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The Cyrenaica Karst Project: Karst Geomorphology and Caves, Al-Jabal Al-Akhdar, NE Libya

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ABSTRACT

This paper introduces the Cyrenaica Karst Project: a collaboration project between the University of Benghazi, Libya and the Hyblean Center of Speleo-hydrogeological of Ragusa, Italy. Among the objectives of the project there are: study the karst geomorphology and caves of Al-Jabal Al-Akhdar, construction of a speleological model consistent with the geodynamic evolution and climate changes taken place in the Tethyan-Mediterranean region; those with application fall-outs into the local socio-economic framework addressing the finding out and protection of new water resources, the mapping of man altered areas, potentially at risk of instability and/or sinking because of the presence of karst voids, and the institution of Karst Geosites and Geopark. The campaign of geospeleological investigations carried out in the 2007/2008/2009 years and most recently in 2022, 2023 and 2024 years, has concerned the karst area of the coastal belt of Benghazi, Sousa and the plateau of El-Marj, Al-Baydah, Dernah and Tobruk. In Benghazi area, the Lethe karst system with a large underground lake is of a particular interest. In the Sousa coastal area, a significant karst outcrop, was surveyed and documented, including Brak Notta karst system, which is constituted by a collapse doline and two large neighbouring doline-lake hydrologically connected by a recent tectonic structure. In the highly elevated areas of Al Baydah and Al Marj plateau, a very interesting geomorphologic and hydrogeologic studies show some large dolines and dip swallow-holes, inserted in the context of a typical cockpit relief, while in the plateau of Darnah the exploration of a complex labyrinthine cave has allowed the discovery of paleontologic and archaeological finds. Speleological/geological investigations of the above-mentioned karst areas are still being carried out in order to formulate a speleogenetic model linked to the tectonic phases and climatic changes that affected the Cyrenaica ridge during the Plio-Pleistocene to Recent.

مشروع دراسة الظواهر الكاريستية بشمال شرق ليبيا: جيومورفولوجية الظواهر الكارستية والكهوف بالجبل الأخضر

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الكلمات المفتاحية:
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ليبيا

الملخص

تهدف الدراسة إلى التعريف بمشروع تعاون دولي بين جامعة بنغازي و مركز هيبلين لأبحاث الظواهر الكارستية. ومن بين أهداف المشروع ما يلي: دراسة الجيومورفولوجية الكارستية وكهوف الجبل الأخضر بشمال شرق ليبيا، بناء نموذج كهفي يتوافق مع التطور الجيوديناميكي والتغيرات المناخية التي حدثت في منطقة البحر الأبيض المتوسط؛ تلك التي لها تداعيات تطبيقية في الإطار الاجتماعي والاقتصادي المحلي الذي يتناول اكتشاف وحماية موارد المياه الجديدة، ورسم خرائط للمناطق المتغيرة، والتي يحتمل أن تكون معرضة لخطر عدم الاستقرار و/أو الغرق بسبب وجود الفراغات الكارستية التحت سطحية، و تحديد المواقع الجيولوجية الكارستية والحدائق الجيولوجية. استهدفت حملة الدراسات الحقلية التي تم تنفيذها أعوام 2009/2008/2007 وآخرها أعوام 2022 و2023 و2024 المنطقة الكارستية بالحزام الساحلي بنغازي وسوسة وهضاب ومرتفعات المرج

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والبيضاء ودرنة. و طبرق. في بنغازي، يحظى نظام ليثي الكارستية مع بحيرة كبيرة تحت الأرض باهتمام خاص. في منطقة سوسة الساحلية، تم مسح وتوثيق ما يعرف ببراك نوتا الكارستي، الذي يتكون من انهيار دولين وبحيرتين كبيرتين متجاورتين و مرتبطتين هيدرولوجيًا ببنية تكتونية حديثة. في المناطق المرتفعة في هضبة البيضاء والمرج، أظهرت الدراسات الجيومورفولوجية والهيدروجيولوجية بعض الدولينات الكبيرة والثقوب التحت سطحية. بينما في هضبة درنة، أدى استكشاف كهف معقد إلى عدة إستكشافات حفرية وأثرية. لا تزال الدراسات الكاريستية و الكهفية المذكورة أعلاه جارية وتهدف إلى فهم نموذج لتكوين الكهوف وعلاقتها بالمراحل التكتونية والتغيرات المناخية التي أثرت على منطقة الجبل الأخضر خلال العصر البليو-البليستوسيني إلى العصر الحديث.

1. Introduction

On the basis of a research agreement signed between the University of Benghazi through the Department of Earth Sciences, Faculty of Science and the Hyblean Center of Speleo-hydrogeological Research, Ragusa, Italy, three campaigns of investigations were conducted in the years 2007-2008-2009 for studying the karst phenomena of Cyrenaica [1, 2, 3, 4]. In June 2022, after 13 years of suspension due to the political events that affected the country, the second phase of research mission started, with a signed Memorandum of Understanding, where the main objective of the research was identified, consisting of the formulation of a model of karst and speleogenetic evolution that have developed in the Al-Jabal Al-Akhdar in the context of the morpho-tectonic evolution of the area and climate changes, in order to understand the possible relation between the Plio-Pleistocene and present tectonic phases and the karst morphogenetic and speleogenetic processes [2. 5. 6, 7].

