Prehistoric exploitation of minerals resources. Experimentation and use-wear analysis of grooved stone tools from Grotta della Monaca (Calabria, Italy)

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Abstract
The Calabria region of Southern Italy is rich in mineralisation. Unfortunately, no consistent data are available about mineral exploitation in the later prehistoric periods. The Grotta della Monaca mine in Calabria is a prehistoric site that is characterised by the mineralisation of iron ores (such as goethite) and copper carbonates (malachite and azurite). For this reason, the site provides an exceptional opportunity to study a prehistoric mine in which several minerals were exploited during the late Neolithic and early Chalcolithic. In this study, we present the results of an experimental protocol and use-wear analysis conducted using macro-lithic tool replicas to extract mineral resources. The experimental test aimed at reconstructing the function of grooved stone tools found at Grotta della Monaca. Use-wear observation, through a combined low- and high-power approach on experimental and archaeological objects, allowed us to define different extraction techniques and methods of mineral treatments. These data enhance our understanding and reconstruction of the chaîne opératoires, economic choices, and cultural aspects that characterised prehistoric miners in Southern Italy.

Keywords Grooved stone tools · Use-wear · Experimental archaeology · Prehistoric mines · Minerals · Italy

Introduction
The study of prehistoric mining practices can enhance our understanding of ancient communities’ socio-economic and cultural complexity and organisation. Indeed, prehistoric exploitation of mineral resources can be related to increasing demand for raw materials by ancient human groups (Binder et al. 2013). The exploitation of minerals produces a series of collateral activities, such as exchanges, contacts between populations, and the development of specific technical skills necessary for the exploitation of the mineral resources. Techno-economy models (Binder et al. 2013; Stöllner 2003) can help illuminate behaviours related to prehistoric social activities, including mining dynamics. Through their technical choices, individuals express their intention. For this reason, the succession of actions is simultaneously the result of technical, social, and cultural choices (Lemonnier 1992, 2010; Pfaffenberger 1998).

In recent years, few methodological studies dedicated to understanding the dynamics of mineral exploitation during prehistory are known. Technological and functional analysis conducted on macro-lithic tools such as ground stone tools, percussion tools (e.g., hammers, picks, and hammer-axes), anvils, crushing tools, and abraders found near and/or in mines has contributed to the identification and understanding of mining activities (Breglia et al. 2016; Caricola and Lemorini 2017; Delgado-Raack et al. 2014; Hamon 2016; Hamon...
The archaeological context

Grotta della Monaca is a karstic cave located in Sant’Agata di Esaro in north-western Calabria at 650 m asl, near the Esaro River (Fig.1). The cave develops for 360 m and revealed a wide chronological range of human occupation, dating from the Upper Palaeolithic (Quarta et al. 2013) to post-medieval periods (16th–18th centuries AD) (Larocca 2012; Levato and Larocca 2015).

This continuity is due, in part, to the presence of massive minerals outcrops. The preponderant iron ores present include goethite [$\alpha$FeO (OH)], which can be associated with lepidocrocite [$\gamma$FeO(OH)], a polymorph of goethite; haematite [$\alpha$Fe2O3]; and yukonite [Ca2Fe3(AsO4)4(OH)·5H2O], a hydrated arsenate of iron and calcium (Garavelli et al. 2009; Levato and Larocca 2015). Additionally, copper carbonates, malachite [Cu2(SO4)(OH)6], libethenite [Cu2(PO4)(OH)], and samplete [NaCaCu5(PO4)4Cl·5H2O] (Dimuccio et al. 2005; Dimuccio et al. 2017; Levato and Larocca 2015).

Grotta della Monaca is conventionally divided into three areas: (1) the entrance gallery, which is called Pregrotta; (2) a second large and dark room, called Sala dei Pipistrelli; and (3) two narrow tunnels called Cunicoli Terminali (Larocca 2005). The minerals are localised differently. Iron ores are found throughout the cave, while copper ores are concentrated at the end of the cave in the Cunicoli Terminali area.

