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CONTRIBUTION TO THE EVOLUTION OF THE PERAMA CAVE (IOANNINA, NW GREECE)

Ifandi E.[1], Tsikouras B.[1,2] and Hatzipanagiotou K.[1]

[1]*University of Patras, Department of Geology, Section of Earth Materials, 265 00, Patras, Greece selena.21@windowslive.com, v.tsikouras@upatras.gr, k.hatzipanagiotou@upatras.gr,*

[2]*University of Brunei Darussalam, Department of Petroleum Geoscience, Jalan Tungku Link, Gadong BE1410, Bandar Seri Begawan, Brunei Darussalam*

Abstract

This study includes the description of thirty three speleothem types, which were found in the Perama cave, Ioannina, NW Greece, according to the international literature, along with the interpretation of their formation, for the first time in Greece. The detailed study of these speleothems coupled with observations of the way of their formation and their spatial distribution enabled us to suggest that the Perama cave evolved through a sequence of episodes that include dissolution of the host Senonian limestone, collapse of its roof formations, as well as alternating events of formation of stalactitic- and stalagmitic-type speleothems with excess water flow and/or flooding, which resulted in the development of stream formations
Key words: *speleothem classification, carbonate minerals, cave formation.*

Περίληψη

Με την έρευνα αυτή δίδεται η συστηματική ταξινόμηση τριάντα τριών τύπων σπηλαιοθεμάτων από το σπήλαιο Περάματος Ιωαννίνων, μαζί με την ερμηνεία σχηματισμού τους, σύμφωνα με τη διεθνή βιβλιογραφία, για πρώτη φορά στην Ελλάδα. Η λεπτομερής μελέτη των σπηλαιοθεμάτων σε συνδυασμό με παρατηρήσεις αναφορικά με τον τρόπο και τη θέση σχηματισμού συγκεκριμένων ομάδων σπηλαιοθεμάτων μας οδήγησαν να προτείνουμε την εξέλιξη του σπηλαίου Περάματος μέσω μιας σειράς διαδοχικών επεισοδίων, τα οποία συμπεριλαμβάνουν τη διάλυση των Σενώνιων ασβεστόλιθων, την κατάρρευση της οροφής του σπηλαίου, καθώς και εναλλασσόμενα επεισόδια σχηματισμού σπηλαιοθεμάτων σταλακτιτικού και σταλαγμιτικού τύπου με εκτεταμένες ροές νερού ή/και πλημμύρες, οι οποίες οδήγησαν στην ανάπτυξη μορφών ροής.
Λέξεις κλειδιά: *ονοματολογία σπηλαιοθεμάτων, ανθρακικά ορυκτά, σχηματισμός σπηλαίων.*

1. Introduction

Although caves represent popular and attractive geological formations, the exact mechanism for the development of speleothems in most cases, is not fully known. Greece has some of the prettiest caves of the world but a systematic classification, according to international standard descriptions (e.g. Hicks, 1950; Cabrol, 1974; Renault, 1976; Hill and Forti, 1997; Charles and Hill, 2003; Fairchild and Baker, 2012) is lacking. Eight types of caves are recognized according to their mechanism of formation. The most common type includes the solutional caves, which are typically formed from karstic weathering of limestones (Galdenzi, 2012). In this case, atmospheric CO_2 reacts with rainwater producing the weak carbonic acid, which subsequently reacts with limestones leading to their karst weathering (Moore, 1962). During the water-filled stage, variable void spaces appear whereas speleothems form subsequently, when $CaCO_3$ precipitates from the supersaturated fluid, due to decrease of P_{CO2}, in the air-filled stage (Fairchild and Baker, 2012). The Perama cave is a solutional cave that has been accidentally discovered during the Second World War and first described thoroughly by Petrocheilou (1952). The scope of this study is to describe, classify and explain the formation of the speleothems from Perama Cave, according to international standards for the first time in Greece, pointing towards the interpretation of its development.