As a result, the main application aspects of this project were the following: (1) Speleological explorations and cave map surveys; (2) Characterization of the karst morphologies (surface and underground); (3) Tectonic structural control in the karstification process; (4) Influence of morpho-tectonic evolution and climate changes on the speleogenesis; (5) Investigate karst aquifer vulnerability in order to formulate protected areas of recharge for springs and wells; (6) Identify areas of geological and geomorphological interest in order to propose the establishment of geoparks and geosites; (7) Investigate the impact of karst hazardness on urban development.

2. General geological context of Cyrenaica

Al-Jabal Al-Akhdar, about 350 km long and 100 km wide, forms a prominent promontory on the edge of the Libyan Mediterranean coast (Fig. 1). From a geological point of view, this area underwent the effects of the Tethys tectonic activities during the Jurassic and the Alpine starting from the end of the Cretaceous period, linked to the relative westward movement of the African plate against the Eurasian one. Structurally, Al-Jabal Al-Akhdar undergoes two main deformation phases: a first phase with prevalent vertical movements linked to the opening of the Tethys during the Upper Triassic-Cretaceous period, the second phase with the beginning of the closure of the aforementioned sea starting from the Upper Cretaceous. In the latter context, the area undergoes the effects of a transcurrent type tectonics in which transpressive structures are also highlighted [8]. From the lithological aspect, in the Al-Jabal Akhdar, limited outcrops of the Upper Cretaceous emerge in the form of inlies delimited by more extensive carbonate outcrops of the Eocene, Oligocene, and Miocene [9].

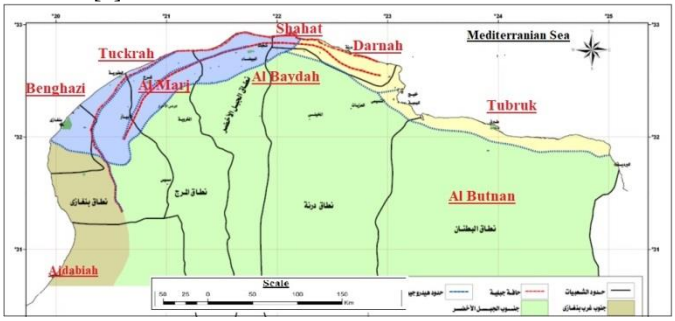

Fig. 1: Location map of the Karstic survey areas, Cyrenaica, northeast Libya.

2.1 Geomorphology of Cyrenaica

Most of the Libyan territory belongs to the Sahara platform. About 95% of Libya is made up of arid, rock-strewn plains and stretches of sand, with two small areas of hills to the northwest and northeast. To the south, the terrain rises to the Tibesti massif along the border with Chad. However, Al-Jabal Al-Akhdar, with its reliefs, occupies a special position in the geotectonic division of Libya. The area of northeast Libya around Al-Jabal Al-Akhdar is geologically divided into three main geomorphological units; the coastal plain, the escarpments and the plateau.

The coastal plain (Benghazi plain) represents the northwestern part of Cyrenaica. It has a triangular shape bounded to the south by latitude 32° N, to the east by longitude 21° E and to the north-east by the Mediterranean coast. It stretches along the coast for about 30 km in width. The surface has large areas of outcropping limestone that dips with modest slopes of no more than 5° towards the sea. This localized surface is divided into blocks by open joints that give rise to morphology such as karren fields.

The second geomorphological unit, which delimits the aforementioned plain to the east, is from the lower coastal escarpment, with altitudes between 100 and 300 m (first escarpment). The area located behind the lower escarpment towards the hinterland is a moderately undulating plateau cut by a system of valleys (wadi). Another step, referred to as the upper escarpment, has altitudes between 350 and 600 m and is best developed in the Al Marj area towards the south; however, its typical shape disappears and turns into a flat plateau, constituting the third geomorphological unit. The relief begins to rise from the upper escarpment towards the hinterland to a maximum altitude of 705 m above sea level, north-east of the village of Jardas al Abid.

3. Discussion

The main karstic features detected during the aforementioned research campaigns in the various areas are summarized below.

3.1 Karst morphology of the Benghazi plain

The main karst morphology present in Benghazi plain are mainly observed in Ayn Zayanah-Coeffiah, Al Magarin-Boudazira and Lethe areas, within which the aquifer flows to partially salted places, fed both by effective infiltrations along the plain and by those coming from the facing first plateau. In this regard, the investigations in this coastal strip involved some dolines, both of solution and of collapse, in the area of Chebnah, Magarin, Bararik ash Sha'i and Lethe. In the latter area, of particular interest, also from a historical-anthropic point of view, is the Lethe karst system consisting of a collapse doline that gives access to a large underground lake (Fig. 2). In this cave, a landing stage and the remains of a lighting system testify to the tourist use made of this cave during the Italian colonial period [10]. In this cave, there are signs and remnants of lighting system installed during the Italian colonial period, they can be a good tourism feature (Fig. 2).

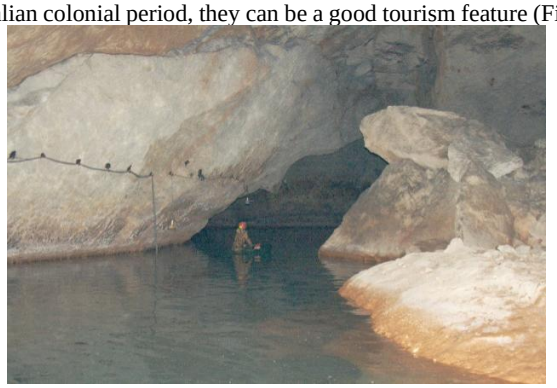

Fig. 2: The Lethe Cave and its groundwater lake, Benghazi city.

