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CAVE GEOLOGY

GEOLOGICAL IMPRINTS ON THE SPELEOGENESIS OF MGHARET AFQA

Les données relevées lors des camps de terrain dans la grotte de Afqa et dans ses alentours montrent que la structure tectonique joue un rôle très important dans le développement de la grotte de Afqa. Les discontinuités structurales dont les fractures et les joints ont influencé la structure de la grotte actuelle. Cependant, les différentes unités lithologiques ont contrôlé l'écoulement vertical de l'eau et ont contribué, avec la tectonique, à la forme générale de la caverne et certains passages de la grotte. Le pendage dans la zone d'étude est approximativement de 15° dans la direction Nord -Sud. L'écoulement général des eaux souterraines dans la zone d'étude suit la direction du pendage des couches géologiques. Les failles orientées N-S qui existent à l'ouest de la grotte sont à l'origine du déplacement de la formation géologique de Hammana qui alternativement a formé une limite/barrière hydrogéologique latérale. Sur les flancs méridionaux, L'eau souterraine circule dans la direction nord et nord ouest, Alors qu'elle circule dans une direction Est Ouest, avant d'émerger de la caverne. D'ailleurs, les passages complexes de la grotte semblent être développés sur deux ensembles de discontinuités de directions approximatives ENE-OSO et NNO-SSE. L'extension de la grotte de Afqa est confinée à une zone de 40m d'épaisseur dans les couches supérieures de marnes et calcaires de la formation géologique de Hammana. Ces intercalations ont permis une érosion différentielle, qui est associée aux discontinuités tectoniques et qui ont permis de former les dix passages complexes de la Grotte de Afqa.

يوجد العديد من الدلائل التي تبين اهمية العوامل الجيولوجية في تكوين مغارة افقا. ان العوامل التكتونية مثل الفوالق والتصدعات بالإضافة الى العوامل النولوجية يعطيان هذه المغارة شكلها الحالي.

Abstract

Field data collected in and around Mgharet Afqa revealed a deep structural impact on the development of the cave. Discontinuities including bedding discontinuities, fracture discontinuities and joint discontinuities have imprints on what Mgharet Afqa looks like at present. However, different lithological units have restricted vertical water flow and contributed, along with the structure, to the general shape of the cave and cave passages. The general inclination of the bedding in the study area especially in the aquiferous formations is approximately 15° to the N and S. The general direction of inclination of bedding is also the general flow of groundwater in the study area. The N-S faults to the West of the cave are the main structural features in the study area causing the displacement of the Hammana Formation which in turn has formed a lateral barrier for ground water flow. Water flowing in the North and North Westerly direction in the southern block banks on the fault then flows in an E-W direction to emerge from the mouth of the cave. Moreover, the intricate cave passages are observed to have developed along two discontinuity sets approximately trending ENE-WSW and NNW-SSE. Mgharet Afqa is restricted to only 40m vertical zone in the interbeds of marl and limestone of the Upper Hammana Formation. These interbeds have allowed differential erosion in combination with the discontinuities to form the 10 cave passages that are found inside Mgharet Afqa.

Introduction

The Lebanese Restraining Bend which is part of the Dead Sea Transform fault system has created a structural framework in Lebanon that has its imprints on a lot of features, specifically cave development and morphology. The inclination of bedding, faulting and jointing are all structural features imprinted on the development of Mgharet Afqa. However, one can not rule out the effect of lithology and the lithological units.

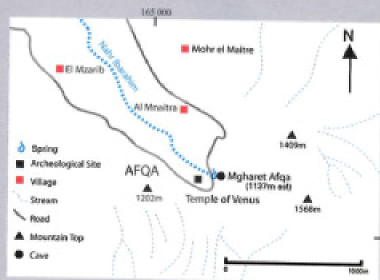

Figure 1
The location of Mgharet Afqa

Mgharet Afqa (the cave of Afqa) is located in central Mount Lebanon, approximately 40km NE from Beirut, and is positioned between the villages of Lassa and Qartaba. Its massive entrance is located at an elevation of 1137m asl (Figure1) with the following geographic co-ordinates, 34° 00' 0" N and 35° 54' 0". A perennial spring issues out of the entrance of Mgharet Afqa called Nabaa Afqa (the spring of Afqa).

