Karst Archaeology of Taposiris Magna Area, West of Alexandria City, Egypt

BY

Mohamed El-Sharkawy ; Shahenaz El-Gammal; Magdy Torab
Geography department, Damanhour University, Egypt
Corresponding author: Torab.magdy@gmail.com

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Abstract

Karst Geoarchaeology is a new branch of applied geoscience and engineering applications. This study provides insight into how karst features affect human activities. To meet the needs of archaeology in karst areas and protect karst objects, we should think about geophysical methods, safety measures, synthetic geokarst models, analysis, specific planning and protection, and a stand-off approach to invasive methods. The Taposiris Magna site is located on Egypt's north coast. This study is concerned with the scientific evaluation of geophysical features such as sinkholes, caves, and archaeological geodatabases. The objective of this study is to conduct a scientific evaluation of geophysical features such as sinkholes, caves, and archaeological geodatabases. A significant number of prominent grottoes open within the vicinity of the seashore trench and high terrace. Another elevated level hosts several other caverns, including crypts and an angular enclosure. Geoelectric mapping within the labyrinth, grottoes, and hill indicates the presence of walls, levels, and floor joints. Postholes provide evidence of prepared construction for the proposed temples. Karst topography symbolically and hermetically influenced the temple planning and ritual approach in a unique and distinguished way. Taposiris Magna's architectural effects reflected the site's economic expectations, as well as its impact on linked settlements and the overall environment. The ancient Egyptian religion, which associated the Eternal House with spiritual and heavenly values, addressed the site's destiny by modifying its natural geography and balancing its social and local components through necessary work and parades.

Keywords: Taposiris Magna; geoarchaeology; karst geomorphology; Alexandria; Egypt.

Introduction

The Taposiris Magna (Abu Sir) archaeological area is located about 45 kilometers west of Alexandria City. The Oolitic limestone ridges, part of the Western Desert region, established the Temple of Taposiris Magna, forming a ridge that stretches from Alexandria City in the east to El Salum City in the west. These elongated ridges have a gentle slope that faces north. We can discern a cluster of cascading rainwater reservoirs and their corresponding quartz geological bedrock, illustrating the shift from limestone landscapes to the sandy deposits of the Alexandria coastal plain. It was also adjacent to dry valleys and caves in the western part of the European-North African Plateaux. In the hills and around the site, there are precipices, rounding spalled blocks, huge pieces of honed stone, and a lot of debris resulting from a stone quarry. Introduction. A variety of karst features, including caves, dry valleys, and geomorphological landscapes, surround many of the archaeological sites established on limestone terrain. Egypt has many sites that are located on limestone terrain and karst topography, mainly from the Western Desert to the Western Coastal Plain. The Taposiris Magna Temple is one of the limestone-illustrated archaeological sites. The Hellenistic and Ptolemaic periods saw the construction of this temple in the northwestern part of Egypt. This chapter aims to illustrate the significance of caves, dry valleys, sinkholes for ponds, dolines, and various residues from the temple's stone quarry in the emergence and disappearance of a significant archaeological site, as well as the burial of human remains and remarkable excavation finds in this region (Youssef, 2024).

1.1. Background and significance

Karst studies led to the discovery and partial documentation of some of the shallow caves in the area. The lithology, stratigraphy, topographical relief, erosional and tectonic landforms, and surficial geology are the geomorphological elements related to the archaeological context. We will use these data to generate three-dimensional geospatial models at appropriate scales, allowing us to analyze the findings in relation to architectural forms and religious elements. With the application of cross-disciplinary methods involving archaeology, architecture, applied geosciences, and environmental science, we hope to establish previously uncharted, holistic, tangible, and sustainable relationships between human beings and geological history, guided by the development and orientation of the sacred landscape.

The resulting knowledge will provide evidence and insights to contribute positively to fulfilled, educated, enlightened, protected, and engaged future societies. The project will demonstrate how important it is to use physical geography skills and knowledge to assist scientists in finding solutions to important problems and useful information that affect long-term cultural heritage management as humans evolve. It will construct a new methodological basis to renew and preserve ancient landscapes. Globally, the project could provide a structured, applied research view on the relationship between al-Khatt's geomorphology and archaeological and architectural evidence. This is part of an investigation into the history of an ancient Egyptian cult that lasted for a long time. We anticipate its contribution to quantifying the geological parameters that influence the underground landscape's evolution, as well as an accurate archaeological study that bridges gaps in our understanding of the caves' use and the resulting geomorphological systems. This will lead to the creation of an innovative geodatabase that includes accurate cave and al-Sadr classifications.

