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PROBLEMATIC KARST FILLINGS OF LATE LOWER PLEISTOCENE AGE IN A CAVE OF THE LESSINI MOUNTAINS (VENETIAN FORE ALPS, VERONA)*

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ABSTRACT: The excavation of a small cave in the Lessini Mountains, north of Verona, allowed a study of an archaeological complex attributable to the Copper Age. A fossiliferous breccia, rich in bones of small mammals and birds has been found below the archaeological levels. During 2005 and 2006, the results of paleontological excavations supervised by Benedetto Sala provided a faunal assemblage correlated to the late Biharian. These excavations stimulated a preliminary study of the geological, geomorphological and morphodynamic context of the cave and its surroundings, in order to understand its genetic context. Particular attention was paid to the breccia, containing numerous small exotic pebbles, mostly 5-12 mm in diameter.
We consider three different hypotheses for the provenience of the exotic pebbles: I) they have been transported and displaced in the area by morphodynamic agents, such as ancient glaciers, and/or watercourses II) they derive from a completely eroded geological formation, that has been reworked and deposited in this karst trap, III) they are the result of "ecofacts" caused by birds. All these possible explanations, have some open issues. The "ecofacts" is the most intriguing hypothesis and perhaps the most likely: pebbles could have been transported by birds which use to swallow them to help digestion, then to expel them in boluses or in the excrements. According to this hypothesis, birds could have chosen the cave, or others connected cavities, as nests or as perches. In fact, in the breccia there are bones of large birds of prey, not jet studied. In time, probably, different species of birds have colonized these natural niches, as: vultures, eagles, owls, ravens, etc. So it is very difficult to state what kind of birds could have brought here their preys (the small mammals of which we find the bones), and what kind of birds could have transported the small pebbles. Only further excavations and studies will perhaps allow a full clarification of the processes of site formation.

Keywords: Limestone cliffs, cave deposits, exotic pebbles, Slivia faunal assemblage, Biharian.

1. INTRODUCTION

The excavation of a small cave, called *Buso della Fadanana*, in the Lessini Mountains, north of Verona, has allowed a study of an archaeological complex attributable to the Copper Age (Sauro et al., 2007). Below the archaeological levels, a fossiliferous breccia has been found, containing a faunal assemblage referable to the late Lower Pleistocene (late Biharian). These excavations stimulated a preliminary study of the geological, geomorphological and morpho-dynamic context in which the cave is located, in order to understand its genetic context.

In particular, the purpose of this note is to analyse a problematic aspect of the fossiliferous breccia, namely the presence of numerous rounded pebbles, referable to lithologies not occurring in this karst system and, in some cases, not even in the pre-alpine group of Lessini Mountains. Based on the current state of knowledge, considering the characters of the pebbles, which fall into a strict dimensional range and largely derive from carbonate rocks, the natural morpho-dynamic processes seem unable to explain this occurrence. On the other hand, the available literature on fossil bearing infillings in karst cavities does not illustrate similar situations. It was therefore decided to analyse this aspect of the breccia searching for its meaning in a paleo-environmental reconstruction. It is hoped that further research on this and other similar cavities will contribute to a deeper understanding of the alpine karst environments during the Lower Pleistocene.

1.1. A COMPLEX KARST SYSTEM AND ITS GEOMORPHOLOGICAL CONTEXT

The entrance of the small cave containing the breccia opens on a rock wall at 752 m a.s.l., hanging about 150 m above the valley bottom, in the upper belt of the right slope of the *Vajo di Squaranto*, a canyon-like valley in the Lessini Mountains (Venetian Fore-Alps), in the municipality of Bosco Chiesanuova, about 20 km north of the town of Verona (NE Italy).

*U. Sauro coordinated this research work; F. Zorzi analysed the small pebbles and took part to the discussion.