The archaeological excavations conducted from 2002 until 2010 allowed us to identify the extraction areas. In particular, a sub-horizontal passage called “Buca delle impronte” that is located in the inner part of the Sala dei Pipistrelli yielded relevant archaeological evidence of mineral exploitation. This passage is 11 m long and...
between 60 cm to 4 m wide (Levato and Larocca 2015). Inside this conduit, well-preserved traces of digging have been found. These imprints on soft goethite veins have been interpreted as traces of deer antlers, animal scapulae, and other unidentifiable tools probably in animal matter. Not flakes of stone tools were found (Levato and Larocca 2015). Radiocarbon dates obtained from charcoal samples of remains of wooden torches of Pinus sylvestris allow the assignment of this exploitation phase to the final Neolithic, between 3800 and 3640 BC and 3780–3630 BC (Larocca...
The excavations carried out in the Cunicoli Terminali highlighted the presence of several other mining areas (Cengia, Ramo delle Vaschette, and right- and left-Cunicoli Terminali), closely related to the outcrops of copper carbonates. Here, several remains of extractive lithic tools have been found intact and associated with flakes as well. The radiocarbon dating assigns these mining activities to a period between the late Neolithic and early Copper Age (Larocca 2012; Levato and Larocca 2015, Quarta et al. 2013) and identify the cave as the oldest known copper mine in Italy. The transition from the Neolithic to the Chalcolithic age is characterised by the Spatarella facies, followed by the introduction of the Piano Conte pottery, widespread in the Aeolian Archipelago and in various peninsular contexts, including the Tyrrenian coast of Calabria Region (Cazzella et al. 2011; Salerno and Vanzetti 2004). To date, however, the scarcity of extensive excavations in the Calabria Region makes it difficult to delineate an organic picture, especially for the Copper Age (Genik 2008). In southern Italy, the cultural relationships and chronological links between the different facies of the Copper Age are still only approximately perceived (Pacciarelli and Talamo 2011).

Grotta della Monaca lies along a low-altitude pass (Passo dello Scalone) that could have favoured and promoted contacts between coastal and inner areas. Such contacts and

| Context | ID sample | Radiocarbon Dating | Reference |
|---------|-----------|--------------------|-----------|
| US1-Ramo delle Vaschette | LTL3583A | 5183 ± 50 BP | Larocca 2012; Quarta et al. 2013 |
| Charcoal | 4230–4200 cal. 2σ BC (2.3%); 4170–4090 cal. 2σ BC (4.9%); 4080–3920 cal. 2σ BC (79.4%); 3880–3800 cal. 2σ BC (8.9%) |
| Pinus sylvestris | 4230–4200 cal. 2σ BC (2.3%); 4170–4090 cal. 2σ BC (4.9%); 4080–3920 cal. 2σ BC (79.4%); 3880–3800 cal. 2σ BC (8.9%) |
| US1-Ramo delle Vaschette, carbone | LTL3584A | 5010 ± 50 BP | Larocca 2012; Quarta et al. 2013 |
| Charcoal | 3950–3690 cal. 2σ BC (95.4%) |
| Pinus sylvestris | 3950–3690 cal. 2σ BC (95.4%) |
| Cengia | LTL5092A | 5216 ± 45 BP | Quarta et al. 2013 |
| Charcoal | 4170–3950 BC (89.6%) |
| Pinus sylvestris | 4170–3950 BC (89.6%) |
| Cengia | LTL5093A | 5194 ± 45 BP | Quarta et al. 2013 |
| Charcoal | 4080–3940 BC (85.2%) |
| Pinus sylvestris | 4080–3940 BC (85.2%) |
| Cunicolo Terminale di Sinistra Superiore | LTL5395A | 5247 ± 45 BP | Quarta et al. 2013 |
| Charcoal | 4180–3960 BC cal. 2σ (95.4%) |
| Pinus sylvestris | 4180–3960 BC cal. 2σ (95.4%) |
| Cunicolo Terminale di Sinistra Superiore | L3579A | 4684 ± 50 BP | Quarta et al. 2013; Levato and Larocca 2015 |
| Goat Horn | 3640–3560 BC cal. 2σ BC (17.1%); 3540–3660 cal. 2σ BC (78.3%) |
| Buca delle Impronte | LTL-3581A | 4880 ± 45 BP | Levato and Larocca 2015; Larocca 2010; Quarta et al. 2013 |
| Charcoal | 3780–3630 BC (89.8%); 3580–3530 BC (5.6%) |
| Pinus sylvestris | 3780–3630 BC (89.8%); 3580–3530 BC (5.6%) |
| Buca delle Impronte | LTL-3582A | 4935 ± 45 BP | Levato and Larocca 2015; Larocca 2012; Quarta et al. 2013 |
| Charcoal | 3800–3640 BC (95.4%) |
| Pinus sylvestris | 3800–3640 BC (95.4%) |
exchange activities are attested by exogenous elements such as obsidian imports from the Aeolian Archipelago during Neolithic and Copper Age (Acquafredda et al. 2016; Acquafredda et al. 2020).

Currently, studies of the pottery from the cave are in progress. These data will provide additional information on the cultural aspects of the groups of miners of Grotta della Monaca. Unfortunately, the interpretation of these aspects is hindered due to medieval mining activities, including excavations in the Pregrotta. The latter represents the area where the prehistoric miners probably stayed and large quantities of ceramics, ground stone tools and abraders have been found as well (Breglia et al. 2016). The ground stone tools show use-wear connected with the treatment of the goethite, while the abraders present traces related to a contact with stone and leather. They are objects connected with the miners and characterise the Pregrotta as a mineral processing area (Breglia et al. 2016; Caricola and Lemorini 2017).