1.2. Objectives

We are combining cave and landscape archaeology concepts into a unified methodology of geospatial technologies, databases, and management tools to find a unique solution for problems related to karst areas. The primary goal of the archaeological study is to conduct a scientific evaluation of geophysical features such as sinkholes, caves, and archaeological geodatabases. The study also wants to collect data, evaluate properties, and figure out how complicated it is for different types of data to interact with each other. The study aims to explore the rich archaeological ruins, including architectural remnants, landmarks, sites, and information layers, for the purposes of documentation, condemnation, and invention. Moreover, we can summarize our study's objectives as follows: Our study aims to explore, map, and interpret the unique speleology, distributed karstic sinkholes, and architectural features of caves. The process involves the documentation, visualization, and stereoscopic reconstruction of subsurface structures, wall paintings, and texts. The interdisciplinary collaboration among geological, geomorphological, and archaeological fields enhances the impartiality of research inquiries.

1.3. Approaches in Karst Geoarchaeology

The fundamental argument in the proposed research project places the sacred landscape of the Taposiris Magna area within an unprecedented realm of universal concern for human beings. This is vital for enriching human experience, expanding historical understanding, and reinforcing the social, cultural, and economic development of the local, regional, and global environments where the human family abides. The archaeological and architectural aspects of the goddess Isis temple, as well as its proximity to Taposiris Magna, are essential parts of its ancient sacred landscape. Using karst geoarchaeological methods and techniques to answer the project's scientific question (Pasierb et al., 2024), this project aims to study the geological and geomorphological parts of the landscape along with its archaeological and architectural parts.

The application of specialized geoarchaeological and geomorphological techniques to karstic terrains is known as karst geoarchaeology. Furthermore, Karst Geoarchaeology leverages the science's inherent multidisciplinary nature, connecting to various complementary scientific fields such as cave art studies, human paleontology, speleology, and paleoenvironment investigation. Such a range of connected disciplines not only provides archaeology with basic data, but can also be an essential instrument for different kinds of evidence planning. In fact, any archaeological survey or excavation in a karst area needs to be based on a scientific study of the natural system. This is the only way to answer all the questions that karst hydrogeology, stratigraphy, and landscapes related to cave development raise (Balbo & Iriarte, 2020).

Generally, people think of geoarchaeology as an approach that uses earth science techniques to define past events and processes, particularly those related to human activity, and to provide the relevant environmental and ecological background. As a result, these techniques aim to place civilizations within their paleoenvironmental section and distinguish mutual dependences between humans and bio-geological spheres. As we know that there is a connection between society's growth, the end date, and the use of soil and natural resources, we can think of the interaction circle as a balance between the economic and social needs of ancient communities and the natural environment's potential (Fig. 1).

Fig.1: One of the limestone quarries that was used in the construction of the Temple of Taposiris Magna and the lighthouse

1.4. Methods

Apart from observing and documenting karst geomorphic features, one of the primary basic steps in karst inventorying was conducting scientific karst investigations through karst geomorphology mapping. This led to the successful identification of the extent of surface and subsurface cavities within a relevant area. An extended scientifically supported karst study led to the collection of various scientific data, statistics, and geological evidence. Researchers should utilize the gathered data for diverse scientific investigations across multiple disciplines. For example, some researchers have attempted to evaluate climatic data linked to levels of cave development using a variety of methods. Some of the caves are large, indicating the existence of a karst aquifer and a connected hydrological network between the subsurface aquifer of the Oolitic limestone ridges and the inland basin of Lake Mariout. Field geological and geomorphological studies were an essential part of the work to recognize and define the karst landforms in the area, especially the caves and caverns of the Taposiris Magna site. We used satellite images and DEM for documentation and thematic mapping of surface karst features. For this purpose, satellite images from Google Earth, as well as detailed topographic maps, were the primary sources. We also used detailed geological maps produced by GUPCO, in addition to the general geological maps of the region. Ground truth documentation was also required to verify and monitor surface karst features, particularly the form and size of the top cave openings and the distribution of other types of surface karst features.

1.4.1. Field surveys and mapping

We investigated natural phenomena such as the formation of grottos, the impact of erosion on prehistoric, megalithic, and ancient structures, the unexplored status of numerous tombs, dry lakes, subsurface aquifers, and the vesicular fills containing the remnants of ancient settlements and objects. We also conducted studies on speleothem formations, collapses, karren, sinkholes, and debris covers. The latter consists mainly of sandy deposits transported from faraway locations by wind action along Mareotis Lake. The ancient structures are the result of rock abrasion. This process is critical to the development of regional archaeological areas. We conducted the surveys and field study in the area of Taposiris Magna (TM), situated 45 km west of Alexandria City along the Mediterranean coast (Fig. 1). We conducted the study with the aim of recognizing karstic and geologic features, mapping their distribution and relationships, and describing the regional aspects and their implications for archaeological visits. Many localities in the TM have had significant meaning across the last 5000 years, but climatic changes, including various sea-level changes and a variable position of the archaeological area relative to the lake, which are associated with active karst and tectonic processes, have led to the partial destruction of the archaeological monuments and their displacement. We conducted the fieldwork on rock areas to the north, west, and south of the identified underground galleries, tombs, wells, and cavities.

