterward, a

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[15] *Ibid.*

[16] Богосављевић 1988; Bogosavljević 1990; Антоновић 2013.

[17] Jovanović 1978; Derikonjić et al. 2015; Craddock et al. 2002; Fuller 2004; Ottaway, Roberts 2008; Stollner et al. 2011; Figueroa et al. 2013; O'Brien 2013; Timberlake, Craddock 2013.

[18] Богосављевић 1988, 37; Bogosavljević 1990.

[19] *Ibid.* 1988, 1990. Thus, it has been determined that the hammerstones from the previous explorations are no different from those gathered during the new campaigns.

[20] According to research seasons: 2011 – 48, 2012 – 19, 2013 – 82, 2014 – 75, 2015 – 169, 2016 – 50, and 2017 – 27 hammerstones.

[21] Analysis along with basic contextual data on the artefacts has included: petrographic determination of the rock that the artefacts were made of, definition of techniques used in their production, measurement of dimensions and weight of artefacts, detailed description, photo-documentation and functional-typological provisions. (An article about a comprehensive study of mining hammerstones from a recent exploration of Prljuša is in process)

[22] Антоновић 2013: 63. A macroscopic petrographic determination of reference rock samples that artefacts are made of was performed by V. Cvetković and K. Šarić at Faculty of Mining and Geology in Belgrade.

[23] *See* Богосављевић 1988; Bogosavljević 1990: 37.

[24] Antonović 2013.

[25] Dimić, Antonović 2018; Antonović Dimić unpublished (an article about this classification is in process)

[26] Reynolds 1999 (Hypothetical-deductive approach).

[27] Coles 1966–67: 1; Coles 1973; Ascher, 1961.

Hafted hammerstones *(Type of hammerstone which is attached to a wooden handle).*	**Pendulum type – hammerstones** *(Type of massive hammerstone which is suspended to a some kind of rope).*	**Hand-held hammerstones** *(for punching, grinding, pulverizing).*
– Dominant type of hammerstones (more than 80%). – They were found in front of each shaft, inside of each shaft, and scattered across the site. – **Weight**: from few hundred grams up to 7–8 and 9 kg (more of the 70% are damaged). – **Shape:** ***very variable***, pear-shaped and egg-shaped are slightly more represented. – **Production technology:** pecking and knapping. – **The groove**: over the entire circumference of a tool, over half of the circumference, only on the lateral edges, and a small number of diagonally cross-shaped grooves were recorded. In cases when the groove was made over the entire circumference of the tool, it is most often very meticulous. – **Traces of use**: on distal end or more often on both ends. Majority of these tools are heavily damaged on the working poll. – **Trace characterisation:** negatives of macroflakes; smaller and bigger dents (mostly shallow, under 3 mm, dens and spread in the arrangement); slightly flattened or rounded working surface.	– They were found in mining shafts usually close to a niche or passage from one shaft to another. – **Weight:** 10–20 kg (just the bigger one of 19,8 kg has been completely preserved). – **Shape:** elongated-irregular rectangular, egg-shaped and pear-shaped forms are dominant. – **Production technology:** pecking and knapping, (in some cases none, used in the natural form). – **The groove:** over the entire circumference of a tool, over half of the circumference, only on the lateral edges, in some cases over a half of the circumference and proximal end. – **Traces of use**: in most cases on one poll, but there are a few double sided hammers. Most of these tools are heavily damaged on the working surface. – **Other traces:** negatives of macroflakes; one-step and multistage breakages; smaller and bigger dents (combined deep and shallow, isolated or spread); slightly flattened or rounded working surface.	– They were found during the excavation of each shaft. – **Weight:** from 500 g up to 1.5 kg. – **Shape:** ball-shaped dominant, **always ergonomic.** The size, weights and the shape of these tools are perfect for holding in hand. – **Production technology:** in most cases they were used in natural form, pecking was used only for the groove production and minor modification. – **The groove**: if it exists, the groove always appears in a place that corresponds to the thumb or thumb and forefinger combined. – **Traces of use**: just at one poll or across the whole circumference of the tool with lateral sides intact. Most of these tools are completely preserved and without major damages. – **Other traces**: smaller dents (dens and spread, very shallow); negatives of microflakes, slightly flattened; rounded or ground working surface.

Table 1. Main characteristics of the three basic mining hammerstone types

Табела 1. Главне карактеристике три основна типа рударских камених батова са Прљуше

more detailed experiment was conducted by B. Craddock at the site of Alderley Edge in 1997, which was based on the reconstruction of the hammerstones according to the well-known analogy from the site of Chuquicamata.[29]

The experiment was designed considering two basic, integral segments and several substages with the goal of investigation of all phases in the „life" of the mining hammerstones:

1. (Re)constructon of mining hammerstones;
   – *Raw material procurement*
   – *Hammerstones head production*
   – *Hafting to a wooden handle and binding*
2. Their experimental usage
   – Fire-setting and use of hammerstones
   – Their reparation
   – Fragmentation and discarding

During the experiment, every stage of the process was carefully documented. The documentation includes photo-documentation, video-documentation, personal observations and experiences related to different elements of the process, measuring time during performance of certain activities, and recording all the details that can be used in the future as reference data.[30] The archaeological experiment was entirely conducted at the Prljuša–Mali Šturac site on Rudnik Mountain.

[28] Pickin, Timberlake 1988.

[29] Timberlake, Craddock 2013.

[30] Photo and video documentation was carried out using the following cameras: Nikon 3100 (*NIKKOR VR AF-S DX 18–55 mm f/3.5–5.6 G*) and Canon EOS 7D MARK II (*EFS 18–135 mm ISM 0.39 mm/1.3 ft.*).

Fig. 2. Examples of three main types of hammerstones from Prljuša: a) hand-held hammerstone (C 7/2015); b) hafted hammerstone (C181/2015); c) pendulum-type hammerstone (C49/2014) (photo V. Dimić)

Сл. 2. Примери три основна типа рударских батова са Прљуше: а) ручни бат/ударач (Ц 7/2015); b) бат који се припаја за држаљу (Ц181/2015); с) масивни бат клатно (Ц49/2014) (фото: В. Димић)

EXPERIMENTAL (RE)CONSTRUCTION AND USAGE

Raw material procurement

The macroscopic analysis of raw materials used for production of the mining hammerstones at Prljuša provided an insight into the usage of rocks that constitute the geological basis of Rudnik Mountain.[31] The following rocks were in use: metamorphosed sandstone, conglomerates, flysch sandstone with alevrolite, quartz sandstone, ignimbrite, quartz latite and latite as

[31] Антоновић 2013: 63.

