

INITIAL GEOLOGIC OBSERVATIONS IN CAVES BORDERING THE SIBARI PLAIN (SOUTHERN ITALY)

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Geologic investigation of caves in the northern Calabria region of Italy has clarified their origin and irregular distribution. Caves and surface karst landforms are not widespread, despite the fact that the local limestones are widely exposed and surface drainage is poorly developed. The caves are located in small limestone hills and mountains around the Sibari Plain and are surrounded by low-permeability rocks. Among them is a significant shaft cave fed by a sinking stream that drains a non-karst recharge area. However, most of the caves are predominantly horizontal and have entrances at low altitudes at several levels. Their origin is due to the rising of thermal waters, which are mineralized after passing through the Neogene formations of the Sibari Plain. The caves can be considered relict hypogenic out-flow caves. The main cave-forming process was probably the oxidation of H₂S, favored by the mixing of thermal water and infiltrating fresh water. Oxidation of H₂S has resulted in gypsum deposits within the caves.

GEOLOGIC SETTING

The tectonic and stratigraphic evolution of the northern Calabria region is very complex, and in the study area a great variety of rocks can be recognized, from Alpine to Apenninic in origin. A major transform fault (Sanginetto Line) divides igneous and metamorphic rocks in the south from the mainly sedimentary rocks in the north (Figure 1).

The sedimentary cover has been chaotically folded by collision between the European and African tectonic plates (Amodio M. et al., 1976). The lower part consists of thick limestone and dolomite deposits of Triassic through Cretaceous age overlain by Paleocene and Miocene calcarenites and marls. The carbonate unit is overthrust by the Liguride Complex, which consists of unconformable ophiolite-bearing marine sequences, shales, and turbidites of Late Jurassic to early Miocene age (Bonardi et al., 1988).

Tectonic uplift continued during the Miocene, and the Apenninic mountain chain became almost completely emergent above sea level. Marine sedimentation continued only around the perimeter of the mountain chain, where terrigenous facies accumulated (claystones, sands, and gravels). Thick gypsum and salt beds were deposited during the Messinian.

During the Pliocene and lower Pleistocene, marine conditions prevailed only in the Sibari Plain, which formed a small gulf within the Apennines chain. A clay and sand succession accumulated in this area to thickness as great as 1000 m. In the middle Pleistocene the entire area became emergent, and alluvial terrace gravels reached 100 m thick.

GEOMORPHOLOGY AND HYDROLOGY

The northern Calabrian region is characterized by mountains rising to more than 2000 m (e.g. Mount Pollino, 2267 m), which descend steeply toward the Mediterranean Sea. Limestones and dolomites are widely exposed throughout the

mountainous area west of the Sibari Plain. To the north, in contrast, low-permeability rocks of the Liguride Complex predominate, and small isolated limestone hills are surrounded by non-carbonate rocks. Also, within the Sibari Plain are scattered limestone hills partly buried by the thick terrigenous Neogene sequence.

The abundant precipitation and extensive limestone exposures have combined to produce a well-developed underground drainage. Many springs are located around the mountain chain, where the low-permeability Neogene deposits have buried the carbonate rocks, and in the vicinity of major faults. Most of these springs consist of calcium bicarbonate waters with low temperatures ranging from 4 to 17° C, depending on