2. Geological Setting

The Perama Cave occurring in the interior of the Goritsa hill, Ioannina, is hosted in brecciated, Senonian limestones that overlie the Vigla Limestone, of the Ionian Zone (Figure 1). The Ionian Zone in western Greece is characterized by evaporitic formations at its base and a subsequent, continuous, carbonate sedimentation from Triassic to Cretaceous (Aubouin and Dercourt, 1962; Thiebault, 1982; Mountrakis, 1987). The Perama cave is located close to the north shores of the Pamvotis Lake, whose water surface apparently controls the aquifer of the broad area.

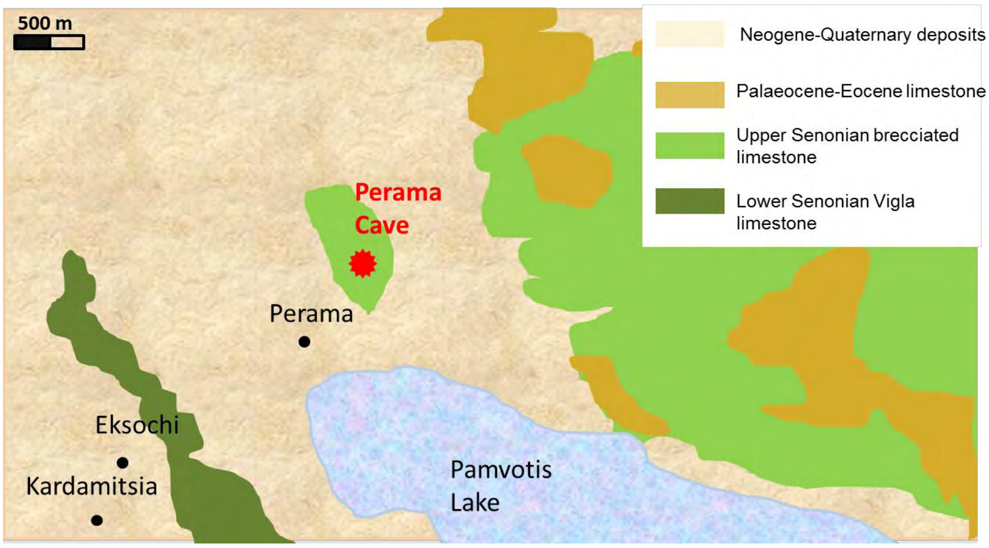

Figure 1 – Simplified geological map of the area around the Perama Cave (modified after IGME 1967).

3. Description of the Speleothems

Thirty three different speleothem types were recognized during this investigation and have been described and classified according to Hill and Forti (1997) and Fairchild and Baker (2012) and references therein; their description below is given in order of decreasing appearance in the Perama cave while photographs of representative types are illustrated:

Flowstones are laminar deposits covering the walls and the floor of the cave (Figure 2A). They arise through deposition of calcite over these surfaces and may adopt a wide variety of shapes, from thin layers to thicker ones. Flowstone masses are often fluted with draperies at their lower end. *Shelfstones* comprise ledges grown from speleothems dipped in pools, at the air/water interface, thus comprising a great indicator of past pool levels (Figure 2B). Calcite commonly precipitates on top of cave pools, hence its deposition continues to add growth laterally and underneath the dipped speleothem. *Soda straws* comprise deposition of calcite on the roof of the cave and are characterized by their cylindrical shape (Figure 2C). They grow downwards until a detrital grain blocks or a calcite grain develops in such a way that obstructs the water drip. *Soda straws with coralloids*, have a soda straw core covered with coralloids (for a description see below) due to the fact that the initial soda straws were sunk in water for a long period (Figure 2D). These types are frequently formed on pre-existing speleothems like columns with shelfstones. *Stalagmites* are observed as floor formations that built up by water dripping, derived either from roof speleothems or directly from roof joints, above it. Unlike stalactites, they grow upwards forming massive calcite mounds (Figure 2E); they lack soda straw interiors. *Stalactites*, one of the most well-known speleothems, are recognized due to their conical form evolving downwards, ranging in size from few centimeters to several meters (Figure 2F). They are developed after water dripping in a soda straw is prevented, as described above. Then, water overflows from the base of the cone resulting in a nearly conical thickening, due calcite deposition sideways the soda straw; typically their interiors contain soda straw reminiscents. In some stalactites, black stained soda straw interiors are most likely due to the presence of organic material, perhaps related to microbial activity (Jones, 2010). *Coralloids* comprise calcite nodules with concentric, botryoidal structure, concentrating in small aggregates (Figure 2G). Some of them show tiny branch-shape terminations. They have no central duct and their colors vary from yellowish white to dark brown, due to the presence of impurities. Coralloids of subaqueous origin display smooth, rounded surface, unlike corraloids that have been formed in a subaerial environment; their underwater formation is also implied from coexisting formations that form in a subaqueous environment. Subaqueous coralloids predominate in the Perama cave whereas fewer subaerial coralloids are observed. *Bottlebrushes* comprise composite speleothems which are composed of a stalactite interior covered by coralloid formations (Figure 2H). They are formed when stalactites are immersed for a long period in cave pools, as it is also implied from coexisting subaqueous speleothems like coralloids. As a consequence of supersaturation of the pool water in $CaCO_3$, stalactite is firstly coated with spar calcite while after a long period it is covered by coralloids. *Microgours* are tiny rimstone dams usually found on flowstone and resemble wrinkles or ripple marks (Figure 2I). Commonly, coralloids have been formed in their inner parts. *Rimstone dams* are floor barriers that prevent flow of streams, hence forming shallow pools in the Perama cave (Figure 2J). They are normally composed of calcite, which grows under running water and its height is more increased in steeper areas. *Lotus rimstones* refer to a subtype of rimstone dams with a circular to convoluted shape resembling that of water lilies/lotus (Figure 3A). They usually coexist with the previous type and are grown locally or in a larger scale. *Columns* are formed by the coalescence of stalagmites and stalactites (Figure 3B). In places, large collapsed blocks of rocks are covered by flowstones, which have reached the cave roof, may be considered as another subtype of columns. *Draperies* are deposited from calcite-laden solutions flowing along an inclined ($\approx 45^o$), overhung surface leaving calcite trails. These initial trails become the preferential routes for continued flow giving rise to the delicate sheets (Figure 3C). *Volcano cones* are found in pools with stagnant water. Their shape resembles truncated cone with a concave, crater-like top (Figure 3D). They grow up vertically like stalagmites from a submerged floor, by water dripping into the pools. *Punched speleothems (also known as bottles)* are very similar to the volcano cones, however their crater-like top is assigned either to drops of low pH water that dissolves their top or to high mechanical energy of the water drops that impact on a stalagmite's surface (Figure 3E). Measurements of pH of the water in the Perama cave revealed that it is neutral to mildly alkaline, therefore the possibility that the punched speleothems formed due to acid water is less likely. *Splattermites* are platy, upright protrusions growing around a central axis fed by rings of drip splash that rebound from the formation's growing tip (Figure 3F). Splattermites tend to form within tall cave chambers, from very rapid calcite deposition, where ceiling drops build up lots of speed and "bounce potential". Their final form resembles that of a cactus. *Boxwork* consists of a mesh network of thin blades of crystalline material protruding along joints of the roof bedrock. It is particularly present in brecciated zones, where the joints act as conduits of the water (Figure