Fig. 3. Raw materials are collected for the production of three or more hammerstones (photo V. Dimić)

Сл. 3. Сировине одговарајућег облика прикупљене за израду батова (фото: В. Димић)

well as dacite.[32] The most numerous hammerstones (over 80%) are those made of very hard rocks – metamorphosed sandstone, quartz sandstone, quartzlatite, latite and dacite, while those made of flysch sandstone with alevrolite, breccia, ignimbrite etc. were identified in far fewer numbers.

The analysis of the mining hammerstones from Prljuša has shown that various rock pieces of a rounded form were used as the basic raw materials for tool production, which could be turned into an efficient tool with less effort and intervention. To date, the main hypothesis regarding the raw material procurement from the riverbed of Jasenica[33] has been based on the assumption that "the river by the strength of its erosion produces various forms of pebbles as the ideal raw material for the hammerstones production".[34] In order to test this hypothesis, a thorough, 2 km-long terrain survey along the riverbed was organised. Even though

[32] The use of dacites was confirmed by X-Ray diffraction analysis. See Bogosavljević 1988: 23–24.

[33] Flows at the foot of the mountain.

[34] Богосављевић 1988: 24.

the idea seemed entirely reasonable, the situation we found was quite different. It was determined that the river breaks through slate, i.e. a rock that could neither have been used for the mining hammerstones production, nor was recorded in the archaeological material. During the investigation of the riverbed, we noticed only pieces of slate of various sizes. This clearly confirmed that the raw material for the hammerstone production had not been collected from this location. On the other hand, based on the survey of the closest surroundings of Prljuša, immediately above the site, along the path that leads to the top – Mali and Srednji Šturac, we noticed scattered accumulations of stones of suitable shape and identical macroscopic features as the raw materials used for the manufacture of hammerstones from Prljuša.

The following raw materials have been recorded: pieces of dacite rocks of egg-shaped form which we found freely or trapped in the bedrock mass and rounded pieces of latit and quartzlatite, most commonly with a single end or edge that needed to be processed. There were other raw materials (metamorphosed sandstone) of various slightly flattened shapes too, however, we focused on the rounded ones. Both raw materials were the part of the geological basis of Mali Šturac, and they had both been detached from the bedrock through various geological processes and erosion from higher ground. On the surface of the raw material ferrous cortex was visible, caused by atmospheric conditions and precipitation of ferrous hydroxide. Most of the raw materials are located in the vicinity of Object 1, along the road partly cut into the hill and passing immediately by the site and heading to the peak of Mali Šturac.

Raw material procurement was not time-consuming, as a result of the large quantity of available material. During our investigation it took twenty minutes to collect thirteen pieces of suitable raw material.[35] All the collected raw materials consisted of dacite, latite and quartz latite of a naturally rounded form that enabled their processing with less effort (Fig. 3) (*see* Table 2).

Hammerstones head production

Since the analysis of the archaeological material determined the existence of three basic types of hammerstones, the next step was to conduct their re(construction), whereby the first segment was the hammerstone head production. According to the analysis of production traces on the hammerstones from Prljuša, the usage of two techniques of raw material reduction was recorded: pecking and knapping.[36] Pecking was the basic technique of raw material reduction and groove production, while knapping was performed on raw materials which naturally do not possess the optimal form for these types of tools, so they primarily had to be roughly processed. The same production technology of these tools was applied on this occasion.

The production of three types of hammerstones was planned: one hand-held hammerstone (handstone), one massive, pendulum type hammerstone and, one hammerstone which would be attached to a handle. Of 13 available pieces of raw material, we tested seven and discarded two of them due to fragmentation and poor quality (Table 2).

For the hand-held hammerstone (hammerstone no. 1) we chose a piece of raw material which was of a very suitable, ball-shaped form, with a natural dent in a shape of a thumb. The raw material had a natural ergonomic shape and fitted well into the hand (Fig. 3a). Minor modifications were carried out by pecking and grinding the existing edge, for the purpose of providing a better grip. No other modifications were performed. Since the raw material was so suitable for purpose, the processing of the hand-held hammerstone took no more than twenty minutes, producing a finished hammerstone head weighing 950 g. During later parts of the experiment, this hammerstone was mainly used as a percussion tool for pecking other hammerstones and for groove production, since its basic function is striking rock or pulverising ore. Only a small amount of malachite nuggets were pulverized using this hammerstone.

The production of the hammerstone which will be attached to a wooden handle was followed by two unsuccessful attempts (hammerstones no. 2 and no. 3), related to a bad choice of raw material. In both cases, after almost one and the half hours of processing, while forming the groove, a micro fracture was noticed on the medial part of a tool, which threatened to spread with each strong blow of the hand – held hammerstone. Subsequently, the tool fragmented in half, after which the fracture was documented and the damaged, semi-finished product was discarded. During closer observation of the fracture it was established that a very thin ferrous layer was formed within the fissure, being of the same origin as the one at the surface of the tool. In order to prevent future mistakes, while selecting each of the raw materials, their whole surface was carefully

[35] Including time spent for photo-documentation *in situ.*

[36] Антоновић 2013: 63.

No.	Row material	Row material shape	Production techniques	Trans-versal groove	Production time of a hammer--stone head	Hammer-stone weight before use	Hafting	Type
1	Quartz latite	Irregular ball-shaped	Grinding	No	20 min	950 g	None/hand-held	Hand-held hammerstone
2	Dacite	Pear-shaped	Pecking/knapping/ direct percusion	/	1 h 27 min	/	/	/ (fragmented during production and discarded)
3	Latite	Pear-shaped	Pecking/knapping/ direct percusion	/	1 h 36 min	/	/	/ (fragmented during production and discarded)
4	Quartz latite	Pear-shaped	Pecking/knapping/ direct percusion and direct inverse percusion	15 mm deep/ 35 mm wide	2 h 30 min	2970 g	Wooden handle/ vine and rope bindings	Hafted hammerstone
5	Dacite	Cylinder-shaped with a wedge-shaped poll	Pecking/knapping/ direct percusion	13 mm deep/ 27 mm wide	1 h 55 min	1400 g	Wooden handle/ vine and rope bindings	Hafted hammerstone
6	Latite	Egg-shaped	Pecking/knapping/ direct percusion	10 mm deep/ 20 mm wide	1 h	370 g	Wooden handle/ vine and rope bindings	Hafted hammerstone
7	Dacite	Irregular, egg-shaped	Pecking/knapping/ Direct percusion and direct inverse percusion	20 mm deep/ 50 mm wide	5 h	11100 g	Wooden handle as axle/wooden cradle (basket)/vine and rope bindings	Pendulum type hamemrstone

