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01
02
03
04
05
06
07
08
09
10
11
12
13
14
15
16
17
18
19
INTERNATIONAL YEAR
2021
OF CAVES AND KARST
20

New insights on the Carburangeli Cave speleogenesis: a flank margin cave in Northern Sicily (Italy)

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Abstract

Flank margin caves form in coastal regions by mixing dissolution. Their development is controlled by the position of the fresh-salt water mixing boundary, which in turn, is related to sea-level position. They are characterized by a typical cave pattern and cave-wall morphologies and represent good indicators of past sea levels.
This contribution shows the results of recent studies conducted in the Carburangeli Cave, a small sub-horizontal cavity developed in Northern Sicily, close to Palermo. This cave was firstly known for paleontological and archaeological findings and for these reasons, along with its speleological and biological interest, a Nature Reserve has been instituted by the Sicilian government, and the cave was put under the management of "Legambiente Sicilia".
Carburangeli Cave opens on a marine palaeocliff at 22 m a.s.l., roughly 500 m far from the coastline, and is partially developed in Mesozoic limestone and in the overlying Pleistocene calcarenites. Its position, pattern, peculiar morphologies, lack of turbulent-flow wall sculptures and alluvial/colluvial sediments suggest an origin controlled by coastal mixing processes giving also important information on the Upper Pleistocene sea level and coastline position in this Northern sector of Sicily.

1. Introduction

Flank margin caves are peculiar dissolution caves which develop along many carbonate coastal regions. These caves form by mixing dissolution processes in the distal margin of the freshwater lens, under the flank of the enclosing landmass (MYLROIE & CAREW, 1990). Their development is controlled by the position of the fresh-salt water mixing boundary, which in turn, is connected to sea-level position.
The first studies demonstrated flank margin caves to be typical cavities of diagenetically immature young carbonates (MYLROIE & CAREW, 1990; FRANK *et al*., 1998; MYLROIE & MYLROIE, 2013). High primary porosity of these rocks favours diffuse flow and the formation of irregular globular rooms, dead-end passages, phreatic, slow-flow morphologies.
Nevertheless, more recent publications have reported flank margin caves to develop also in diagenetically mature carbonate rocks (MYLROIE *et al*., 2008; OTONIČAR *et al*., 2010; RUGGIERI & DE WAELE, 2014; D'ANGELI *et al*., 2015; ARRIOLABENGOA *et al*., 2017). In these rocks primary porosity is often insignificant and water flow is controlled mainly by joints, faults, and bedding planes (PALMER, 1991; FORD & WILLIAMS, 2007), therefore, cave pattern and morphologies of flank margin caves result strictly influenced by discontinuity planes.
This contribution shows the results of recent geomorphological studies carried out in the Carburangeli Cave, a small sub-horizontal cavity developed in Northern Sicily, close to Palermo (Fig. 1). The palaeontological and archaeological importance, along with the speleological and biological interest of this site has allowed its classification as a regional Nature Reserve instituted by the Sicilian government, and the cave was put under the management of "Legambiente Sicilia".

2. Materials and methods

A geomorphological study has been carried out in the Carburangeli Cave to identify its pattern and the main dissolution/erosion and depositional features. Preliminary palaeontological and mineralogical analyses have been performed on cave sediments and bedrock samples of different areas in the cave.