Note the remnants of lighting system on the wall that were installed

during the Italian colonial period. Cyrenaica, northeast Libya.
In another sector of the city, a large active cave (Kaplan Cave) was explored and detected, which was intercepted at a short depth during construction work for residential buildings. The primary purpose of the exploration was to evaluate the possible risks that the building (and its inhabitants), already completed, could run under the conditions of progressive disintegration of the underlying vault, which was already visibly affected by collapsed partitions. In this urbanized area of the Benghazi plain, the research carried out has also highlighted the presence of two main problems: one linked to the pollution phenomena of the karst aquifer, such as salting due to marine intrusion [1], and anthropogenic due to organic spills and losses in the Cheapnah area (sewage, landfills, etc.).

3.1.1 Bukarma-Mirisi-Coeffiah karst system

In Al Coeffiah area not far from the homonymous village, there are several depressions such as solution and collapse dolines, in the limestones of the Benghazi Formation of the lower and middle Miocene, including the Mirisi, Habibi and Boukarma caves on the bottom of which the karst aquifer emerges. In this regard, from tests with tracers and speleosub water explorations, part of the route of the underground waters intercepted at the bottom of the aforementioned doline-caves and their delivery along the coast through connection on the subsurface to the Ayn Zayanah springs in and the fascinating scenario of the Blue Lagoon was deduced [1, 4, 11, 12, 14, 15, 16, 17]. Speleo-diving explorations together with the carrying out of geognostic surveys have highlighted the presence of two karst circuits at different depths connected by two deep wells, of which the shallowest of 18-20 m connected with the Jumar cave (Mirisi), the deeper one of about 80 m with the Bukarmah cave (Fig. 3). In this regard, the shallower circuit drains the groundwater made brackish by sea intrusion along the coast, the deeper one directly drains sea water towards the hinterland.

Fig. 3: Bukarmah cave in Al Coeffiah area, the deepest brackish vertical pit.

The external area surrounding the aforementioned depressions is widely dissected by different systems of structural discontinuity and affected by surface karst morphologies such as furrowed fields and corrosion pans (Fig. 4). An assembled study of Ayn Zayanah project near Benghazi, has been published by Salloum, et. al., [18] where, an updated view of the Hydrogeochemical, structural, hydro-stratigraphic cross section, Karstic development and hazards have been reported.
In this regard, in order to study the geomorphological, structural and hydrogeological aspects and the directions of the water flow of the aforementioned karst system, detailed topographic surveys were carried out of the following explored caves and doline-caves (Fig. 4); (1) Maraisila cave; (2) Al Shaug-Al Khadim cave (Fig. 4a); (3) Al Satira cave; (4) Al Jabah 1 (Fig. 4-b); (5) Al Jabah 2; (6) Habibi doline-cave (7) Bu Snaib doline-cave (Jumard Pit).

Fig. 4: Typical huge karstic features in Al Coeffiah area, including caves and dolines of various sizes, and furrowed fields and corrosion pans and attractive Speleothems.

3.2 Karst morphologies of the coastal strip "Susa - Ra's al Hilal"

In this northern coastal sector, about 14km from Susa (ancient Apollonia), the interesting Brak Notta karst system stands, consisting of three dolines in which the insalinated aquifer emerges. In this regard, the exploration of one of the aforementioned dolines, set on a neo-tectonic structure, was explored reaching the saline level of the aquifer circulating in the two largest neighbouring doline-lakes (Fig. 5).
Along this scenic coastal strip, two other karst morphologies have been explored and documented, consisting of the Rowos Al Slab doline collapsing into the sediments above Quaternary deposits, and the Kaf Hawafte doline whose genesis can be traced back to a collapse which was followed by a subsequent dismantling by marine erosion along the pre-existing paleo-cliff. This karst feature is important from an archaeological point of view as well as geomorphological.

Fig.5. Brak Notta karst system in the Ancient Apollonia characterized by three sinkholes.

3.3 Karst morphology of Al-Jabal Al-Akhdar

This area, morphologically is divided into two main plateaus, has highlighted the presence of karst phenomena of certain interest, partly already known, but most likely only partly explored, documented and studied, consisting of extensive cockpit reliefs, endorheic surfaces such as polje, large dolines, both of solution and of collapse, and both fossil and active caves. Below are the main karst features studied in the different karst areas of the two plateaus.

3.3.1 Karst features in the first plateau

Hawa Al Sagah cave originated in the limestones of the Al-Faidiya

Formation of the Aquitanian, located in the Er Regima area, middle-summit part of the slope of the first terrace overlooking the Benghazi plain, at an altitude of 210 m asl, classified from a speleogenetic point of view as syngenetic cave due to the solution by mixing of differently saline waters, along a paleo Pleistocene cliff.