2. The study area

2.1. Location

The study area is located on the northwestern coast of Egypt between the Burj Al Arab and Al-Hamam regions, west of the city of Alexandria. The area lies between latitudes 30°56'46.34" and 30°56'46.64"N and between longitudes 29°30'49.79" and 29°31'40.57"E. It extends from east to west at a distance of about 1220 meters, and its maximum extension from north to south is about 470 meters. Its area is 549 square meters. The area is located in the Mediterranean coastal zone, close to the international road that links Alexandria and Matrouh and intersects with the New Burj Al Arab City-Matrouh Road. Residential areas, government administrative facilities, and industrial projects partially cover the area as part of the state's plan to develop Egypt's northwestern coast and revitalize areas on both sides of the international road (Fig. 2).

The Abu Sir area is considered an archaeological area located on the shore of the Mediterranean Sea, about 46 km southwest of Alexandria and overlooking the northern coast of Lake Mariout from the town of Burj Al Arab in the Mariout region. The city is close to another important site, also called Kom El Negus. Geologically, the Abu Sir Plateau extends from this region to Abu Qir East, which is the new plateau on which the current city of Alexandria is located. It is a 68-kilometer-long chain of connected crescents. As a result, it is 50 kilometers away from Alexandria and 18 kilometers inside. The region witnessed an important era in the history of the Ptolemies.

Fig.2: Location map of the study area

2.2. Geological setting

Rocks from the Quaternary era, specifically the Pleistocene and Holocene eras (Butzer, 1960 and 1964), cover the Abu Sir area geologically (Fig. 1). The rocks of the Paleo-surface formations from the Pleistocene era, in the form of relatively old cohesive deposits, make up 65% of the Abu Sir region's surface area. Modern, disintegrated, and incoherent surface deposits, along with the subgroups they appear in, also represent the formations of the Holocene era, covering about 30% of the region's area.

2.2.1. Pleistocene Formations

Geological studies have unanimously agreed that they are the oldest and most cohesive formations among the Quaternary sediments. Unlike the Holocene sediments, which are younger and less cohesive (disintegrated sediments), they spread across many sectors along the northwest coast. Their average thickness is about 26 mm. They were characterized by the occurrence of rainy periods. The major fluctuations in the global sea level corresponded, leading to the direct sedimentation of these formations with the receding sea water (Hamdan, 1993). From oldest to youngest, we divide these formations into other sedimentary subgroups (Fig. 3).