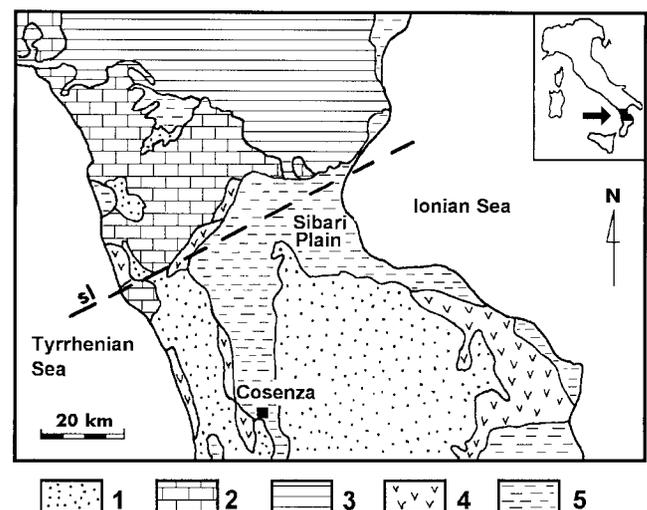


Figure 1. Geologic map of northern Calabria (Italy) 1 = igneous and metamorphic rocks; 2 = limestone and dolomite; 3 = Liguride Complex (low-permeability rocks); 4 = Miocene deposits; 5 = Plio-Pleistocene deposits; sl = Sanginetto Line.

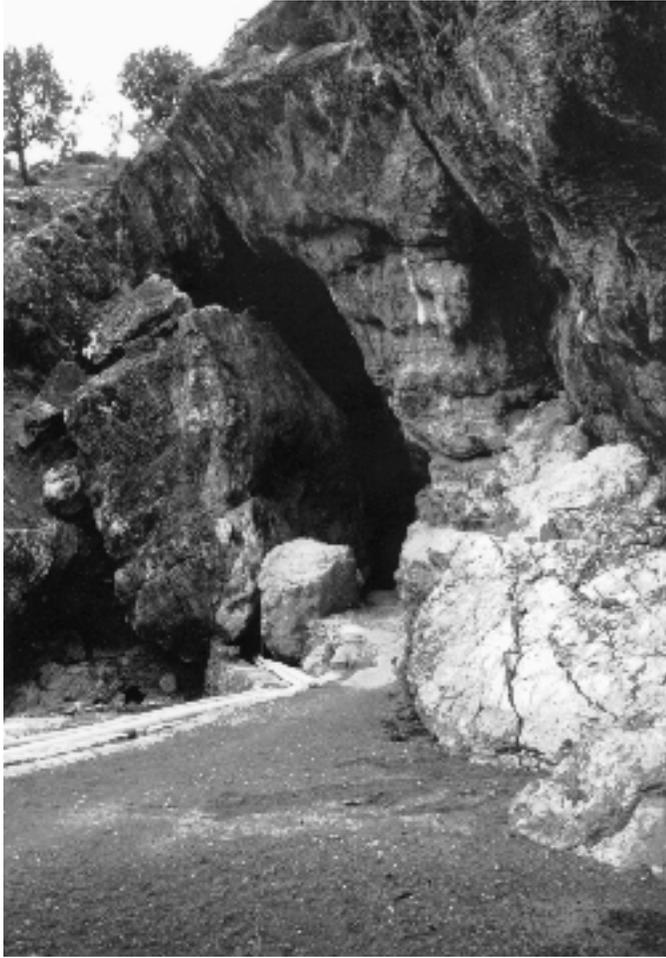


Figure 2. Entrance of Grotta delle Ninfe. This is the main sulfur spring in the Mount Sellaro area. The water emerges at 28° C and is used in nearby thermal baths.

their altitude. They are fed by meteoric waters coming from the uplands through a shallow underground circulation.

However, around the Sibari Plain, there are also thermal springs (23 - 40° C) with sulfate-chloride waters rich in H₂S. Despite their high temperature, their isotopic signatures demonstrate a meteoric origin (Gurrieri et al., 1984). These thermal springs are located near the edges of the Sibari Plain at the base of the isolated limestone hills described above (Figure 2). Also, Duchi et al. (1991) do not believe in a deep origin of these waters; for these authors the weak thermal characteristics could derive from a rapid rise of meteoric waters that have infiltrated into the limestone uplands and that follow a relatively deep circulation path. This deep circulation and the rising flow paths in the downflow ends should be facilitated by the high hydraulic heads in the rugged uplands and by the presence of major faults. The chemical composition of the water is probably derived from mixing with connate water and by dissolution of evaporites within the Neogene deposits of the Sibari Plain.