Materials and methods

The archaeological samples

In this paper, we present the results of the use-wear analyses conducted on 25 well-preserved grooved stone tools found in Grotta della Monaca. At the Pregrotta area, grinding tools, grinders/crushers, and abraders have been found (Breglia et al. 2016; Caricola and Lemorini 2017).
et al. 2016) along with one extractive tool, completely covered by goethite concretions; in the terminal area of the cave, Sala dei Pipistrelli and Cunicoli Terminali, hammers (characterised by two flat ends) (Fig. 2), hammer-axes (consisting of a trenchant opposite to a flat end), and picks (with a pointed end) (Fig. 3), usually characterised by a median grooved and/or notches that were useful for handles, have been found. In addition, numerous flakes and fragments of grooved stone tools have been found in this area (see supplementary materials Fig. 1). The entire collection is composed of 71 mining tools, including intact or semi-intact tools with determinable morphology \((n = 22)\), fragments of different sizes \((n = 20)\), and flakes \((n = 29)\) (Breglia et al. 2016). Only 25 tools \((n = 20\) intact and \(n = 5\) fragments with well-preserved functional surfaces) have been selected for this study’s use-wear analysis. All the selected artefacts come from the inner

![Fig. 3 Archaeological samples of grooved stone tools found in Grotta della Monaca mine. Hammer-axes and picks](image-url)
Moreover, these tools were not affected by patinas or concretions on the surface. Petrographic analyses have identified artefacts made of intrusive igneous rocks and a single tool from sedimentary rock (limestone). The other grooved stone tools are made from metamorphic rocks coming from the Sila area of Calabria (Acquafredda and Piccarreta 2005; Breglia et al. 2016) (Table 2). Therefore, these are local rocks collected from aluvial deposits of the main river courses in the area: the Crati and Esaro. These latter cut the various rock formations exposed in the Sila area and transported the debris downstream (Acquafredda and Piccarreta 2005).

The extractive tools were primarily produced using the direct percussion technique, attested by pits to shape the blank and producing grooves and notches. Cobbles were often selected and subsequently modified or, rarely, blocks of angular rocks. All observed tools present pits. In several cases, this technique is associated with an abrasion that is localised into the groove near the functional areas (e.g., trenchant) or covering the entire surface of the object. The average weight per type are hammer-axes around 2.381 g, hammers 1.227 g, and picks 1.738 g (Table 2).

### Methodology

#### The use-wear analysis

The archaeological samples were studied by combining low and high magnification approaches. At low magnification, the specimens were observed utilising a stereo-microscope Nikon SMZ, with progressive magnifications ranging between $\times 10$ and $\times 75x$ and Toupview USB camera. At high magnification, a reflected-light microscope, Nikon Eclipse with a range of magnification from $\times 50$ to $\times 200$, was used. The experimental samples were

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1. At the Laboratory of Technological and Functional Analysis of Prehistoric and Protohistoric Artefacts (LTFAPA) of the Sapienza University of Rome.
observed following the same methodology. The parameters describing the traces were based on the literature about macro- (Hamon 2006; Jackson and Hitchiner 2013) and micro-traces (Adams et al. 2009; Caricola et al. 2018; Dubreuil et al. 2015; Van Gijn 2010; Lemorini 2000).

The experimental and archaeological samples were first washed with demineralised water and neutral soap (Derquim®). In the case of the experimental samples, several washes to remove the mineral residues were required. All objects were analysed through direct observation; in exceptional cases, silicon molds (Provil Novo Light Fast Heraeus®) were used to observe the micro-traces under the metallographic microscope.

**Experimental framework**

A dedicated experimental reference collection was built in order to interpret the use of the Grotta della Monaca grooved stone tools. The experimental protocol involved the following steps:

- **Raw material collection.** It was necessary to move from Grotta della Monaca area (Sant’Agata di Esaro, Calabria, Italy) to Malvito (Calabria, Italy; 6.5 km away) to identify riverbed deposits of large blocks (70 × 50 cm) of metamorphic rocks, similar to archaeological finds, near the Esaro River. Moving towards Roggiano Gravina (Calabria, Italy; 15 km), widespread deposits of small pebbles and cobbles were collected on the basis of their shape, excluding those on which micro-fractures and cracks, due to weathering, were evident (Fig. 4).

- **Tool production.** The pebbles were modified in order to produce 19 (for detail see Table 3) replicas, including hammers, hammer-axes, and picks. During this stage, we used hard hammerstones (i.e., in metamorphic rock).

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**Fig. 4** Experimental phases. 

- **a, b** Collection of raw materials in the Calabria region (Italy). 
- **c, d** Production of grooved stone tools 
- **e, f** Production of the ropes in plant fibres 
- **g** Production of the ropes in animal skin

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rock) to produce grooves or notches by hammering. Soft stones were found to be unsuitable for this type of percussive activity. The abrasion technique was tested as an alternative or in association with the former activities. Consequently, the object’s surface became very smooth and polished. The abrasion technique was also used to refine the blank during the final stage (Fig. 4).

