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**PATTERNS OF COLLAPSE CHAMBERS IN THE
ENDOKARST OF MALLORCA
(BALEARIC ISLANDS, SPAIN)**

RAZPOREDITEV PODORNIH DVORAN V ENDOKRASU
MALLORCE (BALEARSKO OTOČJE, ŠPANIJA)

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Izvleček

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Àngel Ginés: Razporeditev podornih dvoran v endokrasu Mallorce (Balearsko otočje, Španija)

Prispevek podaja pregled razporeditve podornih dvoran na krasu Mallorce. Na načrtih mnogih jam je mogoče razločiti enostavne podorne dvorane in vrste velikih jamskih prostorov, eno glavnih sestavin tamkajšnjih jam, kar kaže na velik pomen teh dveh elementov. Za opis in boljše razumevanje razporeditve udorov so lahko zelo koristni podatki, pridobljeni s pomočjo podrobnega kartiranja različnih podornih struktur, kot so podorni stožci, nagnjena podorna pobočja, prerezi v obliki obokov, »stičišča«, podorni zamaški in kupolaste strukture.

Ključne besede: speleogeneza, jamski podor, podorne oblike, obalni kras, Mallorca, Balearsko otočje, Španija.

Abstract

UDC: 551.435.84(467.51)

Àngel Ginés: Patterns of collapse chambers in the endokarsts of Mallorca (Balearic Islands, Spain)

A general overview on the patterns of collapse chambers in the karsts of Mallorca is presented. The great significance of single breakdown chambers and strings of large rooms as one of the major constituents of cave patterns is easy to recognize in the cave surveys of many Majorcan caves. Detailed mapping of several collapse features such as breakdown piles, sloped boulder floors, vault profiles, coalescence areas, boulder chokes and dome structures can yield useful information regarding description and better understanding of cave collapse patterns.

Key words: speleogenesis, cave breakdown, collapse features, coastal karst, Mallorca, Balearic Islands, Spain.

INTRODUCTION

Cavern breakdown (Davies, 1949) or incision (Bögli, 1980) is a quite common endokarstic process that results from collapse of cave ceilings and walls. The failure of cave roofs is considered to be an important part of the speleogenetic evolution, namely one of the late stages in the overall degradation of the karst systems (White & White, 2000). The detachment of masses of rock of various sizes from the unstable tension arches, induced by the presence of former cavities, gives rise to domes and vaults whose cross-sections tend to adopt the rounded shapes that better provide equilibrium to the stress distribution in the ceiling bedrock. Fallen blocks accumulate at the centre of the domed collapse chambers to form conical debris heaps on the floor or produce boulder slopes if the vaulted chambers become asymmetrical. Many of these general aspects concerning cave breakdown and collapse chambers are discussed in the available literature (Davies, 1949 and 1951; Montoriol-Pous, 1951; Renault, 1967; White & White, 1969; Bögli, 1980; Jennings, 1985; White, 1988; Ford & Williams, 1989; White & White, 2000), but quantitative and morphometrical data are scarce.

Concerning the Majorcan endokarst, cave breakdown features and collapse chambers appear as one of its most outstanding characteristics (Ginés & Ginés, 1987 and 1989; Ginés, 1995), both in the massive and micritic Jurassic limestones of the mountains as well as in the very porous Miocene calcarenites of the southern and eastern coast of the island. Many well known caves in Mallorca are constituted by single breakdown chambers or by strings of large rooms connected between them through low coalescence areas. In the mountains, the dominant vadose processes are linked to old stages of karstification and high relief gradients. In the coastal post-orogenic calcarenites, the nearby sea level appears even today as the main factor controlling speleogenesis and cave collapse processes. Recent reports (Ginés, 1991; Ginés & Ginés, 1992) emphasize the role played by mixing of fresh and marine waters in the coast-line phreatic zone, specially regarding removal of rock wall and collapse debris by enhanced dissolution (Back et al., 1984).