The main development of Mgharet Afqa is in the southern direction. It can be divided into four sections (Figure 2). The *Outside area* is a large day lit room measuring approximately 60m by 50m with a ceiling height of approximately 30m. It is where all the water collects and emerges from the mouth of the cave. The *Water Passage,* which is the extreme northern and north-eastern end of the cave is approximately 150m long. During the summer it is the only place where water still flows. At nearly 50m from the terminal siphon, the passage splits into two tunnels with the right passage bypassing the first one, leading to a small room, then a ramping zone (with a lot of rock debris) and ending in a low-ceiling siphon. The *Large Rooms and Tunnels section* is an elongate shaped feature separated in the middle by the Labyrinth. Those rooms and tunnels have direct access to the Water Passage. *Large Rooms* have sizes ranging from 5m by 5m to 30m by 20m which contain had a lot of ceiling collapses. *Large Tunnels* reach approximately 4m in height and up to 20m in width. *The Labyrinth* which is the middle section of the cave connects directly to the Outside Room (Figure 2).

The orientations of the cave passages of Mgharet Afqa were plotted on a rose diagram (Figure 3). The major cave passage development is in the NNW-SSE. Two less dominant orientations were observed in the NNE-SSW and ENE-WSW.

Stratigraphy

In the Mgharet Afqa region, the Sannine Formation (dolomite, limestone and some marls), is an excellent karstified aquifer permitting high infiltration of water. The Sannine Formation overlies the Hammana Formation (interbeds of marl and limestone with some underlying volcanics).

Infiltration in the karst of the Sannine Formation reaches 60% and the average rainfall in the area is in the order of 1200mm/year (Atlas Climatique Du Liban, 1977). The discharge from the cave averages 1.5m³/sec (Edgell, 1997) making the catchment area approximately 11km². The Sannine Formation on the plateaus that lies above Mgharet Afqa forms the main catchment area for the spring. Mgharet Afqa is located in the Upper Hammana Formation in a series of interbeds of limestone and marl (Figure 5). The cave has developed in a 40m thick rock sequence, where the baseline water barrier is the lower Hammana Formation volcanics. Therefore it is safe to consider the Hamman Formation as the discharge formation versus the Sannine Formation which is the major source formation.

Figure 2
Sections of Mgharet Afqa with semi quadrant rose diagram showing the main orientation of cave development

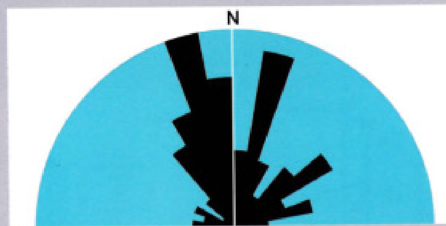

Figure 3
Semi quadrant rose diagram showing the main orientation of cave development

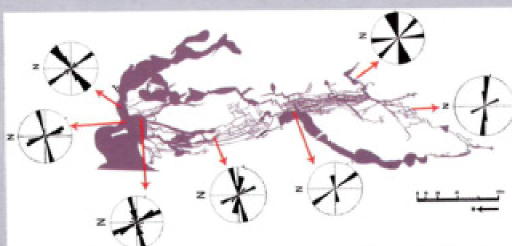

Figure 4
Rose diagrams showing the orientations of discontinuities in different parts of the cave