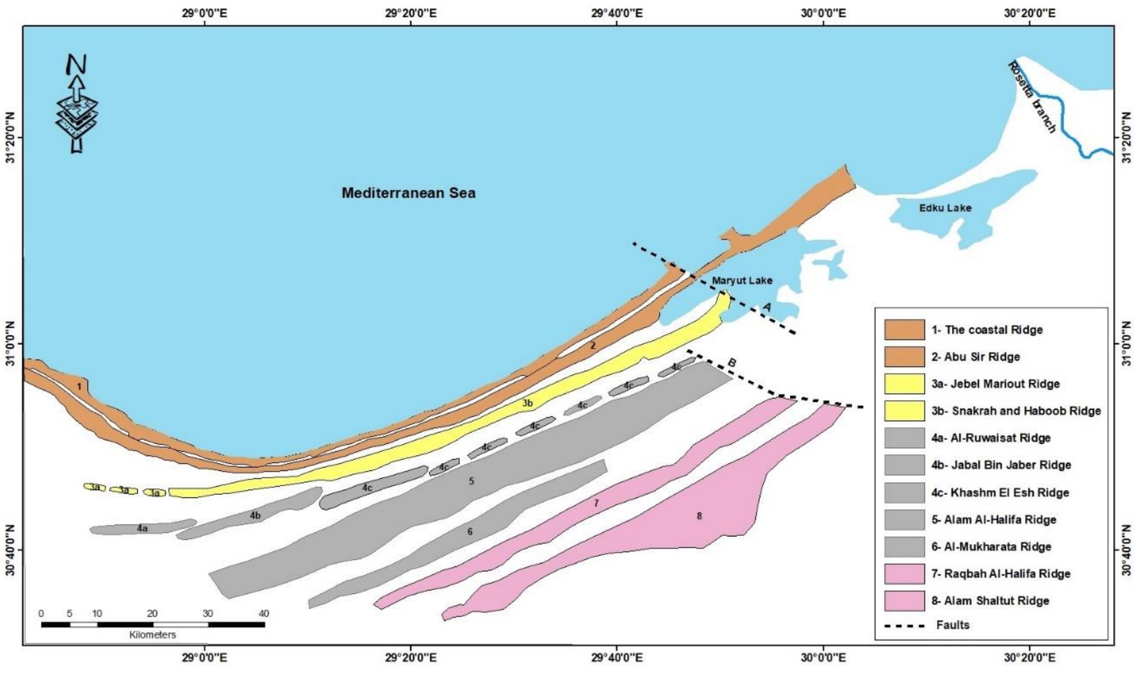

Fig. 3: Geological map of Pleistocene ridges and lagoons in the Arab Gulf region (Modified after: **Butzer, 1960)**

A: Pink limestone

Its formations are characterized by a white-pink color. They are of medium hardness. Their color changes to pink due to oxidation, and sometimes they appear gray. Because it does not oxidize iron, both Butzer (1964) and others attributed it to the Pleistocene era.

B-Cardium shell limestone

According to Stanly (2012), the spread of cardium fossils gave rise to the name "cardium," while the abundance of seashells gave rise to the name "shell." It is topped with pecan limestone rocks, and these formations consist of a mixture of lime grains, pecan, and circular-shaped granules mixed with shells. This type of Pleistocene formation appears in the form of longitudinal ridges parallel to the coastline in other areas on the northern coast, such as Ras Al-Hikma, Marsa Matrouh, and Umm Al-Rakhm. It alternates with the other rims of the Lomia and Marine formations. Carbonate grains coalesce with soft, calcified petrucan grains and shell fragments to form a creamy white color. Said (1962) estimated its thickness at 5 meters.

C-Oolitic limestone

Its formations are the building material for the extended ridges in the study area, the number of which ranges from three to six in some areas (the Arabian Gulf), and they extend continuously, based unconformably on Miocene formations (Said, 1990). A corrosive limestone material holds together grains of calcium carbonate mixed with shell, snail, and fossil remains. These formations are also characterized by a bright white color in the coastal series and a gray color in the older series. From a structural standpoint, we can also distinguish oolitic limestone formations. False bedding is one of the ridge's most significant morphological characteristics.

2.2.2. Holocene Formations

Most of the Holocene formations are surface deposits that sit on top of older formations. These deposits have different types of characteristics and origins, such as dense crust deposits, alluvial deposits, coastal deposits, and pneumatic deposits. They formed under a range of environmental conditions. Aeolian deposits encompass dunes, sand beds, and sabkhas. These sediments make up approximately 30% of the total area of rock formations in the study area (Said, 1962), which are either local or transported deposits. The valleys that descend from the Miocene plateau transport these deposits to the sabkhas. This serves as a local foundation for the valleys in question. Coastal sediments: As the water evaporates, these sediments form around the shores of coastal lakes and appear in the form of fine-grained silty, silty, and sandy sediments. They may also contain the remains of shells, flakes of gypsum, and salt crystals (Said, 1990). The study area's low-lying areas, particularly those near the sea, are where it is most prevalent. It also covers the bottom of the depressions between the pebbly limestone hill ranges. In the Arabian Gulf region (Shukri et al., 1956), the thickness of these sediments is between 1 and 3 meters.

2.3. Integration of geology and archaeology

The archaeological record is varied and important, with classical archaeological occupations formed upon the site's true paleosol. Bedrock-cut chamber tombs. Therefore, we used a comprehensive geological approach to prepare the hydrological, geological, and archaeological map of the study site, a valuable tool for identifying the subsurface environment and various ancient structures. With a focus on certain recognized scientific themes, this study aimed to provide contextual information about human communities in the ancient zones of the Taposiris Magna site and to identify different settlement patterns. The Taposiris Magna site's doline structures consist of numerous fragments of the ancient land surface and dolomite bedrock. This allows for micro-focused geoarchaeological investigations. The potential of this integrated approach at Taposiris Magna is well developed. The study site has a complex geological context of carbonate bedrock and different superficial covers, such as sandy, silty, and salty sediments. The study involves the identification of ancient landforms and paleosol horizons. Study coastal and submerged landscapes. Understanding the characteristics of the sedimentary record is crucial. archaeological predictions and archaeological surveys. The process entails formulating hypotheses and considering the site's general implications. Researchers conduct taphonomy studies and deduce the reasons behind the degradation of artifacts.