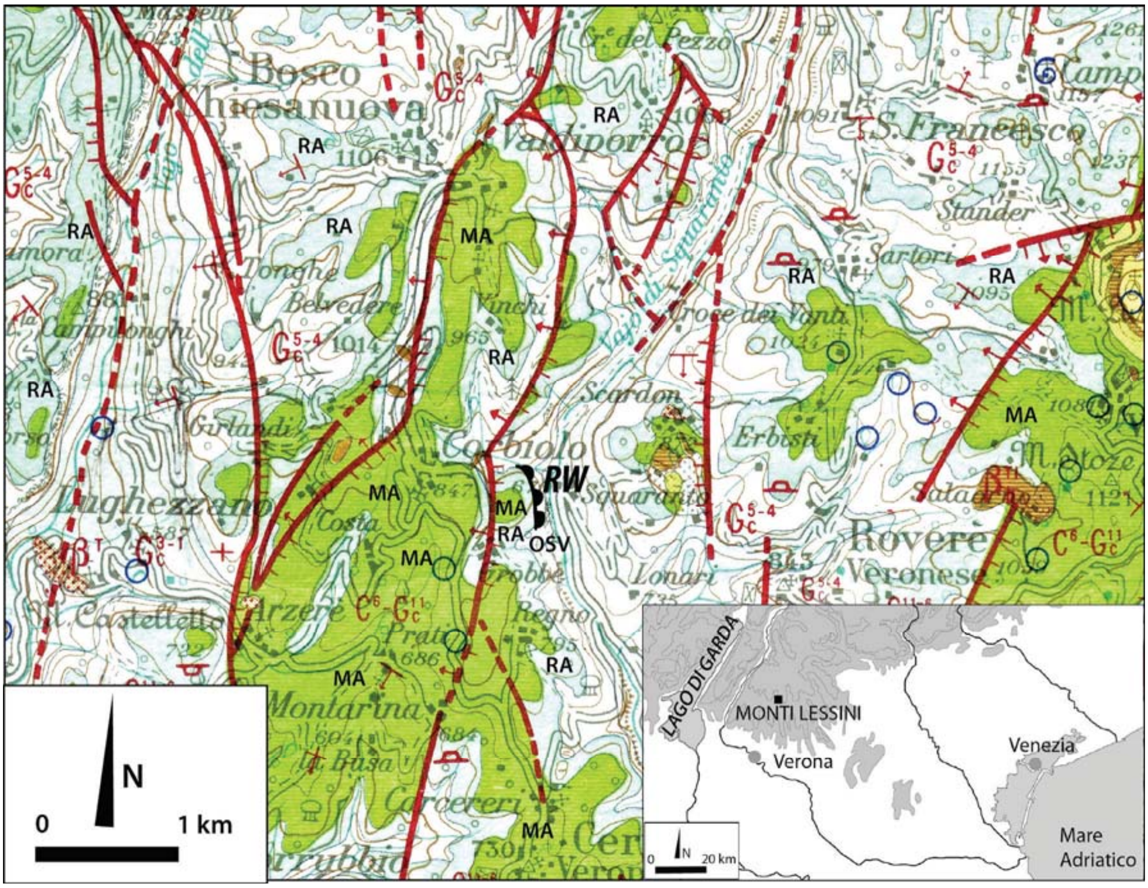

Fig. 1 - Geological map of the area (from the “Carta Geologica d’Italia”, F° 49 Verona, original scale 1:100.000). RW: rock wall described in the paper, MA: Maiolica Formation, RA: Rosso Ammonitico Formation, OSV: Oolite di San Vigilio Formation.

The East facing wall is about 400 m long and 10-80 m high. It consists of Jurassic limestone, with the superimposition of two types of rocks: the *Rosso Ammonitico Veronese* in the upper part and the *Oolite di San Vigilio* in the lower part. The anti-dip slope beds, dipping about 10° WSW (Figg. 1, 2, 3) are capped by the *Rosso Ammonitico*, acting as a caprock. These structural conditions are favorable to the conservation of the rock wall. Only in the southern sector, where *Rosso Ammonitico* has been eroded, the wall tends to retreat faster and its height is decreasing; the cave is located in this sector.

In the rock wall, it is possible to recognize several types of forms (Fig. 2). In particular:
- sub vertical channel,
- entrance of cave,
- sub-horizontal notch, developed either above rock cut terraces and in the vertical surfaces,
- large half-dome niche,
- recess with mostly vertical development.

All these forms are explainable with the geomorphological environment of the rock wall, and in particular with: a) the characters of the different geological formations, b) their tectonic setting, c) the gravity induced processes, d) the karst and weathering processes resulting from the circulation of the karst waters.

With regard to point d), the evolution of the underground karst network is an expression of a downward transition from a horizontal circulation (hanging aquifers hosted in dense lithoclastic networks) to an essentially vertical one (diaclastic circulation), from the *Maiolica* to the *Rosso Ammonitico* and to the *Oolite di San Vigilio* (Mégnien, 1966; Sauro, 1973, 1974, 1999) (Fig. 3). The *Maiolica* is the rock formation above the *Rosso Ammonitico* on the top of the ridge. It is strongly fractured and hosts hanging aquifers which lose waters through the main fractures of the *Rosso Ammonitico*, feeding a circulation in the *Oolite di San Vigilio*. Over time, the water forms shaft cavities inside this rock and bedding plain conduits. The lower part of the *Oolite di San Vigilio* is massive and contains thin clayey layers, that can favour the formation of local hanging aquifers. The perched water bodies feed many tiny temporary karst springs, which favour a relatively faster weathering of the rock wall just above the impermeable layers and the consequent development of niches and large horizontal notches (Figg. 2, 3).

Where the wall is still capped by the *Rosso Ammonitico*, the notches, the half-dome niches, and the recesses are relatively stable forms. Instead, in the areas where the rock is strongly fractured and the caprock has been eroded, sub-vertical channels have formed through the collapse of large blocks. In the faster retreating portions of the rock wall, a hanging rock ter-