Umm Al Majanein cave, is located in Sid Nassir area, about 1.3 km east of the right side of the Wadi al Lawlab, at an altitude of 219 m asl. As regards the lithological aspect, it develops in the Apollonia Formation and from the topographical point of view, the cave consists of a single large room with an average circular shape, with a diameter of about 25 m, a height difference of -14.3 m and a height of between 2.5 - 5 m, with a descending entrance tunnel of 10 m placed on the south-eastern side, which opens on the top of a sloping section of 12.5 m, surmounted by two openings/sky-windows on the vault, descending in the central part of the large room. This cave is also interesting from an archaeological point of view due to the presence of a human settlement inside

Several dolines and caves have been documented in the Wadi Ba al Arid basin between Wadi al Lawlab and Wadi Jarnah, including (1) Hawa Lehgari doline (Lehjeri); (2) Buth-heir doline; (3) Al Hawayat doline (Hawa Bass); (4) Hawa Haitini doline/swallow hole; (4) Hawa Asaad doline. In the first plateau, Wadi Al Dabaa is characterised by surface, structural and tafoni karst morphologies. Karst Morphologies have also been observed in the middle-terminal sector of Wadi Al-Mahbul and in the Wadi Al-Qalah (Ra's Al Hilal area)

3.3.2 Karst features in the second plateau

Hawa Bumaidoha is a vertical cave located in the area of Agfantah, about 10.5 km SSE from El Marj. As regards the topographical aspect, this cave has an altitude of 471m asl, with a total development of 155 m, deepens for about 86 under the surface. From a lithological point of view, the swallow hole develops in the limestones of the Dernah Formation of the Bartonian-Priabonian. The cave constitutes a vadose karst system that captures the effective infiltration waters falling on an area delimited by residual hums/cockpits hills, of about 400 km^2 of surface, of elongated shape NE-SW extended about 3.2 km and 1.4 km wide which could be configured as a polje (Fig. 6).

Fig. 6. Hawa Bumaidoha, a vertical Shaft-Pit / cave located in the area of Agfantah at the second escarpment.

Ustata 1 cave is located on the hills overlooking the plain of Al 'Uwayliyah Ash Sharqiyah - El Marj, the latter about 20 km away towards SSW. As far as the topographical aspect is concerned, it has an altitude of 440 m asl, with a length of about 110 m in the NE-SW direction and with a total height difference of +5 m.

Ustata 2-3 caves. In the area of Ustata 1, two other smaller caves called Ustata 2 and 3 were found, which are characterised as two paleo-springs fossilised with the tectonic uplift that affected the area during the Pleistocene.

Hawa Sgawah doline-cave located at an altitude of 360 m a.s.l., in the Zawait El-argoob area about 9 km east of Qasr Libya, deep about -40 m from the external surface. As regards the topographical profile, the doline has a top opening of an average elliptical shape with a major axis of 15 m and a minor axis of 7.5 m, while the bottom part, in projection on a horizontal plane, has an average circular shape with a diameter of 78 m and 70 m. From the speleogenetic point of view it is a collapse doline developed in the Member of the algal limestones of the Al Baydah Formation

Wadi Al Kuf 1 cave is located at an altitude of 380 m asl in the mid-summit part of the right orographic side of the Wadi Al Kuf valley. As regards the topographical aspect, the cave has an approximately rectangular shape with sides of 30 x 35 m and variable heights from 5 to 20 m. The cave developed in the limestones of the Dernah Formation of the lower Eocene, owes its original formation to meteoric degradation phenomena (tafoni) to which it was followed subsequent enlargements due to the erosion of the paleo-flowing river waters along the wadi (Fig. 7).

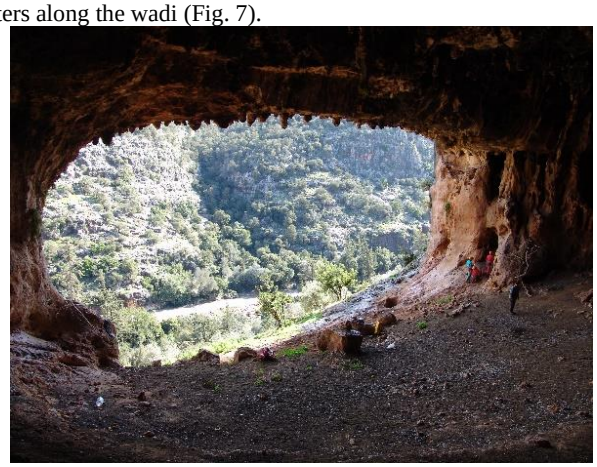

Fig. 7. Wadi Al Kuf cave along the lower Al Kuf road in Al-Jabal Al-Akhdar area.

Wadi Al Kuf cave is located at 343 m a.s.l. in the mid-summit part of the right orographic side of the valley. As regards the topographical aspect, the cave has an overall development of 60 m with a positive difference in height of 10 m and is divided into two main rooms. The cave develops along a bedding plane in the limestones of the Dernah Formation and from the speleogenetic aspects it shows a structural genesis due to the progressive widening of the layer joint, caused both by weathering degradation and Karst corrosion and the subsequent collapses of the relatively inclined strata on the right orographic side of the Wadi Al Kuf.

Hawa Erjiae a doline-cave is located about a hundred meters north of the town of Al Abraq, at an altitude of 655m asl. As far as the topographical profile is concerned, it extends for a total of about 170 m with the lowest point at - 94 m with respect to the outside surface. The doline-cave develops in the calcarenites and in the limestones and dolomites of the Al Abraq Formation of the middle-upper Oligocene dissected by N80 and N-S oriented structural discontinuity systems. It owes its origin to progressive collapses that have brought to light the underlying part of a karst cave set along an oriented tectonic structure. The cave is particularly degraded due to the presence of both waste of various kinds (tires and scrap of various types), and to a black soot and carbonaceous pigments that cover a large part of the floor, also impacting the surface of many speleothems and calcite concretions which show a greyish color (Fig. 8).

Fig.8. Hawa Erjiae a doline-cave in the middle of Al Abraq village.