Table 2. Main characteristics of experimentally made hammerstones

Табела 2. Главне карактеристике експериментално израђених батова

examined both before and after removing the ferrous layer. To avoid the risk of having no working tools, as a result of the unforeseen fragmentation while using this type of hammerstone, it was decided that they should be reconstructed in triplicate (one main and two supporting). All three hammerstones were of different dimensions and weight, so they also represented a set of tools used by prehistoric miners at this site. The selected raw materials for these hammerstones were of different shapes: cylinder-shaped with a wedge-shaped poll, pear-shaped, and egg-shaped (Fig. 3 b, d, e; *see* Table 2). During the processing of all three specimens of hammerstones, the techniques of pecking and knapping were used with direct percussion, held in the hand, on the knee or on an anvil. Primarily, the hammerstone polls were processed in order to annulate the weak spots that could cause fragmentation during work and then the groove was manufactured (Fig. 4 a–f). The transversal groove was formed on all three hammerstones across their circumference and, depending on their size, it ranged from 20 to 35 mm in width and 10 to 15 mm in depth. The approximate time needed to complete the production of a single hammerstone head with a groove was between an hour and two and a half hours. The finished hammerstone heads weighed: hammerstone no. 4 – 2,970 g; hammerstone no. 5 – 1,400 g; hammerstone no. 6 – 370 g (*see* Table 2).

In the same way as previously described, the head of the pendulum type hammerstone was formed. A massive, hard stone of irregular, egg-shaped form was chosen, having sporadic ferrous deposits on the surface (Fig. 3 c). The reduction of raw material on the polls was primarily performed by pecking and knapping in order to discard sharp and irregular edges that could cause undesirable fractures during the work process as well as cleaning the raw material from its cortex. After creating an ideal shape, the transversal groove was manufactured, being formed across the whole circumference of the tool. The groove was 20 mm deep and 50 mm wide (Fig. 4 g). The approximate time needed for the production of the massive hammerstone head was five hours of effective work. After processing, the hammerstone (no. 7) weighed 11,100 g (*see* Table 2).

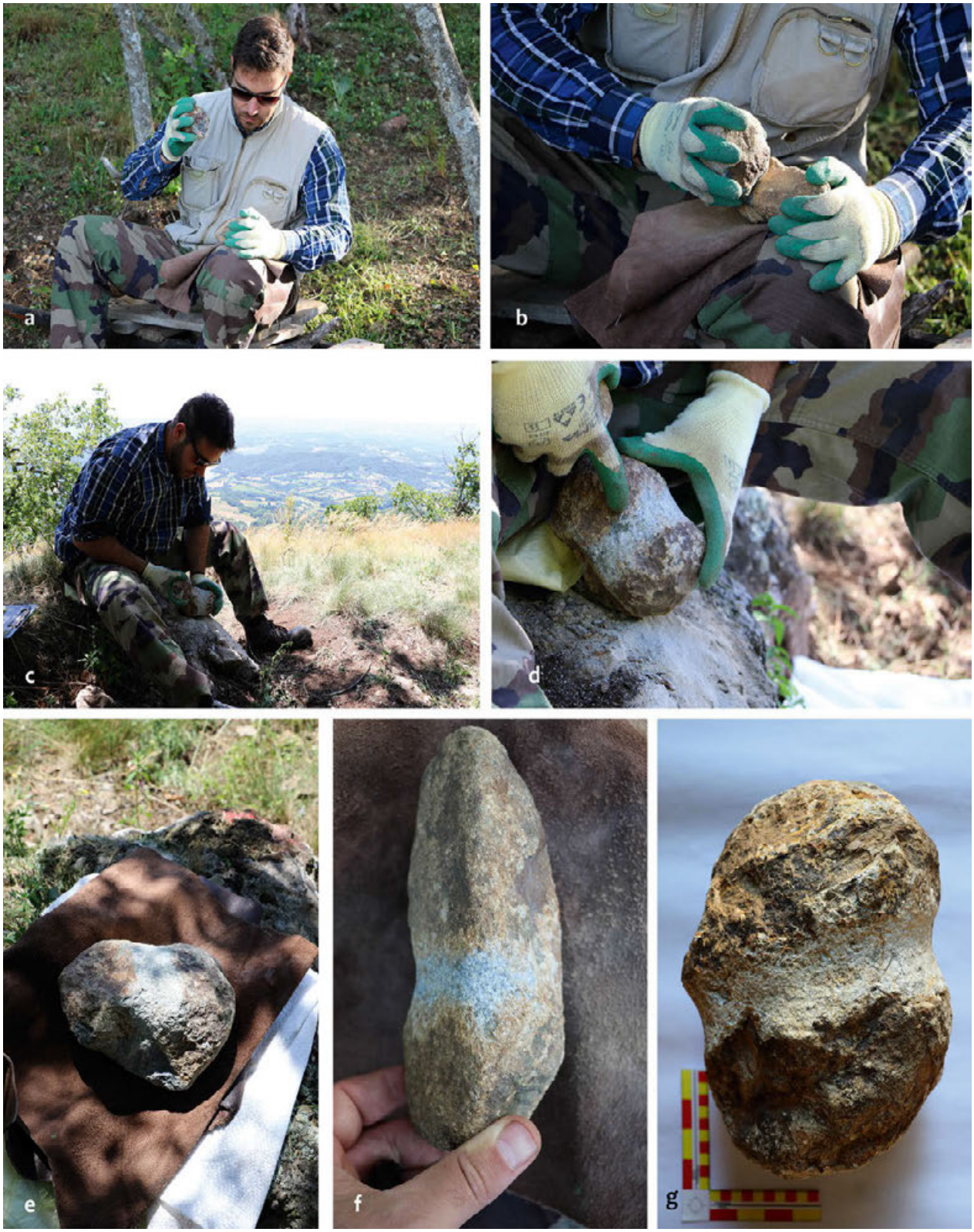

Fig. 4. a, b, c) Raw material processing using the pecking technique and groove making; d–g) appearance of the transversal groove (photo D. Antonović, V. Dimić)

Сл. 4. a, b, c) обрада сировине техником озрњавања и израда жлеба; d–g) изглед попречног жлеба (фото: Д. Антоновић, В. Димић)

Fig. 5. Hafting of hammerstone heads to a wooden handle (photo V. Dimić, S. Vitezović)

Сл. 5. Причвршћивање каменог чекића за дрвену дршку (фото: В. Димић, С. Витезовић)

Hafting and bindings

Data that was taken into consideration in order to reconstruct the binding method of the hammerstones with a handle was related to the existence and morphology of the transversal groove on the tool, the weight and shape of the tool, as well as an examination of the natural materials that have been easy to obtain and which could have serve for this purpose. Additionally, examples of complete tools with handles were seen in archaeological and ethnographic literature, so the impression of their general looks was made.[37]