As a general rule, two major facts related to breakdown chambers must be taken into account. Firstly, it can be assumed that the volume of collapse debris is much smaller than the volume of the total empty space of the chamber, because frequently the considerable amount of boulders and other collapse debris leave many gaps between them. Owing to this apparent increasing volume associated to the growth of boulder heaps, the real enlargement of the caverns is only effective in conjunction with other speleogenetic agents implying rock removal. Secondly, the failure in the tension domes, that develop around the former caves, always progresses upwards. Since sometimes the differences in altitude from the top to the deepest parts of the chambers are remarkable, it means that the starting voids from which the vault or dome have grown are necessarily situated at a quite lower elevation than the surveyed cave. In these cases, the searching for the base level that controlled speleogenesis must reflect this difference in altitude between actual cave passages and initial proto-caves.

COLLAPSE CHAMBERS IN THE ENDOKARST OF MAJORCAN MOUNTAINS

Majorcan mountains are characterized by the dominance of karstic landscapes because massive mesozoic carbonate rocks, Jurassic in age, outcrop widely both in the Serra de Tramuntana and Serres de Llevant mountain ranges. Large overthrusts, produced during Alpine orogeny, imbricated several sheets of pure limestones forming two major mountain chains that reach in many places more than 600 meters of altitude over the sea level. Some great limestone outcrops appear today just in the coast line but others are located far away from the sea, that acts as general base level. It is difficult to know the age of the karstification, but several evidences suggest a pre-Quaternary initiation and further development of karstic processes. So, collapse chambers frequently found in the endokarst of Majorcan mountains are probably the result of older stages of karstification that were of widespread occurrence in the area.

Cave exploration in the Majorcan mountains started during the 19th century. One of the most remarkable events was the discovery and dangerous descent to the Avenç de Son Pou (Conrado, 1865), an impressive open-ceiling dome, accessible through a vertical drop more than 50 meters deep, which results from the overhanging walls of the main chamber. The main chamber occupies a surface greater than 5000 m² (Thomás-Casajuana & Montoriol-Pous, 1952) and shows at the bottom a gigantic block 18 meters tall.

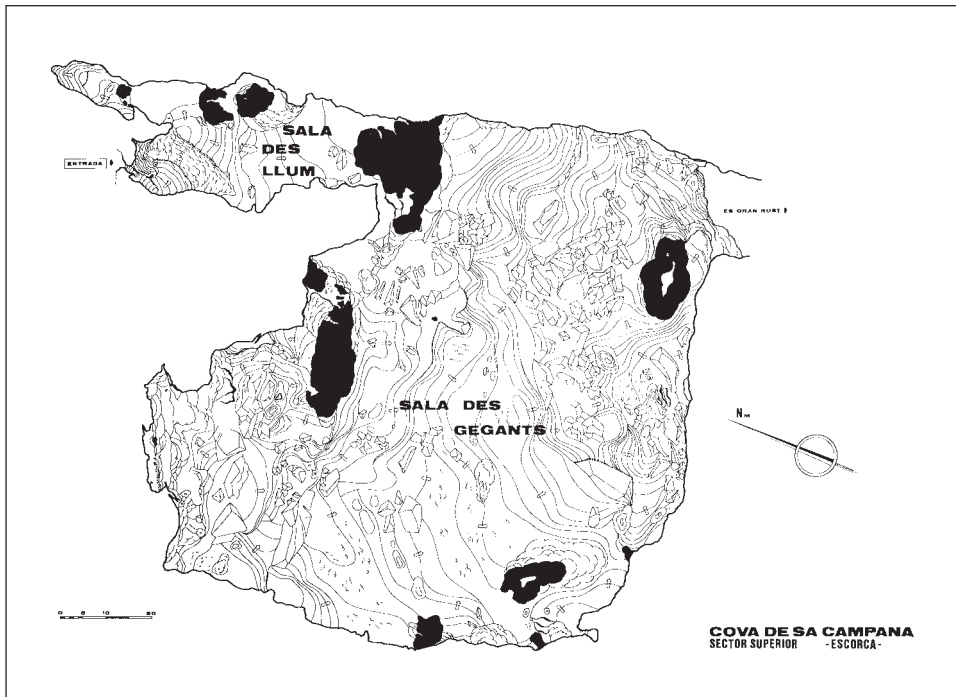


Fig. 1: Plan of Sala des Gegants (Cova de sa Campana), the greatest cave chamber found in Mallorca. After the survey from Hernández et al., published by Ginés & Ginés (1987).

