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Carbonate hostrock weathering by sea salt precipitation in El Orón-Arco Cave (Cartagena, SE Spain)

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Abstract

El Orón Cave, also known as Arco Cave (Cabo Tiñoso, Cartagena), was discovered in 1980 and has been explored by speleologists over the past decade. This cavity has turned into a tourist attraction for the Murcia Region (SE, Spain) because of its striking speleothems and unique morphologies, which considerably differ from other cavities in this region. The main cave passages run along a fracture parallel to the shoreline and are developed in limestones and dolostones of the Alpujarride complex of the Cabo Tiñoso Formation. This fault is closely related to the cave formation and the morphology of the Cabo Tiñoso cliff itself. No clear evidence of phreatic dissolution or signs of subterranean runoff are found in this cave, while two brackish-water lakes at sea-level are the only visible waterbodies at present. The carbonate bedrock shows clear evidence of chemical and mechanical weathering of soluble salts (halite and gypsum) due to seawater seepage and their subsequent precipitation due to evaporation in the cave. This mechanism has produced detachment of rock fragments and mechanical spalling, leading to massive chambers and in-situ accumulations of detrital deposits. The cave also hosts a wide variety of rare speleothems, including monocrystalline gypsum stalactites (chandeliers) with halite apexes and hollow gypsum hemispheres (blisters) associated with carbonate eccentrics. Seawater seepages through the carbonate bedrock and evaporation within the cave created most of these speleothems. Such unique features make El Orón-Arco Cave quite distinctive amongst the caves in Spain.

Keywords: coastal caves, gypsum, halite, speleothems, salt weathering.

1. Introduction

The mechanisms involved in the formation of caves are generally linked to dissolution of carbonate hostrock by waters subsaturated in calcium carbonate (Audra and Palmer, 2015). This karstification process creates voids in the rock and, in subsequent stages, can produce breakdown and collapse of cave ceilings, eventually leading to the formation of large chambers and passages. Regarding coastal caves, the corrosion of the carbonate hostrock is controlled by the mixing of fresh water and seawater that generates solutions subsaturated in calcite and, thus, with a great capability to dissolve limestone (Mylroie and Mylroie, 2007). Recently, Ginés and Ginés (2007) claimed that the detachment and breakdown of blocks is a remarkable agent for the genesis and evolution of caves in coastal areas.

In addition to coastal caves formed by this mechanism of classic karstification, the genetic processes in others are related to the geomorphological evolution of the shoreline, in many cases the result of erosion that causes landslides and fracking of the geology (Moore, 1954). The caves that develop in fractures are generally called flank margin caves, and display distinctive features compared to caves formed by dissolution. For example, these cavities normally lack features generated by subterranean water course or phreatic conduits, such as scallops, smoothed surfaces or cupolas. In the current paper, we examine the geomorphology and speleological features of El Orón-Arco Cave in the Cabo Tiñoso (Cartagena, Murcia). This coastal cave shows distinctive geomorphological characteristics and rare speleothems that lead us to study its mineralogy in detail to be able to shed light on their genetic mechanisms.

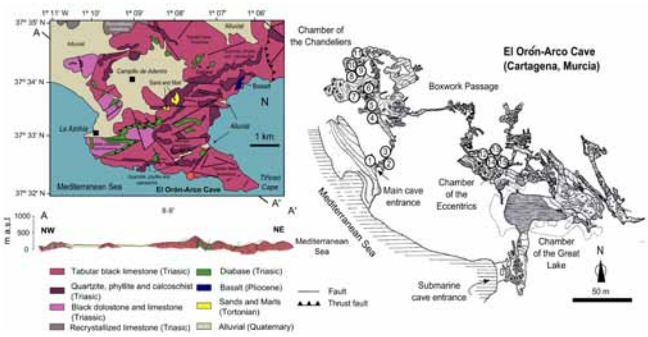

Figure 1. Geological setting of Cabo Tiñoso (after Gordillo et al., 1972) and topography of El Orón-Arco Cave (produced by Llamusí, Inglés and Ros, 1984-1998). Sampling sites are indicated.