3G). *Coral pipes* are thin pipe-like structures, which form in a shallow pool environment. Their height is less than 10cm and form clusters spaced a few cm apart. *Paraschute shields or Jelly-fishes (Meduses)* comprise a subtype of flowstone, which are exclusively present in the biggest hall of the Perama cave. They form voluminous formations occurring as isolated hangings from the cave roof. An initial shield forms on the roof of the cave, from water running through cracks, which subsequently is covered by flowstone giving its characteristic shape (Figure 3H). *Helictites and Heligmite*s are delicate and fragile speleothems whose growth seems to defy gravity, formed exclusively inside cave passages that are protected from air-currents, temperature fluctuations, animal activities etc. and away from the touristic route. They can be filiform, rosary, vermiform or branching. In analogy to stalactites and stalagmatites, helictites and heligmites are formed on the roof (and wall) and on the floor (and over other speleothems), respectively (Figure 3I). *Deflected stalactites* are unusual types that show downwards growth, which however, decline from the vertical position (Figure 3J). Although their growth mechanism is not well understood yet, it is proposed that their curved shapes are due to air currents. *Speleogens* comprise erosional structures due to dissolution of bedrock, forming typical voids on it. Usually, it is reported that they occur on the bedrock of speleothem-free caves. However, this type has been rarely seen on the bedrock of the Perama cave whilst more commonly is observed on older speleothems forming typical cavities (Figure 4A). *Moonmilk* is a white paste-like deposit on older speleothems or on the wall and floor of the cave (Figure 4B). It is typically located near the entrance of the Perama cave, in the twilight zone, and it is composed of a variety of carbonate minerals, mainly hydromagnesite, nesquehonite and huntite. Their genesis is probably related to the action of micro-organisms living in the cave, which are thought to be involved in the breakdown of calcite of the older speleothem. *Crusts* comprise encrustations covering locally the walls, the ceilings and sediments within the Perama Cave (Figure 4C). They are composed primarily of a variety of carbonate minerals where calcite predominates. *Pearls* are concentric, ooid concretions, resembling oolites observed in shallow cave pools (Figure 4D). They usually form from deposition of calcite layers around a nucleus of whatever origin. Their typical round shape is due to the uniform growth of the pearl and not to any sort of rotation due to dripping. This can be explained as the sphere allows the greatest amount of deposition for the smallest surface area and is thus most likely, even if the nucleus is highly irregular. *Turnips*, are stalactite-type speleothems having a bulbous (welt-like) shape and an additional soda straw end beneath. *Orange sticks* include helictites or aragonite flowers of which the free extremities are wrapped in little white tufts of a porous consistency. Their formation is probably attributed to the deposition of magnesium salts on moonmilk type formations. *Rafts* are thin, sheet-like deposits that have been rarely observed on the surface of water of the cave pools. Their formation is assigned to spreading of a calcite crust on the surface of water, when $CaCO_3$-rich water-drops fall on pool surfaces. The periodic change of water level does not allow the extensive growth of these delicate formations. *Soda straw columns with welt* are composite speleothems that have formed from planar excrescences growth along fractures of soda straw columns; their formation is likely only if cracks open very slowly. *Christmas tree* is a composite frostwork stalagmite, constituting mainly of aragonite outlying a form which has spiny limbs like a fir tree. *Rootsicles* are found near the entrance of the cave, along with moonmilk, where the cave roof is rather thin, therefore plant roots extending downwards in a quest for water, appear in the cave interior (Figure 4E). In most cases, they have been coated with calcite, and essentially have been fossilized. The *Cross stalagmite*, is an extremely rare speleothem type, which has been first reported in Perama cave by Petrocheilou (1952) and comprises one of the most attractive shows of the cave. To our knowledge, a similar speleothem has also been reported only in the Grand Roc cave, Dordogne, France (http://www.geolocation.ws/v/W/File%3AGrotte%20du%20Grand%20 Roc%20%20Stalagmite% 20en%20croix%20-%2020090923.jpg/-/en). Obviously, it has a cross shape and despite the fact that it is referred only one individual of this type, during our investigation we have discovered other two similar formations outside the touristic route (Figure 4F). Its formation is interpreted to be the result of a broken piece of stalactite that remained on a vertical position on a stalagmite rough top, perhaps with the assistance of mud. As stalagmite growth persisted, calcite deposition covered the fallen fragment.