After this discovery a great amount of caves constituted by different kinds of collapse structures, single or composed by strings of connected rooms, were reported in the literature. Maybe the most outstanding cave, composed by collapse chamber strings, is Cova de sa Campana, the deepest cave system in Mallorca, surpassing a total depth of 300 meters (Mir & Trias, 1973). The Cova de sa Campana is a complex and uncommon cavern that attains a considerable depth through a succession of randomly connected descending chambers. The main room, called Sala des Gegants (Fig. 1) has more than 10000 m² in surface (Ginés & Ginés, 1987) and is plenty of flowstone and rimstone dams that cover partially the sloped boulder floor. Former solutional rock features are hard to recognize because of the great extent of destructive collapse features.

Many small single chambers, open ceiling domes and vaulted rooms have been reported after surveying in the Majorcan mountains, but perhaps the most remarkable collapse caverns reported recently were a few exceptional caves that can be described as macrochambers. The best examples known are Cova de Can Sion (Encinas, 1994) and Covota de sa Penya Rotja (Trias, 1986). Macrochambers are huge vaulted structures (Fig. 2), frequently opened to the surface through small entrances caused by slope recession and finishing in their deepest parts as very narrow vertical trenches that run around the periphery of the caverns. One noticeable characteristic of Majorcan macrochambers consists in the fact that speleothem growth creates partitions and smaller

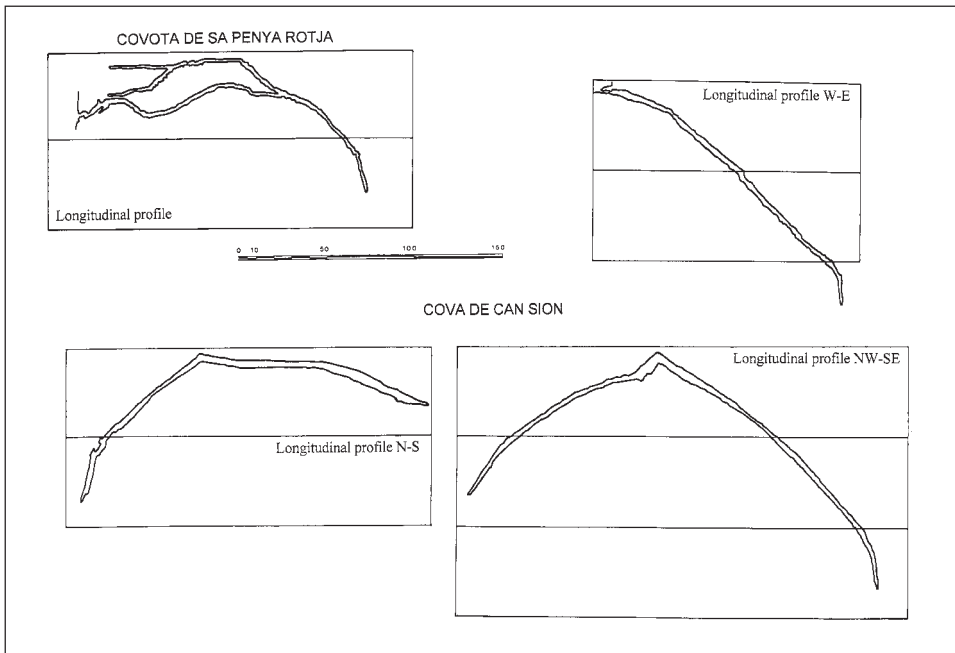


Fig. 2: Longitudinal profiles of Covota de sa Penya Rotja and Cova de Can Sion, after Trias (1986) and Encinas (1994) respectively. Both caves are good examples of megachambers whose axis are longer than 150 meters after the surveys published by Trias (1986) and Encinas (1994) respectively.

pseudochambers, making difficult to recognize the general cavern pattern that only becomes clear after mapping.