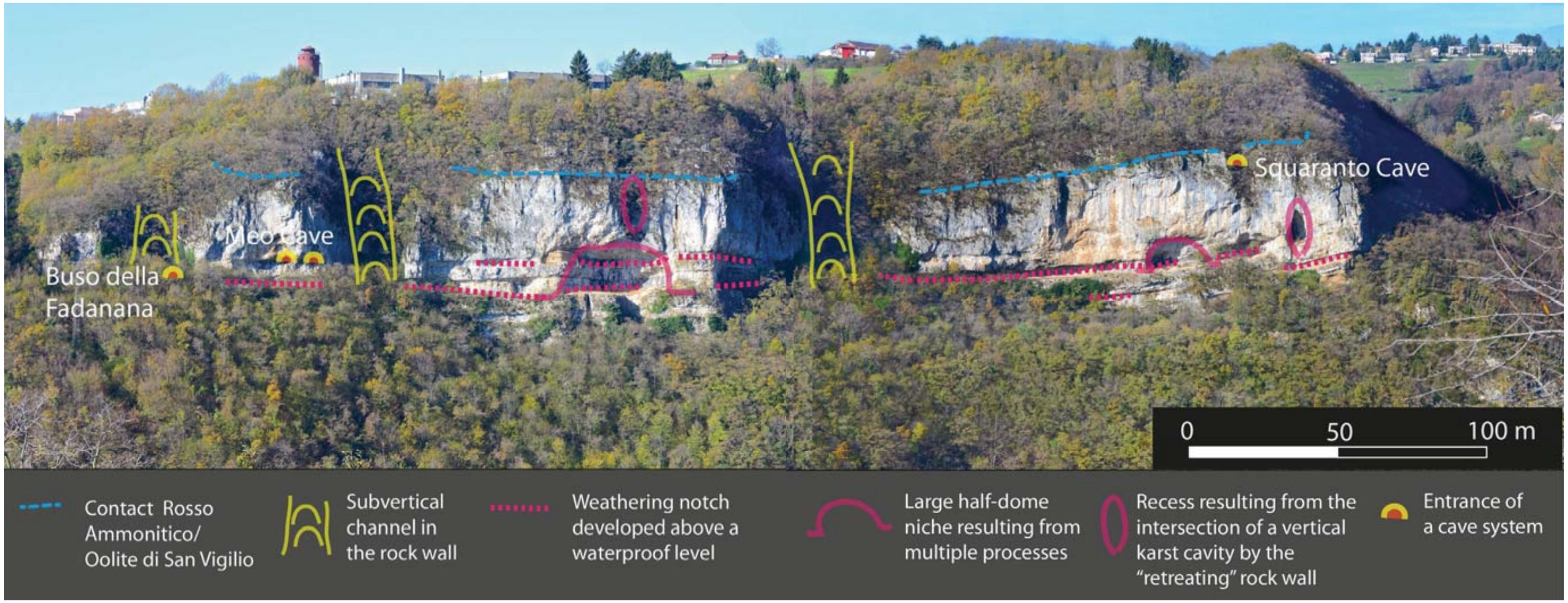

Fig. 2 - Panorama of the rock wall and of its main landforms (the scale is indicative).

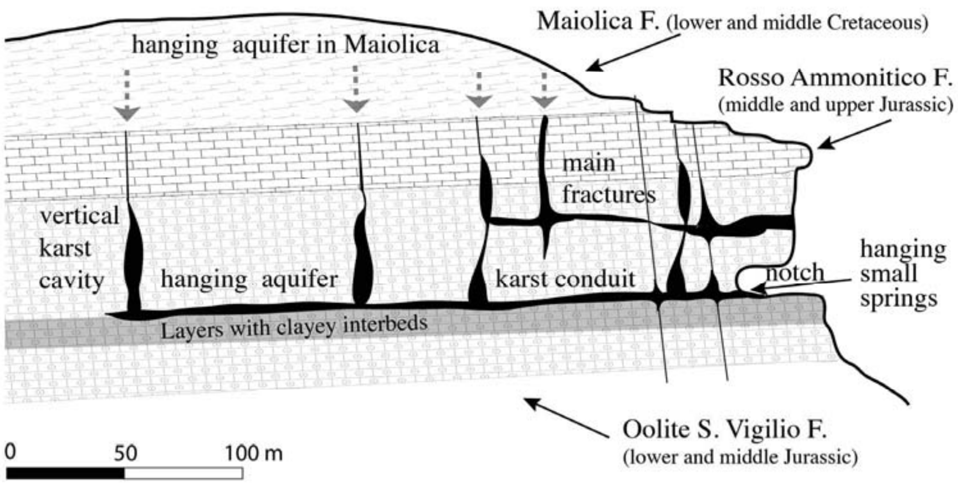

Fig. 3 - Sketch of the section of the rock wall, of its structural setting, hydrogeological characteristics and karst features (the scale both horizontal and vertical is the same and it is indicative).

race may develop above the impermeable layers and in front of the notches.

Two half-dome niches, more than ten meters high, wide and deep, have developed by multiple processes: weathering induced by the karst waters and intersection of vertical karst cavities by the surface of the retreating rock wall.

The recesses with mostly vertical development are also the result of the intersection of karst cavities by the retreating rock wall.

The entrance of the *Buso della Fadanana* cave is located at the base of a sub vertical channel in the wall: a gully which puts it in relation with the gently sloping surfaces of the ridge located upstream. The cave entrance was nearly completely closed by a talus cone, formed by a body of large collapse blocks (SBCB, in Fig. 4), covered by fine clastic deposits, mostly composed by soil and small and medium sized blocks (range between centimetres and decimetres) (LHASC, in Fig. 4). The accumulation of the cover sediments (LHASC) is the result of human impact on the surrounding environment during protohistoric and historic times, consisting in the deforestation of the area and the uses of soil for grazing and agriculture (Sauro et al., 2007). The cavity has, therefore, according with its topographical position, represented a sedimentary trap.

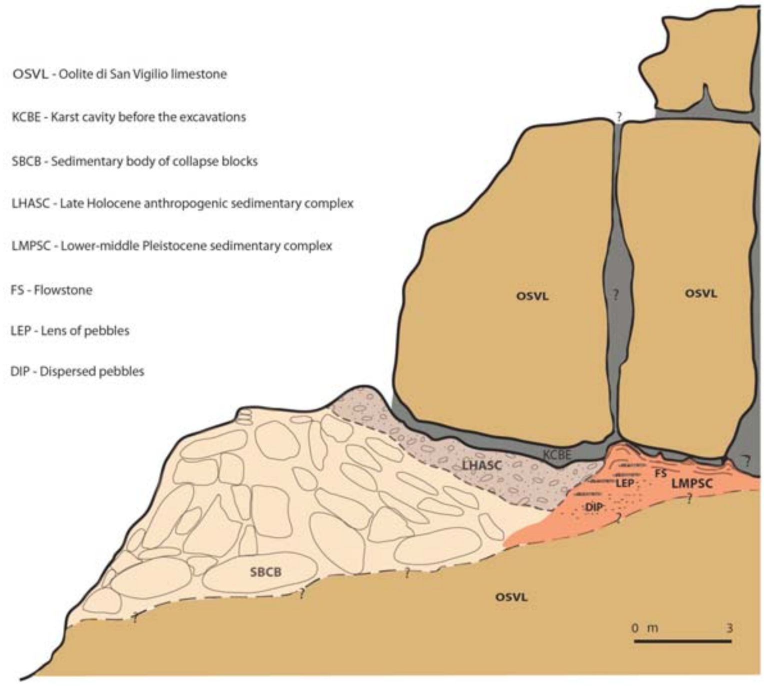

Fig. 4 - Sketch of the section of *Buso della Fadanana*, of the related rock wall and of the main sedimentary complexes filling the cavity (the scale both horizontal and vertical is the same and it is indicative).

Beside *Buso della Fadanana*, three others caves have been explored and mapped along the rock wall. All of them fit within the above-sketched hydrogeological model (Fig. 3). *Buso della Fadanana* is the shortest, developing for about 11 m (but it is possible to see an inaccessible prosecution, inside the sedimentary fillings); *Grotta di Squaranto*, also called *Buso del Beco*, is the longest, about 145 m in development (Salzani & Sauro, 1986).

