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Geochemical and Mineralogical Characterization of Recent Coastal Sediments in Gabes Region, Eastern Libya: Implications for Marine Depositional Processes and Environmental Change

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ABSTRACT

This study provides a comprehensive geochemical and mineralogical analysis of recent coastal sediments in the Gabes region, located east of Tobruk, Libya. The region is predominantly composed of sandy terrain with calcarenite beds, characteristic of recent sedimentary formations. Six samples were collected from various geomorphologic units along the Gabes coastline, including beach sands and coastal rocks, and analyzed using X-ray diffraction and petrographic techniques. The analysis revealed significant mineralogical variations between coastal rocks and beach sands. Coastal rocks are predominantly composed of aragonite (50.4% to 63.6%) and high-Mg calcite (23.5% to 47.5%), indicative of marine biogenic processes. The minimal quartz content suggests a limited terrestrial influence, emphasizing a primarily marine depositional environment. In contrast, beach sands exhibited higher variability, with aragonite ranging from 36.6% to 61.6% and quartz content reaching up to 18%, indicating a mixed depositional environment influenced by both marine and terrestrial inputs. Notably, one sand sample contained 2.2% halite, reflecting localized evaporitic conditions. These findings underscore the complexity of depositional and diagenetic processes in the Gabes region, with the coastal rocks shaped predominantly by marine influences and the beach sands reflecting a dynamic interplay between marine and terrestrial sources. The study contributes to our understanding of sedimentary processes in the Mediterranean coastal region, offering valuable insights into past and present environmental changes in northeastern Libya.

التوصيف الجيوكيميائي والمعدني للرواسب الساحلية الحديثة في منطقة قابس، شرق ليبيا: الآثار المترتبة على عمليات الترسيب البحري والتغير البيئي

محمد احمد مسعود [1] بالقاسم خميس النهوي [2] محمود علي المبروك[3]

تقدم هذه الدراسة تحليلاً جيوكيميائياً ومعدنياً شاملاً للرواسب الساحلية الحديثة في منطقة قابس، الواقعة شرق طبرق، ليبيا. تتكون المنطقة في الغالب من تضاريس رملية ذات طبقات من الكالكارنيت، وهي سمة مميزة للتكوينات الرسوبية الحديثة. جُمعت ست عينات من وحدات جيومورفولوجية مختلفة على طول ساحل قابس، بما في ذلك رمال الشاطئ والصخور الساحلية، وحُللت باستخدام حيود الأشعة السينية وتقنيات البتروغرافيا. كشف التحليل عن اختلافات معدنية كبيرة بين الصخور الساحلية ورمال الشاطئ. تتكون الصخور الساحلية في الغالب من الأراجونيت (50.4% إلى 63.6%) والكالسيت عالي المغنيسيوم (23.5% إلى 47.5%)، مما يدل على عمليات حيوية بحرية. يشير محتوى الكوارتز الضئيل إلى تأثير أرضي محدود، مما يؤكد على بيئة ترسيبية بحرية في المقام

الأول. في المقابل، أظهرت رمال الشاطئ تباينًا أعلى، حيث تراوحت نسبة الأراجونيت بين 36.6% و61.6%، ووصل محتوى الكوارتز إلى 18%، مما يشير إلى بيئة ترسيبية مختلطة متأثرة بالمدخلات البحرية والبرية. والجدير بالذكر أن إحدى عينات الرمال احتوت على 2.2% من الهاليت، مما يعكس ظروفًا تبخرية موضعية. تؤكد هذه النتائج تعقيد العمليات الترسيبية والتغيرات الجينية في منطقة قابس، حيث تشكلت الصخور الساحلية بشكل رئيسي بفعل التأثيرات البحرية، وتعكس رمال الشاطئ تفاعلًا ديناميكيًا بين المصادر البحرية والبرية. تساهم هذه الدراسة في فهمنا للعمليات الرسوبية في المنطقة الساحلية للبحر الأبيض المتوسط، وتقدم رؤى قيّمة حول التغيرات البيئية الماضية والحالية في شمال شرق ليبيا.

