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The Prehistoric Iron Mine of Grotta della Monaca (Calabria, Italy)

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Résumé

La Grotta della Monaca est une cavité karstique située sur la commune de Sant'Agata di Esaro (CS), agglomération de la Calabre nord-occidental, en Italie méridionale. La grotte s'ouvre à l'intérieur d'un pic rocheux à 600 mètres d'altitude a.s.l., le long de la rive gauche de la rivière Esaro. Les prospections, menées vers la fin des années 90 par le Centre Régional de Spéléologie "Enzo dei Medici" avec la collaboration de l'Université de Bari "Aldo Moro", montrèrent que cette grotte est une mine préhistorique ancienne inconnue jusqu'ici. Ces prospections ont ouvert la voie à une période de recherches spéléo-archéologiques qui se sont poursuivies dans les années 2000. La grotte est très riche en minéraux métalliques, en particulier des minéraux de cuivre et de fer. Les minéraux de cuivre sont représentés surtout par la malachite [$Cu_2(CO_3)(OH)_2$] et dans une moindre mesure l'azurite [$Cu_3(CO_3)_2(OH)_2$]. Les minéraux de fer les plus répandus sont les hydroxydes, en particulier la goethite [αFeO(OH)], isolée ou associée à son polymorphe, la lépidocrocite [γFeO(OH)], et se présentent sous la forme de filons entre les couches de roche carbonatée. Les fouilles archéologiques ont révélé la présence, dans les secteurs plus profonds de la grotte, d'activités préhistoriques qui étaient destinées à l'exploitation de ces minéraux ferrugineux.

Les fouilles ont permis de distinguer deux cycles miniers principaux, l'un qui se rapporte au Néolithique final (fin du V^{e} - première moitié du IV^{e} millénaire calBC) et relié à l'extraction des hydroxydes de fer, l'autre qui s'inscrit dans le Énéolithique initial (première moitié du IV^{e} millénaire calBC) et destiné à l'approvisionnement en carbonates de cuivre. Les traces d'exploitation des minéraux de fer ont été reconnues à l'intérieur de deux secteurs nommés la "Buca delle impronte" et le "Ramo delle vaschette". La présence d'une variété extrêmement tendre de goethite a permis la conservation de nombreuses traces, qui attestent l'utilisation avérée d'outils en os et de pics en andouiller. L'étude de ce contexte minier ancien offre des informations importantes sur les techniques d'extraction des minéraux de fer vers la fin du Néolithique. L'accès à ces ressources se faisait en évoluant dans une cavité karstique, en utilisant des torches en Pinus sylvestris *pour illuminer les coins plongés dans l'obscurité totale. Le filon était exploité directement ou bien les niveaux concrétionnés étaient atteints par des terrasses. Enfin, des piliers de soutien ont été observés pour empêcher l'écroulement de la voûte. Une analyse techno-fonctionnelle récente a été conduite sur les meules et sur les molettes, probablement de la fin du Néolithique et qui proviennent de la zone à proximité de l'entrée. Celle-ci montre diverses activités comme la mouture et le bris des blocs de goethite. Le lieu où ces minéraux étaient transportés, n'est pas identifié, ni les modalités d'utilisation du produit fini. Cette Grotta della Monaca est l'une des cinq mines préhistoriques exploitant des oxydes de fer en Europe et la seule aujourd'hui étudiée et datée sur le territoire italien.*

Mots-clés *: mines, minerai de fer, Préhistoire, Grotta della Monaca, Calabre, Italie.*

Keywords: mines, iron ore, Prehistory, Grotta della Monaca, Calabria, Italy.

1. INTRODUCTION

Grotta della Monaca is a karstic cave located within the municipality district of Sant'Agata di Esaro (CS), a small town in north-western Calabria, southern Italy (Fig. 1:1). Its imposing entrance is set 600 metres high a.s.l. on a mountainous peak, alongside the hydrographic left bank of the Esaro River (Fig. 1:2-3). Being highly visible and easily reachable, it has been occasionally explored and subjected to speleological surveys of which we can find traces in some literary sources and explorative reports dating back to the 19th and 20th centuries. In particular, one of these references reports for the first time the presence of archaeological evidence within the cavity: it is an unpublished note about an expedition of the Swiss Speleological Society in 1975. The text relates the finding of bone remains, potsherds, and a grooved stone tool. Subsequently surveys carried out in the 1990s by the "Enzo dei Medici" Regional Centre of Speleology in collaboration with the "Aldo Moro" University of Bari confirmed the statements made by Swiss speleologists: a hammer-axe and other fragmentary polished lithic tools were found in