The third stage of the experiment was the manufacture of wooden handles for the hammerstones and their hafting and fixing. It was necessary to choose tree species that existed in this area and the appropriate period of time[38], which was flexible (although not too flexible) and was able to endure the vibration and friction with the hammerstone head. The selection was narrowed to the following species: willow, hornbeam and hazel. Since willow is too flexible and soft it was immediately discarded, while hornbeam was a somewhat better choice, although slight defects were recorded during its processing. Hence, our choice fell on hazel. In the woods in the vicinity of the site, two straight hazel branches[39] (of around 2 m long and c. 4 cm in diameter at their thickest part) were selected and cut. The branches were soaked in water overnight with the aim of improving their flexibility.[40] After a few failures of banding the whole branches around the hammerstone heads (as done in the experiment at Alderley Edge[41]), they were split in half longitudinally. Segments for three handles were made out of the first branch, while both halves from the other branch, with minor reductions, were used to manufacture the handle for the massive pendulum-type hammerstone. The processing of the longitudinal branch segments (potential handles) was conducted as follows. Firstly, the segments were reduced to the desired length, thickness and width, then the processing of central part and the bending of the handle took place. The handle was bent very gradually, using a foot to put pressure on the middle the thinnest part, while the ends were pulled by hand towards the centre. It is crucial to note that the outward part of the branch was turned inward. After gradual, controlled bending, the central part of the handle was carefully beaten with the hammerstone in order to soften and to expand and loosen the plant fibres, which significantly sped up the bending process and prevented premature tearing of the fibres leading to the branch splitting. Then the handles were banded around the hammerstones, i.e. around their transversal groove, thus forming firm contact. The handles and hammerstone heads were joined by a rope and then set aside to dry for five days, after which they were disassembled and permanently fixed again. Drying was necessary so that the handles could adapt to their newly formed shape as well as to prevent the hammerstone head fall-

Fig. 6. Reconstruction of the hafted hammerstone and the massive pendulum-type hammerstone (photo V. Dimić)

Сл. 6. Реконсшрукција башова са држаљом и масивної баша – шипа клашно (фошо: В. Димић)

[37] Craddock, Craddock, Langenscheidt 2002; Figueroa et al. 2013, Fuller 2004.

[38] Filipović et al. 2018; Filipović, Challinor, Andrič 2017.

[39] *Corylus avellana.*

[40] Their processing was carried out by (using) metal tools.

[41] Timberlake, Craddock 2013.

Fig. 7. Reconstruction of the massive pendulum-type hammerstone, rope and the construction from which it was suspended (photo V. Dimić)

Сл. 7. Реконструкција масивног бата – тип клатно, ужета и конструкције о коју је окачен (фото: В. Димић)

ing out of the handle after fixing as a result of the shrinking of the wood while drying. If the soaking of the handles in water over night is excluded, the handle production process and the primary binding to the hammerstone heads took around two and a half hours. The handle thickness, at the assembled ends of the grip part was 35 mm and 25 to 30 mm wide, where the massive hammerstone handle thickness was 45 mm and 40 mm wide. The handle length, excluding the part bent around the hammerstone head, was 40–50 cm.

The next task was the permanent hafting and binding of the hammerstones to their handles. It was necessary to fix the hammerstone as tightly as possible, so as to prevent any wobbling of the hammerstone head and the potential for it to fall out of the handle while being used. According to the analogy of these tools

from the site of Chuquicamata, the hammerstones might have been fixed to the handles with rawhide stripes[42]. However, for the purposes of this experiment, material of plant origin was used, which exists in abundance in the woods in the vicinity of the site, such as durable plant vine. Consequently, our choice was the so-called Wild Clematis[43] (Fig. 5a–b). Young, strong and flexible stems of 10–20 mm in diameter were collected, and used for binding, being cross-interwoven around the hammerstone head and the wooden handle. After that, the lower parts of the handle up to the tool head were bound neatly with industrial hemp rope[44] of 3 mm in diameter, in order to fix the handle in the best possible way (Fig. 5c–g, Fig. 6). Head binding of the massive pendulum-type hammerstone was carried out using the same principle, except that the interweaving of these vines, thin branches of hornbeam[45] and the supporting handle, as an axle were formed into a type of basket or cradle (Fig.7a–c). The basket and handle had the purpose of carrying the hammerstone weight and preventing its swaying while being hung on the rope, and consequently, preventing a lack of precision during use. The whole process of this stage of the experiment, from collecting lianas to binding hammerstones and handles as well as creating the basket (cradle) for the massive hammerstone took around three hours of effective work.

Since it was necessary to make a construction on which the massive pendulum-type hammerstone would be suspended, it was decided that a trestle (bipod) should be made for placing the horizontal beam.[46] Four straight, relatively young hornbeam trees of 10 cm in diameter were cut. The poles were cross-placed (in the shape of X) and bound tightly with vine and rope. A beam was placed on the top of them and also bound tightly, so as to avoid swaying during use. The construction was placed on the location where the experiment would be conducted, and the lower trestle parts were jammed with stones in order to put pressure on them and keep them stable (Fig.7 f). After that, a rope was made, on which the massive hammerstone would be hung. For this purpose, vines, i.e. lianas with sprouts were used and made into a plait. At one end of the rope a loop was made on which the massive hammerstone was hung (Fig.7 d–e). The construction of the trestle and rope took about one hour.

Usage

The second integral segment of the experiment, after the production of the mining hammerstones, was their testing, i.e. the (re)construction of their usage. This was both an inspiring and demanding task, since the experiment could not be conducted in the original shafts, which are protected by law as part of the site. In order to make the use of the hammerstones more convincing and thus the results veridical, the mining technology at Prljuša had to be observed, including the variables regarding the type of rock intended to process and its heat-treatment without posing any hazard to the site itself. Therefore, the original rocks obtained during former excavations from the collapsed ceiling of Object 1 were used for the experiment. Three massive and compact stone blocks were separated and placed into a semicircle next to each other. Since the fire-setting for weakening of rocks has been undoubtedly archeologically documented at Prljuša, the logs were piled and the fire was set right beside the rocks (Fig. 8 a–c). A strong fire (≥800 C°) was maintained for almost an hour and a half. Although it was summertime, very cold water obtained and bought from the nearby mining shaft, where had been naturally deposited. After the fire extinguished and the logs burned down, water was poured over the rocks. During heating and afterwards with the cooling by water, the rocks reacted and started to crack (Fig. 8 d). The hammerstone testing (hitting) was started with the massive pendulum-type hammerstone (11,100 g), which weakened the rock and promptly separated the first large pieces of stone (Fig. 8 e–f), while further work was performed using the hafted hammerstone (2970 g) (Fig. 8 g–h). After the primary testing of the pendulum-type hammerstone and the hafted hammerstone, it was proceeded by their alternate use depending on the needs (Fig. 9 a). Blows were struck with full strength, from different angles in order to get an insight into the range of possible movements and usage potential of hammerstones during work in a cramped space. It is important to note that during the work, minor formations and a thin scum of malachite and azurite were observed inside the rock (Fig. 9 b–c). For the purpose of estimating the needed effort and possible dynamics of crushing larger volumes of rock during the work, the

[42] Fuller 2004; Figueroa et al. 2013; Timberlake, Craddock 2013.