INTRODUCTION

This recent study provides a detailed examination of a coastal area characterized by pure sandy terrain. The majority of the exposed rocks are relatively recent and consist primarily of calcarenite beds. Investigating these recent sediments offers valuable insights into climate change in the Mediterranean region. Research conducted by Khameiss and Zubi (2020, 2024) Microfacies investigation of Wadi Al-Zaytoun in Eastern Libya shows a variety of depositional habitats, ranging from low-energy lagoonal settings to high-energy inner shelf and shallow marine situations Masoud and Khameiss (2025). The limestone cliffs of Wadi Al-Suwani in the Al-Bardia Region, east of Tobruk City, Libya, are primarily comprised of calcite, with traces of quartz and halite occurring occasionally. Calcite represents the dominant carbonate mineral identified within the rock cliff terraces along the Tobruk coast Masoud et al. (2020). The carbonate nature of these formations, which are distinguished by fossiliferous limestone, is reflected in the high calcite content. Masoud and Khameiss (2024). .on recent sediments in northeastern Libya uncovered significant evidence, based on benthic fauna, of human impact on sedimentation and contamination. In a related study, Masoud et al. (2021) performed a microfacies analysis and examined the depositional environments of the Shahhat Formation along the Tobruk coast, of Libya. Their findings, along with those from Khameiss (2024), who conducted a petrographical and mineralogical investigation of El-Baradaa Island, west of Tobruk, revealed a mixture of minerals including aragonite, high-Mg calcite, calcite, halite, and quartz. Aragonite, which made up 42% to 51% of three samples, indicates shallow marine conditions with high levels of calcium carbonate saturation. High-Mg calcite was particularly abundant in a fourth sample, comprising 59.9% of its composition, indicating variations in the depositional environment. The microfacies analysis identified sedimentary structures such as foraminiferal and algal grainstone, bryozoan floatstone, and echinoid oolite, indicative of a high-energy, shallow marine setting. These findings suggest that El-Baradaa Island has undergone complex depositional and diagenetic processes typical of a temperate to warm, shallow marine environment with significant evaporitic influences. Additionally, Mohamed (2019) studied the textural composition and bulk mineralogy of sabkha deposits in the coastal region of the Al Dafna plateau, east of Tobruk City. His research found that these sabkhas are predominantly composed of carbonate and mud with minor sand content, and silt was the dominant texture class in both intertidal and supratidal deposits. The bulk mineralogy of the sabkhas includes quartz, calcite, halite, bassanite, dolomite, albite, gypsum, microcline, and hematite.

MATERIALS AND METHODS

The Gabes region, located approximately 50 kilometers east of the coast in eastern Libya near the city of Tobruk, is geologically part of the Al Brdai Plate. This plate includes several formations, with the most notable being, the Darnah, Al Bayda, Al Abraq, Al Faidiyah, and Al Jaghbub formations. The coastal geology of the Gabes region is primarily covered by the Quaternary Ajdabiya Formation, which is the focus of investigation in this area (Figure 1).

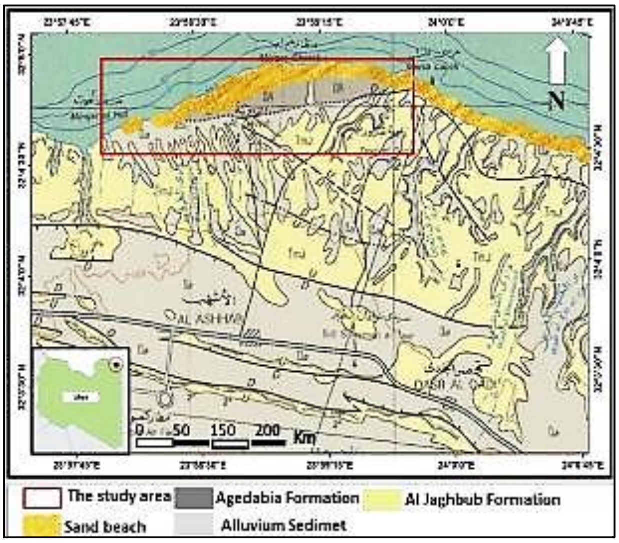


Fig.1. Shows the geological map of the study area. (Modified from Industrial Research Center, 1977.

METHODOLOGY:

In May 2023, two field trips were conducted to the research site, during which six samples were collected from two geomorphologic units along the Gabes coastline. These included three beach sand samples and three coastal rock samples, taken from different locations across the study area, spanning east to west (Figures 2 and 3). Each sample was securely placed in a plastic bag, along with key information such as latitude, longitude, and collection site details, before being sent to the Arab Republic of Egypt for mineral content analysis.

At the Metallurgy Institute of Minerals in Cairo, the samples underwent analysis using a PW3710 X-ray diffractometer, equipped with Cu Kα radiation. Scanning was conducted at a speed of 2θ 2 min^{-1}, covering a 2θ range from 3° to 60°. The diffraction peaks in 2θ and corresponding d-spacing (Å) were measured using a computerized X-ray diffractometer, and the mineral percentages were determined through specialized software, following X-ray powder diffraction patterns as described by Chao (1969) and Chen (1977). For thin section petrographic analysis, an Olympus BX51 polarizing microscope was employed, and digital photomicrographs were captured. The depositional conditions and subsequent diagenetic alterations were identified, with the microfacies relationships of limestones classified using the modifications by Embry and Klovan (1971) and the classification system proposed by Dunham (1962).