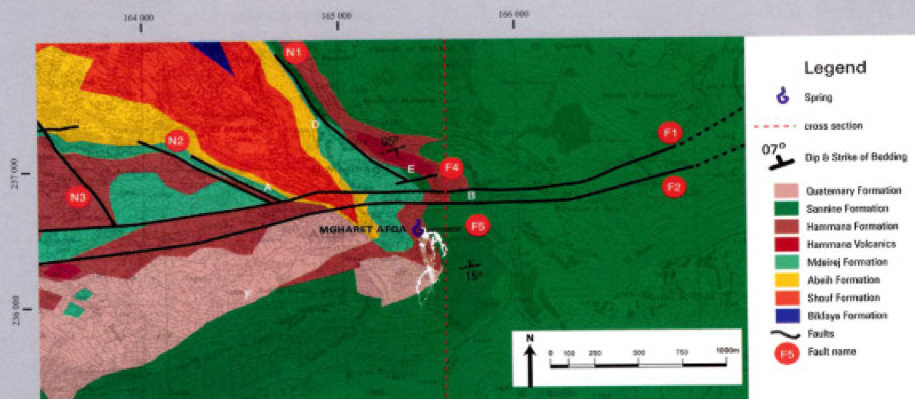

Figure 5
The geology around Mgharet Afqa. Mgharet Afqa is in white.

Structural Geology

There are three main structural components (discontinuities) relevant to the development of Mgharet Afqa; the bedding discontinuity, the faulting discontinuity, and the jointing discontinuity.

Bedding

The study area is divided into two main geological blocks, the northern and southern blocks. They are separated by a major E-W fault. The general inclination of the bedding in the southern block ranges from 10° to 20°, towards the NNW (Figure 4). In the southern block the Sannine Formation units and the upper Hamman. Formation units are dipping towards the E-W fault. Although water percolating in these formations follows the fracture system in the area, it will generally flow towards the N-NW direction. This is mainly due to the inclination of bedding present in this block.

In the northern block, the bedding is approximately dipping 5° towards the SE. It is not clear yet whether the groundwater from this block contributes to the discharge of Afqa spring.

Faults

Five minor NW-SE trending faults (N1, N2, N3, N4) were observed in the Afqa region. These have fault planes inclinations in the order of 70° and fault plane lineations apparently 60°. Vertical displacement in the field was measured to be in the order of 5m. These NW-SE normal fault terminate (on their southern end) at a major E-W fault zone which is bounded by fault planes F1 and F2 (Figure 4). This E-W trending fault consists of a 25m wide zone of breccia and gouge, and lies about 150m east of the cave entrance. Its orientation is 230/80° with a vertical displacement of approximately 50m judging from the displacement of the distinctive blue marl layer on either side

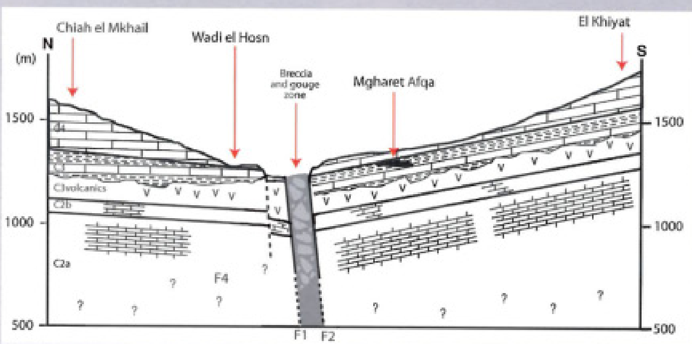

Figure 6
Geological Cross section revealing the underground geology and showing E-W fault placing the volcanics of the Lower Hammana Formation along side the limestone of Sannine Formation.

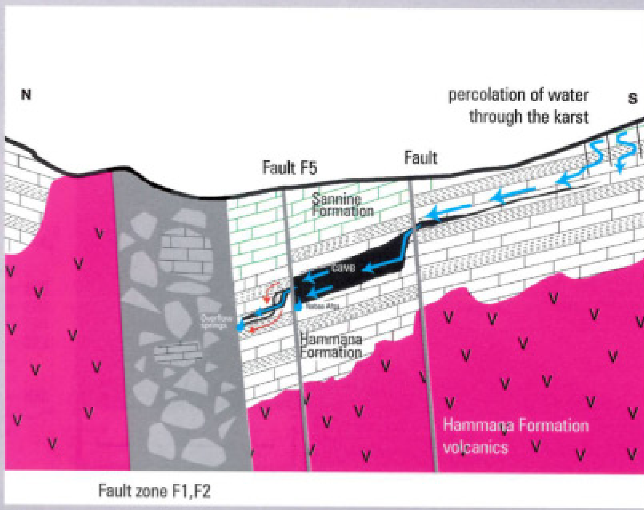

Figure 7
Schematic of the damming model in Mgharet Afqa

of the fault. The resultant displacement along the E-W faults has caused the Lower Hammana Formation volcanics on the northern block to uplift by about 50m placing them alongside the Sannine Formation limestone (Figure 6). These volcanics are relatively impermeable creating a lateral barrier or damming effect for groundwater movement (Figure 7).