[43] *Clematis vitalba L.*

[44] *Cannabis sativa L.*

[45] *Carpinus betulus L.*

[46] Analogy of wooden bipod in top chamber of Zawar Mala Magra mine (Craddock 1995, Figure 2.36).

Fig. 8. a–c) Fire-setting and rock heating; d) cracks in the rock produced by high temperature; e, f) use of pendulum-type hammerstone; g, h) use of hafted hammerstones (photo V. Dimić, S. Vitezović, D. Antonović)

Сл. 8. а–c) паљење ватре и загревање стене; d) пукотине у стени произведене високом температуром; e, f) употреба масивног бата – типа клатно; g, h) употреба батова са дршком (фото: В. Димић, С. Витезовић, Д. Антоновић)

Fig. 9. a) The amount of crushed rock after 1 hour of work and the combined use of a pendulum – type hammerstone and a hafted hammerstone; b, c) the remains of malachite and azurite mineralisation inside the rock; d) the second crushed stone block (photo. V. Dimić)

Сл. 9. а) количина разбијене стене након сат времена рада и комбиноване употребе бата – типа клатно и батова са држаљом; b, c) остаци минерализације малахита и азурита унутар стене; d) разбијени други блок стене (фото: В. Димић)

Hammer-stone type	Activity performed	Kind of blows/ working surface	Work intensity (force applied)	Number of blows per minute	Weight before use	After 1 h of use	After 2 h of use	After 4 h of use	Repa-ration	Total working time	Amount of crushed rock per time unit	Damages	Traces of use on the hammerstone head
Hand-held hammer-stone	Pecking/ knapping of stone/ pulverize-ing of malachite lumps	Direct hitting by distal end	Intensive and moderate	40-70	950 g	/	920 g	900 g	None	8 h	?/ 40 g of malachite/ 20 min	None/ just typical use wear	Smaller dents (shallow, dens and spread in the arrangement); flattened/battered working face
Hafted hammer-stone	Crushing of heated and non-heated rock	Direct hitting by distal and proximal end	Very intensive	50-65	2970 g	2757 g	2735 g	/	Refixing and rebinding in 15–20 min interval	2 h	cca 300 kg/ 1 h	1 macroflake on the working poll/ wooden handle damaged	1 macroflake negative; smaller dents (shallow, dens and spread in the arrangement), flattened/battered working surface on both faces
Pendulum type hammer-stone	Crushing of heated and non-heated rock	Direct hitting by distal end	Moderate and intensive	30-40	11100 g	8600 g	/	/	None	1 h	cca 200 kg/ 1 h	Extensive damage of the working poll/ handle and the basket without damages	Extensive damage of the working poll (distal and medial part); bigger dents – spread, combined deep and shallow, battered working face

Table 3. Basic data of the experiment related to the use of mining stone hammerstones

Табела 3. Основни подаци експеримента који се односе на употребу рударских камених батова

number of blows exerted on the rock was measured, including the volume of crushed rock over a given time span (Table 3). Both hammerstones were alternately used for about three hours, not counting the short rest breaks or time needed for the reparation of the hammerstones. The reparation of the hammerstones involved their rebinding and reattachment to the handle after falling out of it. The stones selected for the hammerstone testing were crushed (Fig. 9 d), and the damage on the hammerstones which successively occurred during their use was recorded (*see* Table 3, Fig. 11 and 14). The hafted hammerstone head was not damaged but only its handle broke, while with the massive hammerstone the handle and the basket were quite intact, whereas its head was somewhat damaged and was rendered unusable (Fig. 11 a–d). The use of two auxiliary hammerstones with handles (no. 5 and 6), which were produced in case of the main hammerstone (no. 4) fragmentation, was not necessary since the envisaged task was successfully accomplished by the main hammerstone.

The hand-held hammerstone was primarily used as a percussion tool in the production of other hammerstones (7.40 h). It was used for making a transversal groove, for pecking sharp edges, knapping etc. After the primary usage, a clearly visible working surface was created which became relatively flat, out of the rounded – convex face by the end of six-hours of effective work (*see* Fig. 14 f, Table 3), After that, the hand-held hammerstone (no. 1) was also used for the pulverization of small malachite lumps (20 min). During the pulverization of the smaller amount of malachite (40 g), a green colour was clearly observed on the working surface of the hammerstone, deriving from the penetration of the malachite remains into the microfractures and dents of the rock surface.

OBSERVATIONS AND RESULTS OF THE EXPERIMENT

– The hypothesis that the raw materials used for the production of hammerstones were collected in the form of river pebbles, which were formed by the fluvial erosion of the Jasenica river[47] is disputed. On the other hand, macroscopically identical raw materials that we recorded in archaeological material were found and documented in the closest surroundings of Prljuša. They are all a part of the geological basis of the mountain top of Mali Šturac and the slope of Prljuša. They were all detached from the bedrock and scattered along the slopes under the influence of various geological processes (Fig. 10).

[47] Богосављевић 1988: 24

Fig. 10. Egg-shaped stones fallen from the bank on the side of the road which leads to the mountain top (photo V. Dimić)

Сл. 10. Јајолико камење (камене куīле) исīало из обале/īрофила īуīа који води ка врху īланине (фоīо: В. Димић)