2. Geological Setting

El Orón-Arco Cave is located in the southern flank of Cabo Tiñoso (Scabby Cape) in Cartagena, Murcia Region, SE Spain. The part of the cave so far surveyed is the result of the connection of El Arco Cave, surveyed in the 1980s (Llamusí *et al.*, 1990) and El Orón Cave (Puch, 1998). The subterranean network extends over 1500 m and has two entrances. One of them is a submarine access to the Arco Cave, also known as

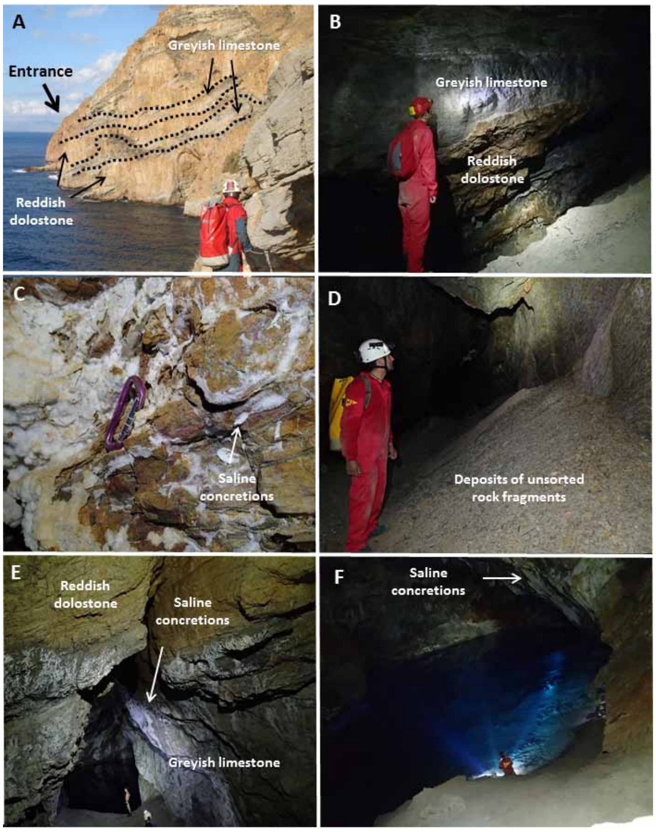

Figure 2. A. Interbedded highly foliated greyish limestones and reddish dolostone in which El Orón-Arco Cave is hosted; B. Contact between the limestones and the dolostone inside the cave; C. Saline concretions on the cave walls. D. Piles of unsorted rock fragments on the cave walls; E. Altered limestone and saline concretions; F. Saline concretions on the walls of the Chamber of the Great Lake.

Cave of the Lake because it hosts a 1200 m^2 brackish lake. The subaerial entrance is 200 m to the northwest of the submarine access, in the cliff of Cabo Tiñoso, lying at 10 m. a.s.l. (Fig. 1). The cave is developed along a fracture running W to E and parallel to the shoreline, in the slightly metamorphosed Triassic limestone and dolostone of the Alpujarride Formation of Cabo Tiñoso (García-Tortosa *et al.*, 2000). A series of greyish limestones and interbedded reddish dolostones outcrop both in the cave (Fig. 2A) and outside (Fig. 2B).

3. Methods

3.1. Reconnaissance of geomorphological features and sampling of speleothems

We performed a detailed photographic study of the geomorphological and speleothemic features of El Orón-Arco Cave (Figs. 2 and 3). In addition, we collected 15 mineral samples for mineralogical analysis. Saline concretions on the cave walls and appearing in foliation planes of the host rock (Orón-01; Orón-02, Fig. 3A; Orón-03, Fig. 3B; Orón-04, Fig. 3D; Orón-05, Fig. 3C; Orón-06, Fig. 3G) were sampled in different sectors of the cave (see Fig. 1 for sampling site locations). We took samples of the foliated greyish and reddish materials that comprise the cave hostrock (Orón-07 and Orón-08). A sample of yellowish unconsolidated, sandy material (Orón-09) was taken from a fracture following the foliation of the greyish host rock.