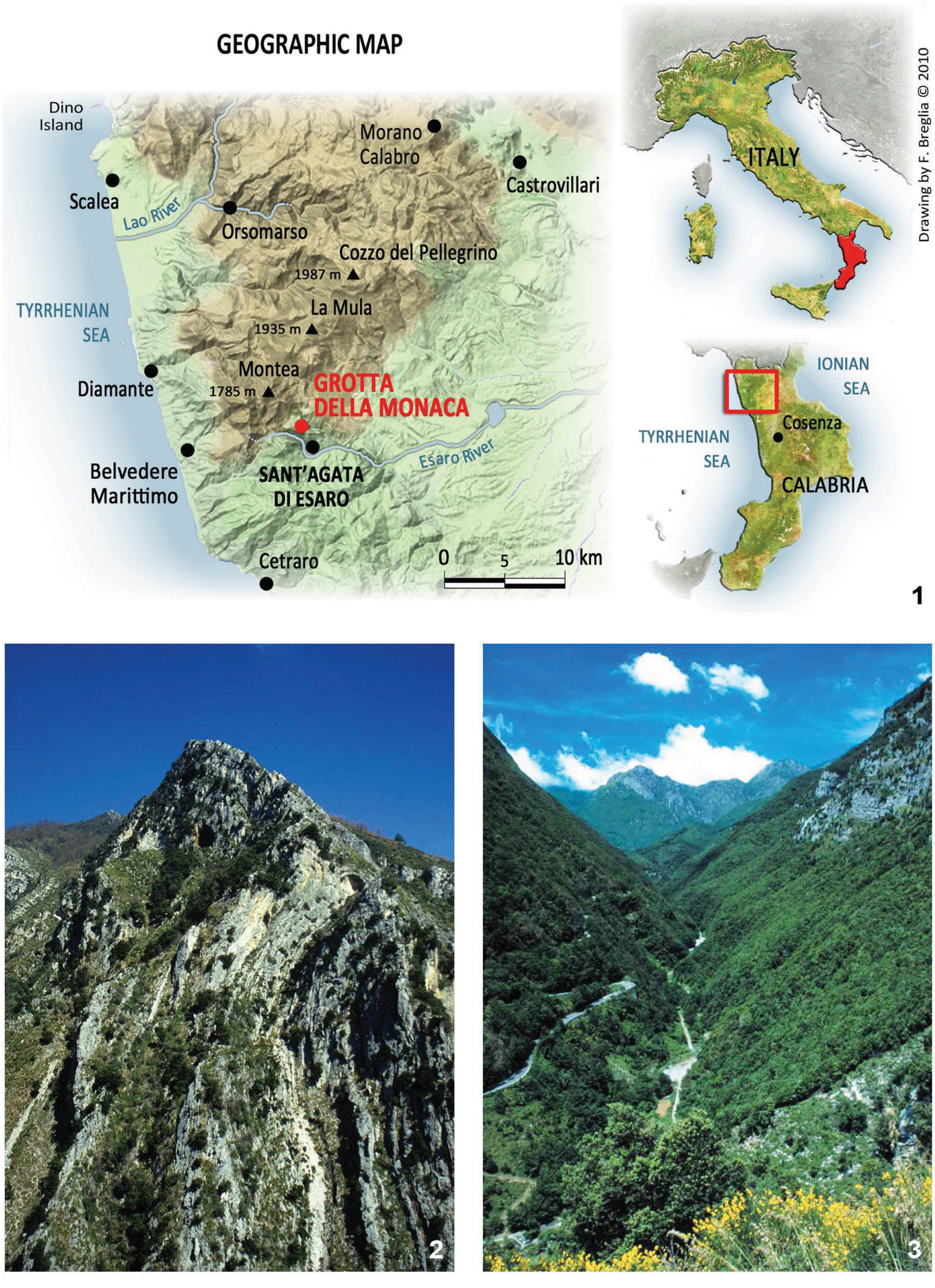

Fig. 1 – 1. Geographical setting of the prehistoric mine of Grotta della Monaca (drawing by F. Breglia © 2010); 2. The huge entrance of the cave on the top of a massive rocky peak (photo by F. Larocca); 3. View of the Upper Esaro River Valley from the access of the cave (photo by F. Larocca).

the same area previously noted, the deepest sector of the cavity. As a consequence, it was immediately recognized as an ancient and unknown prehistoric mine, giving birth to an intense period of speleo-archaeological research beginning in 2000 (Larocca, 2005a; Larocca & Dimuccio, 1997; Larocca & Lorusso, 1998).

The cave sets in the north-western sector of the Calabrian-Peloritan Arc, along a fault called "Sangineto line" marking the boundary between the metamorphic crystalline Calabrian units and the Apennines carbonate domains. The cavity develops within Mesozoic carbonate units [(Triassic) (Dimuccio, 2005: 25-26)] for about 500 metres in length. It is characterized by several spaces differing in size and morphology that can be schematically divided in three main sectors: "Pregrotta", a wide gallery near the cave entrance; the so-called "Sala dei pipistrelli", a huge chamber in the middle of the cave system; and "Cunicoli terminali", a series of low and narrow passages at the end of the underground system (Fig. 2:1) (Larocca, 2005b). The cave is particularly rich in metallic minerals, both iron and copper ones. Cupriferous minerals, outcropping mainly in the Cunicoli terminali, are represented primarily by malachite [$Cu_2(CO_3)(OH)_2$], and, to a lesser extent, by azurite [$Cu_3(CO_3)_2(OH)_2$] (Fig. 2:2). This mineralization is often associated with copper sulphates and phosphates such as brochantite [$Cu_4(SO_4)(OH)_6$], libethenite [$Cu_2(PO_4)(OH)$], and sampleite [$NaCaCu_5(PO_4)_4Cl{\cdot}5H_2O$].