From a speleogenetical point of view, the collapse chambers that characterize Majorcan the mountain endokarst are related to vadose processes and long-term evolution of old pre-Quaternary karstification. Lowering of base level over time has produced cave decay in a rather conventional manner, like it occurs in the majority of the cases reported in the available literature. In this respect, only the great dimensions of some chambers are striking, but not the breakdown processes involved, that are the common ones. Perhaps the most important contribution that results from our increasing knowledge on the Majorcan mountain endokarst concerns macrochambers. The case studies of macrochambers here reported (Cova de Can Sion and Covota de sa Pena Rotja) are linked to large scale collapse processes. But it seems that this kind of caves could be relatively neglected in the literature since only accurate mapping can give substantial evidence on such special cave patterns.

COLLAPSE CHAMBERS IN THE ENDOKARST OF MAJORCAN POST-OROGENIC REEF

Majorcan post-orogenic reef developed during the Upper Miocene around the former Alpine structured mountains and became intensely karstified since the Messinian times till today. The reefal carbonate platform presents a rather flat relief, lower than 40 meters in altitude above sea level, and fringed in many places with small cliffs. Coral patches, bioclastic calcarenites, shelly and oolitic limestones present diverse solutional features, but in all the cases the karst development is strongly conditioned by the great porosity of the rock. The proximity of the coast line, together with the high rock porosity, produces a remarkably continuous phreatic zone whose water table sets up in hydrostatic equilibrium with the sea level. The whole karst, including the cave systems, remain affected by the position and migration of both the water table and the mixing zone, where chemical interactions between fresh and salt waters provides enhanced aggressiveness. The age of the main karstification stages is difficult to ascertain because, in spite of the recurrent sea level shifts and the related water table fluctuations in altitude that may disturb slow cave enlargement, the vertical migration of geochemically active zones permits a renewal of speleogenetic processes time after time.

Cave exploration in the Majorcan post-orogenic reef also started during the later 19th century, specially as a result of the pre-tourist visits to the celebrated Coves del Drac. After the successful discoveries of Martel (1896, 1903), several caves from this karstic area, like Cova des Pont, Coves del Pirata and Coves dels Hams, were also described in the international papers. Some of the old surveys of these caves already showed the presence of large vaulted rooms floored with boulder heaps which lower parts appeared drowned by brackish water pools. Such characteristics were later confirmed in almost all the caves developed in the young and porous calcarenites from this karstic area, as it has been documented in Ginés & Ginés (1977) and Mir & Trias (1977), whose report includes significant surveys. Recent contributions about speleogenesis in the Majorcan post-orogenic reef (Ginés, 1991; Ginés & Ginés, 1992) emphasize both, the typical characteristics of the caverns formed in this coastal environment and the role played by the shifts (recurrent rises and falls) of the water table as a consequence of sea level oscillations occurred during the Quaternary.

Till the last years the exploration of these coastal caves, drowned by the post-glacial sea level rise, was stopped in the brackish pools, being limited to the upper parts of the caves not invaded by the water table. But technical changes in exploration devices, like wetsuit clothes for swimming and scuba diving equipments for underwater survey, have focused the more recent findings near the water surface and even below the water level. After the successful exploration of Cova des Pas de Vallgornera (Merino, 1993), a cave mainly developed close to the current sea level, several underwater discoveries have been carried out by speleo-divers (Gracia et al., 1997; 1998a; 1998b). Among the remarkable observations gathered by them, some are significantly related to the subject of this paper. In this respect, the fairly good surveys obtained yield many evidences of drowned collapse features, such as boulder piles, vaulted roofs and coalescence areas connecting adjoining chambers (Fig. 3). New data available have shown unexpected extensions below the water table that, at least in Cova des Ases and Cova des Coll, permit to communicate with the sea. Another caves like Cova de sa Gleda and Cova des Serral, whose wide entrance pits are similar to cenotes, have revealed the existence of submerged chambers and passages previously ignored, some of them several kilometres in length. In all the cases, large room strings stands out as the most common cave pattern found.