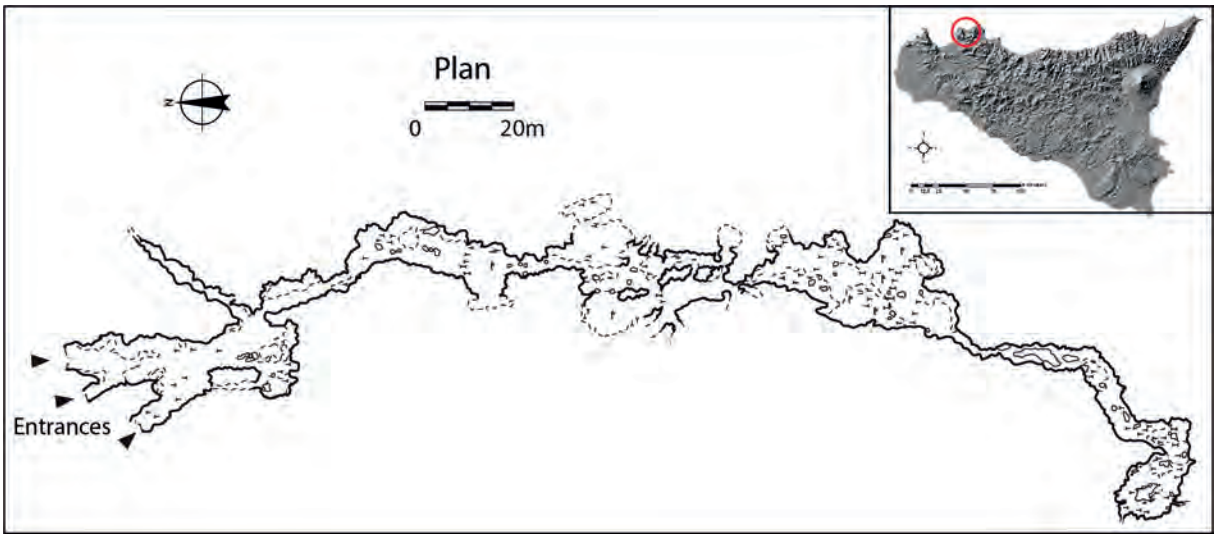

Figure 1: Plan view and location of the Carburangeli Cave (modified from: archive of Carburangeli Cave Nature Reserve).

3. Results

The Carburangeli Cave opens at the foot of a marine palaeocliff at 22 m a.s.l., roughly 500 m far from the current coastline (Fig. 2A). The cave develops horizontally for about 400 m in the N-S direction, only a few meters below the external surface (Fig. 1). From the entrance area to about 300 m from the entrance, the cave is carved in Calabrian marine calcarenites and conglomerates, whilst the innermost sector is hosted in Lower Jurassic-Triassic limestones and dolomitic limestones.
The cave morphology is different in the two host rocks. In the porous and permeable Calabrian calcarenites and conglomerates the cavity consists of wider than high irregular chambers with a flat roof connected by narrow galleries (Fig. 2B, 2C), dead-end passages, characterized mainly by phreatic, slow-flow features such as wall and ceiling cusps, intricate dissolutional wall sculptures, small phreatic tubes, pillars, ceiling pockets and spongework (Fig. 2D). In the entrance area the cuspate morphologies occur both on the ceiling and on the floor (Fig. 2B). The ceiling and walls show very weathered surfaces caused by condensation-corrosion processes.

The morphology varies radically in the telogenetic Mesozoic carbonate rock, where the cave is articulated along a narrow passage, which is clearly developed along a discontinuity plain. In this sector bedrock pendants, small phreatic tubes and curvilinear bedrock surfaces have been observed (Fig. 2E). The cavity ends with a breakdown chamber where collapse deposits obliterate the early morphologies.
The cave communicates to the outside through three openings, the largest of which shows a well pronounced intertidal wall notch, clearly visible also in the first room of the cavity (Fig. 2A, 2B), and in the deeper parts of the cave where the contact between the Pleistocene calcarenites and the Mesozoic limestones is recognizable. The marine influence is testified also by numerous distinct *Lithophaga litophaga* boreholes which cut mainly the Mesozoic carbonate bedrock (Fig. 2F). The cave lacks high flow velocity features, such as scallops or similar flow marks on the walls.