Ayn Al Hufrah, a cave-spring is located at the beginning of a short wadi, at an altitude of 552 m asl, about 1 km north of the village of Shahat. From the topographical point of view, the cave-spring with entrance on the right side of a deep sub-rock/paleo-notch, extends for about 80 m with a positive difference in height of 9 m. more over the cave develops in the algal limestone member of the Al Baydah Formation, of the Rupelian (Lower Oligocene) dissected by a system of fractures. In this regard, the cave alternates sections developed along both structural fracture/bedding plane.

Al Shigeia cave is located about 9 km south of Darnah city on the left

orographic side of Wadi Ehtass (Wadi Zarwit), at an altitude of 274 m above sea level. As regards the topographical aspect, the cave has a generally labyrinthine course, divided into two main sectors connected by a conduct. The cave develops in the Al Baydah Formation the algal limestones member, in this area it is composed of cemented aggregate of large blocks. This structural arrangement, is probably due to local slumping phenomena, and has influenced the karst processes relating to the genesis of the cave which, in the face of a general extension towards the north-west, does not show preferential directions of development along pre-existing discontinuities, but rather an average labyrinthine trend. The cave is particularly concretionary with some corroded speleothems due to the presence of guano. In the cave during the explorations some archaeological finds have come to light such as a wreck of a vase and a lamp still intact in the left branch, other fragments of a vase, one of which with drawings and fragments of colored glass

Al Dabusiah spring-cave's water supplies the nearby cities of Gubba and Al Abrag for domestic purposes. The cave channel was investigated upto ~700 m and partially survey. Of particular interest was the presence of scallops on the walls, indicating both the flow of water into the cave-spring and the subcutaneous corrosion from percolation and corrosion of water threads at the contact between limestone walls and a pre-existing clayey-sandy filling (Fig. 9). However, El-Shawaihdi et al [19] studying the water flow, quality, resources, sustainability and development of the spring. They found the spring discharge between 190-220 liter/second of fresh water. The spring-cave lithology is mainly composed of creamy to yellowish mudstone, chalky, soft, with chert nodules of Apollonia Formation overlain by greyish brown, limestone alternating with soft mudstone, highly fossiliferous, jointed and karstified of Dernah Formation.

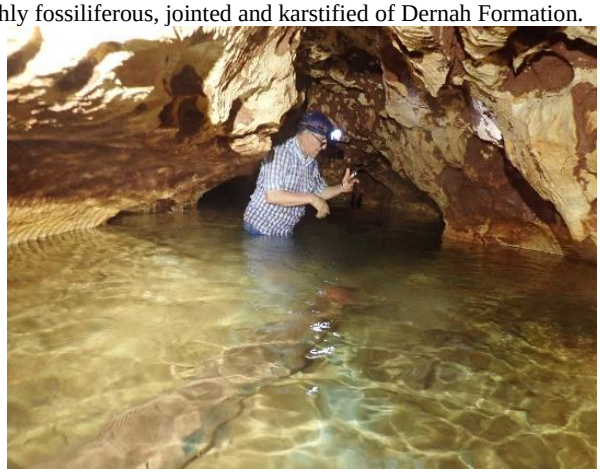

Fig.9. Al Dabusiah spring - Long highly karistified tunnel.

4. Research areas and documented caves between Massah-Al Bayda - Shahat - Al Abraq-west Dernah.

Wathen cave (El Bomb cave) is located in the area of Iblekhnah village, at an elevation of 619 m asl. The entrance to the cave is given by a pit of about 8 m at the base of which a first room is about 8 m wide opens. The cave, occupies an area of about 450 m2, has a total length of 92 m and a total height difference of -31 m. against the particular aesthetic beauty of the two aforementioned chambers. However, the presence of the accumulation of waste of various kinds, covering the descending floor of the aforementioned environments, unloaded into the cave from the entrance opening above, acts as a strong and strident impact which can has harmful effects on the underlying karst aquifer.

Qattarah doline is located 5.8 km south of Apollonia, in the Alsattyah area, at an elevation of 398 m asl. As regards the topographical aspect, it has an opening roughly shaped elliptical oriented in a north-south direction 40 m long and 20 m wide, which stretch up to f 54 x 42 m respectively if we consider the innermost covered sectors. Vertical tectonic structures variously oriented dissect the nummulitic limestones of the Dernah Formation along the walls. In the top part there are remains of tombs of probable Greek age. The doline owes its genesis to collapses which in the past progressively affected the vault of a karst cave whose deepest sector for this reason remains inaccessible (Fig. 10).

Fig.10. Qattarah (Al Gater) doline in Shahat plain.

Habon cave located in the area of Iblekhnah village at an elevation of 610m asl This karst feature, whose entrance is given by three skylights in the ceiling is located in its southern portion, appears as a single large room consisting of a sub-circular hall, with a diameter of about 32m and a maximum depth of 23m. It develops in the calcarenites of the Al-Abraq Formation and regards the aspect of environmental vulnerability, the presence of a large accumulation of waste, also of an organic nature, in the central northern portion, highlights how this cave was used as a landfill can also constitute a potential point of pollution for the underlying groundwater karst aquifer.

Al Ejel spring-cave located in the Habon area, 3 km east of Shahat, is at an elevation of 620 m asl. It develops in the Al Baydah Formation, at the transition between the Shahat Marl Members, which acts as an impermeable substrate, and the overlying Algal Limestone Members, with a single tunnel dug artificially for a length of 23.5 m to drain and collect the flowing waters in the fractured-karstified portions of the walls.