Iron minerals are present from the cave access to the deepest recesses of the cavity; the most widespread ones are hydroxides, particularly goethite [$\alpha FeO(OH)$], occurring either isolated or associated with lepidocrocite [$\gamma FeO(OH)$], a polymorph of goethite. Iron minerals outcrop as veins embedded between the carbonate layers (Fig. 2:3); due to varying mineral subdivision and purity degree, they exhibit different colours: from black with sub-metallic lustre, for example in some stalactitic and stalagmitic formations, to yellow in the friable cryptocrystalline variety. Other minerals present are hematite [αFe_2O_3], an iron oxide detected near the entrance, and yukonite [$Ca_2Fe_3(AsO_4)_4(OH){\cdot}12H_2O$], an hydrated arsenate of iron and calcium found in the area of Cunicoli terminali. Particularly, the presence of hematite is linked with thermal transformation of goethite, as clearly visible near some fireplaces of historical age set on iron hydroxides beddings (Dimuccio *et al.*, 2005; Garavelli *et al.*, 2009; Garavelli *et al.*, 2012; Larocca, 2010: 267-268; Larocca, 2012: 251). The carbonate substrate in which Grotta della Monaca develops (Unità di San Donato) contains, among others, scattered primary iron sulfide mineralizations [(e.g. pyrite - FeS_2) (Amodio Morelli *et al.*, 1976; Bonardi *et al.*, 1982; Boni *et al.*, 1990; Dimuccio, 2005; Ietto *et al.*, 1992; Lorenzoni *et al.*, 1983)], which form in oxygen-poor environments. It seems plausible to assume that the iron oxide/hydroxide minerals (essentially massive dyke/stratiform facies), observed inside the cave (Larocca & Dimuccio, 1997; Dimuccio *et al.*, 2005), are the result of pyrite oxidation in oxygen-rich environment. Grotta della Monaca seems to be a typical example of polygenetic cave (i.e. has experienced more than one type of origin) where the mixing of hypogenic ascending flows (rising along fractures and inclined bedding planes) with probable infiltrating oxygen-rich epigenic meteoric waters (descending vadose flows) caused the cave development (by corrosion) and a concurrent precipitation of massive ferruginous mineralizations. An important role of microbial activity, especially in catalysing the precipitation of iron during the active speleogenetic phases, cannot be excluded (Dimuccio Luca Antonio, personal communication).

Archaeological excavations confirmed the presence of prehistoric activities aiming to the exploitation of metallic minerals in the deepest sectors of the underground system. Two main mining phases can be recognized: exploitation of iron hydroxides dating to the final phase of the Neolithic (between the end of the V and the first half of the IV millennium calBC), and exploitation of copper carbonates during an early phase of the Copper Age (first half of the IV millennium calBC). The iron hydroxides were exploited once again during Post-Medieval times (XVI-XVIII century AD) in the area near the entrance of the cave (Larocca, 2012: 251; Larocca & Levato, 2013: 23). Prehistoric mining phases were followed during the middle Bronze Age (between 1700 and 1400 calBC) by the use of the cavity as an underground burial-place approximately within the same sectors in which prehistoric mineral mining activities were previously carried out (Arena *et al.*, 2013).