Geoarchaeology is the process of integrating geological and archaeological data for contextual archaeological interpretation. Both disciplines can contribute to the site's study, encourage scientific investigation, and improve the knowledge and experience of all researchers. Ideally, excavations and explanations of the site should integrate geological information (Flaux et al., 2021).

3. Results and discussions

3.1. Overview of Karst Landforms

At present, karst areas cover about 15% of the Earth's surface. Karst aquifers serve as a freshwater source for 27% of the world's population. Due to this demand, numerous activities, such as urbanization, industry, and agriculture, compel humans to use the karst for their needs. We refer to karstic sites, or cave cities, which are karst sites where similar civilizations surrounded themselves with cultural layers, houses, protective walls, and fortifications, sometimes even within caves. At these sites, knowledge about the internal and external characteristics of the geological properties is vital. These geological properties play a crucial role in the historical evolution of judgment, and risk directly impacts future human lives through interpretation and truth.

Landscapes underlain by karstified rocks are known as karst. It is characterized by the presence of caves, dolines, uvalas, and other karstic features, each having its own geological origin, morphogenesis, and forming circumstances. Karst areas have some attributes, such as rapid surface runoff, absence of surface drainage, ceilings in reverse redisposition positions, and many high intermittent and siphonal springs, that make them very attractive for human habitation (Fig. 4).

Fig. 4: A karstic cave inside a limestone quarry

3.2. Karst processes in the region

We can, therefore, say that the topography of the presently investigated area was an ideal place for settlers to use the natural caves and land to support their life needs, possibly including accommodation, food storage, ancient hydrogeological resources, worship, and the origin and development of the Taposiris Magna Temple nearby. The area's karst geomorphological investigations indicate that these aquifers developed during the humid periods of the Lower and Middle Pleistocene. The aquifers are located between 3.6 and 50 meters above the present-day sea level due to the post-karstic subsidence effect. Recent karst phenomena, such as salt dissolution, show that the formation is still in a karstifiable state. Due to seasonal changes in groundwater and the repeated cycles of wetting and drying, land subsidence affects plastic soil masses. Furthermore, the dry season causes microcaves to develop. The formation can provide ancient and abundant supplies of water during its upper low stand periods.

The exposed beds would have been an ideal place for ancient communities to reside, having access to shelter, water, and arable land. The Al Agamy Formation, which crops out widely within the Western Desert of Egypt, shows various karst features that developed from the late Pliocene to the present. The formation is aeolian friable; fine- to medium-grained sandstones with localized lagoonal or Sabkha sedimentation form it. In the coastal parts, the formation contains freshwater to brackish limestones that form the main aquifers of the region, together with the Quaternary coastal dune sand aquifer. Ancient communities have primarily used developing karst terrains like caves for residential and religious purposes because of their microclimate. This microclimate, characterized by elevated humidity and stable temperature, sustains water resources for their needs, fosters the growth of herbage for livestock, supports a variety of wildlife species, and facilitates isolation.

Over geological timescales, contact with mildly acidic rainwater, enhanced by organic acids from ground-decaying vegetal cover, dissolves carbonate rocks, primarily limestones. Karst landscapes have certain hydrogeological features that make them stand out. These include more holes in the rock, mostly in the form of dissolution voids; rapid underground drainage through sinkholes and caves; connections with large, deep aquifers, such as fissure aquifers; and controls over the flow of water at the surface and below the ground. These features, as well as the ability to rapidly distribute stored groundwater derived from karstic rocks, have made these terrains important sources of freshwater in various arid and semiarid environments (De et al., 2020). Many geological, hydrogeological, chemical, and physical factors have a big impact on the processes that create karst landforms and their growth in different areas. These factors include tectonics, lithology, topography, climate, and groundwater hydrology. Some of the things that control karst landforms are carbonate rocks like limestones, fractures, and bedding planes; sediments like clays, marls, and sands that lie on top of or near karst features; and geochemical features like dissolution, precipitation, hydrolysis, and gorge-collapsing sink holes. These all play a big part in the karstification process and make it more likely to happen (De Castro & Bezerra, 202).

3.2.1. Chemical weathering and dissolution

Calcite is stronger than other minerals, so when the less stable minerals subside or disintegrate, the rock disintegrates. It is already clear from the inspection of the dry and disturbed cores. The degradation is distinct, primarily due to the presence of varying-sized chloride inclusions in the material. These inclusions have likely been present for an extended period, allowing them to become hygroscopic, meaning they can absorb water and other substances. The bottom 20–30 cm of the most fractured Pharaonic soil contains a significant amount of granular calcite, resembling sellotape, both inside the holes and within the interconnected network of holes. They are strong and can withstand 5% water with weights before and after. Under binoculars, they look like flakes or powder and come in many different colors. Hydrochloric acid treatment of the soil does not alter its characteristics. These features are caused by the type of stress, the minerals present, the environment, and the depth of 80–100 cm in the Roman-era part of the Taposiris Magna limestone (Fig. 5).