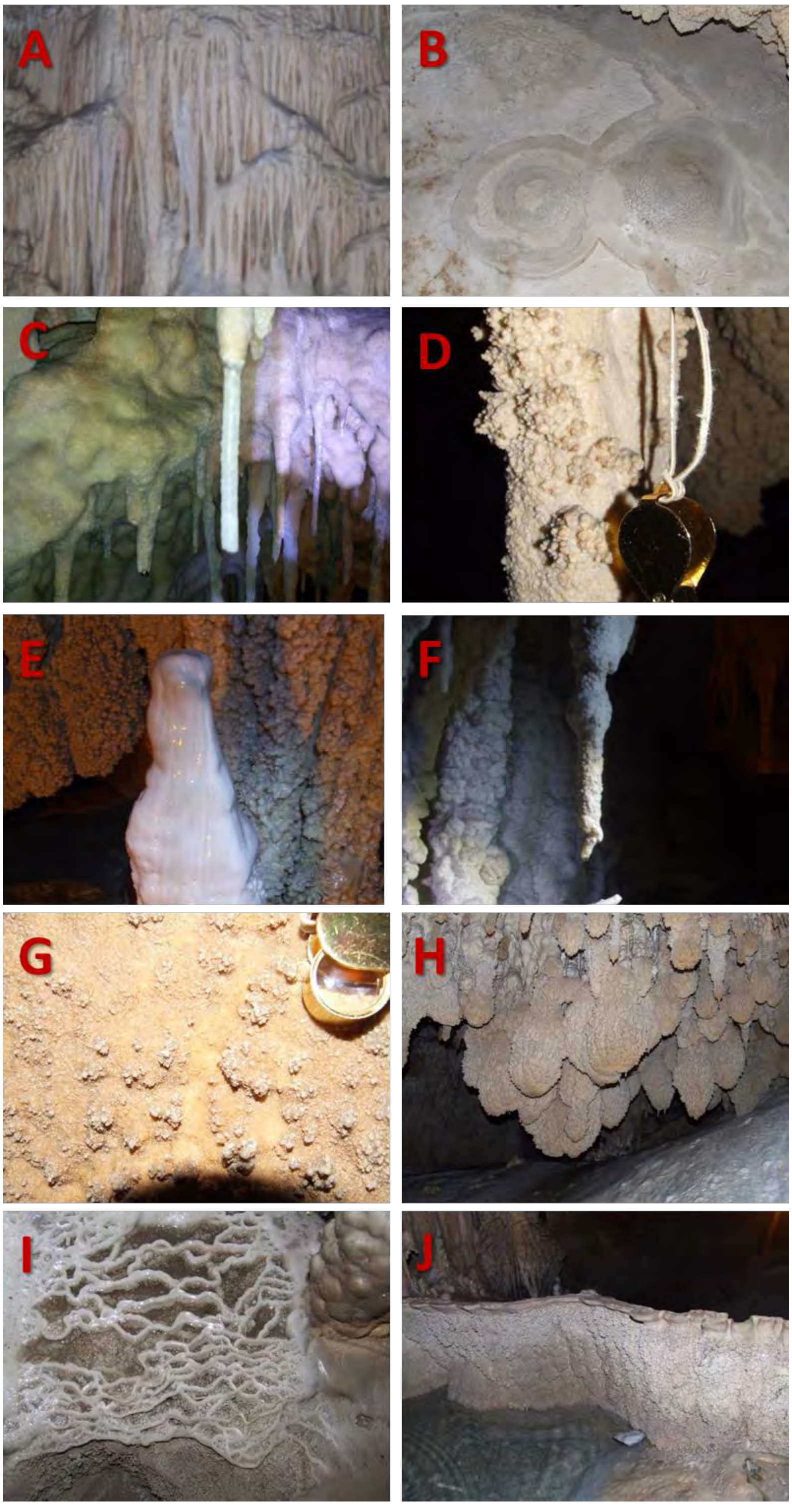

Figure 2 - Speleothem types observed in the Perama cave: A) Flowstone, B) Shelfstones, C) Soda straws, D) Soda straw with coralloids, E) Stalagmite, F) Stalactite, G) Coralloids, H) Bottlebrushes, I) Microgours, J) Rimstone dam.