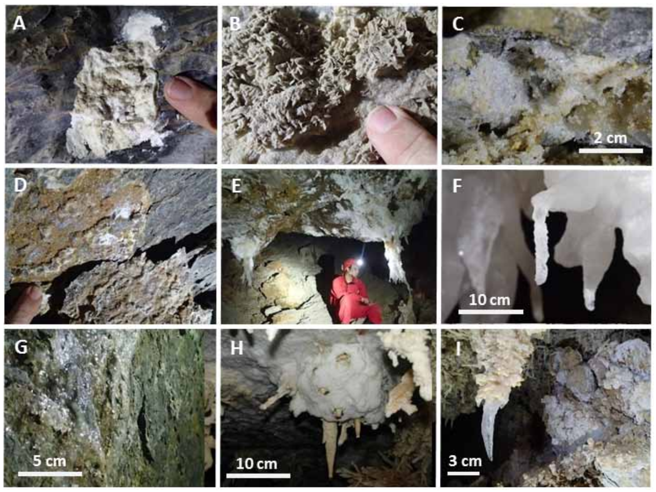

Figure 3. Speleothems in El Orón-Arco Cave: A. Concretions of gypsum on the carbonate hostrock; B. Aggregate of gypsum crystals covered by sandy materials; C. Saline concretions (gypsum + halite) in planes of the hostrock; D. Sugar-textured calcite infillings in planes of the hostrock; E. Gypsum "chandeliers"; F. Details of the apex of a "chandelier"; G. Saline coating on the cave walls; H. Hollow gypsum hemispheres ("blisters") perforated by carbonate eccentrics; I. Gypsum single crystals hanging from the tip of a carbonate dripstone.

In the Chamber of the Chandeliers, a sample of the whitish microcrystalline crust that occurs all over the ceiling in this location was collected (Orón-10; Fig. 3E). Another sample comprised fragments of a c. 1 m long transparent crystal that hung from the cave ceiling, reassembling a "chandelier" (Orón-11; Fig. 3E). In places, the apex of these crystals show a c. 10 cm long and 1 cm wide hollow cylinder, resembling a soda straw, made of a transparent microcrystalline mineral (Orón-12; Fig. 3F). In the Chamber of the Eccentrics, we took a fragment of a hollow hemisphere c. 10 cm in diameter from the cave ceiling (Orón-13; Fig. 3I), which was perforated by carbonate speleothems (Orón-14; Fig. 3I). Lastly, a transparent single crystal detached from the tip of a stalactite, similar to that in Fig. 3J, was collected (Orón-15).

4. Results And Discussion

Evidence for carbonate host-rock weathering by sea salts precipitation

El Orón-Arco Cave shows no signs of dissolution processes – either phreatic or vadose – that could support an origin linked to conventional karstification mechanisms. Indeed, the cave lacks both the typical morphologies related to water flow and any signs of subaqueous carbonate dissolution, including scallops, smoothed surfaces or cupolas. In contrast, the cavity displays clear evidence for chemical/mechanical weathering processes, which are behind the formation of its passages and chambers.

The most striking vestiges of such mechanisms are probably the deposits of unsorted carbonate hostrock fragments (<1 mm to tens of centimetres), which rest against the walls of the passages into the Chamber of the Chandeliers and in the entrance of the Boxwork Passage (Fig. 2D). The appearance of these passages reassembles that of a mine gallery riddled with mine debris; however, this cave has not been subject to mining activity and all its geomorphological features are original. The cave walls and ceilings are made of easily detachable rock that crack and eventually fall naturally to the cave floor and accumulate as piles of unsorted detritus. This mechanism is currently active and was observed during our visits to the cave. Indeed, the accumulation of rock debris in the smaller passages (e.g. the access to the Boxwork Passage) represents a serious challenge to accessing the cave: these galleries are prone to obstruction and frequently need to be unblocked by speleologists.

The cave host rock is made of greyish limestone and reddish dolostone, the latter containing small amounts of iron oxides (Table 1). In the planes of the carbonate beds, whitish and yellowish saline concretions and efflorescences are observed projecting out into the cave (Figs. 2 and 3). The mineralogical analyses (XRD and Raman spectroscopy) of these materials reveal the presence of minerals typically derived from evaporated seawater, including halite, gypsum and occasionally calcite (Table 1). We suggest that capillary uplift and infiltration of seawater through the carbonate formation of Cabo Tiñoso, and subsequent evaporation of the solution in the cave produces the crystallization of evaporites in planes and pores of the host rock.