2. THE FILLINGS OF THE CAVE

The deposits inside the *Buso della Fadanana* have been partly excavated between 2000 and 2003, in order to analyse their archaeological content (Sauro et al., 2007). The digging has evidenced that the upper sedimentary complex has accumulated in a time range between copper and modern age. The over 2 meters' thick deposit is rich in archaeological materials (ceramics, lithic industry, bones). It presents the structure of a sedimentary cone with layers inclined towards the interior of the cavity (Fig. 4). At the base of this upper complex, the loess-like sediments found in the not far *Grotta di Squaranto* (Salzani & Sauro, 1986) are completely missing. This could be probably linked to the occurrence of large collapsed blocks (SBCB) completely closing the cave (see Fig. 4).

The excavations carried out in the years 2005 and 2006 and supervised by Benedetto Sala have uncovered different sediments below this upper complex and in the inner part of the cave. This "lower complex" mainly consists of a reddish (Munsell color: dry 5YR 6/6, moist 4/6) matrix-supported breccia, made up of a red clay containing clasts as stones, pieces of flowstone, pebbles and fossil bones (LMPSC, in Fig. 4). Inside the breccia, some thin flowstone levels, and other discontinuities, such as levels of pebbles, slope mostly towards the entrance of the cave, i.e., in opposite direction of the upper complex.

Some sedimentary structures, as flowstones located under a vertical chimney, in which there is an alternation of calcitic levels and thin levels of red soil sediments, would suggest that at least part of the material present within the breccia could come from karst cavities located above, as the occurrence of vertically-developed cavities in all the karst systems of the area seems to indicate.

The reddish clayey matrix (Munsell color: dry 5YR 6/6, moist 4/6) clearly represents sediments transported from outside the cave by the erosion of *terra rossa* type paleosols, perhaps of Hapludalfs, Hapludults and Fragiudalfs type (Magaldi & Sauro, 1982). The main entry routes of the soil sediments were along the underground karst network, which consists of both vertical and sub-horizontal cavities. The cementation of the sediment is discontinuous: alternating portions of the breccia are extremely hard and others are rather fragile. In some parts, the absence of sedimentary structures suggests the occurrence of solifluction episodes during the deposition.

Probably, the most singular aspect of the sediments of the lower complex (LMPSC, in Fig. 4) is the presence of thousands of small pebbles, mostly limestone, dispersed in the reddish matrix, or concentrated to form sub-horizontal levels or lenses.

3. LITHOLOGY OF THE SMALL PEBBLES OF THE LOWER COMPLEX

To better understand the lithology of the pebbles and their possible origins, two different approaches were carried out: (A) observations under the polarized-light microscope of thin sections from 3 representative reddish breccia bulk samples; (B) X-ray powder diffraction (XRPD) of the red matrix and about 20 pebbles, (divided by color) from the same 3 samples.

Size and shape of clasts in the reddish breccia are heterogeneous, but there is a fraction of the pebbles that is widespread and often concentrated in small beds (Fig. 5). These pebbles have a size range from of 0.5 cm to 1.2 cm, generally rounded to well-rounded ellipsoidal, flattened ellipsoidal, or discoidal in shape. Clasts with angular and non-spherical shape are also present and their size ranges from 1 mm to 5 cm or more; most of them are fragments of flowstones (especially the larger clasts), bone fragments, micritic limestones and cherts. The sections and the thin sections of the reddish breccia after resin impregnation (Fig. 6) revealed a wide lithological variety of the clasts, mainly from carbonate rocks. All clasts are floating within fine-grained or clay matrix (with a size <10 micron), rich in Fe oxides.

Most of the pebbles are attributable to the geological formations of the Lessini area (Bosellini et al., 1967) (Fig. 7). Micritic limestones, grainstones and wackestones with ooids, peloids, crinoids and bivalves are very common and can be related to the Jurassic formations. Many pebbles are cherts and micritic limestone with the typical paleontological content (calpionellids, radiolarians, globotruncanae) of Cretaceous formations. Also, grainstone-packstone facies with foraminifera and echinoderms are frequent and they can be related to Cenozoic formations.

Some pebbles are clearly exotic, as they are of metamorphic origin: mica-schist, quartz-schists/gneiss and serpentine-schists (Fig. 6).

It is also possible to macroscopically recognize some of the lithologies described above: Jurassic limestones are grey, cherts are pure white with a black or brown external rim, serpentine-shists are pale green, mica-schists and quartz-schists/gneiss are dark grey or almost black. X ray powder diffraction analyses (XRPD) were carried out on pebbles and matrix of the reddish breccia using a Panalytical X'Pert PRO diffractometer, equipped with Co anode, Bragg Brentano HD mirror, sample spinner and solid state detector (X'Celerator). The XRPD analysis of the clay matrix (Fig. 8) shows a mineralogical composition typical for a soil: the main phases are smectite (montmorillonite-like), quartz and calcite and the minor phases are muscovite/illite, kaolinite goethite and hematite.

Most of the pebbles (with colors: grey, pale gray,

Fig. 5 - Block of the breccia with a pebbles level. In the center of the breccia there is a 5 cm bone fragment and below there is a 7,5 cm flowstone fragment.