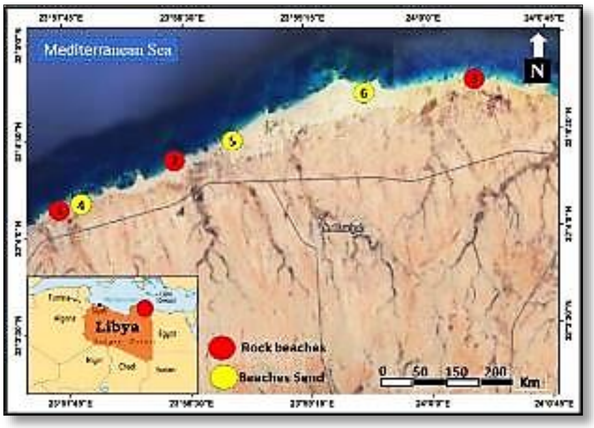


Fig.2. Location of the study coastal area of Gapes area (● ●Stations).

Fig. 3. A&B Show the rock in the area. C: Collecting beach sand samples .D: Recording latitude and longitude. E: Beach rocks. F: Calcarenite rocks

RESULTS AND DISCUSSION

GEOCHEMICAL ANALYSIS:

BULK MINERALOGY OF THE EXPOSED ROCK:

Table 1 presents the bulk mineralogy of coastal rock and beach sand, highlighting variations in carbonate, evaporite, and detrital mineral content across two geomorphological units. The beach rock samples exhibit significant concentrations of high-Mg calcite, dolomite, and aragonite, with aragonite being particularly dominant in some samples, ranging from 50.4% to 63.2%. Calcite is only present in One of the beach rock samples, comprising 14.9%. Quartz content is consistently low across these samples, with values ranging from 2.2% to 3.9%. The sand beach samples show a higher variability in mineral composition, with calcite ranging from 17.5% to 27.8%, high-Mg calcite from 18.2% to 30.4%, and aragonite from 36.6% to 61.6%. Notably, one sand beach sample contains 2.2% halite, an evaporite mineral, and significantly higher quartz content (18.0%) compared to other samples. Overall, the table illustrates the complex mineralogical
composition of the coastal rocks and sands, reflecting the diverse depositional environments and diagenetic processes at play along the studied shoreline. (Figs. 4,6&8). Percentages of bulk minerals obtained are summarized in Table (1) and represented graphically in Fig. (5,7&9).

Table.1. Bulk mineralogy of coastal rock and Sand Beach.

S. No.	Geomorphologic units	Carbonate minerals				Evaporite minerals	Detrital minerals
		Calcite (%)	High-Mg- Calcite	Dolomite (%)	Aragonite (%)	Halite (%)	Quartz (%)
1	Beach Rock	-	27.5	5.5	63.2	-	3.9
2	Beach Rock	14.9	23.5	-	58.7	-	2.9
3	Beach Rock	-	47.5	-	50.4	-	2.2
4	Sand Beach	27.8	29.8	-	36.6	-	5.8

5	**Sand Beach**	17.5	30.4	-	47.5	-	4.6
6	**Sand Beach**	-	18.2	-	61.6	2.2	18.0

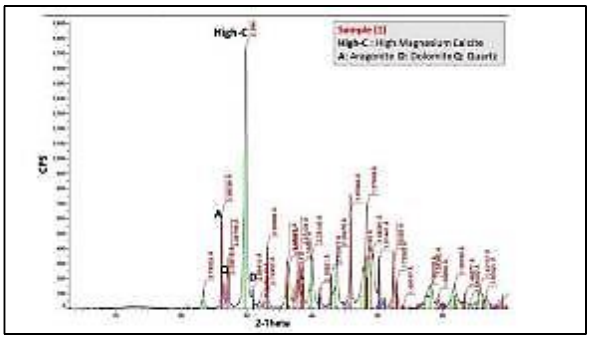


Fig. (4): Representative X-ray diffraction patterns showing the bulk mineral components identified in rock.

