Available online http://amq.aiqua.it
ISSN (print): 2279-7327, ISSN (online): 2279-7335

Alpine and Mediterranean Quaternary, 27 (2), 2014, 105 - 118

AN INTEGRATED RESEARCH ON THE CAPRELLE CAVES (CENTRAL ITALY): GENESIS AND PALAEOENVIRONMENTAL INFERENCES FROM THE UPPER PLEISTOCENE DEPOSITS.

Sandro Galdenzi[1], Mara Loreti[2], Anna Maria Mercuri[2]

[1] Viale Verdi 10, Jesi (Italy)
[2] Lab. Palinologia e Paleobotanica, Dip. Scienze della Vita, Università di Modena e Reggio Emilia, Italy
Corresponding author: M. Loreti <heidi52it@yahoo.it>

ABSTRACT: This paper reports on geomorphologic, geochronologic and hydrologic data, interrelated with pollen data from the sediments of the Caprelle caves, located in the Umbria-Marche Apennines. The paper is a contribution to the understanding of cave genesis.

The caves open between 795 and 880 m of altitude in the steep slope at the northern margin of the Piani di Monte Lago, and their present entrance is due to the headward erosion of a minor subsequent valley. The two caves belong to the same hydrogeologic system, even if they are not directly interconnected. The Grotta Piccola di Caprelle (GPC) is a ~100 m long tube that feeds a permanent spring, while the Grotta di Caprelle (GC) is a mainly vertical cave (76 m deep), with some sub-horizontal passages at different levels in its lower part; excluding the permanent stream in the GPC, an intense flow of vadose water occurs only in the GC during the wet periods.

The geomorphic setting suggests that the cave development begun before the deepening of the hydrographic surface. Excluding abundant clastic autogenic deposits, the cave fills are mainly calcite speleothems, fine-grained floor deposits with a minor sand content, and thin muddy wall coating. Morphological analysis shows that same processes with different intensity acted several times during the history of these caves. In particular, in GC the predominance of vertical water flows has produced an overlapping of forms and deposits, making difficult the stratigraphical analysis of continuous sequences.

Calcite and sediment samples were dated with the U/Th method. They showed that the chemical deposition inside the caves had occurred since before 92.5 ka BP, when the carving and enlargement of the caves by water flow action had already allowed the formation of concretions. The genesis of the Caprelle caves has to be placed at a moment preceding this date, when cave morphology was already similar to the present-day structure. An iron-manganese sediment sample dated to 37.6 ka BP, and the overlying thin crust of calcite on the wall gave an age of 28.4 ka BP. Pollen analysis of the sediment contributed to the reconstruction of the environmental context and permitted some inferences on climate. Pollen spectra suggest, in fact, that the sediment containing pollen, together with gravels and sand, might have episodically deposited during short dry/cold, and probably wet/cool climatic phases, as expressed by steppe, grassland and a poor woodland cover.

Keywords: Quaternary, karst caves, geomorphology, geochronology, palynology, palaeoenvironment, Late Pleistocene, central Apennines, Italy.

1. INTRODUCTION

Epigenic caves are common throughout the mountain chain of the Umbria-Marche Apennines, in central Italy (Galdenzi, 1988, 1996; De Waele et al., 2014). These caves are related to fast surface water flow circuits and are formed by the dissolution action of the CO_2, which is present in infiltrating meteoric water. Two main types of caves are common in the area: vertical shafts that open on the mountain upper surface, and active or temporary active emergences at foot of the mountain, generally located few tens of meters above the local base level.

The caves presented in this paper are located near the Agolla Village in the commune of Sefro (Macerata, Marche; Fig. 1). They represent an atypical situation in the region, as a mainly vertical cave, the Grotta di Caprelle (GC), is almost directly connected with a horizontal active emergence, the Grotta Piccola di Caprelle (GPC), at high elevation in the mountainside. The general features of the caves and their relation with the geologic setting have been described elsewhere by Galdenzi (1983) and Galdenzi et al. (2008).

This paper reports on new data on geomorphology, geochronology and hydrology of the caves, and presents pollen analyses carried out on sediments collected into the caves. Although the complexity of their morphology makes it difficult to interpret unambiguously the stratigraphic situation, this study contributes to understanding cave development in the area and provides suggestions on which palaeoclimatic and palaeovegetational conditions existed in the region during the latest Quaternary.

2. THE STUDY AREA

2.1. Geographical and geological setting

The studied caves are located in the inner ridge of the Umbria-Marche Apennines, 60 km from the Adriatic Sea, between the valleys of the rivers Chienti in the south and Potenza in the north (Fig. 1a). The mountain chain consists of northeast verging folds and thrust belt, involving the mainly carbonate rocks of the Umbria-Marche Meso-Cenozoic sequence (Minetti et al., 1991, and references therein). Specifically, in the cave area, there are two main overthrusting anticlines trending N-S and formed by Jurassic and Early Cretaceous units; they are divided by an interposed synform structure with Upper Cretaceous and Paleogene deposits, that comprises two main synclines (Mt. Lago and Agolla) (Fig. 1b). The eastern anticline (Mt. Torroncello-Mt. di Mistrano) overthrusts the Miocene terrigenous sequence outcropping

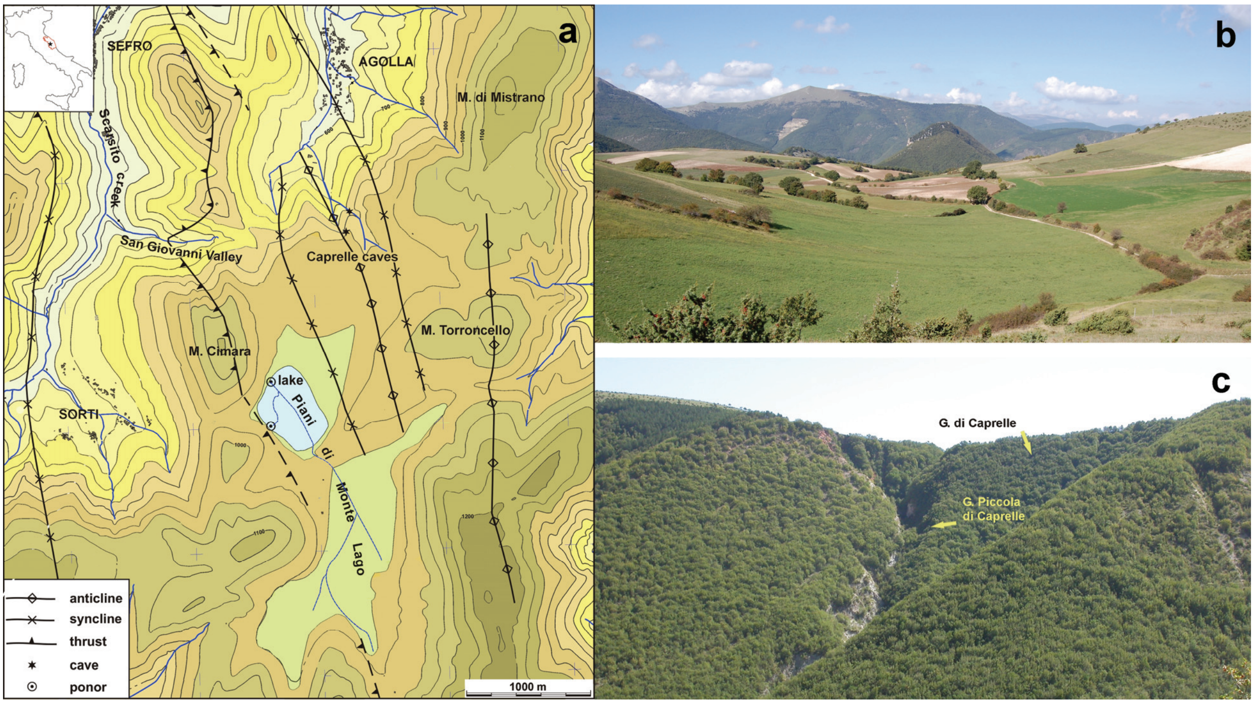

Fig. 1 - Study area: a) location map; b) the upper part of the valley, above the entrances of the two caves; c) the steep slope at the head of Agolla valley, with the location of the caves.

at the foothill (Mt. Primo - Mt. Cavallo thrust) (Calamita & Pierantoni, 1993), while the inner one (Mt. Cimara anticline) has a minor throw on the carbonates of the interposed syncline. This syncline corresponds to a morphological depression and comprises some minor folds. The chain has been in part dissected by Plio-Quaternary normal faults.

One of the most important geomorphic structure of the area, the Piani di Monte Lago, formed by two close depressions, almost 2 km wide developed in the central syncline. This morphological structure represents a remnant of the erosion surface that evolved during the Late Pliocene and Early Pleistocene, when in the whole area large paleovalleys formed into a pre-existing "planation surface" (Ciccacci et al., 1985). The regional uplift at the end of the Early Pleistocene enhanced the linear erosion in the river valleys that entrenched into the old surface producing the present deep valleys (Ambrosetti et al., 1982; D'Agostino et al., 2001; Bartolini et al., 2003).