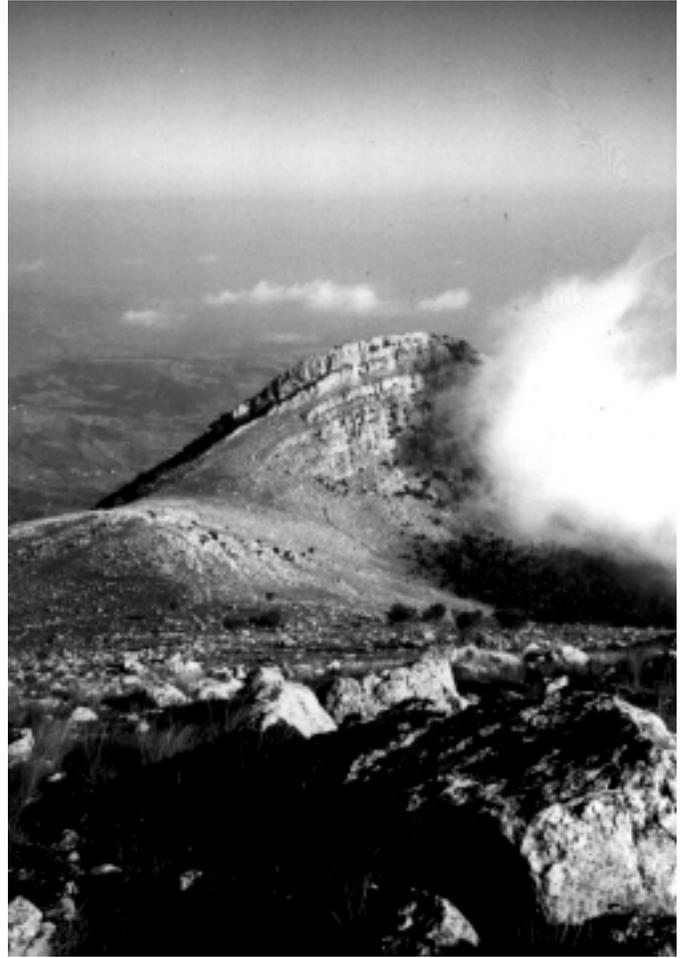


Figure 3. Surface karst landforms on Mount Sellaro (1439 m msl). The main caves of northern Calabria are located in this mountain. The bare landscape and the general lack of surface drainage are typical characteristics of the karst in this area.

CHARACTER OF THE CAVES

Surface karst landforms and caves are fairly rare in the extensive carbonate outcrops, despite the rugged topography and the lack of a well-developed surface drainage. The paucity of karst features cannot only be attributed to limited exploration of the area, which began in the 1960s. However some large caves, described in detail by Larocca (1991), are known in the isolated mountains and hills of the Sibari Plain (Figure 3). Their geomorphic and hydrologic characteristics will be briefly analyzed.

ABISSO DEL BIFURTO

This shaft cave, explored in 1961, is one of the deepest in southern Italy. Its entrance is located on the west side of Mount Sellaro at 920 m msl. It consists of a pit series (Figure 4) interrupted by short meandering canyons that reach 680 m deep, close to the local base level (springs at 200 m msl). The



Figure 4. A typical scene in the shaft cave Abisso del Bifurto.

cave clearly originated as the result of the partial sinking of a surface stream at the boundary between the low-permeability rocks of the Liguride Complex and the underlying Cretaceous limestone (Figure 5). The cave is still active (Figure 6), but the recharge area for the sinking stream on the non-karst rocks appears to have been reduced by piracy into neighboring valleys.

SERRA DEL GUFO CAVES

Many caves have developed in the eastern side of Mount Sellaro at 200 - 500 m msl (Figure 7a). Their entrances are located near the transform fault that forms the tectonic boundary between the Carbonate rocks on the southwestern side of Mount Sellaro and the low-permeability Liguride Complex. The lower caves reach the phreatic zone and are notable for their sulfur-rich water, which has temperatures varying from 28° C at the springs to 40° C in the bottom of the "Balze di Cristo" cave, a 100 m deep shaft that reaches the water table. Within these caves gypsum replacement crusts form on the limestone walls above the water table as the result of H₂S oxidation.