The bar chart for "Sample (1)" presents the percentage composition of various minerals. Aragonite and High-Mg-Calcite are the most dominant minerals, each constituting 60% of the samples. The other minerals—Calcite, Dolomite, Halite, and Quartz—are either absent or present in negligible amounts, with only Quartz showing a minimal presence of about 5%. This chart highlights the predominance of Aragonite and High-Mg-Calcite in this particular sample

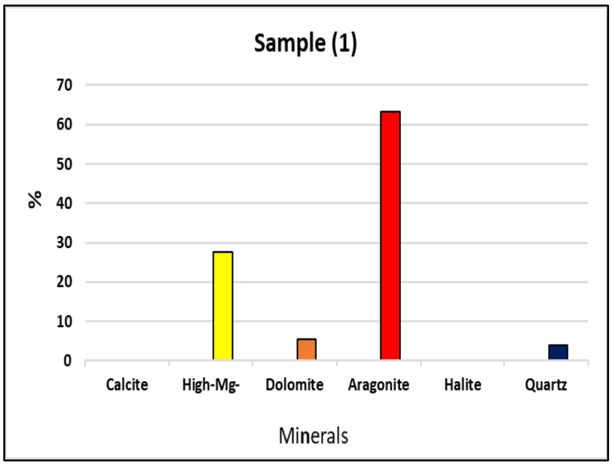


Fig. (5): Bar graph representation showing the relative percentages of the bulk minerals in the Sample (1).

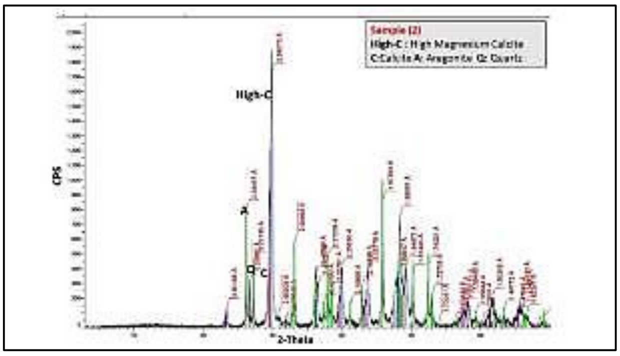


Fig. (6): Representative X-ray diffraction patterns showing the bulk mineral components identified in rock.

The bar chart for "Sample (2)" presents the percentage composition of various minerals. Aragonite and High-Mg-Calcite are the most dominant minerals, each constituting 20% to 50% of the sample. The other minerals—Calcite, Dolomite, Halite, and Quartz—are either absent or present in negligible amounts, with only Quartz showing a minimal presence of about 2%. This chart highlights the predominance of Aragonite and High-Mg-Calcite in this particular sample.

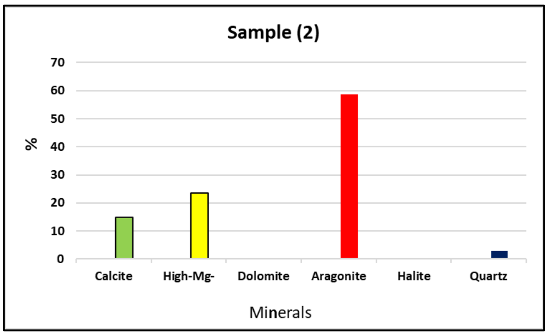


Fig. (7): Bar graph representation showing the relative percentages of the bulk minerals in the Sample (2).

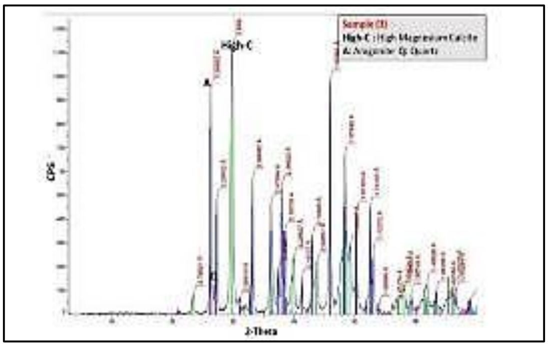


Fig. 8): Representative X-ray diffraction patterns showing the bulk mineral components identified in rock.

The bar chart for "Sample (3)" presents the percentage composition of various minerals. Aragonite and High-Mg-Calcite are the most dominant minerals, each constituting 50% of the samples. The other minerals—Calcite, Dolomite, Halite, and Quartz—are either absent or present in negligible amounts, with only Quartz showing a minimal presence of about 1%. This chart highlights the predominance of Aragonite and High-Mg-Calcite in this particular sample.

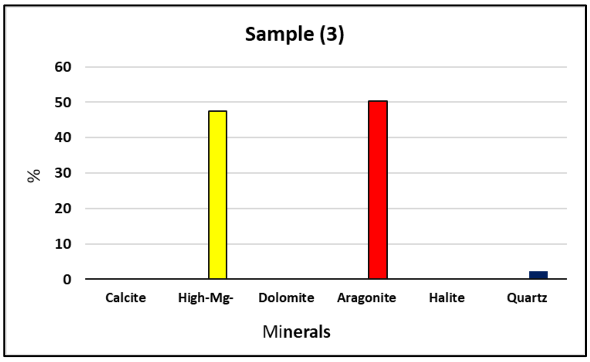


Fig. (9): Bar graph representation showing the relative percentages of the bulk minerals in the Sample (3).