Three minor E-W faults (F5) were observed inside the entrance of the cave. The inclination on these minor fault planes are 84°, 82° and 80° with strike measurements 264°, 262° and 010° respectively. On these fault planes, slickensides were observed plunging approximately 15° toward the west. Consequently these faults were identified as strike-slip faults with some normal dip-slip component. The vertical displacement on these faults was observed in the cave to be in the order of approximately 1.5m. Also identified was the telltale corrugation structures apparent on some faultplanes. From the fault plane architecture which includes comb fracture, slip parallel fractures, tool tacks and corrugations these E-W are believed to be dextral in nature.

Considering the minor NW-SE normal faults and the minor E-W dextral strike slip faults to be secondary faults generated by the major E-W fault. It is probable that the E-W fault is a dextral strike slip fault with an observable 50 m normal component. The dextral movement on this fault is not observable due to the gentle inclination of the bedding. This coincides with the dextral nature of the E-W faults in Lebanon (Gedeon, 1999) and coincides with the transpression caused by the Lebanese restraining bend.

The damming effect in Mgahret Afqa created by the F5 E-W faults can also explain the presence of three overflow springs observed in different locations around the cave (Figure 7). These only tend to flow when the water emanating from the cave entrance is at its strongest surge. The water during the rainy season dams behind the barrier caused by the F5 E-W faults and only when there is flooding during heavy rain fall or snow melt the water passes above the barrier to reach the ultimate barrier created by the F1 and F2 faults which is quite unrealistic to pass and then emerge later on the surface as overflow springs. And effectively these springs are the tell tale sign that water is damming behind the F5 E-W fault.

Joints and Fractures

Approximately 94 discontinuities (Joints and Fractures) were measured inside the cave. A correlation was made between the orientation of these fractures and the passage development of the cave.

In the Outside Area fracture discontinuities where measured. Close to the F5 fault 17 joints were measured. The general orientations of these sets were NE-SW and SE-NW.

Considering the nature of the F5 faults these conjugate set of joints are the result of compression on this dextral strike slip fault. It is not clear whether they have any effect on the development of the cave passages. Moreover, 24 fractures were measured in the Outside Area. The general orientations of these sets were ENE-WSW and NNW-SSE. This correlated well with the general direction of the tunnels. The majority of the fractures measured were in the ENE-WSW direction because they cut perpendicular to the tunnel direction and were easier to see. The SSE-NNW fractures along which the tunnels formed so for most of the time they were visible in one direction and not as many were measured explaining the difference in the number of joints that were measured in each direction.

In the Labyrinth section (in five different locations) 42 fractures were measured. The dominant orientations of these fractures were ENE-WSW and to a lesser degree ESE-WNW and NNW-SSE. Those three sets follow the general orientation of the cave passage development.

Passage Morphology and Speleogenesis

Cave passage morphology in Mgharet Afqa reveal much about the speleogenesis of the cave. Vertical, tilted and horizontal discontinuities along with the presence of marly layers sandwiching limestone beds play important roles in the development of the cave passages in particular and the development of the cave in general. Vadose and phreatic flows can also be a factor in the shapes of the tunnels.

The labyrinth has 9 distinctive passage shapes (Figure 8). The Circular passage is formed by erosion at the intersection between two discontinuities. Further erosion along the horizontal discontinuity causes the formation of the Circular with Wings passage. Further erosion at the top on the vertical discontinuity on the Circular passage allows the development of a Tear Drop passage. The Tilted Ellipse passage is formed along an angled discontinuity. The Pinched Ellipse passage is formed along a vertical discontinuity. The T-Shaped passage is formed by the variation of water flow strength, were the initial flow is stronger then later flow making the cutting more localized at the base of the T. The inverted T-Shaped passage is formed when a passage intersect a softer material at the base making them more vulnerable to erosion and allowing the build up of the base at a faster rate. When the bases of several inverted T-Shaped meet they form what is called the Overhang or the Composite passages.