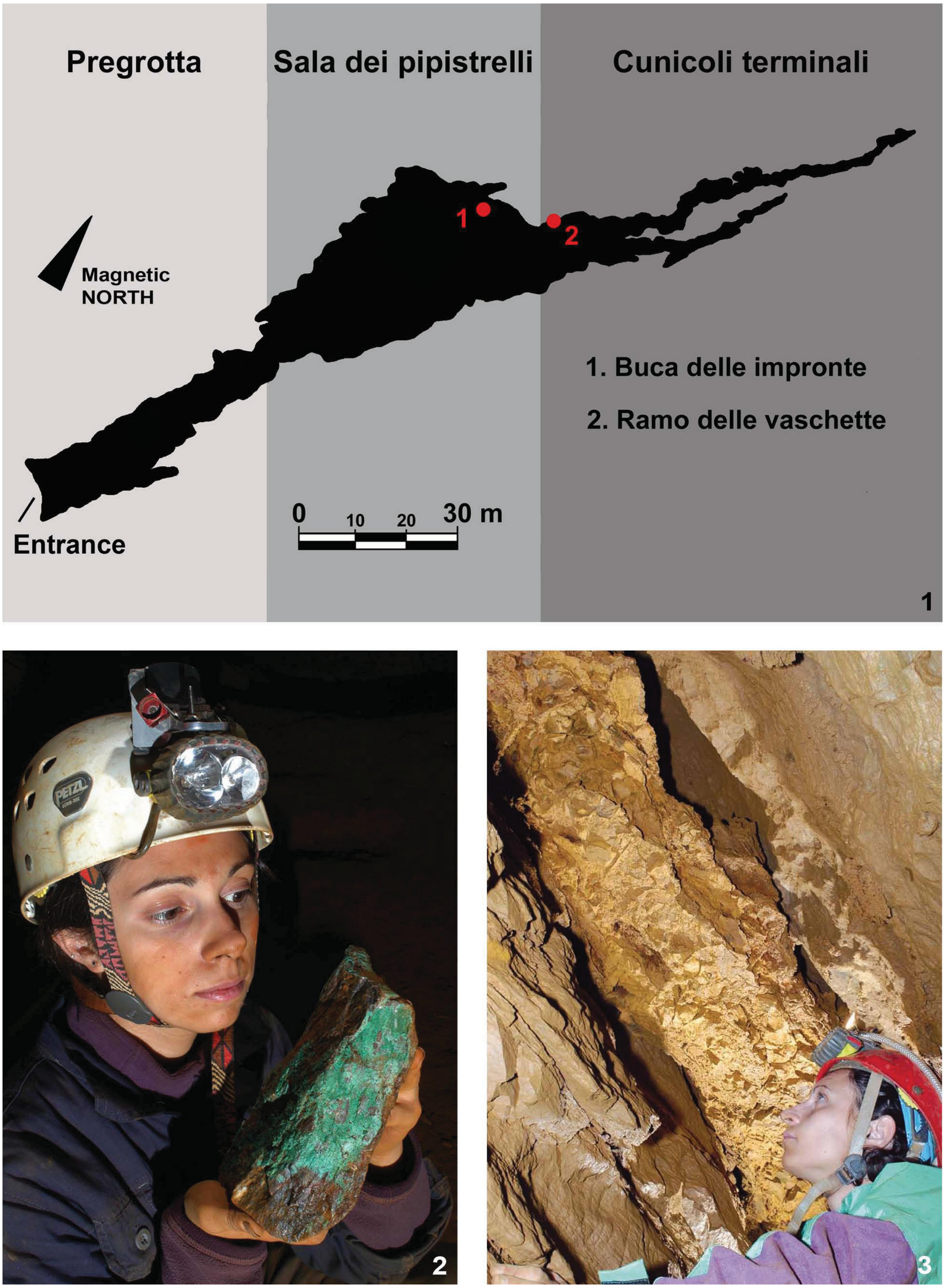

Fig. 2 – 1. Schematic plan of Grotta della Monaca; highlighted the mining sectors used for the exploitation of iron hydroxides during the final Neolithic (data and digital processing by F. Larocca); 2. Malachite smearing on a carbonate rock boulder (photo by F. Larocca); 3. Goethite vein within a fracture of the carbonate rock walls (photo by F. Larocca).

2. The prehistoric exploitation of iron hydroxides

Traces of Post-Medieval iron exploitation can be found in Pregrotta and beneath Sala dei pipistrelli. These activities almost totally destroyed evidence of possible earlier exploitation of which we found traces within deposits located at the entrance, such as loose blocks of hydroxide retaining digging traces from non-metallic tools, and atypical flint tools found within fractures full of goethite. From the same levels containing these flint tools comes a human ulna deliberately placed under a rocky boulder, and AMS radiocarbon dated to 18250-17800 calBC (84.6 %) / 17750-17600 calBC (10.8 %) (LTL-3580A - 16761±100 BP). It is not to be excluded that this oldest frequentation could be associated to the exploitation of the iron hydroxides outcropping near the cave entrance (Larocca, 2010: 268; Larocca, 2012: 251). However, the most clear and best preserved contexts of iron minerals exploitations are located in the innermost and darkest underground sectors. Inside the Sala dei pipistrelli a mining sector called "Buca delle impronte" has been investigated; it was detected thanks to hundreds of digging traces visible on iron hydroxides veins outcropping within it. This goethite is so soft that it preserved for thousands of years negative imprints of the tools used to work it (Larocca & Levato, 2013: 23-24). Radiocarbon dating demonstrates a late Neolithic mining phase. This chronological assignment is supported by research carried out in another mining area called "Ramo delle vaschette", near the Cunicoli terminali. The secluded position of these two sectors allowed the preservation of an archaeological context that has reached us almost untouched by later activity.