- **Handle manufacture.** Near the cave, different types of wood were selected, including oak (*Quercus ilex*) and three types of local willow wood (*Salix viminalis*; *Salix caprea*; *Salix purpurea*), based on their flexibility and hardness properties. Different types of handles were produced. The first comprises a length of wood with a V-shaped termination, intended for the insertion of the tool; the second type was created by rolling the flexible wood around the groove. Additionally, ropes were produced using hide and vegetable 3-braided fibres. The ropes were used to affix objects to the handles (Fig. 5).

- **Experimentation.** Specific sectors 4 within the Grotta della Monaca were chosen in order to conduct the experimental tests. Two replicas were used to perform the exploitation of a deposit of soft/hydrated goethite located in the terminal area of the Sala dei Pipistrelli; two replicas were used for the exploitation of a vein of compact goethite within the Bivacco area; four replicas were used to excavate a calcite deposit and concretions layers in the Sala dei Pipistrelli; nine replicas were employed for extraction of copper carbonates on the walls of the Bivacco area; and two replicas were used for mixed activities on all minerals (hard and soft goethite; copper carbonate and calcite) (Fig. 6).

| N. | Type of Tool | Mineral extraction | L. (mm) | Wi. (mm) | T. (mm) | Weight (g) | Duration of use | Preservation |
|----|--------------|---------------------|--------|---------|--------|------------|----------------|-------------|
| 1  | Hammer       | Copper Carbonates   | 104    | 80      | 40     | 889/610    | 1 h 30 m      | Fracture, 2 longitudinal fragments+micro-flakes |
| 2  | Hammer       | Copper Carbonates   | 90     | 70      | 40     | 580/530    | 1 h 45 m      | Intact, reduced |
| 3  | Hammer       | Soft/hydrated goethite | 110  | 89      | 45     | 720/450    | 3 h 30 m      | Intact |
| 4  | Hammer       | Hard/compact goethite | 111  | 87      | 50     | 850/500    | 1 h 30 m      | Intact |
| 5  | Hammer       | Copper Carbonates   | 150    | 98      | 60     | 1654/1500  | 1 h 30 m      | 3 fragments+micro-flakes |
| 6  | Hammer       | Copper Carbonates   | 165    | 100     | 73     | 1850/1600  | 1 h 15 m      | Fracture, 2 longitudinal fragments+micro-flakes |
| 7  | Pick         | Calcite             | 170    | 99      | 78     | 1700/1400  | 1 h 30 m      | Intact |
| 8  | Pick         | Mixed deposit       | 110    | 85      | 47     | 890/790    | 3 h           | Intact |
| 9  | Hammer-axe   | Copper Carbonates   | 120    | 84      | 46     | 1140/1100  | 2 h           | 1 oblique fragment |
| 10 | Hammer-axe   | Copper Carbonates   | 98     | 80      | 39     | 1130/715   | 3 h           | 1 oblique fragment+micro-flakes |
| 11 | Hammer-axe   | Copper Carbonates   | 112    | 79      | 47     | 836/875    | 3 h           | Intact, reduced |
| 12 | Pick         | Calcite             | 99     | 82      | 47     | 780/780    | 3 h           | Intact |
| 13 | Pick         | Copper Carbonates   | 100    | 80      | 45     | 1120/1000  | 3 h           | Intact, reduced |
| 14 | Hammer-axe   | Calcite             | 80     | 69      | 40     | 500/500    | 1 h 30 m      | Intact |
| 15 | Hammer-pick  | Copper Carbonates   | 89     | 78      | 48     | 702/650    | 2 h           | Intact, reduced |
| 16 | Hammer       | Soft/hydrated goethite | 87   | 77      | 47     | 680/680    | 1 h 30 m      | Intact |
| 17 | Hammer       | Mixed deposit       | 90     | 79      | 48     | 790/790    | 2 h           | Intact |
| 18 | Pick         | Calcite             | 80     | 70      | 45     | 560/560    | 2 h           | Intact |
| 19 | Hammer       | Hard/compact Goethite | 100  | 90      | 47     | 800/800    | 1 h 15 m      | Intact |

After the experiments, we have made the following observations:

1. The extraction of goethite (soft/hydrated and hard/compact) and calcite did not cause breakage or fractures on the experimental tools, which did not change their morphology.
2. During the extraction of the copper carbonates, the objects fractured, and several flakes were detached; thus, the functional areas were significantly reduced. We observed different patterns: longitudinal split fractures, oblique damage, and micro-flakes removals (Figs. 7, 8).
3. The extraction of copper minerals required a specific chaîne opératoires. The heavier tools (such as hammers and picks, average weight = 1300 g) were used to break up the large deposits of calcite concretion and unearth copper ore by removing the goethite layer. The smaller tools (hammer-axe or hammers on average 600 g) were used directly on copper ore. Hammer-axes were particularly functional. Their cutting edge allowed them to penetrate the strata, facilitating the detachment of intact blocks without damaging the copper ore. Three hours of work were needed to extract approximately 1 kg of carbonates.