The early stages in the development of the cave passages are the development of the Circular and Elliptical passages. Further development and erosion leads to the development of the T-shaped and inverted T-Shaped passages. Further development and erosion leads to the development of the Overhang and Composite passages (Figure 9).

The big rooms and large passages in the cave have no distinctive shapes but show large elongate tunnels, slab like, that are distinctive of collapse structures. They developed from collapses of passages in labyrinths. The shape and the size of the rooms are dictated by the size of the collapse and whether the collapse material is washed away by running water or not. The entrance section for example is the largest part of the cave in terms of width and height, with frequent collapses occurring. With a constant water flow, collapsed blocks have been moved and washed away by the running water allowing the cave entrance to increase in size with each collapse effectively growing upwards. Recent rockfalls have occurred in 2005 when a huge slab of the ceiling collapsed in the outside area of the cave, and in 2007 when there was a huge collapse of the cliff-face above the entrance causing the entire waterfall issuing from the entrance to be covered with boulders (Figure 10). The collapse at the entrance of Mgharet Afqa may have been triggered by solution action along discontinuities, gypsum wedging and/or earthquake activity. Already some of the material collapsed has been washed away by the large amount of water exiting the cave during wet seasons. This is different from the room collapses. In the rooms there isn't enough water flow to move the blocks and so rooms tend to become tighter with increased collapses. The large rooms inside the cave (Salle Nayla) have formed in similar fashion but the size of the room stays approximately the same for minimal material is carried away from the collapse by running water.