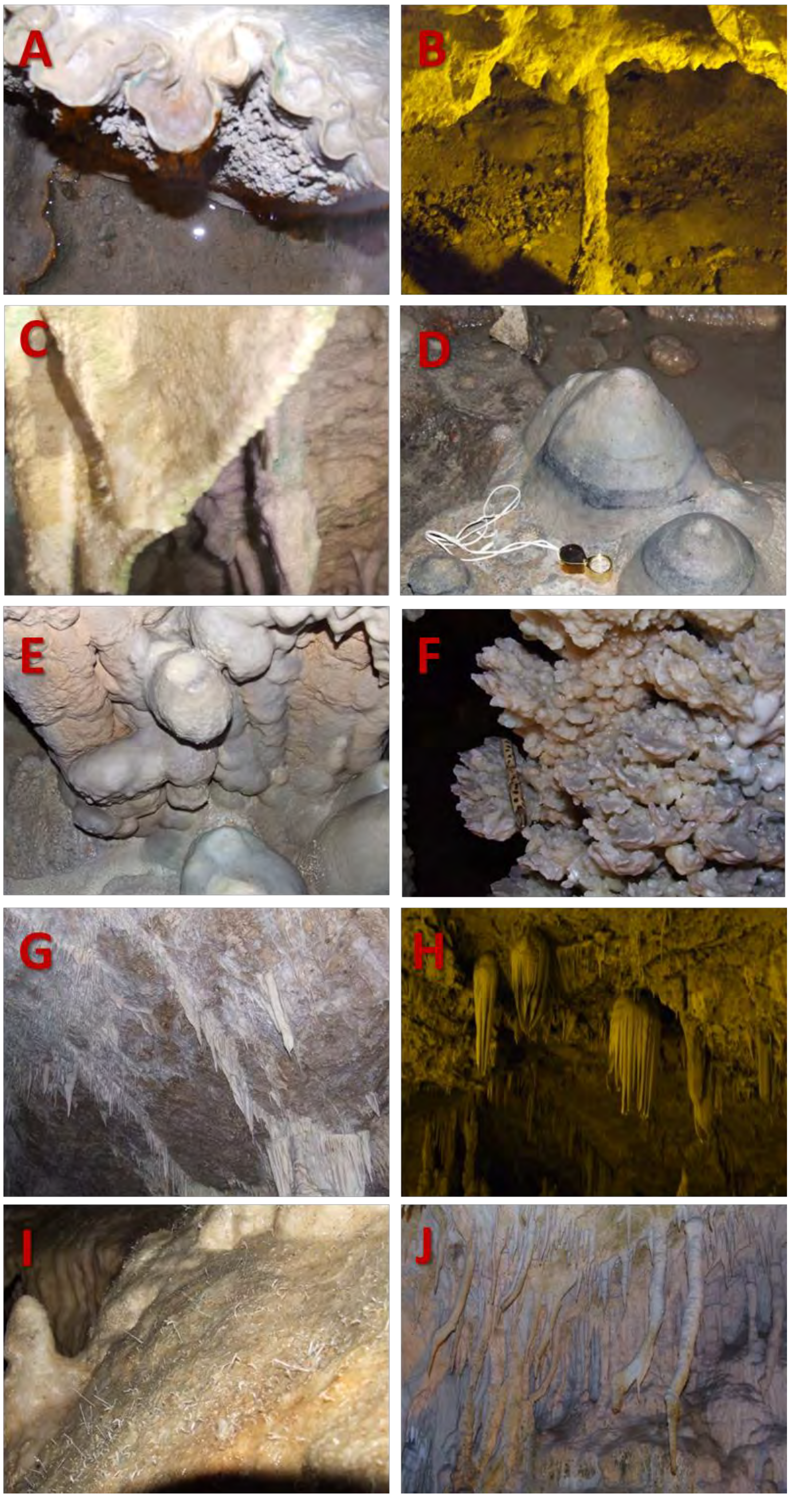

Figure 3 - Speleothem types observed in the Perama cave: A) Lotus rimstones, B) Columns, C) Draperies, D) Volcano cones, E) Punched speleothems, F) Splattermite, G) Boxwork, H) Paraschute