4.1.2 BULK MINERALOGY OF THE SAND BEACH:

Moving on to the beach sand samples, we observe the presence of carbonate minerals. The most prevalent mineral is Aragonite, which ranges in percentage from 36.6 to 61.6%. It is followed by calcite, which is High-Mg-Calcite has a percentage between 18.2 and 30.4%. The presence of halite was noted in sample number six, and dolomite was not found in the beach sand. Quartz was found to contain a little larger amount of minerals than the rocks in the area, coming in at 18%... (Figs. 10,12&14). Percentages of bulk minerals obtained are summarized in Table (1) and represented graphically in Fig. (11,13&15).

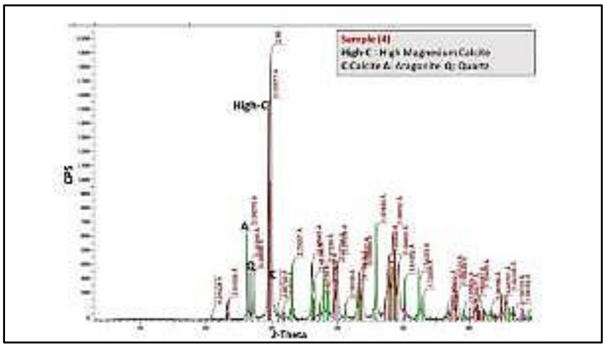


Fig. (10): Representative X-ray diffraction patterns showing the bulk mineral components identified in Sand Beach

The ring chart for "Sample(4)" shows the distribution of minerals as follows: High-Mg-Calcite is the most prevalent, making up 36% of the sample. Aragonite is close behind at 30%, followed by Calcite at 28%. Quartz is the least abundant mineral, accounting for 6% of the sample. These percentages reflect the relative proportions of each mineral within this specific sample

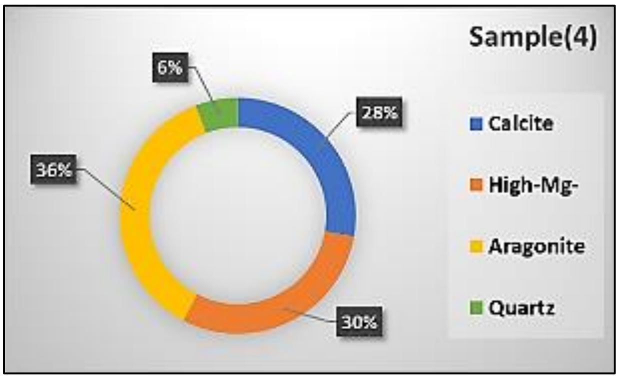


Fig. (11): Diagram representation showing the relative percentages of the bulk minerals in the Sample (4).

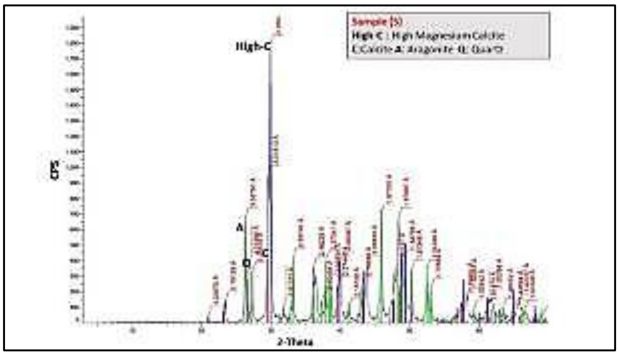


Fig. (12): Representative X-ray diffraction patterns showing the bulk mineral components identified in Sand Beach

The ring chart displays the mineral composition of "Sample(5)," where High-Mg-Calcite is the most abundant, constituting 48% of the sample, followed by Aragonite at 30%. Calcite makes up 17%, while Quartz is the least prevalent, accounting for 5% of the sample. These percentages illustrate the relative distribution of these minerals within the analyzed sample.

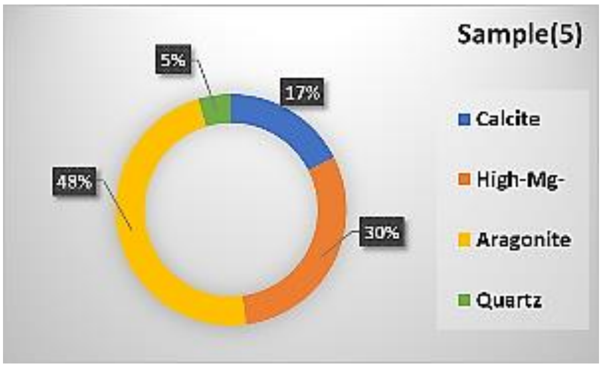


Fig. (13): Diagram representation showing the relative percentages of the bulk minerals in the Sample (5).