– The best results in processing raw materials during the production of these tools were achieved using direct percussion on stone anvils. A technique of inverse direct percussion is also very efficient, especially if operating with raw materials of somewhat larger dimensions (≥2.5 kg). On the other hand, when it is necessary to process the hammerstone head more finely, it is better to hold it in the hand or leaning against the thigh, because a hard anvil, such as stone, provides a return wave and vibrations that can damage the object if there are any microfractures in it.
– Raw material processing, particularly the groove formation, is rather exhausting work that requires a lot of physical strength and patience.
– From 40 to 70 blows with a hand-held hammerstone (that weighed 950 g) were counted per minute, which meant that during one hour of effective work we lifted a hammer that weighed almost 1 kg and struck a blow between 2,400 and 4,200 times (*see* Table 3). A similar situation was observed during the use and testing of the other two hammerstones, therefore, short rest breaks were unavoidable.
– Long continuous work with a hand-held hammerstone (as a percussion tool) is very tiring and can lead to injury (swelling of the hand in this case). Hence, it is quite possible that hafted hammerstones of smaller dimensions (500–1,000 g) were also used for the hammerstone head or groove manufacture, not only for rock crushing and ore processing. In this way, the handle would absorb the vibrations and, using the extended arm principle, a more efficient and precise blow could be accomplished.
– Depending on size, it took one to two and a half hours to produce a single hammerstone head with a transversal groove, except for the massive pendulum – type hammerstone, for which it took about five hours (*see* Table 2).
– It took about five and a half to collect the necessary material (branches and lianas) to process branches, make shafts, and fix and permanently bind the hammerstone heads, and one more hour to make the trestles and the rope. In the hafting process, it appeared to be very important not to use the whole branch, but to longitudinally split it in half and then use those halves, otherwise the whole branch will not withstand the bending around the hammerstone head.
– Fire-setting, rock heating (≥800 C°) and sudden cooling by cold water were extremely effective. After 40 minutes of heating at high temperatures changes could be observed in the rock. The colour of the rock surface became red and black, and the scattered microfractures became clearly visible. An even more forceful reaction then happened, followed by a cracking sound, when the cold water was poured onto the rock, causing a thermal shock.
– The usage of the pendulum-type hammerstone during the rock crushing was very efficient, particularly if the rock had been previously treated by fire and sudden cooling. The hammerstone weight and mass were almost eliminated by using a rope and the trestle on which it was hung; making working with it was easy and not requiring much physical effort.
– For usage of the pendulum-type hammerstone, the help of another person was useful, to hold and control the rope on which the hammerstone was hung. Help was not strictly necessary as the rope could be controlled by the person who was working the hammerstone, but in that way, the agility and manoeuvrability of the user were significantly reduced.
– During testing of the hafted hammerstone, a very wide range of potential movements and angles were identified from which it was possible to strike the rock. On the other hand, the manipulation of the massive pendulum-type hammerstone, in the sense of striking a rock from different angles proved to be limited, with only height correction being possible (from the knee to the miner's head).
– With the alternate use of the pendulum-type hammerstone and the hafted hammerstone, during one hour of intensive work, 500 kg of rock was crushed (*see* Table 3).
– During the work, reparation of the hafted hammerstone was needed every 15–20 minutes (*see* Table 3). In the mentioned time interval, the handle was worn out and expanded due to the intensity of blows, which caused the hammerstone head to dislodge from the handle. The time needed for the rebinding and refixing of the hammerstone was two to five minutes, depending on whether the hammerstone head needed rebinding or just fixing back in its place on the handle. There was a general observation that a thorough binding of the hammerstone head was not so effective, hence it wasn't necessary since it would loosen and fall out either way during longer periods of usage.
– Reparation of the pendulum-type hammerstone was not required until damage occurred after one hour of effective work. The handle and the basket/cradle were completely undamaged, while the hammerstone head suffered severe damage and could no longer be used. (Fig. 11 c–d).

Fig. 11. Table represents damage that occurred on the working faces on the hammerstones and their reparation

Сл. 11. Оштећења на батовима и њихова репарација (фото: В. Димић, Д. Антоновић)

– After 2 hours of effective work, the hafted hammerstone head was not severely damaged, but the wooden handle had been broken and it could not be used further (Fig. 11b).
– During the hammerstone usage, it was noticed that the transversal groove is of crucial importance and one of the main factors that keep the tool firmly in place. The depth of the groove, and its careful and thoughtful processing in the places where the head of the hammerstone has the most contact with the handle, and thus the greatest friction, are of crucial importance and can enable better stability of the hammerstones head in the shaft.
– During work, traces of use were successively created on the hammerstones, which were identical to those documented on the hammers from Prljuša (*see* Table 3, Figure 14).

Fig. 12. a) Burn traces on the surface of the wall in Shaft 6 at Prljuša; b) soot formed on the wall of the stone block during its heating at the beginning of the experiment; c) traces of punching/crushing on the surface of the wall in Object 1; d) traces of punching/crushing on the stone block surface documented during the experiment (photo V. Dimić; D. Antonović)

Сл. 12. а) трагови горења на зидовима стене у Окну 6 на Прљуши; b) гареж која је формирана на зиду стене током њеног загревања на почетку експеримента; c) трагови ударања на површини зида из Објекта 1; d) трагови ударања на површини стене документовани током експеримента (фото: В. Димић, Д. Антоновић)

– Hand-held hammerstone traces of use: smaller dents (shallow, dense and spread in their arrangement); flattened/battered working face after pecking of other hammerstones. By using a hand-held hammerstone to pulverize the 40 g of malachite lumps, only a small amount of malachite scum and intrusion was recorded in the previously occurred dents. The weight of the hammerstone before usage was 950 g, after 2 hours of work – 920 g, after 4 hours – 900 g. Hence, a reduction of rock mass of about 10–12 g per hour of work was evident.
– Hafted hammerstone traces of use: 1 macroflake negative; smaller dents that are shallow, dense and spread in their arrangement, flattened/battered working surface on both faces. The weight of the hafted hammerstone before usage was 2,970 g and after effective work for 2 h, the weight was 2,735 g which meant that during an hour of usage it lost about 20 g of its mass if we exclude one bigger detached flake of 195 g.
– Pendulum-type hammerstone traces of use: Extensive damage of the working poll (distal and medial part); other traces: bigger dents – spread, combined, deep and shallow, battered working face. Before use the weight was 11,100 g, and after usage and damage 8,600 g.
– On the rock, which was afterward crushed with the experimental hammerstones, percussion marks were recorded that are identical to the traces documented on the walls of all explored mining shafts at the site. (Fig. 12).
– By fire-treatment, identical burning traces like those documented on Prljuša were produced on the surface of experimental stone blocks (Fig. 12).

DISCUSSION AND CONCLUSION

By conducting an archaeological experiment, data has been obtained regarding the operational sequence and wide range of activities from the raw material procurement for the production of this category of tools and their reconstruction, to the reconstruction of their usage. The new experiences that have been acquired, along with the results, data and observations derived from such an approach to this specific issue will be of importance in the future interpretation of mining hammerstones. Through the performance of this experiment some new knowledge and experiences were acquired, but it also opened up some new questions that need to be answered in the future.

Locations have been identified from which, in prehistory, the procurement of raw materials was most probably carried out. With the survey of immediate surroundings of Prljuša site, a large amount of the appropriate raw material was discovered. The entire area of Prljuša–Mali Šturac is rich with high quality, hard rock suitable for the production of hammerstones. Therefore, it is quite certain that prehistoric miners produced these tools at this location, from the raw material of local origin they collected, if not at the very site, then certainly in the immediate surroundings (Fig. 10). They chose raw material of suitable shape, with a smooth rather than rough, and a rounded rather than angular form. Thus, they saved a lot of time and particularly physical energy, needed for the procurement and transportation of raw materials from its source to the mine, and afterward for shaping into a suitable form, which was an extremely favourable factor for the Prljuša miners.