Fig. 5: Rainwater dissolves the limestone cliff's rocks, causing a limestone crust to hang from the top.

Soils that contain rhizospheres facilitate weathering processes since they contain organic acids emanating from the plant roots. The different amounts of halloysite and gibbsite in Taposiris limestone and most other cores that have been studied usually show that chloride has little to no effect on the top part. This is in contrast to the other salts (Phases 1–7). In the impacted 200 cm-deep areas of the waste's core (Phase 3), the chloride content reaches its highest level, 4.1 (Eltarahony et al., 2021) (Fig. 6).

Fig. 6: Rainwater dissolution and weathering affect the limestone facade of the Taposiris Magna Temple.

3.3. The archaeological significance of karst geomorphic features.

The principal argument for the significance of karst is the economic concept of specibesity. Unique identifiers for karst features, as opposed to a multitude of different karst objects, networks, and their surrounding areas, influence planning, land use, and the accessibility of these features. Karst features are contextual, and many appear to have a specific place within that context. This is especially visible in cave or grotto temples, while karst is also a key factor in understanding burial and habitation communities. This version of the survey aims to provide a comprehensive glimpse of the karst features and their relationship to the peripheral settlement in the Taposiris Magna area, which extends along the coast road. This is a first step toward a detailed analysis of some karst features on the Taposiris Magna site, reflecting a unique kind of Egyptian religious and burial site (Hussain et al., 2022; Hussain et al., 2020) (Fig. 7).

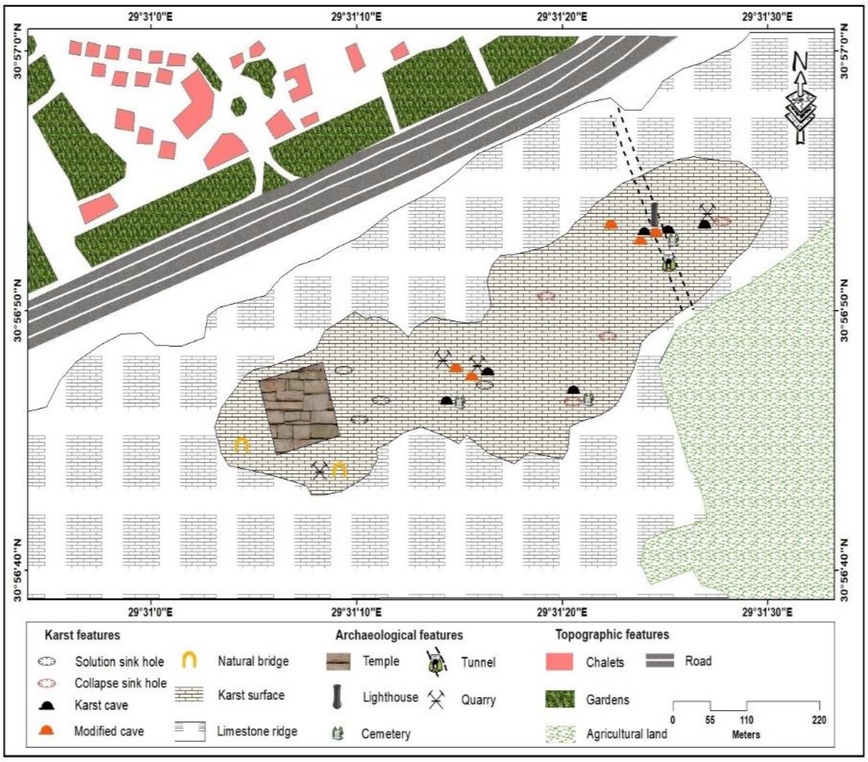

Fig.7: Geomorfo-archaeological map of the study area (Source: field surveying)

3.4. Cave use in ancient civilizations

Karst caves, with their charming architectural aesthetics for human activities, were the earliest and most representative religious architectural objects for temples in Egyptian civilization. The ancient Egyptians held the belief that their existence stemmed from the universe, which served as a framework to counteract the dangerous forces of entropy and chaos, ultimately expanding the universe and maintaining its internal equilibrium. The characteristics of cave architecture in Egypt are similar to those of ancient religious architecture in China's cold, snowy mountains and seabed landscapes. Using the Taposiris Magna area as a model, we conducted a thorough investigation into the long-lasting use of the architectural forest in caves, utilizing textual, material, and physical evidence. We also explored the significance of this longest-standing development in ancient civilization. We evaluate the transformed cultural significance of the ancient Egyptian use of the Taposiris Magna caves from the perspective of global civilization (Figs. 8 and 9).