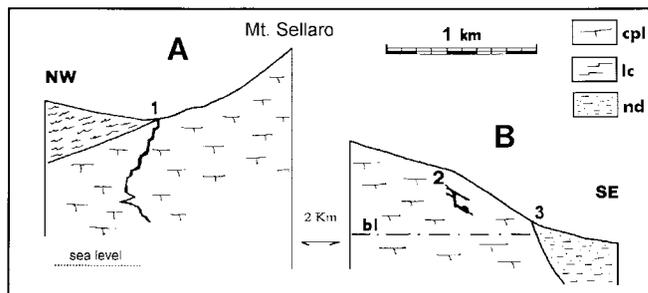


Figure 5. Schematic cross-section through Mount Sellaro. A = Abisso del Bifurto area; B = thermal spring area. Abisso del Bifurto feeds the Mount Sellaro aquifer, but there is probably no direct karst connection between the cave bottom and the thermal sulfur spring. cpl = Cretaceous and Paleocene limestone; lc = Liguride Complex; nd = Neogene deposits; bl = present base level; 1 = Abisso del Bifurto; 2 = Grotta di Serra del Gufo; 3 = thermal spring.



Figure 6. Entrance of Abisso del Bifurto. After heavy rain-fall a surface stream draining from non-karstic rocks floods the cave.

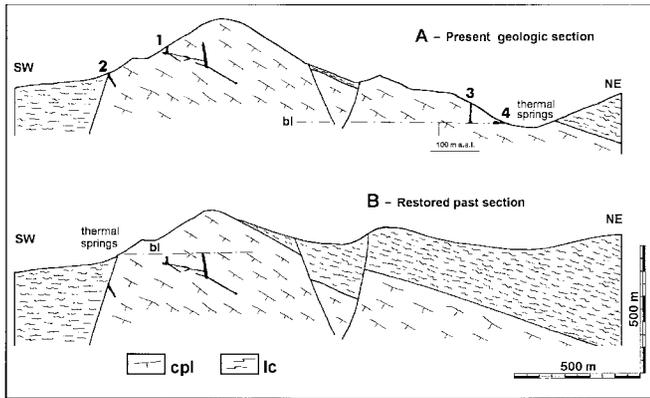


Figure 7. A = cross-section through the southeastern side of Mount Sellaro, showing the present caves and geology; B = interpretation of conditions during previous cave development. Note the denudation of the limestone surface and the migration of springs as surface streams erode to lower levels. Cpl = Cretaceous and Paleocene limestone; lc = Liguride Complex (low-permeability rocks); bl = base level; 1 = Grotta di Serra del Gufo; 2 = Damale cave; 3 = Balze di Cristo cave; 4 = Ninfe cave.

The main cave (Grotta di Serra del Gufo, about two kilometers long) is a relict cave containing inclined passages that rise toward the land surface (Figure 8). The cave pattern is strongly controlled by the dip of the limestone and by faults. Phreatic tubes are common (Figure 9), but breakdown and carbonate speleothems have obliterated many of the original features. The cave also contains some gypsum deposits. The upper passages reach approximately 550 m msl, which probably represents a former base level (Figure 7b). This level also corresponds to alluvial gravel terraces of middle Pleistocene age on the nearby Sibari Plain.

CASSANO ALLO JONIO CAVES

Cassano allo Jonio is a small town situated near a steep isolated limestone hill surrounded by low-permeability strata of the Liguride Complex and the Neogene terrigenous sequence. The most important caves (e.g. Grotte di Sant' Angelo) open at about 450 m msl in a steep slope along the main fault. Altogether these caves are more than 2000 m in length. They consist of several sub-parallel horizontal passages at slightly different elevations, which intersect a large room (Figure 10). These caves are characterized by abundant gypsum deposits, which were partly quarried away in the past. A sulfur spring is located at the foot of the limestone hill at 200 m msl.