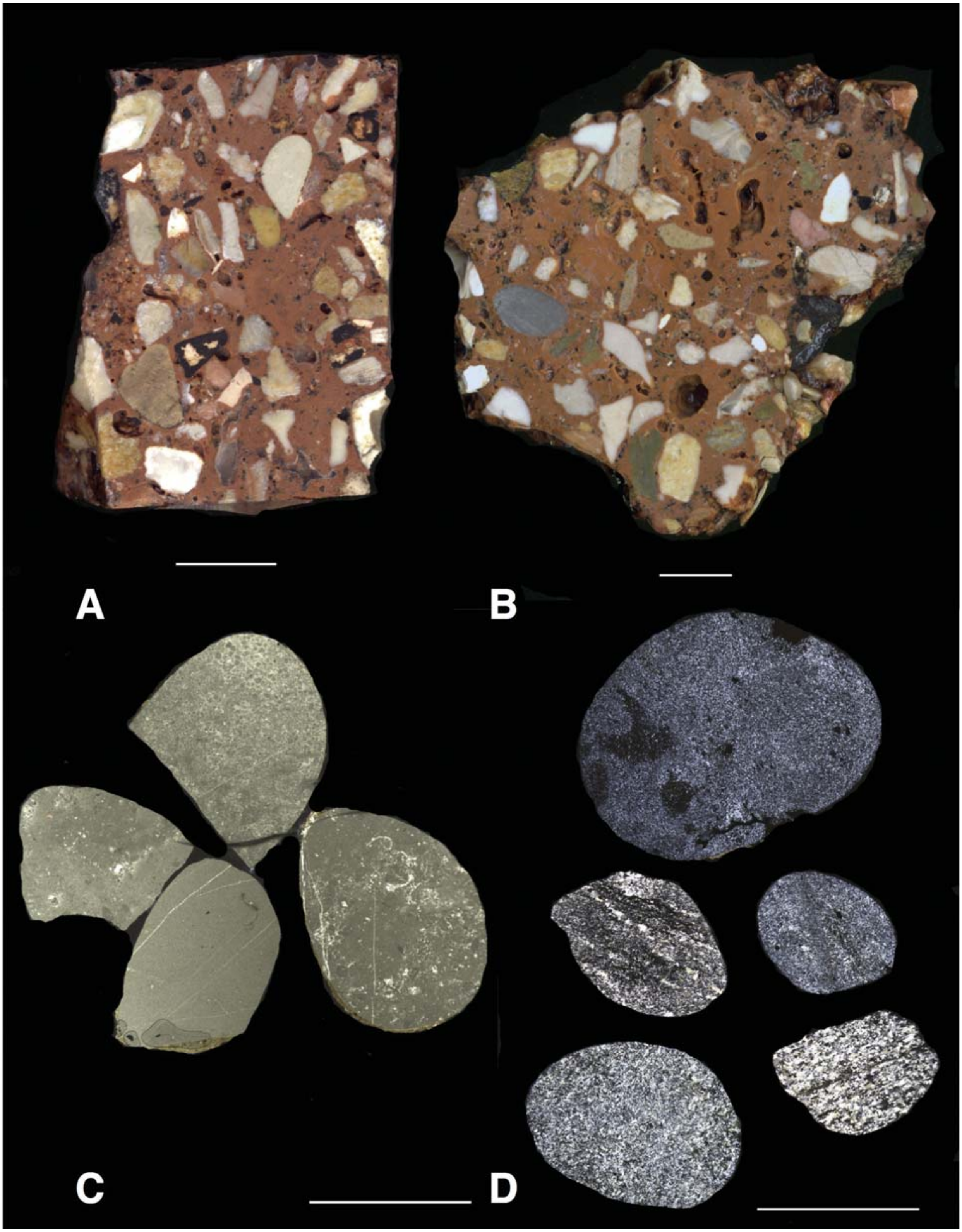

Fig. 6 - Sections: A) Section with carbonatic clasts; B) Section with carbonatic clasts and metamorphic clasts (green and black clasts). Pebbles thin sections under crossed polarizers: C) Pebbles of micritic limestone; D) Bluish pebbles of serpentinite and lighter pebbles of quartzite. Scale bar 1 cm.