Fig. 8: A karst cave with trimmed edges and right-angled corners for human use

Fig. 9: Three karst caves below the lighthouse show the effects of human intervention in refining the entrance to the middle cave for human use.

The investigation of Taposiris Magna Cave systems aligns with an interpretive perspective, highlighting key aspects that archaeological methods should consider when exploring other caves. Ancient civilizations extensively utilized them prior to the construction of artificial underground structures. As far back as the Palaeolithic, humans occupied, decorated, or used the underground chambers or entries of caves that served as a place of worship, a storage site, a residence, a burial ground, a workshop for burial goods, a drinking water resource, or a hiding cave to prevent loss of life and property. Cave entrances are frequently the earliest architectural works created by humans as part of purposefully planned or constructed architectural systems. The caves integrated many ancient religious architectural complexes, including those for ancient Egyptian temples (Bajec & Kranjc, 2023) (Fig. 10).

Fig. 10: A collapsed sink hole near the lighthouse, with the edges trimmed for housing or grain preservation.

3.5. Geophysical and geochemical analysis

We found the localized alkaline-alkaline earth geochemical field at the center of the entire geo-mapping area in the northwestern part of Taposiris Magna ridge. We believe that this field signifies the productive resources of fresh karst underground water, located east of the area's center, north of Mariout Lake. Thus, these sources could be essential not only for the old Egyptians but also for providing any dig zone-harbor location—the underground karst water needed today. Geomorphic mapping partially confirmed the architectural features observed at Taposiris Magna. Pleistocene rain periods inundated the lowlands around limestone ridges, resulting in the appearance of a small sea island (14–15 m high) on the lake's northern bank. When the sea level dropped in the Quaternary, the porous limestone plateau cover dried out. Tough Miocene calcareous silt and clay lake-margin breaks combined to create the multilevel karst bottom landform you see today. Both of these significant geological factors dictated the location of the city and harbor, with the harbor located in the north and the Roman and Ptolemaic cities situated in the southeast and west of the western depression. The floor-detected structure, with Caesarion-Augusta capitals bearing device decoration, is a part of the deep central western building.

3.6. The Taposiris Magna Area is home to karst geomorphological features.

Widespread beliefs in the region still center around the Taposiris caverns, natural solution caves, karst natural bridges, solution sink holes, collapse sink holes, and their unique fertility story. Moreover, during the 4th century AD, the Taposiris caverns served as a well-known site of political and religious conflict between pagans and early Christians, as emperors and rulers from the Late Roman period competed to occupy the 'Throne of the Pharaohs' in the Abu Sir area. This paper's primary goal is to provide an overview of the current karst features, along with a summary of suggestions and recommendations for the restoration and replication of these areas and their surroundings in the near future. The Taposiris Magna and its surrounding region are notable for hosting an important ancient Egyptian city and archaeological sites in western Alexandria (Fig. 11).

Fig.11: A natural karst bridge whose edges have been trimmed for human use

This paper specially addresses five major karstic features of the Taposiris Magna area that have undergone either natural or anthropogenic processes including: (1) the rock cut of the ridge which represents a weathered and eroded Pleistocene limestone hill (25 m in altitude) with several natural shelter caves; (2) a concerned outcrop of a limestone ridge representing the stratigraphic formation mixture that serves as a quarry or depression for the construction of the temple and the tower; (3) the caves and the discovered tunnel as potential targets for undergoing archaeological investigations, as they both contain rock cut decorated rooms; (4) the artificial rock-cut solution caves of the Taposiris temple to remove rocks for the construction of the temple's columns and urns; and last but not least (5) the exclusively Taposiris caves that has a controversial legend related to both historical and archaeological beliefs (Fig.12).

Fig. 12: A karstic cave connected to a collapsing sink hole, demonstrating the effect of human intervention in refining the edges and cutting stairs to descend to it.

3.6.1. Caves, natural bridges, and sinkholes

Karst cavern systems, with notable accumulations of archaeological material, are known in some areas and may present high potential as sensitive and integral source zones. Recognized as one of the attractive features for tourism and recreation, such as speleology, cultural tourism, or spiritual travel, the cultural heritage of karst settings requires careful management due to the caves' susceptibility to human and environmental impact. Caves, natural bridges, and sinkholes were well-received and appreciated, out of both fear and admiration, by the Roman communities and then the Islamic period, who settled and built structures around and inside them for their diversified functions, such as temples, animal enclosures, storage spaces, water containers, or habitation sites. At present, various archaeological investigations have exposed the structures and cavities, along with the subterranean levels that karst processes can take, providing valuable information that contributes to our understanding of the cave's geomorphology and geological setting. Impressive natural phenomena adorn the landscape in various parts of the world. Eocene rocks, deposited on top of a layer of Miocene clastics with a complex topography, created all the karst features in the Taposiris Magna area. Caves and sinkholes are the two main types of karst phenomena visible in the study area. Because limestone contains fossils, the entire area is karstified. Rainwater's contact with these fossils triggered a chemical process that led to the surface's slow corrosion and the formation of the observed forms. The most aggressive water can penetrate deeper into the soil (Fig. 13).