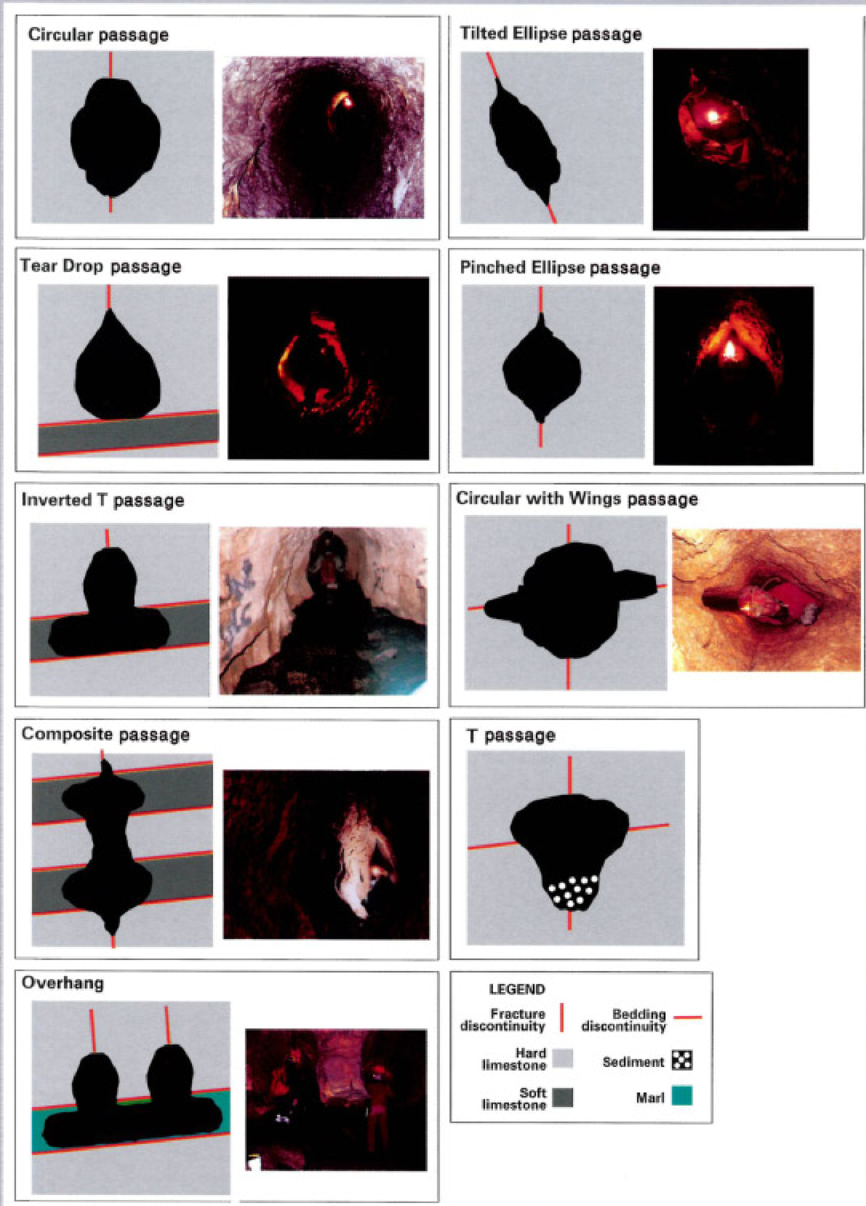

Figure 8
Shapes of passages in the labyrinth in Mgharet Afqa

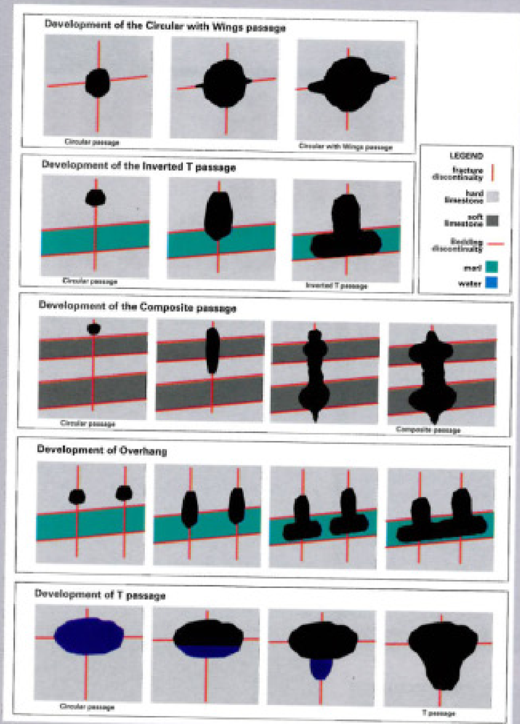

Figure 9
Speleogenesis of passages in Mgharet Afqa

Conclusion

There is a clear imprint of geological features on the development and speleogenesis of Mgharet Afqa. The location of the cave in relation to the major faults in the area, the location of the cave in specific units in the Hammana Formation, the direction of the cave passages in relation to discontinuities, the cave passage morphology in relation to discontinuities and lithology, last but not least the triggering of the collapses in the cave by seismic activity and solution and gypsum wedging on discontinuities have contributed to what Mgharet Afqa looks like today.

Acknowledgements

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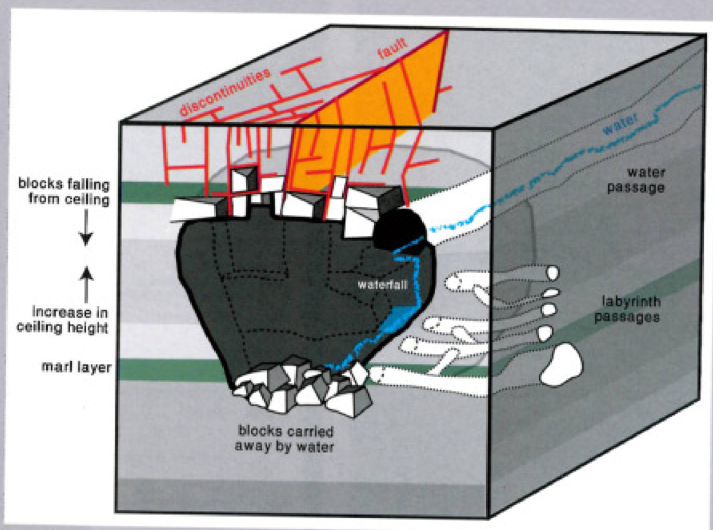

Figure 10
Schematic of the entance of Mgharet Afqa