2.1. Buca delle impronte

Buca delle impronte is a sub-horizontal passage 11 m long, and about 60 cm to 4 m wide, varying in height from 25 cm to 1 m; it is located in the inner part of the Sala dei pipistrelli (Fig. 2:1). It has a complex structure: a sub-round shaft with a downwards bottleneck opening at its bottom gives access to a slightly sloping passage; at the end of the bottleneck two pillars still support the vault and prevent it from collapsing (Fig. 3:1). This area presents a nearly flat surface on which archaeological excavations were conducted, covering an area of 7.5 square metres, with a height from the surface level to the roof between 20 and 60 cm. During the first investigations, this deposit proved to be artificial; in fact, it partially overlaid a hydroxide vein that bears digging traces. Beneath a first layer of mining debris, a beaten earth layer was uncovered. It is 1.90 m in length, a maximum of 1.05 m in width, with a concavo-convex longitudinal section sloping down towards the inner part of the chamber, with a cross-section that is concave in the centre and convex at the side edges (Fig. 3:2). This level is clearly recognizable due to its compactness and blackish colour resulting from charcoal remains scattered on its surface. The deposit has reached a maximum depth of -90 cm, partially stopping at the carbonate rock emerging from the cave floor. During excavations, four main stratigraphic units were recognized, allowing the identification of the extractive phases carried out in this sector. Prehistoric miners first dug out all of the goethite vein, proceeding from the outside to the inside of Buca delle impronte, and they disposed waste materials within the same digging area, successively mining its inner part. Due to the small distance between the floor and vault (only 70 cm on average), they proceeded by crawling on the debris previously generated, compacting the deposit and so creating the beaten earth layer. New debris progressively accumulated on the latter until the cessation of mining activities (Levato, 2012: 187-197; Levato, 2013).

This extractive technique implies the direct excavation of the vein, selecting the soft goethite variety and discarding the more compact one. In case the carbonate rock on top of the vein risked collapse, the miners left sections of mineral, as evidenced by the pillar designated "P1" and the semi-pillar designated "P2", both made of goethite (Fig. 4:1-2). Soft goethite was certainly extracted using tools made of antler, bone, and probably horn or wood. Though no material remains of these tools have been found, they can be identified through digging traces. The latter can be grouped as:

- imprints of deer antlers used as picks (Fig. 4:3);
- imprints of animal scapulas used as shovels (Fig. 4:4);
- imprints of unidentifiable tools.

Whilst digging traces of antler tools can be easily recognised from the presence on their surface of lengthwise stripes, and imprints of

Fig. 3 – 1. Goethite vein within Buca delle impronte, in the area next to the bottleneck. On the left can be seen the P1 pillar, while to the right of the metric gauge can be seen one end of the P2 semi-pillar (photo by F. Larocca); 2. Beaten earth layer detected within Buca delle impronte (photo by F. Larocca).

Laboratory number	*Material*	*Context*	*Radiocarbon dating*
LTL-3581A	*Pinus sylvestris* charcoal	Buca delle impronte	4880±45 BP 3780-3630 calBC (89.8 %) 3580-3530 calBC (5.6 %)
LTL-3582A	*Pinus sylvestris* charcoal	Buca delle impronte	4935±45 BP 3800-3640 calBC (95.4 %)
LTL-3583A	*Pinus sylvestris* charcoal	Ramo delle vaschette	5183±50 BP 4230-4200 calBC (2.3 %) 4170-4090 calBC (4.9 %) 4080-3920 calBC (79.4 %) 3880-3800 calBC (8.9 %)
LTL-3584A	*Pinus sylvestris* charcoal	Ramo delle vaschette	5010±50 BP 3950-3690 calBC (95.4 %)

Tab. 1 – Grotta della Monaca (Italy). Radiocarbon dating of the final Neolithic iron hydroxide mining (from Larocca, 2010; Quarta *et al.*, 2013).

scapulas by a small raised section corresponding to specific bone morphology, for other imprints we can only propose the use of a raw material different from antler (bone, horn, wood). Imprints have also been found on loose blocks of iron hydroxide contained in the archaeological deposits (Larocca & Levato, 2013: 23-24).

Working activities set in an underground environment so distant from the outside and therefore from natural light required the utilization of artificial lighting systems. Within Buca delle impronte, more than one hundred charcoal samples have been collected, and archaeobotanical analysis indicates they derived from *Pinus sylvestris*. These represent almost the totality of organic remains found, and are the only archaeological evidence, in terms of absolute chronology, that allows the assignment of this exploitation phase to the final Neolithic. The dispersion of the same material within the entire investigated deposit, their dimension, their occurrence on the beaten earth layer, the same wood species suggest a derivation from torches used to light the hypogean areas (Larocca, 2012: 254).

Unfortunately, as previously stated, apart from charcoal remains of torches no other artefacts have been found. This exploitation chronology is based on the AMS radiocarbon dating of burnt remains of *Pinus sylvestris* that yielded dates between 3800-3640 calBC [(95.4 % - LTL-3582A) and 3780-3630 calBC (89.8 % - LTL-3581A) (Tab 1) (Larocca, 2010: 268; Larocca, 2012: 254; Quarta *et al.*, 2013)].