Fig. 13: There are two karst caves; the right cave is natural, while the left cave has undergone renovations for housing or grain preservation.

3.6.2. Subsurface water systems

The cliffs in the Taposiris Magna area have numerous vugs, causing the slopes to crumble. The area clearly demonstrates Roman water exploitation, with various cisterns constructed and a newly discovered tunnel. The discovered tunnel, which extends from the southern slopes of the limestone ridge to the shore of the Mediterranean Sea in the north, is about 70 centimeters wide and about two meters high. We believe that the tunnel's purpose was to balance the lake's water level by moving it towards the sea during flood periods and, in the opposite direction, from the sea to the lake. During periods of fire and low water levels in the lake, the tunnel is believed to have served this purpose (Kuta, 2022). Carved passages and the base of a small artificial cave also show up on the road descending from the northwestern corner of the hilltop to the surrounding lowlands. The details of such water systems need further studies on the unexcavated parts of the western field and trenching in the eastern sectors. Early Roman times appear to be the most probable date for the rock-cut systems, as ancient historical texts mention cistern construction as a response to the extreme drought (Figs. 154 and 15).

Fig. 14: The tunnel discovered under the limestone ridge and the lighthouse (Kuta, 2022).

Fig. 15: Entrance to the tunnel dug below the limestone ridge; it starts from the southern slopes overlooking Lake Mariout to the shore of the Mediterranean Sea, with a length of about 1.3 km.

3.7. Sustainable tourism initiatives

We will launch new initiatives at Taposiris to entice tourists traveling from or to Egypt's archaeological sites on the north coast. With landscape planning and appropriate paths, visitors can walk under the tips and peaks and observe the visitor stands, explanatory boards, visitor centers, etc. The cave administration can provide scientific, educational, and recreational content for visitors on their itineraries. At the same time, it is important (for cave admission and simple knowledge acquisition) that visitors be aware of the existence of the caves. Cultural and aerial views of the cave content, along with the cave openings and nearby relevant attractions, serve as suitable promotional material for local tourism. Such cave tourism can generate added value for the local economy and prevent overdevelopment. Egypt has a plethora of ancient and culturally significant sites, many of which are archaeological sites that have remained neglected for many years. Most archaeological sites do not receive the attention they deserve due to a general lack of resources or poor treatment, such as damage from heavy traffic, which could disrupt the ecological balance of the surrounding area. There is a global concern to reduce interventions at archaeological or geological features and develop sustainable geo- and eco-tourism packages for visiting unique natural sites such as caves, rock art sites, and remote geological formations. This would increase the potential visitor's understanding and respect, as well as create a sense of valuing the ecological significance of the heritage site itself and the related ecosystems. In many countries, the ministries responsible for the cultural heritage have shown little interest or few capabilities when it comes to the administration of subterranean (and hence 'geological') phenomena and sites.

4. Conclusion

A structural engineer would also need to conduct individual Taposiris structure-specific assessments, determining the site's condition and specifying the necessary actions to prevent the corrosion of metallic elements used in concrete reinforcement structures. In general, the maintenance and end-use programs should guarantee the safety and conservation of the particular structures. Ensuring compliance with mandatory laws and regulations is crucial for both consulting engineering studies and actual interventions aimed at securing construction elements. Moreover, ba Moreover, providers and local operators should consider basic respect and conservation, or the enhancement of the site's architectural heritage, as their operational guidelines. This will guarantee the highest possible levels of fruition and end use, as well as the durability of heritage structures in their cultural, landscape, and urban settings, ensuring their continued enjoyment by the entire society. Future karst-geotouristic studies in the Taposiris area would be of enormous importance as a means of promoting the geotouristic benefit of the site. The continuous contact between the natural caves and the archaeological sites has promoted integration outcomes in both respecting, preserving, and safeguarding them. As a result, such interactions enhance appreciation and protection of cave and karst geoarchaeological sites. As a result, the area's significance would improve Alexandria's reputation and boost its competitive tourism potential. At all archaeological sites, the best strategy is to involve all monument specialists. Such involvement should be carried out with the least transformation action possible, and the utilization and display of the constructed architectural structures on the site itself are also important.

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