4. Each of the grooved stone tools manufactured was capable of extracting the hard (5 degrees on the Mohs scale) and soft goethite. One hour of work was required to obtain 6 kg of minerals.

5. V-shaped handles were not adequate for sustained tool use. During the experimentation, the tools required continuous adjustments. The most functional handles were those made out of willow wood, closely fitted around the groove.

6. The depth of the grooves or notches was a further factor determining the resistance of the handle.

Results

Technological traces: a comparison between archaeological and experimental samples

Technological traces were found preserved on the archaeological grooved stone tools from Grotta della Monaca. The initial
blanks were constituted by natural cobbles, selected based on
their shape. Macro-pits resulting from blank modification and
from producing the grooves or notches are found extended to
the whole body, or just to some areas of the objects, depending
by the location of the convexities to be refined. Thus, no
standard relationship between morphology of the blanks and
related technological modifications are attested. Additionally,
micro-traces connected to the adoption of abrasion technique
were also found (both located in the grooves/notches and
along the body of the object). Similar traces have been docu-
mented on the experimental samples, in particular those pro-
duced by using a sandstone slab (Fig. 9a, b). As result, the
polishes are localised on the top of the levelled areas,
characterised by oriented polishes and long striations with
smooth texture and flat topography (Fig. 9c–f).

Use-wear analysis of experimental samples
Macro-traces
The macro-traces observed on the replicas consist generally in
macro-pits (observed at × 10 of magnification) and macro-
cracks on the grains’ surface (observed at × 50–80 of magni-
fication). The morphology of macro-cracks differs according
to the extracted mineral.

![Fig. 6 Experimental extraction of several minerals at Grotta della Monaca. a, b Copper ore extraction. c Calcite excavation. d Vein of compact goethite. e Compact goethite extraction. f Soft/hydrated goethite extraction](image)
In the case of goethite, micro-fractures exhibit conchoidal morphology and the grains surface, observed at × 80 of magnification, is characterised by a rough/glazing appearance (Fig. 10a, b, Table 4).

The functional area of the replica used in calcite extraction shows grains with tetrahedron and pointed morphology. The grains have a sheen (Fig. 10c, d, Table 4), probably due to contact with wet calcite. Often, calcite retains dripping water.

The extraction of copper carbonates produces deep macro-fractures, with quadrangular detachments, giving the grain a characteristic “step” appearance (Fig. 10e, f, Table 4).

**Micro-traces**

The micro-traces observed on the experimental replicas are characteristic for each of the extracted minerals. The features used to describe the polishes are (a) the distribution which indicates the areas affected by the development of the micro-wear (magnification at × 50); (b) the extension of the polishes on the top and/or bottom of the grains (magnification at × 100); (c) the linkage represent the structures, intended as the degree of connection of the micro-wear (magnification at × 200); and (d) the texture and topography which describe the surfaces of the polishes (magnification at × 200). Striations have also been described (i.e., they can be long, short, superficial and/or deep, chaotic, oriented, concentrated, sporadic, or polished (Table 5).

The polishes relating to the extraction of goethite are characterised by rough texture and granular topography, highly developed on the top and the bottom of the grains (Fig. 11c–e, Table 6). The calcite use-wear is characterised by rough to smooth texture and domed topography. The sheen is high (Fig. 11g, h, Table 6). The polishes related to the extraction of copper carbonate (azurite and malachite) are associated...
with long and oriented striations; the traces extended on the top of the grains with smooth texture and flat topography (Fig. 11a, b, Table 6). Finally, the polish distribution changes according to the mineral, its hardness, and hydration.

The replicas used to extract mixed minerals featured wear traces characterised by chaotic polishes, with rough and flat/granular spots (Fig. 11f, Table 6).

Use-wear analysis of archaeological samples

The archaeological samples, twenty-five grooved stone tools, showed well-preserved use-wear traces (see supplementary materials Tab. 1). The lithic surfaces were partially affected by orange patinas due to contact with residue of goethite, a mineral found everywhere inside the cave, covering both the walls and the floor level of the mine. White patinas are instead related to the deposit of calcium carbonates. The traces observed on the functional areas of the samples allowed us to identify specific uses for the extractive tools found at Grotta della Monaca site.