2.2. Ramo delle vaschette

Ramo delle vaschette is a sub-horizontal passage of 6 m in length, 1.6 m in maximum width, and 90 cm average height. It is adjacent to a nearly flat area that gives access to the Cunicoli terminali (Fig. 2:1). Extensive archaeological excavations have been carried out, excluding part of the deposit in the area close to the end of the passage. Nearby the access, it was possible to excavate only a restrained portion of the deposit because part of it was covered by a thick stalagmitic crust. In this deposit, we detected a small depression in the ground full of sediment, designated “Depressione I”, where 28 lithic flakes were found. These clearly derive from a not diagnostic fragment of a schist tool found on the surface. The middle portion of the passage has been extensively investigated; in fact the majority of the deposit in this area reached a maximum depth of -90 cm. A single layer of accumulation of mining debris was found, including several broken stalagmites and calcitic flowstones; the latter, together with carbonate rock boulders, iron hydroxides, and yukonite, filled a second and wider depression in the ground designated “Depressione II”.

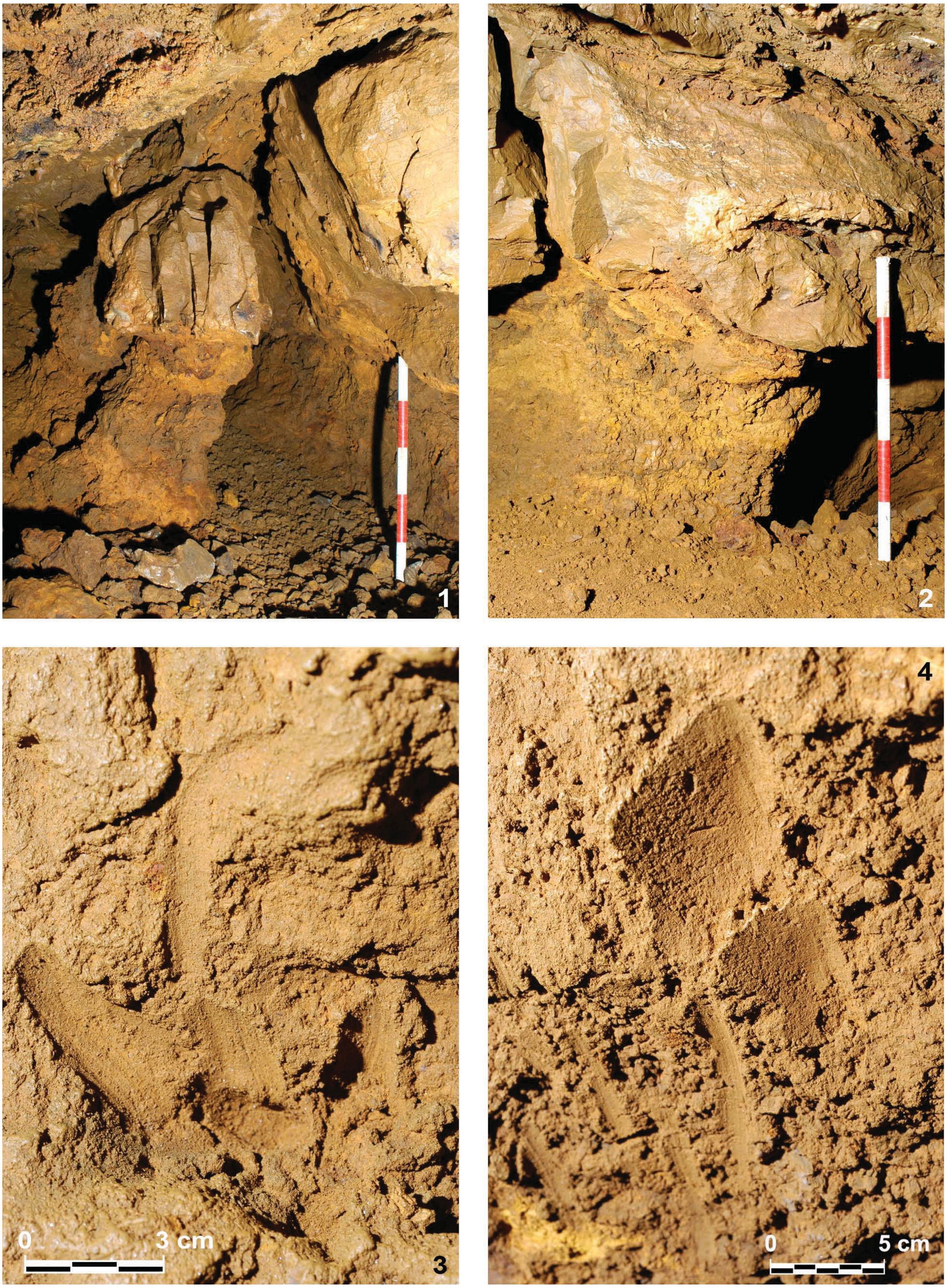

Fig. 4 – 1. Supporting pillar designated "P1" (photo by F. Larocca); 2. Supporting semi-pillar designated "P2" (photo by F. Larocca); 3. Imprints of deer antlers on a vein outcropping along the area subjected to archaeological excavation (photo by F. Larocca); 4. Imprints of blows with scapula shovels made from two different distances (photo by F. Larocca).