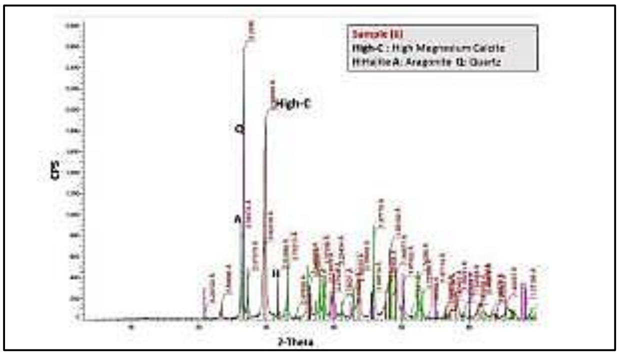


Fig. (14): Representative X-ray diffraction patterns showing the bulk mineral components identified in Sand Beach.

The ring chart illustrates the mineral composition of "Sample(6)," with Aragonite being the most abundant at 62%, followed by High-Mg-Calcite at 18%. Quartz also constitutes 18% of the sample, while Halite is the least prevalent, making up 2%. These percentages represent the relative distribution of the minerals within the analyzed sample.

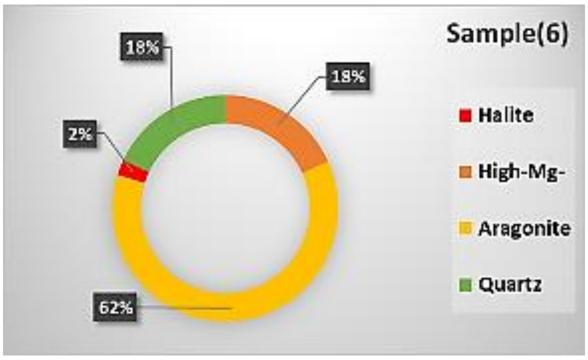
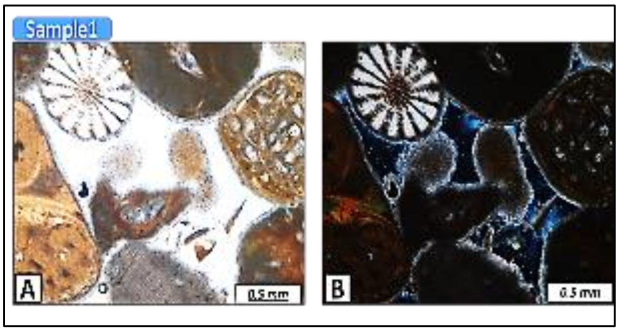


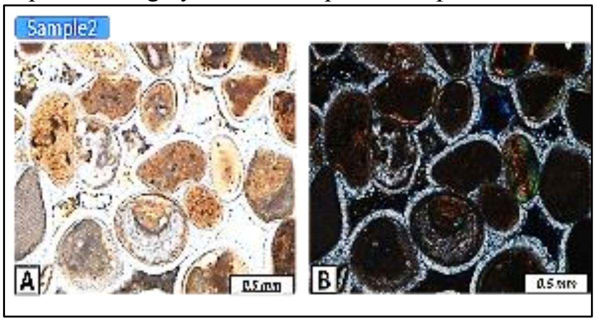
Fig. (15): Diagram representation showing the relative percentages of the bulk minerals in the Sample (6).

4.2.3. Sedimentological" and micropaleontological analysis:

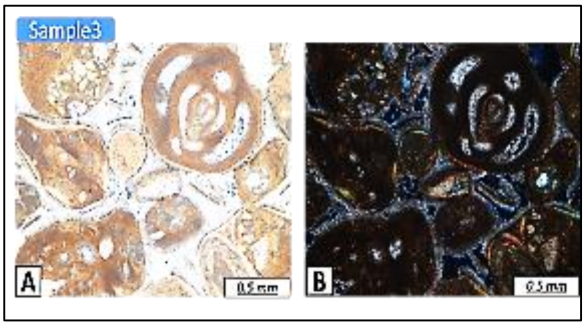
Sample no. 01: The images display a diverse assortment of grains, likely composed of various minerals and microfossils, embedded within a clear and well-preserved matrix. Prominently featured is a white, circular structure with radial lines, characteristic of a benthic foraminiferal test. Surrounding this are grains with distinct shapes and textures, suggesting the presence of different microfossil types or mineral fragments. When viewed under crossed polarized light, the optical properties of these components become more evident, with the foraminiferal test and accompanying grains exhibiting noticeable birefringence indicative of anisotropic mineral composition. The resulting variations in color and intensity effectively highlight and differentiate the mineralogy and structural details of the individual grains within the sample.