shields, I) Heligmites, J) Deflected stalactites.

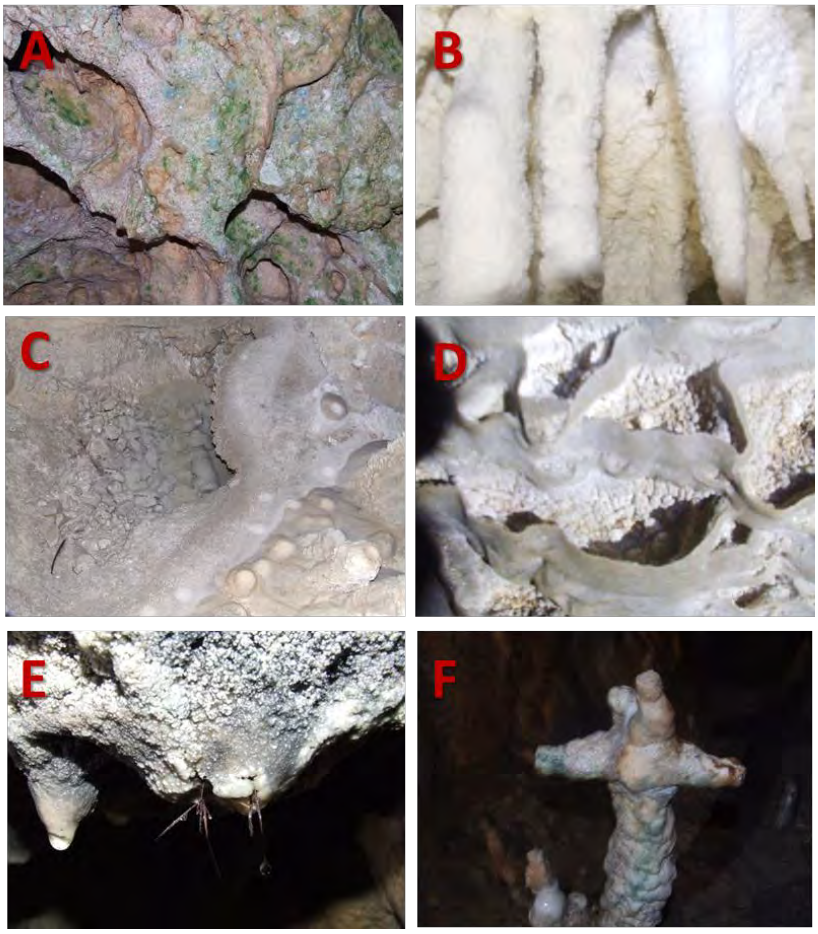

Figure 4 – Speleothem types observed in the Perama cave: A) Speleogens, B) Moonmilk, C) Crusts, D) Pearls, E) Rootsicles, F) Cross stalagmite.