Apollo spring-cave of historical importance located in the Archaeological Park of Cyrene north of Shahat at 33.7 km from the coast, at an elevation of 562 m asl. It develops for 304 m along a conduit excavated in the Greek period, in the Al Baydah Formation, at the passage between the Shahat Marl Members, which acts as an impermeable substrate, and the Algal Limestone Member. Along various tracts of the conduct there is the presence of sandy and clayey silts, concretions in the vault and rimstone pools on the bottom of the channel, the latter frequently blackish in color most likely due to the presence of transported organic substances from the waters. In this regard, it has been reported that the waters of the spring would be polluted probably caused by leaks coming from the homes and/or activities in the area of the city of Shahat, located within its recharge basin (Fig. 11).

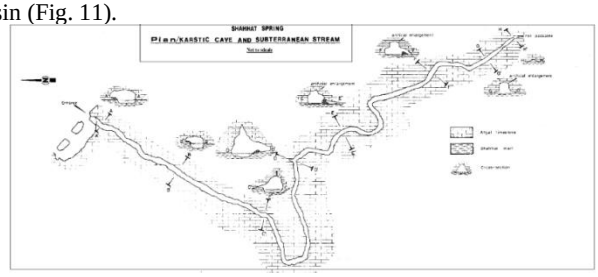

Fig. 11. A plan-view of Apollo Shahat spring-cave [20] and remapped by Ruggieri et al. [21].

Hawa Al Gaigab cave is located north-east of Al Gaigab village (Fig 12)., with elevation at 690 m asl. The cave which develops in the limestones of the Al Faidiyah, consists of a single large chamber having a surface area of 546 m2 of roughly rectangular shape, to which can be accessed from two skylights on the vault. From a topographic point of view, it has an average width of 29 m along its longer side in the NE-SW direction and 19 m on the smaller side in the NW-SE direction. This unique environment is highly degraded, having been used as a dumping ground for waste of various kinds (among which rusty tin boxes prevail), infested by a multitude of mice, while a considerable colony of pigeons nestles on the walls.

Fig. 12. Hawa Al Gaigab cave in south Al-Abraq village.

Hraishaya cave (Cave of the Hayena) is located in the Sidi khaled area, with entrance at an elevation of 355 m asl. The cave develops in the nummulitic limestones of the Dernah Formation, without a preferential direction of development, thus assuming a labyrinthine structure, with an overall development of the various rooms equal to approximately to 110 m with a maximum depth of -3.7 m. As for the mineralogical aspects, it presents numerous calcite deposits of various nature and dimensions (flowstones, columns, curtains, stalagmites and stalactites, popcorn speleothems), variously colored due to the presence in the infiltration waters of humic and fulvic acids (Fig. 13).

Fig.13. Hraishaya cave (Cave of the Hayena) located in the Sidi Khaled, west of Dernah.

Shower cave (Uglah cave) a cave of marine-littoral origin, located in the Egla area at an elevation between 6.4 and 13.2 m asl, north of Asdos in the Mirad Masoud region, locally called by the fishermen Wadi Sho Wear (Slave's Cave). The importance of this cave lies in the recent archaeological discovery of various prehistoric engravings on the walls, while in the further west, pieces of flints and bones were also found on the floor (Fig. 14).

Lamluda 1 cave located in Budhara, at an altitude 668 m asl, with access via a shaft of about 37 m, at the bottom of which it opens into a large bell-shaped room. In this cave we detected high values of CO2.

Lamluda 2 cave located about 1,2 km south of Lamluda, partially explored due to the high presence of CO2 levels at the base of the entrance shaft approximately 25 m deep.

Al Sakhra cave with entrance located on the upper part of the left side of the wadi Sakhra, at an altitude of 210 m above sea level. The cave develops on a single fossil level in which large rooms alternate with lower passages up to the terminal part consisting of a low rolling mill that cannot be further accessed. From a geological point of view, the cave develops in the limestones of the Dernah Formation with an overall development of 140 m and a positive difference in height of 1 m along a bedding plane dissected by structural discontinuity systems (Fig. 15).

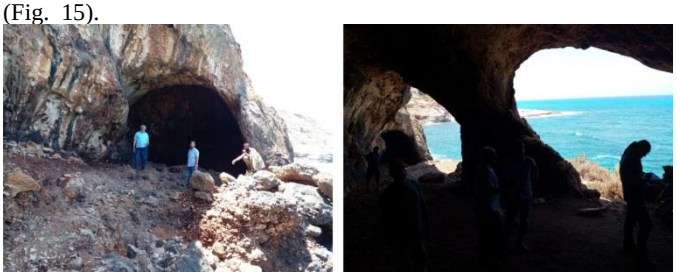

Fig. 14. Shower ((Uglah) (historical cave) in coast of Murid Masoud area, east of Marj city.

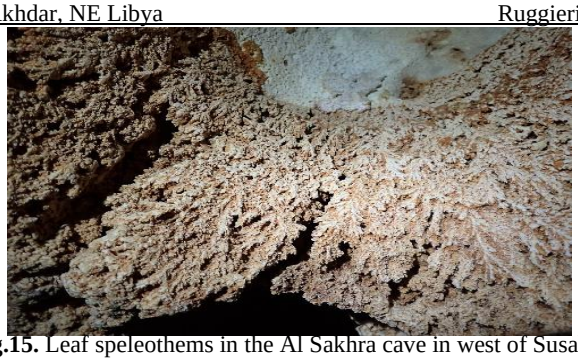

Fig.15. Leaf speleothems in the Al Sakhra cave in west of Susah city.