The surface drainage is scarce in the limestone outcrops at the surface of the mountains, where a diffuse autogenic recharge feeds the karsic circulation of water, though typical surface landforms, as dolinas, are uncommon. In the syncline, the two close areas of Piani di Mon-

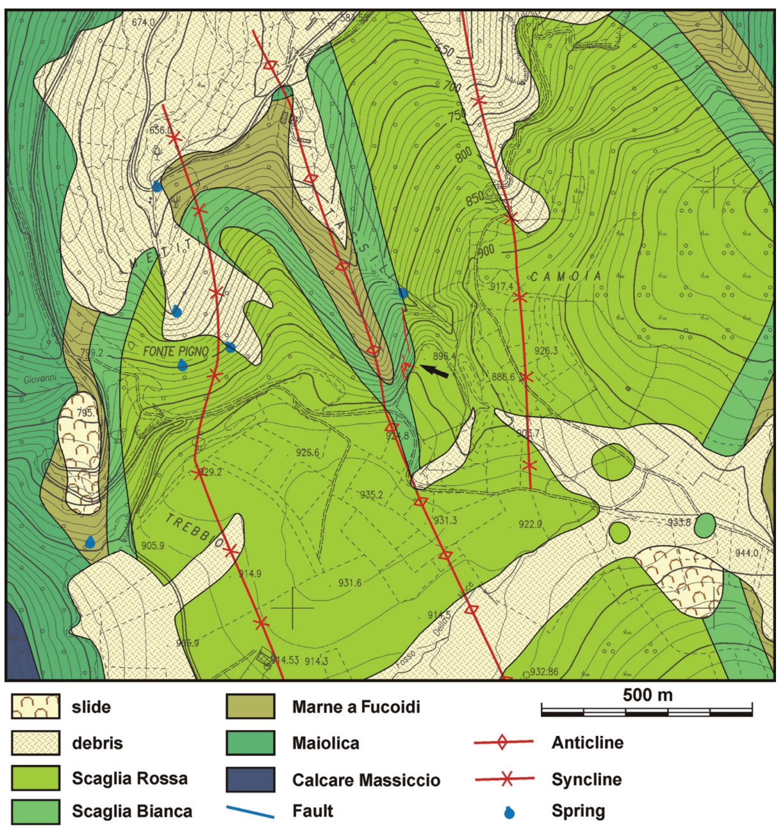

Fig. 2 - Geologic map of the study area (after Galdenzi *et al*., 2008, modified).

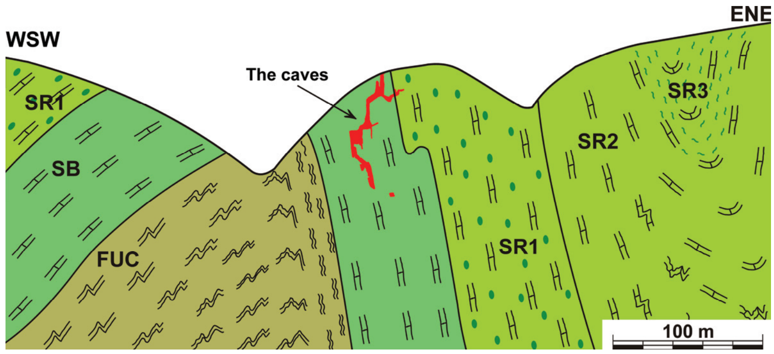

Fig. 3 - Geologic cross section at the cave entrance. Legend: FUC: Marne a Fucoidi; SB: Scaglia Bianca; SR1: Scaglia Rossa, lower part; SR2: Scaglia Rossa, central part; SR3: Scaglia Rossa, upper part.

te Lago are filled by thin sediments and drained by a ponor. These two poljes were joined through a deep artificial trench dug in 1458 to facilitate the drainage of the upper polje (Falaschi, 1987). After rain periods and during the snow melting, a wide temporary lake is formed in the lower plain.

At North, the valley of the river Potenza incised transversally the mountain ridge, and the steep head of its southern tributaries reaches the margin of the Piani di Monte Lago, in the area where the studied caves are located (Fig. 1c).

Particularly, the caves developed in the central synform structure, formed in the thin-bedded Cretaceous formations (Maiolica, Marne a Fucoidi, Scaglia Bianca and Scaglia Rossa) (Fig. 2). In detail, both the caves open in the vertical eastern limb of a minor anticline that divides two main synclines, and are wholly comprised in the upper member of the Scaglia Bianca formation (Fig. 3). The Scaglia Bianca (Upper Albian-Lower Turonian) comprises two members: the upper one is ~30 m thick, and is formed by white limestone with black chert beds; while the lower member consists of ~30 m thick body of whitish marly limestone with chert beds. The underlying formation (Marne a Fucoidi, Lower Aptian-Upper Albian) is an alternation of polychrome marls, marly limestones and marly claystones, with a total thickness of ~40 m. The overlying Scaglia Rossa (Lower Turonian-Lutetian) is formed by reddish limestone, and comprises levels with different contents of chert or marl, and has a total estimated thickness of ~250 m. Scaglia Bianca and Scaglia Rossa form a permeable hydrogeological complex, while the underlying Marne a Fucoidi represents an aquiclude interposed between the Scaglia hydrogeological complex and the underlying Maiolica (Upper Tithonian-Lower Aptian), which is another thick, permeable carbonate unit.

The attitude of the low-permeable marlstone (Marne a Fucoidi) has an important influence on the groundwater drainage, dividing the Scaglia aquifer in the core of the synclines from the underlying permeable limestone. For this reason, small springs are in the lower part of the Scaglia complex at the head of the Agolla valley (Fig. 2). One, perennial, is located near the entrance of the GPC, at a high elevation above the local base level, and is fed directly by a stream flowing in the cave.

2.2. Modern vegetation

The Marche region is part of the Apennine-Balcanic biogeographical province. The most characteristic vegetation series include the hop hornbeam series in the meso-temperate belt, and the low mountain mixed beech woods in the supra-temperate belts (Biondi et al. 2010, p. 255).

The area around the studied caves shows a typical vegetation of hill-mountain elevations (e.g. Biondi et al., 2014).

The mountain landscape, located at 800-900 m a.s.l., has a homogeneous and uniform morphology with a soft outline and gentle slopes, in some cases planted with cereals or fodder crops. In the steep side of the mountains facing to the North, at the cave entrances, the vegetation is characterized by a copse wood with predominance of hop hornbeam (*Ostrya carpinifolia* Scop.) and south European flowering ash (*Fraxinus ornus* L.). Also lindens (*Tilia platyphyllos* Scop., *T. cordata* Mill.) and ivy *(Hedera helix* L.) live near the entrance of the cave complex. In the southern side, there is the pubescent oak (*Quercus pubescens* Willd.), thermophilous broadleaved that prefers calcareous and marl slope soils and doesn't tolerate hydro-stagnation. Moreover, there are *Staphylea pinnata* L., a rare small tree with vesicle fruits, and *Daphne laureola* L., *Hepatica nobilis* Schreb., *Dactylorhiza maculata* (L.) Soó, *Campanula trachelium* L.

Semi-mesophilous pastureland, formed by *Bromus erectus* Huds., is especially developed on the top of hill-mountain while xeric pasturelands are spread on sunny and partially eroded slopes. On calcareous rocks exposed to the south, there is the holm oak (*Quercus ilex* L.); inside the valley hygrophilous vegetation is present, composed by several species of willows, such as *Salix purpurea* L. and *Salix alba* L., both common along the banks of Scarsito Creek.

3. THE CAPRELLE CAVES

A geological survey inside the cave and in the surroundings, together with the analysis of cave morphologies and deposits, was made to define the conditions of the cave development and history. The existing cave long section (Galdenzi, 1983) was revisited and corrected after a detailed survey with a hydraulic digital level. This permitted to verify the absolute altitude of the different cave zones, and to re-drawn the cave map and long section. This revision was necessary to reconsider the old rough magnetic survey (Galdenzi, 1983), made with a grade 4 BCRA, where the bottom of GC resulted deeper than the permanent stream in GPC.

The present hydrologic characteristics of groundwater drainage were monitored in the cave into a more general research on the groundwater hydrology of the whole area, thank to a logger for temperature, level and conductivity that was placed for one year in the perennial stream inside the GPC.