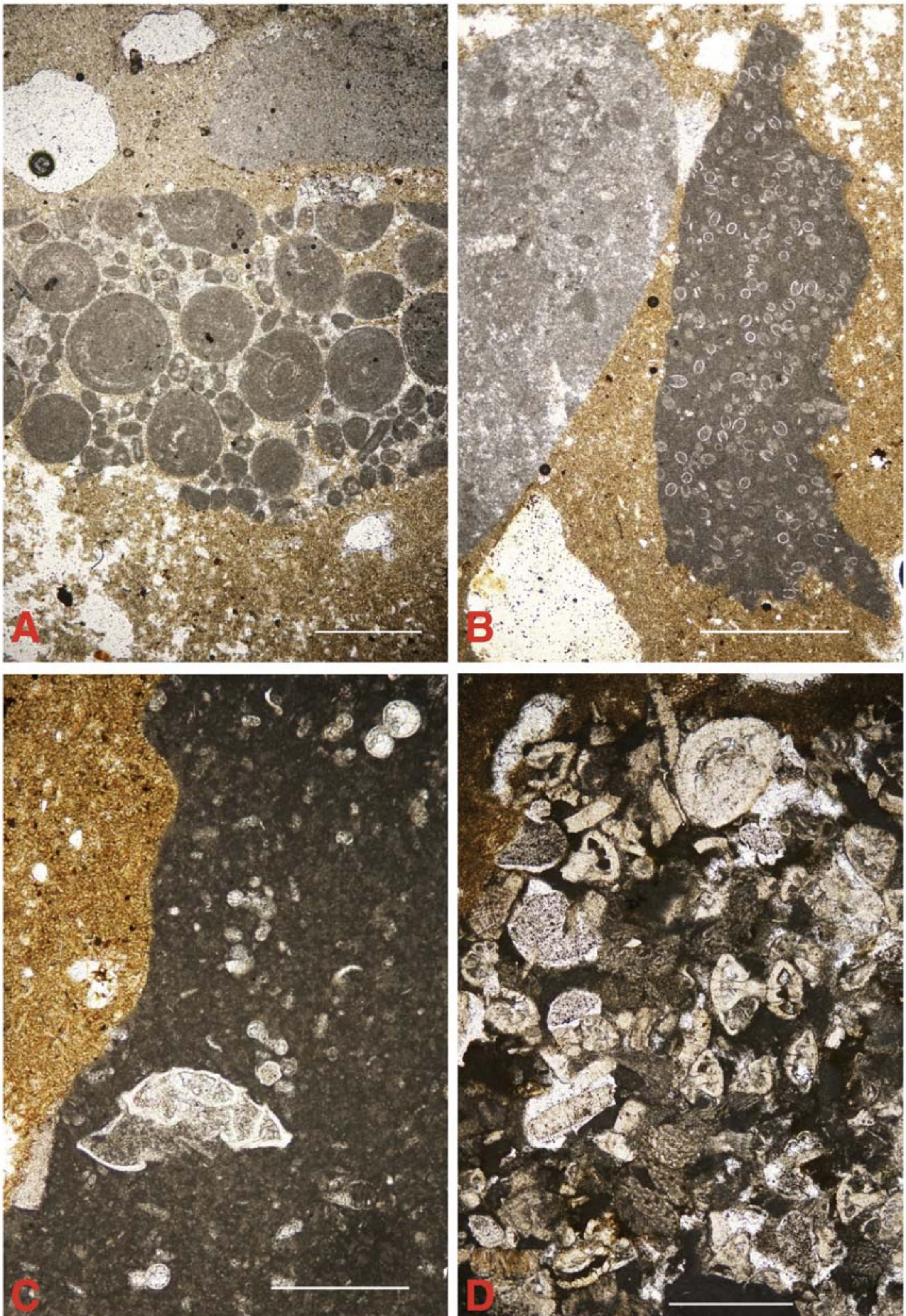

Fig. 7 - Pebbles thin sections under uncrossed polarizers: A) Oolitic grainstone; B) Micritic limestone with calpionellids; C) Wackestone with Globotruncana sp.; D) Grainstone with cenozoic foraminifera and echinoderms. Scale bar 1 mm.

white, beige and pale yellow) consist of calcite (Fig. 9). Some pure white pebbles are composed of quartz and moganite, a common mineralogical paragenesis in cherts (Fig. 10). Black or dark grey pebbles are composed of quartz and mica (quartzite and mica-schist) (Fig. 11). Pale green pebbles are totally made of antigorite, a mineral of serpentine group, the major constituent of serpentinites (Fig. 12).

Serpentinites occur in different parts of the Alps (mainly in the West Alps) and they are associated with the Penninic Ophyolities. The larger serpentinites outcrops are present in the West Alps (Aosta Valley, Lanzo Valley, Susa Valley, Voltri Massif), 200-300 km away from the *Buso della Fadanana*. The nearest sources of serpentinites (100-150 km away) are in the Vizze Valley (Pfitschtal), Fundres Valley and Ultimo Valley (De Vecchi & Baggio, 1982; De Vecchi, 1989). Pebbles of serpentinites derived from these localities are also found in the fluvioglacial fan of the Adige river not far form this area (linear distance of about 20 km) (Bertola et al., 2013).

4. SIGNIFICANCE OF EXOTIC PEBBLES IN THE KARST FILLINGS

Part of the pebbles is certainly exotic in origin (Fig. 5). Here we consider exotic both the pebbles made up by lithologies not present in this mountain group, and the pebbles consisting in lithologies not existent in the karst system, although present in some areas of the Lessini Mountains.

It should be emphasized that the red clay matrix and the pebbles must belong to different environments. In fact, the small limestone pebbles are not present in the clay paleosols of the external environments, since these are completely decalcified. It is also evident that the flowstone fragments and the carbonate cement of the breccia are the results of processes that have taken place inside the cave, during and after the emplacement of the sediments described above.

The occurrence of exotic pebbles in the karst systems is not rare. In the Northern Calcareous Alps, dispersed on the surface or inside the karst fillings pebbles of siliceous rocks with diameters of a few centimetres can be found. They are called "Augenstein" for their dimensions similar to that of an eye (Fink, 1975; Frisch et al., 2002). Similar pebbles also occur in some dolomitic plateaux, such as Fanes, Sennes and Fosses (Bini et al., 1990, 1997) and in the Slovenian Alps (Audra et al., 2007).

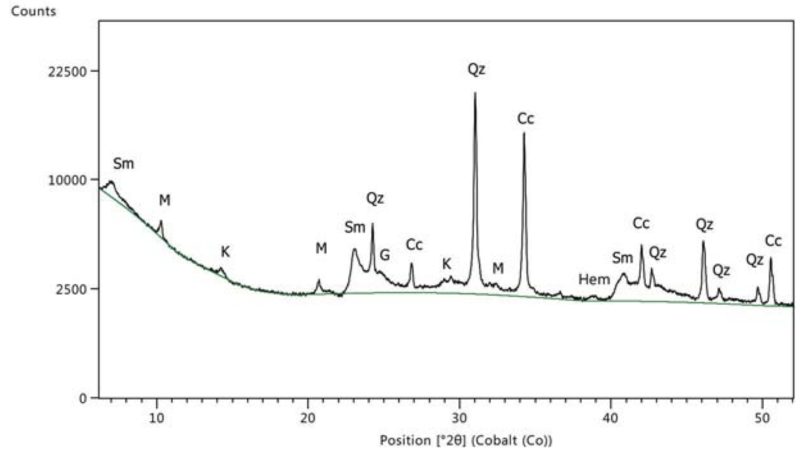

Fig. 8 - XRPD profile of the clay matrix. Legend: Sm=smectite, M=muscovite/illite, K=kaolinite, Qz=quartz, Cc=calcite, G=goethite, H=hematite.

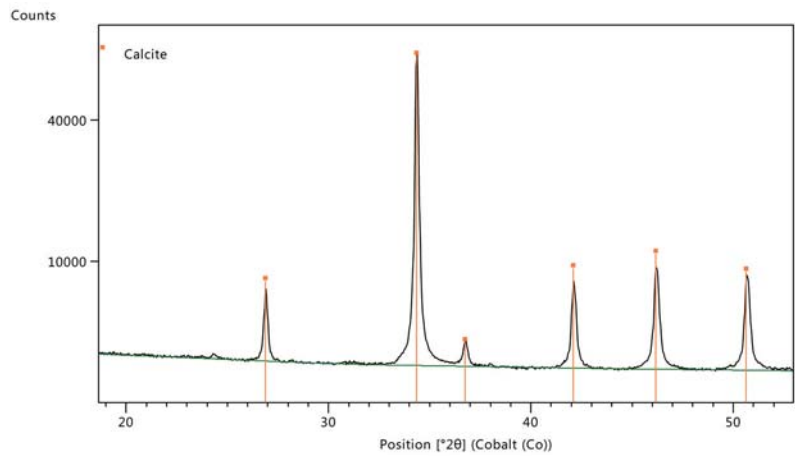

Fig. 9 - XRPD profile of grey pebbles.