From a speleogenetical point of view, the collapse chambers that characterize the Majorcan post-orogenic reef endokarst are related to recurrent rises and falls of the water table, befallen during the Quaternary within the framework of a special coastal karst environment. The cave systems were always controlled by the sea level changes, being subjected to repeated phases of invasions and retreats of the phreatic waters. Each time that water table moved downwards the loss of buoyant support increased the mechanical stress of the vaults, triggering local collapses. On the

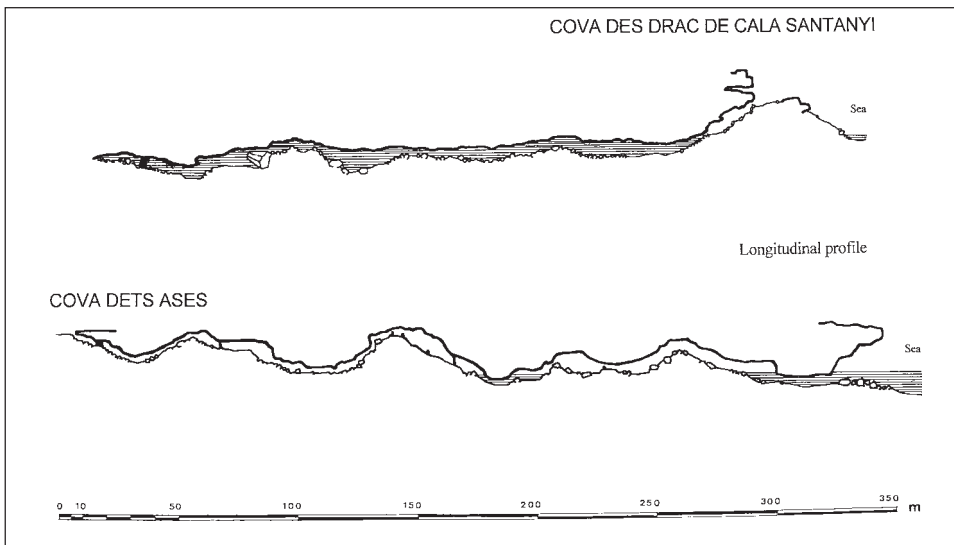


Fig. 3: Longitudinal profiles of Cova des Drac de Cala Santanyí and Cova des Ases, after the surveys published by Gracia et al. (1997 and 1998). The coalescence of several collapse units can be recognized after the topographical surveys.

other hand, each time that water table moved upwards the rock vaults and the boulder floors were drowned by mixtures of fresh and marine waters, causing further limestone removal. Owing to these alternating processes, fluctuations of the sea level and subsequent rises and falls of the brackish pools inside the caves have to be envisaged as a major speleogenetic factor in the Majorcan post-orogenic reef endokarst. So, in coastal karst environments, where cave systems remain closely adjusted to the sea, breakdown occurrence spans over long time periods and it is not only limited to the older stages of cave development.

CONCLUSIONS

Cavern breakdown is a general trend that affects most of the Majorcan caves as a result of the long term evolution of the karst systems developed in the mountain outcrops of micritic limestones as well as in the coastal platform of young and porous calcarenites. In both cases, collapse chambers are major endokarst features showing distinctive patterns associated with different genetic processes, as it can be seen after an accurate surveying of the caves.

Major advances in the knowledge of our caves have been recently obtained by means of detailed exploration of some low debris-choked passages and lateral narrow trenches that characterize respectively the vault top and the sides of several macrochambers located in the mountain karst. Furthermore, significant achievements have been produced during the last years as a result of systematic scuba-diver exploration of many drowned caves located in the coastal platform karst. Also in this case, the exceptionally accurate surveys carried out by the Majorcan divers have entirely modified our perception of the real size and extent of underwater collapse features which can be observed below the current sea level.