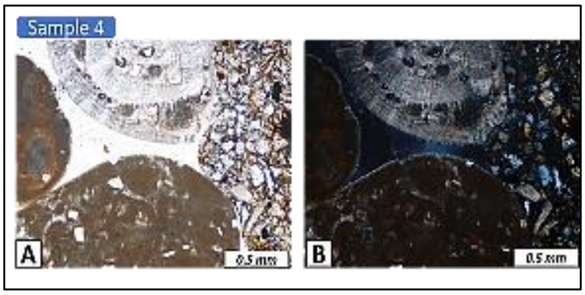
Sample no. 02: The section is characterized by rounded to sub-rounded grains, likely including fossil fragments such as foraminifera and various mineral grains, suggesting deposition in a high-energy environment like a beach or shallow marine setting. Some grains show internal structures, including concentric growth lines typical of foraminiferal tests. The grains are embedded in a less prominent matrix, possibly due to fine-grained material or a lack of cementation, indicating loosely packed sediment before lithification or later-stage dissolution. The brown coloration suggests the presence of minerals like quartz or feldspar with potential iron oxide staining, and the uniform texture across the grains implies sorting by a similar depositional process.



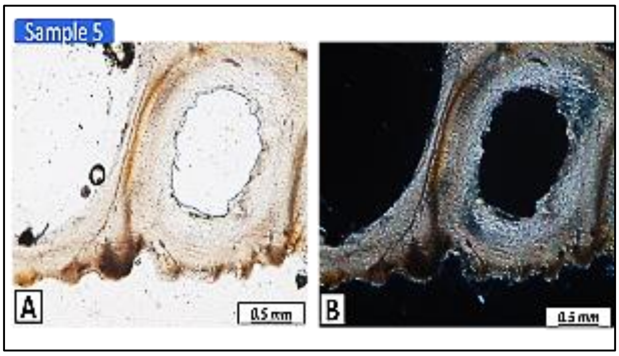
Sample no. 03: This section is characterized by rounded to sub-rounded grains, which may include fossil fragments like foraminifera, along with various mineral grains. These features suggest deposition in a high-energy environment, such as a beach or shallow marine setting. Some grains exhibit internal structures, and they are set within a less distinct matrix, possibly due to fine-grained material or limited cementation. This indicates that the sediment was loosely packed prior to lithification or experienced dissolution at a later stage. The brown coloration hints at the presence of minerals like quartz or feldspar, potentially stained by iron oxides, and the consistent texture across the grains suggests they were sorted by a similar depositional process.



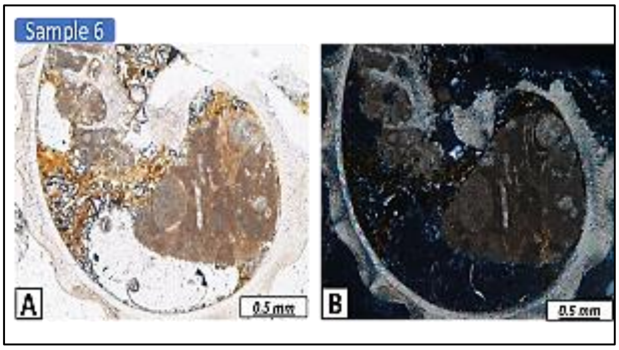
Sample no. 04: The first image (PPL) reveals foraminiferal shells with clear internal structures, showing varying shades that likely represent different minerals or organic content. The largest specimen on the left exhibits a spiral structure typical of rotaliid foraminifera, while the surrounding mineral grains appear well-sorted with a range of colors indicating diverse mineral compositions. In the second image (XPL), taken under cross-polarized light, the internal structure of the foraminifera and the surrounding matrix becomes more distinct, with evident birefringence and colors ranging from dark browns to bright blues and whites, highlighting specific features of the shell structure. Based on the spiral structure in the large specimen, it is likely a member of the Rotaliidae family, including genera like Ammonia and Elphidium, suggesting a shallow marine environment, potentially indicative of a coastal or lagoonal setting.



Sample 05: The photomicrograph displays a well-preserved ooid with distinct concentric layers surrounding an irregular central nucleus, indicative of formation in a high-energy, shallow marine environment. The layers within the ooid vary in thickness and color, possibly due to differences in mineral composition or depositional conditions, and are slightly darker, suggesting the presence of iron oxides or other impurities. The surrounding fine-grained matrix, containing smaller grains, likely represents micritic calcite that cements the ooid within the limestone. This thin section exemplifies an oolitic limestone, characteristic of warm, shallow waters with an active wave or current agitation, and shows minimal diagenetic alteration, preserving the original depositional features.