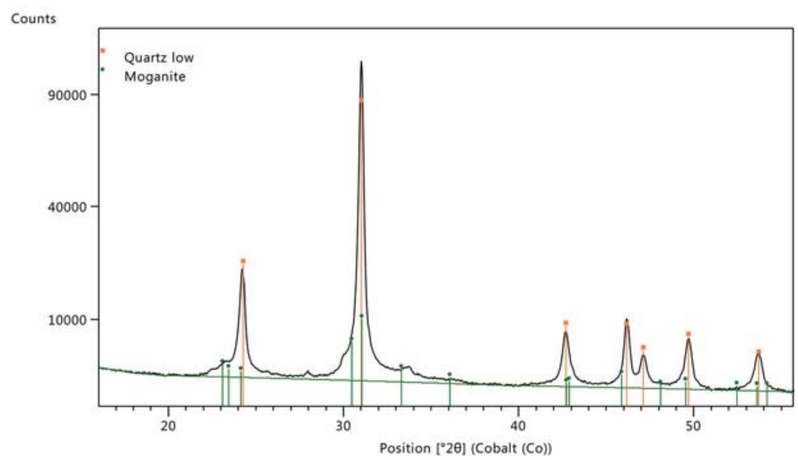

Fig. 10 - XRPD profile of white chert pebbles.

Exotic pebbles, mostly of siliceous rocks of a relatively large size range (between millimetres and several decimetres) have been found also on the plateau of the Berici, to the SSE of the Lessini Mountains (Sauro, 2002, 2005; Sauro & Ferrarese, 2016).

There are three possible general explanations for the origin of the exotic pebbles:

I) they have been transported and displaced in the area by morphodynamic agents, such as ancient glaciers and/or watercourses;
II) they belong to a completely eroded geological formation, some elements of which have been trapped in the karstic environment;
III) they are the result of "ecofacts" caused by animals.

Thus, in the case of the Dolomites it is known that the pebbles come from a recent geological formation, of which remains a small strip, trapped within a tectonic structure. Instead, in the case of the Berici Mountains, the presence of exotic pebbles has been explained as linked to the activity of a large river, which could have flattened the "plateau" surface by fluvial abrasion and then entrenched its meanders inside the uplifting relief, before the Messinian episode of desiccation of the Mediterranean (Sauro, 2002, 2005).

The case of the pebbles of the *Buso della Fadanana* Lower Complex (LMPSC, Fig. 4) is different from those previously described for the reduced dimensional range of the pebbles and for the predominance of lithologies referring to soluble rocks completely missing in the other cases described above. Therefore, these pebbles could not go through large-scale transport processes by water, that would have caused their dissolution. According to us, a reasonable explanation is that these pebbles are "ecofacts", i.e: pebbles transported by the birds which use to swallow them to help digestion, then to expel them in the form of boluses or excrements (Wings, 2004, 2007; Laudet F., Selva N., 2005; Rosin & Kwiecinski, 2011; Denys C., et al, 2017).

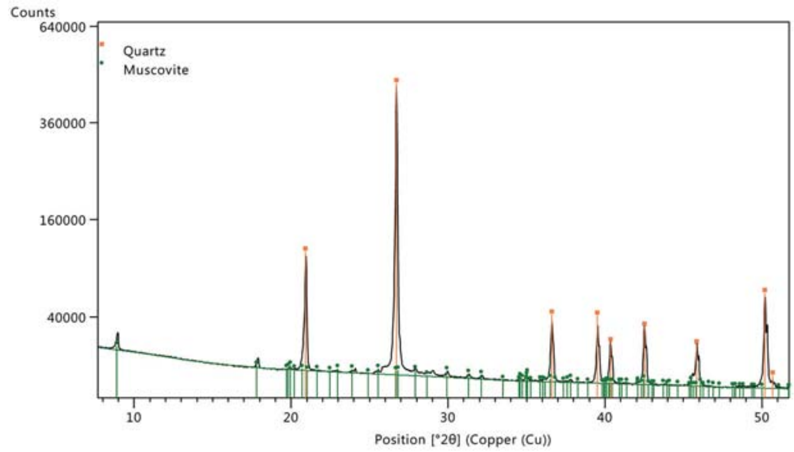

Fig. 11 - XRPD profile of black pebbles.

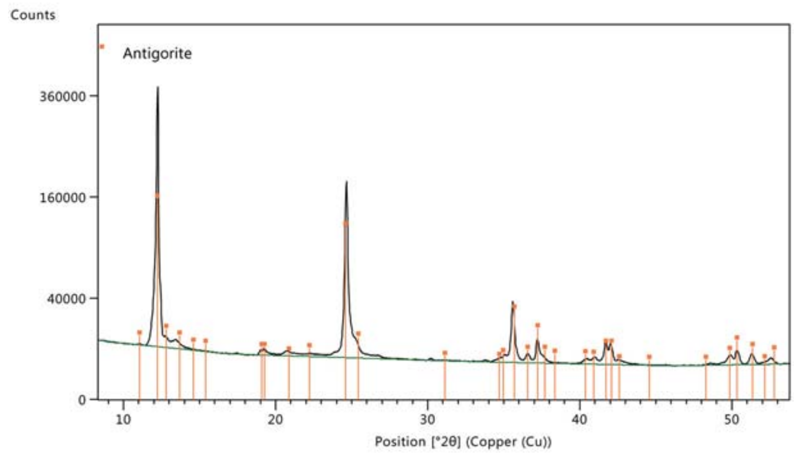

Fig. 12 - XRPD profile of pale green pebbles.