Besides the local interest of the speleological data provided over the last decades by renewed exploration and surveying tasks, it seems that some specific contributions obtained from Majorcan caves can be useful on a wider scope. Let me summarize three of them:

1. Collapse macrochambers, as described in this paper, are probably rather neglected in the available literature because only after accurate surveyings can be deduced the real pattern of such huge collapse structures, that furthermore are frequently masked by the growth of speleothems like flowstone and columns.
2. Strings of large vaulted rooms are a quite common pattern in coastal karsts resulting from random collapse coalescence of solutional voids promoted by the recurrent loss of buoyant support that occurs when sea level falls, specially during glaciacions.
3. Exploration and cave surveys have not finished their former basic role in speleological sciences, because many endokarst features are ignored even today or scarcely known. On the other hand, descriptive and morphometrical approaches can only be based on good topographical surveys; able enough to inform with objectivity about the dimensions, geometry and shapes observed inside the caves. In my opinion, breakdown features and collapse chamber patterns are among the cave subjects that claim for a more detailed documentation in the future.

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RAZPOREDITEV PODORNIH DVORAN V ENDOKRASU MALLORCE (BALEARSKO OTOČJE, ŠPANIJA)

Povzetek

Podori v jamah so tisti splošni proces, ki mu je podvržena večina jam na Mallorci, saj je posledica dolgega razvoja kraških sistemov, nastalih tako v izdankih mikritskih apnencev v gorah kot tudi v mladih in poroznih kalkarenitih obalne ravnine. V obeh primerih so podorne dvorane glavne endokraške oblike. Njihova razporeditev je odvisna od različnih razvojnih procesov, kot je mogoče razbrati iz natančnih jamskih načrtov.

Največji napredek v poznavanju naših jam, dosežen v novejšem času, je bilo podrobno raziskovanje nizkih, s podori zasutih rogov in ozkih stranskih prehodov, ki so v resnici prostori tik pod oboki ali ob straneh velikih dvoran v gorskem krasu. Pomemben napredek v zadnjih letih je bil dosežen tudi s sistematičnimi avtonomnimi potapljaškimi raziskavami številnih potopljenih jam v zakraseli obalni ravnici. Tudi v tem primeru smo, zahvaljujoč izredno natančnim raziskavam, ki so jih opravili potapljači z Mallorce, popolnoma spremenili naš predstave o resničnih velikostih in obsegu podvodnih podornih oblik, ki jih je mogoče opazovati pod današnjo morsk gladino.

Poleg ožjega pomena speleoloških podatkov, pridobljenih v zadnjih desetletjih ob ponovljenih raziskavah in meritvah, kaže, da je lahko nekaj posebnih opažanj iz jam na Mallorci koristnih tudi v širšem pogledu. Naj povzamem tri izmed njih:

1. Velike podorne dvorane, kot so opisane v tem prispevku, običajno niso upoštrevane v dostopni literaturi, kajti samo natančna izmera lahko poda pravo razporeditev podornih struktur, ki so povrhu vsega pogosto zakrite s sigo in kapniki.
2. Nizi velikih kupolastih dvoran so pogost pojav v obalnem krasu. Nastanejo zaradi naključnih sovpadanj podorov korozijskih votlin, povzročenih z znižanjem morske gladine, posebno v glacialih, ko so stropi izgubili vzgonsko podporo.
3. Raziskovanje in merjenje jam še ni izgubilo nekdanjega temeljnega pomena, saj je še danes neznanih ali le slabo poznanih mnogo endokraških oblik. Po drugi strani pa opisi in morfometrične raziskave lahko temelje le na dobrih topografskih raziskavah. Te morajo biti take, da je iz njih mogoče dobiti objektivne podatke o merah, geometriji in oblikah znotraj jame. Po mojem mnenju so podorne oblike in podorne dvorane tiste jamske oblike, ki v prihodnosti zaslužijo podrobnejšo obdelavo.