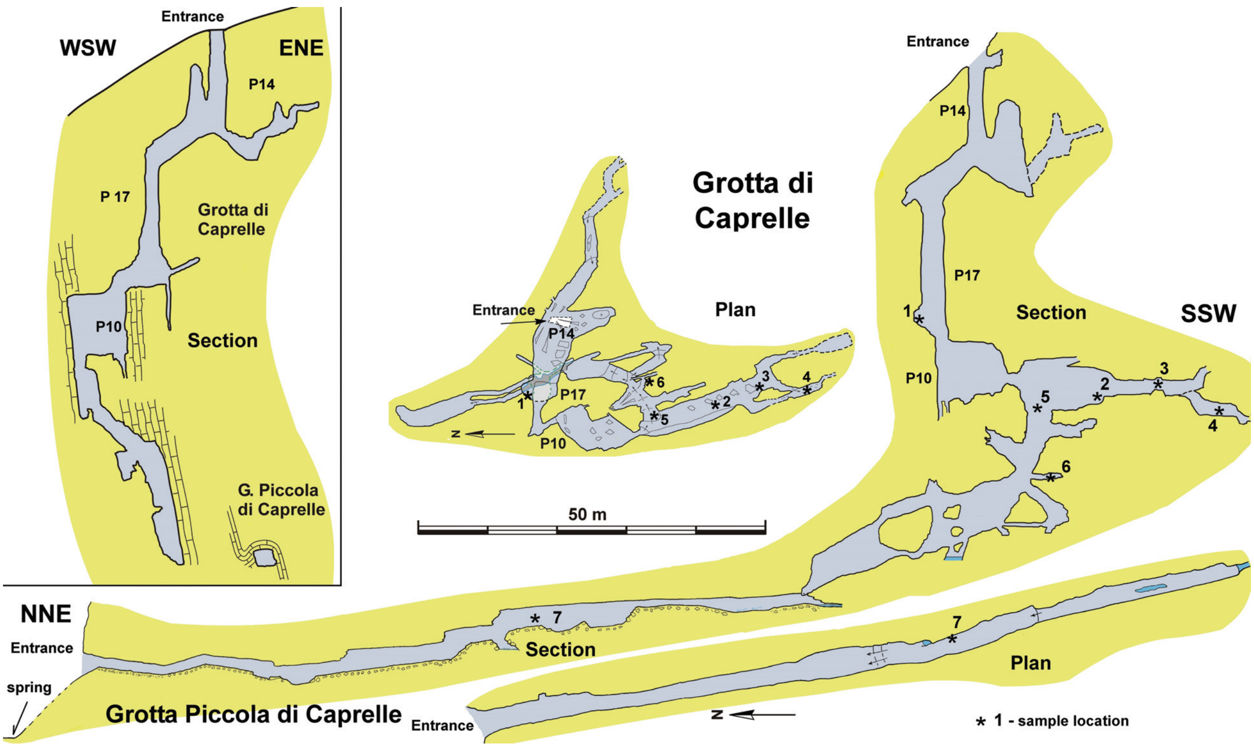

Fig. 4 - Map of the caves, and localization of pollen samples (*). The cave section NNE-SSW is projected on a vertical plane along the bedding strike, and the ENE-WSW section along the bedding dip. survey: Grotta di Caprelle - Galdenzi, 1977-79; Galdenzi and Cotechini, 2009; Grotta Piccola di Caprelle - Galdenzi *et al.*, 2008.

3.1. General characteristics (Fig. 4)

The caves have different morphologies. Both the cave entrances open in the steep slope at the northern margin of the Piani di Monte Lago, below the slope break that divides the upper part of a gentle valley from the actively eroded head of the minor tributaries of the River Potenza. The headward erosion in this subsequent valley is the cause of the present opening of the caves to the surface. At 880 m a.s.l., a steep slope cuts the entrance shaft of GC, while at 795 m a.s.l. the GPC entrance opens in the deepest part of the small ravine formed by the stream.

GC is ~200 m long and reaches a depth of 76 m. An upper part consisting mainly of a sequence of shafts (maximum length 17 m) reaches a more complex zone with some sub-horizontal passages at different levels. Steeply inclined passages are present throughout the cave. GPC is only a sub-horizontal passage with an average diameter of ~2 m, without lateral branches, and reaching a total length of ~100 m, while rising ~10 m higher than the cave entrance.

The bottom of GC is close to the termination of the GPC, and the new measurement with a digital level shows that it stays above the stream in the GPC, which is different than in the old maps created with rougher surveys. The expeditious plan of the caves makes uncertain their real horizontal distance, and there are no useful elements to suppose the existence of a practicable direct connection.

The general pattern of the cave is strongly influenced by the geological setting (Galdenzi, 1983). Both caves developed inside a few beds of the Scaglia Bianca (Fig. 2), and the shafts and passages developed along the vertical beds of the limestone. GPC, in particular, strictly follows the core of a meso-anticline.

GC, despite its short development, has a complex structure resulting from the combination and superimposition of different types of cave passages. The upper part has mainly vertical development (Fig. 5). The entrance shaft and a parallel shaft join in the first cave room, leading to a further descending shaft (P17 in Fig. 4).

At the bottom of this last true shaft, a small inclined passage leads to the top of a large room where the cave structure changes, assuming a mainly sub-horizontal development. Some tubes (Fig. 5b) are present at different levels; these horizontal passages have no present active hydrological role in the cave, and are intersected by steeply inclined passages or by vertical zones.

Inclined passages are in both the upper and lower parts of the cave, generally with active seasonal water flows. An ascending branch departs below the entrance shaft, small rising passages are below the P17, a steep descending zone connects the central rooms with the lowest zones, and an ascending passage is in the southern termination of the cave.

The present cave morphology in many zones is influenced by breakdown and clast detachment, which can erase the original forms. Old corrosion features are preserved in some tubes (Fig. 5d) and in small areas of the cave walls and roofs, where they are often mixed

Fig. 5 - a) The cave entrance, a shaft in the steep slope cut by the surface erosion (Photo by Eugenio Pistolesi); b) A cave tube in the deep zone of the Grotta di Caprelle; c) Soft mud flowing in the wall due to seepage water, which has an encrusting action on the mud itself; d) Old deposits in a pocket in the ceiling, and e) on the cave walls (one pollen sample was taken from this point).

with more recent physical deposits due to descending water. The running water locally produces active forms of corrosion, and flowstone deposition is actively occurring in the cave, even if the chemical deposits do not generally reach a large diffusion and thickness. Gours are forming in the inclined active passages.

GPC has a simple structure, consisting of a single sub-horizontal passage, while clast detachment from the roof is the main morphogenetic agent, and the floor is entirely formed by fallen small boulders and cobbles. In the cave, an active deposition of dripstone is scarce or absent due to the lack of seepage water. The detachment process has almost completely destroyed the pre-existing wall features, and only in a few points old erosional and depositional forms are preserved in the cave walls.

The two caves have different hydrological behaviours. In GC, a strongly variable flow of vadose water occurs during the year. During the dry periods, a reduced amount of seepage water causes calcite deposition in a large part of the cave, while during the rainy period, and in particular during the snow melt, a diffuse flow of seepage water occurs in the cave. The descending water flows as a sheet on the floor of the inclined passages and creates small streams that partly intersect the main voids. During the wet periods, several temporary pools form mostly in the lower branches of the caves. GPC, on the contrary, is almost totally devoid of dripping water, while a permanent stream flows in the inner part of the cave and feeds the permanent spring that gushes out below the cave entrance. The water flow occurs mainly within the debris in the floor, and in only a few points the water runs directly in the passage. The water discharge is low, and in normal conditions does not exceed a few litre/second of volume flow rate. Based on the geologic setting, a direct recharge from the ponors should be excluded, considering that they drain water inside the underlying Maiolica in a different syncline.

The water characteristics were monitored for one year (September 2006-September 2007), thanks to a logger placed in the stream, and the water was sampled bimonthly for its chemistry. The water drainage in the cave was permanent. The measured changes in the water level did not exceed a few centimetres in the stream, but the presence of dry pools with muddy deposits suggests that in periods with more rain the water level can rise inside the bottom debris, reaching the cave floor at a few further points.

The cave water has a relatively low

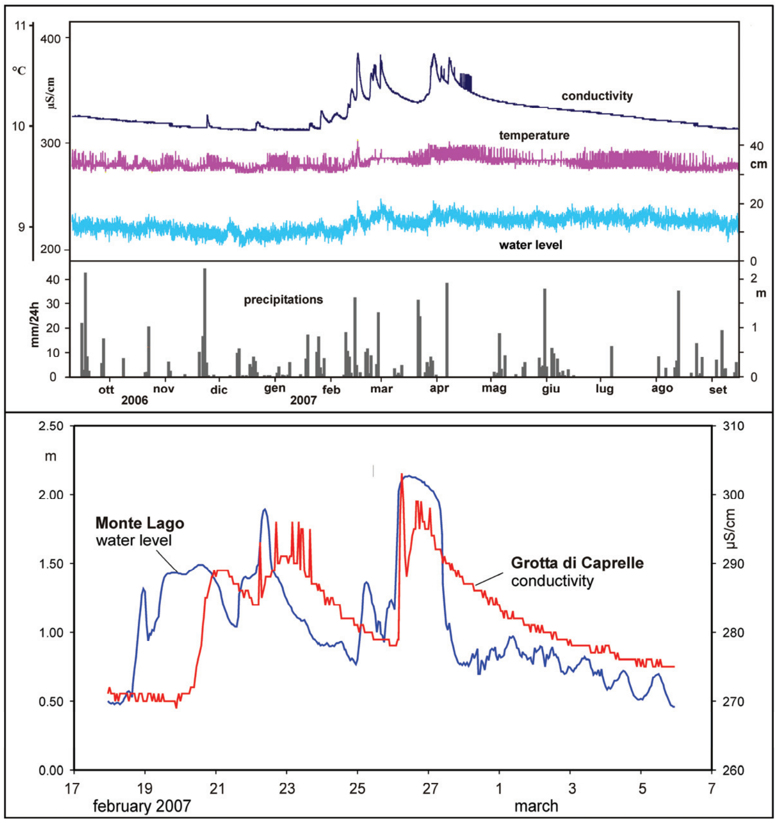

Fig. 6 - Top: Conductivity, temperature and water level in the cave, related to precipitations during the monitoring period. Bottom: Hourly changes of the water conductivity in the cave stream, compared to the water level in the temporary lake of Monte Lago.