Cave deposits consist of different kinds of carbonate vadose speleothems (Fig. 2C), which often obliterate pattern and erosion features, and great amounts of physical deposits localized on the floor and locally in the wall niches.
The mineralogical and palaeontological composition of the physical deposits vary in relation to the cave area where they occur. In the entrance area the deposits unfortunately appear highly reworked as they were removed and studied during several palaeontological and archaeological excavation campaigns between the end of the 19th and the beginning of the 20th century. These investigations revealed the presence of important Upper Palaeolithic vertebrate fossils, and remains of meals and artifacts dating back to the Palaeolithic and the Bronze Age (GEMMELLARO, 1886; BURGIO & DI PATTI, 2001).

In some wall niches a more preserved aeolian deposit consisting mainly of quartz grains has been discovered.
In the middle part of the cave, sedimentary cave deposits can reach thickness up to about 50 cm. They are made of coarse sands and fine gravels and are composed mainly of calcite with small amounts of quartz and halite. At places phosphate has been found. Palaeontological analysis reported the presence of foraminifera, such as *Elphidium Crispum, Rosalina sp., Ammonia Beccarii,* and remains of echinoids and bryozoans. Bat bone fragments also occur.
In the inner area, where the cave is carved in the Mesozoic limestones, red and brown sterile silty sediments infill some wall niches.

Stream-laid sediments and other types of fluvial features have not been recognised.

Figure 2: Typical morphologies in the Carburangeli Cave. A) Entrance of the Carburangeli Cave carved in Pleistocene calcarenites, exposed by sea-cliff retreat. A distinct horizontal marine wall notch on the left of the entrance is visible. B) Cusp morphologies on the roof and floor in the first chamber, near the entrance. The wall notch is well distinguishable. C) A classical chamber with flat roof developed in the calcarenite rock, characterized by great amounts of vadose carbonate speleothems. D) Some phreatic, slow-flow features developed in the calcarenite. E) Pendants and small phreatic tubes developed in the Mesozoic carbonate bedrock. F) Lithophaga litophaga *boreholes cut in the Mesozoic carbonates*.

4. Discussions and Conclusions

Geographic position, sub-horizontal setting, presence of low galleries with a flat roof and developed in width rather than in height (at least along the calcarenite level), occurrence of phreatic, slow-flow features, and lack of fluvial deposits clearly indicate the Carburangeli Cave to be a flank margin cave controlled by coastal mixing processes. These caves

form along the distal margin of the freshwater lens, whose position is closely tied to the sea level at the time of cave formation. Here the maximum dissolution occurs by freshwater mixing, organic decay, and enhanced lens flow velocities (MYLROIE J.E. & MYLROIE J.R., 2007).

Carburangeli Cave began to form during a sea level highstand. In this phase, the first phreatic voids formed as cavities with poor connection with the exterior environment. In the Quaternary bedrock, given the high porosity of the calcarenites and conglomerates, water was able to dissolve the rock in all directions, creating large and rather low rooms shaped by typical phreatic features; in the Mesozoic carbonate level, on the other hand, the dissolution processes acted along preferential discontinuity planes with a N-S direction, generating rather narrow passages more developed in height, as joints provided preferential flow paths in the fresh-water lens, and therefore mixing environments (MYLROIE *et al.*, 2008).

After a first phase of phreatic void formation by mixing water, the cave was breached and intercepted by marine erosional processes and sea-cliff retreat. Preliminary analyses of sediments did not allow to discriminate whether they are marine deposits formed during this phase or are the weathered product of the original rock, as they show similar features to those of the Pleistocene host rock. Analysis of some morphologies, like the marine wall notch and *lithophaga* boreholes, confirm anyway that the cave was intercepted by sea water.

By relating the altitude at which the cave develops with the heights of the internal margins of the marine terraces (DI MAGGIO, 2000), the Carburangeli Cave most likely formed during the MIS 5e sea level highstand. The cave appears to be the result of a single sea-level highstand phase, as such its pattern and morphologies do not seem overprinted by successive phreatic conditions.

Following the relative lowering of the sea level, the cavity passed to continental conditions, as evidenced by the likely aeolian sediments, and the great amounts of speleothems.

Condensation-corrosion processes and vadose speleothem formation mainly characterise the current speleogenetic phase.

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