DISCUSSION

The irregular distribution of caves in northern Calabria is clearly controlled by geologic factors. There are no significant caves in the extensive high-altitude carbonate mountain chains, but caves are abundant in the narrow limestone outcrops along

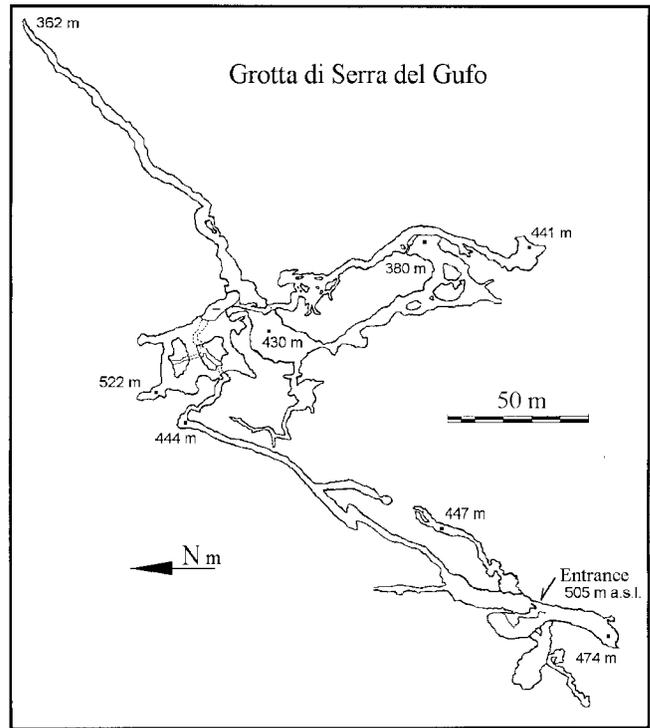


Figure 8. Map of Grotta di Serra del Gufo, the largest cave in the study area (survey by the Sparviere Speleological Group).

the edges of the Sibari Plain (Figure 11), despite their relatively small recharge areas and small relief. Shaft caves are rare throughout the area, with Abisso del Bifurto the only significant exception. Sub-horizontal caves are the most common and are concentrated at low altitudes in the sides of the limestone hills and mountains around the Sibari Plain (e.g. Cassano allo Jonio caves) or rise toward the outer edges of the mountains (Serra del Gufo caves). Abundant gypsum was formed



Figure 9. Grotta di Serra del Gufo consists of relict passages, mostly steeply inclined, with phreatic characteristics.

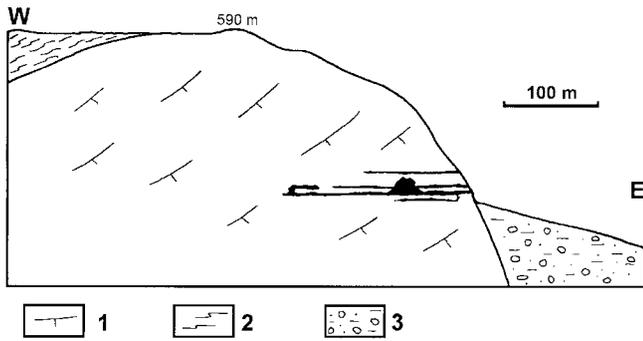


Figure 10. Schematic cross-section through Grotte di Sant'Angelo, at Cassano allo Jonio. 1 = Triassic dolomite; 2 = Liguride Complex; 3 = Neogene deposits.

during the cave origin as the result of sulfide-rich water flow, and sulfur springs fed by phreatic water are still present at low altitudes.

The cave features, limited recharge area, and the lack of connection with the rare influent caves preclude an origin by shallow meteoric water. On the contrary, the rising of H₂S-rich water within the limestone seems to be the principal cave-forming agent. The chemical characteristics of the waters, the hydrogeologic setting, and the gypsum deposits suggest that

the oxidation of H₂S to sulfuric acid is the main source of solution aggressiveness. This redox reaction and the mixing with fresh meteoric water descending along faults probably occurred in the upper part of the phreatic zone. Deepening of surface drainage channels interrupted the cave development, leaving relict gypsum-rich caves at several levels, while cave-forming processes began to operate more deeply toward the present base level.