Caprelle Complex	room/shaft	pollen sample	depth (m) from the entrance of caves	Dating Th/U	Notes/description
Grotta Grande	base 2nd shaft	1	35		silt sediment - presence of organic material
	tube at the base of 3rd shaft	2	45		silt sediment - scarce presence of organic material
	tube at the base of 3rd shaft	3	50	48,2 Ky - stalagmite	silt sediment collected among the stalagmites - scarce presence of organic material
	tube at the base of 3rd shaft	4	55		silt sediment collected around bottom bowles - scarce presence of organic material
	base 3rd shaft	5	45		silt sediment (pocket on the wall) - presence of organic material
	collapse room at the base of 3rd shaft	6a	60		silt-clay sediment - presence of organic material
	collapse room at the base of 3rd shaft	6b	60.1		silt-clay sediment - presence of organic material
	collapse room at the base of 3rd shaft	6c	60.2		silt-clay sediment - scarce presence of organic material
Grotta Piccola	sez.E tube	7	70	37,6 Ky black silt - iron and manganese	debris rich of black iron and manganese oxides, dehydrated and dry - scarce presence of organic material

Tab.1 - Pollen samples taken from the Caprelle caves.

salinity (about 210 mg/l) and is mainly bicarbonate, with low sulphate and chloride contents. The water parameters have low seasonal fluctuations: the average temperature and conductivity were 9.6°C and 328 µS/cm (at 20°C) (Fig. 6). The lowest conductivity value (312 µS/cm) was measured during a dry period, and the values increased up to 384 µS/cm during the period of high discharge. The water temperature varied with a similar trend between 9.5 and 9.8°C.

The stable chemical and physical parameters of the cave water testify to the storage capacity of the aquifer that feeds the spring. The small increase in the water conductivity during the wet season is closely related to the meteoric precipitation (Fig. 6).

The hydrological data confirm that the water sunk in the Mt. Lago ponor has not an important role in the recharge of the cave stream, and it is likely fed through diffuse infiltration in the Scaglia Bianca and Scaglia Rossa on the karst surface. In fact, the increase in temperature and conductivity in the cave water cannot be due to the direct arrival of cold and low mineralized water from the sinking points. Besides, the increase in the conductivity and water level in the stream occurred with a significant delay, compared to the changes that were recorded in the surface stream at the ponor and in the main known resurgence (Galdenzi, unpublished data).

In addition to widespread clastic materials, dominant in both caves due to the thin bedding and high plicative deformation of the bedrock, different types of physical and chemical deposits are present. They are more abundant in GC, where the depositional processes are still active. Only small old deposits were found in the walls of GPC.

3.1.1. GC - Grotta di Caprelle and GPC - Grotta Piccola di Caprelle

Dripstones, flowstones and gours are actively forming in a large part of the Grotta di Caprelle (GC), even if they only reach a large volume locally. This encrusting action due to seepage water is sometimes associated with a slow flow of a thin layer of soft sediment that covers the wall (Fig. 5d). A thin old coating of black sediment, containing Fe and Mn oxides and hydroxides, locally covers the cave walls. A similar deposit is also present in Grotta Piccola di Caprelle (GPC).

Sediment deposits containing thin levels of cherty sand are common in the cave, deposited by the descending water that flows inside. Some of these deposits are sub-recent but most of them are attributable to ancient depositional events: the latter deposits remain as suspended deposits in the roofs or inside pockets in the walls (Fig. 5e).

In GPC, the floor is covered by clastic debris fallen down from walls and ceiling. This process is still active and thus unstable. Partly detached rock pieces are common in the ceiling. Only in a few points there are old deposits preserved in the cave walls, testifying to past moments of the cave evolution. The lack of any recent significant morphogenetic role of the seepage water simplifies their analysis. Small amount of old calcite deposits are locally present as dripstones, flowstones and thin wall sheets.

The most interesting depositional sequence is preserved in the eastern wall of the central part of the cave (analysed for pollen, see below). The wall shows clean eroded surfaces, without scallops, with notches in the wall and small holes developing along the ceiling fractures. The cave wall and calcite deposits are heavily fractured, with open fissures up to a few centimetres wide caused by the decompression processes responsible for the diffuse clast detachment in the cave. The limestone surface is in large part covered by a thin sheet of crystalline calcite forming small stalactites, deposited by seepage water coming from the surface, and by a thin coating of black sediment which is rich of Mn and Fe hydroxides. This black sediment underlies the calcite sheet.

In GCP, in the lower part of the same wall, small stream deposits, consisting of intra-formational gravel with an abundant sediment matrix, stay on small wall notches. The pebbles are often coated by black sediment, as with the nearby wall. Gravel deposition by the stream alternated with the encrusting action due to seepage water, so that the stream deposits are encrusted by calcite, but can also stay above the carbonate sheet in wall notches. This complex relationship is evidence that calcite deposition by the vadose water coeval with the gravel deposition due to the stream, prevailing the one or the other process depending on changes in the hydrological conditions.

3.1.2. Chronology

Several samples were dated with the U/Th at the IGAG-CNR Laboratory, at Montelibretti, Roma (Voltaggio, 2010): i) in GCP, a small stalagmite, found at the surface of the ground debris in the cave termination, has a radius of 2 cm and is 6 cm long; the age of core and surface are 92.5±3.4 ka and 48.5±1.3 ka, respectively; ii) in GC, a stalagmite coming from the central zone (point 3 in Fig. 4) is asymmetrical and grows directly on a boulder with an interposed, thin and discontinuous layer of detrital material; its length reaches 14 cm and maximum radius of 6 cm, while there is no macroscopic evidence of internal discontinuities; the age in the core of the stalagmite resulted in 48.2±1.7 ka BP, while the surface has an age of 4.1±0.3 ka BP; iii) a thin crust of calcite on the wall of GCP has an age of 28.4±1.2 ka; iv) an iron-manganese black sediment gives an age of 37.6±0.6 ka in GCP (the latter two are described in par. 3.4.2).

4. POLLEN ANALYSIS

4.1. Pollen samples

Nine sediment samples were collected for pollen analysis aiming to study the palaeoenvironmental characteristics during the cave formation. The sampling points were selected to avoid the risk of contamination by modern pollen (Tab. 1).

In GC, pollen samples were collected between 35 and 60 m from the cave entrance. Sample 1 is the nearest to the entrance. Samples 2, 3, 4, 5 come from the main sub-horizontal passage below the shafts, in an area containing many old deposits preserved on walls and the ceiling. In particular, sample 2 was collected from a notch in the wall and sample 5 in a wall pocket (Fig. 5e). The samples 6 a,b,c were close, in a clino-stratified deposit below a steep passage, not directly involved in the current flowpath of running vadose water.

In GPC, sample 7 was taken at about 70 m from the entrance and was dated at ca. 37.6 ka BP (see above; Fig. 4).

The samples have been treated for pollen extraction using a concentration method (sieving, and floatation with heavy liquid; for a description see Florenzano et al., 2012). The residues were partly mounted in glycerine jelly, and slides were directly observed or permanently sealed with paraffin. All the treated material was analysed. Pollen analysis was done by light microscope at 400x, and at 1000x for critical identifications, with the help of atlases (e.g. Reille, 1992) and the reference pollen collection. The pollen percentages were calculated on a sum which includes all pollen grains identified (Spermatophytes = trees + shrubs + lianas + herbaceous; Berglund & Ralska-Jasiewiczowa, 1986).

4.2. Results of pollen analysis (Tab. 2; Fig. 7)

In three samples (4, 6c, 7) a light presence of calcium carbonate resulting from the alkaline substratum did not allowed sufficient pollen preservation. Therefore, only the row number of counted pollen grains (sum < 40) is reported in Tab. 2.

In the other six samples (1, 2, 3, 5, 6a, 6b) pollen preservation was good, but the amount of pollen was so low in each slides that the analyses were time-consuming. A mean count of about 190 pollen grains per sample was attained. Although the preservation of most pollen grains was good, it is probable that some loss of pollen occurred (Berglund & Ralska-Jasiewiczowa, 1986; Horowitz, 1992). This is supported by the presence of high amount of Cichorieae in all samples (*sensu* Florenzano et al. 2014; 10% on average). The Cichorieae pollen has very resistant exine that survives even when some selective corrosion destroyed the thin pollen grains (e.g. Cupressaceae).