According to the data currently available, the extractive technique consisted of a stripping action: it involved the removal of the calcitic bulk formerly spread on the floor and on the side walls of the passage. This action is demonstrated by nine strips of calcitic flowstone alongside the passage perimeter at a height of 23 to 70 cm above the surface level (Fig. 5:1). The presence within the deposit of smashed stalagmites and flowstones validates the hypothesis of a stripping activity. Specifically, it was observed that these stalagmites were actually whole, so the smashing activity must have been carried out alongside their perimeter where calcite dripstone is generally thinner (Fig. 5:2). The only tool found in this context is the before-mentioned schist percussion tool, designated "L15", which was used in the underground area, scattering tens of lithic chips on the ground (Fig. 5:3). Technological analysis allowed re-assembling of the flakes on the hammer edge of the implement, proving their actual association with the tool; this analysis highlighted traces of manufacturing, which aimed to create a groove or notch, and of shaping by pecking the tool (Breglia, 2013: 87, 129). Goethite exploitation is suggested by the limited remains of an iron hydroxide vein, which is now largely worn out, but extends underneath the original flowstone, and by the abundance of loose goethite boulders detected within the deposit (Levato, 2012: 237; Levato, 2013).

As in the Buca delle impronte, the presence of charcoal remains, deriving from the combustion of *Pinus sylvestris*, implies the use of torches for underground lighting (Larocca, 2012: 254). Two AMS radiocarbon dates on charcoal of this same wood type set the exploitation in the Ramo delle vaschette between 4080-3920 calBC [(79.4 % - LTL-3583A) and 3950-3690 calBC (95.4 % - LTL-3584A) (Tab. 1) (Larocca, 2010: 268; Quarta *et al.*, 2013)].

3. CONCLUSIONS

Mining evidence found within Buca delle impronte and Ramo delle vaschette certainly raise the issue of iron oxide/hydroxide exploitation and use during Prehistory. Thanks to the research carried out within both contexts it has been possible to improve our knowledge of the acquisition phase for iron minerals and of the techniques used by the miners of the Grotta della Monaca during the end of the Neolithic Age. The first notable feature is the access to mining resources through a karstic cave, a feature that has no comparison with the other prehistoric iron oxide/hydroxide mines. The bright chromatism of iron hydroxide veins outcropping near the wide entrance probably made their identification easier, encouraging miners to follow their veins to the deepest sector of the cavity, using torches of *Pinus sylvestris* to illuminate these completely dark places. Two different extraction techniques can be observed: direct excavation of veins outcropping on the surface, and flowstone stripping for veins located beneath them. In the most extreme cases, pillars of iron hydroxide were spared, helping to sustain the unsteady vault. Digging traces allowed to detect exploitation, and to identify some tools used, as deer antler picks and shovels made of large mammal scapulas (Larocca & Levato, 2013: 23-24). Except for a schist percussion tool, no other artefact has been found within the investigated sectors. Whilst the absence of bone and antler tools cannot be satisfactorily explained, pottery can be considered as equipment not directly linked with extraction, for example, it was likely not used for mineral transport. Work carried out in such narrow spaces might have required perishable animal or vegetable materials that would better comply with the morphology of the underground environment, allowing an easier transport of extracted raw material.

Mining activities occurred between the end of V and the first half of IV millennium calBC, during an advanced and transitional phase of the final Neolithic into the succeeding Copper Age. It is a period marked in a large part of southern Italy by the dispersal of Diana style pottery – found in the Pregrotta of Grotta della Monaca – and by the diffusion of engraved ceramics, absent in the cavity. The appearance of the first metallurgic activities to produce copper artefacts – on the Acropoli of Lipari – stands out among the other innovations of this period (Larocca, 2012; Pacciarelli, 2011; Pessina & Tiné, 2010: 48-49, 132-134; Salerno & Vanzetti, 2004: 215).