The archaeological remains from Prljuša clearly indicate the use of fire for primarily weakening the ore-bearing rocks, whether surface or underground exploitation is concerned.[48] Fire-setting, heating and sudden cooling with water were extremely efficient, while burning and working traces identical to those recorded at Prljuša were produced on the experimental rock (*see* Fig. 12). On the other hand, the performance of this stage of the experiment also raised some new questions:

– During the experiment, it was proven that the use of fire is very effective. Nevertheless, to what extent could it be controlled/not controlled within a relatively narrow space in the mining shaft?

– Were only the surrounding bedrock affected by the fire, or did the fire affect the ore veins too?

– How high a temperature could be reached in the relatively cramped space of the shaft and was there sufficient fresh air intake needed to achieve the optimum temperature?

– On the walls of almost every mining shaft on Prljuša, soot marks are clearly visible; therefore, what was the impact of smoke on the formation of reduction burning conditions and the achievement of optimum temperature.

– In our experiment, very cold capillary water from the nearby mining shaft was poured on the hot rock immediately after the fire was extinguished in order to achieve a thermal shock. However, is it reasonable to assume that the prehistoric miners could enter the mine shaft to pour the water immediately after the fire was extinguished, given that these shafts are relatively closed units that behave in these conditions probably as furnaces, whose walls accumulate a great amount of heat which they will radiate?

Where the hammerstones are concerned, the experiment has proved that all three types are very functional, and the traces of use on them completely correspond to those recorded on the original artefacts from Prljuša. However, during the experiment, the use of the hafted hammerstone and the pendulum-type hammerstone produced some new questions when it comes to their mutual differentiation and recognition.

– For example, under which type would the hammerstone with the transversal groove be defined if the traces of use occured on both working faces, and if the weight of the hammerstone was about 7, 8 or 10 kg?

– What is the possible weight that could be withstood by handles (on hafted hammerstones) during intensive work, so as not to be prematurely severely damaged?

– Also, which maximum weight of the hafted hammerstones is suitable for intensive and efficient work; and which weight makes the handling either aggravating or even impossible?

– Hence, a question of great importance arises from all of this: what is the threshold value of weight/massiveness that clearly makes the boundary between hafted hammerstones and those that are used with the pendulum principle, if there is no clear difference in traces of primary use, secondary use, or recycling?

Our pendulum-type hammerstone was used only on one side; therefore, the traces of use are located on that side only. Pickin and Timberlake[49] suggested through their experimentation a similar method of suspension

[48] Antonović, Dimić 2017

[49] Pickin and Timberlake 1988: 165–167

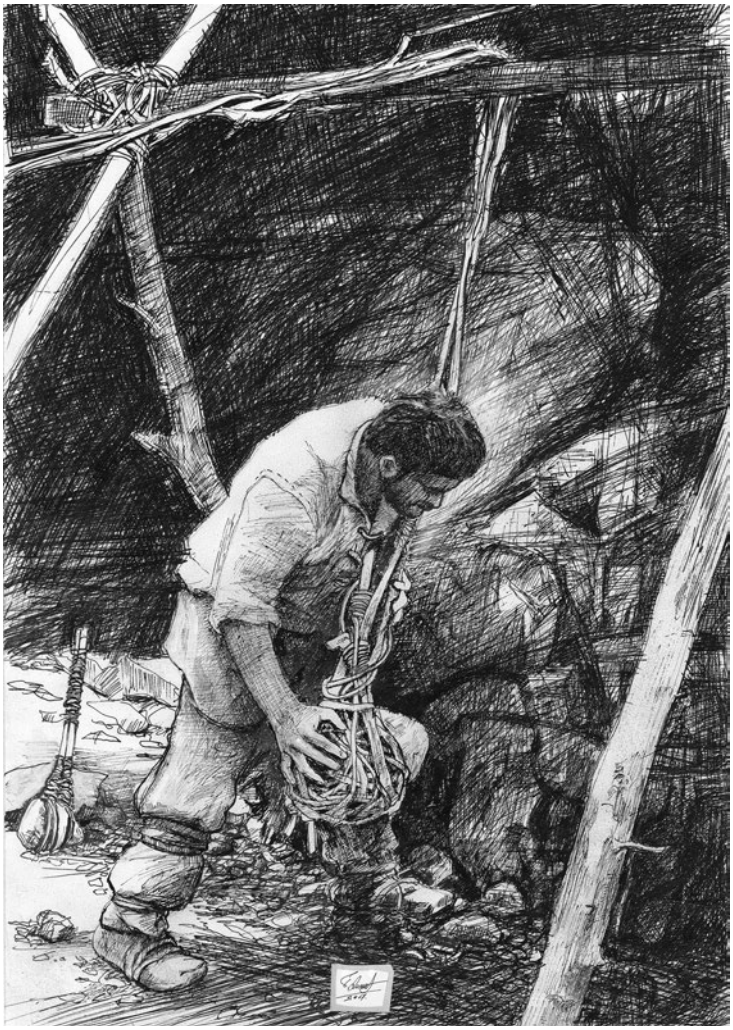

Fig.13. Reconstruction of the usage of the massive pendulum-type hammerstone (drawing by Blagoje Dimić ©)

Сл. 13. Реконструкција употребе масивног бата – типа клатно (цртеж: мр Благоје Димић)

of massive hammerstones (without basket/cradle) with the possibility of hitting the rock with both faces. Although their suspension method is quite possible, we think that it would not be overly effective because we did a similar thing at the beginning of our experiment and we immediately gave up because that kind of suspension drastically reduces manoeuvrability and impact force. The basket, in our case, although disabling working with both sides, kept the hammerstone steady without wobbling during impact and allowed us to strike the rock with precision (Fig. 13). With our method of fixing, there is also a reasonable opinion that, if the head of the massive hammerstone was damaged on one side, the other one could be turned to continue the work. In addition, Pickin and Timberlake used a massive hammerstone in one different method which we did not test on this occasion. They used it kneeling on the ground, sending the blow in an up and down motion, lifting the hammer over the head and lowering it onto a stone plate where the ore-bearing rock was collected. This kind of use of the massive hammerstone absolutely makes sense, and would also explain the working surface on both ends/faces. However, then the question arises, how long is it possible to work in this manner without excessive tiredness of the back and arm muscles, which would make any longer, continuous work almost impossible. Again, besides other factors, that is a question of optimal weight.

The experimental usage of the hafted hammerstone and the pendulum-type hammerstone also suggested that the use of the massive hammerstone is most effective at the beginning of the work for detaching bigger pieces of heat-treated rock. In the further flow of work, it was effective but not as much as the hafted hammerstone because of the reduced manoeuvrability and the possibility to strike a rock from different angles.