The mean pollen concentration was about 450 pollen grains/g (p/g). Although this value is very low, it may be considered relatively high compared with the low concentrations found in other cave deposits of central Italy (e.g. 242 p/g were observed in Grotta di Valle delle Vacche, Abruzzo; Loreti & Mercuri, 2007).

As a whole a list of 56 taxa (21 of woody plants, and 35 of herbaceous plants) was compiled. The sum of woody plant percentages resulted 20-40% in samples 1,2,3,5, and about 70% in samples 6a,6b.

Among conifers, *Pinus* subgen. *Strobus, P.* subgen. *Pinus* (they correspond to *haploxylon* and *diploxylon* pine pollen types, respectively: Fralish & Franklin, 2002, p. 59) were found with *Abies*, *Picea* and *Cupressus*. Among broadleaved trees, there were *Alnus*, *Betula*, *Fraxinus ornus* type, *Salix, Tilia*. Also few deciduous *Quercus*, *Castanea* and *Erica* were identified. In total, there are low values of oak wood (2% on average). Asteraceae including *Artemisia* (2%), *Ambrosia*, *Aster, Centaurea*, *Crepis* cf., Cichorieae, Asteroideae undifferentiated (17%) and Poaceae (12%), with Cyperaceae (3%), were predominant in the herb taxa.

4.3. Pollen supply into the cave

Cave deposits are known to be generally poorly preservative for pollen because alkaline or oxidised substrata are common and may destroy exine, the external pollen wall (Navarro Camacho et al., 2000, 2001; McGarry & Caseldine, 2004). However recent research of terrestrial carbonates from central Italy documented that the pH of the solutions from which travertine or tufa precipitate is not a limiting factor in causing corrosion and/or destruction of pollen grains (Bertini et al., 2014). Moreover, pollen sources (*i.e.*, plants) grow outside the cave and therefore the amount of pollen in sediments largely depends on the cave morphology. Pollen could enter the caves by: 1) air from the entrances; caves could have only one break with limited exposure to the air or, differently, many openings with air flow entrance. Any supply of pollen circulating in the atmosphere is obviously poorer into the cave, particularly in deepest sectors and away from the entrance, than in open spaces; 2) water, by seepage or underground flow; 3)-animals, by paws, fur, body or excrements (Garofalo et al., 2009). Pollen already included in sediments can enter the cave by water or animals transporting the sediments.

In these study, the presence of pollen into the caves is a good evidence that some organic material arrived from outside into the caves. Considering that GC has mainly a vertical structure, and pollen samples were collected deep inside the caves, the pollen was probably transported by water, the carrier that may have equally filled the underground sectors of these caves.

Pollen of oak and other elements typical of mixed oak woods have low values in the studied pollen spectra, and this may be due to different reasons: considering the known high productivity of oaks this may be a further evidence that wind-transport inside the caves was low, or/and that in the nearby of this cave a mixed oak woodland was absent at the time of deposit formations.

4.4. Palaeoenvironmental inferences

Pollen spectra are prevalently characterized by a low percentage of trees/shrubs and by a prevalence of pollen produced by plants growing in grassland or steppe vegetation. As a general remark, woodlands seem to have always been at a certain distance from the water flooding pathways, or from the opening of the cave itself. Another possibility is that mesophilous elements were quite rare as in other central Italian regions (Follieri et al., 1998; Magri 1999; Magri and Sadori 1999; Chiarini et al., 2007; Giardini, 2007).

Pinus and *Artemisia*, which are, during the latest Quaternary, the main makers of glacial phases with cold climate and steppe vegetation, are ubiquitous in these spectra as well as Poaceae and other Asteraceae. However they are always accompanied by low values of deciduous *Quercus* and other broadleaved trees suggesting that these spectra do not belong to full glacial phases or that the temperature was probably not too cold or that the humidity was enough even during glacial phases. Actually, thermophilous and mesophilous plants are known to have survived in refugia also during the acme peak of the glacials in Italy (Follieri et al., 1988,

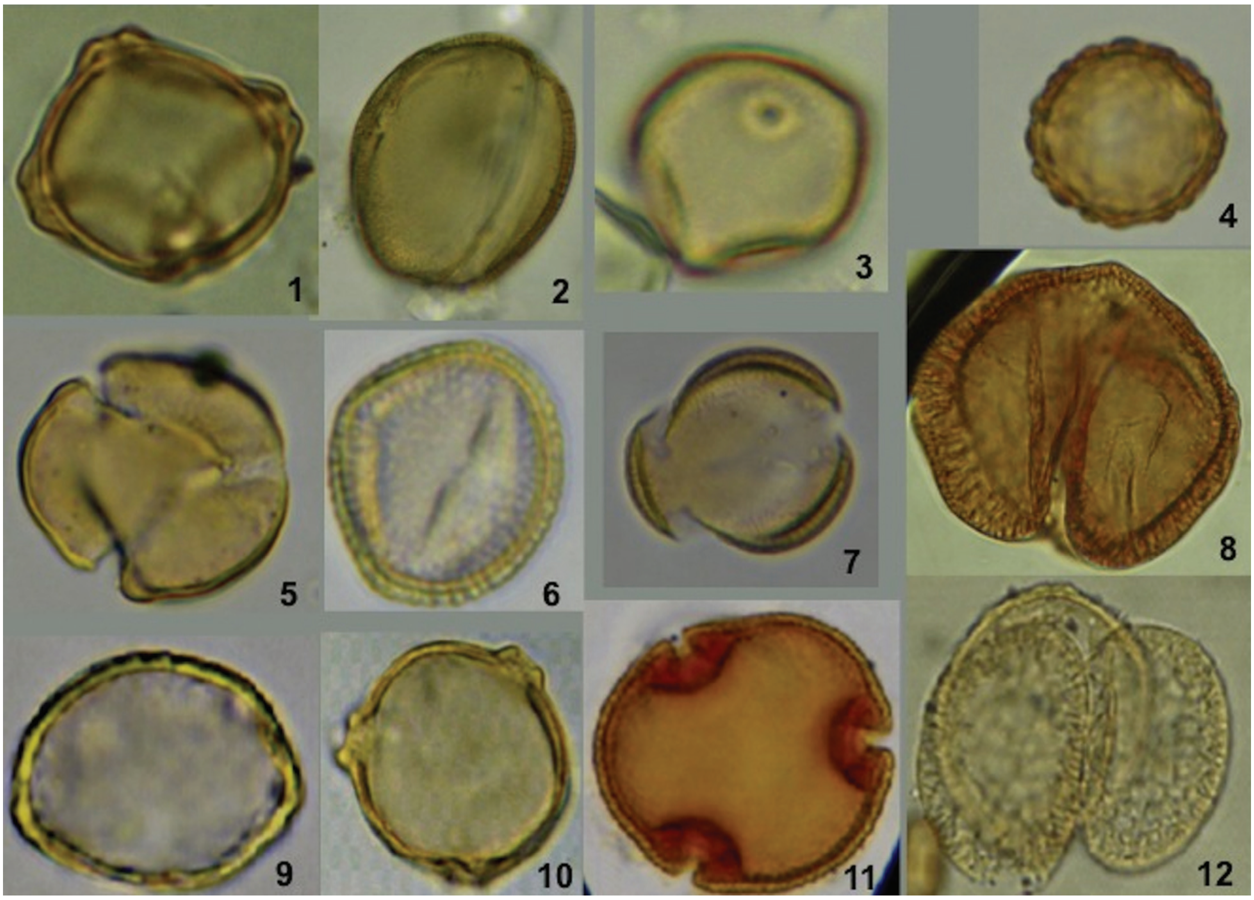

Fig. 7 - Pollen grains from the mud samples of Caprelle caves: 1) *Alnus* (29 μm); 2) *Helianthemum* (30 μm); 3) Poaceae (40 μm); 4) *Plantago media* type (23 μm); 5) deciduous *Quercus* (29 μm); 6) *Fraxinus ornus* type (24 μm); 7) *Artemisia* (24 μm); 8) *Picea* (110 μm); 9) *Ulmus* (29 μm); 10) *Ostrya* (26 μm); 11) *Tilia* (43 μm); 12) *Pinus* subgen *Pinus* (75 μm) (Photos by Mara Loreti).

1998; Magri, 1989, 1999; Allen & Huntley, 2000; Watts et al., 2000; Follieri & Magri, 2001; Tzedakis et al., 2001; Yll et al., 2006; Bertini, 2010; Facenna et al., 2008; Pini et al. 2010; Moreno et al., 2014).