The crystallization pressure of salts causes fracking and disaggregation of the original carbonate materials. Besides, the motion of the faults in the Cabo Tiñoso may have favoured the enlargement of the cave voids and the ejection of the disaggregated materials. To the best of our knowledge, this mechanism has not been described in other caves to date; however, similar processes of capillary uplift of saline waters and crystallization of salts are broadly known to be responsible for the decay of building materials and limestone sculptures (e.g. Gázquez et al., 2015)

4.1. Genesis of singular gypsum/halite speleothems

Infiltration and capillary uplift of seawater and subsequent evaporation in the cave is also responsible for the formation of singular speleothems in El Orón-Arco Cave. Evaporation of infiltrated seawater is favoured by the relatively high air temperature in the cave (c. 19°C during our visit) and likely low relative humidity (not measured). The crystallization of halite in the form of crusts and soda-straws strongly suggest the presence of relatively dry conditions, so halite dissolves in an atmosphere where relative humidity is above ~75% (Wexler and Hasegawa, 1954). In some of these speleothem formations – for example in the gypsum chandeliers of the Chamber of the chandeliers – a typical mineral series of seawater evaporation can be observed, starting with microcrystalline gypsum and selenite gypsum (Fig. 3E), and finishing with halite in the form of a soda-straw in the tip of the selenite crystals (Fig. 3F). These gypsum chandeliers are similar to those described in Lechuguilla Cave, New Mexico, EEUU (Davis, 2000); however, in El Orón-Arco the origin of SO_4^{2-} and Ca^{2+} is likely seawater.

El Orón-Arco Cave also hosts gypsum "blisters" speleothems on the ceiling of the Chamber of the Eccentrics. These speleothems comprise hollow gypsum hemispheres that, in places, are perforated by aragonite stalactites and eccentrics (Fig. 3H). Similar blister speleothems have been described in Cupp-Coutunn Cave (Turkmenistan), where their formation seems to be related to oxidation of pyrite (FeS_2). Again, in El Orón-Arco Cave the infiltration and evaporation of seawater is proposed as the main source of SO_4^{2-} and Ca^{2+} for the crystallization of gypsum. How these speleothems form is not yet clear, and their genetic mechanism will be the subject of future investigation.

5. Conclusions

The formation mechanisms of El Orón-Arco Cave have been linked to the motion of a fault that runs parallel to the cliff of the Cabo Tiñoso, and to salt weathering of the carbonate host rock by infiltration and capillary uplift of seawater that subsequently evaporates within the cave, leading to precipitation of evaporite minerals (gypsum and halite) in pores and planes of the carbonate. The crystallization pressure of salts produces cracking of the hostrock at different scales. The detached rock fragments accumulate in piles that rest against the cave walls. The same process of seawater infiltration is responsible for the

Table 1. Mineralogy of the spelothems and hostrock of El Orón-Arco Cave.

Sample	Description	Mineralogy
Orón -01	Saline concretions in planes of the host rock	Halite, Gypsum
Orón -02	Whitish coatings on the cave wall	Gypsum
Orón -03	Aggregate of planar crystals	Gypsum
Orón -04	Sugar-textured infillings in planes of the host rock	Halite
Orón -05	Saline concretions in planes of the host rock	Halite, Gypsum
Orón -06	Transparent coatings on the cave wall	Gypsum
Orón -07	Greyish carbonate host rock	Calcite
Orón -08	Reddish carbonate host rock	Dolomite, Goethite
Orón -09	Yellowish sand in planes of the host rock	Halite, Gypsum, Quartz
Orón -10	Microcrystalline coatings on the ceiling over a chandelier	Gypsum
Orón -11	Chandelier	Halite, Gypsum
Orón -12	Transparent "soda-straw" from the tip of a chandelier	Halite
Orón -13	Hollow hemisphere ("blisters")	Gypsum
Orón -14	Eccentric from inside a gypsum blister	Aragonite
Orón -15	Single crystal from the tip of a carbonate stalactite	Gypsum

precipitation of gypsum and halite in speleothems of uncommon morphology, including gypsum chandeliers, halite soda-straws and gypsum blisters.

Future studies will address the corroboration the proposed model of cave formation using geochemical data. This will include analysis of stable isotopes of gypsum, and investigations of the assembly of secondary minerals and the original carbonate hostrock at microscale. In addition, genetic models for the formation of the gypsum chandeliers and the blisters of El Orón-Arco Cave will be developed.

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