The following aspects were identified:

1. Fifteen samples present macro-pits and at × 85 of magnification are visible grains with “step” morphology. At high magnification, long and oriented striations are observed on levelled areas and associated with polishes characterised by smooth texture and flat topography; the micro-traces extend to the top of the grains. The functional areas of these objects are often reduced by use. These traces can be interpreted as the result of the tools’ contact with a copper mineral (Figs. 12, 13) and are present on 6 hammers (average weight of 874 g), 6 hammer-axes (average weight of 1000 g), 1 hammer-pick (weight 1641 g), and 3 fragments/undefined tools;

2. Five tools present rougher smooth polishes with domed topography and have a high sheen. The macro-topography appears sinuous. This trace finds a correlation with the calcite contact (Fig. 14) and is present on 3 picks (with an average weight of 2026 g), 1 hammer (3112 g), and 1 hammer-axe (1044 g);

3. On 4 tools, there are traces characterised by chaotic polishes, with rough and flat/granular spots associated. These use-wear signatures have been interpreted as the result of contact with different minerals (copper ore/calcite or...
calcite/goethite) (Figs. 15, 16). Samples showing this type of traces are 1 pick (973 g), 1 hammer-axe (1584 g), and 3 hammers (with an average weight of 1348 g).

**Discussion**

Through a combined low- and high-power approach, it was possible to define and interpret the precise function of the grooved stone tools found at the Grotta della Monaca mine. This method allowed us to identify specific surface grain morphologies related to the exploitation of different outcrops and type of minerals on the analysed tools. Additionally, the micro-polishes were found to be a discriminant feature to identify the extracted minerals.

The data obtained allowed us to reconstruct the *chaîne opératoires* of minerals exploitation at Grotta della Monaca, consisting (a) the adoption of heavy tools for the excavation of calcite planes, which sometimes are still very thick (5–10 cm) and which can cover the floors with mineralisations. The objects used for this kind of excavation were picks and hammer-axes of weights between 2 and 3 kg. This extraction technique is partly confirmed by Larocca (2008), who identified many calcite fragments, stalagmites, or stalactites on the ground near the mining sectors, supporting this type of extraction technique; (b) tools employed in the excavation of mixed deposits, probably covering the copper ore outcrops, showing traces of
mixed minerals (copper/calcite or calcite/goethite). No single trace indicating the exclusive excavation of goethite are attested in the analysed samples. The objects used in these activities are very variable, both in type (hammer-axes or hammers) and size; (c) finally, a higher number of grooved stone tools exhibiting wear traces due to the contact with copper ores and featuring a clear reduction of the functional areas. Use-wear resulting from copper minerals extraction is also present on a fragmentary object and its associated flakes from the Ramo delle Vaschette sector. This is the case of L15, which was discovered in association with flakes and charcoal samples dated to the late/final Neolithic. The objects used in the copper extraction were small hammers and hammer-axes, with an average weight between 800 and 1000 g. As observed during the experimental tests, the axes-hammers are very useful objects in the excavation of copper deposits. Indeed, their trenchant is functional to penetrate the cracks in the rock and weaken the stratified levels in which the copper minerals emerge. These observations are confirmed by some objects analysed with preserved macro-residues of copper minerals on the grains within the functional areas. Also residues of goethite are present on entire collection and are often placed without a particular direction, generally around the tool’s perimeter. This is likely due to the ubiquitous and massive presence of goethite, that are localised on the ground and on the walls of the cave. It is thus possible to assume that the goethite residues are due to the objects’ contact with the ground, as documented in the experimental phase.

It is interesting to observe the different choices adopted by the prehistoric communities, related to the technology for the exploitation of goethite deposits and copper ores. In particular, the discovery of the mining sector Buca delle Impronte shows us that during the final Neolithic (c. 3780–3630 BC/3800–3640 BC), the goethite was extracted to a great extent with techniques that included the use of tools made from hard animal matter—proved by the presence of excavation imprints on hydrated goethite—according to a well-organised workspace and waste materials management (Levato and Larocca 2015). Instead, grooved stone tools were produced and used to exploit copper deposits during the late/final Neolithic (Cengia: 4170–3950 BC/4080–3940 BC; Ramo delle Vaschette: 4080–3920 BC/3950–3690 BC). A single sample the goat horn has been dated to the early Chalcolithic (3540–3660 BC). It is clear, therefore, that

| Mineral                | Macro-traces                              |
|------------------------|-------------------------------------------|
| Goethite               | Micro-fracture with conchoidal morphology; grains with rough/glazing appearance |
| Calcite                | Micro-fractures with tetrahedron and pointed morphology of the grains; sheen appearance |
| Copper carbonate       | Deep macro-fracture with “step” appearance |

Table 4 Macro use-wear observed on the experimental replicas. Graphic representation of grains morphology and modifications for each mineral extracted.
prehistoric miners approached two different outcrops—iron and copper ores—within the same mine using different excavation techniques and tools. This factor may depend on various aspects, such as functional choices, chronological differences or social aspects. However, the currently available data do not allow us to formulate a precise hypothesis, as there

**Fig. 10** Experimental macro-traces. a, b Use-wear of goethite, micro-fractures with conchoidal morphology and grains with rough/glazing appearance. c, d Use-wear of calcite, micro-fractures with tetrahedron and pointed morphology of the grains. e, f Use-wear of copper ore, grains with “step” appearance