In samples 1, 2, 3, 5 pollen diversity ranges from 26 to 36 taxa per sample. The woodland cover is always < 40% and includes *Pinus* subgen. *Pinus* (almost one third of *P.* subgen. *Strobus*), and several deciduous trees (*Quercus*, *Betula*, *Fraxinus* cf. *excelsior*, *Tilia*; Tab. 2). Conifer woods were probably distributed on mountains, sometimes mixed to deciduous trees as *Betula, Tilia* and *Castanea* while mixed oak woods were probably more distributed on the hilly belts. *Hedera* was part of the broadleaved woodlands while *Alnus* and *Salix*, the latter especially well represented, are evidence of the hygrophilous woodland that was distributed along river shores. Spectra show evidence of wet grassland (Poaceae, Cyperaceae), and xerophilous associations with Chenopodiaceae, Cichorieae and *Artemisia*; other Asteroideae, Brassicaceae, Caryophyllaceae, *Helianthemum*, Rosaceae may be part of shrubby grassland vegetation.

Only samples 6a and 6b show a higher value of arboreal pollen sum (ca. 70% on average) mainly due to the predominance of *Pinus* (here subgen. *Pinus* is double than the subgen. *Strobus*), and to relatively high amount of *Quercus* types. It is noteworthy that in these two samples, there are the only evidences of *Quercus* cf. *cerris*, *Cupressus* and *Ulmus*; *Picea* has the highest values while *Abies*, *Betula* and *Tilia* are absent. There are several signs of aridity: hygrophilous trees are low and represented only in sample no. 6b; among herbs, Cyperaceae and *Nymphaea* are absent. Actually, these two samples show the lower pollen diversity (number of taxa = 15, 21) and describe a more forested, cold and dry environment with respect to the above-described samples.

Altogether, pollen spectra are concordant with the geochronological context of the caves (see above par. 3.1.2). They are in agreement with data from glacial phases within the interval 37-28 ka BP in Italy, as studied at Lagaccione (Magri, 1999), Valle di Castiglione (Follieri et al., 1988; Magri, 1989; Follieri & Magri, 2001), Vico (Magri and Sadori, 1999), Stracciacappa (Giardini, 2007), Corvaro (Chiarini et al., 2007), Lago Grande di Monticchio (Allen & Huntley, 2000; Watts et al., 2000) and Lago di Fimon (Pini et al. 2010). Interestingly, the samples may be attributed to a colder and drier phase (samples 6a, 6b) and to a relatively warmer and wetter phase (samples 1, 2, 3, 5). Although the distribution of

Cave		GC								GPC
sample no.		**1**	**2**	**3**	**4**	**5**	**6a**	**6b**	**6c**	**7**
Arboreal Plants %		*38.6*	*26.2*	*17.7*		*34.9*	*71.9*	*65.8*		
Non Arboreal Plants %		*61.4*	*73.8*	*81.8*		*65.1*	*28.1*	*34.2*		
ARALIACEAE	*Hedera helix*	0.5	1.5	0.4		0.8	0.0	0.0		
BETULACEE	*Alnus*	0.5	0.0	0.0		0.4	0.0	0.9		
	Betula	0.5	0.5	0.4		0.0	0.0	0.0		
CISTACEAE	*Helianthemum*	0.0	0.0	0.0		0.4	0.0	0.9		
CORYLACEAE	*Carpinus betulus*	0.0	0.0	0.0		0.0	0.8	0.0		
CUPRESSACEAE	*Cupressus*	0.0	0.0	0.0		0.0	0.8	0.9	1	1
EPHEDRACEAE	*Ephedra*	0.0	0.0	0.0		0.0	0.0	0.9		
ERICACEAE	*Erica*	0.5	0.0	0.0	1	0.0	0.0	0.0		
FAGACEAE	*Castanea*	0.5	0.0	0.0		0.0	0.0	0.9		
	Quercus deciduous	0.9	1.5	0.4		1.6	3.9	1.8	1	3
	Quercus cf. *cerris*	0.0	0.0	0.0		0.0	1.6	0.9		1
	Quercus ilex type	0.0	0.0	0.9		0.8	0.0	0.9		
OLEACEAE	*Fraxinus ornus* type	1.4	0.5	0.4		0.0	1.6	0.9		
PINACEAE	*Abies*	0.9	1.0	0.4	1	0.8	0.0	0.0		
	Picea	0.0	0.5	0.4		0.0	2.3	1.8		1
	Pinus subgen. *Strobus*	9.3	5.9	4.3	1	7.0	19.5	19.3	2	2
	Pinus subgen. *Pinus*	20.5	12.9	8.2	2	20.5	39.1	34.2	3	5
ROSACEAE	*Sorbus*	0.0	0.0	0.0		0.0	0.0	0.0		1
SALICACEAE	*Salix*	2.8	2.0	1.7		2.3	0.0	1.8	1	
TILIACEAE	*Tilia*	0.5	0.0	0.0		0.4	0.0	0.0		
ULMACEAE	*Ulmus*	0.0	0.0	0.0		0.0	2.3	0.0		
ASTERACEAE	*Ambrosia* type	0.5	0.5	0.9		0.8	0.0	0.0		
	Artemisia	1.9	1.5	2.6	1	2.3	1.6	1.8		1
	Aster	0.0	0.0	0.4		0.4	0.0	0.0		
	Carduus	0.0	0.0	0.0		0.0	0.8	0.0		
	Centaurea	0.9	0.5	0.4		0.4	0.0	0.0		
	Asteroideae indiff.	12.6	20.8	28.6		15.5	11.7	16.7	7	
	Cichorieae	13.5	14.9	13.4	5	12.0	3.1	0.9	4	1
	Crepis cf.	4.7	6.4	5.6		5.4	0.0	0.0		
	Senecio cf.	0.0	0.0	0.0		0.4	0.0	0.0		
BORAGINACEAE		0.0	0.0	0.0		0.0	0.0	0.0		
BRASSICACEAE		0.0	0.0	0.9		0.4	0.0	0.0		
CARYOPHYLLACEAE		2.8	1.0	1.7		1.2	0.0	0.0		
CHENOPODIACEAE		0.9	0.0	0.4		1.6	0.0	0.0		
CISTACEAE	*Cistus*	0.0	0.0	0.4		0.4	0.0	0.0		
CONVOLVULACEAE	*Convolvulus*	0.0	0.0	0.0		0.4	0.0	0.0		
CYPERACEAE		5.1	7.4	4.3	10	3.1	0.0	0.0		
DIPSACACEAE	*Scabiosa* cf.	0.0	0.0	0.0		0.0	0.0	0.9		
EUPHORBIACEAE	*Mercurialis*	0.0	0.5	0.4		0.4	0.0	0.0		
FABACEAE	*Trifolium*	0.0	0.0	0.4		0.4	0.0	0.0		
	Fabaceae indiff.	0.0	0.0	1.3	1	0.8	0.0	0.9		
	Vicia type	0.0	0.0	0.0		0.0	0.0	0.9		
GENTIANACEAE		0.0	0.5	0.4		1.6	0.0	0.0		
GERANIACEAE	*Erodium*	0.0	0.0	0.0		0.4	0.0	0.0		
LABIATAE	*Mentha* type	0.0	0.0	0.4		0.4	0.8	0.0		
LILIACEAE	*Scilla*	0.0	0.0	0.0	1	0.0	0.0	0.0		
NYMPHAEACEAE	*Nymphaea*	0.9	0.5	0.9		0.4	0.0	0.0		1
POACEAE		10.2	16.8	15.2	12	12.4	10.2	9.6	3	7
POLYGONACEAE	*Rumex*	0.5	0.5	0.9		1.9	0.0	0.0		
RANUNCULACEAE	*Helleborus*	0.5	0.5	0.0		0.0	0.0	0.0		
	Ranunculus type	5.6	0.5	0.9		0.0	0.0	0.0		
ROSACEAE	*Filipendula* type	0.0	0.0	0.0		0.0	0.0	2.6		2
RUBIACEAE	*Galium*	0.0	0.0	0.4		0.8	0.0	0.0		
SCROPHULARIACEAE	*Plantago media* type	0.0	0.0	0.9	1	0.4	0.0	0.0		5
	Verbascum cf.	0.5	0.5	0.0		0.0	0.0	0.0		
URTICACEAE	*Urtica dioica* type	0.5	0.5	0.0	2	1.2	0.0	0.0		
POLLEN SUM		**215**	**202**	**231**	**38**	**258**	**128**	**114**	**22**	**31**
Pollen concentration p / g		**384**	**369**	**386**		**589**	**565**	**442**		
No. of taxa		**28**	**26**	**34**		**36**	**15**	**21**		

Tab.2 - Pollen data from the Caprelle caves; percentages are calculated on the total pollen grains that were found in each sample. The grey columns are semi-sterile samples (pollen counts are reported as row numer of grains found).

samples could have also been partly responsible for the different relevance of some taxa in these spectra, we think that the hard conditions of deposition and the very low amount of pollen that has reached these underground deposits may give some confidence to this interpretation. The presence of different 'degree of cold' in samples that were deposited during a relatively short glacial interval is well compatible with the known phases of MIS3 (Van Meerbeeck et al., 2009).