What happened within Grotta della Monaca testifies to the first phase of the operative sequence that leads from mineral extraction to the final product. The most recent techno-functional analysis carried out on macrolithic tools – upper and lower grinding stones – found within the

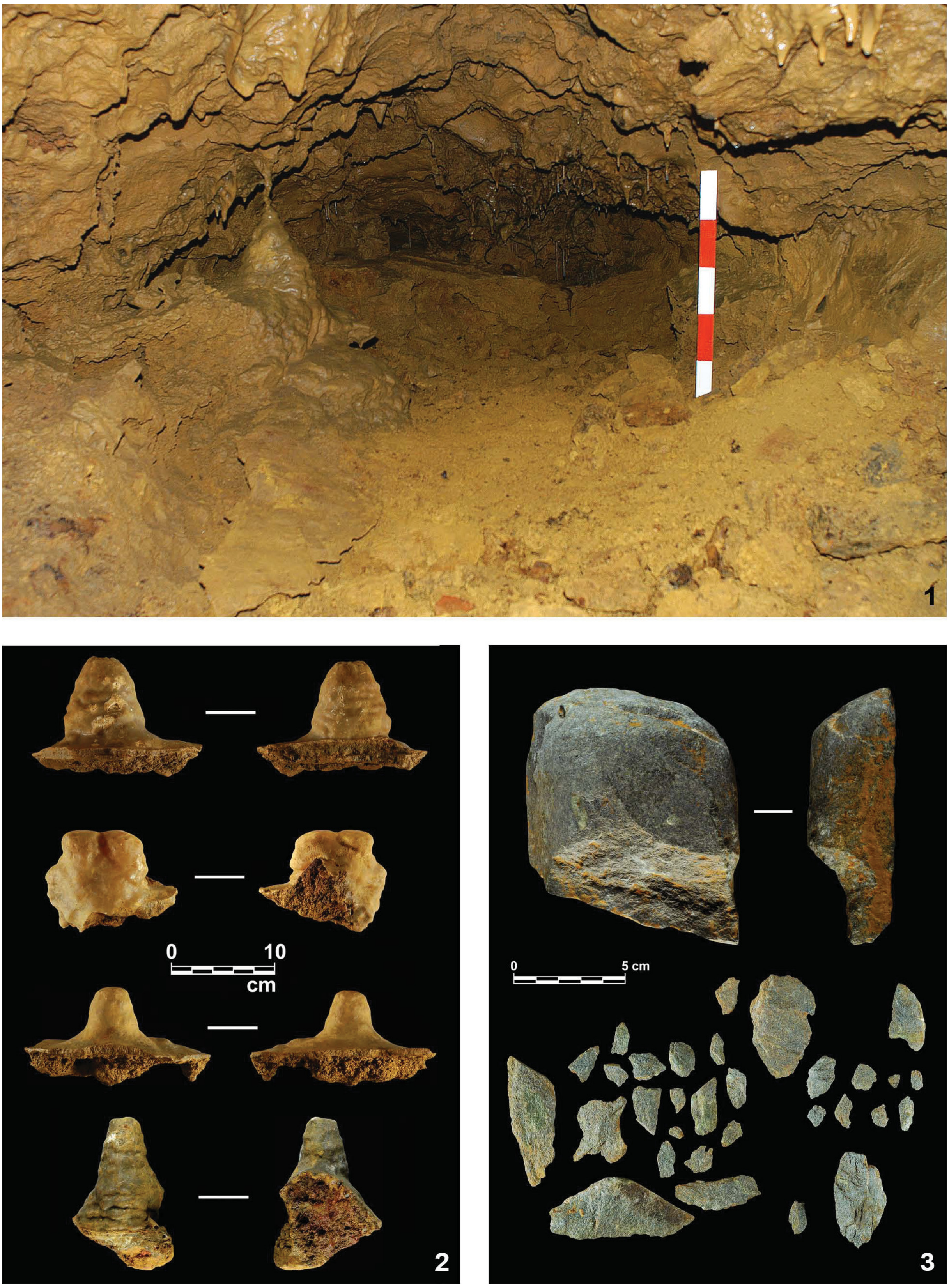

Fig. 5 – 1. Stripping traces on a calcitic flow within Ramo delle vaschette (photo by F. Larocca);
2. Smashed stalagmites found within the debris deposit (photo by F. Larocca);
3. Fragment of a lithic tool made of schist designated “L15”, seen with its associated flakes (photo by F. Larocca).

Pregrotta imply that these kinds of tools were used near the entrance to smash and grind goethite blocks. Unfortunately, their typology and the lack of a reliable stratigraphic context do not provide chronological information, but it is unlikely their attribution to Post-Medieval times, as a more complex mineral processing method – carried out in places outside from the extractive site – is attested (Caricola, 2013: 157-159). However, this is one of the rare sites in which there is both iron mineral exploitation and evidence linked to raw materials processing (Goldenberg *et al.*, 2003; Vaughn *et al.*, 2013). Unfortunately, it is not possible to evaluate the use of the resulting finished product, as no coeval open-air villages have been found in the surrounding area.

The site can be included along with at least five prehistoric iron oxide/hydroxide mines investigated in Europe to date (Dobosi, 2006; Goldenberg *et al.*, 2003; Weisgerber *et al.*, 2008; Schild *et al.*, 2011). Ongoing archaeological excavations within Grotta del Tesauro, another iron hydroxide mine located in the surrounding area, will help improve our knowledge about dynamics of supply of these raw materials within the Upper Esaro River Valley and clarify the chrono-cultural context of these mining activities (Garavelli *et al.*, 2012).

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