**Table 5** Parameters adopted in the description of the micro-traces

| Features of polishes | References                           |
|----------------------|-------------------------------------|
| Distribution         | Covered-separated | Covered-closed | Covered-connected | – | – | Adams et al. 2009 |
|                      | Loose-separated     | Loose-closed   | Loos-connected    | – | – | Adams et al. 2009 |
|                      | Concentrated-        | Concentrated-closed | Concentrated-connected | – | – | Adams et al. 2009 |
| Extension            | Top                  | Bottom         | Top and bottom    | – | – | Caricola 2017     |
| Linkage              | Open                 | Tight          | Half tight        | Reticulated | – | Lemorini 2000     |
| Texture              | Rough                | Smooth         | Rough to smooth   | Grooved     | – | Dubreuil et al. 2015; Van Gijn 2010 |
| Topography           | Flat                 | Domed          | Granular          | Pitted      | Cratered | Van Gijn 2010     |
are still many gaps regarding both the destination of the minerals and the identity of the miners in the region.

Currently, no traces of an initial treatment of copper ores have been found inside the mine. In fact, the ground stones and grinders/crushers discovered at the entrance to the mine, and probably connected with prehistoric exploitations, present traces of the treatment of goethite, as confirmed by the use-wear analysis conducted on these items (Caricola and Lemorini 2016; Breglia et al. 2016). The wide and well exposed Pregrotta area is thus interpreted as an *atelier*, a specific place for the first treatment of goethite, transported outside the cave in the form of powder (Caricola and Lemorini 2016). During the Middle Ages, the Pregrotta area was largely excavated by medieval miners and the result is a deposit of mixed materials, dating from the Neolithic to Middle Ages (Breglia et al. 2016). We hypothesise that grinding stone tools were connected to prehistoric miners since the few items found (n = 11 ground stones; 17 = grinders/crushers) would be not able to satisfy the processing of huge quantities of goethite extracted during the Middle Ages. Moreover, during medieval and post-medieval times, the iron ore treatment—crushing, washing, and enrichment—was more complex. It is known from literature that these activities were carried out downstream using a water wheel (Šebesta 2000).

Iron ores are known to have different properties. For example, they can be used in the artistic and decorative fields (Levato 2013), thanks to their colouring quality (Salomon 2009). Among traditional societies, iron ore has several practical uses. It was likely used in body painting, hide processing, organic matter preservation, and medical remedy (Levato 2013: 20), perhaps as an ingredient in compound adhesives (Wadley 2005, 2010; Wolf et al. 2018). Among the Australian Aborigines, red ochre has a role in religious contexts, where it is used as a pigment and magical substance (Sagona 1994).

Copper ore extracted from Grotta della Monaca might have had another destination, currently unidentified. Even the use of this mineral is uncertain. We can, however, hypothesise different purposes, for example as a dye or employed in the production of metal tools. This latter is difficult to prove, due to the age of the context and the lack of compositional analyses of the isotopes of copper ores from Grotta della Monaca, that could allow us to investigate the provenance of metal tools found in Calabria.

The first evidence of smelting activities is attested in Italy during the late/ final Neolithic (c. 4500–3800 BC and c. 3800–3600 BC) (Dolfini 2014; Dolfini et al. 2020). In particular, the oldest objects and smelting evidence are mostly present in northern Italy and are dated to the third quarter of the 5th millennium BC (Dolfini 2014; Mazzieri and Santo 2007; Visentini 2006). In Southern Italy, there is a little evidence related to Pizzica Pantanello, dated c. 3800-3550 BC (Giardino and D’Annibale 2014). As is the case at Grotta della Monaca, no traces of smelting inside or near the cave have been found. However, it is likely that after its extraction, the copper ore was not treated (i.e., ground) on-site but transported elsewhere.

Grotta della Monaca thus represents an exceptional mining context for several reasons. Firstly, the early date of the frequent uses is noteworthy. Secondly, it is not an open-air or subterranean artificial mine, featuring artificial wells and vertical tranches. The site is a karstic cave, used for millennia not only for extractive purposes but also for sepulchral and probably ritual ones (Larocca 2005). A very similar karstic cave is Grotta del Tesauro, located in the proximity of our site in the Upper Esaro Basin. Here, few grooved stone tools were found, most likely also related to the extraction of copper minerals during the prehistory (Garavelli et al. 2012; Caricola 2017). The data from Grotta del Tesauro and Grotta della Monaca highlight the systematic character of this search for copper ores through time implying an intense mining.
activity in the Calabrian Region, probably connected to emerging economic and social developments.