5. THE FAUNA OF THE LOWER COMPLEX

The fauna of the "lower complex" (LMPSC in Fig. 4), still under study, contains Erinaceomorpha, several Soricomorpha among which *Beremendia* sp., Chiroptera, a primate, *Macaca sylvanus*, a large sciurid, a glirid, and several arvicolids among which *Mimomys savini*, *Clethrionomys* sp., *Pliomys episcopalis*, *Pliomys coronensis*, *Dinaromys* sp., *Microtus arvalidens*, *Microtus nivaloides*.

The small mammals assemblage is characterized by Late Biharian species: *Mimomys savini* and *Microtus arvalidens* (*sensu* Fejfar ed Heinrich, 1990) and *M. nivaloides*, and the absence of the small *M. pusillus* and of *Allophaiomys*. The *Mimomys savini* zone corresponds to the large mammals Slivia Faunal Unit, referred to the reversal magneto-stratigraphic sequence between the Jaramillo Subchron and the Brunhes Chron (0,78-0,99 Ma) (Sala & Masini, 2007; Masini & Sala, 2011) (Benedetto Sala, personal communication).

These paleontological remains could be attributed, according to their excellent state of preservation, to the hunting and transport by birds (Andews, 1990; Denys C., et al, 2017; Laudet F., Selva N., 2005). Probably, the birds used, as diurnal refuges, one or more cavities above the *Buso della Fadanana*, and were transporting remains of preyed animals or regurgitating their wads containing small bones. The deposits originated by these processes have been, later, partly removed and re -deposited in the *Buso de la Fadanana* as sediments.

6. DISCUSSION AND CONCLUSIONS

The upper sedimentary complex (LHASC in Fig. 4), rich in archaeological recent Holocene finds (late Neolithic and Copper Age), is the result of repeated episodes of frequentation by man, with reworking of sediments in relation to periods of use of the cavity for burial, alternating with periods of use as a dwellings site. The accumulation of these sediments is the result of human impact on the surrounding environment during protohistoric and historic times (Sauro et al. 2007).

Considering the cave as a sedimentary trap, the sedimentation gap of about 0.8 - 1.0 myr, between the upper and lower sedimentary complex, entails important remarks. Since the *Buso della Fadanana* lacks loess-like sediments, recognized in other caves of the area, it is possible that the cavity has been sealed by the cone of large collapsed blocks (SBCB, in Fig. 4) until recent Holocene.

A detailed sedimentological study of the sediments of the lower complex has not been carried out yet, and the excavations have involved only the superficial part of such complex, thus only preliminary hypotheses may be developed about the occurrence of pebbles coming both from local geological formations and from lithologies typical of remote areas (Alto Adige Alps or even the Western Italian Alps; but pebbles made up by similar lithologies are present also in the not far fluvial and till deposits of the Adige River and Garda moraine amphitheatre). As we have seen, the possible hypotheses about the origin of exotic pebbles are:

I) the pebbles could have been transported and displaced in the area by morphodynamic agents, such as ancient glaciers, and/or watercourses;

II) the origin of the pebbles is a geological formation of the area, now completely removed by erosion, constituted by a deposit of pebbles from local and exotic provenience; such pebbles were reworked within the underground karst system, until their emplacement in the described sediments;

III) the presence of pebbles is expression of "ecofacts" of animal origin: birds could have swallowed the pebbles to aid digestion, passively transporting them and subsequently expelling them in boluses as pellets, or in excrements.

The first hypothesis seems unlikely, because glacial or fluvioglacial deposits are not known in the area (the nearest local glacial deposits are about 8 km north, and consist only of carbonate rocks; the nearest till deposits of the Adige system are located more than 10 km east and in different geomorphological contexts), and, in the case of several episodes of reworking, most of the pebbles, formed by soluble rocks would have been dissolved, and besides, based on natural morphodynamic processes, it is very difficult to explain the narrow dimensional range of the pebbles, as well as the fact that most of them are exotic in the context of this local karstic basin.

With reference to the second hypothesis, the materials from which the pebbles originate could have been a geologic formation now completely eroded (Cenozoic clastic formation of coastal or continental environment related to the lifting and erosion of the inner Alps); the metamorphic pebbles of the cenozoic clastic formation could derive from the erosion of exposed rocks of Alto Adige Alps, because ophiolite (serpentine) and gneiss pebbles from Penninic units of Tauern window already started to be eroded and redeposited by around 13 My (Kuhlemann, 2006 and Brugel, 1998); nevertheless this hypothesis implies particular conditions: the Cenozoic deposit had to be well sorted and loose because the pebbles in the lower complex breccia are always separated and the pebbles reworking had to be very low, otherwise carbonate pebbles should be missing.

Therefore, at the moment, the third seems to be the only one hypothesis capable of explaining the presence of pebbles in this context and with the features illustrated. The association of animal bones and pebbles is perhaps due to the presence in this rock wall of different environmental niches, frequented by several species of birds: both predatory birds and other birds (as: vultures, eagles, owls, ravens, etc), which may have transported animal remains as food resources; beside this, some birds, not necessarily of the same species of those related to the presence of bones of mammals, could have swallowed up and then expelled the pebbles in the karst cavities; the pebbles' origin areas could have been the nearby torrent beds of the valleys of the Lessini Mountains, and, for the pebbles in metamorphic and crystalline rocks, the riverbed and the fluvioglacial fan of the not far Adige river (linear distance of about 20 km).

The extraordinary abundance of small pebbles could, perhaps, be explained by the preferential choice of cavities open on this rock wall by birds for very long time intervals, of the order of several tens of thousands of years. It should, however, be underlined that the described sediments have unique features, very problematic and not described until now in other alpine karst areas, and that further excavations could, perhaps, help to clarify interesting aspects of the paleoenvironmental evolution of this mountain area.

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