Werdama (Death cave). Cave located north of the homonymous settlement, inside the Al Figh Rest house, with an entrance on the left orographic side of an incision at an altitude of 545 m asl. The predominantly vertical cavity consists of an initial sub-horizontal conduit extending approximately 31 m, a large shaft 82 m deep followed by a second pit of 22 m and a terminal room. From a geological point of view, the cave develops in the Eocene limestones of the Dernah Formation along a notable tectonic discontinuity (fault) oriented NE-SW, with a total extension of 194 m and a depth of -109 m.

Fig.16. Werdama vertical shaft (Death cave) north of Albydah city.

Nessi (Al-Thabaa) cave is located in wadi Al Dabaa at an altitude of 407 m asl. The cave develops in the limestones of the Dernah Formation along bedding planes dissected by structural discontinuities, for a total length of 206 m with a positive difference in height of 24.5 m, The latter is corresponding to the upper part of a pit located in the final part of the cave about 13 m deep. Along the galleries of particular interest is the presence of corrosion domes (Fig. 17).

Fig.17. Nessi (Al-Thabaa) long cave open into a doline.

Al Aslak 1 doline is located approximately 24 km south-east of El Abyar at an altitude 477-472 m a.s.l. It is a large collapse doline developed in the limestone of Benghazi Formation of Miocene, with a sub-circular top section measuring 58 x 55 m, and a hypogeal sector extending in a NE direction of approximately 41 m. The sinkhole overall has a maximum length of 116 m extended in a NE direction and a depth of 107 m. It is strongly advised not to go down into this sinkhole due to the real danger represented by the presence of a significant quantity of war material scattered on the bottom of its surface.

Al Aslak 2 doline is located approximately 28 km south-southeast of El Abyar at an altitude of 310 m asl. It is a large collapse doline developed in the limestone of the Benghazi Formation of Miocene, with a summit rim measuring 49 x 36 m, elongated in a NNW direction, with a truncated pyramid shape, deep, from the highest external point, approximately 50 m.

Tecthana spring-cave is located in the Sedi Al Himri area, at an altitude of 784 m asl. The cave extends over a single level with an initial large room that continues with a low and narrow conduit in the

final part of which a pool of water emerges. As regards of the geological aspect, the cave develops in the marly limestones of the Al Abraq Formation with an overall development of 60 m and a difference in height of -1.5 m, along a bedding plane occasionally dissected by diaclases.

5. Karst and artificial features surveyed in the Marmarica Region

Marsa Lak doline is located in Al Butnan District (Marmarica Region), at an altitude of 29 m asl. The doline has a first upper as a section of sub-circular shape with an average diameter of 36 m and a depth of 9 m. The remaining section of the sinkhole at the water table has a lobate shape of approximately 30 m in a N-S direction and a sub-elliptical shape with a major axis of approximately 28 m in a NW-SE direction. The collapse doline develops in three formations from Late Eocene to Early-Middle Miocene succession (Fig. 18).

Fig.18. Marsa Lak doline in eastern Tobruk city.

Discussion

Najb doline is a solutional type located in the Al Butnan District (Marmarica Region) at an altitude 40 m asl. It has an approximately elongated sub-circular shape with a major axis of 109 m in a NE-SW direction and approximately 106 m in a NW-SE direction and an altitude of the flat surface of the bottom of 35 m above sea level

Omar Al Mukhtar cave. Artificial cavity and is located in the Marmarica Region at an altitude of 30 m above sea level. In this cavity dug by man, tradition passes down the birth of the hero of the Libyan resistance Omar Al Mukhtar. The cave is inserted in a larger memorial context consisting of a fenced area in which is a tall obelisk falls from which the path leading to the aforementioned hypogeum departs (Fig. 19)

Fig.19. The Historic Omar Al Mukhtar cave inside view in east of Toburk city (Bir Alashab).

6. Conclusion

The campaign of geospeleological investigations carried out in the 2007/2008/2009 years and most recently in 2022, 2023 and 2024 years on an updated Memorandum of Understanding, has concerned the karst area of the coastal belt of Benghazi and Sousa and the plateau of Al Marj, Al Baydah, Dernah and Tobruk. The study of a series of large collapse dolines, connected with the network of conducts draining the groundwater along the coast, was started in the area of Benghazi. Still in the same area, the Lethe karst system with a large underground lake, which was the subject of a tourist fruition during the Italian colonial period, is of particular interest, even historic. In the coastal area of Sousa a significant karst outcrop, surveyed and documented, is the, Brak Notta karst system constituted by a collapse doline and two large neighbouring doline-lake connected hydrologically by a recent tectonic structure draining the brackish ground water sometimes towards the sea, sometimes towards the hinterland, depending on the tidal excursions. In raised areas of El Bayda and Al Marj plateau a very interesting geomorphologic and hydrogeologic study shows some big dolines and dip swallow-holes, inserted in the context of a typical cockpit relief, while in the plateau of Dernah the exploration of a complex labyrinthine cave has allowed also the discovery of paleontologic and archaeological finds. Speleological explorations and geological investigations of the above mentioned karst areas are still being carried out in order to formulate a speleological model consistent with the geodynamic evolution and climate changes taken place in the Tethyan-Mediterranean region from the end of the Cretaceous; those with application fall-outs into the local socio-economic framework addressing the finding out and protection of new water resources, the mapping of man altered areas, potentially at risk of instability and/or sinking because of the presence of karst voids, and the institution of Karst Geosites and Geopark of a particular scientific, environmental or aesthetic value.