5. THE CAVE DEVELOPMENT

The caves history is long, as documented by the co-existence and superimposition of different morphologies. The geological structure and, in particular, the setting of the folds involving the underlying low-permeable Marne a Fucoidi, influenced the drainage pattern throughout the cave history. The water recharge, based on the results of the hydrological monitoring and hydrogeological setting, can be attributed mainly to diffuse infiltration on the karst surface, while the contribution from sinking points in Piani di Monte Lago, if existing, had a minor importance, in the past and in the present.

In the caves, no direct evidence of the first speleogenetic phases is preserved. It can be hypothesized that the flow of water inside the limestone produced a progressive widening of the fissures, increasing the permeability and the possibility of the infiltration of water in the vadose zone. The flow of vadose water was influenced by the vertical dip of the limestone, which facilitated the descent towards the depth along the bedding planes. In the phreatic zone, the underlying marl formation maintained the drainage of the water parallel to the bedding, towards the emergence, creating the sub-horizontal passages existing in the lower parts of the caves.

The high elevation of the cave passages in the mountain is not due to permeability changes inside the rock mass. Instead, it is probable that these passages formed at the same elevation of the old local base level during the first phases of the cave evolution, before the valleys deepened to the present situation. The distribution of these cave passages on many levels, none of them well developed, could be related to a progressive lowering of the emergence point.

The limestone dissolution also produced an increase in the permeability of the vadose zone, well testified by the present fast drainage of infiltration water. Inside the cave, this flow caused the development of some shafts and inclined passages that are still in active evolution, alternating depositional and corrosion actions. At the surface, the increase in the permeability caused the total disappearance of water circulation.

The permanent water flow in GPC and the stability of the chemical and physical parameters throughout the year testify to the storage capacity of the limestone. The great difference in elevation between the spring and the present local base level is probably related to a diminution of the permeability in the limestone. It implies that the karst solution has not yet acted significantly in the deep zones of the aquifer, maintaining the drainage setting which existed before the headward erosion in the Agolla valley reached the cave area.

The wide dimensions of the cave voids and the high elevation of the sub-horizontal passages above the present local base level suggest that the cave formation is likely to have begun before the rivers cut the present deep valleys inside the pre-existing erosion surface. As this event is generally referred to the end of the Early Pleistocene, it is likely that the first phases of cave development occurred during that period.

Despite pollen is an interesting presence in these caves, the chronology of the samples is fairly uncertain because the deposition of sediment is a long-time event, which continued until recent times. Although the problem cannot be resolved for all the contexts, the depositional features of GPC and some characters of the pollen data can help us to infer the most probable chronology for the samples that were taken for pollen analyses. In fact, we observed that pollen preservation looks similar, and the list of taxa was fairly coherent in all the samples suggesting that the same original sediment entered many parts of the caves. If one/few rapid deposition event/s can be argued, some inferential reasoning may help to define the chronology of pollen samples: a) the deposition of black sediment took place in a relatively short time, and the studied deposits were substantially of the same age; b) the black sediment in GCP corresponding to sample no.7 was dated to 37.6 ka BP; c) here, as in other spots, the sediment was deposited under concretions dated to 28.4±1.2 ka. This means that most of the sediment was deposited into the caves between about 37.6 and 28.4 ka BP. Pollen samples, therefore, are expected to belong to a period corresponding to the Marine Isotope Stage 3 (MIS 3), recorded between 60 and 27 ka ago, during the last glacial cycle that experienced several abrupt climatic oscillations (Follieri et al., 1996; Van Meerbeek et al. 2009): warming phases known as Dansgaard-Oeschger events alternated to cold phases such as the so-called Heinrich events (e.g. Labeyrie et al., 2013 and references therein).

In the Late Pleistocene, the cave had already reached shape and morphology similar to the present one, as testified by the age of calcite deposits in the cave passages, up to 92.5 ka BP. During the same period, the infiltrating water carried a significant amount of sediment, with a minor sandy content, which deposited in the cave zones not directly involved in the flow of water. This depositional phase, based on the geochronological and pollen data, should have occurred during the cold phases of the Late Pleistocene, most probably during the MIS3 oscillations, when steppe and grassland prevailed at the surface and woodland cover was poor.

At the end of this period, before the Last Glacial Maximum, calcite deposition probably prevailed on the sediment deposition, as shown by the depositional relationship between the sediment and calcite on the walls in the GPC. The deposition of a similar calcite sheet is also common in other caves of the area, and in the Pozzo di Fonte Fragola it was U/Th dated to 31.3±1.5 ka (Galdenzi, 1996).

After this event, the caves evolved mainly from the erosion and corrosion actions of the infiltration water. The encrusting action of the water reduced, and a large part of the old calcite sheets were corroded and partly destroyed, as verified also in other caves in the same area.

6. CONCLUSIONS

The multidisciplinary research in the Caprelle caves has permitted a more complete and detailed comprehension of the conditions and processes that influenced the history of the caves, providing, at the same time, interesting information on the environmental setting.

The caves pattern is strongly influenced by the geologic setting in the limb of a minor anticline, where the vertical beds and the underlying marl deposits guided drainage both for the infiltration water in the vadose zone and the horizontal flow to the emergence. In the cave, the sub-horizontal passages located at different altitude testify to the progressive lowering of the drainage inside the limestone. The emergence, however, is ~200 m higher than the presence local base level, probably due to a decrease of karstification degree in the deep zones of the aquifer. The cave deposits dated back to 92.5 ka and the pollen content in the cave sediments suggest that the caves had already reached the present setting and dimension in the Upper Pleistocene. For these reasons, it is probable that the cave enlargement began before the deepening of the hydrographic surface, an event that is in general referred to the end of Early Pleistocene.

The pollen spectra from all samples were probably fairly coeval. Grasslands and steppe, typical of glacial phases, characterized the palaeoenvironment. The chronological elements available for the caves suggest that the arid and probably cold period recorded between 37 and 28 ka BP was characterized by conifer woods with pine, fir and spruce, accompanied by significant broadleaved trees such as oaks, birch, ash, linden and chestnut.

ACKNOWLEDGEMENTS

Dating of speleothems and preliminary pollen analysis were done in the project "L'area carsica di Monte Lago e le Grotte di Caprelle", developed by Gruppo Grotte Recanati, G.S. CAI Macerata - C. R. S. “Nottoloni” Macerata, G.A.SP. Civitanova Marche - G.S. AL.VA.P. Pioraco - CAI Camerino. This project, coordinated by Alfredo Campagnoli† and Giulio Cotechini was financed by Regione Marche in range of intervention for Speleology (L. R. 12/2000).

Authors thanks: Gruppo Speleologico AL.VA.P. Pioraco - CAI of Camerino and, particularly, Giulio Cotechini, Silvano Piazzoli, Roberto Correnti and Federica Cotechini, about the contribution to sampling operations; Giulio Cotechini and Geol. Eugenio Pistolesi, who took part to speleology cartography review; Prof. Pietro Paolo Pierantoni, Università degli Studi di Camerino - Scuola di Scienze e Tecnologia, sezione Geologia. Prof. Piero Farabollini Università degli Studi di Camerino - Scuola di Scienze e Tecnologia, sezione Geografia fisica e Geomorfologia; Prof. Carlo Renieri, director of Scuola di Scienze Ambientali dell’Università degli Studi di Camerino. Thanks to Dott.ssa Roberta Tacchi, Curatore dell’Orto Botanico “Carmela Cortini” about her availability to use the microscope for examination and taking pictures of pollen particles.

We are indebted to the two referees who greatly improved the clarity of the paper with their comments.

REFERENCES

Allen J.R.M., Huntley B. (2000) - Weichseilan palynological records from southern Europe: correlation and chronology. Quatern Intern 73/74, 111-125.

Ambrosetti P., Carraro F., Deiana G., Dramis F. (1982) - Il sollevamento dell'Italia Centrale tra il Pleistocene inferiore e il Pleistocene medio. C.N.R., P.F. “Geodinamica”, Pubbl. 513, p II, 219-223.

Bartolini C., D’Agostino N., Dramis F. (2003) - Topography, exhumation, and drainage network evolution of the Apennines. Episodes, 23 (3), 212-217.

Berglund B.E., Ralska-Jasiewiczowa M. (1986) - Pollen analysis and pollen diagrams. In, Berglund B.E. (ed.) Handbook of Holocene Paleoecology and Palaeohydrology. Chichester, 455-484.

Bertini A. (2010) - Pliocene-Pleistocene palynoflora and vegetation in Italy: State of the art. Quatern Int, 225, 5-24.

Bertini A., Minissale A., Ricci M. (2014) - Palynological approach in upper Quaternary terrestrial carbonates of central Italy: Anything but a ‘mission impossible. Sedimentology, 61, 200-220.

Biondi E., Casavecchia S., Pesaresi S. (2012) - Nitrophilous and ruderal species as indicators of climate change. Case study from the Italian Adriatic coast, Plant Biosyst, 146, 134-142.

Biondi E., Allegrezza M., Casavecchia S., Galdenzi D., Gasparri R., Pesaresi S., Vagge I., Blasi C. (2014) - New and validated syntaxa for the checklist of Italian vegetation, Plant Biosyst, 148, 318-332.