Sample no. 06: The thin section likely represents a bioclastic limestone or an oolitic limestone with a complex depositional history. The central grain, possibly an ooid or a bioclast, suggests a shallow marine depositional environment with sufficient energy to support the formation of such grains. The presence of iron oxide staining indicates some level of diagenetic alteration, possibly during burial or exposure to oxidizing conditions. The overall structure and composition suggest this limestone has undergone both depositional and post-depositional processes, including cementation and recrystallization.



5.Paleontological data:

Benthic foraminifera;

It is highly abundant in sample four. The only species documented is *Amphistegina lessonii*. *Amphistegina lessonii* is a species of large benthic foraminifera commonly used in paleoenvironmental reconstructions. This species, part of the genus Amphistegina, is typically found in shallow marine environments, particularly in tropical to subtropical regions. Amphistegina species, including *Amphistegina cf. lessonii*, are primarily present in sediments from the Paleogene to the present. However, *Amphistegina cf. lessonii* itself is most frequently associated with the Miocene to recent deposits. The Miocene Epoch spans approximately 23 to 5.3 million years ago. These species are key indicators of warm, shallow marine environments, often found in reef or near-reef settings. They thrive in areas with high light availability, clear water, and stable salinity levels—conditions typical of tropical to subtropical shelf environments. These environments enable them to contribute significantly to carbonate production in the sedimentary record. The presence of Amphistegina cf. lessonii in paleoenvironmental reconstructions suggests a warm, shallow marine environment with good water circulation, likely near a reef or in a lagoonal setting. Additionally, their distribution indicates relatively low nutrient levels, as they prefer oligotrophic (nutrient-poor) conditions. (Fornasini, 1903; Gross, 2001; Deshayes, 1830 and 1832; Cowan, 1971).

6. **Discussion**

The geochemical analysis of the Gabes region reveals significant mineralogical distinctions between the coastal rock and beach sand samples. Coastal rocks exhibit a dominance of aragonite and high-Mg calcite, minerals typically associated with marine biogenic processes. Aragonite, constituting over 50% of the mineral composition in these samples, indicates a carbonate-rich environment, likely influenced by the precipitation of calcium carbonate from marine waters. The presence of high-Mg calcite further underscores the marine origin of these rocks, with contributions from organisms like coralline algae and other marine biota. The minimal presence of quartz suggests a limited terrestrial influence, pointing to a predominantly marine depositional environment with minor siliciclastic input. This mineralogical composition suggests that the coastal rocks in the Gabes region have been primarily shaped by marine processes, with diagenetic alterations playing a secondary role.

In contrast, the beach sand samples show a more varied mineral composition, reflecting a dynamic interplay between marine and terrestrial processes. While aragonite remains a significant component, the higher quartz content in the sand samples, particularly in one where it reaches 18%, indicates a notable detrital input, likely from nearby terrestrial sources or fluvial systems. The presence of halite in one of the samples points to localized evaporitic conditions, possibly associated with tidal flats or lagoonal environments where seawater evaporation is significant. These findings suggest that the beach sands are products of mixed depositional environments, influenced by both marine biogenic activity and terrestrial inputs. The variations in mineral composition between the coastal rocks and beach sands highlight the complexity of the sedimentary processes at play in the Gabes region, offering insights into the geological history and environmental dynamics of this coastal area.

CONCLUSION

The geochemical and mineralogical analysis of the Gabes coastal region reveals a distinct contrast between the coastal rocks and beach sands, highlighting the complexity of the depositional environments. The dominance of aragonite and high-Mg calcite in the coastal rocks points to a marine origin with limited terrestrial influence, suggesting that these formations have been primarily shaped by biogenic processes in a carbonate-rich marine environment. The minimal presence of quartz further supports the notion of a predominantly marine setting with minor siliciclastic input. These findings underscore the significance of marine processes in the geological evolution of the Gabes coastline.In contrast, the beach sands display a more diverse mineralogical composition, reflecting a dynamic interplay between marine and terrestrial influences. The higher quartz content in some samples indicates a notable detrital contribution, likely from nearby land sources, while the presence of halite suggests localized evaporitic conditions. This variability in mineral composition across the beach sands highlights the complex sedimentary processes at play, shaped by both marine and terrestrial factors. The study's findings provide crucial insights into the environmental dynamics and geological history of the Gabes region, contributing to a broader understanding of the Mediterranean's recent geological evolution.

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