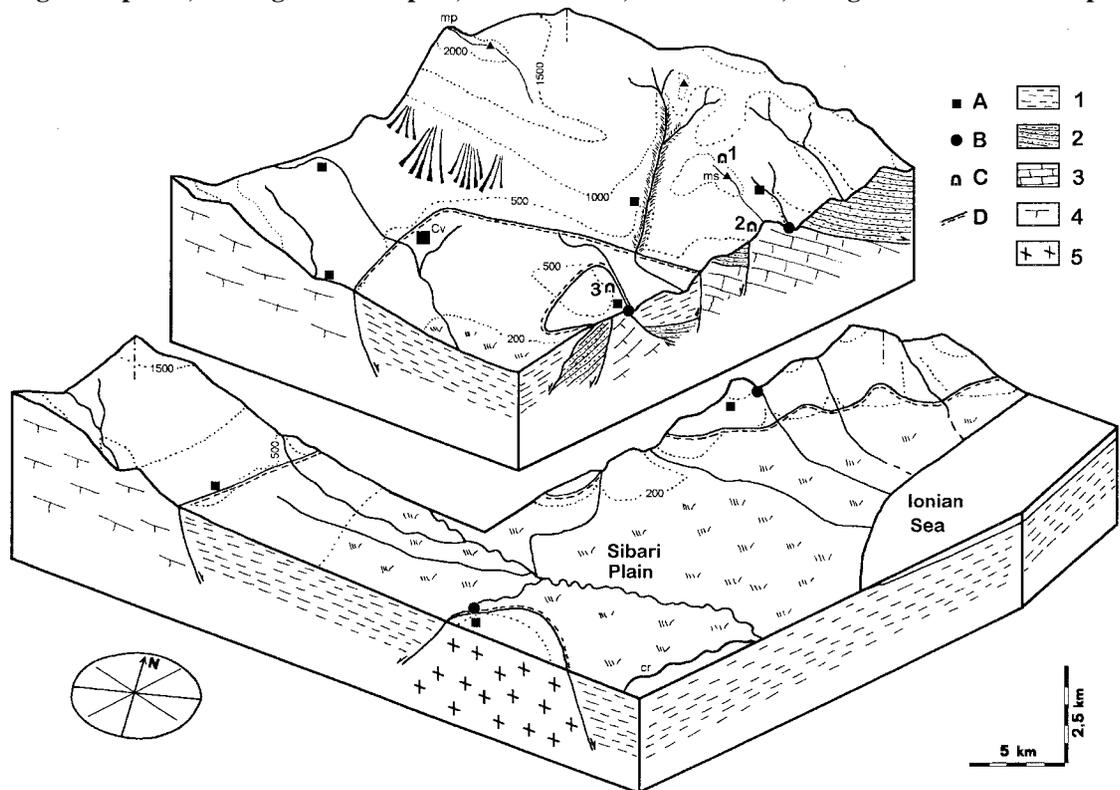
This hypogenic origin can also explain why the major caves in northern Calabria do not occur in the largest carbonate massifs. The thermal, H₂S-rich waters rise only in the narrow karstified limestone belts around the Sibari Plain, where mixing with superficial calcium bicarbonate waters is possible.

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Figure 11. The extensive limestone and dolomite outcrops in the mountain chain permit well-developed underground drainage. Thermal water, mineralized in the Neogene formations, rises around the Sibari Plain in small limestone massifs, where hypogenic caves originate. An allogenic shaft cave opens at the boundary between the limestone and the low-permeability cover. 1 = Neogene deposits; 2 = Liguride Complex; 3 = limestone; 4 = dolomite; 5 = igneous and metamorphic rocks;

- A = town (Cv = Castrovillari);
- B = thermal spring;
- C = caves
- 1 = Abisso del Bifurto;
- 2 = Serra del Gufo caves;
- 3 = Cassano allo Jonio caves;
- D = boundary of Neogene deposits;
- mp = Mount Pollino;
- ms = Mount Sellaro;
- cr = Crati River.



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