For the reasons listed above, there are substantial differences between the mines of Calabria, in particular Grotta della Monaca, and the other Italian and European/western Mediterranean mines. However, the grooved stone tools from the site certainly share a morphological correspondence with the tools found in the copper mines of...
northern Italy, such as Libiola (3490–3120 BC) and Monte Loreto (3500–2500 BC) in Sestri Levante, Liguria (Maggi and Pearce 2005). Sub-spheroidal cobbles of basalt, dolerite, gabbro, sandstone, and diorite collected near the mine and modified for hafting with notching or single/double grooving (O’Brien 2014) have been found in this district. The predominant minerals are malachite, the main target in the Libiola mine, and chalcopyrite, probably extracted also thanks to the use of the fire setting (O’Brien 2014). This extraction technique seems not to have been used in Grotta della Monaca but is attested at other copper mines (as well as other materials; see Poggiali et al. 2017 for the cinnabar mine of Spaccasasso). The fire setting technique is documented in the Cabrières (Hérault) district in France, with dates that set the first mining between the late Neolithic/early Chalcolithic (i.e., Pioch Farrus 448, 3100–2800 BC; Espérou et al. 1994). Quarzite mining tools (Ambert 2002) are very common in the Cabrières district, but differ greatly from those of Grotta della Monaca in terms of morphology and type of raw material. In addition, La Capitelle du Broum is used for the melting and production of metal objects (Ambert et al. 2005). However, to date no smelting area has been found near Grotta della Monaca.

Alternative uses of copper ores, as well as the exploitation of malachite and azurite are attested in Serbia during the Middle Neolithic for bead production (Boric 2009). Nevertheless, only during the Late Neolithic is the exploitation of mines for metallurgical purposes recorded (e.g.,
Rudna Glava, from 5400–5300 BC to 4700–4600 BC) (Jovanovic 1979).

Grooved stone tools are widespread not only in relation to copper mines, but there are examples of their use also in the exploitation of other minerals. A relevant case is represented by the Neolithic haematite mine in Bad Sulzburg (South West Germany), which was exploited around 5000 BC, and stone tools with notches and grooves were found in raw materials such as quartzites, granites, diorites, amphibolites, and various sedimentary rocks (Goldenberg et al. 2003).

The absence of a certain destination for the copper ore extracted at Grotta della Monaca does not allow us to formulate, at the present stage, hypotheses regarding the role of this mine during the late Neolithic/early Chalcolithic in Calabria, although it is clear that the miners went in search of copper outcrops, probably due to a specific demand of copper ores. The use-wear analysis of the macro-tools, to extract malachite and azurite, indicate that the miners had a good degree of specialisation since the early periods. This exploitation must have been motivated by a growing demand for resources on the part of prehistoric communities. This fits well with the European archaeological evidence referable to the Neolithic-Chalcolithic transition, when an intensification of mining activities and the circulation of products is testified (Müller 2013; Vandkilde 1996).

To date, Grotta della Monaca is the only known prehistoric mine in Calabria, but there is a high probability that new investigations in the region will reveal new ancient extractive sources or settlements associated with
them. Currently, research on the Calabrian Region have made it possible to identify copper minerals outcrops in the north-western, central-eastern, and south-eastern parts of the region. It is unclear whether these outcrops were exploited during prehistoric times or not (Larocca and Breglia 2016). In the nearby of these latter, high concentrations of grooved stone tools have been found (Larocca and Breglia 2016). The functional study of these tools will contribute to the comprehension of these aspects.

It cannot be excluded that this region could have played a role also in the distribution and circulation of minerals and other raw materials. The discovery of exotic objects such as Lipari’s obsidian at Grotta della Monaca, starting from the
Neolithic, allows us to speculate that the area has been place of exchanges and contacts over the millennia. In addition, Grotta della Monaca is located along a strategic route in the Scalone Pass, which facilitates the transition from the inner mountainous territory to the coast.

**Conclusions**

During the late Neolithic and early Chalcolithic, Grotta della Monaca was the subject of minerals mining. The analysis of grooved artefacts confirms that they were related to the exploitation of copper ores. The miners used specialised technology and mining organisation, which demonstrates a high degree of knowledge of mineral stratifications and extractive methods. The discovery of Grotta del Tesauro, a small mine near Grotta della Monaca, where grooved stone tools with similar functional traces were found, indicates that groups of miners moved throughout the territory in search of copper ores. In this period, there was likely a specific need that motivated the mining activity. We have no evidence regarding eventual mineral processing workshops near the mine. We hope that future research in the area will shed light on the use of copper minerals extracted from Grotta della Monaca, as well as new radiocarbon dates could highlight more extraction phases, that those known to date at the site, in the sector certainly exploited for the extraction of copper minerals.
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Data availability No permits were required for the described study as the co-corresponding author, Dr. Felice Larocca, is Director of the excavation at the site of Grotta della Monaca and responsible for the scientific activity carried out on the archaeological findings recovered from the site. Dr. Larocca received permits for all aspects of this work from the archaeological authority.

Compliance with ethical standards

Conflicts of interest The authors declare that they have no conflict of interest.

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Fig. 16 Archaeological sample, n. L22 interpreted like a multiple contact with goethite and calcite. a Rough micro-polishes. b Rough tending smooth/domed polishes.