Calamita F., Pierantoni P.P. (1993) - Il sovrascorrimento di M. Cavallo-M. Primo (Appennino umbro-marchigiano). Boll. Soc. Geol. It., 112, 825-835.

Ciccacci S., D'Alessandro L., Dramis F., Fredi P., Pambianchi G. (1985) - Geomorphological and neotectonic evolution of the Umbria-Marche Ridge, Northern Sector. Studi Geologici Camerti 10, 7-15.

Chiarini E., Giardini M., La Posta E., Papasodaro F., Sadori L., (2007) - Sedimentology, palynology and new geochronological constraints on Quaternary deposits of the Corvaro intermontane basin (central Italy). Rev Micropaléont 50, 309-314.

D’Agostino N., Dramis F., Funiciello R., Jackson J.A. (2001) - Interactions between mantle upwelling, drainage evolution and active normal faulting: an example from the central Apennines (Italy). Geophys J Int 147, 475-497.

De Waele, J., Galdenzi, S., Madonia, G., Menichetti, M., Parise, M., Piccini, L., et al. (2014). A review on hypogene caves in Italy. Special Publication 18, Selected papers and abstracts (February 2-7), 2014, San Salvador Island, Bahamas, 28-30.

Facenna C., Soligo M., Billi A., Filippis L., Funiciello R., Rossetti C., Tuccimei P. (2008) - Late Pleistocene depositional cycles of the Lapis Tiburtinus tra-

vertine (Tivoli, Central Italy): Possible influence of climate and fault activity. Global Planet Change 63, 299-308.
Falaschi P.L. (1987) - La signoria di Giulio Cesare da Varano, in Camilla Battista da Varano e il suo tempo. Atti del Convegno di Studi sul V centenario del Monastero delle Clarisse di Camerino (Camerino 7-9 settembre 1984). Camerino, 31.
Florenzano A., Mercuri A.M., Pederzoli A., Torri P., Bosi G., Olmi L., Rinaldi R., Bandini Mazzanti M. (2012) - The significance of intestinal parasite remains in pollen samples from Mediaeval pits in the Piazza Garibaldi of Parma, Emilia Romagna, Northern Italy. Geoarchaeology 27, 34-47.
Florenzano A., Marignani M., Rosati L., Fascetti S., Mercuri A.M. (2014) - Are Cichorieae an indicator of open habitats and pastoralism in current and past vegetation studies? Plant Biosyst. 10.1080/11263504.2014.998311
Follieri M., Magri D. (2001) - Middle and Upper Pleistocene natural environment in the Roman area: climate, vegetation and landscape. The World of Elephants. International Congress, Rome.
Follieri M., Magri D., Sadori L. (1988) - 250,000-year pollen record from Valle di Castiglione (Roma). Pollen Spores 30, 329-356.
Fralish J.S., Franklin S.B. (2002) - Taxonomy and Ecology of Woody Plants in North American Forests (Excluding Mexico and Subtropical Florida). John Wiley & Sons.
Galdenzi S. (1983) - Geomorfologia delle grotte di Caprelle. In: Atti XIV Congresso nazionale di speleologia, Bologna 1982. Gr. It. XI, 443-452.
Galdenzi S. (1988) - Il carsismo nei calcari pelagici dell'Appennino Umbro Marchigiano: il ruolo degli orizzonti impermeabili nella canalizzazione sotterranea in una catena a pieghe. In: Actes XIV Cong. Nat. Speleol. (Nancy-Metz, 1985). Spelunca Memories, 14, 143-146.
Galdenzi S. (1996) - Il carsismo profondo nell'Appennino Umbro Marchigiano (Italia). Proceedings International Congress "Alpine Caves: Alpine Karst Systems and their Environmental Context", Asiago, 11-14 June 1992, 229-242.
Galdenzi S., Paggi S., Pistolesi E., Cotechini G. (2008) - Grotte e Carsismo nel territorio di Sefro. In: Di Martino V., Pedrotti F. & Valeriani P. (Eds.). Atti Conv., "Per l'istituzione del Parco Naturale Regionale dell'area Monte Pennino, Vallescurosa e Monte Lago". Sefro, 2006.
Garofalo P.S., Matias B., Fricker M., Gunther D., Forti P., Mercuri A.M., Loreti M., Lauritzen S.E., Constantin S., Capaccioni B. (2009) - Climatic control on the growth of gigantic gypsum crystals within hypogenic caves (Naica mine, Mexico), EPSL 289, 560-569.
Giardini M. (2007) - Late Quaternary vegetation history at Stracciacappa (Rome, central Italy). Veg Hist Archaeobot 16, 301-316.
Horowitz A. (1992) - Palynology of arid lands. Amsterdam, Elsevier.
Labeyrie L., Skinner L. C., Cortijo, E. (2013) - Submilankovitch (DO/Heinrich) events. In: Encyclopaedia of Quaternary Science. Elsevier, Amsterdam, 200-208
Loreti M., Mercuri A.M. (2007) - La ricostruzione del paleoambiente attorno alla Grotta delle Vacche: Parco Naz. D'Abruzzo, Lazio e Molise: un'ipotesi su base speleopalinologica. In: Loreti M. e Salerno P. (a cura di). "Una cavità dalle mille sorprese: Grotta delle Vacche Parco Nazionale d' Abruzzo, Lazio e Molise". Arduino Sacco editore, Bella (PZ), 43-67.
Magri D. (1989) - Interpreting long-term exponential growth of plant populations in a 250,000 - year pollen record from Valle di Castiglione. New Phytol, 112, 123-128.
Magri D. (1999) - Late Quaternary vegetation history at Lagaccione near lago di Bolsena (central Italy). Rev Palaeobot Palynol, 106, 171-208.
Magri D., Sadori L. (1999) - Late Pleistocene and Holocene pollen stratigraphy at Lago di Vico (central Italy). Veg Hist Archaeobot, 8, 247-260.
McGarry S.F., Caseldine C. (2004) - Speleothem Palynology: an undervalued tool in Quaternary studies. Quatern Sci Rev, 23 (23-24), 2389-2404.
Minetti A., Nanni T., Perilli F., Polonara L., Principi M. (Eds.) (1991) - L'ambiente Fisico delle Marche, Regione Marche, Giunta Regionale, S.EL.CA, Firenze.
Moreno A., Svensson A., Brooks S. J., Connor S., Engels S., Fletcher W., Genty D., Heiri O., Labuhn I., Persoiu A., Peyron O., Sadori L., Valero-Garces B., Wulf S., Zanchetta G. and data contributors (2014) - A compilation of Western European terrestrial records 60-8 ka BP: towards an understanding of latitudinal climatic gradients. Quatern Sci Rev, doi: 10.1016/j.quascirev.2014.06.030.
Navarro C., Carrion J.S., Navarro J., Munuera M. (2000) - An experimental approach to the palynology of cave deposits, J Quatern Sci, 15, 603-619.
Navarro C., Carrion J.S., Munuera M., Prieto A.R. (2001) - Cave surface pollen and the palynological potential of karstic cave sediments in palaeoecology. Rev Palaeobot Palyno, 117, 245-265.
Pini R., Ravazzi C., Reimer P.J. (2010) - The vegetation and climate history of the last glacial cycle in a new pollen record from Lake Fimon (southern Alpine foreland, N-Italy). Quatern Sci Rev, 29, 3115-3137.
Reille M. (1992) - Pollen et spores d'Europe et d'Afrique du Nord. Laboratoire de botanique historique et Palynologie , CNRS, Marseille, France.
Tzedakis P.C., Andrieu J.V.L., De Beaulieu H.J.B., Birks D., Crowhurste S., Follieri M., Hooghiemstra H., Magri D., Reille M., Sadori L., Shacklrton N. J., Wijmstra T. A. (2001) - Establishing a terrestrial chronological framework as a basis for biostratigraphical comparisons. Quatern Sci Rev, 20, 1583 -1592.
Voltaggio M. (2010) - Relazione riguardante i campioni esaminati per spettrometria di massa provenienti dalla località Piani di Monte Lago. Unpublished IGAG report to Gruppo Grotte Recanati.
Watts W. A., Allen J.R.M., Huntley B. (2000) - Paleocology of three interstadial events during oxygen-

isotope Stages 3 and 4: a lacustrine record from Lago Grande di Monticchio, southern Italy. Palaeogeogr Palaeoclimatol, 155, 83-93.
Yll R., Carrion J.S., Marra A.C., Bonfiglio L. (2006) - Vegetation reconstruction on the basis of pollen in Late Pleistocene hyena coprolites from San Teodoro Cave (Sicily, Italy). Palaeogeogr Palaeoclimatol Palaeoecol, 237, 32-39.
Van Meerbeeck, Renssen H., Roche D.M. (2009) - How did Marine Isotope Stage 3 and Last Glacial Maximum climates differ? - Perspectives from equilibrium simulations. Clim. Past, 5, 33-51.

Ms. received: June 19, 2014
Final text received: December 18, 2014