The experimental use of hammerstones also provided information regarding the inevitability of their

Fig. 14. A comparison of: a, c, e) original artefacts from Prljuša–Mali Šturac (C165/2015, C48/2015, C91/2015); b, d, f) experimentally made artefacts

Сл. 14. Упоредни приказ: a, c, e) оригинални артефакти са локалитета Прљуша–Мали Штурац (Ц165/2015, Ц48/2015, Ц91/2015); b, d, f) експериментално израђени артефакти

need for reparation and, therefore, the organisation of work. The hafted hammerstones' reparation had to be carried out every 15 to 20 minutes. It is quite certain that one member of the mining team was specifically entrusted with the reparation and production of the hammerstones. In this case, reparation meant the production and repair of the handles, reattachment of the hammerstones to them, and reparation of the hammerstone heads in case of damage etc. It was also made clear that there must have been a number of spare hammerstones which were alternately used under a rotation method – when one was damaged it would be replaced by another, allowing it to be repaired.

When it comes to the presumed typology, the possible appearance and the method of use, this experiment has shown that all these factors can be considered to

have been affirmed. However, during work with these three types of hammerstones, there was also a need to use a wider range of other tools, which we think would have facilitated the job. When we say a wider range, we mean antler tools, wooden stakes, and wedges, or some other pointed stone tools which were not found at the site at the time the experiment was conducted but their occurrence (especially antler and other stone tools) is possible and quite expected.

An active, more detailed view was obtained by performing the archaeological experiment and documenting the information and the experiences that this approach allows. This is the first experiment conducted with the aim of moving a step closer to the general knowledge of mining technology at the Prljuša–Mali Šturac site. It opens the door for other tests and perspectives which may be directed towards the study of all the aforementioned questions and at the organisation of labour and the logistics that the team of miners required in order to perform the ore exploitation and its further processing.

Translated by Dragana Šolajić

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Резиме: ВИДАН Б. ДИМИЋ, Археолошки институт, Београд

РАСКУЦАВАЈУЋИ ПРОШЛОСТ: ЕКСПЕРИМЕНТАЛНА (РЕ)КОНСТРУКЦИЈА И УПОТРЕБА ПРАИСТОРИЈСКИХ РУДАРСКИХ КАМЕНИХ БАТОВА СА ЛОКАЛИТЕТА ПРЉУША – МАЛИ ШТУРАЦ НА ПЛАНИНИ РУДНИК

Кључне речи – Прљуша – Мали Штурац, технологија рударења руде бакра, експериментална реконструкција, рударски камени батови, израда и употреба

Локалитат Прљуша – Мали Штурац на планини Рудник један је од најбогатијих праисторијских локалитета рударског карактера у Европи, гледано према броју забележених, сакупљених и анализираних рударских камених батова. Засновано процењен број тих алатки на 2000 и више, врло јасно осликава интензитет рударења на овој локацији током енеолита, као и очигледност рударског потенцијала који је ова планина поседовала. Током досадашњих истраживања локалитета сакупљено је и анализирано 688 батова, од којих 478 током нових истраживања. Из тих су анализа проистекли резултати на основу којих су оформљене претпоставке о начину њихове израде и употребе. Сходно томе, током лета 2017. године спроведена је експериментална (ре)конструкција и тестирана су три основна типа овог оруђа као комплементарни сегмент сету функционално-типолошких анализа. Циљ експеримента била је акумулација података и искустава који у будућим тумачењима могу омогућити већи степен објективности. Експеримент је имитативног типа, а методолошки је конципиран према Рејнолдсовом цикличном методу. Постављен је и успешно реализован тако да се у њему истраже све фазе у „животу" рударских камених батова: од сакупљања сировина од којих су прављени, преко начина израде и реконструкције њиховог изгледа, до реконструкције начина употребе, њиховог оштећења, репарације и, на крају, одбацивања. Током експеримента је спроведен велики број операција, те је стога приликом њиховог извођења акумулиран и велики број података.

Утврђене су локације са којих је било могуће сакупљање сировина. Рекогносцирањем непосредног окружења локалитета пронађене су веће количине одговарајуће камене сировине која има исте макроскопске карактеристике као оне што су коришћене за израду рударских батова на Прљуши. Када је израда ове категорије алатки у питању, практиковањем основних забележених техника редукције сировине стечена су нова искуства и сазнања о напору и времену потребном да се од комада сировине изради глава бата.

Према резултатима анализе батова, а затим и структуре рударских окана на Прљуши и траговима горења и ударања на њиховим зидовима, извршена је идеална (ре)конструкција технологије рударења кроз употребу сета батова као основних рударских алатки. Паљење ватре уз стену, њено загревање и нагло хлађење водом било је изузетно делотворно, а на самој стени су произведени идентични трагови горења попут оних забележених на Прљуши. Тако ослабљена стена примарно је разбијана масивним батом – типа клатно, а потом комбинацијом тог бата и бата припојеног за држаљу. Употреба масивног бата – типа клатно показала је велику ефикасност када је реч о разбијању и растресању већих комада стене. Међутим, манипулисање њим, у смислу упућивања удараца из различитих углова, ограничено је. За сада, најмасивнији пронађени примерак овог типа на Прљуши тежак је 19,8 кг. Носећа конструкција масивних батова при површинској експлоатацији руде вероватно је могла имати изглед сличан нашој, коришћеној током експеримента, док су за подземну експлоатацију сасвим сигурно коришћене само попречне греде о које је качено уже што је носило корпу (колевку) и бат. Оне Греде су ослањане на посебно израђена удубљења у стени, каква су забележена готово у свим окнима на локалитету. С друге стране, батови припојени за држаљу представљају изузетно ефикасно оруђе, којим се ударац ка стени могао упутити из различитих праваца и углова и различитим интензитетом. Употребом експерименталних батова, поред осталих, стечене су и информације које се односе на неминовност њихове репарације, а самим тим и на организацију рада. Током употребе батова је уочено да је попречни жлеб од пресудне важности и да је један од главних фактора који утиче на стабилност алатке. Дубина жлеба и његова педантна и осмишљена израда на местима где држаља са главом бата има највише контакта, а самим тим и највеће трење, од круцијалног су значаја и могу омогућити, бар за нијансу, бољу стабилност главе бата у држаљи.

Задатак овог рада био је да се извођењем археолошког експеримента омогуће „активни" подаци и информације који се не могу стећи увидом у „пасиван" археолошки материјал, чиме би сазнања о рударским каменим батовима са локалитета Прљуша била употпуњена. Веома успешно су (ре)конструисани изглед и начин употребе масивног бата – типа клатно. Такође, утврђена је изузетна ефикасност и друга два типа батова. Трагови употребе на њиховим теменима, трагови горења и трагови разбијања на стенама показали су у потпуности исту слику коју имамо и на самом локалитету.