4. Discussion

4.1 Evolution of Speleothems

In this work, the speleothems from the Perama cave are classified into five main categories, on the basis of their main mechanism of formation. Stalactitic-type speleothems are found on cave roofs and formed by dripping water. As the water drop falls down, the dissolved in water CO_2 escapes in the atmosphere of the cave, hence P_{CO2} in the fluid along with the solubility of $CaCO_3$ content decrease, leading to its precipitation. Continuous calcite precipitation is always preceded by the formation of a soda straw, which is the core of all stalactitic-type speleothems, such as soda straws with corals, soda straws with welts, stalactites and turnips. Air currents may affect calcite deposition, forming the deflected stalactites. Another composite variety of the stalactitic-type speleothems are the bottlebrushes, which initially formed subaerially, like typical stalactites, and subsequently their surface covered by subaqueous poolspar or corralloids, when the cave flooded again. Stalagmitic-type speleothems are products of calcite deposition on a surface, ordinarily on the cave floor. The distance of the dripping spot, various flooding and tectonic episodes led to the formation of a large variety of stalagmitic-type speleothems, such as common stalagmites, coral pipes, splattermites, volcano cones, punched stalagmites and cross stalagmites. The Christmas tree is stalagmitic-type speleothem, which has an aragonitic core formed in a first stage, while in a second stage calcite covered the surface of the aragonitic frostwork, giving the speleothem its final shape. Stream formations are very common in the Perama cave including flowstones, draperies and crusts that developed through calcite precipitation on layers, when water run on an uneven surface. Rimstone dams formed when calcite deposited on inclined surfaces, where the water locally acquired a zero mechanical energy. If this process happens on an existing flowstone, microgours appear. On the contrary, when calcite deposition occurs due to the combined action of water flow and dripping, then the speleothem shape is more circular creating lotus rimstones. Pool speleothems were generated into cave pools, leading to the formation of more botryoidal speleothems with smooth surfaces like coralloids, and pearls. Rafts and flowstone developed on the water/air interface due to CO_2 escape during light rippling. Shelfstones created a thin crust that covered the pools planes. The last category, unclassified speleothems includes all other speleothems that do not fit in the previous categories, such as columns, helictites, heligmites, boxwork, moonmilk, rootsicles and speleogens, which usually involve very complex growth mechanisms, perhaps except columns.

4.2 Evolution of the Perama Cave

Several speleogenetic episodes have been implicated in the evolution of the Perama cave. Superposition of younger speleothems over older ones, referred as coras (Charles and Hill, 2003), is frequent and must not be misinterpreted as a single formation. Careful observations of the complex speleothem layers that occur in the Perama cave enabled us to unravel the sequence of the processes that took place during its development. Firstly, some stalactitic- and stalagmitic-types speleothems had an extended growth, in places leading to formations of columns. A tectonic event of unknown age most likely affected the cave by causing significant collapse of its roof and rupturing of the existing speleothems. This is particularly evident in the central part of the cave, which is poor of speleothems. A period with vast quantities of flowing water led mainly to the development of stream formations, so that flowstones covered the collapsed rock blocks along with the largest part of the cave. A new episode of stalactitic- and stalagmitic-types formation is implied by the superposition of new speleothems of these types over older ones. A later major flooding episode has affected the western part of cave as it is implicated by the growth of subaqueous formations over older speleothems. Such This event is followed by a stage of large water flow, which covers all the previous speleothems. Nowdays, the Perama cave is still very active with several growth mechanisms in operation, but water dripping and flowing are mostly dominant.

5. Conclusions

The Perama cave has a large variety of speleothems, which have been recognized, classified and categorized in certain types. It contains at least thirty three different speleothem types, which reveal the sequential episodes that involved in its development. The Perama cave developed through multiple events whose initial formation from the dissolution of Senonian limestone (water-filled stage) was followed by various air-filled (or semi air-filled) stages that formed the marvelous and complex decoration in its interior. This new entry to the Greek bibliography is intended to act as a guide for further study of the evolution of Greek caves and their speleothems, as well as to provide complementary information for geotouristic purposes. Due to the fact that limestone outcrops are very extensive in Greece, and so are the caves, the geologists, the speleologists, the cave-funs and the speleological societies can be offered a database of speleothem types and formations.

6. Acknowledgments

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