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References

[1]- Abdelmalik, M.B., El Moursi, M.E.E., Salloum F. N., (2007). The Environmental Impact of The Karstic Feautures of Ayn Zayana-Kuwifia Near Benghazi, Libya. Proceedings of the 2nd International Karst Symposium, Ragusa. Speleologia Iblea 12, 147-152

[2]- Ruggieri R. and Abdelmalik K.M., (2009). Cyrenaica Karst Project (North Eastern Libya), 15th International Congress of Speleology. Proceedings, Volume 3, 1667-1671.

[3]- Ruggieri R., (2010). Cyrenaica Karst Project, Report of the 2004 preliminary reconnaissance and 2007-2008-2009 campaigns of karst and speleological research.

[4]- Elshaafi A., Bilal A, Awami Y., Salloum F., (2021). Development of collapse dolines in Al Jabal Al Akhdar, NE Libya: geomorphic analysis and numerical modeling-based approach. Carbonates Evaporites 36, 54. https://doi.org/10.1007/s13146-021-00714-9

[5]- Elshaafi A, Bilal A, Salloum F, Ruggieri R, El-Shawaihdi M., (2023). Hawa Fteah Collapse Doline-Cave in Al-Jabal Al-Akhdar Area, NE Libya: one of the Oldest Caves in North Africa and the Mediterranean Basin. Man and Karst 2022 International Scientific Conference. September 12th-17th 2022 Custonaci, Italy. XVII: 257–263.

[6]- Ruggieri R., Bambina A., Ingallinera A., Mazzara G., Elshaafi A., Bilal A., Salloum F. & El-Shari S. (2022). Karst of Cyrenaica: 2022 Second Phase of Research on Al Jabal Al Akhdar, North-East Libya. Man and Karst 2022 International Scientific Conference. September 12th-17th 2022 Custonaci, Speleologia Iblea Vol. XVII, pp. 63-77.

[7]- Ruggieri R., Bambina A., Ingallinera A., Dipasquale M., Gianninoto G., Mazzara G., Elshaafi A., Bilal A., Salloum F. & El-Shari S. - Karst of Cyrenaica, 2024: 2023 Second Phase of Research on Al Jabal Al Akhdar, North-East Libya. In: Man and Karst 2024, International Scientific Conference, Abstract, p. 53.

[8]- El Amawy, M.A., Muftah A.M., Abdelmalik M.B., 2010 - Karst Development And Structural Relationship In The Tertiary Rocks Of The Western Part Of Al Jabal Al Akhdar, NE Libya; A Case Of Study In Qasr Libya Area. Speleologia Iblea 14, 173-189.

[9]- El-Hawat A.S. and Abdulsamad, E.O. 2004 - The Geology of Cyrenaica A Field Seminar. RWE, Libya, P. 130.

[10]-Marchetti M., 1938 - Idrologia Cirenaica. Firenze Istituto Agricolo Coloniale Italiano, 1938 - XVI.

[11]-Al-Rayani A., Salloum F., Elshaafi A, Bilal A, Eldursi K., (2024). Assessment of geohazards of karstified limestone in Al-Coeffiah area, Benghazi plain, NE Libya, Journal Carbonates Evaporites 39,23 (2024) https://link.springer.com/article/10.1007/s13146-024-00933-w

[12]-Dobrilla, J-C (1991). Plongées spéléologiques en Libye (recherche d'eau douce 1975). Scialet, 20, p. 142-152; Genoble (France).

[13]-Guerre A, Davis R (1980). Ground water in Benghazi plain and Ayn Zayanah, Evaluation and analysis, internal unpublished report, General water Authority, Benghazi, Libya.

[14]-Kósa A., 1977 - Hydrogeological Problems in the Ayn Zayanah System, Benghazi, Libya. Proc. 7th Speleol. Congr. Sheffield, England: 275-277.

[15]-Kósa A. and Csernavölgyi L., 1983 - Barlangok a Libiai Al Akhdar-Hegységben. Karst ès Barlang, 1983. Évf. I-II. füzet, p. 35-42, Budapest.

[16]-Potié L., 1975a - Investigations on the subterranean flow in the karstic area near Benghazi. Final Report, Part A, SEM, COMEX, Coyne et Bellier, 10p.

[17]-Potié L., 1975b - Investigations on the subterranean flow in the karstic area near Benghazi. Final Report, Part B, SEM, COMEX, Coyne et Bellier, 41p.

[18]-Salloum F. M., Al Amin A. A. El-Shawaihdi M. H. El Amawy M. A. Muftah A. M. Al Riaydh M. H. (2022). Impact of structural fabric on development of karst aquifer in Ayn Zayanah-Al Coeffiah area in Benghazi plain, NE Libya.Carbonates and Evaporites. Springer Nature 2022.

[19]-El-Shawaihdi M., Ibrahim N., Awami Y., Al Riaydh M. Salloum F.(2024) - Al Dabusiah Karstic Spring Water its Resources, Sustainability and Management. - In: Man and Karst 2024, International Scientific Conference, Abstract, p. 41.

[20]-Hydrogeo Consultant Engineering Piza, Itali (1982). Groundwater resources evaluation, Technical report N0.7. On land Springs Studies for GWA Benghazi, Libya.

[21]-Ruggieri R., 2010 - Cyrenaica Karst Project, Report of the 2004 preliminary reconnaissance and 2007-2008-2009 campaigns of karst and speleological research